DOCUMENT RESUME

06794 - [B2307379]

Liquefied Energy Gases Safety, Volumes 1, 2, and 3. EMD-78-28; B-178205. July 31, 1978. 3 vols. (various pagings).

Report to the Congress; by Elmer B. Staats, Comptroller General.

Issue Area: Energy: Role of Fossil Fuels in Meeting Future Needs (1609); Consumer and Worker Protection (900); Transportation Systems and Policies (2400).
Contact: Energy and Minerals Div.
Budget Function: Natural Resources, Environment, and Energy: Energy (305); Commerce and Transportation: Other Advancement and Regulation of Commerce (403); Commerce and Transportation: Ground Transportation (404).
Organization Concerned: Department of Commerce; Department of Energy; Department of Transportation; Interstate Commerce Commission.
Congressional Relevance: Congress.
Authority: Transportation of Explosives Act of 1908 (18 U.S.C. 831). Hazardous Materials Transportation Act (49 U.S.C. 1801). Natural Gas Act of 1938 (15 U.S.C. 717). Department of Transportation Act of 1966, as amended (49 U.S.C. 1651). Ports and Waterways Safety Act of 1972, title I. 30 U.S.C. 1. 33 U.S.C. 401. 49 U.S.C. 1. 16 U.S.C. 1451. =46 C.F.R. 151. =46 C.F.R. 152. =33 C.F.R. 6. =33 C.F.R. 124. =46 C.F.R. 30. =49 C.F.R. 171. =18 C.F.R. 3. =33 C.F.R. 209. =14 C.F.R. 139. =40 C.F.R. 51. =40 C.F.R. 79. =40 C.F.R. 55. =40 C.F.R. 116. =40 C.F.R. 1510. =49 C.F.R. 177.

In this 3-volume report, the results are presented of an analysis of the critical safety issues in transporting and storing liquefied energy gases--liquefied natural gas and liquefied petroleum gases (propane and butane). Volume 1 of the report contains the Executive Summary and 21 chapters, as follows: Introduction; Primer; Vulnerability of Storage Tanks and Containment Dikes to Natural Forces; Crack-Induced Failure of Metal LNG Tanks; Flow Over Containment Dikes; Ship Design, Personnel, and Operations; Truck Shipments; Train Shipments; Vulnerability of LEG Facilities to Sabotage; The Cleveland LNG Accident of 1944; Liability and Compensation; Detonation and Flame Propagation Research; The Capability of Non-Urban Sites To Meet Total U.S. Import Requirements for LPG; The Capacity of Non-Urban Sites To Meet Total U.S. Import Requirements for LNG; Federal, State, and Local Regulations; Federal Regulation of LEG Trucks and Railcars; The Federal Power Commission; LNG Use in Japan; Overall Conclusions and Recommendations; and GAO Treatment of Agency and Company Comments. Volume 2 is comprised of 14 appendices that support and supplement the chapters. In Volume 3, comments on a draft of the report by the Departments of Commerce, Energy, State, and Transportation, the Interstate Commerce Commission, and the National Transportation Safety Board are provided. (SC)

7379

BY THE COMPTROLLER GENERAL

Report To The Congress

OF THE UNITED STATES

Liquefied Energy Gases Safety

VOLUME 1 OF THREE VOLUMES

Liquefied energy gases--liquefied natural gas, propane, and butane--could become an increasingly important part of U.S. energy supplies, but moving and storing these liquefied gases pose serious dangers. To minimize the public risk involved in meeting the country's needs for these fuels:

--Future facilities for storing large quantities of these gases should be built in remote areas.

--Facilities already in other than remote areas should not be permitted to expand in size or in use, and the safety of each should be evaluated by the Federal Government.

--Large quantities of liquefied energy gases should not be transported through densely populated areas unless delivery is otherwise impossible.

--The Congress should consider consolidating into one agency many Federal responsibilities for evaluating and controlling the adverse consequences on energy operations.

--The Congress should create a Federal Hazardous Materials Compensation Fund to supplement private liability insurance.

UNITED STATES GENERAL ACCOUNTING OFFICE

EMD-78-28

JULY 31, 1978

COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

B-178205

To the President of the Senate and the
Speaker of the House of Representatives

This report presents our analysis of the critical safety issues in transporting and storing liquefied energy gases--liquefied natural gas and liquefied petroleum gases (propane and butane). We have identified what we believe to be significant problem areas that warrant the immediate attention of the Congress and the cognizant Federal agencies.

We made the review pursuant to our authority in the Budget and Accounting Act, 1921, 31 U.S.C. 53 (1970); the Legislative Reorganization Act of 1970, 31 U.S.C. 1154 (Supp. V 1975); and the Federal Energy Administration Act of 1974, 15 U.S.C. 771 (Supp. V 1975), made applicable to all of the Department of Energy by Section 207 of the Department of Energy Organization Act (Public Law No. 95-91).

If liquefied energy gases spill from their tanks, they vaporize rapidly and become highly flammable and explosive. A major spill in a densely populated area--whether by accident, natural forces, or sabotage--could result in a catastrophe. Because of the potential danger and the possible increase in the use of these liquefied gases, we believe that it is appropriate now to take any needed actions to protect the public.

We believe that future, large-scale liquefied energy gases facilities should be located away from densely populated areas; that any such existing facilities should not be permitted to expand, in size or in use; and that present urban facilities should be carefully evaluated to ensure that they do not pose undue risk to the public.

We believe that large quantities of these substances should not be transported through densely populated areas unless they cannot otherwise be delivered. We also see the need for the Congress to consider consolidating in a single Federal Energy Health and Safety Regulatory Agency many such responsibilities currently scattered throughout many departments and agencies.

The report is presented in three volumes. Volume 1 contains the Executive Summary and the report chapters; Volume 2, the appendixes that support and supplement the chapters; and Volume 3, the full texts of the official comments we received from Federal agencies.

In the Executive Summary, we have attempted to summarize and simplify the most significant points from the chapters.

Copies of this report are being sent to the Secretaries of Commerce, Energy, State, and Transportation; the Chairman of the Interstate Commerce Commission; the National Transportation Safety Board; and the chairmen of energy related congressional committees and subcommittees.

Elmer B. Staats
Comptroller General
of the United States

EXECUTIVE SUMMARY

OF

LIQUEFIED ENERGY GASES SAFETY

C O N T E N T S

ABBREVIATIONS

DOE	Department of Energy
DOT	Department of Transportation
FPC	Federal Power Commission
GAO	General Accounting Office
ICC	Interstate Commerce Commission
LEG	Liquefied Energy Gas (LNG and LPG)
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas (Propane and Butane)
OHMO	Office of Hazardous Materials Operations (DOT)
UBC	Uniform Building Code

SECTION 1

INTRODUCTION

CONTENTS

This Executive Summary contains brief discussions of the critical safety and security issues covered in GAO's full report, Liquefied Energy Gases Safety (EMD-78-28). The report consists of three volumes.

--Volume 1, the Executive Summary and the main text.

--Volume 2, appendixes that support and supplement the main text.

--Volume 3, comments on a draft of this report by the Departments of Commerce, Energy, State, and Transportation, the Interstate Commerce Commission, and the National Transportation Safety Board.

This Executive Summary highlights GAO's findings, conclusions, and recommendations. The body of the report contains the full supporting data and additional, more detailed conclusions and recommendations.

PURPOSE OF THE STUDY

Energy gases are liquefied in order to reduce their volume hundreds of times. This facilitates their transportation and storage, but magnifies the potential hazard.

Liquefied energy gases (LEG) are often transported and stored in densely populated areas. If these liquids spill from their containers, they rapidly vaporize and become highly flammable and explosive gases. One cubic meter of liquefied natural gas (LNG) makes 424,000 cubic feet of highly flammable natural gas-air mixture. One cubic meter of liquefied petroleum gas (LPG) makes a slightly larger volume of flammable gas-air mixture. A major spill in a densely populated area, whether by accident, natural forces, or sabotage, could be catastrophic.

Because of this potential danger and the possible increase in the use of these liquefied gases, LEG safety issues should now be carefully examined and any needed actions taken to protect the public.

This report analyzes these safety issues, identifies problem areas, and recommends corrective actions to the Congress and the cognizant Federal agencies. We believe that the Nation's LEG needs can be met without posing undue risk to the public if the recommendations developed in this report are adopted by the Congress and the Federal agencies involved.

A BRIEF PRIMER

Although there are many differences in their physical properties and technologies, LNG and LPG are similar substances and have many safety and security problems in common. This has made it convenient to consider them together as LEG. Naphtha, a less hazardous substance, is included in the report to compare its regulations and handling with those of LEG.

LNG, LPG, and naphtha together make up about 3 percent of the energy used in this country. They are produced domestically and are imported. All three are used to supplement domestic natural gas supplies. As America's energy demand grows, imported LNG and LPG are likely to become increasingly important energy sources. LPG and naphtha also have important industrial applications.

<u>Physical Properties of LEG and Naphtha</u>

Natural gas is an odorless, colorless mixture of hydrocarbons, 65 to 99 percent methane, with smaller amounts of ethane, propane, and butane. Chilled to -260 degrees (F), the gas becomes a liquid about one-600th of its volume at atmospheric pressure. Therefore, a tank of LNG has 600 times as much energy as an equal-sized tank of natural gas.

LPG (propane and/or butane) is processed from natural gas or crude oil. Both propane and butane liquefy under pressure at atmospheric temperature, or when cooled at atmospheric pressure. Propane liquefies at -44 degrees (F); butane at 31 degrees (F).

Naphtha is a group of heavier hydrocarbons separated from crude oil in the refining process. It is transported and stored as a liquid at atmospheric temperature and pressure.

LNG and LPG will only burn at the surface of the liquid. When spilled, however, both substances quickly vaporize.

Because LPG vapor and cold LNG vapor are heavier than air, a spill forms a low spreading cloud, which becomes highly flammable as it mixes with air. An LNG vapor cloud is flammable when the LNG concentration is between 5 and 14 percent (the balance being air). The flammable range of an LPG cloud is between 2 and 9 percent LPG.

Naphtha is between kerosene and gasoline in volatility. All three, being liquids at atmospheric temperatures and pressures, are much less volatile than LNG and LPG; that is, they evaporate much more slowly.

Overview of LNG Storage and Transportation

In the summer, when natural gas demand is low, some excess gas is liquefied and stored in highly insulated tanks. A typical LNG storage tank can hold 95,000 cubic meters--enough to make nearly 2 billion cubic feet of natural gas. When demand peaks in cold weather, the LNG is either regasified and pumped through gas pipelines to customers, or delivered by truck to other gas companies where it is similarly processed.

Such "peakshaving" plants have been operating in the United States for several years. Most large LNG storage facilities are for peakshaving. There are currently 45 of these which hold more than 23,000 cubic meters. There are about 75 LNG trucks, each with about 40 cubic meters capacity.

Recently, LNG has been imported in ships. These imports, which now supply less than one-tenth of one percent of U.S.

natural gas demand, could supply up to 15 percent by 1985.* This would require more than 40 LNG tankers to operate regularly in and out of U.S. harbors. A typical new LNG tanker carries about 125,000 cubic meters.

The 14 major LNG import terminals now operating throughout the world are "base-load" facilities. The LNG is piped from the ship to storage tanks from which it is constantly regasified or re-shipped, instead of being saved for peak demand periods.

There are two LNG import terminals currently operating in this country. The Everett, Massachusetts terminal began operations in 1971. The new Cove Point, Maryland terminal began operations in March 1978, and the Elba Island, Georgia terminal is ready to begin. One other terminal is under construction, and several more have been proposed.

Overview of LPG Storage and Transportation

The much greater use of LPG has drawn less public attention than the relatively new LNG industry. LPG has been used for many years for a variety of purposes, including making synthetic natural gas and providing power on farms.

About 85 percent of the LPG in bulk storage is kept under pressure in underground salt domes or mined caverns. LPG is also stored in aboveground tanks, many of which are small.

---

*Office of Technology Assessment, Transportation of Liquefied Natural Gas, September 1977, p.5.

There are only 20 LPG aboveground storage facilities that hold more than 23,000 cubic meters.

Domestic transportation of LPG is mostly by pipeline, with the remainder distributed in trucks or railcars. There are 70,000 miles of LPG high-pressure pipeline, 16,000 LPG rail cars, and 25,000 LPG transport and delivery vehicles. A large LPG truck trailer holds about 40 cubic meters.

Ten major LPG import terminals are now operating in the United States, and imports of LPG may rise substantially. LPG ships are smaller than LNG ships; typical new ones hold 75,000 cubic meters.

SECTION 2

LEG STORAGE FACILITIES

VULNERABILITY TO NATURAL FORCES

LEG storage tanks are usually designed to the Uniform Building Code (UBC) standards for their particular geographic areas, the same standards used for most inhabited buildings. They essentially require that LEG tanks be able to withstand the largest earthquake, wind, flood, etc., locally experienced in the last 50, 100, or 200 years.

The probability of these natural forces exceeding UBC standards at a given site in a given year is low. However, the probability that the standards will be exceeded some time at some facility increases with the number of facilities and with the number of years each facility operates.

Because there are already many large LEG facilities, it is virtually certain that during their lifetime many of them will experience natural forces greater than those the UBC standards require them to withstand. This does not necessarily mean that the facilities will fail. The UBC standards are minimum criteria, and most structures have built-in "safety margins"--they are designed to be stronger than the standards require.

By "failure" of a tank, we mean a permanent distortion or rupture that causes significant leakage of the contained fluid. A failure is not necessarily a complete collapse.

We evaluated the LEG tank designs at five sites and found that, while they were adequately designed for the UBC earthquake and 100-year wind criteria, tanks at three of the sites had very small earthquake safety margins--two of these three sites, containing three large tanks, are located next to each other in Boston Harbor.

Nuclear power plants are built to higher standards than any other type of energy installation, much higher than those for LEG installations. Nevertheless, they are never located in densely populated areas. We believe that new large LEG facilities also should not be located in densely populated areas.

Most LNG storage tanks have double metal walls with insulation in between. Some are made of prestressed concrete. LPG and naphtha tanks have single walls.

The outer steel walls of LNG tanks are not normally made to withstand intense cold. Thus, if the inner tank alone fails for any reason, it is almost certain that the outer tank will rupture from the pressure and thermal shock.

The most likely cause of failure of large steel LEG tanks in an earthquake appears to be from breaking the steel straps which anchor the steel tank sides to the concrete foundation. The tank's walls will then separate from its bottom, causing a massive spill.

Large LEG tanks made of prestressed concrete are usually much more resistant to natural forces than those made of steel.

THE ABILITY OF DIKES TO CONTAIN LARGE SPILLS

National Fire Protection Association standards require that each large LEG tank, or group of tanks, be surrounded by a dike which can hold at least the volume of the largest tank. However, most of these dikes are only designed to contain LEG spilled from relatively slow leaks. They cannot contain the surge of LEG from a massive rupture or collapse of a tank wall.

We selected six LEG facilities--with dikes built to National Fire Protection Association criteria--and calculated how much liquid could escape over the dikes. Our calculations were verified by experiments.

Our results indicate that a massive rupture or collapse of a tank wall could spill over 50 percent of the LEG at five of the facilities. The sixth facility would probably spill no more than 13 percent of its LEG, because it has a close, high dike--however, a force that could destroy the tank might also destroy this dike.

The following table shows the maximum calculated spillage from single tanks at each of the six facilities.

Facility	Volume spilled (cubic meters)	Percent of tank capacity spilled
Algonquin LNG, Providence, RI	52,000	55
Columbia LNG, Cove Point, MD	31,200	52
Distrigas, Everett, MA		
Tank 1	37,200	62
Tank 2	60,800	64
Philadelphia Electric, Philadelphia, PA	7,100	13
Southern Energy, Elba Island, GA	36,500	58
Exxon LPG, Everett, MA	36,500	58

Our calculations assumed an immediate, total spill of a full tank, with the fluid moving toward the nearest dike wall. Such an LNG spill occurred in Cleveland in 1944. A similar, much larger LPG spill occurred in the country of Qatar in 1977.

THE ADVANTAGE OF INGROUND LNG STORAGE

Liquid spills from inground tanks are nearly impossible. Many LNG tanks in Japan, the world's largest importer of LNG, are built in the ground for greater safety. Japanese inground tanks are operating satisfactorily and cost about the same there as aboveground tank and dike installations.

VULNERABILITY TO SABOTAGE

Public utilities and petroleum companies in this country have often been the targets of sabotage. Many domestic and foreign groups have the weapons, explosives, and ability to sabotage LEG facilities. Successful sabotage of an LEG facility in an urban area could cause a catastrophe.

We found that security procedures and physical barriers at LEG facilities are generally not adequate to deter even an untrained saboteur.

None of the LEG storage tanks we examined are impervious to sabotage, and most are highly vulnerable. Some designs provide greater protection than others against explosive penetration. Stronger designs complicate sabotage by requiring specially designed charges, more powerful explosives, and more on-site preparation. Concrete tanks are much more resistant to penetration than single-wall LPG tanks. Double-wall metal LNG tanks fall in between.

In many facilities, by manipulating the equipment, it is possible to spill a large amount of fluid outside the diked area through the draw-off lines.

LEG storage facilities in cities are often adjacent to sites that store very large quantities of other hazardous substances, including other volatile liquids. Thus, a single cause might simultaneously destroy many tanks, or a spill at one facility might cause further failures at adjacent facilities.

MAJOR CONCLUSIONS AND RECOMMENDATIONS

Conclusions

--It is virtually certain that the level of natural forces LEG facilities are required to withstand will be exceeded at many facilities in the next 50 years. This could lead to tank failure, particularly where safety margins are low.

--Little attention has been paid to sabotage at LEG facilities, and most of them are inadequately protected and highly vulnerable to sabotage. Sabotage could also lead to tank failure.

--If an LEG tank fails in a densely-populated urban area, it could cause a catastrophe.

--In the event of a massive rupture or collapse of a tank wall, over 50 percent of the LEG could escape over the dikes at five of the six LEG facilities we examined.

Recommendations to Federal Agencies

1. We recommend that the Secretaries of Transportation and Energy and the Federal Energy Regulatory Commission take steps to ensure that

--all new, large LEG storage facilities are built in remote areas; and

--no existing, large LEG storage facilities in other than remote areas are expanded in size or in use.

2. If, despite our recommendation, new, large LEG storage facilities are built in other than remote areas, or existing ones are expanded in size or use, we recommend that

--all storage tanks be in the ground with the highest level of fluid below ground level; or

--all storage tanks be built and operated to standards similar to those applied to the construction and operation of nuclear plants.

3. We recommend that the Secretary of Energy evaluate each existing, large LEG storage facility and recommend to the President and the Congress the actions necessary to protect the public from the hazards associated with them.

Recommendations to the Congress

We recommend that the Congress:

--Enact legislation requiring that guards at LEG facilities carry weapons and be authorized to use them if necessary to avert sabotage.

--Enact legislation extending Federal authority to cover large LEG storage facilities which are presently not covered by Federal regulation.

SECTION 3

LEG TRANSPORTATION

LEG SHIPS

LNG ships, which hold up to 165,000 cubic meters, are probably the least vulnerable of all the systems involved in LNG transportation and storage. They are double-hulled and have insulated cargo tanks made of welded 9 percent nickel-alloy steel or aluminum alloy, both of which can withstand intense cold. Two basic types of tanks are used--free standing tanks which are anchored in the ship's hull, and "membrane" tanks supported by insulation lining the hull. The double hull helps protect against collisions or sabotage.

On the other hand, most LPG and naphtha ships are single-hulled, and are thus much less resistant to collisions and sabotage than LNG tankers. The largest new LPG ships hold 100,000 cubic meters.

Ships are most susceptible to collision while entering ports through narrow, winding ship channels. They are most vulnerable to sabotage while tied up at terminals.

Since human error is a contributing factor in 85 percent of all marine casualties and operating problems, the best precaution against accidents and sabotage is to have highly-skilled, well-trained personnel operating the ships, ports, and terminals.

We have studied the Coast Guard's port operating procedures, and the training requirements for LEG ships' crews, and believe that they need to be improved.

Most Coast Guard personnel, including some Hazardous Materials Officers, have little training in LEG hazards.

Some training for ships' crews is covered in the Coast Guard's proposed Tankerman Requirements. We do not believe these proposed requirements will be adequate, because

--only one or two crew members responsible for cargo handling are required to receive formal training;

--requirements for practical experience are inadequate; and

--instruction in emergency procedures is not required.

We found similar weaknesses in the training requirements being considered for LNG terminal personnel. These are included in the Coast Guard's contemplated Waterfront Facilities Regulations for LNG in Bulk, and in the LNG terminal regulations being considered by the Office of Pipeline Safety Operations of the Department of Transportation (DOT). Similar regulations for LPG waterfront facilities have not yet been proposed.

The Coast Guard inspects all LNG ships before they enter U.S. harbors. These inspections do not include the operating condition of control equipment such as steering engines, propulsion machinery, and electronic devices.

In February 1976, the Coast Guard issued Liquefied Natural Gas - Views and Practices, Policy and Safety. The publication offers valuable guidance, but its procedures are not mandatory. Its implementation is left to the discretion of each Captain of the Port. It is the Captain of the Port who decides whether malfunctions in ships' safety systems are serious enough to bar their entry into a U.S. harbor. There are no specific Coast Guard guidelines covering LPG.

Another problem is the proximity of some shipping channels to airports. For example, LEG tankers regularly enter Boston Harbor through a shipping channel adjacent to Logan International Airport. On one occasion, an airplane crashed into the seawall of the shipping channel. The Federal Aviation Administration plans to adopt our suggestion that landings on the adjacent runway be suspended during the few minutes that an LEG ship in the channel is in line with the runway.

LEG TRUCKS

While LEG trucks carry only 40 cubic meters, far less than LEG ships, they move routinely through major metropolitan areas, where a relatively small spill can have very serious consequences.

LNG truck trailers have a higher center of gravity than most tank trucks, which makes them particularly susceptible to rolling over. However, they have inner and outer tanks with insulation in between and thus are quite resistant to puncture and cargo loss. LPG trucks also have a high center of gravity, although lower than LNG trucks; but they are single-walled and pressurized, and are therefore more vulnerable than LNG trucks to cracks and punctures and more likely to explode in fires.

We confirmed through discussions with LNG transport companies at least 12 LNG trailer accidents. Two of the accidents, which led to LNG spills, pointed out two vulnerable areas on LNG truck tanks--the unprotected portion of the trailer face, and the rear piping.

There have been many LPG truck accidents, some with severe consequences. For example, a 1975 LPG truck accident near Eagle Pass, Texas, caused explosions which killed 16 people and injured 45.

If an LEG truck fell from an urban elevated highway, it would probably split open on the street below. LEG and its vapors could then flow down into sewers, subways, and basements. Because of its low boiling point, LEG would quickly vaporize, generating a pressure which would spread the invisible, odorless, explosive gas. The 40 cubic meters of LNG in one truck, vaporized and mixed with air in flammable proportions, are enough to fill more than 110 miles of 6-foot diameter sewer line, or 15 miles of a 16-foot diameter subway system. Other types of large trucks have fallen off urban elevated highways.

DOT has no special inspection program for LEG trucks. For all U.S. trucking, there are only 128 inspectors to monitor 160,000 licensed carriers and 3 million commercial vehicles.

The Interstate Commerce Commission (ICC) issues special certificates for LNG transport, but LNG can also be hauled under ICC certificates for the bulk transportation of petroleum products or liquid chemicals. An ICC certified company can hire 'leased operators' to operate under its certificate. This means that LNG may be trucked by companies which have not had to prove their competence to ICC. ICC certificates do not restrict truck routes.

LEG trucks could be easily hijacked or sabotaged. A truck might be hijacked for extortion or for malicious use of the cargo. Trucks that routinely operate over established routes are easy targets for saboteurs. LEG trucks are particularly dangerous, because they allow the easy capture, delivery, and release of a large amount of explosive material any place the terrorist chooses.

LPG RAILCARS

Ten percent of America's 1.7 million railroad freight cars are hazardous materials tank cars. About 16,000 of these, each with approximately 115 cubic meters capacity, carry LPG. LNG is not transported by rail.

LPG cars are involved in many of the 10,000 railroad accidents that occur in this country each year. There are often more than 10 consecutive LPG cars on a train. If vapors from one LPG car ignite, the fire may cause a second, unpunctured car to rupture in a "Boiling Liquid Expanding Vapor Explosion," or BLEVE. Each fire and explosion contributes to the heating and weakening of neighboring cars and makes additional explosions more likely. A BLEVE can rocket a 45,000 pound steel section of a tank for a quarter of a mile. This is what happened in a derailment near Oneonta, New York, in 1974. LPG vapor from a crushed LPG car quickly ignited and formed a fireball. Fire fighters attempting to cool down several other LPG cars were caught in a subsequent explosion; 54 were injured.

Other types of LPG railroad accidents have also occurred. In a 1974 railyard accident near Decatur, Illinois, an LPG railcar was punctured; the resulting cloud did not ignite immediately, but spread and then exploded over an area one-half by three-quarters of a mile. There were 7 deaths, 349 injuries, and $24 million in damages. Litter and debris from the fire and explosion covered 20 blocks of the city.

The latest LPG railroad catastrophe occurred February 1978, in Waverly, Tennessee. An LPG car exploded two days after a derailment, apparently as a result of internal damage during the accident and a rise in the atmospheric temperature. Fifteen were killed and over 40 injured.

LPG railcars travel through densely populated areas of cities, even cities which prohibit LPG storage. If these LPG railcar accidents (or the LEG truck accidents) had occurred in densely populated areas, far greater damage might have resulted.

The LPG industry and DOT recognize the danger in LPG rail movement, and have collaborated in identifying and correcting deficiencies in tank car design. In September 1977, as a result of a long inquiry, DOT amended its regulations to require that all LPG tank cars have safer couplers, headshields, and thermal protection; old cars were required to have the safer couplers by June 30, 1979, and headshields and thermal protection by December 31, 1981. However, after the Waverly accident, subsequent recommendations from the National Transportation Safety Board, and Congressional inquiries, DOT has proposed regulations to require the couplers by December 31, 1978, and the other features by December 31, 1980.

DOT and the industry oppose restrictions on LPG railcar routing for several reasons. These include:

--it is simpler and cheaper to regulate tank car design than tank car movement;

--trains move more slowly in congested areas, decreasing the chance of an accident; and

--some accidents occur while handling and switching cars, more of which would be necessary in circuitous routing.

DOT believes that the new regulations for tank car construction are sufficient for their safe operation. We believe that restriction of routes is also necessary.

LPG tank cars are as vulnerable to sabotage as LPG trucks. The tanks can be breached with readily available weapons and explosives, and the cars can be derailed at predetermined times and places. The fact that they must stay on the tracks, however, greatly limits the possibility of hijacking and the places they can be taken.

THE LOCATION OF IMPORT TERMINALS

Locating LEG import terminals in non-urban areas would be an important safety step.

Existing and planned non-urban LPG import terminals will have the capacity to receive all projected LPG imports in 1985. We did not determine the cost of distributing the LPG from those terminals.

With some expansion, existing and planned non-urban LNG terminals could handle all of the LNG imports projected between now and 1990. We did not look at the capacity of the main gas transmission lines to distribute this gas to customers. To our knowledge, the Federal Power Commission (disbanded with the formation of DOE) has not considered the alternative of using only non-urban sites to receive all LNG imports.

MAJOR CONCLUSIONS AND RECOMMENDATIONS

LNG ships are probably the least vulnerable of all the systems involved in LNG storage and transportation. LPG and naphtha ships with single hulls are more vulnerable than LNG ships in the event of an accident or sabotage. No plans or equipment exist to cope with a major LEG spill. If the Coast Guard is to effectively supervise the increasing number of LEG cargo transfer operations, it will need more money and manpower, revised regulations, and new plans and policies.

LEG trucks and railcars moving through densely populated areas pose a serious threat to public safety. The dangers present in trucking LEG are far greater than those involved in trucking less volatile petroleum products such as fuel oil, naphtha, and gasoline. Both LEG trucks and LPG railcars are vulnerable to accidents and sabotage. An LEG spill in a densely populated area could lead to a catastrophe.

We recommend that the Secretary of Transportation and the ICC:

--Prohibit trucking of LEG through densely populated areas and any areas that have features that increase the vulnerability to a major LEG spill (e.g., sewer systems, tunnel openings, subways) unless delivery is otherwise impossible. DOT should also give particular attention to avoiding routes with highway configurations which make tank rupture accidents likely (e.g., elevated roadways, overpasses, high-speed traffic, roadside abutments).

--Prohibit the travel of LPG railcars through densely populated areas unless it is impossible to deliver the LPG otherwise.

We also recommend that the Secretary of Transportation:

--Develop a computer program able to analyze the capability of the national LPG storage and distribution system. Such a program should be able to determine the rate at which LPG can be delivered (as LPG or as synthetic natural gas) from any point to any other point and the cost to increase this capability by any desired amount.

We recommend that the Secretary of Energy and the Federal Energy Regulatory Commission:

--Require a staff study of the feasibility of using only non-urban sites to receive all LNG imports and developing a gas exchange program using existing pipelines to ensure appropriate distribution of gas supplies.

SECTION 4

THE POTENTIAL CONSEQUENCES

THE EFFECTS OF A LARGE LEG SPILL

While LEG storage and transportation in densely populated areas are very hazardous, it is difficult to estimate the effect of a large LEG spill.

The only significant U.S. LNG spill, in Cleveland in 1944, involved a relatively small amount compared to the quantities stored in urban areas today, about one-fifteenth of one large modern tank.

Some insight can be gained from the spill of naphtha into the sewers of Akron, Ohio, in June 1977. Although naphtha is much less volatile than LEG and less than 15 cubic meters were spilled, the incident caused violent explosions more than 8 miles from the point of the spill.

LEG vapors are highly explosive in confinement, and can explode in the open air--although the conditions which allow this are not completely understood. In Port Hudson, Missouri, in 1970, a relatively small propane leak from a pipeline break led to a large detonation propagating through the open air.

If LEG spreads across a city through sewers, subways, or other underground conduits, or if a massive burning cloud is blown along by a strong wind, a city may be faced with a very large number of ignitions and explosions across a wide area.

No present or foreseeable equipment can put out a very large LEG fire.

THE CLEVELAND ACCIDENT

The only major LNG spill in the United States occurred in Cleveland, on October 20, 1944. It resulted in fires and explosions that killed 130 people, injured 225 more, and resulted in property damage estimated at $7 million.

Casualties could have been much higher if the spill had taken place at a different time of day. At the time of the fire, most children were at school and most men were at work. Furthermore, the National Fire Protection Association Newsletter of November 1944 said:

> "The fact that the wind was blowing away from the congested part of the area is believed to have been a major factor in prevention of an even more devastating conflagration which could have destroyed a very large part of the East Side."

The Cleveland accident virtually halted LNG use in this Nation for 20 years.

This disaster demonstrates the danger of a spill in an urban area, and gives some indication of the potential consequences of a major LNG accident. It was the subject of three independent studies:

--A Technical Consultants Board of Inquiry for the Mayor of Cleveland.

--The Bureau of Mines of the U.S. Department of the Interior.

--The Coroner of Cuyahoga County, Ohio--whose conclusions and recommendations were included in the Mayor's report.

The accident occurred in the liquefaction, storage, and regasification (peakshaving) plant of the East Ohio Gas Company, the first peakshaving plant built in America.

At 2:40 p.m., a 4,200 cubic meter LNG tank collapsed. Although that tank and the three others were surrounded by dikes and had individual drains leading to a pit, some of the liquid escaped the site and spread into streets, storm sewers, and basements. The vapors quickly ignited, setting off explosions and fires.

About 20 minutes later, the legs holding a second tank failed from the heat, releasing another 2,100 cubic meters of LNG. The subsequent explosion shot flames more than half a mile into the air. The temperature in some areas reached 3000 degrees (F).

The following facts are significant.

--Both the tank manufacturer and the gas company assumed that a small leak would precede any more serious spill, and that it would be detected and repaired.

--The gas company took precautions to control small and moderate rates of LNG spillage. They assumed that a sudden, massive spill was extremely unlikely and, therefore, not a matter for concern. The same assumption is made today in designing dikes around LEG facilities.

--The plant site was selected because it was already company property and was appropriately located on the gas distribution system. The company felt it was building a safe plant that could be located anywhere. Similar assumptions about the safety of LEG plants in urban areas are made today.

--The proximity of other industrial facilities, residences, storm sewers, or other conduits was not considered.

--The Cleveland accident was caused by an amount of LNG which is very small by modern standards. Less than 6,300 cubic meters of LNG spilled and a large portion of that remained on the company property. Typical large LNG storage tanks today can hold up to 95,000 cubic meters, and one site may have several tanks.

The 1945 Bureau of Mines study of the Cleveland accident contained the following recommendations, which have yet to be generally adopted.

1. Plants dealing with large quantities of liquefied flammable gases should be isolated at considerable distance from inhabited areas.
2. Extreme caution should be taken to prevent spilled gas from entering storm sewers or other underground conduits.

SECTION 5

LIABILITY, RESEARCH, AND REGULATION

LIABILITY AND COMPENSATION

A major LEG accident could cause damage of such severity that injured parties could not be fully compensated under existing arrangements. Present corporate structures and legal limits on liability offer great protection to the parent corporations. This may diminish their incentives for safety. At present, no Federal agency addresses the question of offsite liability for LEG accidents.

Each LNG ship is usually owned or leased by a separately incorporated subsidiary of a parent firm, and the LNG is stored in terminals owned by other subsidiaries. In many cases, the parent firms are wholly-owned subsidiaries of still larger firms.

Most of the assets in the system are protected by these corporate chains, and the top corporations, which derive all of the profits, would generally not be liable for the consequences of an accident. The front-line companies, which are most vulnerable to liability claims, are usually the most thinly capitalized in the chain. Most of their assets may be the ship or terminal itself, which is unlikely to survive an accident that does extensive offsite damage.

The liability of shipowners and bareboat ship charterers is limited by U.S. statute to the post-accident value of the vessel, plus any amounts owing for freight, if they can prove that they did not know about the causes of the accident.

Claimants after a major LNG accident would face long, complex, and expensive litigation involving potential complications at every step in the legal process. If the defendant corporation is foreign-owned, it and its assets may be out of reach--in fact, it may be impossible to serve legal papers on the corporation unless it maintains an agent in the United States.

It is not always possible to prove the primary cause of a major accident, since critical evidence may be destroyed by the accident itself. If the accident resulted from sabotage or natural forces, the company may not be liable at all.

Present and planned liability coverage for LNG import terminals ranges from $50 million to $190 million per incident. Ten states require proof of liability insurance for LPG facilities, but the maximum required is only $100,000 per incident.

LEG SAFETY RESEARCH

All LEG safety research has involved quantities which are very small compared to those in large commercial facilities. The Coast Guard has done some good quality hazard analyses, primarily on the effects of small LEG spills on the water.

Isolated pieces of research of varying quality have been done by other government and private laboratories around the world.

We believe that much more research needs to be done, on an expedited basis, in many areas of LEG safety. In particular, the following areas need much more attention:

--The interaction of spilled LEG with man-made structures, such as buildings, subways, sewers, and ships.

--The conditions under which a large LEG cloud ignited on its downwind side will burn back to its source.

--The conditions under which LEG clouds can detonate.

--The distances that large LEG clouds can travel, under varying atmospheric conditions, before they are safely dispersed.

The present plan to channel the bulk of LNG safety research through the Department of Energy (DOE) is faulty and will not produce timely or useful safety results. DOE plans to support LNG research in a manner analogous to its support of basic research in other areas. This is entirely inappropriate because of the number of facilities now under development, under construction, or in use. LNG facilities may only be importing for the next 20 or 30 years. The research needed for current, temporary technology is different from that which is needed for long-term and not yet perfected technologies. At the same time, the organizations responsible for safety regulations and enforcement have inadequate budgets and personnel to make informed technical judgments on safety.

LEG risk assessment studies have not reached a stage where they give confidence in their conclusions. Therefore, safety decisions cannot logically be based on them. Regulatory agencies will have to attempt to make timely, prudent decisions with the realization that many important questions cannot currently be answered with confidence.

FEDERAL, STATE, AND LOCAL REGULATIONS

LNG and LPG are very hazardous substances. Federal regulation and inspection of their importation, transportation, and storage have not been adequate to ensure the public safety.

Federal safety responsibilities are shared by many departments and agencies.

The Department of Transportation has overall authority for the movement of hazardous materials. Specific authority has been delegated to several agencies within the Department. Among them:

--The Materials Transportation Bureau promulgates regulations for all hazardous materials transportation. It includes the Office of Pipeline Safety Operations which regulates and inspects pipelines and connected storage facilities; and the Office of Hazardous Materials Operations (OHMO) which prescribes regulations for other modes of transportation.

--The Coast Guard promulgates regulations for ships and waterfront facilities. It also has broad enforcement authority for its own regulations, and for OHMO's.

--The Federal Railroad Administration and the Federal Highway Administration prescribe and enforce regulations, including OHMO's, in their respective jurisdictions.

The Department of Energy has the authority to certificate some LNG facilities. This authority is vested in the Economic Regulatory Administration and the Federal Energy Regulatory Commission, which can impose requirements beyond the DOT minimum standards on facilities under their jurisdiction.

The Interstate Commerce Commission has economic authority over interstate trucks and railroads, and can consider safety matters in its certification process.

These agencies have generally failed to give adequate attention to the unique dangers presented by LEG. Rulemaking has been too slow. Regulations for LEG facilities have been partly based on outdated National Fire Protection Association standards, some of which we have shown to be inadequate. Many LEG facilities have not been subjected to Federal regulation at all, partly because of a failure of the cognizant agencies to fully assert their authority.

The regulation of LEG and naphtha by state and local governments varies widely. Some jurisdictions have no specific regulations other than normal fire hazard restrictions.

Others, such as the New York State Public Service Commission and New York City Fire Department, have more stringent regulations than the Federal Government.

The problem is further aggravated by a shortage of trained inspectors at all levels of government.

MAJOR CONCLUSIONS AND RECOMMENDATIONS

Liability and Compensation

The present liability and compensation system is not equitable and does not provide sufficient incentives for safety. We believe that the corporate owners who profit from LEG operations should bear liability for a major accident.

The banks and insurance companies which finance LEG ships and terminals insist that all companies in the corporate chain co-sign notes. This insures that, in the event of a catastrophic accident, the lending institutions will be protected by the assets of the whole corporate chain. Public safety deserves no less protection.

Recommendations to the Congress

We recommend that the Congress enact legislation which would:

--Require corporations transporting, storing, or using significant amounts of flammable materials to (1) carry the maximum liability insurance available from the private sector, and (2) contribute money to a Federal Hazardous Materials Compensation Fund.

--Provide that the United States be subrogated to the rights of injured persons compensated by the fund so that the Attorney General of the United States can sue the companies or persons responsible for an LEG incident to recover whatever monies the fund has paid out.

--Allow injured parties to sue all companies in the corporate chain for all damages beyond those covered by insurance and the fund.

We also recommend that the Congress:

--Enact legislation which requires that strict liability be applied in all accidents involving LNG and LPG, and consider requiring that strict liability be applied to other highly hazardous materials.

--Amend the 1851 Act (46 U.S.C. 183) which limits the liability of owners and bareboat charterers of ships and barges by substantially raising the statutory limit for vessels carrying hazardous materials.

Recommendations to the Secretary of Energy and the Federal Energy Regulatory Commission

We recommend that the Secretary of Energy and the Federal Energy Regulatory Commission:

--Ensure that adequate compensation for offsite damage will be available to injured parties before permitting LNG projects to proceed.

--Use their authority to require that importers and LNG tanker companies maintain agents for the receipt of legal documents in all states in which they operate.

LEG Safety Research

The limited research that has been carried out on LEG spills and LEG vapor cloud behavior does not provide a sound basis for assessing LEG hazards.

LEG risk assessment studies have not reached a stage where their conclusions can be relied on. Until they do, regulators will have to attempt to make timely, prudent, siting and other critical judgments with the realization that many important safety questions cannot yet be answered with confidence.

DOE's currently planned LNG safety research program will not provide answers soon enough. We believe that an effective safety research program, focusing on those issues most important to decision makers, can be carried out within two years for less than one-fifth of the $50 million DOE is planning to spend on long-term LNG research. We have made detailed suggestions for such a program in the body of the report.

Federal Regulation of LEG and Naphtha

Present Federal efforts to regulate LEG and naphtha do not adequately protect the public. We believe that many Federal regulatory responsibilities for energy health and safety should be consolidated into a single, independent agency. This was one of the options for Congressional consideration provided in GAO's 1977 report, "Energy Policy Decisionmaking, Organization, and National Energy Goals".

With a mandate to adequately protect the public health and safety, such an agency could assemble a technical staff capable of developing appropriate regulations and inspecting and enforcing the implementation of those regulations.

We recommend that the Congress:

--Consider creating an Energy Health and Safety Regulatory Agency. The new agency could include the Nuclear Regulatory Commission; the pipeline safety aspects of fuel transportation on land, now handled by DOT; and safety aspects of importing energy, now handled by DOE, plus all safety responsibilities formerly carried out by the Federal Power Commission.

--Consider including within the Energy Health and Safety Regulatory Agency the safety regulation of LEG carried by truck and train. DOT would continue to be responsible for all safety regulation of motor carriers and railroads, except those transporting nuclear materials and LEG. The Environmental Protection Agency should retain the responsibility for setting air and water quality standards impacting on energy development, use, and waste disposal.

--Consider making the Energy Health and Safety Regulatory Agency completely independent of DOE, or including it within DOE with strong statutory provisions to insure its independence.

SECTION 6

THE BASIS AND SCOPE OF GAO'S STUDY

For GAO, this study was unique in several ways. It covered highly complex subject matter, required the use of many technical consultants and contractors, and involved laboratory and field experiments to verify certain calculations.

The purpose of the study was to determine whether, under current practices and regulations, the public is adequately protected from the dangers of LNG and LPG. Naphtha, a much less volatile mixture of hydrocarbons, was included to permit comparisons of its handling with that of LNG and LPG.

We conducted an extensive review of LEG safety literature, including previous studies, company literature, government reports, and technical journals.

We visited 37 import, storage, shipyard, transportation, and design facilities in the United States and Japan, and made a detailed study of the blueprints of many of them. We spoke with concerned Federal, state, and local officials, and industry and citizen organizations. Each group we visited was offered a briefing on the problems we were examining, and we suggested that they look into the same areas so they would be in a position to comment on our findings. On the whole, we received excellent cooperation from companies, organizations, and Federal agencies.

COMMENTS FROM THE INDUSTRY AND FEDERAL AGENCIES

In keeping with GAO policy, we provided a draft of the full report to all cognizant Federal agencies for their review and comment. In addition, we provided over 50 LEG companies with copies of those chapters of the draft in which they were discussed.

We received official comments from six Federal agencies, and 34 private LEG organizations. We considered all of these comments before preparing the final report.

While we can only briefly summarize the comments here, many of them are addressed on a chapter-by-chapter basis in the full report. The final chapter discusses general concerns of agencies and companies that are not covered in specific chapters. In addition, the full texts of the Federal agencies' comments have been printed as Volume 3 of this report. Many of the LEG companies' comments also are addressed in the report chapters; the full texts of those comments are available for review at the U.S. General Accounting Office, 441 G Street, N.W., Washington, D.C.

We greatly appreciate the time and effort that many of these organizations spent on the report. Their comments contributed significantly toward assuring the quality and accuracy of the report, and in lending balance to the positions we have taken.

The comments generally fell into the following four categories:

1. Concern that GAO had singled out LEG, to the exclusion of other hazardous substances.

   Yes, we did single out LEG for this study, because it is an important energy source, its use may increase substantially, and it is potentially very hazardous. We do not, however, mean to suggest that LEG is the only commodity for public concern. There are other hazardous substances that may pose considerable threat to the public, and many of the issues discussed in this report are applicable to them.

2. Concern that GAO had overlooked the safety record of the LEG industry.

   There is a long history of accidents in all aspects of LPG use. There have been fewer accidents in the relatively new LNG industry. Nonetheless, there have been many documented incidents in LNG production, storage, and transportation.

   The only catastrophic LNG accident occurred in Cleveland, in 1944. We discuss that accident for two reasons. While the amount spilled is small compared to the quantities stored in urban areas today, it gives some indication of what the effects of a major accident in a metropolitan area might be; and it still offers lessons to be learned.

The Cleveland facility was the first U.S. LNG plant. After the plant was destroyed, LNG was not used in this country for 20 years.

3. Concern about the discussion of sabotage.

   We believe that the possibility of sabotage must be considered and carefully treated in any complete evaluation of LEG safety.

   In preparing the report, we tried to ensure that the sabotage discussions were free of inflammatory statements or expressions, and that they contained no detailed information that could be used by saboteurs or terrorists.

4. Disagreement with specific statements in the draft.

   Where comments pointed out errors in the draft, we have made the appropriate corrections. Some of the comments with which we disagreed are evaluated in the chapters of the report.

CONTENTS

VOLUME I

EXECUTIVE SUMMARY

*A more detailed table of contents is provided at the beginning of most of the individual chapters.

APPENDIX

APPENDIX

XIV-1	LPG DEMAND
XIV-2	LPG MARINE IMPORT TERMINALS
XVI-1	IDENTIFICATION OF FACILITIES
XVI-2	DESCRIPTION OF 12 LEG FACILITIES
XVI-3	FEDERAL REGULATIONS
XVI-4	STATE REGULATORY SUMMARY
XVI-5	SPECIAL ISSUES ANALYSES
XVI-6	SOME PERTINENT STATUTORY CITATIONS
XVIII-1	APPLICATIONS TO THE FEDERAL POWER COMMISSION FOR LNG TERMINAL FACILITIES
XVIII-2	LIST OF SAFETY EVIDENCE PRESENTED TO THE FEDERAL POWER COMMISSION
XIX	JAPANESE ENERGY USE

VOLUME 3

FEDERAL AGENCY COMMENTS

DEPARTMENT OF COMMERCE

DEPARTMENT OF ENERGY

DEPARTMENT OF STATE

DEPARTMENT OF TRANSPORTATION

INTERSTATE COMMERCE COMMISSION

NATIONAL TRANSPORTATION SAFETY BOARD

ACRONYMS

AAR	Association of American Railroads
ACI	American Concrete Institute
ALJ	Administrative Law Judge
ANSI	American National Standards Institute
API	American Petroleum Institute
ASLAB	Atomic Safety and Licensing Appeals Board
ASLB	Atomic Safety and Licensing Board
ASME	American Society of Mechanical Engineers
BLEVE	Boiling Liquid Expanding Vapor Explosion
BMCS	Bureau of Motor Carrier Safety, DOT
BNG	Bureau of Natural Gas, FPC
CBI	Chicago Bridge and Iron Company
CFR	Code of Federal Regulations
COTP	Captain of the Port, U.S. Coast Guard
CPUC	California Public Utilities Commission
CTIAC	Chemical Transportation Industry Advisory Committee
DEIS	Draft Environmental Impact Statement
DH	decision height
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
EHSRA	Energy Health and Safety Regulatory Agency (proposed)
EIS	Environmental Impact Statement
EOG	East Ohio Gas Company
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration
FBI	Federal Bureau of Investigation
FERC	Federal Energy Regulatory Commission
FHWA	Federal Highway Administration, DOT
FPC	Federal Power Commission
FRA	Federal Railroad Administration, DOT
HMD	Hazardous Materials Division, FRA
HMCF	Hazardous Materials Compensation Fund (proposed)
HMO	hazardous materials officer, Coast Guard
ICC	Interstate Commerce Commission

IHI	Ishikawajima-Harima Heavy Industries Company
IMCO	Intergovernmental Maritime Consultative Organization
LEG	liquefied energy gases
LNG	liquefied natural gas
LOC	Letter of Compliance
LPG	liquefied petroleum gases
MHI	Mitsubishi Heavy Industries
MSA	Maritime Safety Agency, Japan
MTB	Materials Transportation Bureau, DOT
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards, DOC
NFPA	National Fire Protection Association
NFPCA	National Fire Prevention and Control Administration, DOC
NHTSA	National Highway Traffic Safety Administration, DOT
NRC	Nuclear Regulatory Commission
NNG	Northern National Gas Company
NTIS	National Technical Information Services
NTSB	National Transportation Safety Board
NYCFD	New York City Fire Department
OCA	Office of Crash Avoidance, NHTSA
OHMO	Office of Hazardous Materials Operations, MTB
OPSO	Office of Pipeline Safety Operations, MTB
PAD	Petroleum Administration for Defense
PDM	Pittsburgh-Des Moines Steel Company
PWSA	Ports and Waterways Safety Act of 1972
SAI	Science Applications, Inc.
SNG	synthetic natural gas
SSE	safe shutdown earthquake
TET	Texas Eastern Transmission Corporation
TID	Technology Information Division, Atomic Energy Commission
UBC	Uniform Building Code
USC	United States Code
VTS	Vessel Traffic Service

ABBREVIATIONS OF UNITS

BBL	=	barrels
BTU	=	British thermal units
cal	=	caliber
cm	=	centimeters
cps	=	cycles per second
CV	=	horsepower (metric)
d	=	days
ft	=	feet
^oF	=	degrees Fahrenheit
g	=	acceleration of gravity (32 ft/sec^2)
gm	=	grams
gpm	=	gallons per minute
hp	=	horsepower
hr	=	hour
Hz	=	hertz
in	=	inches
kcal	=	1000 calories
k-ft	=	1000 foot-pounds
kg	=	kilograms
kip	=	1000 pounds
km	=	kilometers
ksi	=	kips per square inch
kt	=	1000 metric tons
kts	=	knots
lbs	=	pounds
LT	=	long tons (2240 lbs)
m	=	meters
m^3	=	cubic meters
MBBL	=	1,000 barrels
MCF	=	1,000 cubic feet
MCM	=	1,000 cubic meters
min	=	minutes
mm	=	millimeters
MM	=	1,000,000
MMCF	=	1,000,000 cubic feet
MMCFD	=	1,000,000 cubic feet per day
MMm^3	=	1,000,000 cubic meters
mph	=	miles per hour

MMSCF	=	1,000,000 standard cubic feet
MMSCFD	=	1,000,000 standard cubic feet per day
MT	=	metric tons (1,000 kilograms)
MW	=	1,000,000 watts
NM	=	nautical miles
psf	=	pounds per square foot
psi	=	pounds per square inch
psia	=	pounds per square inch (absolute)
psig	=	pounds per square inch (gauge)
SCFM	=	standard cubic feet per minute
sec	=	seconds
T	=	tons
yr	=	years

CHAPTER 1

INTRODUCTION

Liquefied natural gas (LNG), liquefied petroleum gas (LPG), and naphtha together make up about 3 percent of the energy we use. All three are used to supplement natural gas. LPG and naphtha also have other important uses. This study is about the safety of these fuels.

Outside their containers, LNG and LPG rapidly vaporize and become highly flammable and explosive gases. A major spill in a densely populated area could be catastrophic. The report examines whether these fuels are being stored and moved without undue risk to the public.

Although there are many differences in their physical properties and technologies, LNG and LPG are similar substances and have many safety and security problems in common. This often makes it convenient to speak of them together as liquefied energy gases (LEG).

Naphtha, a mixture of hydrocarbons between kerosene and gasoline in volatility, was included to allow us to compare this much less dangerous material with LNG and LPG.

LNG and LPG are not the only highly dangerous materials which are transported and stored in large quantities, and some of our work is applicable to a broader class of hazardous materials. We have made more general conclusions and recommendations where they were warranted.

The report is intended to serve two purposes: to discuss issues, and to serve as a source of basic, relevant information. It is divided into three volumes. The executive summary and the main text appear in Volume 1. The appendixes, containing basic information which supplements the text or technical material which supports it, appear in Volume 2. The comments we received on our draft from Federal agencies make up Volume 3.

The second chapter is a brief primer to introduce the basic concepts on which the rest of the chapters are based. We strongly urge any reader not already familiar with this area to read it before reading the later chapters.

The next three chapters deal with the potential for large spills from LEG storage tanks. Chapter 3 examines the vulnerability of storage tanks to earthquakes and other natural forces. Chapter 4 estimates the "critical crack length" of metal LNG tanks. Cracks larger than this may cause a tank wall to suddenly unzip, immediately releasing all the enclosed fluid. Chapter 5 calculates the amount of fluid that could vault over the dike if there is a sudden, massive spill from an LEG tank, even though the dike meets current safety standards.

Chapters 6,7, and 8 explore safety problems of LEG ships, trucks, and railcars. Chapter 9 analyzes the vulnerabilities of LEG storage and transportation systems to sabotage, and the level of current safeguards.

Chapter 10 covers the only catastrophic LNG accident, which occurred in Cleveland, Ohio in 1944. While the amount of LNG involved is much smaller than that stored in current facilities, it indicates the type of effects that can occur in a major LEG spill in an urban area. Chapter 11 examines the adequacy of present LNG liability and compensation arrangements.

LEG research (including LEG cloud dispersion models and detonation and flame propagation in LEG clouds) is evaluated in Chapters 12 and 13.

Chapters 14 and 15 discuss the ability of non-urban terminals to handle all needed LEG imports.

Chapters 16 and 17 deal with LEG regulations: Federal, state, and local regulations in Chapter 16, and Federal regulation of LEG trucks and railcars in Chapter 17. The Federal Power Commission's performance is evaluated in Chapter 18.

LEG systems used in Japan, the world's largest importer of LNG, are covered in Chapter 19, including a discussion of Japanese LNG inground storage tanks.

Many chapters include specific recommendations to improve the safety and security of LEG operations. Each chapter, however, focuses on a narrow aspect. Chapter 20 draws general overall conclusions and recommendations, based on the findings and recommendations in the previous chapters.

Chapter 21 discusses the general comments on the report that were submitted to GAO by Federal agencies and by companies. Comments on specific chapters are handled at the end of those chapters.

Methodology

We started by isolating what we believed to be the critical questions about LEG and naphtha safety. We then determined what answers were available to these questions and on what the answers were based. On this basis we decided how deeply to explore each question. Because this exploration often needed skills beyond those available at GAO, a great deal of the work was done by contractors and consultants. We demanded that such companies and consultants meet two criteria: that they be eminently qualified in the area they were investigating and that they be independent, having no financial or intellectual stake in the answer. The major exception was that companies with previous activity in the area were allowed to bid competitively on a contract to compare Federal, state, and local regulations. The contractors and consultants who made major contributions to the study are listed in Appendix I-1.

The reports received from companies and consultants were broken up, edited, added to, corrected, and incorporated into various places in the final document. The GAO staff planned the study, hired the participants, and wrote the text, findings, conclusions, and recommendations. No chapter is the responsibility of any particular consultant, company, or staff member.

We visited 37 import, storage, shipyard, design, and transportation facilities in the United States and Japan (listed in Appendix I-2), and made a detailed study of the plans and blueprints of many of them. We spoke with Federal, state, and local agencies, industry and citizen organizations, and members of Congress. We offered each group we visited a full (more than one hour) briefing on the problems we were examining. We suggested to each of them that they look into the same problems, so that they would have substantive comments to make. On the whole, we received excellent cooperation from companies, organizations, and Federal agencies, and we are most grateful. We could not have done the study without it.

Because of the innovative nature of this report, a number of eminently qualified consultants were asked to review the accuracy of the material and provide us with their criticisms, comments, or recommendations. They include present or former leaders of industry, labor, government, consumer groups, science, law, and security. (See Appendix I-1.) None had any other interaction with the study. Further, they were not asked to evaluate findings, conclusions, or recommendations.

Eight Federal agencies have reviewed the entire report, and 52 companies and industry organizations were sent the parts of it in which they were mentioned. We received extensive comments from both groups. Formal comments, received from six agencies, are reproduced in full in Volume 3. Company, industry, and organization comments will be available at GAO to interested readers.

We have carefully considered all the comments and made revisions where appropriate.

Although this report has looked deeply into highly technical areas, we have tried to make the text understandable to non-technical readers. A few chapters required highly technical discussions. We have put these sections in italics, to indicate that non-technical readers may wish to omit them.

CHAPTER 2

PRIMER

This primer is meant to give an overall view of a very complex subject in a few pages. As such, it has less precision than the rest of the report and should be read only as a general introduction to the field. It does not summarize the rest of the report.

Energy gases are liquefied in order to reduce their volume. This facilitates transportation and storage, but increases the potential hazard. Liquefied natural gas (LNG) and liquefied petroleum gas (LPG)-- together called liquefied energy gases (LEG)--are produced domestically and imported. As the nation's natural gas supplies dwindle, imported LEG could become an increasingly important source of energy.

Natural gas is a mixture of hydrocarbons, 65 to 99 percent methane, with smaller amounts of ethane, propane, and butane. Chilled to -260 degrees Fahrenheit (^{o}F), natural gas becomes an odorless, colorless liquid one-600th of its volume at atmospheric pressure. Thus, a 150,000 cubic meter LNG tanker can carry the equivalent of 3.2 billion cubic feet of natural gas. (Table 2-1 provides a volumetric conversion table.) When LNG is warmed, it turns into natural gas again.

LPG--propane and butane--is processed from natural gas or crude oil. LPG liquefies and contracts in volume when stored under pressure at ambient temperatures, or when cooled at atmospheric pressure. Propane, for example, is reduced to one-270th of its volume at normal temperature

Table 2-1 LNG VOLUME, MASS, AND ENERGY EQUIVALENTS

		Volume Natural Gas	Volume LNG				Mass	Energy Content
		MCF	cubic meters	barrels	cubic feet	gallons	Metric tons	Therms
volume natural gas	1 MCF (1000 cubic feet)	--	0.04569	0.28735	1.6134	12.070	0.02123	10.860
volume LNG	1 cubic meter	21.886	--	6.2888	35.314	264.16	0.46463	237.68
	1 barrel	3.48008	0.15901	--	5.6148	42.005	0.07388	37.794
	1 cubic foot	0.61980	0.02832	0.17810	--	7.4811	0.01316	6.7311
	1 gallon	0.08285	0.00378	0.02380	0.13367	--	0.00176	0.89975
mass	1 metric ton (2204 lbs.)	47.103	2.1522	13.535	75.996	568.53	--	511.54
energy content	1 Therm (100,000 Btu's)	0.09208	0.00421	0.02646	0.14856	1.1114	0.00195	--

Source: Office of Technology Assessment, "Transportation of Liquefied Natural Gas" September 1977, p. 2.

and atmospheric pressure so it can be transported easily. Propane liquefies at -44°F; butane, at 31°F. Methane cannot be liquefied by pressure at temperatures above -116°F.

LPG vapor is heavier than air. Any spill or leak will collect on the ground or water and form a dense, spreading cloud which is explosive. The flammable range in an LPG vapor cloud is between 2 and 9 percent. Very cold natural gas is also heavier than air and forms a low, spreading cloud. When the natural gas content of the cloud is between 5 and 14 percent, the mixture is flammable. Eventually both types of clouds will dissipate. Both LPG and LNG clouds can explode in confined spaces. Table 2-2 gives the physical properties of LEG.

Naphtha is a generic term for various mixtures of hydrocarbons extracted from crude oil in the refining process. Its physical properties are not defined precisely. Naphtha is denser than LNG and LPG, and its vapor is heavier than air. The boiling point of naphtha ranges from 100° to 500°F. This means that, when exposed to the atmosphere, it evaporates slowly—at about the rate of water on a dry day. Naphtha is between kerosene and gasoline in volatility.

LNG has been used for several years in this country to supplement natural gas supplies. During the summer, when demand is low, utilities liquefy and store gas in specially designed tanks. When the weather is cold and demand is high, the LNG is regasified and pumped through gas mains to consumers. More than 100 of these "peakshaving" plants are operating throughout the United States, including 45 that hold at least 23,000 cubic meters.

TABLE 2-2 PHYSICAL PROPERTIES OF LEG

Property	Methane	Ethane	Propane	Butane
Boiling Point	-263°	-127°	- 44°	31°
Specific Gravity	0.466 at -263°	0.546 at -127°	0.585 at -49°	0.601 at 31°
Vapor Density at 32° (Air = 1.0)	0.555	1.04	1.56	2.04
Flash Point	-306°	-211°	-156°	-76°
Auto-Ignition Temperature	1004°	950°	871°	806°
Flammable Limits (concentration)	5.3-15.0%	3.0-12.5%	2.2-9.5%	1.8-8.4%
Laminar Burning Velocity	0.87 mph	0.92 mph	0.98 mph	1.03 mph
Gas-to-liquid Volume ratio (Gas at 32°, Liquid at boiling point)	650	410	290	230

All temperatures in degrees Fahrenheit.

Sources: Chemical Rubber Company Handbook of Chemistry and Physics, 57th ed., 1977; U.S. Coast Guard CHRIS Handbooks, 1974.

Propane is also used to supplement natural gas supplies. Since propane gas is heavier in molecular weight and has up to three times the energy density of natural gas, it is diluted with air or converted into synthetic natural gas (SNG) before being added to the gas stream. There are more than 450 domestic propane/air plants for standby and full-time use,[2] and five SNG plants use propane as a feedstock component. A new method injects liquid LPG directly into a passing gas stream.

Some 13 million customers used LPG in 1976. Most of these customers are in rural areas, including approximately 1.4 million farms. Many factories also rely on propane as a back-up fuel in case their natural gas supplies are reduced.

LPG and naphtha are used as feedstocks for petrochemicals. Naphtha is also used as jet fuel. Butane is a feedstock for aviation fuel, high octane gasoline, and synthetic rubber.

About 2 percent of the nation's energy is supplied by LPG, primarily propane. (LEG and naphtha consumption data are contained in Appendix II.) Over the years, a widespread LPG storage and distribution network has developed in the United States: 16 import terminals, 70,000 miles of cross-country pipelines, 16,300 LPG rail tank cars in service, and 25,000 LPG transport and delivery trucks.[3] In addition, more than 8,000 LPG storage and distribution facilities are scattered throughout the country.

About 86 percent of the LPG in bulk storage is kept under pressure in underground salt domes or mined caverns.[4] LPG is also stored at $-44^{o}F$ in large, steel, single-walled, aboveground tanks ranging in capacity up to 80,000 cubic meters. There are 20 LPG aboveground storage facilities that hold more than 23,000 cubic meters. Insulating big tanks is less expensive than building them strong enough to resist high pressure. Smaller amounts of LPG are stored in pressurized containers called "bullet tanks", which run from 8 up to 450 cubic meters in capacity.

In 1976, 95.2 percent of the LPG shipped in the United States was pumped under pressure in LPG pipelines to distribution points, where it was loaded into pressurized tank trucks or railroad tank cars and carried to rural and industrial customers. Only 3.4 percent of the LPG was transported the entire way by trucks (which carry as much as 45 cubic meters), and 0.9 percent was transported in pressurized railcars (which hold up to 125 cubic meters).[5]

Around 18.2 million cubic meters of LPG moved in international trade in 1976, transported primarily by 83 tankers, each with a capacity of at least 10,000 cubic meters. With the increasing demand for LPG, larger ships—of 50,000, 75,000, and 100,000 cubic meters capacity—are coming into use. These ships are refrigerated to keep propane and butane liquefied. Some LNG ships can and do carry LPG instead.

Large LPG tankers have about half the capacity of those carrying LNG because LPG has a greater density. A 75,000 cubic meter LPG tanker has a draft of 38 feet, while a 125,000 cubic meter LNG tanker has a draft of 36 feet. Smaller 50,000 cubic meter LPG tankers have a draft of 35 feet and can be received by all of the major LPG marine terminals in the U.S.

LNG is harder to handle than LPG because it is intensely cold. The -260°F temperature of LNG makes complex shipping, storage, and handling techniques necessary. LNG exporters, such as Algeria, Brunei, and the United States, liquefy natural gas and pump it into unique tankers which are like floating thermos bottles. The five separate tanks on a typical carrier are heavily insulated to prevent the LNG from vaporizing or "boiling off" during a voyage. The small amount that does vaporize provides most of the fuel to power the ship.

The insulated tanks holding the LNG are made of welded 9 percent nickel alloy steel or aluminum alloy that can withstand the intense cold and great temperature changes. Two types are used: free-standing tanks which are anchored in the ship's hull, and "membrane" tanks supported by insulation lining the inner hull.

LNG carriers have to meet far more exacting specifications than oil tankers. LNG ships are double-hulled. They are equipped with methane detection devices and fire-fighting systems that deliver high pressure foam, dry powder, or water sprays. Other systems cool and warm the storage tanks and fill them with inert, non-combustible gas when the ship is empty. The newer LNG carriers have bow thruster propellers and other features which give them greater maneuverability.

The 38 currently operating LNG tankers carry an average of 46,000 cubic meters of LNG.[6] By 1980, about 80 LNG ships will be in service.[7] At least one will have a capacity of 165,000 cubic meters—enough liquid to cover a football field to a depth of 130 feet. But the industry seems to be settling on 125,000-130,000 cubic meter capacity vessels as a standard. Such tankers will be 1,000 feet long, 150 feet wide, and able to cruise at 20 knots.

When an LNG carrier reaches an import terminal, it unloads in 10-15 hours at a rate of up to 190 cubic meters a minute. Jointed marine loading arms on the dock are attached to the ship and the LNG is pumped into huge storage tanks. The insulated piping is made of cold-resistant (cryogenic) steel or aluminum alloy. Emergency shutdown systems automatically cut off the LNG flow in case of a mishap.

Major LNG terminals generally have more than one storage tank. A typical tank has a capacity of 95,000 cubic meters of LNG. Such a tank is 140 feet high and 190 feet in diameter. Its inner walls are made of cryogenic 9 percent nickel alloy steel, aluminum alloy, or pre-stressed concrete. Surrounding this inner tank is about 3 feet of perlite, a non-flammable insulating material. The tank's outer wall is usually built of non-cryogenic carbon steel. Inside the tank's dome is an insulated, suspended ceiling.

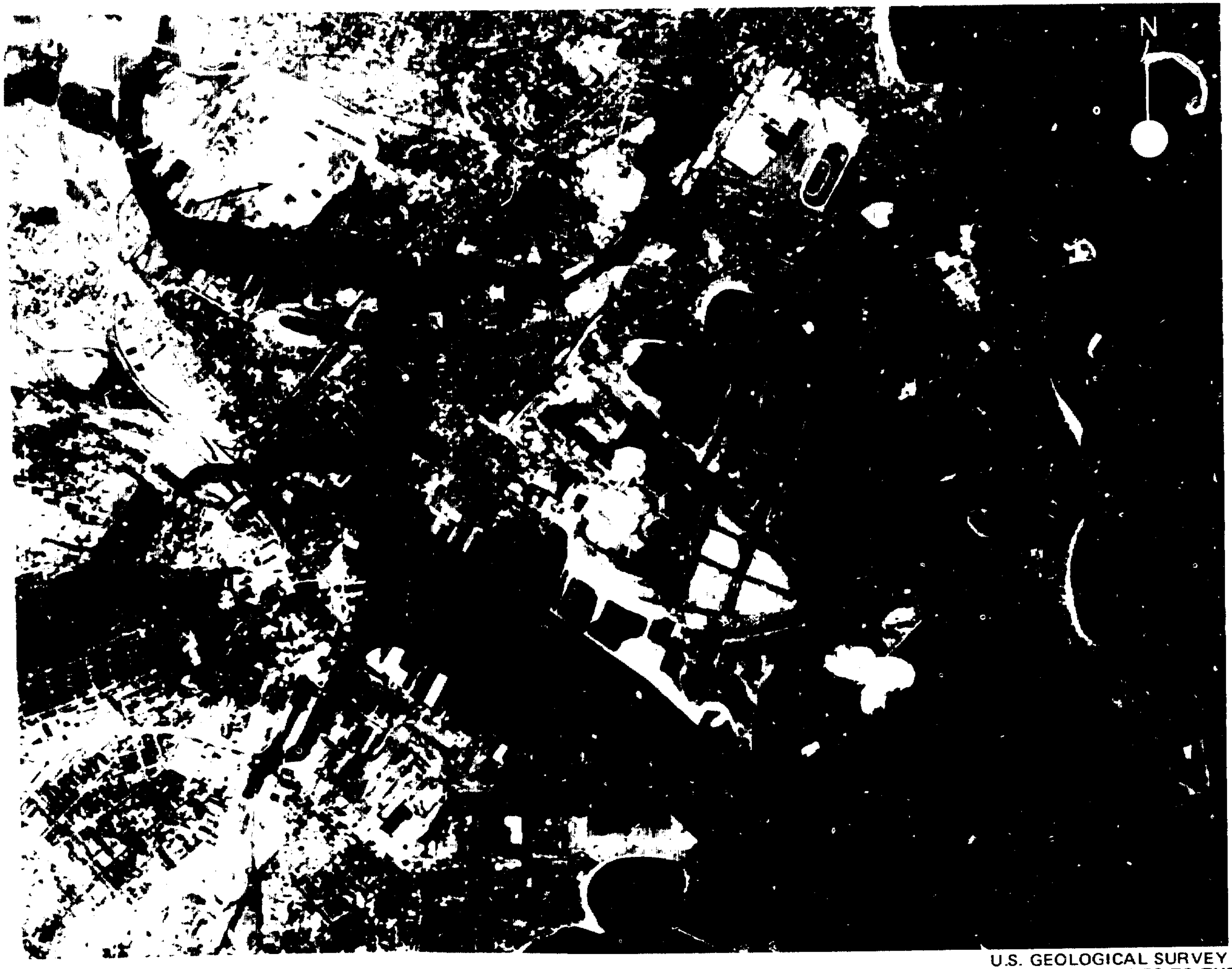
LNG storage tanks in this country are built aboveground, and most are enclosed by earthen dikes. The volume of the diked area is usually equal to the volume of the fluid in the largest tank enclosed by the dike. The Japanese, however, are constructing many new LNG storage tanks in the ground. The cryogenic inner liner is surrounded by thick insulation and a concrete outer shell. Many Japanese engineers say that such below-ground tanks are intrinsically safer.

The 14 major LNG import terminals now operating throughout the world are "base load" facilities in which incoming LNG is constantly regasified and pumped into utility distribution lines. European nations have been bringing in LNG through such facilities since 1964. Imported LNG now accounts for 80 percent of Japan's natural gas consumption.[8]

LNG imports now supply less than one-tenth of one percent of U.S. natural gas demand, and there are only two import terminals in this country. Another new base load facility will go into operation in the near future, and several more have been proposed. LNG could supply up to 15 percent of the nation's natural gas needs by 1985,[9] with more than 40 LNG tankers operating regularly in and out of U.S. harbors. Imports of LPG are also expected to rise sharply, from 1.9 million cubic meters in 1976 to 26.9 million cubic meters by 1985.[10] The photographs show the sites of two existing LEG terminals and a proposed LNG terminal site.

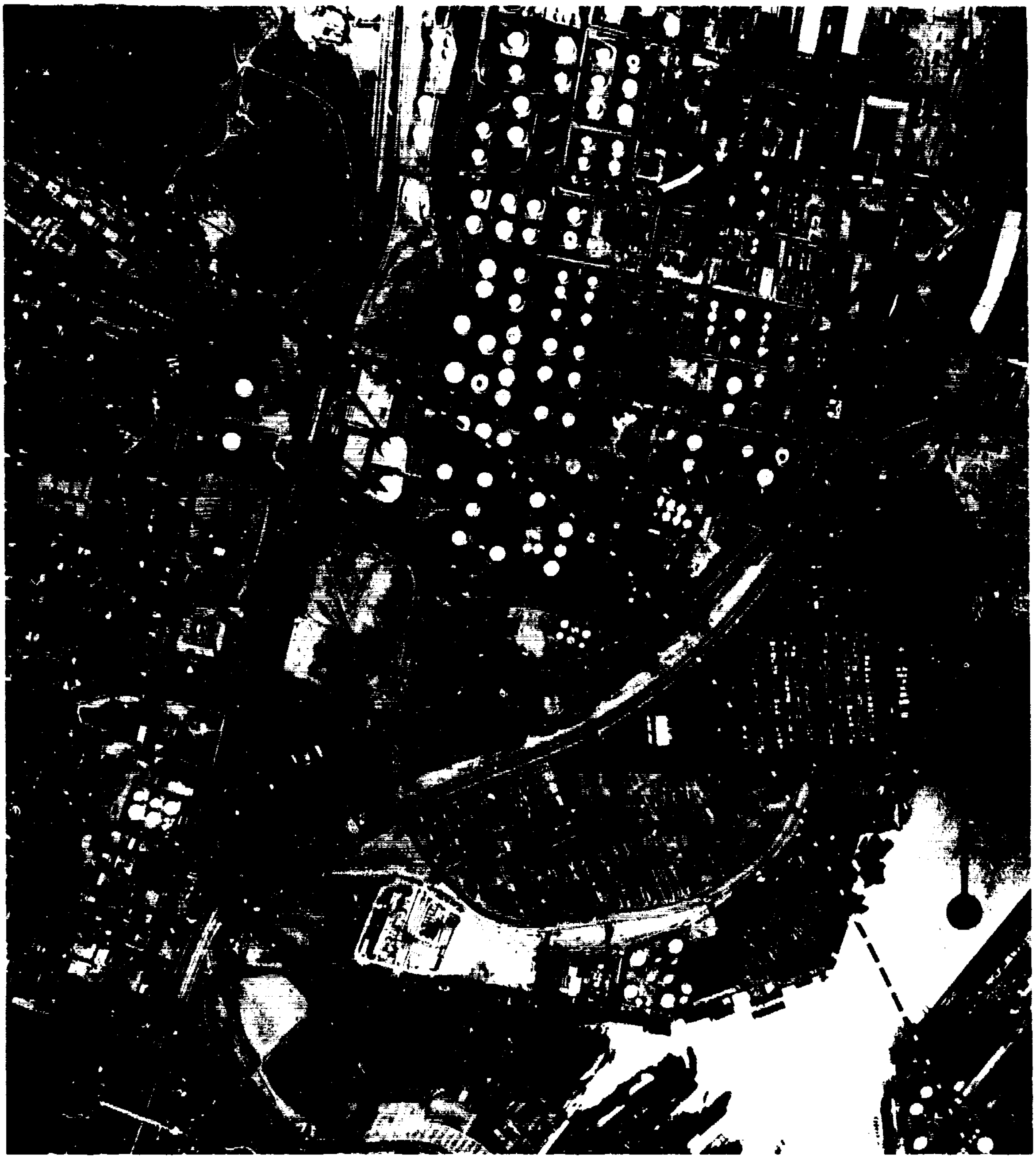
In the short history of LNG use in this country there has been only one major accident at an LNG facility. On October 20, 1944, a 4,200 cubic meter LNG storage tank at a peakshaving facility in Cleveland suddenly gave way. Vapor from the spilled liquid ignited as it spread into streets, storm sewers, and basements. Later, another tank containing 2,100 cubic meters failed, shooting flames nearly 3,000 feet into the air. The fires and explosions killed 130 persons and injured 225 more.[11] Property damage was estimated at $7 million.

The Cleveland disaster halted the use of LNG for twenty years. It was not until the mid-1960's that natural gas utilities again began using LNG.



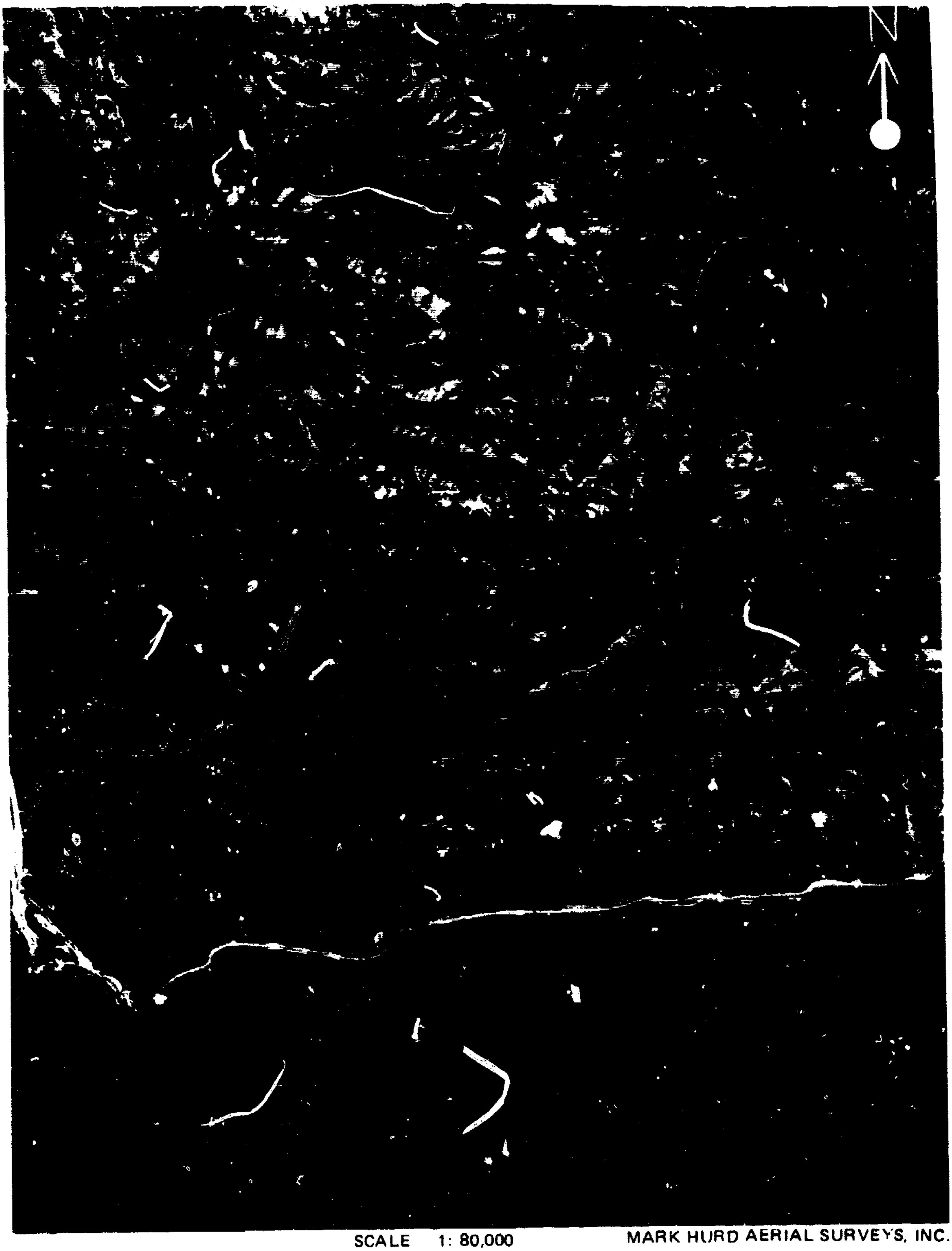
U.S. GEOLOGICAL SURVEY

THE PHOTOGRAPH ABOVE IS AN EXAMPLE OF AN LNG IMPORT TERMINAL LOCATED IN AN URBAN AREA. THE ARROW POINTS TO THE DISTRIGAS TERMINAL IN EVERETT,MASSACHUSETTS, IN OPERATION SINCE 1971. LNG SHIPS REACH IT THROUGH BOSTON HARBOR, PASSING LOGAN INTERNATIONAL AIRPORT AND BOSTON AS THEY GO UP THE SHIP CHANNEL. NEXT TO THE TERMINAL ARE EXXON'S LPG RECEIVING TERMINAL, OTHER INDUSTRIAL FACILITIES, AND POPULATED NEIGHBORHOODS.



SCALE 1:12,000 AMERICAN AERIAL SURVEYS, INC.

THIS PHOTOGRAPH SHOWS THE URBAN LOCATION OF PETROLANE, INC'S LPG RECEIVING TERMINAL NEAR LOS ANGELES HARBOR IN CALIFORIA. THE ARROW INDICATES THE COMPANY'S TWO LARGE PROPANE STORAGE TANKS NEAR THE TERMINAL ARE THE PALOS VERDES FAULT, (DOTTED LINE) A U.S. NAVY FUEL DEPOT, A COMPLEX OF STORAGE TANKS, AND A RESIDENTIAL AREA THAT GOES FOR MANY MILES.



SCALE 1: 80,000 MARK HURD AERIAL SURVEYS, INC.

POINT CONCEPTION, CALIFORNIA, SHOWN IN THE PHOTOGRAPH ABOVE, IS AN EXAMPLE OF A PROPOSED LNG IMPORT TERMINAL SITE WHICH HAS A VERY LOW POPULATION DENSITY FOR MANY MILES AROUND IT. THE PROJECT IS A PROPOSAL OF WESTERN LNG TERMINAL ASSOCIATES, INC.

The first U.S. LNG import terminal began operations at Everett, Mass., in 1971. In 1973 the Federal Power Commission asserted jurisdiction over the Everett facility and any new LNG import terminals. Although FPC has been disbanded, its functions have been assumed by the Federal Energy Regulatory Commission (FERC) and other parts of the Department of Energy (DOE). The U.S. Coast Guard and the Office of Pipeline Safety Operations (OPSO), both in the Department of Transportation (DOT), also have regulatory responsibilities for LNG import terminals.

LNG peakshaving plants involved in interstate commerce come under the jurisdiction of both DOE and OPSO. OPSO also regulates LPG and naphtha pipeline facilities in interstate commerce.

LEG trucks and railcars under Federal jurisdiction are regulated by a number of agencies within DOT. The Interstate Commerce Commission (ICC) is also involved, since only it can revoke or suspend the certificates of interstate motor carriers found to be unsafe.

The U.S. Coast Guard has been given broad authority to regulate all aspects of LEG shipping, including the design and construction of vessels, the training of crew members, the movement of vessels in U.S. ports and waterways, and harbor security.

Throughout the report liquid volumes are given in cubic meters, in order to make it easier to compare the volumes held or carried in various storage and transportation systems. All temperatures are given in degrees Fahrenheit (F).

REFERENCES

1. "Scorecard," Pipeline and Gas Journal, November, 1977.

2. Solomon and Scherb, Chapter 5 (Draft), California Energy Resources Conservation and Development Biennial Report, November 30, 1976, p. 36.

3. See Chapter 14.

4. American Petroleum Institute, "API Monthly Report Covering Inventories of LP-Gas and LR-Gas as of September 30, 1977," October 25, 1977.

5. National LP-Gas Association, "1976 LP-Gas Market Facts," p. 7.

6. E. Drake and R. Reid, "The Importation of Liquefied Natural Gas", Scientific American, April, 1977, p.24.

7. Office of Technology Assessment, "Transportation of Liquefied Natural Gas," September 1977, p. 12.

8. Drake and Reid, p. 22.

9. Office of Technology Assessment, p. 5.

10. See Chapter 14.

11. Coroner's Report on East Ohio Gas Company Disaster, Cuyahoga County, Cleveland, Ohio, July 1945.

CHAPTER 3

VULNERABILITY OF STORAGE TANKS AND CONTAINMENT DIKES TO NATURAL FORCES

CONTENTS | PAGE

CONTENTS | PAGE

INTRODUCTION

The first part of this chapter evaluates the ability of selected LEG storage facilities to withstand earthquakes and tornadoes. The conclusions reached should be generally applicable to U.S. LEG storage facilities, since most designers use the same codes and standards and employ similar analytical methods and design assumptions.

The second part of the chapter evaluates the effects of flooding and the pot ıtial for foundation failure from ground liquefaction in earthquakes. These phenomena tend to be highly site dependent and site specific.

SITE LOCATION AND DESCRIPTION

The specific storage facilities evaluated are described in Table 3-1. We consider them representative of the types of storage facilities currently in use or planned in the United States:

- Insulated Storage Tanks and Containment

  Double-Wall Steel LNG Tank - Figure 3-1.

  Prestressed Concrete LNG Tank - Figure 3-2.

  Prestressed Concrete High Dike - Figure 3-3.

  Single-Wall Steel Propane Tank - Figure 3-4.

- Pressure Storage Tanks

  Vertical Steel Propane Tank - Figure 3-5.

TABLE 3-1 DESCRIPTION OF LNG AND PROPANE STORAGE TANK FACILITIES EVALUATED FOR SEISMIC AND WIND LOADS

	Facility Location	Tank Capacity Cubic Meters	Tank Dimensions*	Tank Designer	Remarks
1.	LNG Storage Tank Distrigas Corp. Everett, Mass. (designed 1970)	55,000	150' I.D. x 123' Ht. to S.L.	Chicago Bridge & Iron	Tank consists of a primary and secondary steel vessel as shown in Fig. 3-1
2.	LNG Storage Tank Public Service Electric & Gas Rossville, Staten Island, N.Y. (designed 1970)	143,000	240' I.D. x 117' Ht. of Cyl. Wall	Preload Technology	Tanks consist of an inner and outer circular prestressed concrete wall and reinforced concrete berm as shown in Fig. 3-2.
3.	High Dike for LNG Storage Tanks Western LNG Terminal Associates Oxnard, Calif. (planned)	87,000	259' I.D. x 81' Ht. to top of Containment wall	Chicago Bridge & Iron (The facility, including the dike, was designed by Fluor Engineers and Constructors)	The dike containment acts to contain the LNG in the event of a rupture of the primary double-wall metal storage tanks as shown in Fig. 3-3.
4.	LPG Storage Tank Exxon Co., U.S.A. Everett, Mass., (designed 1972)	64,000	190' I.D. x 80' Ht. to S.L.	Pittsburgh-Des Moines Steel Co.	The storage tank is a single wall storage vessel as shown in Fig. 3-4.

TABLE 3-1 DESCRIPTION OF LNG AND PROPANE STORAGE TANK FACILITIES EVALUATED FOR SEISMIC AND WIND LOADS (continued)

	Facility Location	Tank Capacity Cubic Meters	Tank Dimensions*	Tank Designer	Remarks
5.	LPG "Bullet" Tank Boston Gas SNG Plant Everett, Mass. (vertical pressurized cylinder installed 1947)	114	8.6' I.D. x 66' Cyl. Ht. with 2:1 Ellipse Head	J.F. Pritchard & Co.	This vertical cylindrical pressurized storage tank is shown in Fig. 3-5.
6.	LPG "Bullet" Tank (horizontal pressurized cylinder designed 1977)	342	9.75' I.D. x 133' Cyl. with Spherical Head	Trinity Industries, Inc.	This horizontal cylindrical pressurized storage tank is shown in Fig. 3-6.

*I.D. = Internal Diameter
Ht. to S.L. = Height to Springline (the Springline is the top of the cylinder wall).

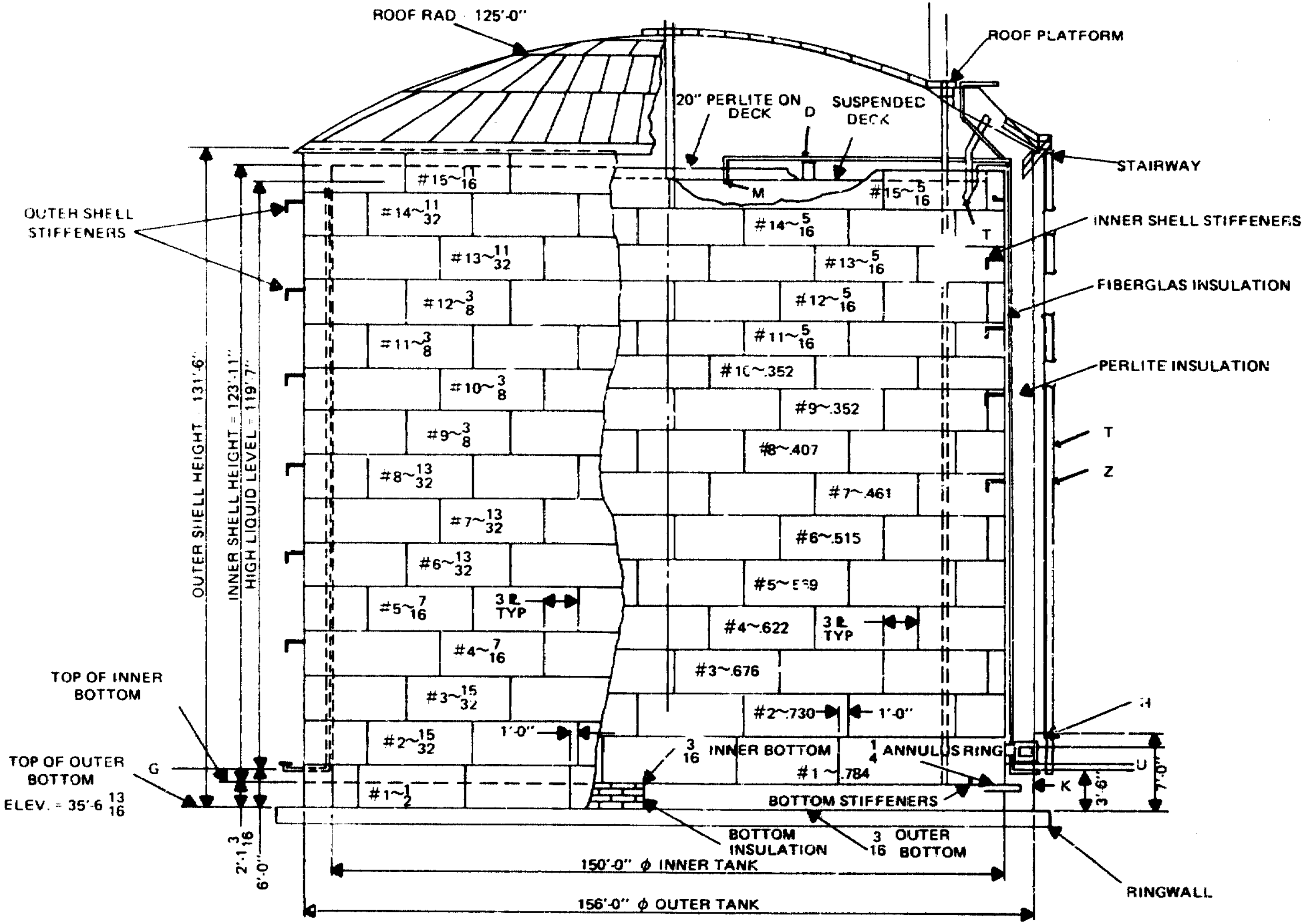


FIGURE 3-1a – EL..VATION VIEW OF A TYPICAL DOUBLE WALLED LNG STORAGE TANK OF THE TYPE BUILT BY CB&I FOR DISTRIGAS IN EVERETT, MASS.

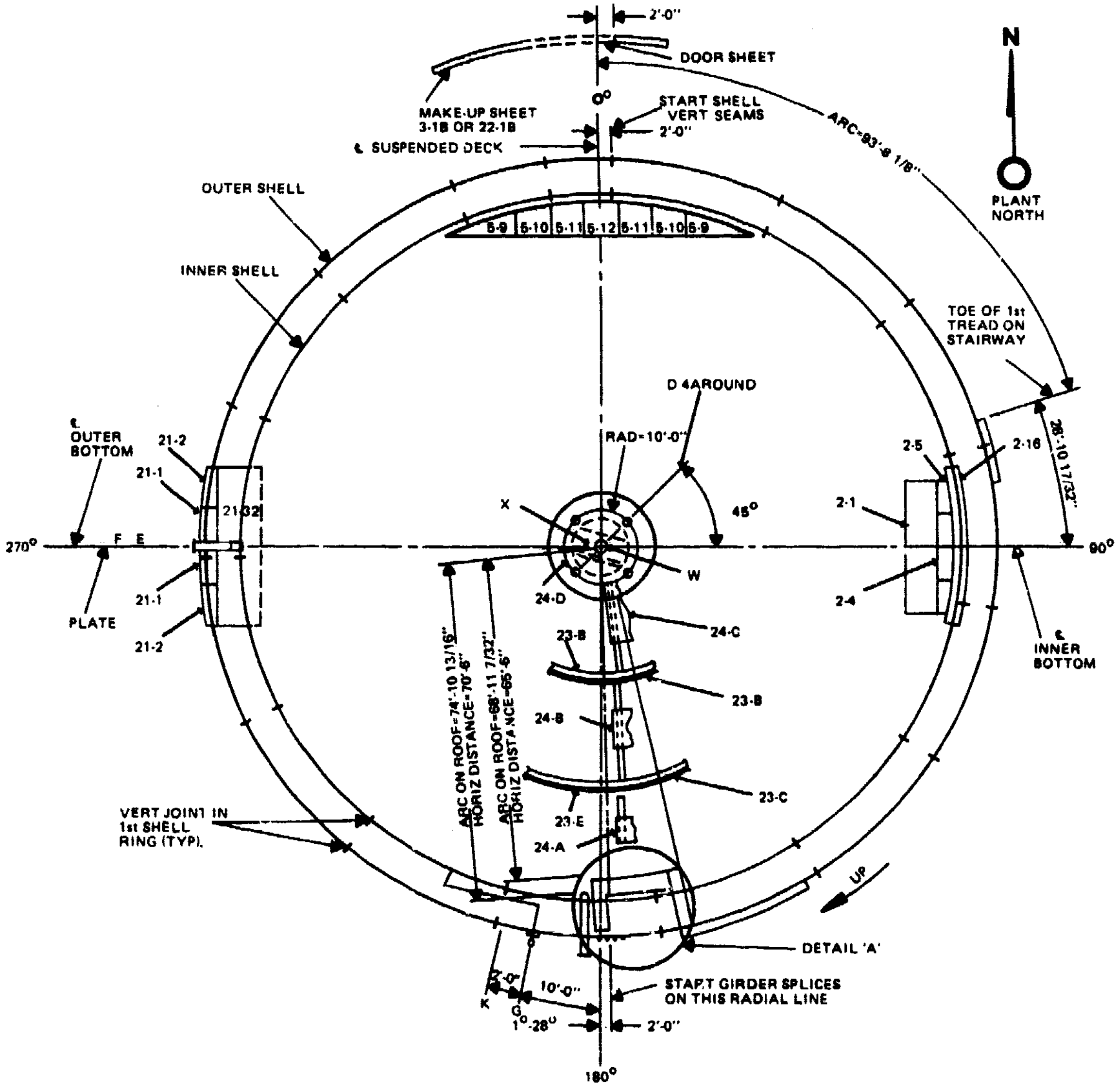


FIGURE 3-1b – PLAN VIEW OF A TYPICAL DOUBLE WALLED STEEL LNG STORAGE TANK OF THE TYPE BUILT BY CB&I FOR DISTRIGAS CORP. IN EVERETT, MASS.

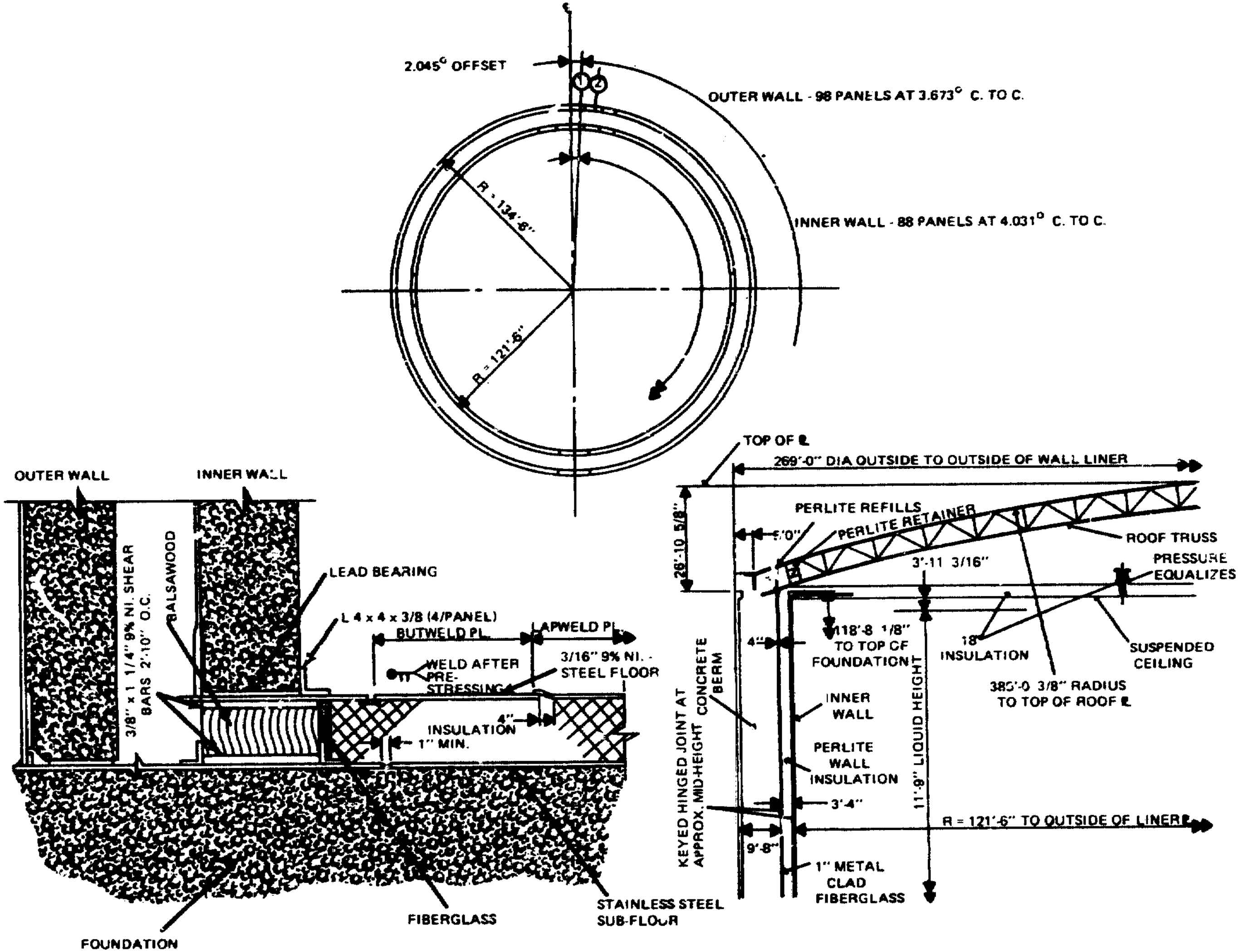


FIGURE 3-2 – PLAN AND ELEVATION SECTIONS OF THE PUBLIC SERVICE ELECTRIC AND GAS DOUBLE-WALLED PRESTRESSED CONCRETE LNG STORAGE TANK BUILT BY PRELOAD AT ROSSVILLE, STATEN ISLAND, NEW YORK.

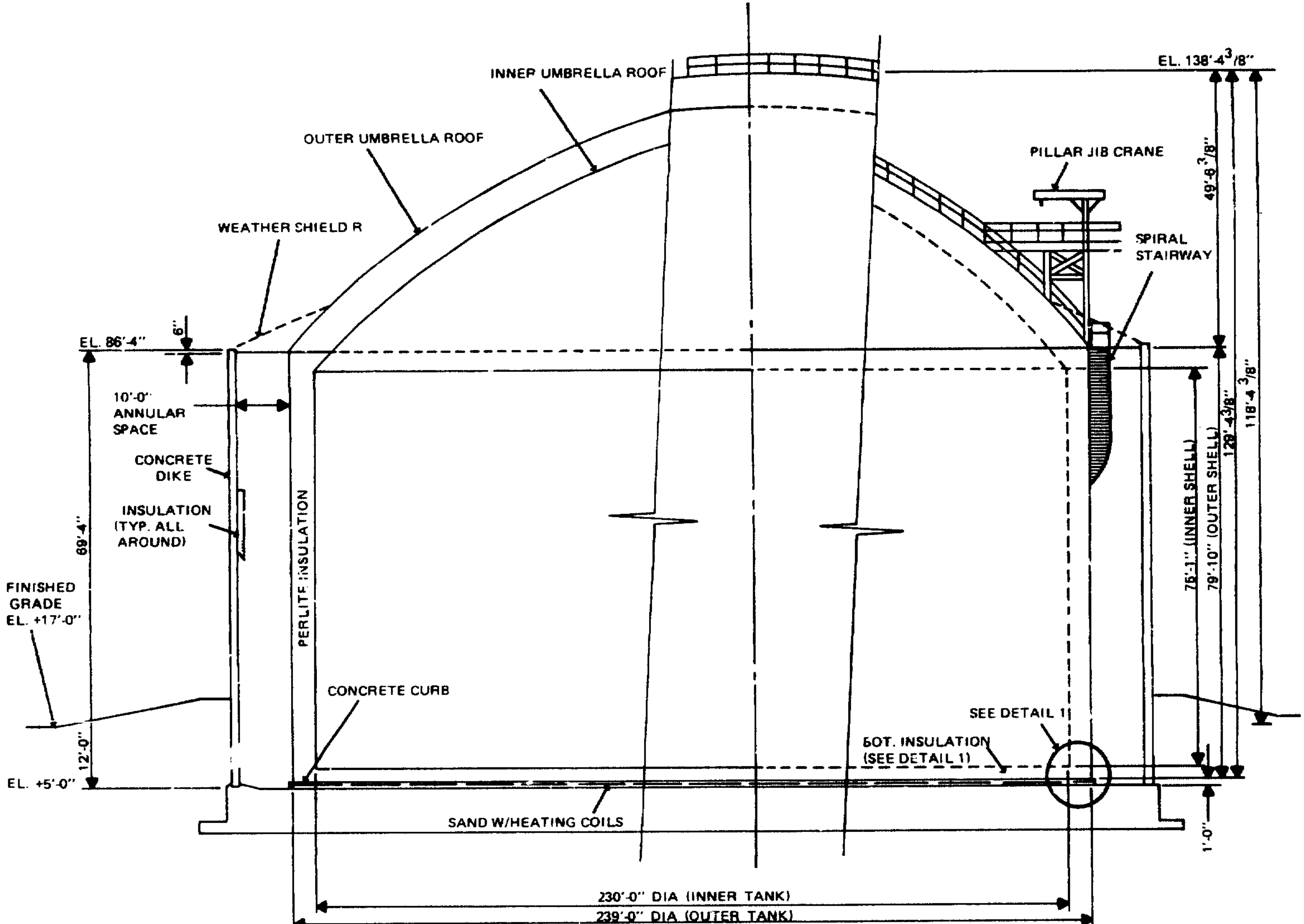


FIGURE 3-3 – ELEVATION VIEW OF PROPOSED OXNARD LNG STORAGE FACILITY FOR WESTERN LNG TERMINAL ASSOCIATES, SHOWING A PRESTRESSED CONCRETE HIGH DIKE.

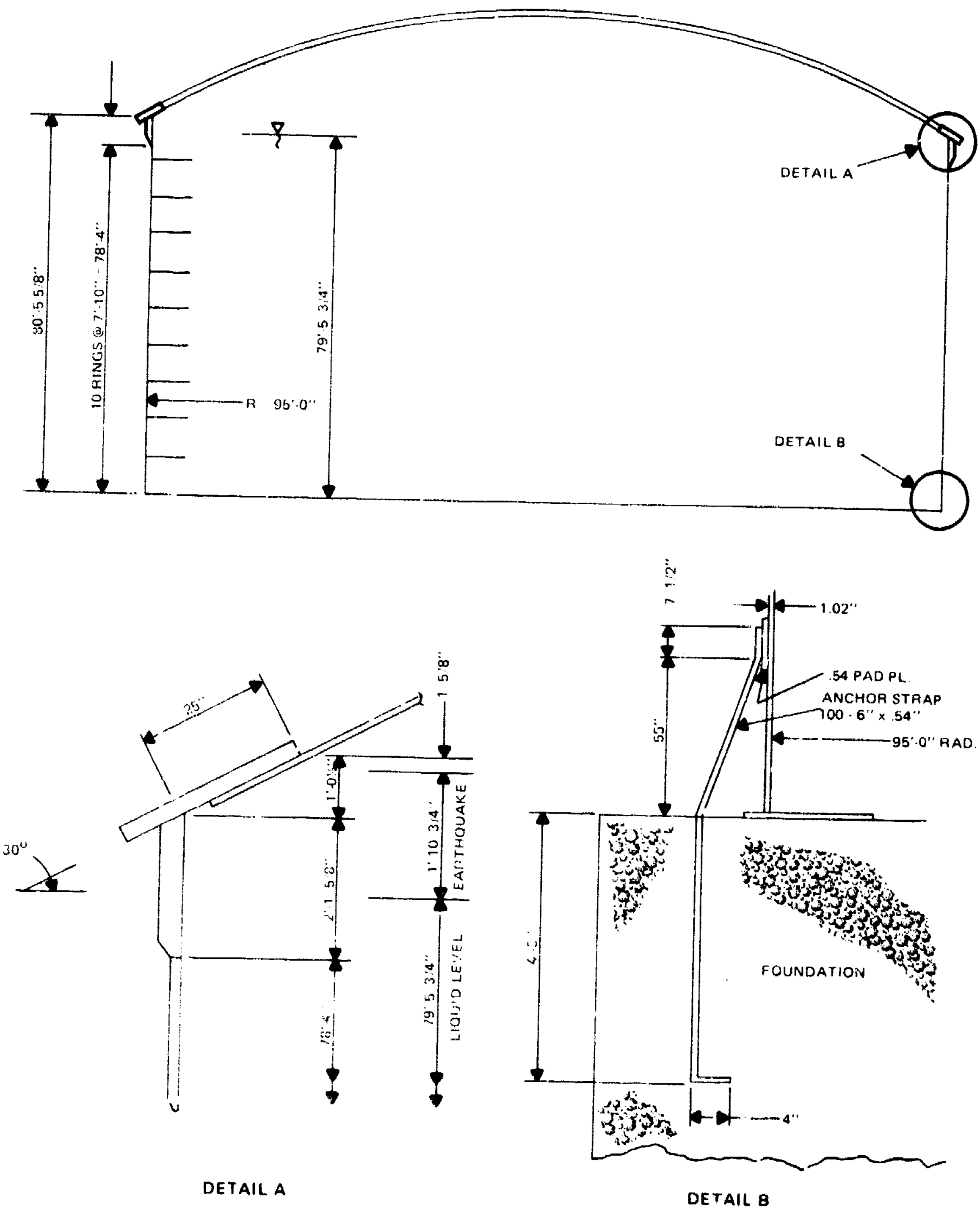


FIGURE 3-4 – ELEVATION VIEW AND DETAILS OF EXXON STEEL PROPANE STORAGE TANK DESIGNED BY PDM AT EVERETT, MASS.

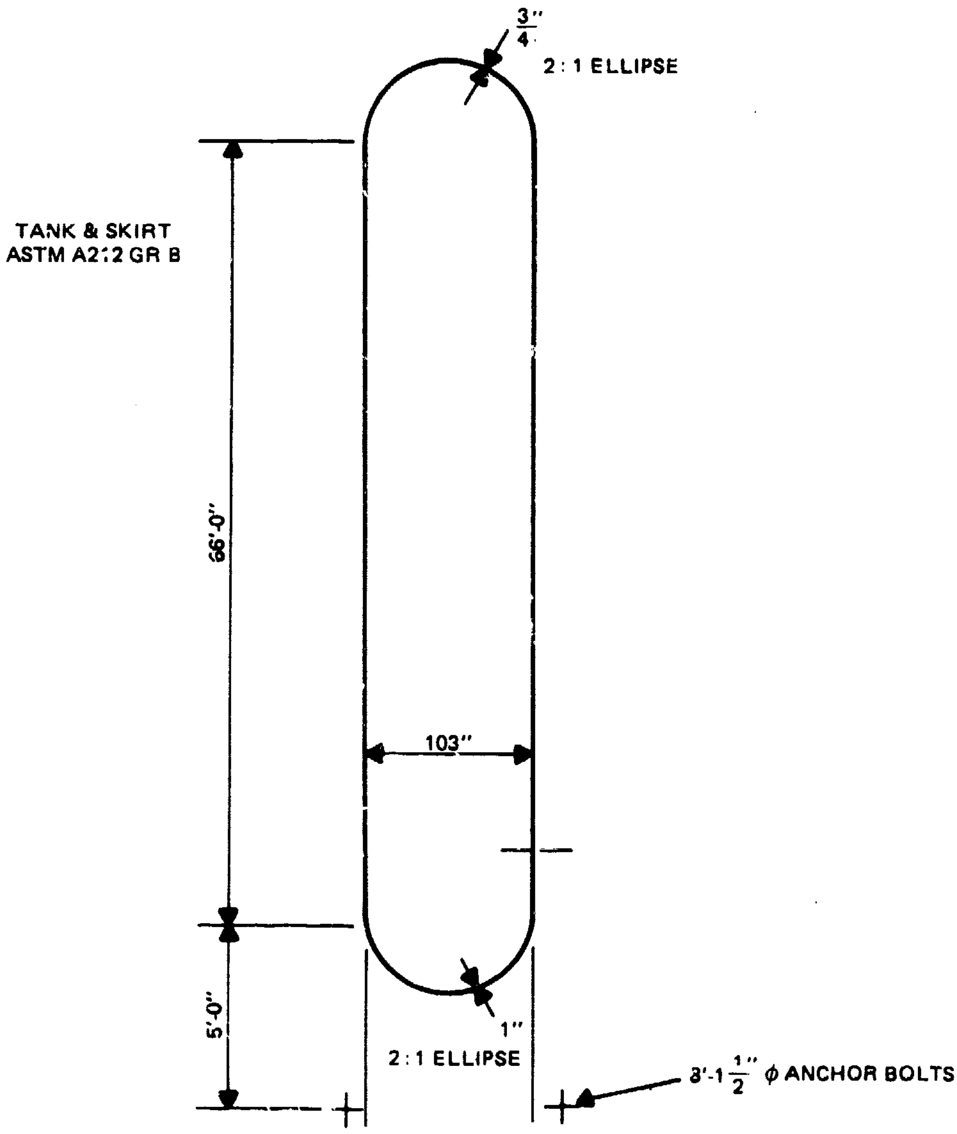


FIGURE 3-5 – ELEVATION VIEW OF BOSTON GAS COMPANY STEEL VERTICAL PRESSURIZED PROPANE "BULLET" TANK AT EVERETT, MASS. MANUFACTURED BY J. F. PRITCHARD & CO.

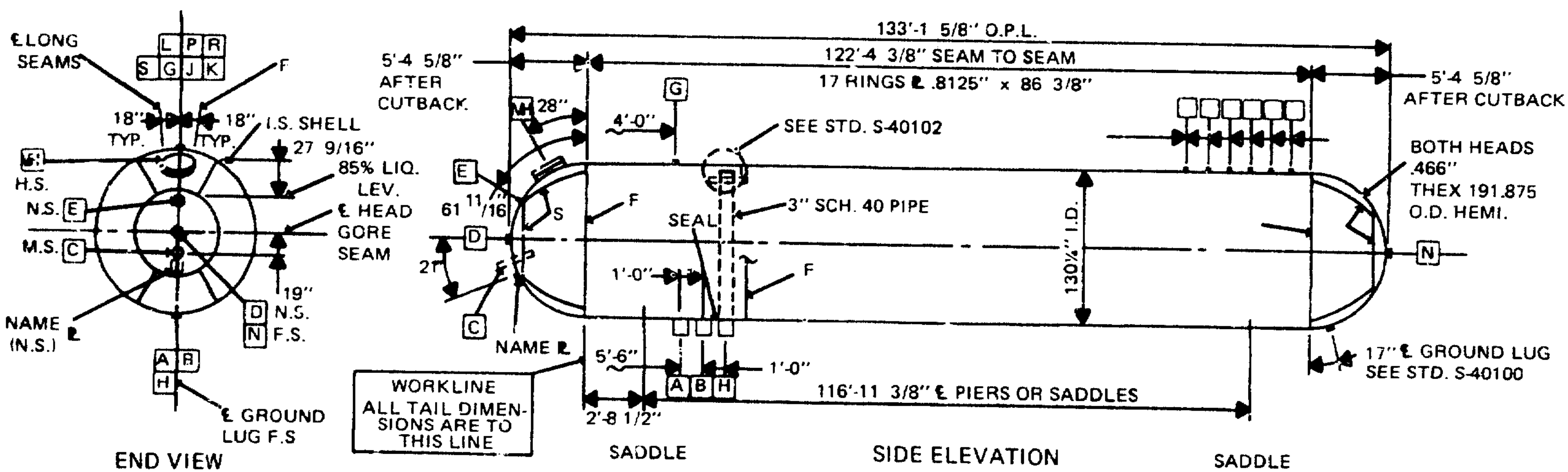


FIGURE 3 6 – ELEVATION VIEWS OF TYPICAL STEEL HORIZONTAL PRESSURIZED PROPANE "BULLET" TANK MANUFACTURED BY TRINITY INDUSTRIES.

Horizontal Steel Propane Tank - Figure 3-6.

EARTHQUAKES AND TORNADOES

Two specific levels of earthquake and wind loadings are considered. The lower level for earthquake evaluation corresponds to the Uniform Building Code (UBC) requirement.[1] This is the minimum level that is required for any commercial building. Seismic standards in NFPA 59A (1975)[2] are based on the UBC requirement, except that site-specific geotechnical analyses are required in Seismic Zones 2 and 3. The higher level for earthquake evaluation is approximately that currently used on commercial nuclear power plant facilities at the locations evaluated. This is the most stringent standard applied to commercial facilities.

For extreme wind loading, the lower wind load is the maximum wind associated with a 100 year return cycle for a level C exposure as defined in ANSI A 58.1-1972, and is used for the design of ordinary buildings and other structures.[3] The chance that a 100-year wind, earthquake, or flood will be exceeded at least once at any given site, if the three phenomena are independent, is 3 percent per year and 78 percent during a nominal 50-year lifetime of a facility. There is better than a 99 percent chance that the design basis will be exceeded more than 75 times during the nominal lifetime of the present 100 large storage facilities. (This assumes that the average facility uses a 100 year repeat interval for natural phenomena design. Some use a shorter interval, and some a longer one.) In general, structures can survive stresses greater than design stresses (those generated by design events). For a more complete analysis, see Fig. 16-1 and the discussion in

Chapter 16 of requirements for resistance to natural phenomena (special issue 5).

The higher wind loading, that associated with nuclear power plant design, is a tornado so large that there is only one chance in 10 million that one at least that large would hit the site in a given year.[4]

Earthquakes

While earthquakes can be caused by volcanic action, water inclusion (such as pumping water into deep wells), and major changes in loading (such as filling a dam with water), the cause of most damaging earthquakes is believed to be tectonic in origin (e.g., as the result of fault movement). Modern seismology views earth's crust as a series of large plates which are in motion relative to each other and the semi-liquid magma underneath. There are seismically active zones along the U.S. West Coast.

Although most damaging earthquakes originate at plate boundaries, about 5 percent of all earthquakes have occurred in regions located within plates where there had been little known seismic activity or active faulting. Within the past 250 years, at least five major earthquakes in the United States have followed this pattern—Boston (Cape Ann), Massachusetts in 1755; New Madrid, Missouri, 3 earthquakes within a six month period in 1811 and 1812; and Charleston, South Carolina in 1876. The New Madrid and Charleston earthquakes were of major magnitude, causing either significant epicentral* damage or changes in

*The epicenter is the part of the earth's surface directly above the origin of the earthquake.

topography. Each was felt over an area of 2,000,000 square miles. West Coast earthquakes caused by fault movement, even those which do considerable local damage, are seldom felt over an area of more than a few thousand square miles.

Seismologists and geologists have generally not been able to identify tectonic structures which cause the earthquakes east of the Rocky Mountains. It is the existence of this unexpected and usually unexplained 5 percent which has prompted regulating authorities, industrial standards, and prudent owners to insist upon earthquake or seismic design requirements being incorporated into hazardous facilities design regardless of the recorded seismic history of the site.

The earthquake design criteria we used in evaluating storage facilities were in accordance with the UBC requirements and the U.S. Nuclear Regulatory Guide 1.60, Horizontal Response Spectrum[5] as shown in Fig. 3-7 for 5.0 percent critical damping for steel and 7.0 percent for concrete. The zero period surface accelerations (the acceleration of a particle rigidly attached to the ground) assumed in the evaluation as a function of geographic location, are shown in Fig. 3-8, which is a modification of the current zone map which appears in the UBC.[1]

The maximum seismic acceleration which nuclear power plant are designed to withstand is known as the Safe Shutdown Earthquake (SSE). At the 6 sites examined in this chapter, the chance that there will be an earthquake at least as large as an SSE in a given year varies from one in 10,000 to one in 10 million.[6]

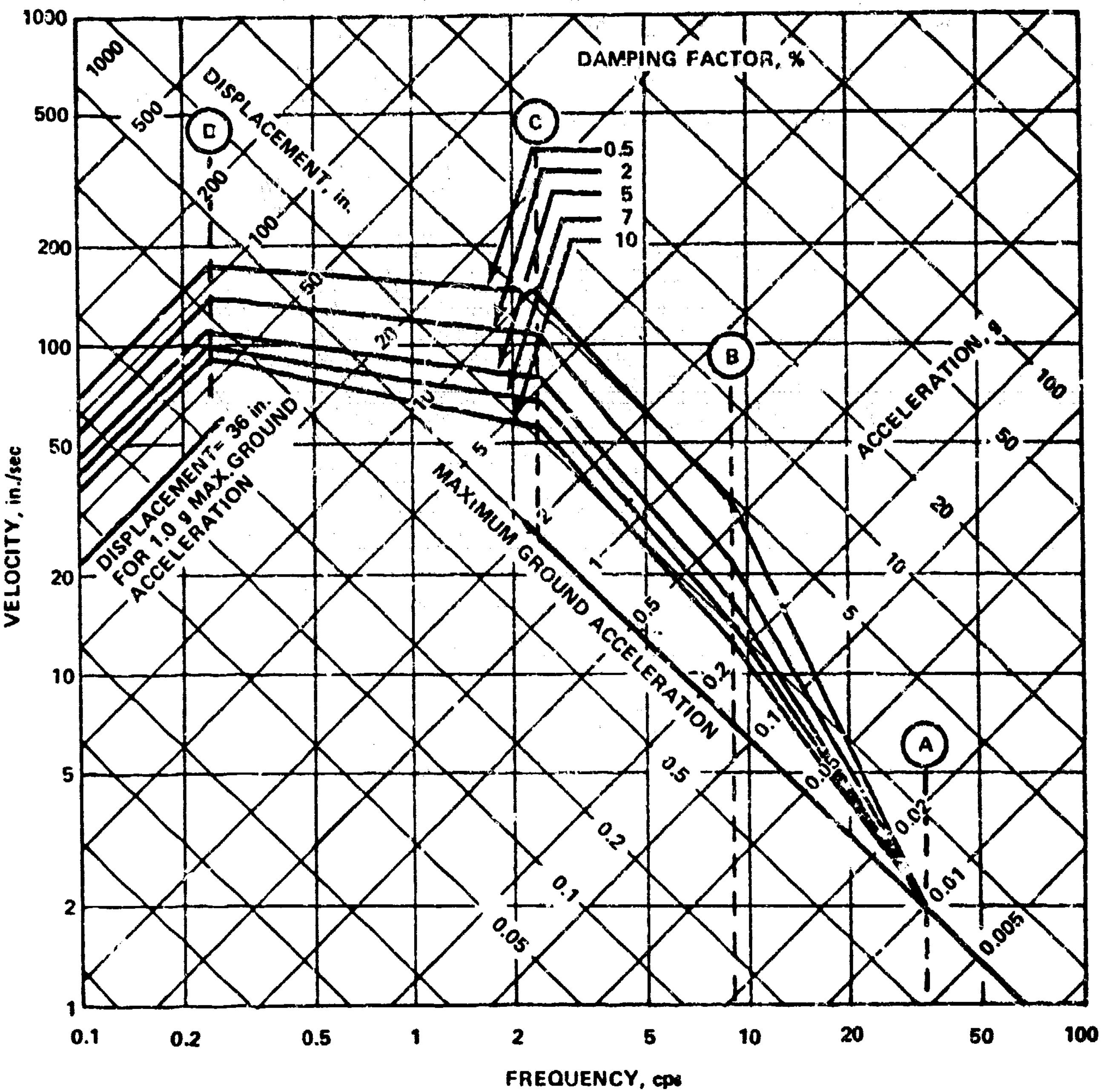


FIG. 3.7 HORIZONTAL DESIGN RESPONSE SPECTRA – SCALED TO 1g HORIZONTAL GROUND ACCELERATION

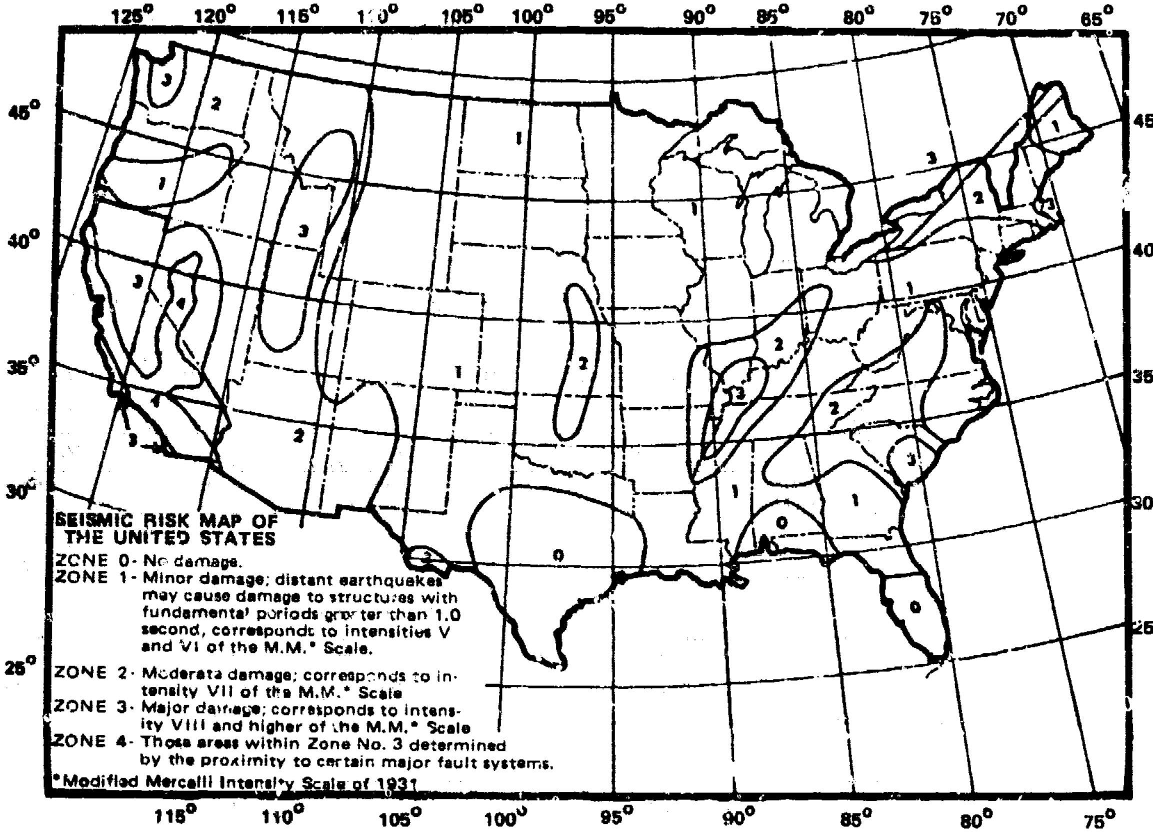


FIGURE 3-8 – TYPICAL ZERO PERIOD FREE FIELD SURFACE GROUND ACCELERATION USE IN SAFE SHUTDOWN DESIGN OF NUCLEAR POWER STATIONS

ZONE 0 0.1g

ZONE 1 - 0.15g ± 0.05g as a function of foundation condition.

ZONE 2 - 0.20g ± 0.05g as a function of foundation condition.

ZONE 3 - 0.3g ± 0.1g as a function of foundation conditions and proximity to areas of historical major seismic disturbances.

ZONE 4 - 0.55g ± 0.15g as a function of foundation conditions and proximity to known active faults.

Tornadoes

Nuclear power plants are designed to withstand the wind pressure and differential pressure drop from a "design tornado." The design tornado is chosen so that a nuclear power plant at a particular site will have only one chance in 10 million of being hit by a tornado at least that large in any given year.[4] To simplify design, the United States is divided into three regions as shown in Fig. 3-9[8]. In Region 1 the design wind speed is 360 MPH. In Regions 2 and 3 the design wind speed is 300 and 240 MPH, respectively. Differential negative pressure design varies from 3.0 psi at 360 MPH to 1.5 psi at 240 MPH.

Design Evaluation of Tanks

Design calculations, specifications, and drawings associated with the facilities described in Table 3-1 were obtained directly from owners or designers. We did not evaluate their numerical accuracy, but only the applicability of the calculations to current methods of analysis and to the design assumptions used for nuclear power plants.

The results in Tables 3-2, 3-3, and 3-4 are based upon stress levels. The "design load stress" in a structure is the stress produced by the force (i.e., normal load, earthquake, wind) which a building code requires a structure to withstand. The code also specifies the "allowable stress." The ratio of the allowable stress to the corresponding design load stress is called the "safety factor". A safety factor greater than one indicates that a structure is stronger than required by a particular code. If the safety factor is less than one, then the structure

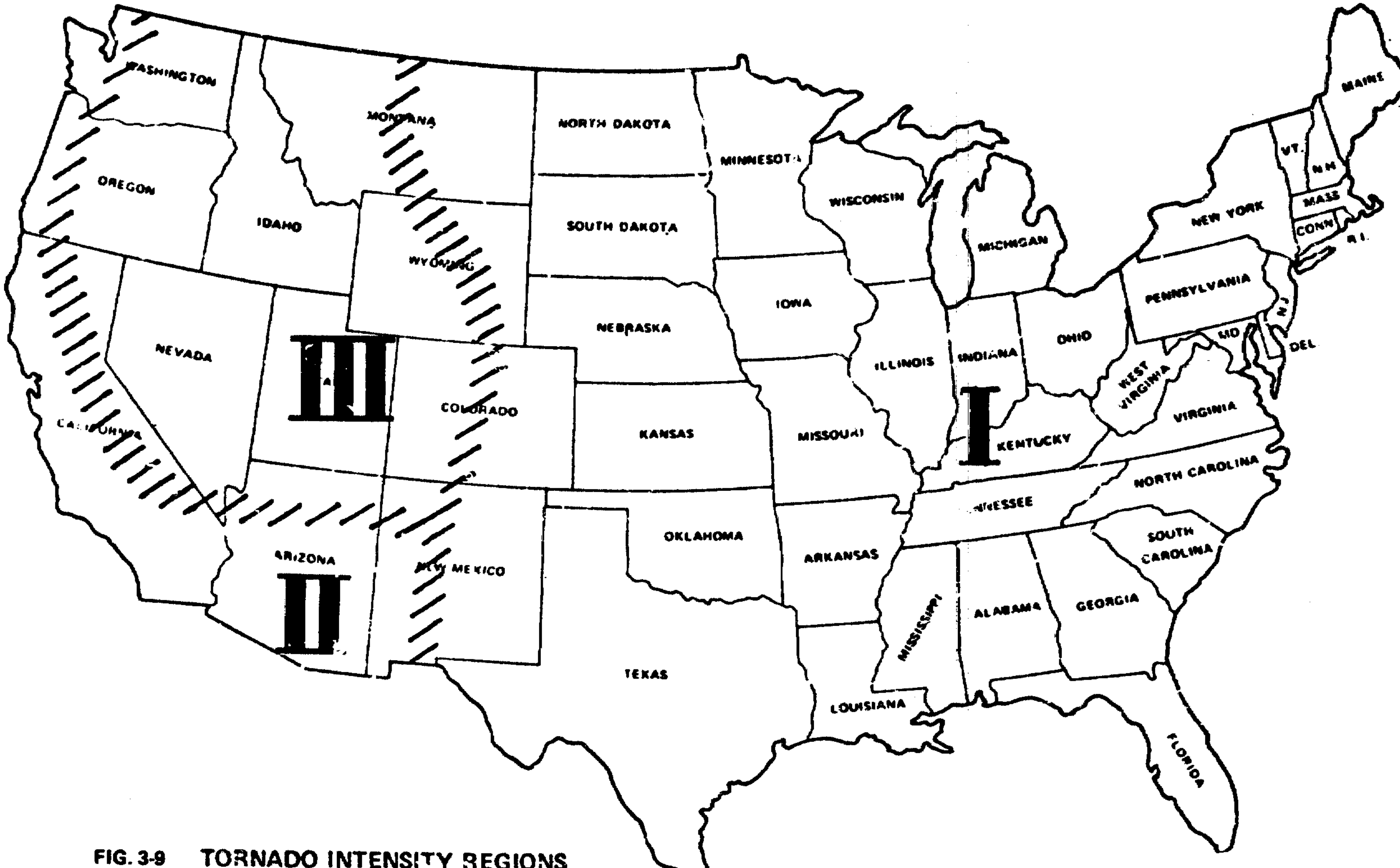


FIG. 3-9 TORNADO INTENSITY REGIONS

TABLE 3-2 STEEL TANK SEISMIC DESIGN PARAMETERS, FAILURE MODES, AND SAFETY FACTORS

	FACILITY	DESCRIPTION	ORIGINAL SEISMIC CRITERIA	NUCLEAR PLANT SEISMIC CRITERIA	MOMENT OF LIMITING FAILURE MODE(5) (10^3 K-ft.)		FACTOR OF SAFETY			
							All. Stress in Tie Down Straps or Bolts Kip/Sq. in. (Ksi)		Design Load Stress in Tie Down Straps or Bolts Kip/Sq. in. (Ksi)	
					UBC	Nuclear Criteria	UBC	Nuclear Criteria	UBC	Nuclear Criteria
1	LNG Marine Terminal for Distrigas Corporation Everett, Massachusetts Designed - 1970	55,000 m^3 150 ft. dia. x 123 ft ht. to Springline (Inner Tank)	UBC Zone 2 0.05g static load in accordance with TID 7024 Chapter 6 (Rigid Tank) method of analysis.	0.20g Safe Shutdown Earthquake Zero Period Ground Acceleration 5.0% Damping for Reg. Guide 1.60 Response Spectrum.	258	[illegible]241	Material: ASTM TP 304 (9) f_a = 22.5 Ksi f_y = 30.0 Ksi f_u = 75.0 Ksi (1) 1.33 x 22.5 = 29.9 Ksi	1.2 f_y(2) =36.0 Ksi	25.8 Ksi F.S. = 1.16(8)	153.9 Ksi(3) F.S. = 0.24
2	LPG Marine Terminal for Exxon Co., U.S.A. Everett, Mass. Designed - 1972	64,000 m^3 190 ft. dia. x 80 ft. ht. to Springline	Same as 1. above	Same as 1. above	293	875	Material: ASTM A 537 B f_a = 23.3 Ksi f_y = 50.0 Ksi f_u = 70.0 Ksi 1.33 x 23.3 = 31.0 Ksi	.7 f_u(2) =49.0 Ksi	25.1 Ksi(4) F.S. = 1.23	64.3 Ksi(3)(4) F.S. = 0.76
3.	Vertical Pressurized LPG "Bullet" tanks for Boston Gas SNG Plant Everett, Mass. Designed - 1947	114 m^3 cylinder 66 ft. long with 2:1 elliptical heat closure supported on a 5 ft. high, 3/4 in. thick skirt anchored by 8 - 1-1/2" A 193 bolts.	None specified but assumed for evaluation purposes the same as 1. above, except sloshing neglected.	Same as 1. above.	0.463	5.14	Material: (AISC) ASTM A 193 Bolts f_a = 63.0 Ksi f_y = 105.0 Ksi f_u = 125.0 Ksi 1.33 x 63.0 = 83.8 Ksi	.7 f_u(2) = 87.5 Ksi	Act. M = 463 K-ft. Lim. M = 3150 K-ft. F.S. = 6.8(7)	154.1 Ksi F.S. = 0.57
4.	Typical Horizontal Pressurized LPG "Bullet" Tanks Supported by Two Piers Designed by Trinity Industries, 1977	342 m^3 horizontal cylinder with hemispherical ends, 116 ft. between support saddles. Total length is 133 ft. I.D. of cylinder is 130 in.	None specified but assumed for evaluation purposes the same as 1. above, except sloshing is neglected.	Same as 1. above.	0.381(5)	5.55(5)	Material: (ASMC Sec. ASTM SA 612 PL (VIII) f_a = 20.2 Ksi f_y = 50.0 Ksi f_u = 81.0 Ksi E.Q. All.=20.2Ksi Div. 1 E.Q. All.=27.0Ksi Div. 2	.7 f_u(2) = 56.7 Ksi	18.6 Ksi F.S. = 1.08(6) F.S. = 1.42	22.0 Ksi F.S. = 2.58

(1) Allowable stress for both Earthquake and Wind based on 1.33 times normal allowable in accordance with 3.06.5 of API 620 Sup. No. 3.
(2) Based on Faulted Condition of Appendix F, ASME Section III Criteria for Component Supports.
(3) Note that this comparison is based on simple tensile stress calculation, neglecting shear carried by tie down straps or bolts. If two horizontal components of motion are considered such that significant shear and tension occur simultaneously and the friction capacity between the tank bottom and foundation are exceeded, tie down straps or bolts required to carry seismic shear, all safety margins shown for nuclear criteria would be reduced by at least a factor of 2.
(4) Tie down straps assumed to carry both internal pressure uplift and seismic with thermal stress neglected.
(5) Limiting Failure mode for Tank 1, 2, and 3 base overturning moment to be carried by anchor straps or bolts. For tank 4 limiting failure mode is bending moment plus pressure tensile stresses at center of span of tank. No saddle designs were evaluated.
(6) This Safety factor is based on ASME Section VIII Div. 1 allowables; if Div. 2 allowables are used, F.S. is increased as shown.
(7) With UBC E.Q. Base Moment = 5.56 K-ft. there is no up-lift on bolts. F.S. is ratio of the base moment to moment required to overstress anchor bolts.
(8) F.S. = Safety Factor = Allowable Stress/Design Load Stress.
(9) f_a = normal load allowable stress

f_y = yield stress

f_u = ultimate stress

1.33 x f_a = earthquake/wind load allowable stress

TABLE 3-3 PRESTRESSED CONCRETE TANK AND DIKE SEISMIC DESIGN PARAMETERS FAILURE MODES AND SAFETY FACTORS

FACILITY	DESCRIPTION	ORIGINAL SEISMIC CRITERIA	NUCLEAR PLANT SEISMIC CRITERIA	MOMENT OF LIMITING FAILURE MODE: Design Load Moment, M (10^3 k-ft.) Design Load Shear, V (10^3 Kips) UBC	Design Load Moment / Shear: Nuclear Criteria	Moment or Shear to cause lift off or sliding: UBC	Moment or Shear to cause lift off or sliding: Nuclear Criteria	FACTOR OF SAFETY: Ratio of Lift Off Moment or sliding shear to design load moment or shear: UBC	FACTOR OF SAFETY: Nuclear Criteria
1. LNG Marine Terminal[(1)] for Public Service Electric & Gas Rossville, Staten Is. N.Y. designed - 1970.	143,000 m^3 Capacity Prestressed concrete tank. 240 ft. dia. with ht. to spring line of 117 ft.	UBC Zone 1 static load in accordance with TID 7024 Chapter 6 (Rigid Tank) method of analysis.	0.20g Safe Shutdown Earthquake Zero Period Ground Acc. 7% damping of Reg. Guide 1.60 Spectrum.	M = 270 V = 5.7	M = 1933 V = 45.4	M = 1843 V = 11.1	M = 1474 V = 12.5	6.83 6.15	0.76 0.19
2. High Dike for LNG Marine Terminal for Western LNG Terminal Associates, Oxnard, Cal. (planned)	87,000 m^3 Capacity Prestressed concrete high dike. 259 ft. I.D. x 80 ft. to Springline.	Equivalent to Nuclear Plant Design Criteria for a 0.3g zero period ground acc. and 5% damping expect allowable stress limited to 1.33 x allowable.	0.6g[(3)] zero period ground acc. for 7% damping in accordance with R.G. 1.60 spectra with stress limited to 1.6 x allowable.	M = 1756 V = 53.9	M = 23.3 V = 107.2	M = 2745 (2)	M = 1568 (2)	1.56 (2)	0.67 (2)

(1) In this analysis, it is assumed radial shear bars carry shear in excess of 0.3 x Dead weight of concrete in tank walls (4608 Kips). The bearing bars have an assumed capacity of 1.6 Ksi for UBC and 1.92 for Nuclear Criteria. Factor of Safety shown is the ratio of the allowable stress in the bearing bars to the design load stress, assuming that the bars must carry shear load in excess of the shear load carried by friction.

(2) Shear capacity not evaluated since design of base detail not complete. However, because of the magnitude of forces, some positive membrane shear resistance system might be required.

(3) Value of 0.6g selected as representative of current design conservatism imposed on Nuclear Stations in Coastal Zone of Southern California.

TABLE 3-4 SUMMARY OF ANALYTICAL RESULTS AND COMPARISON OF 100-YEAR WIND TO TORNADO DESIGN MARGINS FOR CONCRETE AND STEEL LNG AND LPG STORAGE TANKS

	FACILITY	ORIGINAL WIND DESIGN CRITERIA	NUCLEAR PLANT TORNADO CRITERIA	MOMENT OF LIMITING FAILURE MODE (10^3 K-ft)		FACTORS OF SAFETY: Allowed Stress, Moment on Shears		FACTORS OF SAFETY: Design Load Moment, Shear, and Stresses and Factors of Safety	
				100-Year Wind	Tornado	100-Year Wind	Tornado	100-Year Wind	Tornado
1.	LNG-Distrigas Everett, Mass.	25 psf 0-30 ft. 35 psf 30-50 ft. 45 psf 50-100 ft. 55 psf > 100 ft. App. = 100 MPH EXP.C	360 MPH Wind 3.0 psi pressure drop	36.4	296.2	Material: ASTMA-36 f_{all} = 20.0 Ksi f_y = 36.0 Ksi f_u = 58.0 Ksi 1.33 x 20.0 = 26.6 Ksi	.7 f_u 40.6 Ksi	16.9 Ksi F.S. = 1.58	78.1 Ksi F.S. = .52
2.	Propane - Exxon Everett, Mass.	30 psf Const. Approx. = 90 MPH EXP. C ANSI A 58.1	360 MPH Wind 3.0 psi pressure drop	16.6	151.3	Material: ASTM A 527B f_a = 23.3 Ksi f_y = 50.0 Ksi f_u = 70.0 Ksi 1.33 = 23.3 = 31.0 Ksi	.7 f_u = 49.0 Ksi	9.53 Ksi F.S. = 3.25	55.0 Ksi F.S. = .89
3.	Propane - Boston Gas Everett, Mass.	Unknown	360 MPH Wind 3.0 psi pressure drop	.455	3.7	Material: (AISC) ASTM A 193 f_a = 63.0 Ksi f_y = 105.0 Ksi f_u = 125.0 Ksi 1.33 x 63.0 = 83.8	.7 f_u = 87.5 Ksi	Act M = 955 K-ft Lim M = 3150 K-ft F.S. = 6.9	83.17 Ksi F.S. = 1.05
4.	Trinity Industries Typical 90,000 gallon LPG "bullet" tank.	None specified	360 MPH Wind 3.0 psi pressure drop	.284	3.63	Material: (ASME Sec. VIII) ASTM SA 612 PL f_a = 20.2 Ksi f_y = 50.0 Ksi f_u = 81.0 Ksi E.Q. All. = 20.2 Ksi Div. 1 E.Q. All. = 27.0 Ksi Div. 2	.7 f_u = 56.7 Ksi	18.6 Ksi F.S. = 1.08 F.S. = 1.42	19.5 Ksi F.S. = 2.90
5.	Public Service Electric & Gas Staten Is., N.Y.	Unknown	360 MPH Wind 3.0 psi pressure drop	46.5	321.3	M = 1161	M = 1542	F.S. = 25.0	F.S. = 4.8
6.	LNG Dike, Western LNG, Oxnard, California	Unknown	240 MPH Wind 1.5 psi pressure drop	16.0	53.9	M = 3920	M = 3920	243.7	72..7

(1) For notes applicable to material properties and allowable stresses, see Table 3-2.

does not fulfill the code's requirements.

Typical values for various allowable stresses are shown in the chart below. All values are expressed as fractions of the ultimate (breaking) stress (f_u) of the construction material.

Normal load allowable stress	$0.3f_u$
Earthquake/wind load allowable stress	$0.4f_u$
Yield stress	$0.4-0.6f_u$
Nuclear design earthquake/wind load allowable stress	$0.7f_u$

In this chapter we use "facility failure" to mean significant uncontrolled leakage of LEG from the primary (insulated) container. Generally, such failure will occur as a result of plastic (inelastic) deformation of the structure. Plastic deformation begins when a material's yield stress is exceeded.

The calculations of failure and safety factor depend upon conventional engineering techniques, which involve simplifications. The exact stress needed to produce failure is almost never determined because it is so difficult to do so. It is possible, however, to find the weakest or most vulnerable component in a structure. The "limiting failure mode" is the process most likely to cause this component to fail. Appendix III-3 is a more detailed discussion of these factors.

Seismic Design

Prior to the mid-1960's, there appears to have been no general requirement for seismic design evaluation. The seismic designs of those tanks designed after the mid-1960's meet or exceed the UBC requirements for the area in which they are built and use a seismic static horizontal coefficient.[2] The proposed Oxnard LNG facility has design criteria which generally follow and are equivalent to those required for nuclear power plants. It is not, however, designed to withstand as large an earthquake as would a nuclear plant at the same site.

Steel Tanks Containing Stored Liquid

In general, our evaluations of tanks and dikes for seismic loads follow the same procedures used in the original design and are described in TID 7024,[9] which has been used as a standard method for several years, except that we considered tanks to be flexible rather than rigid* (as discussed by Veletsos and Yang).[10] As can be seen from Fig. 3-7, the dynamic response of flexible tanks can increase response inertia shear and moment by a factor of two or three times over that used in the rigid assumption.

The most likely cause of failure due to seismic loads on steel tanks containing LNG or liquefied propane appears to be shear and overturning moment induced forces in the steel straps that anchor the steel cylinder sides of the tanks to the concrete flat bottom foundation. In other words, if a tank fails because of an earthquake, it is likely to be by tensile rupture of the hold-down straps, which would permit the tank walls to lift off and separate from the tank bottom. The next most likely cause of

*The impulse mass of the fluid in a rigid tank is assumed to have the same acceleration as the ground. In a flexible tank the fluid mass acceleration is a function of the tank frequencies, including the effective mass of both tank and fluid. Typical flexible tank fundamental frequencies occur between 1 and 4 cycles per second.

failure would probably be buckling of the walls due to overturning moment compression. However, since failure of the anchor straps would occur at much lower acceleration and would result in a significant spill of the contained fluid, the effect of less likely failure causes has not been evaluated in detail.

The base shear, overturning moments, and safety factors determined for the UBC seismic criteria and those determined for nuclear plant seismic criteria are summarized in Table 3-2. The full SSE earthquake has been assumed in the "Nuclear Criteria" column. The results show that the tanks, while adequate using the UBC criteria, come nowhere near meeting nuclear seismic criteria.

Steel Outer Tanks

Many LNG storage vessels consist of two steel tanks with the outer tank protecting the insulation and the inner tank from the weather and wind. In general, if the inner tank fails due to seismic effects, the outer tank will fail also. The outer Distrigas tank, for example, was evaluated for seismic load assuming the inner tank had failed and the LNG was bearing on the outer tank. In such an instance, the factor of safety against outer tank lift-off failure for the SSE event is 0.28, compared to 0.24 for the inner tank; and for the UBC earthquake, the factor of safety is 0.70 for the outer tank compared to 1.16 for the inner tank. Furthermore, the outer tanks are not normally made of cryogenic material. If the inner tank fails, the outer tank is almost certain to rupture from the resulting pressure and thermal shock.

Concrete Tanks Containing Stored Liquid

Under the UBC criteria, concrete tanks for containing stored liquid use their own dead weight to resist seismic overturning moment; hence, no tensile or uplift ties are provided to anchor the concrete cylinder to the base mat. These two-way prestressed tanks are generally fabricated from precast, vertically prestressed panels. After erection, the panels are spirally wound to provide horizontal prestress. Radial shear lugs are used to provide seismic shear resistance. As in the case of steel tanks, seismic-induced lift-off of the tank walls and shear appear to be the most likely failure modes. The seismic base shear and overturning moment safety factors determined for the actual UBC design criteria and those determined for nuclear plant seismic criteria are summarized in Table 3-3.

Concrete High Dikes

The design details of concrete high dikes are similar to those used for concrete tanks, except that the insulation details between the wall and base mat can be much simpler, and radial shear lugs may not be required since overall height to width ratios have been significantly reduced. It was assumed, in performing the earthquake analysis shown in Table 3-3, that the diked area was filled with LNG.

Earthen Dikes

Earthen dikes are normally made of selected engineered backfill designed for optimum density and slope stability, which precludes their failure during earthquakes. Usually they are significantly more earthquake resistant than the surrounding foundation media, unless that is also engineered fill.

Tornado Design

The tanks analyzed were designed as detailed in ANSI A 58.1-1972, to withstand a wind which has only one chance in 100 per year of occurring at the site, except that velocity is considered constant with height and the gust factor is taken as a constant 1.0. Tornado design wind speeds typically range, as a function of location, from 240 to 360 MPH, while normal design wind velocity ranges from 100 to 130 MPH. Since wind loads vary as the square of velocity, tornado wind loads are typically 5 to 10 times greater in magnitude than normal 100-year wind design load. Tornado design also considers differential pressures.

Tornado winds have been known to generate significant missiles. A 360 MPH tornado wind can propel missiles at velocities between 200 and 300 MPH. We have not done a detailed evaluation of tornado-borne missiles, but, in general, to stop missiles at these velocities, cylindrical shells require a thickness between 1.0 and 1.5 inches of steel, or between 18 and 24 inches of concrete. LNG and LPG steel outer tanks would be penetrated by some tornado-borne missiles.

Table 3-4 summarizes and compares overturning moments, shear, forces in tie-downs, and factors of safety for the ANSI A 58.1-1972 design for the 100-year wind with nuclear plant tornado design requirements. For double-wall tanks, this analysis is applicable to the outer tank. Two of the six facilities evaluated fail to meet the tornado resistance requirements demanded of nuclear plants.

UBC Earthquake and 100-Year Wind Evaluation

All the LNG and LPG tanks and dikes we evaluated, as summarized in Tables 3-2, 3-3, and 3-4, were adequately designed for the UBC earthquake and the 100-year maximum wind design criteria. The smallest factor of safety was 1.08. This is not to say that, if this 8 percent margin were exceeded, failure would result. Given the stress levels which were allowed for this load case, gross failure would probably not occur until loads exceeded by 30 to 75 percent those loads which would be determined with a safety factor of 1.0. However, when overturning moment or gross stability values are the limiting behavior or failure mode, there is little excess capacity and the 30 to 75 percent margin should not be assumed available.

In addition to meeting the minimum UBC earthquake and 100-year wind criteria, all the tanks and dikes were adequately designed for their own facility specific criteria, which were in some instances more stringent than the UBC requirement; the Oxnard concrete dike is an example.

Nuclear Standards: Safe Shutdown Earthquake and Tornado

These input loads are significantly larger than the UBC earthquake and 100-year wind, in many cases more than 10 times greater. In general, the tanks evaluated fail to meet these standards. Also, since the allowable stresses permitted for this load case are significantly greater than those used for the UBC earthquake and 100-year wind, the additional margin above a 1.0 safety factor on stresses to actual failure has probably been reduced to the 20 to 40 percent range. The results of this evaluation indicate that most LNG and LPG storage facilities would fail if they were subject to the same seismic load phenomena that nuclear power plants are designed to resist. The limiting seismic and wind loads used in the design of nuclear plant facilities have a probability of occurrence between 1/100,000 to 1/10,000 per year.

LIQUEFACTION

The specific earthquake phenomenon called liquefaction has been generally considered in seismic design only in the past ten to fifteen years. The term liquefaction refers to the development (due to cyclic loads) of pore water pressure equal to the confining pressure in sands and silts. When this happens, particularly in relatively loose soils, very large deformations can occur, and the foundation acts like water, with little or no shear strength. This can result in catastrophic failure of the building foundation. Liquefaction normally occurs in poorly graded, saturated sands and silts, with a relative density from 35 to 70 percent. Since most engineered or selected backfill is made up of relatively well-graded materials and is compacted to a relative density between 70 and 90 percent, it is unlikely such materials will liquefy.

FLOODING AND TSUNAMI

Flooding and tsunami at a site could cause a tank to shift or lift off from its foundation, causing a massive spill. This could be caused by the buoyancy of the tank or by the drag resistance of the tank to the flow of the flood water. The procedure normally followed to prevent this is to locate the tank above the flood plain, or to use high enough dikes or levees to keep potential flood water from reaching the storage tanks.

Evaluation

From the responses we received to the questionnaire in Appendix III-1, we determined the site conditions and the design procedures that were followed at a number of LEG storage facilities. A summary of the responses is given in Table 3-5 for liquefaction and Table 3-6 for flooding and tsunami.

When liquefaction analysis was done for a site, it was generally done in accordance with the simplified procedures of Seed and Idriss,[11] which have been used as more or less standard practice in the industry for evaluating liquefaction potential since their publication in 1971.

Sites on rock or on cohesive clay type foundations are generally not susceptible to liquefaction, and no such evaluation is made in these cases.

For one of the two facilities built on piles, no evaluation was made of the potential loss of lateral pile support due to liquefaction. This could lead to significant lateral deformation of the tank.

Some evaluations of the forces associated with liquefaction, flood, and tsunami on LEG storage facilities have been much better than others. The facilities whose design work began after the period 1972 to 1974 have had much more attention devoted to extreme natural loads and hazards than have the tanks designed earlier. In many

TABLE 3-5 SUMMARY OF LIQUEFACTION EVALUATION PERFORMED AT TYPICAL LNG AND LPG STORAGE TANK SITES

	FACILITY AND LOCATION	FOUNDATION POTENTIALLY SUSCEPTIBLE TO LIQUEFACTION	ANALYSIS PERFORMED	MINIMUM FACTOR OF SAFETY	REMARKS
1.	Port O'Connor, Tex., Proposed LNG Marine Terminal, El Paso LNG Terminal Co.	Yes	Seed & Idriss (11)	2.0	Based on 0.07g Zero Period Ground Acceleration. Final foundation system - Flexible mat or piles.
2.	Cove Point, Md., LNG Marine Terminal, Columbia LNG Corp. (Designed - 1972)	Yes	Liquefaction Analysis made in accordance with Seed & Idriss (11) with conclusion reached that there was little potential for liquefaction. However, no analysis available for review.	N/A	No analysis available for review.
3.	Oxnard, Cal. Proposed LNG Marine Terminal, Western LNG Terminal Associates	Yes, Top 20 ft. of foundation material was determined to liquefy and is to be removed and replaced with selected backfill.	Seed & Idriss (11) Donovan (12)	1.44 1.21	Based on free field ground acceleration of 0.37g and acceleration at tank foundation level of 0.21g.
4.	Staten Island, N.Y. LNG Peakshaving Facility Texas Eastern Transmission Co. (Designed - 1972)	Yes	Apparently no specific liquefaction evaluation was made. Site employs selected backfill for 25 feet below tank. This backfill should not be susceptible to liquefaction.	N/A	The selected backfill is underlaid with approximately 17 feet of well-graded sand. Potential for liquefaction in this layer is unknown based on data supplied.
5.	Lake Charles, La. Proposed LNG Marine Terminal Trunkline LNG Co.	A friction pile foundation was used.	Seed & Idriss (11) Opinion of design engineer was that foundation could take 4 Kip/pile lateral transient load.	N/A	Analysis not available for review. Not clear how the capacity stated compares with potential lateral earthquake load.
6.	Elba Island, Ga. LNG Marine Terminal Southern Energy Co. (Designed - 1972)	A friction pile foundation was used	Lateral capacity of pile not stated.	N/A	Not enough data furnished to evaluate either liquefaction potential or lateral load capacity of the pile system. UBC Zone III used in design of facility although it is in Zone II.
7.	Plymouth, Wash. LNG Peakshaving Facility Northwest Pipeline Corp. (Designed - 1975)	Probably not. Foundation media is gravel 50 ft. deep over basalt rock.	No	N/A	
8.	Everett, Mass. LNG Marine Terminal Distrigas Corp. (Designed - 1970)	Probably not since foundation below fill either stiff clay or dense coarse sand.	Not apparent from data furnished.	N/A	Site design for UBC Zone 2.
9.	Houston (Galena Park), Tex., LPG Marine Terminal Warren Petroleum Co.	Yes	Not performed.	N/A	Potential for tank foundation liquefaction not considered as a design parameter.
10	West Deptford, N.J. Proposed LNG Marine Terminal Tenneco LNG Corp.	Yes, Founded on sand.	Not performed.	N/A	UBC Seismic Zone I.

TABLE 3-6 SUMMARY OF FLOODING AND TSUNAMI EVALUATION PERFORMED AT TYPICAL LNG AND LPG STORAGE TANK SITES

	FACILITY AND LOCATION	POTENTIAL FORMALLY EVALUATED		CRITERIA OR ANALYTICAL METHOD USED IN EVALUATING DESIGN BASIS		FACTOR OF SAFETY		REMARKS
		FLOODING	TSUNAMI	FLOODING	TSUNAMI	FLOODING	TSUNAMI	
1.	Port O'Connor, Tex. Proposed LNG Marine Terminal, El Paso LNG Terminal Co.	Yes	No	100 yr. Storm	N/A	30/27.1= 1.1 (1)	N/A	Tank also designed to withstand flood load as buoyancy force assuming tank full.
2.	Cove Point, Md. LNG Marine Terminal Columbia LNG Corp. (Designed - 1972)	Yes	No	10 yr. Local Run Off	N/A	N/A	N/A	Tank foundation located 110 ft. above mean sea level. This height differential considered sufficient to preclude possibility of coastal flooding.
3.	Oxnard, Cal. Proposed LNG Marine Terminal, Western LNG Terminal Associates	Yes	Yes	Probable Maximum Flood	500 yr. Return Period	15/12=1.25 (2)	15/14.7= 1.02	Since tank located approx. 1200 ft. inland and surrounded by 80 ft. dike, tsunami and storm damage not considered credible.
4.	Staten Island, N.Y. LNG Peakshaving Facility, Texas Eastern Transmission Co., (Designed - 1972)	Yes	No	Based on Historical Records	N/A	None Stated. Max. historical flood has not reached height of base	N/A	Since reported height of tank bottom is only 10 ft. above mean sea level, potential for flooding probably not adequately covered by historical data.
5.	Lake Charles, La. Proposed LNG Marine Terminal, Trunkline LNG Co.	Yes	No	100 yr. Flood	N/A	12/7=1.7 (3)	N/A	Tsunami not considered credible since site is 20 miles from coast.
6.	Elba Island, Ga. LNG Marine Terminal Southern Energy Co. (Designed - 1972)	Yes	No	100 yr. Flood & Storm	N/A	15.69/13.0= 1.2 (4)	N/A	
7.	Plymouth, Wash. LNG Peakshaving Facility Northwest Pipeline Corp. (Designed - 1975)	No	No	N/A	N/A	N/A	N/A	Tank base located ½ mile from Columbia River +30 ft. above controlled height of river.
8.	Everett, Mass. LNG Marine Terminal Distrigas Corp. (Designed - 1970)	Yes	No	Based on Historical Record	N/A	34.4/16= 2.15 (5)	N/A	Bottom of tank located 1000 ft. from shore and 18 ft. above highest recorded flood level.
9.	Houston (Galena Park), Tex., LPG Marine Terminal, Warren Petroleum Co.	Yes	No	N/A	N/A	N/A	N/A	Maximum recorded flood height 10 ft. below bottom of tank.
10.	West Deptford, N.J. Proposed LNG Marine Terminal, Tenneco LNG Corp.	Yes	No	50 yr. Storm	N/A	25/8.8= 2.84 (6)	N/A	Design still in preliminary stage.

(1) Height of sea wall protecting site = 30.0 ft.; combined 100-year tide and wave surcharge 27.1.
(2) 15 ft. height of protective sand dunes and perimeter road; 12 ft. height of storm wave run up; 14.7 ft. height of tsunami run up.
(3) 100-year flood stage 7.0 ft. above mean sea level; base of tank equal to or greater than 12.0 ft.
(4) Bottom of tank = 15.69 ft.; 100-year flood height 13.0 ft.
(5) Bottom of tank = 34.4 ft.; historical flood height equal 16.0 ft.
(6) Plant elevation = 25 ft.; highest recorded flood level 8.8 ft. in 1933.

cases these higher levels of concern may be associated with increased State and Federal regulatory interest. However, in some cases (e.g., the proposed Port O'Connor Terminal, El Paso LNG Terminal Company), the level of engineering effort appears to significantly exceed the efforts expended on similar facilities anywhere in the United States, except California. This great variation in engineering effort appears to result partly from the lack of consistent State or Federal regulatory requirements in these areas.

Most LEG storage facilities are being designed for at least the 100-year flood and associated storm. The potential for seismic-induced flooding, separate from storm flooding, is currently being evaluated only in the recognized high seismic zones, such as the California coast. The evaluation of the potential for liquefaction due to seismic excitation also seems to be restricted in general to high seismic sites, although it is interesting to note that a low seismic site, Magnitude 4.8 in Texas, was also formally evaluated for liquefaction.

FINDINGS

- About 5 percent of all earthquakes in the United States have occurred in regions located within tectonic plates where there had been little known seismic activity or active faulting. Within the past 250 years, at least five major earthquakes have followed this pattern. The ones at New Madrid, Missouri, and Charleston, South Carolina, were each felt over an area of two million square miles. On the other hand, West Coast earthquakes which do considerable local damage are seldom felt over an area of more than a few thousand square miles.

- It is very likely that many large LEG facilities will be impacted by winds, floods, or earthquakes greater than those they are required to withstand. However, structures can generally withstand stresses somewhat greater than those required by regulations.

- If a tank fails because of an earthquake, high wind, or flood, it is likely to be by tensile rupture of the hold-down straps, which would permit the tank walls to lift off and separate from the tank bottom. This would result in a massive spill of the contained fluid.

- The seismic designs of those tanks designed after the mid-1960's meet or exceed the requirements of the Uniform Building Code used in the area in which they are built. Prior to this period, there appears to have been no general requirement for seismic design evaluation.

- All the LEG tanks we evaluated at five sites were adequately designed for the Uniform Building Code earthquake and the 100-year maximum wind design criteria, but tanks at three of the five sites had earthquake safety margins less than 25 percent. Two of these sites (a total of three tanks), the Distrigas LNG import terminal and the Exxon propane import terminal, are next to one another in Boston Harbor.

- Most LEG storage facilities come nowhere near meeting nuclear criteria and would fail if they were subject to the same load phenomena that nuclear power plants are designed to resist.

- Large LEG tanks made of steel are usually much less resistant to natural forces than those made of prestressed concrete.

- Steel outer tanks could be penetrated by some tornado-borne missiles.

- The outer steel walls in double-wall tanks are not normally made of material designed to withstand intense cold. Thus, if the inner tank fails, the outer tank is almost certain to rupture from the pressure and thermal shock.

- There is a very large difference in the level of engineering effort that has been expended by owners in evaluating the extreme natural forces associated with liquefaction, flood, and tsunami on LEG storage facilities. This difference appears to result partly from the lack of consistent State or Federal regulatory requirements in these areas.

CONCLUSION

There is no reason why storage tanks in densely populated areas, holding large amounts of highly hazardous materials, should have to satisfy very much weaker standards for resistance to natural phenomena or sabotage (see Chapter 9) than do nuclear plants in remote areas.

REFERENCES

1. Uniform Building Code, 1973 Edition, Volume 1, International Conference of Building Officials, 1973.

2. Storage and Handling of Liquefied Natural Gas, NFPA No. 59A, National Fire Protection Association, 1975.

3. ANSI Standard A 58.1-1972, Building Code Requirements for Minimum Design Loads in Buildings and Other Structures, American National Standards Institute, 1972.

4. Markee, E.H., Jr., Beckerley, J.G., and Sanders, K.E. "Technical Basis for Interim Regional Tornado Criteria," U.S. Atomic Energy Commission, Office of Regulation, WASH-1300, May 1974.

5. NRC Regulatory Guide 1.60, "Design Response Spectra for Nuclear Power Plants," Division of Standards, U.S. Nuclear Regulatory Commission, 1973.

6. ANSI Standard N-635, "Guidelines for Combining Natural and External Manmade Hazards at Power Reactor Sites," (DRAFT) - May 1976.

7. Stevenson, J.D. "Rational Determination of the Operational Basis Earthquake and Its Impact on Overall Safety and Cost of Nuclear Facilities," Nuclear Engineering and Design, Vol. 35 (1975) North Holland Publishing Company.

8. NRC Regulatory Guide 1.76, "Design Basis Tornado for Nuclear Power Plants," U.S. Atomic Energy Commission, Directorate of Regulatory Standards, April 1974.

9. Nuclear Reactors and Earthquakes, TID 7024, 1963.

10. Veletsos, A.S. and Yang, J.Y. "Dynamics of Fixed-Base Liquid Storage Tanks," Presented at U.S.-Japan Seminar for Earthquake Engineering with Emphasis on Lifeline Systems, Tokyo, Japan, November 8-12, 1976.

11. Seed, H.B., and Idriss, I.M. "Simplified Procedures for Evaluating Soil Liquefaction Potential," Journal of the Soil Mechanics and Foundation Division, ASCE, Vol. 97.

12. Donovan, N.C. "A Stochastic Approach to the Seismic Liquefaction Problem," Statistics and Probability in Civil Engineering, Hong Kong, September 1971.

CHAPTER 4

CRACK-INDUCED FAILURE OF METAL LNG TANKS

CONTENTS

DISCUSSION

Our assessments of the vulnerability of LNG systems in Chapters 3, 6, 7, 8 and 9 are partly based on our calculations of crack behavior in the spherical and cylindrical metal tanks used for transporting and storing LNG.* It is generally accepted that the two materials currently used for LNG tanks, 5083 aluminum alloy and 9% nickel alloy steel, are very resistant to crack growth under cryogenic conditions. Most small-scale tests (with some significant exceptions) have produced very stable tearing of cracks, rather than rapid crack propagation. Nevertheless, under the dead weight of LNG, a large, fully-loaded tank can suffer catastrophic failure (immediate, total collapse) if a sufficiently long crack is suddenly created by sabotage or natural forces. Cracks long enough to cause catastrophic failure are called "critical".

Federal agencies responsible for LEG safety have not made calculations of critical crack lengths of LEG tanks.

The critical crack lengths we calculated range between 4-1/2 and 8-1/2 feet. These calculations are far from exact, but we have done them in a way that we believe is conservative. We have neglected plasticity, and inertial thermal and slosh loading stresses in our calculations. The inclusion of these would make the calculated critical crack lengths shorter.

The catastrophic failure we observed in our sabotage experiments further strengthens our belief that our

*The technical discussion that goes with this chapter is given in Appendix IV.

estimates are conservative. They imply that a perfect crack is not needed for catastrophic failure; a hole with jagged edges may be sufficient.

Moreover, the numbers we have calculated for critical crack length should not be interpreted as saying that shorter cracks will be "safe", i.e., non-propagating. Present technical knowledge is insufficient to support such a claim in the crack-size range we are discussing.

Columbia LNG Corporation, in reviewing a draft of this chapter, commented that the critical crack lengths for cylindrical tanks are between 1 and 1-1/2 feet for 9% nickel alloy steel tanks and between 3 and 4 feet for aluminum alloy tanks.

CONCLUSION

We estimate that crack lengths between 4-1/2 and 8-1/2 feet are long enough to cause catastrophic failure in cylindrical and spherical LNG tanks. We believe these estimates to be conservative. (Lengths calculated by Columbia LNG Corporation are much shorter).

RECOMMENDATION

We recommend that the Secretary of Energy institute a testing program to accurately determine the critical crack lengths for the various types of tanks used to store and transport LNG and LPG. The critical crack lengths should be determined for real types of tanks under real types of static and dynamic stresses, including those that might be caused by sabotage.

AGENCY COMMENTS AND OUR EVALUATION

The Coast Guard comments on this chapter make three points:

(1) Although the Coast Guard has not determined critical crack lengths of ship cargo tanks, it does require such calculations from ship designers.

(2) Testing and inspection during tank construction insure that flaws are limited to a very small size.

(3) If a crack were to grow, a leak would be detected before the critical length was reached.

The Coast Guard approach may be adequate for cracks that develop in ordinary use, but it ignores the possibility that grounding, collision, or sabotage may produce a sudden, large crack. The danger of catastrophic failure from these causes cannot be adequately assessed until critical crack lenths are adequately determined.

CHAPTER 5

FLOW OVER CONTAINMENT DIKES

CONTENTS | PAGE

INTRODUCTION

National Fire Protection Association safety standards require that every group of LNG storage tanks be surrounded by a dike which can contain at least the volume of the largest tank. Dikes have not been designed to prevent the overflow of a rushing liquid, and, in fact, little is known about such problems. We examined the consequences of a massive rupture or collapse of the tank wall which releases a large amount of liquid in a short period of time. We found that a substantial part of the stored fluid can surge over the dike and escape the containment area. Design criteria will have to be modified if such surges are to be contained.

It is not improbable that the same natural or man-made cause could rupture more than one tank. If more than one tank ruptures within the same dike, the overflow would be even greater. In our analysis, however, we assumed that only one tank is enclosed by the dike. A dike may be constructed with either vertical or sloping sides. A schematic configuration is shown in Fig. 5-1.

We also examined the possibility of fluid spurting over the dike from a sizable puncture of the tank at some distance above ground level. Figure 5-2 demonstrates such "spigot" flow where all "dike" dimensions meet or exceed safety requirements. The volume of the demonstration "tank" pictured is two quarts. This is slightly less than the containment capacity of the surrounding "dike". A puncture results in a fluid jet whose parabolic arc easily clears the safety barrier. We calculated the amount of spillage from a puncture in the wall of actual facilities and its dependence on geometrical parameters.

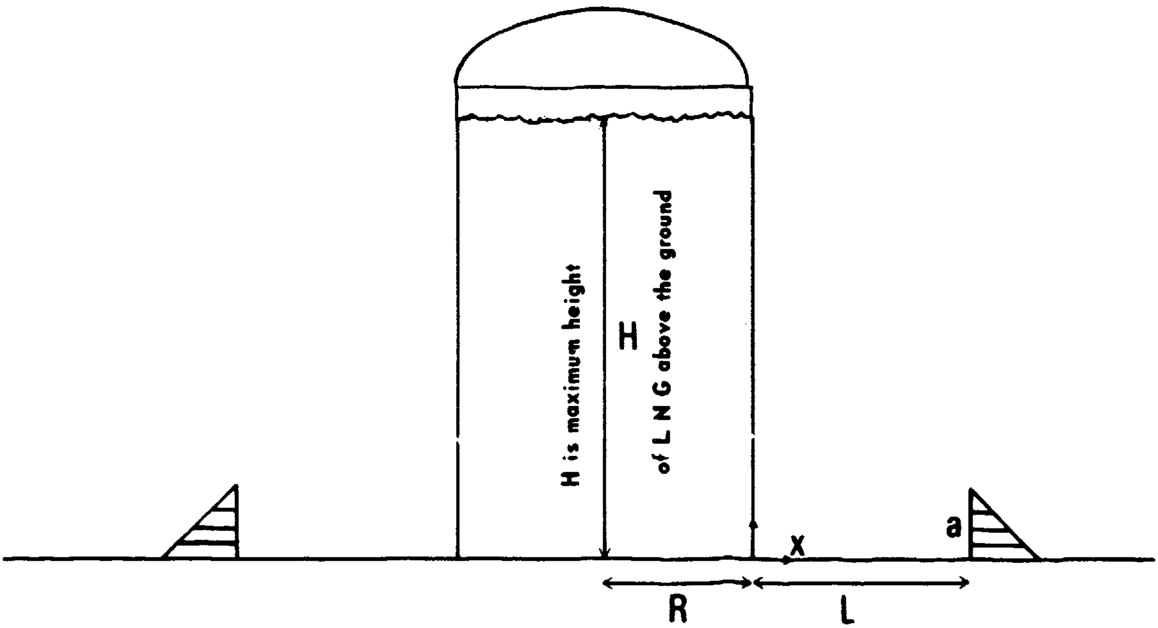


FIG. 5-1

SIMPLIFIED CROSS SECTION OF A STORAGE FACILITY SHOWING THE TANK AND DIKE. THE LABELLED CONFIGURATION TO THE RIGHT OF THE SYMMETRY AX:S CORRESPONDS TO THE TWO DIMENSIONAL PROBLEM STUDIED.

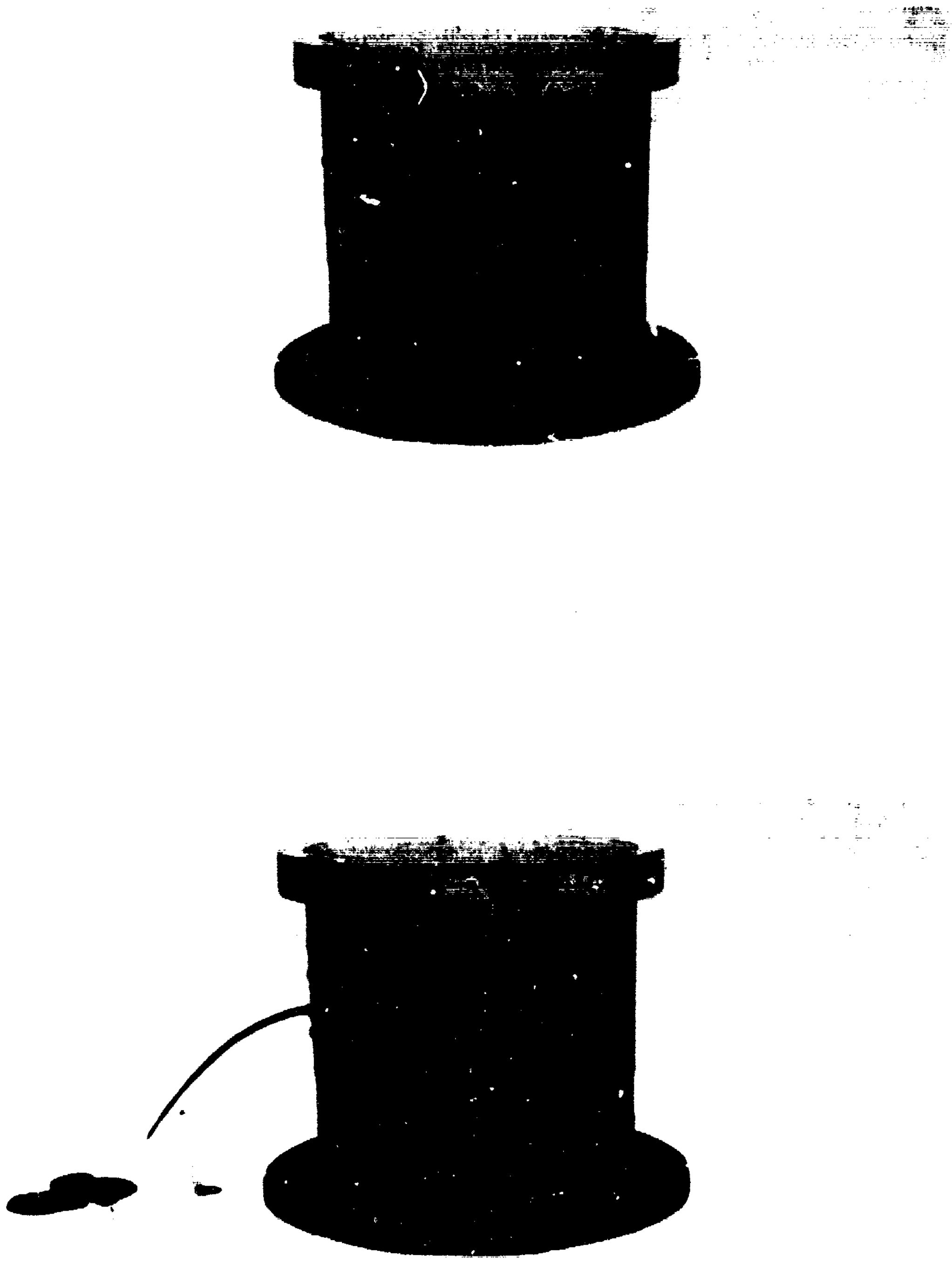


FIG. 5-2

A MODEL OF A STORAGE TANK AND A SURROUNDING DIKE. THE VOLUME CAPACITY OF THE DIKE IS SLIGHTLY LARGER THAN THAT OF THE TANK. A PUNCTURE PRODUCES A SPIGOT FLOW WHICH ARCS OVER THE BARRIER.

The theoretical work and computer model we developed for the analysis in this chapter were validated by experiment.

Although the relevant mathematical formalism, the details of the analysis, and the computer program results appear in Appendix V, much of the discussion in this chapter is still quite technical. The highly technical sections are italicized. Non-technical readers may omit them.

FLOWS OVER DIKES

If a tank wall ruptures or collapses because of an earthquake, flood, high wind, or sabotage, a mound of liquid will move rapidly and hit the containment dike. The way in which the fluid surmounts the barrier depends in part on the design of the dike. The rushing liquid may simply vault an inclined side, or it may pile up very rapidly at the face of a vertical wall and then flow over the top. In either case, a strong shock wave forms at the dike and returns towards the storage tank. The process is a very complicated, highly non-linear, dynamical interaction. However, the essential features of surge and overflow can be explained by examining the fluid motion in simpler and closer to ideal conditions. To do this, we built a two-dimensional model whose cross section is shown in Fig. 5-1. Liquid is released when the wall of the tank at $x = 0$ collapses (vanishes) at time zero. In the experimental arrangement the tank is a cube 9 inches on a side. The inner wall is a movable slide which is pulled out quickly to simulate a massive rupture. The fluid released flows along a 48 inch long channel that is open at the other end. A vertical dike of height a is placed at $x = L$. The specific dike height that satisfies the two safety criteria—equal storage and containment volume, and

L=.6 (H-a)—will be referred to as the "prescribed height" and written a_p. Flow against inclined dikes is examined below.

Since no exotic properties of the liquid were considered in this analysis of dynamical effects (e.g., evaporation of LNG), water was used as the fluid in the experiments.

Fig. 5-3 is a typical sequence of photographs showing the fluid motion after the wall of the tank is pulled out. (The total time period involved is about one second.) Water rushing towards the dike at high speed catapults high into the air upon impact. The fluid piles up and pours over the dike as a shock returns to the region of collapse. The overflow, designated by Q_0, and defined as the fraction of the original fluid volume that escapes upon impact, is the primary quantity that is measured in these experiments. Shock reverberations between dike and wall may involve additional spillage. However, the total overflow, denoted by Q_1, is found to differ little from Q_0. *For L/R = 2, the maximum difference is 5% of the fluid in the tank.*

Overflow is also calculated on the basis of a theoretical model. The comparison of theory and experiment for the same simple geometry establishes the accuracy of the model and the specific approximations used.

The description of impact provided by the theoretical and numerical analysis is reasonably accurate as indicated by the comparison of Figs. 5-3 and 5-4. An account of the quantitative agreement achieved is given after the following general discussion of the theoretical model.

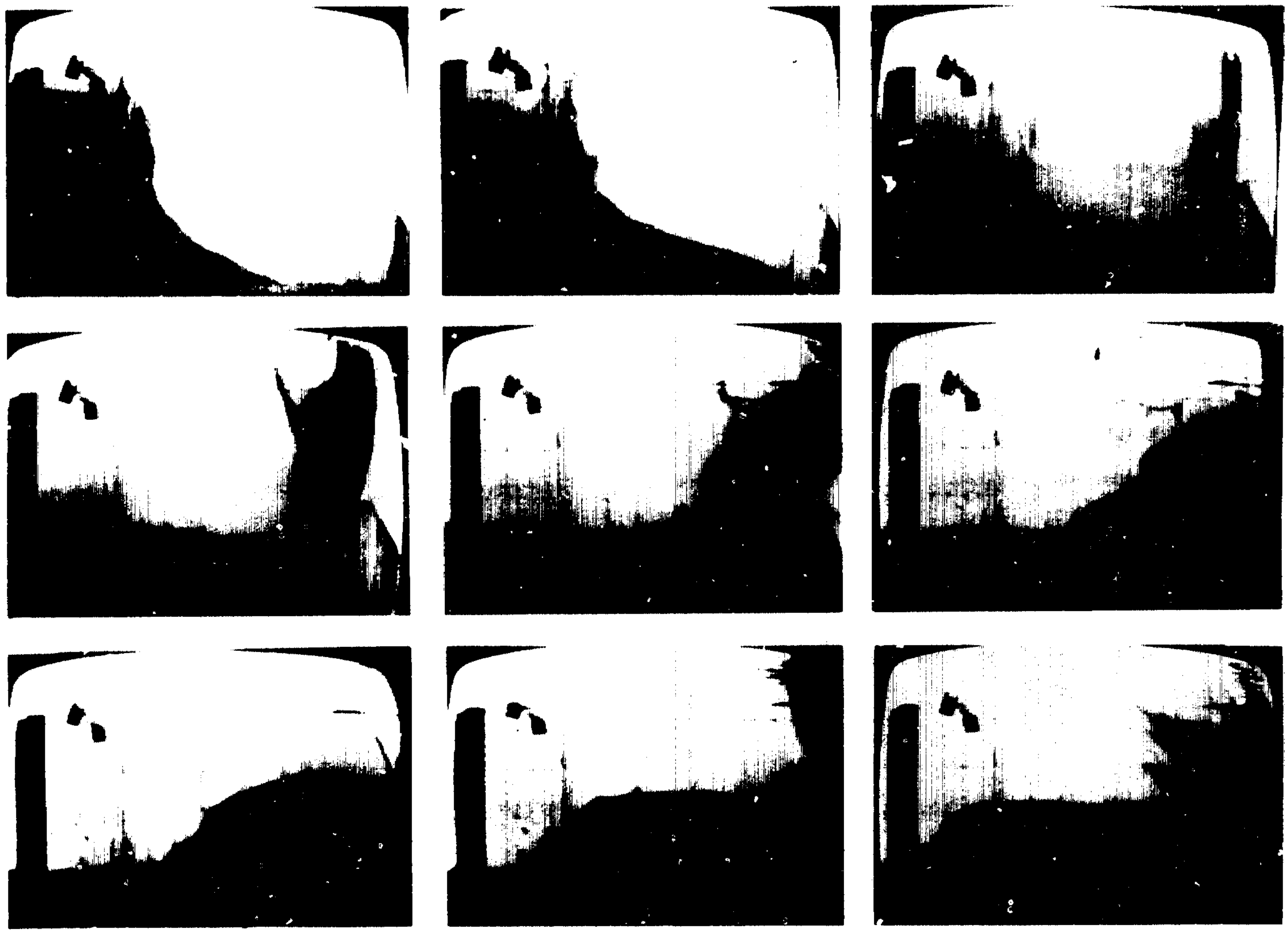


FIG. 5-3

COLLAPSE AND SURGE AGAINST A DIKE SHOWING OVERFLOW AND THE FORMATION OF A SHOCK. PHOTO SEQUENCE CORRESPONDS APPROXIMATELY TO .1 SECOND INTERVALS, IN NOTATION OF FIG. 5-1, H=8", R=9", L=9", A=4".

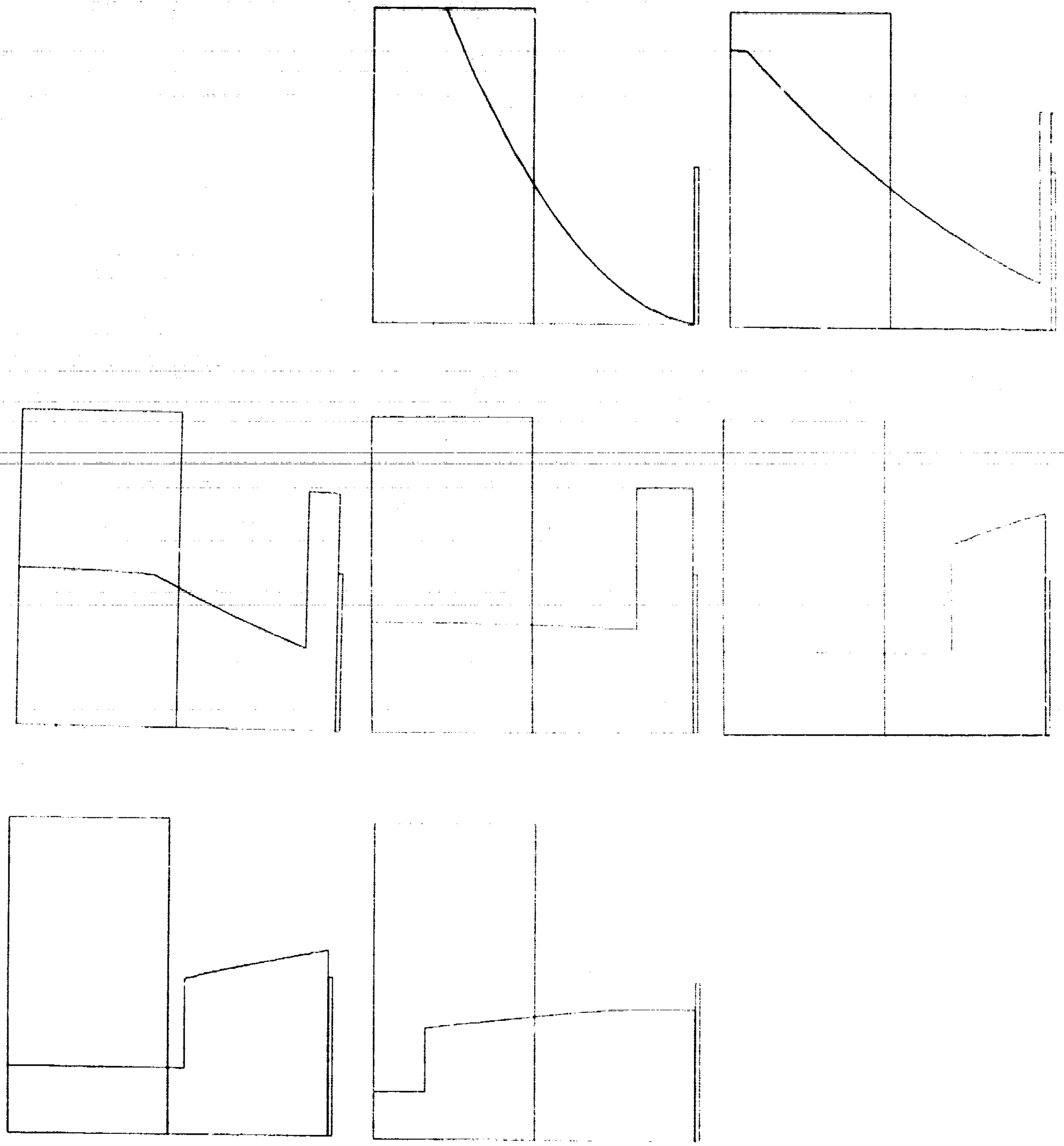


FIG. 5-41

COMPUTER SIMULATION OF THE COLLAPSE AND SURGE SHOWN IN FIG. 5-3. GRAPHS ARE ARRANGED IN CORRESPONDENCE WITH THE PHOTO SEQUENCE

The fluid velocity in the idealized geometry has only x and y components and all physical quantities are independent of the third coordinate that measures horizontal distance along the wall (i.e., perpendicular to the plane of the page). However, the exact theory is still intractable and we employ instead the non-linear shallow water equations which are essentially depth-averaged versions of the conservation laws of mass and momentum. The vertical coordinate is thereby eliminated from the formulation and a much simplified problem is obtained for the mean horizontal velocity and free surface height as functions of distance x and time t. A dimensionless notation is adopted to render results independent of scale and directly applicable to other geometries.

Non-linear shallow water theory has had a long and fruitful history in hydraulics[1], and it has been applied with remarkable success in "dam-break" problems of the type under investigation.

The fluid is assumed to be inviscid; turbulence and ground resistance are also neglected. The errors introduced by these approximations are small, although the theory can be modified to account for such effects.[2,3]

An exact theoretical solution exists for the initial phase of collapse which lasts until the surging water meets the dike. This allows a detailed check of the numerical program that is used to determine the motion in later and more difficult stages. Analysis of the initial impact and shock formation provides the information and conditions that are required to start the computer routine. The theory yields an accurate approximate solution for large times as well, as long as no spillage occurs. Only then does the computer become invaluable. The boundary condition to describe overflow states that the wave speed and local fluid velocity are equal atop the dike. This means that fluid which passes over the wall ceases to influence the main body of water still within the containment area.

Experiments were performed to motivate, verify, and assess theoretical hypotheses, approximations, and conclusions and also to explore quickly a number of modifications of the basic configuration. Among these variants are inclined dikes, multiple barriers, partial wall collapse, and lateral spread of the surge.

RESULTS

The principal finding concerning flow over a vertical dike is that, within the parameter range studied, the volume fraction of fluid that escapes depends mainly on a/H, the ratio of the dike height to that of the fluid level in the tank. Fig. 5-5 shows the volume fraction that escapes, Q_0, versus a_p/H in the situation where containment and storage capacities are equal. Theory is in good agreement with observations; the larger values of Q_0 predicted are due in part to having neglected ground resistance and turbulence. The amount of fluid that escapes increases as the dike is placed further from the wall and its height decreased accordingly. Ground friction ultimately negates this finding when extremely large distances are involved, but this is not the case in existing facilities. *Fig. 5-6 indicates that the overflow Q_0 is mainly a function of a/H for all combinations of barrier and maximum liquid heights, $\frac{1}{3} \leq \frac{L}{R} \leq 4$. In fact the calculations show very little dependence on L/R. Fig. 5-6a compares the curve fit to the experimental data where the dike holds the same volume as*

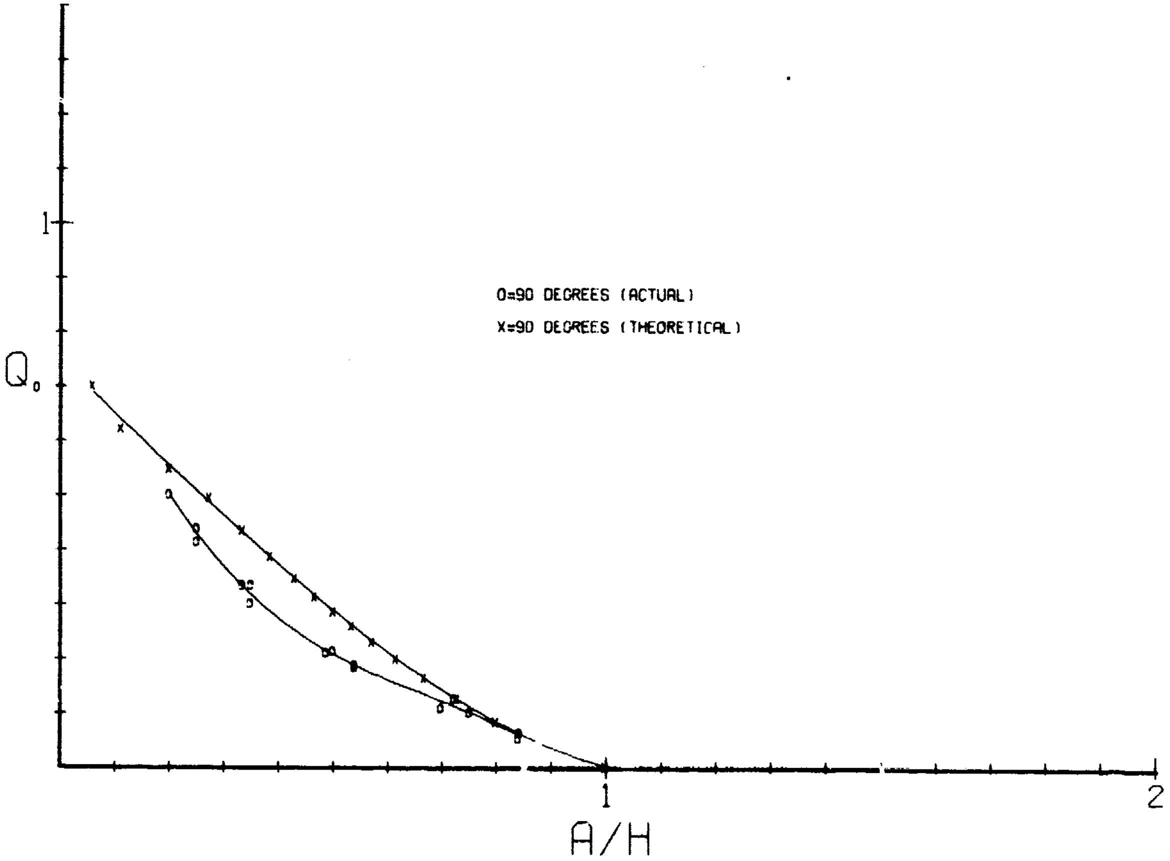


FIG. 5-5

COMPARISON OF EXPERIMENTAL DATA AND THEORETICAL CALCULATIONS FOR VERTICAL DIKES, WHERE CONTAINMENT AND STORAGE CAPACITIES ARE EQUAL.*

*** THE POINTS IN FIGS. 5-5 AND FIGS. 5-10 THROUGH 5-13 WERE FITTED WITH AN EQUATION OF THE FOLLOWING FORM:**

$$Q_0 = A(X^3 - 1) + B(X^2 - 1) + C(X - 1), \text{ Where } X = a/H.$$

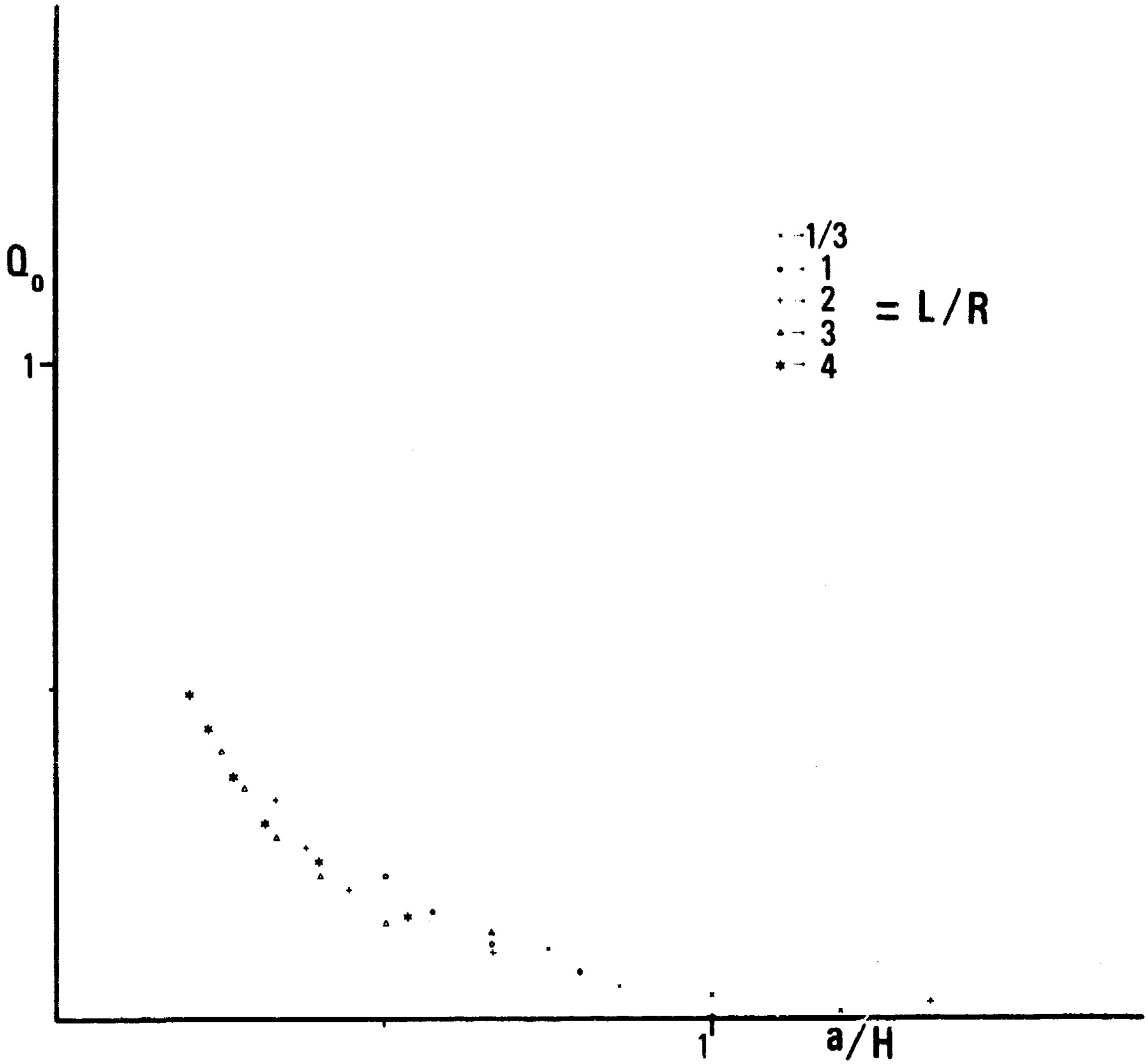


FIG. 5-6

SPILLAGE FRACTION VERSUS THE RATIO OF HEIGHT OF THE DIKE TO THAT OF THE TANK.

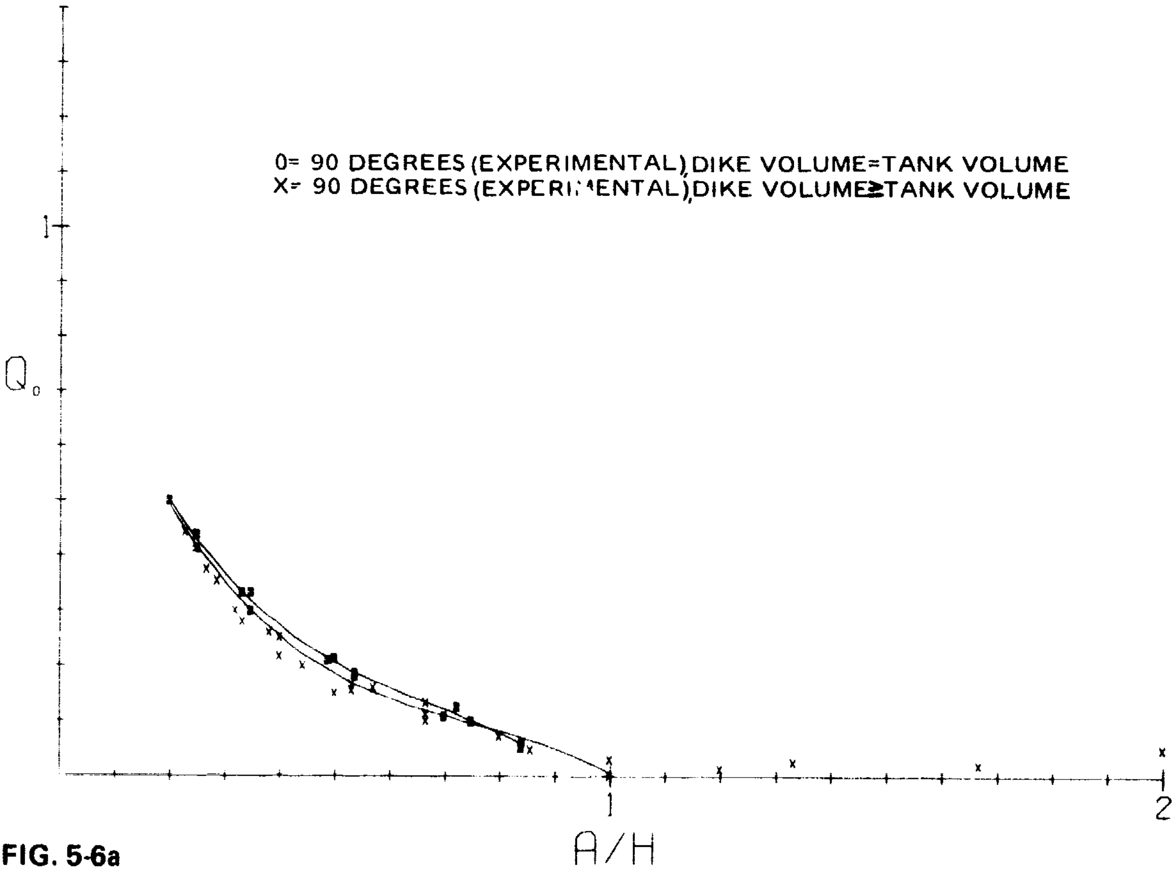


FIG. 5-6a

COMPARISON OF EXPERIMENTAL RESULTS FOR OVERFLOW OF VERTICAL DIKES WHEN DIKE VOLUME EQUALS TANK VOLUME AND WHEN DIKE VOLUME IS GREATER THAN OR EQUAL TO TANK VOLUME

the tank with the curve fit to all the experimental data, including points where the dike holds more than the tank.

Flows over a 90° (vertical) dike and over dikes with 60° and 30° slopes are shown in Figs. 5-7, 5-8, and 5-9 respectively. *Comparisons of observed versus theoretically calculated spill fractions, Q_0, for dike inclinations of 30°, 60°, and 90°, are presented in Figs. 5-10, 5-11, and 5-12. The theoretically calculated values of Q_0 versus a/H for dikes with inclinations of 30°, 60°, and 90°, are compared in Fig. 5-13. The supporting analyses are presented in Appendix V.* Obviously, a decrease of inclination allows more liquid to escape because the surging fluid retains much of its forward horizontal momentum during and after impact. As a result, for less steeply angled slopes the water vaults over the barrier and lands a considerable distance away, as shown in Fig. 5-9.

Some of the fluid that hits the face of a vertical dike is catapulted straight up, about three times the original height of the fluid in the storage tank, i.e., 3H. The main body of fluid piles up quickly, its top rising slightly higher than H, which is more than needed to cause flow over the smaller dike.

Raising the movable slide only 30% of the full distance, in order to simulate a partial rupture of tank wall, decreases the overflow by about 6%, a very small change. Indeed, none of the slight modifications of design attempted significantly reduced the overflow.

Spillage from a puncture is easily calculated using Bernoulli's theorem and simple geometry (see Appendix V-3). If $L+a > H$ or $H < (R+L)^2/(2R+L)$, no spigot flow from a

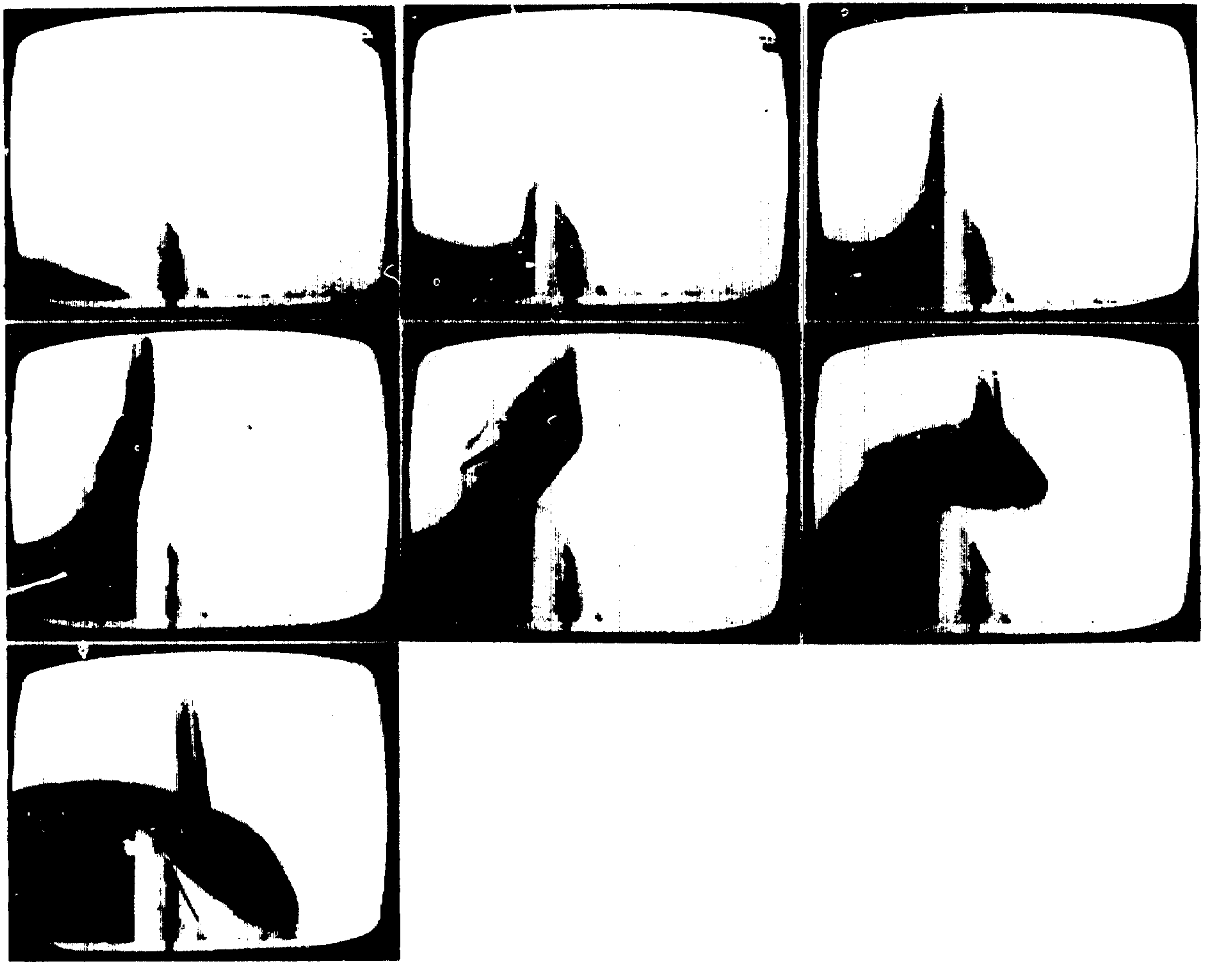


FIG. 5-7

DIKE OVERFLOW WHEN H=8", R=9", L=9", A=4", θ=90°. (CONTAINMENT VOLUME EQUALS STORAGE VOLUME.) PHOTO SEQUENCE CORRESPONDS, APPROXIMATELY, TO .07 SECOND INTERVALS.

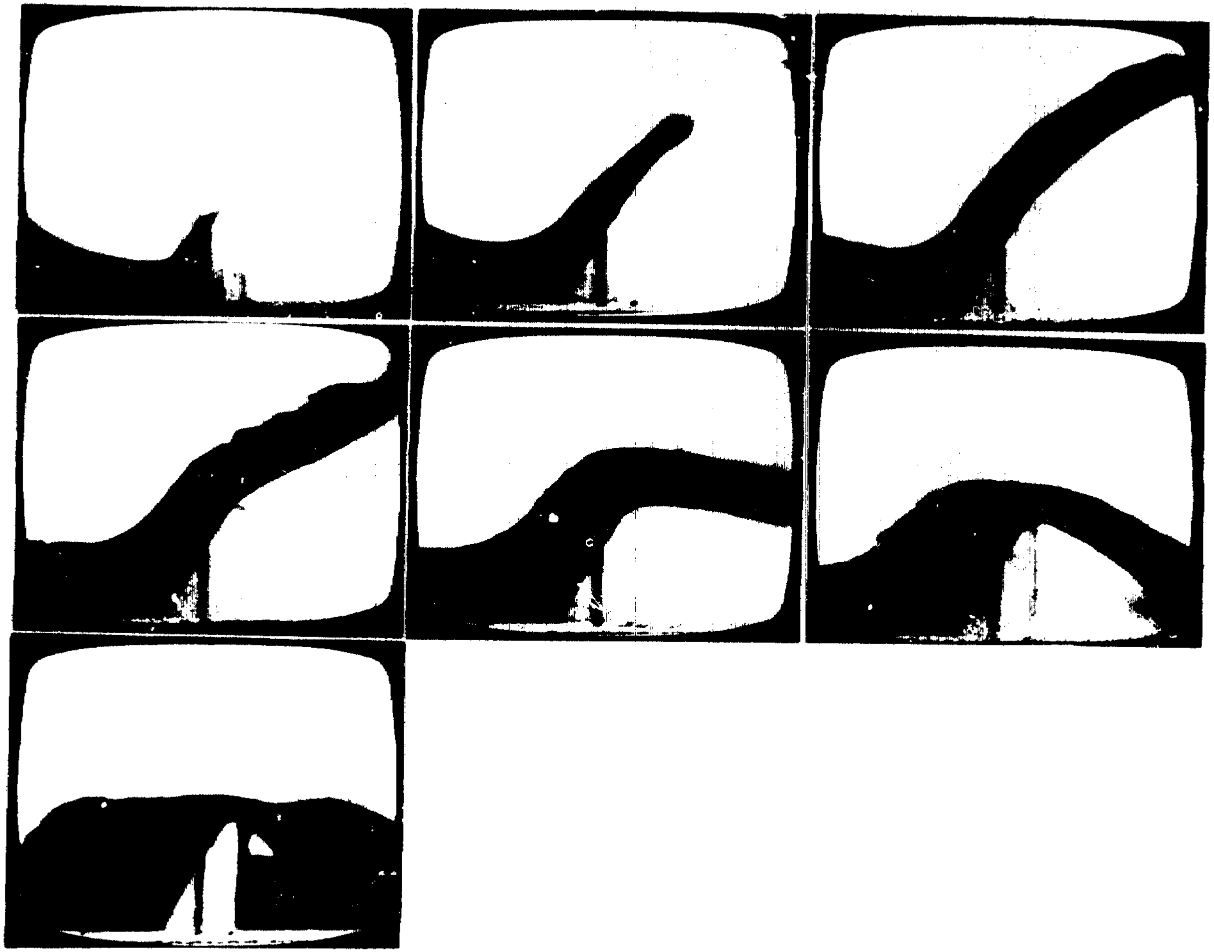


FIG. 5-8

DIKE OVERFLOW WHEN H=8", R=9", L=9", A=4", θ=60°. (CONTAINMENT VOLUME EQUALS STORAGE VOLUME.) PHOTO SEQUENCE CORRESPONDS, APPROXIMATELY, TO .1 SECOND INTERVALS.

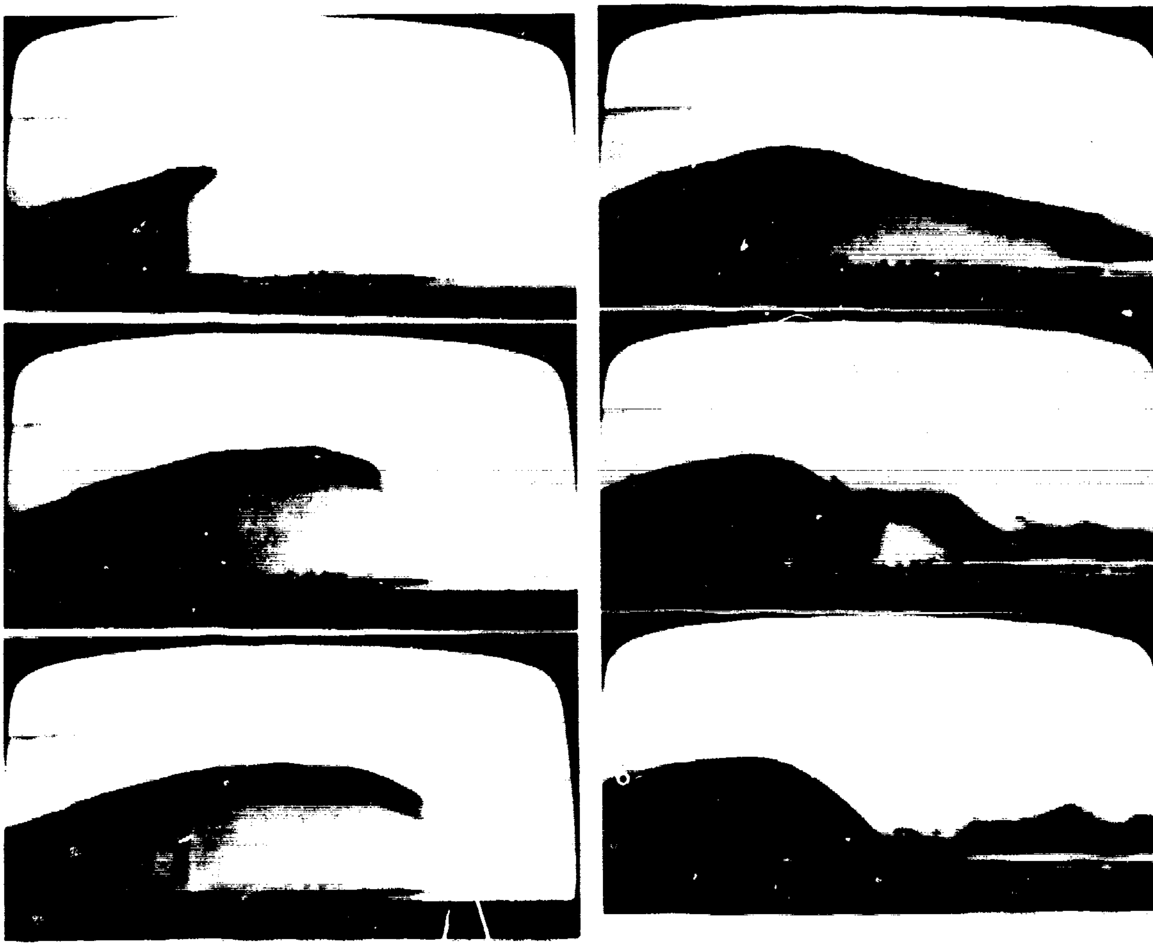


FIG. 5-9

SURGE VAULTING A 30° II ICLINED DIKE, H=8", R=9", L=9", A=4".

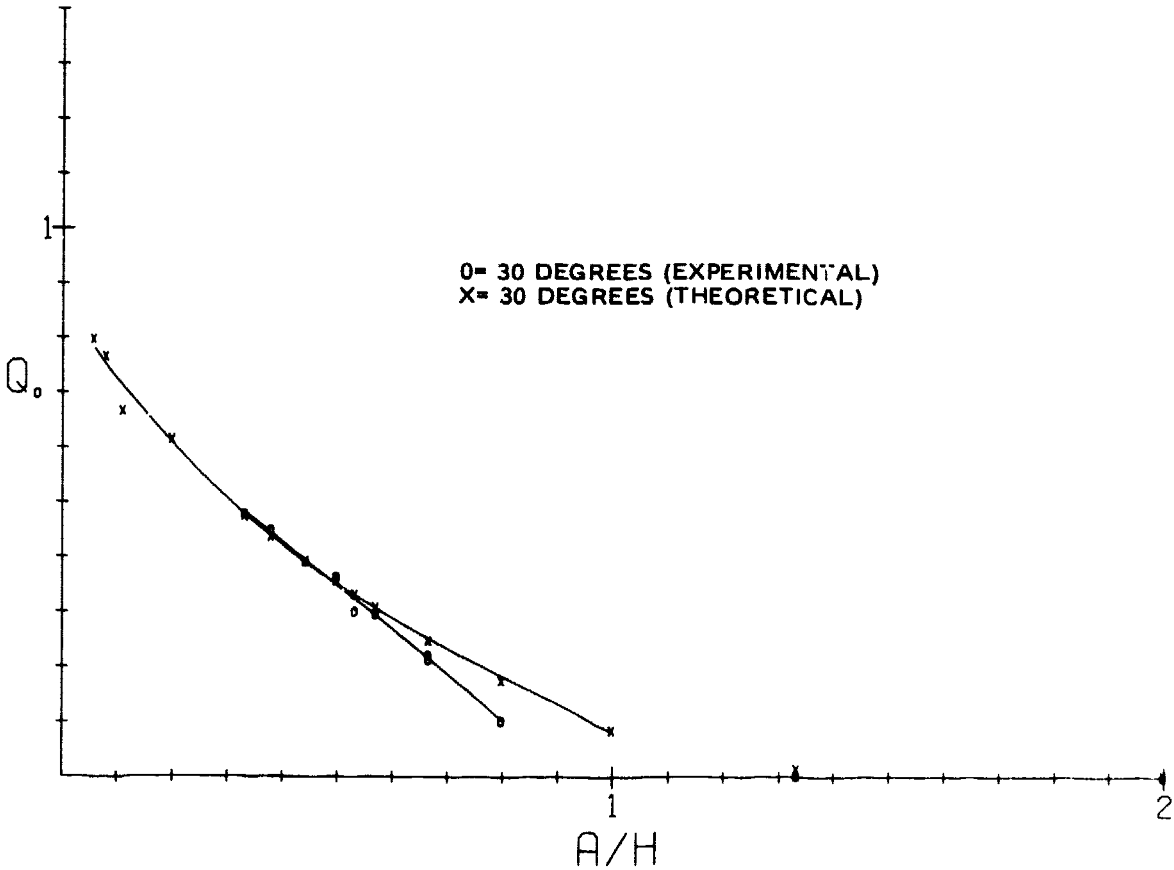


FIG. 5-10

COMPARISON OF EXPERIMENTAL DATA AND THEORETICAL CALCULATIONS FOR 30° DIKE, WHERE CONTAINMENT IS GREATER THAN OR EQUAL TO STORAGE CAPACITY.

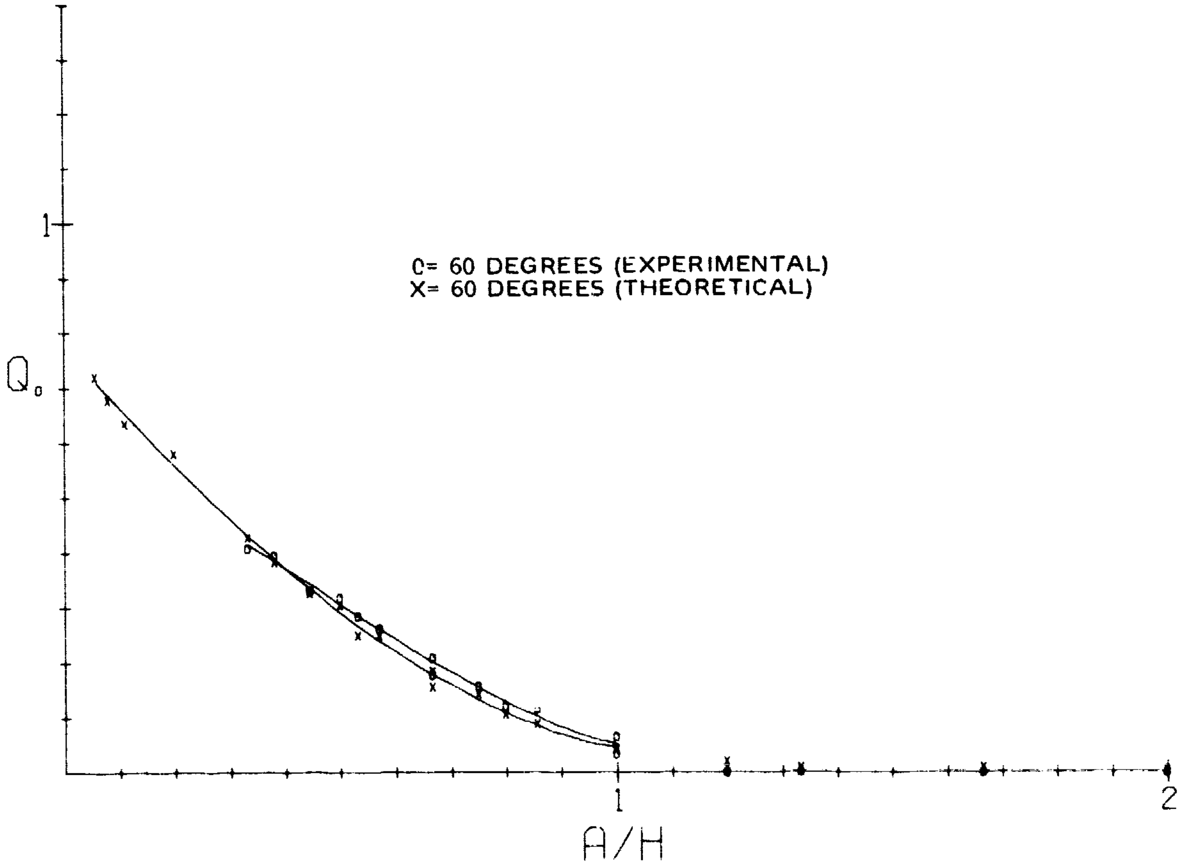


FIG. 5-11

COMPARISON OF EXPERIMENTAL DATA AND THEORETICAL CALCULATIONS FOR 60° DIKE, WHERE CONTAINMENT IS GREATER THAN OR EQUAL TO STORAGE CAPACITY.

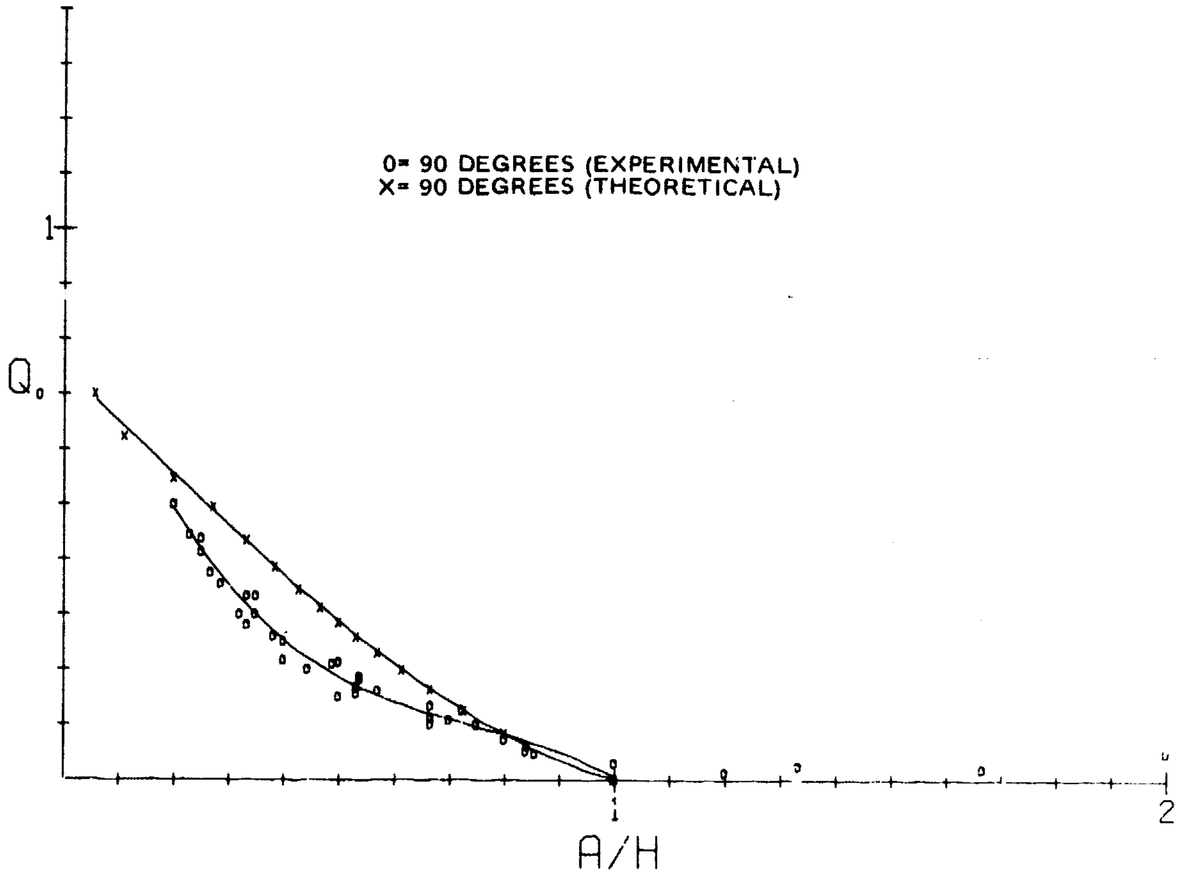


FIG. 5-12

COMPARISON OF EXPERIMENTAL DATA AND THEORETICAL CALCULATIONS FOR VERTICAL DIKE, WHERE CONTAINMENT IS GREATER THAN OR EQUAL TO STORAGE CAPACITY.

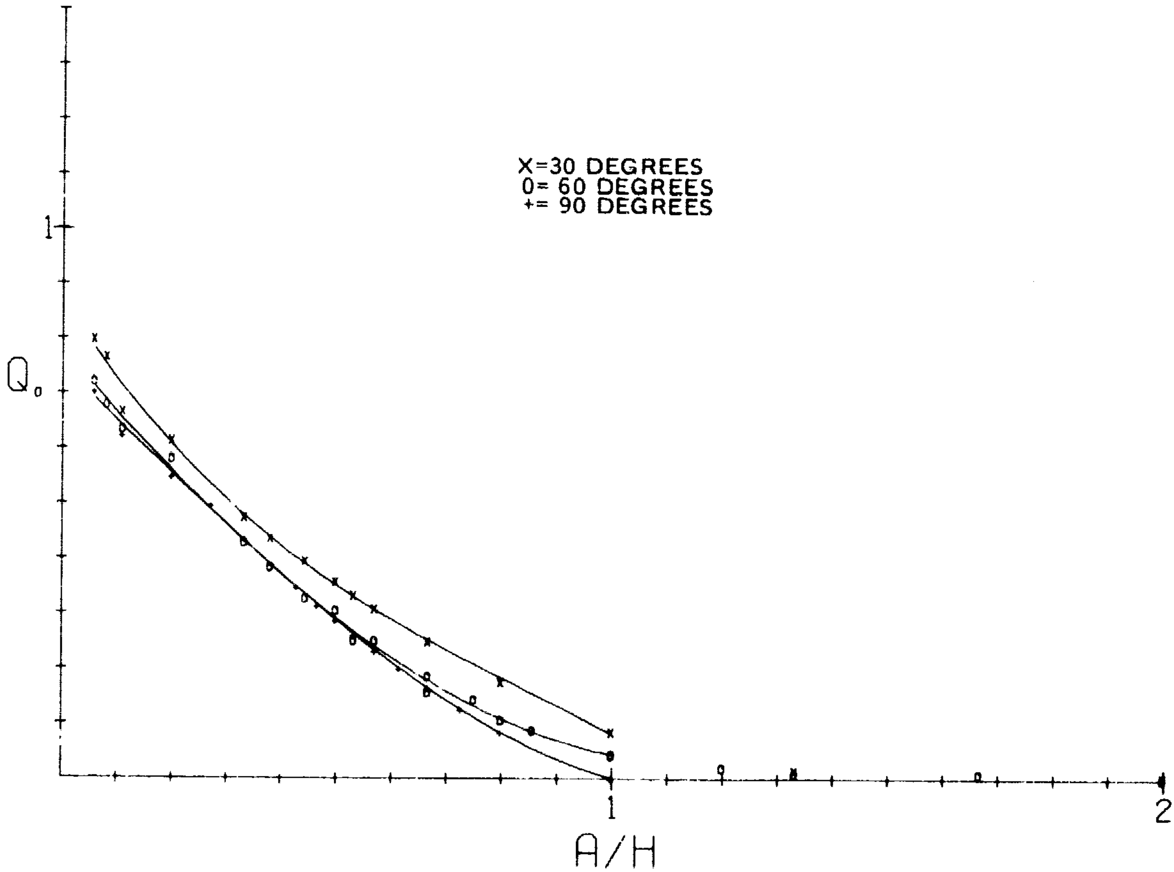


FIG. 5-13

COMPARISON OF THEORETICAL CALCULATIONS FOR DIFFERENTLY SLANTED DIKES — TWO-DIMENSIONAL— CASE—WHERE CONTAINMENT EQUALS STORAGE CAPACITY.

puncture at any location can clear a dike of height a_p *(see Fig. 5-14). However, if these absolute criteria are not met, the fluid can arc over the dike. Dikes built under the NFPA standard,* $L > .6(H-a)$*, therefore, do not necessarily prevent spigot overflows. The maximum possible spillage fraction* Q_m *(the ratio of spillage to storage volumes) is given as a function of R/H in Fig. 5-14. The same figure also shows the height, z, of the puncture that produces this maximum overflow. Slight modifications of configuration, to include a tank pedestal for example, lead to small changes in these results.*

Table 5-1, based on spigot flow calculations in Appendix V-3, shows the maximum possible spillage from tanks at certain existing LEG facilities. The maximum spillage amount ranges from 0 to 46 percent of tank volume. Friction, viscosity, air resistance, and vaporization would reduce the amount of spill, but the effects are impossible to determine accurately, and are not included in the calculations. In double-wall tanks, the insulation could significantly affect the flow.

Table 5-2, based on the calculations in Appendix V-1 and V-2, shows the maximum calculated overflow from tanks at certain existing LEG facilities. The maximum overflow ranges from 13 to 64 percent of tank volume. The calculations do not include viscosity, ground friction, and turbulence. These would all lessen the overflow. In addition, since the calculations are two-dimensional, the spreading of the wave front is also neglected. This would also reduce the overflow. However, for a given tank and distance to a dike, the required height of the dike for a three-dimensional model is always less than the dike height in the corresponding two-dimensional case.

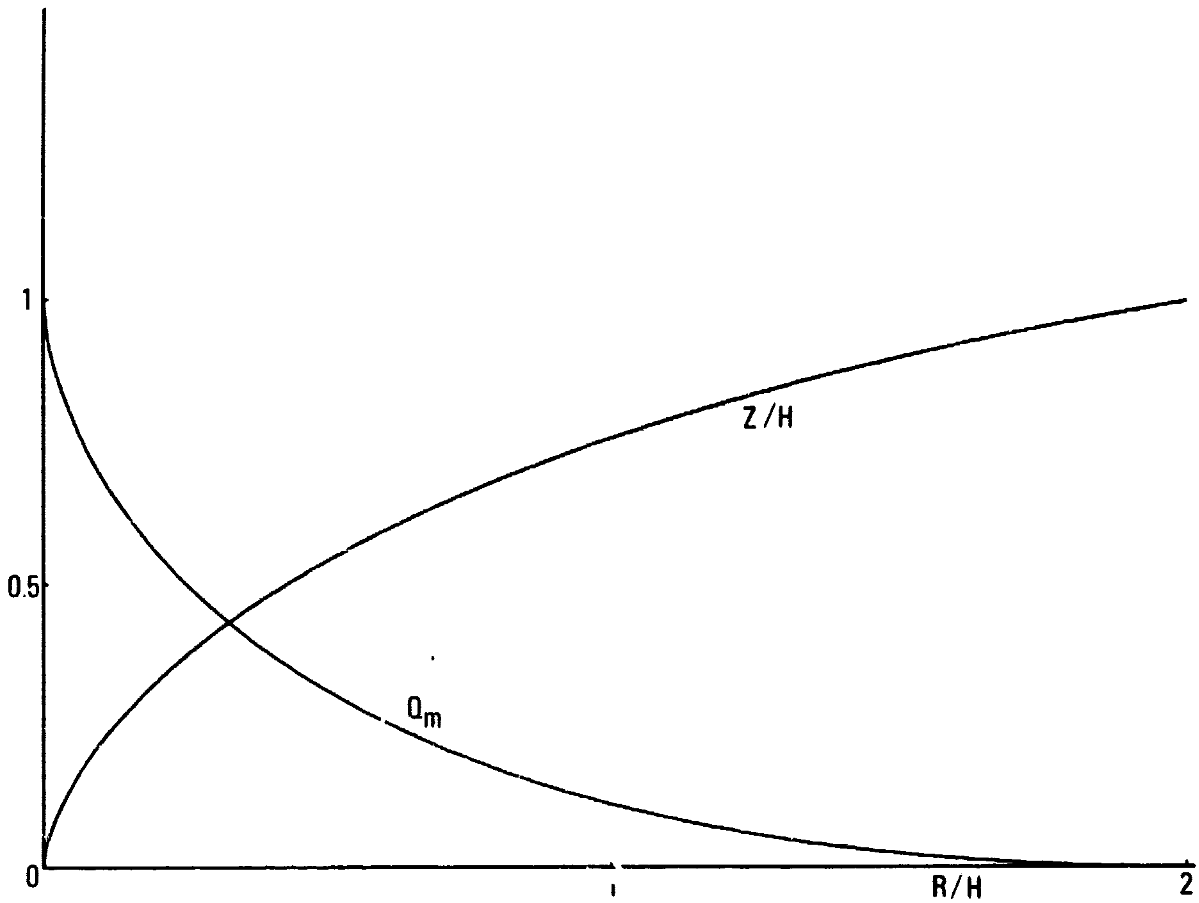


FIG. 5–14
MAXIMUM SPILLAGE FRACTION Q_M ANP (HE RELATIVE HEIGHT OF THE PUNCTURE VERSUS R/H. NO LIQUID ESCAPES THE CONTAINMENT AREA WHEN $a \geq a_p$ AND R/H> 2.

Table 5-1. Maximum Possible Spillage from Horizontal Spigot Flow for Tanks at Certain LEG Facilities.*

Facility	Volume Spilled (cubic meters)	Percent of Volume Spilled
Algonquin LNG	26,300	28
Columbia LNG	12,000	20
Distrigas, Everett, Mass.		
Tank 1	27,800	46
Tank 2	17,700	19
Philadelphia Electric	10,600	19
Southern Energy	0	0
Exxon LPG	0	0

* Friction, viscosity, air resistance, and vaporization would reduce the amount of spill, but the effects are impossible to determine accurately, and are not included in these calculations. The calculations also assume the optimal height for the hole on the side of the tank closest to the dike.

We believe that this difference between two- and three-dimensional models more than makes up for the neglect of viscosity, ground friction, turbulence, and wave spreading. Thus, we think our results are at least as likely to understate as to overstate the amount going over the dike. In addition, we plot Q_0, the fraction of the original value that escapes upon initial impact, rather than Q_1, the total overflow. And in those cases where tanks rest on pedestals, we considered the pedestal height to be zero. These factors make the overflow estimates even more conservative. The calculation may not be conservative in the case of a high, close-in dike, such as at Philadelphia Electric, where shallow water theory is not as good an approximation.

CONCLUSIONS

- Dikes constructed to NFPA safety criteria generally cannot contain the surge of liquid from a massive rupture or collapse of a tank wall. Our calculations show from 13 to 64 percent of the tank volume can escape the dikes in six accual facilities. For the reasons given in the text, we believe these estimates to be conservative. A sloping dike permits a somewhat larger amount of spillage than a vertical dike. Low, distant dikes allow a greater overflow than high, near ones. If more than one tank ruptures within the same dike, the overflow would be even greater.

- Spigot flows from punctures high up on the tank may be able to arc over the dike and escape containment. The actual spillage depends on the dimensions involved and on the amount of friction in the hole. Since the friction is impossible to calculate accurately, the only safe criterion is one which ensures that no fluid will arc over the dike from the spigot effect, even if there is no friction in the hole. The NFPA safety criterion allows large amounts of fluid from a frictionless hole to arc over the dike wall. According to our calculations, from 0 to 46 percent of the fluid from a frictionless hole would arc over the dikes in the six facilities studied.

AGENCY COMMENTS AND OUR EVALUATION

The Department of Commerce comments that the methodology by which we calculated overflow for various facilities is unclear. The calculations are all based upon design specifications of the facilities, which we obtained from the facility operators or designers. The spigot flow was calculated with the theoretical results derived in Appendix V-3. The dike overflow was estimated by using Figs. 5-10, 5-11, and 5-12, which are based upon the theoretical calculations and experimental verifications described in this chapter and in Appendix V-1 and V-2.

Commerce suggests that we should estimate the chance of a massive failure occurring. We do not believe that such a probability can be calculated. For example, causes such as sabotage cannot be treated probabilistically.

Commerce also comments that dikes at new LEG storage facilities will generally be able to hold a volume greater than the volume of the enclosed tank. As we have shown in this chapter, it is not the volume contained by the dike which is the important factor in overflow, but the ratio of the height of the fluid in the tank to the height of the dike. Within the scale that LEG facilities are being built or planned, the distance from the tank to the dike has little effect on this overflow.

The Department of Energy asks what changes in dike design would ameliorate the overflow problem. Building dikes vertically and higher would be one improvement; but more research needs to be done to determine the most effective and efficient way to design enclosure systems.

REFERENCES

1. Henderson, F.M. (1966), Open Channel Flow, MacMillan, NY.

2. Dressler, R.F. (1950), J. Res. Nat. Bur. Stud. 49, 217.

3. G.B. Whitham (1955), Proc. Roy. Soc. 227, 399.

CHAPTER 6

SHIP DESIGN, PERSONNEL, AND OPERATIONS

CONTENTS | PAGE

INTRODUCTION

Three factors determine the safety of transporting LEG over water: the design, personnel, and operation of ships carrying the fuel.

Safety features must be built into the vessels; some to prevent leaks and spills, others to control them should they occur.

LEG ships and terminals are sophisticated, complex, and expensive; highly trained personnel are required to operate them.

SECTION I. SHIP DESIGN[1,2,3,4]

LNG SHIPS

Only LNG carriers designated for the U.S. trade will be discussed here. Most of the LNG tankers flying the American flag in the next decade will carry about 125,000 cubic meters. A typical ship of this capacity is approximately 930 feet long, with a beam (width) of 140 feet, a draft (under water) of 36 feet, and a freeboard (above water) of 50 feet. Deadweight is approximately 60,000 long tons, displacement 95,000 long tons. (One long ton = 2240 lbs. = 1016 kg; one short ton = 2000 lbs. = 907 kg.) Service speed is about 20 knots with a main steam propulsion plant of 43,000 shaft horsepower.

An LNG tanker differs from a traditional tanker in several respects. Because its cargo is lighter, the LNG tanker has a higher center of gravity. The LNG ship's double hull gives it improved stability after one or more compartments have been filled with sea water and provides it with greater collision resistance. The double hull is also used to carry ballast water, which allows the vessel to reach full draft when cargo tanks are empty.

LNG ships are usually equipped with bow thrusters, which improve maneuverability. Other measures that can improve maneuverability include precision position fixing equipment, bridge control of main engine, and collision avoidance systems. LNG ships built under the Maritime Administration program all have, or will have, this equipment on board. Ships that are not built under this program are not required to have it.

An LNG tanker's relatively high freeboard limits the view from the bridge and exposes a greater proportion of the ship to wind. Both characteristics could add to navigational risks.

Only limited inspections can be made of cargo containment systems, but several leak detection systems have been developed.

In U.S. waters, the U.S. Coast Guard has devised several navigational traffic control procedures which can reduce the chances of collision or grounding. (See Section III.)

Design Considerations for LNG Ships

From a designer's point of view, the most important hazards presented by the transportation of LNG are:

- The low temperature of the liquefied gas and its effect on the storage structure design.

- The volatility of the LNG and the resultant danger of fire or explosion.

In ship design, these problem areas are considered from two approaches—preventive and reactive safety.

Preventive safety hardware and operational features eliminate, control, or at least reduce the risk of an accidental cargo spill. Examples include secondary barriers, stronger cargo tanks, greater collision resistance, and better manueverability.

Reactive safety features reduce the effects of a spill after an accident has occurred. Examples include crack arrestors, leak detection devices, and fire fighting equipment.

While reactive safety features are necessary, the primary objective in LNG ship design should be the incorporation of preventive safety components.

Reactive Safety Equipment

A list of the reactive safety equipment carried by a typical LNG tanker is given in Appendix VI-1.

Most reactive safety equipment is required by Coast Guard regulations and differs only slightly from ship to ship. Aside from increased personnel training in the use of equipment (which will be covered later in this chapter), little can be done to significantly improve reactive safety.

Preventive Safety Design Characteristics

The containment system for an LNG carrier consists mainly of those structural and outfit items associated with the storage of cargo. It is made up of three major components—the primary barrier, insulation, and the secondary barrier.

Current LNG ships have one of two basic containment designs. In the self-supporting (or free-standing) design, the cargo tank itself has sufficient structural strength to withstand the loads imposed by the cargo. In a membrane (or integrated) design, the cargo is contained in a thin metallic liquid-tight lining supported completely by a load bearing insulation, which in turn is supported by the ship's structure.

Each of the basic designs has two variations. The self-supporting type is constructed either with spherical tanks (the Moss Rosenberg design) or with prismatic tanks (the Conch II design), both of which use aluminum alloy for the primary barrier. The difference between the two membrane designs lies in the material used to construct the primary barrier. In the Technigaz design it is made of corrugated stainless steel; in the Gaz Transport design it is made of flat Invar steel (an alloy of nickel and iron).

The primary barrier of an LNG containment system contains the cargo. The insulation protects the ship's hull from the extremely low temperatures of the liquefied gas and reduces the flow of heat into the cargo tanks, thereby cutting down boil-off (the generation of vapor). Many different insulation materials are used. The insulation must:

- be impervious to water;

- possess good aging properties;

- be flexible enough to withstand dimensional changes and remain elastic; and

- be able to bear heavy loads in some design systems.

Insulation is either loadbearing, such as balsa and plywood, or non-loadbearing, such as fiberglass, mineral wool, and perlite. Polyurethane foam and polyvinyl chloride may be loadbearing or non-loadbearing.

If the primary barrier fails, the secondary barrier must contain the cargo safely for at least 15 days, and insulate the ship's structure against the low temperatures of the LNG. Among materials used to construct the secondary barrier are hardwood, plywood, polyurethane, Invar steel, and stainless steel.

The size and shape of the spherical tanks, and the greater average transverse distance between the tank and the ship's side, suggest that they are the least vulnerable of all designs in the event of a collision (as discussed in more detail below). However, other designs offer other safety advantages. The Conch II's self-supporting design, with its internal bulkheads, reduces free surface effects* as well as the amount of LNG spill in case of a tank rupture. The membrane designs

*Free surface effects are those due to sloshing of fluid in the tanks.

provide good hull utilization, good visibility from the bridge, and a reduced windage area. Appendix VI-2 provides detailed descriptions and diagrams of the four containment systems.

LPG SHIPS

A typical LPG carrier is usually smaller and slower than its LNG counterpart. Because it has a lower center of gravity (higher cargo density) than an LNG tanker, an LPG ship has greater initial stability, better visibility from the bridge, and a reduced windage area.

LPG carriers are built in a great variety of sizes and designs. Unlike LNG ships, they are not required to have double hulls, and most do not. A typical ship has 50,000 cubic meters capacity, 34,000 tons deadweight, 615' length, 100' beam, 35' draft, and 26' freeboard. They usually have independent, prismatic cargo tanks, and the LPG is carried refrigerated at atmospheric pressure. Ship tanks are usually designed for a minimum temperature of $-58^{o}F$ and a maximum working pressure of 4 pounds per square inch above atmospheric pressure (psig). The tanks are of the A type in the Intergovernmental Maritime Consultative Organization (IMCO) gas code. This means that stress analysis is less stringent than for LNG ships. Typical tank material is 2.5% nickel alloy steel. A full secondary barrier is required. The tanks are usually divided into two compartments, liquid-tight below liquid level, to reduce free surface effects. The tanks usually rest on top of the double bottom tanks and are supported by wood-lined beds and longitudinal and transverse "slides."

Appendix VI-2 provides a detailed description and shows diagrams of an American-designed, double-hulled LPG tanker offered by Avondale Shipyard.

SHIP HAZARD SCENARIOS - TANK RUPTURES

As long as liquefied gas is contained in a ship's tanks, it poses no danger to the public. The hazard a gas carrier poses to people, ports, and surrounding facilities lies in the possibility of a spill or uncontrolled leak, which could lead to a fire or explosion.

The most serious potential accident would follow the rupture of a cargo tank. This can be caused by a collision, grounding, tank failure, or sabotage.

Collision Hazards

In order to minimize the danger of ship collisions, any U.S. Coast Guard's Captain of the Port (the commanding officer in each major harbor area) may require special vessel traffic control systems. These regulations are discussed in Section III of this chapter.

Nevertheless, the resistance of these vessels to a collision is an important consideration. So far as we could determine, the only published studies of collision resistance have been done on ships with spherical tanks, which appear to be the least vulnerable to collisions. Similar studies on the other three major tanks designs are needed.

Studies on theoretical collision damage to ships with spherical tanks have been carried out by the Norwegian classification society, Det Norske Veritas (unpublished, but discussed in Ref. 6); General Dynamics; and by P.S. Allan, A.A. Brown, and P. Athens.[5] The Coast Guard has done a study on Tanker Structure Analysis (NTIS AD-A03-103), but this also dealt only with spherical tanks.

Figure 6-1 shows some results of the Norske Veritas study. Two impact locations were assumed, one at a main transverse bulkhead between cargo tanks and one at the center of a tank. The latter case is worse because the distance between the shipside and cargo is least. The "hump" in critical speeds for striking vessels of more than 50,000 ton displacement is due to the bulbous bow fitted on the larger vessels.

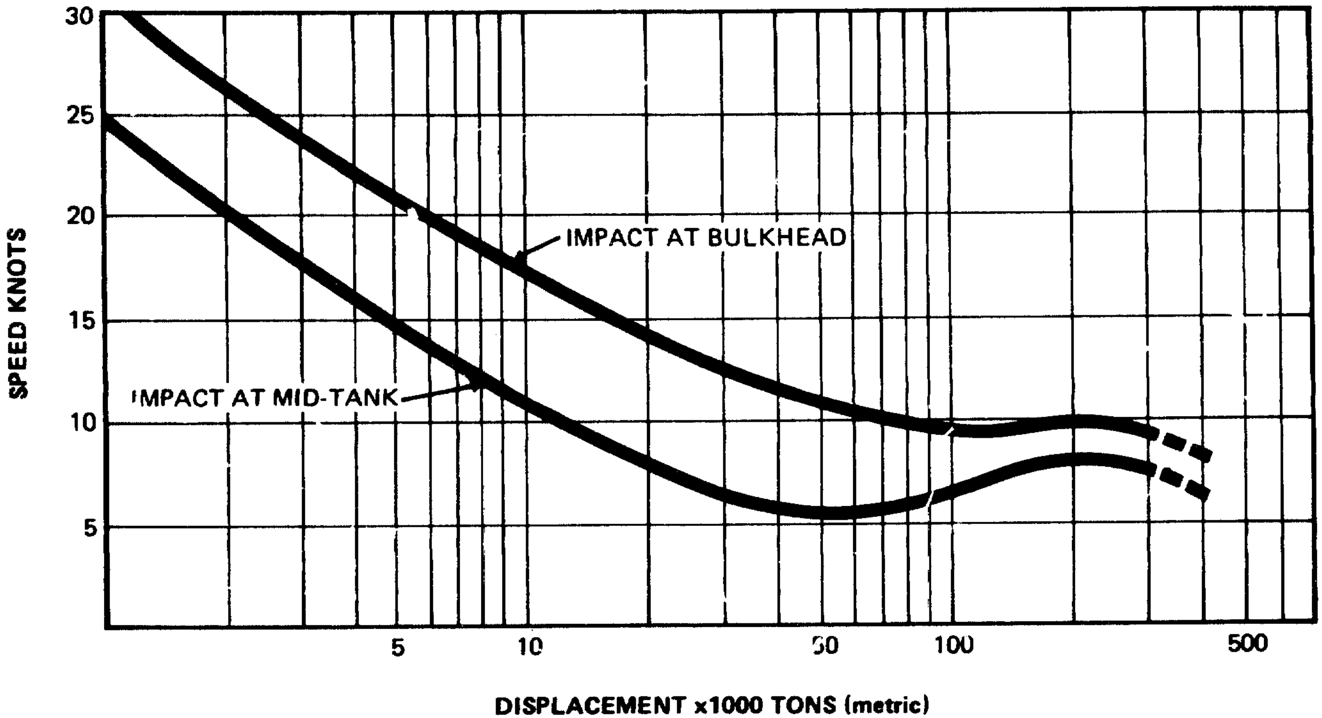
Two main observations may be made:

1) The critical speed and/or the displacement of the striking vessel would have to be much higher to penetrate an LNG vessel's tank than to penetrate an oil tanker.

2) Buckling and/or tearing of the side structure need not have any direct effect on the structural integrity of the spherical cargo tank

Ship collision analysis must also consider ship survivability in the event of flooding. All new gas carriers must meet the IMCO and Coast Guard rules on two-compartment subdivision and limited heel stability.

FIG. 6-1 SOME RESULTS OF THE NORSKE VERITAS COLLISION RESISTANCE STUDY.



Critical Speeds of a range of vessels colliding with a 125,000m^3 Moss-Rosenberg type LNG Carrier, assuming a broadside collision into the LNG Carrier. The point of impact is assumed both at a transverse bulkhead and at the midpoint of a cargo tank. Critical Speed is maximum striking speed without touching cargo tank.

SOURCE: REFERENCE 6.

Tank Failure

Cargo tanks may also rupture from either general fatigue failure or over-pressure. Fatigue failure refers to the possibility of a defect, present in the tank on delivery, growing to a critical size as a result of fatigue from service. Howard and Kvamsdal[6] suggest that a crack of this type will grow slowly, leaving time to detect the leak through sampling instrumentation (gas detectors and liquid and temperature sensors in cargo holds) and remedy the situation. Under the Coast Guard's Letter of Compliance program and the proposed Coast Guard rules, tank design load calculations must include plastic deformation and fatigue life, combining strains from static, dynamic, and thermal loads. However, data on buckling of membrane designs are not required. (Proposed 46 CFR Parts 154.428 and 429). In 1969 the Polar Alaska experienced bulging of the Primary Membrane of No. 1 Cargo Tank "due to crew negligence during gas freeing operations ... Bulging caused by overpressuring the barrier space with nitrogen."[7] See Appendix VI-3.

Over-pressure

Pressure is one of the crucial factors affecting the safety of an LEG ship. The formation of a flammable mixture in the cargo tanks is prevented by maintaining a positive pressure differential between the cargo tanks and the atmosphere, and between the cargo holds and the atmosphere.

The required tank-to-atmosphere differential pressure is maintained by the vaporizer and the gas compressors control system (LNG) or the reliquefaction control system (LPG). The required hold-to-atmosphere differential pressure is maintained by a nitrogen make up system (LNG) or an inert gas generator system (LPG) and an automatic system of innerbarrier pressure relief valves. It is critical to maintain these differential pressures close to their design values.

An LEG carrier can be sabotaged by improperly operating the pressure control systems to overpressurize the cargo tanks or cargo holds.

According to their LNG ship specifications, a General Dynamics LNG ship's vaporizer can generate 12,000 cubic meters of LNG vapor per hour, with a vapor temperature of 184°F, which can be handled by the safety valves. A saboteur would have to close the relief valves, either by blocking the valves (which can be done on some of the free-standing tank design ships), or by blind-flanging the vapor outlets. The actual bursting or buckling pressures of the cargo tanks are not published, since these calculations are not required by regulatory bodies.

Failure to Take Prompt Action

A minor LNG spill can escalate to a major spill through failure to take prompt corrective action. The ability to prevent a larger spill depends on a ship's operational and emergency procedures and the training of its crew.

Fire Hazard

The major threat of fire on an LNG ship comes from a collision with another vessel. During general LNG ship operations, small leaks in the cargo handling system usually will cause at most only relatively small gas fires on deck or near the ship. Because of the inert atmosphere maintained by nitrogen, it is unlikely that a fire would take place between the cargo tanks and the cargo hold. A collision, on the other hand, could lead to larger oil/gas fires enveloping major portions of the ship. Such large fires may be difficult to control and could endanger the ship.

Analyses done by Det Norske Veritas[8] show that most gas carriers can sustain extremely large fires without hull and tank breakdown as long as only one side of the ship is exposed to the fire. This study indicated that a free standing cargo tank would probably contain its cargo (LNG) during and after the fire. A membrane design, however, would release the cargo into the cargo hold or ballast tanks. This would probably cause the hull to rupture.

The effects of such a collision-induced fire on cargo tank insulation have also been studied. Results show that insulation, even fire-resistant insulation, may be subjected to temperatures that would cause it to deteriorate or to melt.

For example, Det Norske Veritas research showed that in the event of fire the ship's inner and outer hull might become hotter than 1,472°F. At temperatures in the 212°F to 392°F range, most ordinary plastic foam materials experience deterioration of mechanical and thermal properties. At higher temperatures, such as over 572°F, complete thermal decomposition takes place.

The results of a similar study are discussed in the LNG Safety Manual issued by Energy Transportation Corp. for its LNG ships. If a tank fails, according to the manual, the spilled LNG will take six minutes to burn. The temperature at the wing tanks (ballast tanks between the inner and outer hull) could reach 700°F, and the temperature of the tank covers of the LNG cargo tanks could reach 716°F.

A possible way to reduce the effects of a fire might be to pump water rapidly into strategically located ballast tanks. This will require a higher ballast pump capacity than is presently common. Fire resistant insulation in critical places would also be useful.

REGULATION OF SHIP DESIGN

LEG ship design is influenced by a code adopted by IMCO and by regulations promulgated by the U.S. Coast Guard.

IMCO, whose purpose is to provide internationally agreed standards on design, construction, and operation of ships, adopted a code for gas ships (Resolution A.328 (IX)) in late 1975. Although IMCO resolutions are only advisory, they are usually incorporated into the national regulations of member governments and thus have a strong impact on the international shipping industry.

The Coast Guard, which was actively involved in the development of the IMCO Code, published its proposed rulemaking (46 CFR, Parts 31, 34, 54, 98, 154) in October 1976. Although the proposed Coast Guard rules correspond closely to the IMCO Code, they go beyond the Code in that they would require a lower ambient design temperature, better steel grades in crack arrestors, cargo venting restrictions in port, and a higher safety factor for allowable tank stresses.

Reaction to the stronger rules proposed by the Coast Guard included a joint protest from nine foreign governments. According to an Aide-Memoire received by the Coast Guard's Marine Safety Council February 17, 1977, the governments of Denmark, Finland, the Federal Republic of Germany, Greece, Italy, Japan, Norway, Sweden, and the United Kingdom joined in the opinion that national regulations concerning the design, construction equipment, and manning applicable to foreign vessels should be based on internationally agreed standards formulated after consideration within IMCO. They asked that the proposed regulations be amended so as not to exceed the code.

SECTION II. PERSONNEL TRAINING

Well-trained personnel reduce the chance of an unintentional release of LEG. They are also more capable of controlling the situation once an incident has occurred.

An LEG tanker is a highly sophisticated and expensive transportation system. Ships and terminals are complex and heavily instrumented; cargo handling is complicated and hazardous. Skilled operators are needed for safe operations.

Some companies have designed training programs that exceed the present and proposed requirements of regulatory bodies. Other companies, however, have done very little about personnel qualifications, particularly training. Some of the reasons are:

- Marine transportation of liquefied gas is a relatively new technology. Lack of operational experience is typical for the industry, including management personnel.

- Human factors are difficult to quantify. It sometimes seems easier to reduce the possibility of human error by increasing automation.

- Training regulations covering LEG personnel are lacking.

A study sponsored by the Maritime Administration, entitled "A Model Economic and Safety Analysis of the Transportation of Hazardous Substances in Bulk," concluded that marine transport was the safest method of moving such products. But the data collected on marine casualties also indicated that human error was the contributing factor in 85 percent of all casualties and operating problems.

TRAINING PHILOSOPHY

In order to establish qualifications needed by personnel involved in LEG marine transportation, it is necessary to know the design and operation of the ships, terminals, and equipment they will be dealing with, as well as the constraints under which their ships operate.

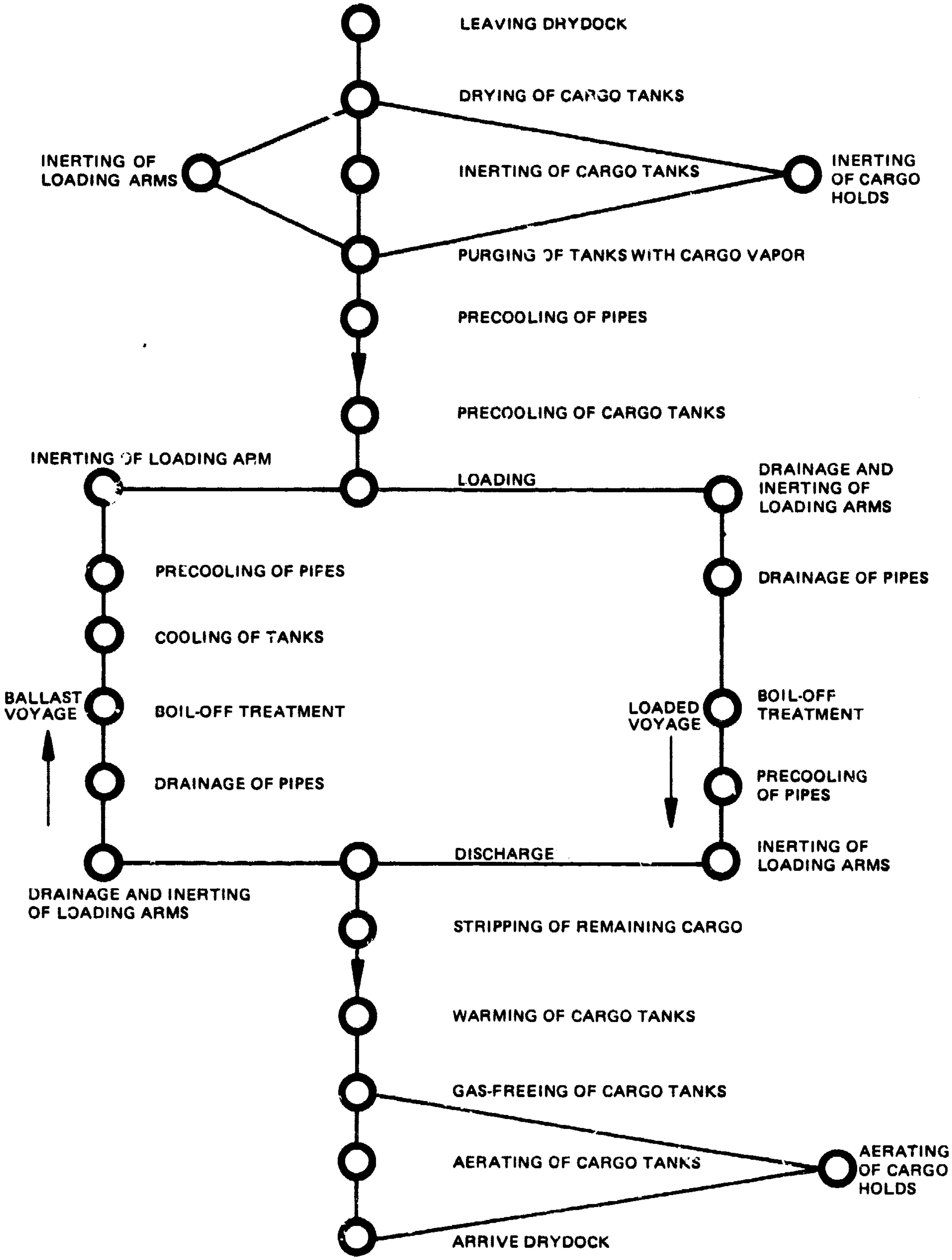
Design. Because LEG must be kept fully enclosed and separated from the atmosphere, monitoring internal pressures and maintaining them are extremely important to the safety of the system. The relationship between the LEG terminal and ship involves a two-way flow of information and an interconnection of safety and control subsystems. Therefore, a terminal operator should be familiar with the ship subsystems, and ship personnel should at least know the shore systems that will influence their actions.

Operation. A somewhat simplified typical operational schedule is shown in Fig. 6-2. The diagram demonstrates clearly the efforts made to prevent the mixing of air and cargo vapor.

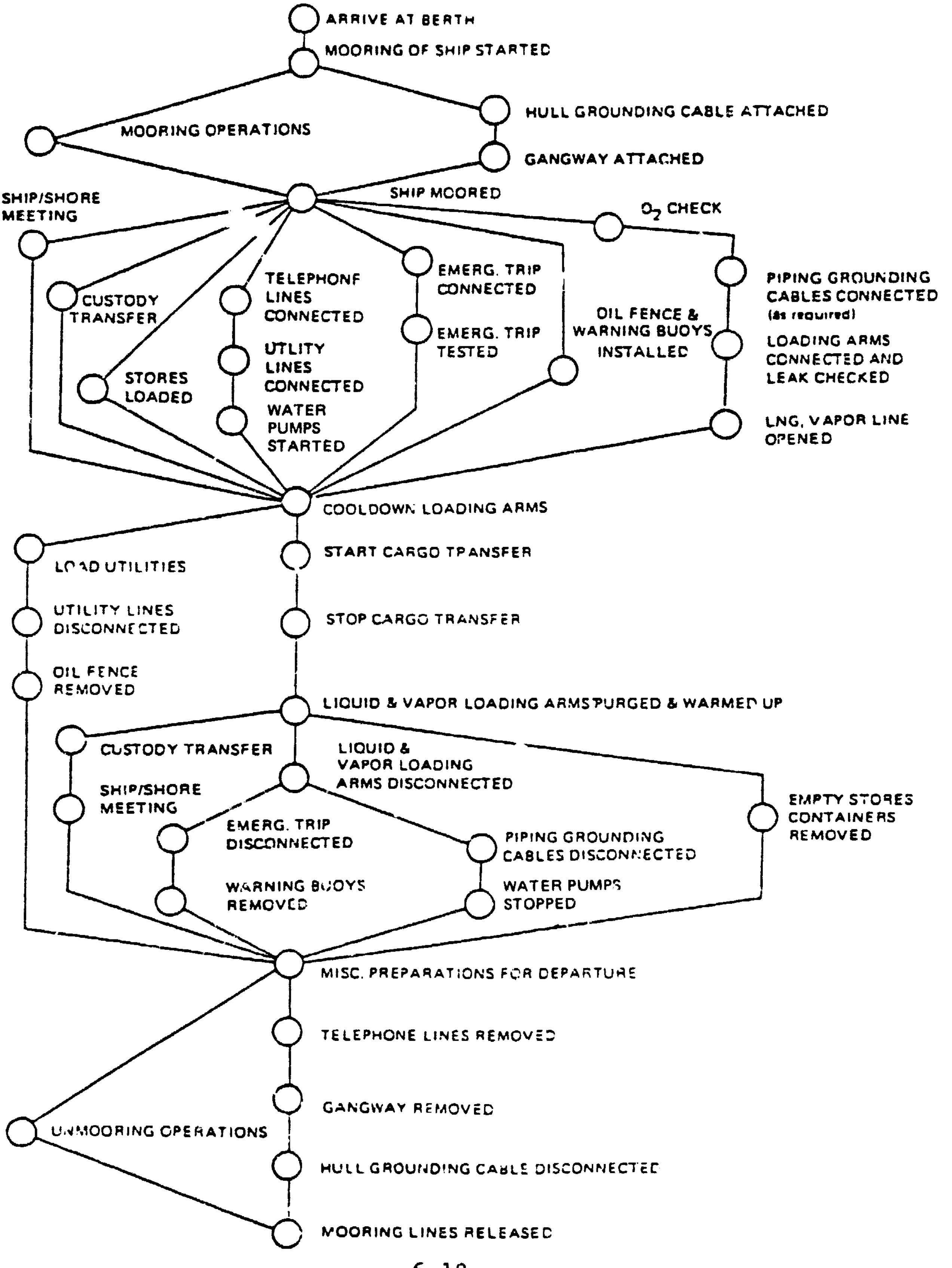
A cargo transfer is further subdivided into the different events shown on Fig. 6-3, where the relationship between the terminal and the ship is shown in some detail.

An extensive task analysis for personnel on LNG ships and barges (NTIS-AD-A026108) was sponsored by the Coast Guard in 1976. The project was conducted by Operations Research, Inc. and Engineering Computer Optecnomics, Inc. See the bibliography at the end of the references for other studies.

FIG. 6-2 – TYPICAL LEG CARGO OPERATION SCHEDULE



TYPICAL CARGO TRANSFER SEQUENCE
FIG. 6-3



CONSTRAINTS

Personnel aboard LEG ships operate under more difficult conditions than workers at LEG terminals. Hazards, for example, are greater aboard ship because a vessel operates in an environment that is continually changing and that cannot be accurately predicted. Nevertheless, many members of an LEG ship's crew have a less technical background than the engineers and technicians who typically operate an LEG terminal. Furthermore, members of a ship's crew may not have the same opportunity to specialize in LEG operations as do their counterparts ashore. A deck officer aboard an LEG tanker must consider gas cargo handling as only one of his many assigned duties, along with ship handling, navigation, and other tasks. In addition, there may be times when a ship's officers work longer hours than permitted under regulations, and may be physically and mentally less prepared for a given cargo handling operation.

On U.S. flag LNG ships the Coast Guard requires that the ship have a non-watchstanding Chief Mate to serve as the cargo officer, and a non-watchstanding 1st Assistant Engineer to serve as the cargo system engineer. The Coast Guard imposes these requirements, under 46 U.S.C. 222, in issuing the ship's certificate of inspection. Only two out of 38 current LNG ships are U.S. flag. There are no U.S. flag LPG ships.

There are no similar non-watchstanding requirements for cargo officers and engineers on foreign flag LEG ships. IMCO has not addressed this issue, although it may be discussed in its June 1978 meeting.

TRAINING CRITERIA

As part of our study we made an extensive review of existing and proposed industry training criteria and those proposed and required by U.S. and foreign governments. The criteria below seem to us to be particularly important.

1. Advanced, formalized shore-based training should be given to all personnel with duties connected with handling LEG.

2. The training should provide a basic understanding of LEG behavior under all conditions.

3. The unusual hazards of LEG and the preventive and reactive safety features involved should be emphasized throughout the training.

4. Hands-on training should be provided in fighting fires on water and high-pressure-vapor fires.

5. Supervisory personnel should be required to understand the operations of all components and instruments involved, even if they are actually operated by others.

6. Training in emergency procedures should be emphasized.

7. Training in teamwork situations should be provided, involving personnel with responsibility for different subsystems, such as ship and shore terminals, and personnel with different professional training. This

could be done on the job, but can be done more efficiently on a simulator.

8. Personnel should be trained to use their acquired knowledge in realistic operations, including troubleshooting and decision-making in emergency situations. This training can only be done in a simulated environment.

Although the above list indicates a sophisticated and demanding training program, the general concept is accepted by the industry; each of the criteria can be found in existing and planned training programs, even if few companies have adopted all of them. They should be required for both marine terminals and the ships.

PROPOSED REGULATIONS

Shore Terminals Two regulations concerning personnel qualifications at LNG terminals have been proposed:

1. The Coast Guard is considering a proposal developed by the Chemical Transportation Industry Advisory Committee (CTIAC) for revising 33 CFR Part 126, entitled Waterfront Facility Regulation , Liquefied Natural Gas in Bulk, October 1977. The proposed revisions describe three levels of training for supervisory, operating, and maintenance personnel respectively. According to the Coast Guard, however, no "approval" of training programs is envisioned, and the training "requirements" will not be enforced. The proposed revisions are general in scope, and do not cover criteria 7 and 8, above.

2. The Office of Pipeline Safety Operations' proposed rules (49 CFR Part 193), Liquefied Natural Gas Facilities, cover operations only to a limited extent. They state that an initial training program shall provide instructions in the characteristics and hazards of LNG, in the operation of plant equipment, and in emergency procedures. The Office of Pipeline Safety Operations has not proposed requiring that training programs be approved. Finally, criteria 2, 4, 7 and 8 are not covered.

No regulations setting forth qualifications of personnel working at LPG waterfront facilities have as yet been proposed. However, CTIAC is planning such work for all liquefied gases, including LPG, after the final LNG regulations are adopted.

Ships Both the U.S. Coast Guard and IMCO have developed proposals for the training of LEG ship personnel. IMCO's detailed recommendations will be evaluated by the government members before the IMCO Convention in London, June 1978.

Acceptance by the Convention is important to the United States; if IMCO member governments in turn incorporate the training recommendations in their national regulations, their enforcement would assure that personnel operating foreign flag carriers have received acceptable training. The Coast Guard need not wait, however, for member governments to take this step. Once the IMCO Convention has adopted these recommendations, the Coast Guard could require that all foreign flag vessels operating in U.S. ports meet the new IMCO standards.

The IMCO recommendations include three levels of training directed at:

a) all crew members;

b) those with duties specifically involving the cargo; and

c) the person in charge of cargo handling.

All crew members would receive a basic shore-based training course, including hands-on fire fighting, prior to assignment to a ship. Those involved in cargo handling would have more in-depth training and would be required to serve aboard a gas carrier for at least two months. This training for group "c" would satisfy all of the criteria except No. 8.

The U.S. Coast Guard has proposed training regulations (46 CFR Parts 10, 12, 30, 31, 35, 70, 90, 98, 105, 151 and 157), Tankerman Requirements. These regulations would attempt to put IMCO approved recommendations into effect. However, the proposed Coast Guard regulations differ from the proposed IMCO rules in that:

- Formalized training would be required only for a limited number of personnel who have duties in connection with the cargo. The regulations are unclear on this point, but they would probably include only the person in charge and his assistant.

- Instructions concentrate on cargo transfer operations (loading and discharging). The regulations do not reflect the fact that these operations are only a part of LEG carrier operations.

- Instruction in emergency procedures is not required.

In addition, the Coast Guard's proposed requirements for practical experience would enable a person to qualify by participating in relatively brief discharge operations. The proposed regulations are not found to cover satisfactorily training criteria Nos. 1, 6, 7, and 8.

EXISTING AND PLANNED TRAINING

Training of both ship and shore personnel is characterized by the lack of regulatory guidelines and the wide variety of training approaches. Comments on some approaches follow.

Shore Terminals. Most operating LPG receiving terminals use principally on-the-job training without any specified training schedules. Key personnel are given hands-on fire fighting training in designated schools. The Distrigas LNG terminal in Everett, in addition to on-the-job training, periodically conducts a 16-hour formalized course in safety and plant operation. All operating personnel are sent to fire fighting school.

Columbia LNG's Cove Point terminal provided a six-week course for all operating personnel, including four hours a day of classroom instruction and four hours a day of hands-on experience. Further training was given in a "simulated" cargo transfer operation, using an empty LNG ship berthed at the dock. Cove Point also held three two-day fire fighting sessions, which included small LNG pool fires.

Southern Energy's Elba Island LNG terminal is planning a similar training program. An interesting feature is the intended use of the control room console in training exercises, simulating plant conditions by means of a computer.

Improved training courses are now being conducted by the equipment manufacturers. All of the training criteria discussed above are satisfied collectively by the planned training programs of the Cove Point and Elba Island terminals. This indicates that these criteria are realistic.

Ships A great majority of the LPG carriers and approximately 50% of the LNG fleet to be involved in U.S. trade will be of foreign flag. The French Gazocean Company, one of the largest gas ship operators in the world, is representative of the companies that offer no organized training in the field, except on-the-job indoctrination.

The British P & O Steam Navigation Company provides a one-week classroom course in handling of liquefied cargoes at the Southhampton School of Navigation, operated by the General Council of British Shipping. In addition, P & O requires two months of on-the-job training and a four-day safety course in Leith, Scotland.

Norwegian companies also provide on-the-job training in addition to a two-week gas carrier safety course at the state operated School of Ships Safety and Damage Control in Haugesund. Some of the companies sporadically offer a one week cargo-handling course, conducted by the shipping industry.

The Algerian state-owned company, CNAN, is expected to carry about 20% of the expected LNG to be imported to the United States. In sharp contrast to the more established European companies, CNAN is planning a training institute outside Arzew to provide a 1-1/2 year extensive training program for deck officers, marine engineers, shore officers, and management personnel. The institute plans to have a $2 million cargo handling simulator, as well as fire fighting facilities, a number of laboratories, and a complete loading arm set up. The simulator will provide training in teamwork situations for all personnel involved with the cargo. Training in troubleshooting and emergency situations will be emphasized. As far as we know, the training program is the most extensive planned today.

In the United States, maritime training at this level is generally provided by the maritime unions. Since 1974 the Maritime Institute of Technology and Graduate Studies, operated by the International Organization of Masters, Mates, and Pilots, and the shipping companies, has had a four-week course in gas carrier operations, including fire fighting. The school plans to incorporate a simulator comparable to the Algerian model.

More recently a six-week LNG fundamentals course, including fire fighting, has been offered by the Calhoon MEBA Engineering School, operated by the Marine Engineers Beneficial Association. The Energy Transportation Corporation requires its deck, engine, and radio officers to be graduates of this program.

Both of these courses seem to meet the standards contained in the IMCO recommendations as well as the proposed Coast Guard Tankerman Requirements.

The Seafarers International Union's Harry Lundeberg School also gives a four-week LNG program for unlincesed ship personnel.

In addition to these training facilities, the El Paso Company will conduct its own training program. Expected to cost $9 million over a five-year period, it will be carried out on the ships and at shoreside facilities. It will include the use of a LNG cargo handling simulator and a shiphandling simulator, both to be operated by Marine Safety International.

SECTION III. SHIP OPERATIONS

The safety of domestic LEG ship operations depends heavily on the Coast Guard's management of LEG traffic and off-loading operations. Assessing the quality of that management is the purpose of this section.

LPG maritime traffic in this country is steadily growing and involves many ports, but until early 1978 the only active LNG import terminal was in Boston Harbor, where one LNG ship docks every three weeks. An LNG export terminal at Kenai, Alaska has been operating since 1968. Consequently, the Coast Guard has had limited operating experience with LNG. It is important for the Coast Guard to promptly develop operating and contingency procedures for LNG, because LNG traffic is beginning to grow. The new LNG terminal at Cove Point, Md. has received its first shipload of LNG, and will eventually be receiving one LNG ship every 2-1/2 to 3 days. The Elba Island, Georgia terminal is also expected to begin operations in 1978.

LPG vapor has significantly different density, vaporization temperature, detonatability, and burning characteristics than LNG vapor. Current Coast Guard operating procedures do not reflect these differences.

Under Title I of the Ports and Waterways Safety Act of 1972, the Coast Guard has certain powers to prevent damage to land structures and shore areas immediately adjacent to U.S. navigable waters resulting from vessel or structure damage, destruction, or loss. The Coast Guard informed us, however, that it is not currently capable of monitoring all the land-side dangers from hazardous materials. In the case of LNG storage tanks, for example, it examines only the peril the tanks pose to ships and docks but not to surrounding communities. After more than three years of discussions, the Coast Guard and the Materials Transportation Bureau have recently agreed on a two-page Memorandum of Understanding which clarifies their respective responsibilities for regulation of waterfront LNG facilities and sets forth procedures for cooperating in carrying out those responsibilities. A more extensive discussion of this issue is given in Appendix XVI-3.

HISTORICAL BACKGROUND

Large-scale petrochemical trade between America and Europe and Japan began in 1964. The Coast Guard soon became concerned that the ships involved in the trade, all of which were of foreign registry, would not be equipped with the safeguards necessary to ensure containment of hazardous cargo. Consequently, the Coast Guard required that any ship planning to carry hazardous cargo in U.S.

ports submit plans of the vessel's containment area, related piping, and electrical systems for review and approval by the Coast Guard's staff of technical personnel.

This submission of plans was the forerunner of the Coast Guard's current Letter of Compliance (LCC) program. Under the LCC program all foreign vessels of novel design that carry hazardous bulk liquid cargo must be inspected by Coast Guard personnel and issued a Letter of Compliance before they are permitted to transport these cargoes in U.S. waters. The inspection takes about 4½ hours and the Letter of Compliance is valid for two years. All foreign tankers are given a navigation safety examination at least once a year.

NEED FOR SPECIFIC LEG DIRECTIVES
FROM COAST GUARD HEADQUARTERS

Discussions with senior officials at Coast Guard Headquarters showed their awareness of the agency's statutory responsibilities for the safe operation of vessels transporting hazardous materials such as LEG. The Coast Guard's publication CG-478, "Liquefied Natural Gas - Views and Practices, Policy and Safety," dated February 1, 1976, gives a comprehensive, technical discussion of most aspects of the procedures recommended for the movement and transfer of LNG in U.S. ports. However, this publication is a statement of policy and not a directive. It specifically states that implementation of the policies contained therein is at the discretion of the local Captain of the Port (COTP). Since each port has different geographic features, patterns of harbor traffic density, and prevailing weather conditions, a large delegation of authority and responsibility appears to be justified.

Furthermore, most local regulations issued by the COTP's encompass the guidance in CG-478. (See the discussion below on LNG inspections in Boston Harbor.)

On September 22, 1977, the Coast Guard published an amendment that more clearly defines the jurisdiction of each COTP and Officer in Charge, Marine Inspection (OCMI), and delegates more authority to each COTP. One of the changes strengthens the COTP's ability to manage LEG and other hazardous materials moved or stored in his area. The Commandant of the Coast Guard, however, has retained the authority to prescribe minimum safety equipment requirements.

While most regulations generally conform to the policies set forth in CG-478, there are inconsistencies. One involves the means by which COTP's redirect harbor traffic when an LEG vessel is arriving or departing. Some COTP's alert ships in the area through publication of a local Notice to Mariners. A Notice to Mariners becomes a matter of record. It also is likely to be received by vessels that may not be monitoring local harbor radio frequencies. Local security broadcasts, on the other hand, provide instantaneous information. Using both of these methods would enhance navigational safety.

The Coast Guard is experienced and capable in carrying out its responsibilities for vessel traffic, communications, and compliance with accepted marine navigational procedures. It is less experienced in dealing with LEG cargo transfer operations. It presently has insufficient resources for supervising these operations and preparing to deal with LEG emergencies.

Planning for a local disaster such as a major LEG spill varies among the COTP's but generally places heavy reliance on industrial (terminal) resources and local fire departments. No specific plans exist for coping with a major LEG spill and there appears to be little agreement among responsible officials as to what should be done if one occurs.

Although some COTP's have adapted CG-478 for LPG as well as LNG, no similar document has been issued by the Commandant, U.S. Coast Guard, specifically for the movement and transfer of LPG.

COAST GUARD PERSONNEL TRAINING

The Coast Guard has no mandatory training program in LEG hazards except that included in the Marine Safety Basic Indoctrination Course required for officers and warrant officers. This is a 12-week survey course. The only safety training offered to enlisted personnel is a five-week Marine Safety Petty Officer Course.

The Coast Guard has several times offered a four-day training course on liquefied gas carriers in Yorktown, Va. It has also offered a three-week hazardous chemicals course in Yorktown of which one week focuses on LEG training. Both courses cover cargo operations only superficially. The Coast Guard is also aware of and has recourse to the training courses being given outside the Coast Guard, described earlier.

The Coast Guard does not require the officers and enlisted personnel who are involved in LEG ship operations to attend any of these specialized LEG courses. Of particular concern are the qualifications of the Hazardous Materials Officers (HMO's) on the staff of each COTP. Although some of the HMO's we interviewed were well-qualified by experience or education, most had little training in the hazards of LEG. For example, the HMO of a port that imports both LNG and LPG told us, incorrectly, that propane is lighter than air at ambient temperatures and that the vapors from a spill would rise up and disperse in the upper atmosphere as it warmed up. On the basis of this he said his advice to the COTP would be the same for an LPG spill as for an LNG spill.

Coast Guard people responsible for LEG ship movements may be unaware of the conclusions of the Coast Guard's own research. Coast Guard researchers told us, for example, that, if there is a large LEG spill (25,000 cubic meters or more) from a ship, nothing useful can be done about the resulting vapor cloud, whether or not it is ignited. If Coast Guard personnel were aware of this and other pertinent information, they would understand better the need for extreme care in LEG cargo handling.

The Coast Guard's annual operational readiness inspection at each port is only an administrative evaluation of prescribed procedures, rather than an actual test at ports handling LEG. An adequate test would require manning of Coast Guard emergency stations and equipment in a simulated LEG spill situation, in order to judge the training and performance of personnel and the efficiency of equipment.

COAST GUARD PORT ACTIVITIES

The discussion in this subsection is based on meetings with personnel on the headquarters staff of the Commandant, and with COTP's or their designated representative at the following six ports: Boston, New York, Philadelphia, Baltimore, Houston, and Savannah. We made several visits to Boston Harbor, since it was the only port through which LNG was then being imported.

In addition, we reviewed various documents including the regulations on LEG safety issued by the COTP's, and harbor navigational charts for the ports, issued by the National Oceanic and Atmospheric Administration.

LNG Offloading in Boston Harbor

During our visits to the Port of Boston we observed offloading from three LNG carriers: the Descartes, a 50,000-cubic meter French flag ship, owned by Gazocean; the Kenai Multina, a 35,000-cubic meter Liberian flag ship, owned by Multi-Meyer; and the Lucian, a 29,000-cubic meter Norwegian flag ship, owned by Reksten.

Security Authority

Under 33 CFR Parts 125 to 127, the Commandant, U.S. Coast Guard, is authorized to require certain precautions against the sabotage of vessels and waterfront facilities handling explosives, or flammable or combustible liquids or fuels. Nevertheless, no COTP has made any specific provisions to prevent or mitigate the consequences of sabotage of an LEG ship or terminal. They rely on the minimal industrial security forces at each terminal and on the ship's masters. The inadequacy of the present security arrangement is discussed in Chapter 9.

Minor LNG Spills

On both the Lucian and the Kenai Multina we observed small leaks due to malfunction of equipment. The Lucian had two minor gasket leaks, both of which were stopped by tightening bolts.

On April 3, 1977, we saw several gallons of LNG spilled on the deck of the Kenai Multina as the result of a leaky gasket in the liquid line from tank no. 5. The crew sprayed water throughout the discharge operation, which probably prevented the deck from cracking.

Last winter the Descartes spilled about one cubic meter (264 gallons) of LNG, when valves in the ship's liquid lines were left open. The ship's plates did not crack, although a similar accident in Stade, Germany, involving ethylene (-155°F) caused damage which required replacement of several steel plates on the deck and the ship.

The Lucian had a minor spill on March 8 caused by a poor connection with the loading arms; another occurred on March 9, due to open valves in the ship's liquid lines.

Smaller ships, such as the Kenai Multina and the Lucian, face an additional hazard. The berth and mooring system at the terminal is designed for larger ships, such as the Descartes, and does not provide the same support for shorter vessels, which can use only one of the two 52 ton breasting dolphins.

Coast Guard Inspections

The Coast Guard carries out a 2-1/2 hour inspection before an LNG ship is permitted to enter Boston Harbor, but it does not include the operating condition of ship control equipment such as steering engines, propulsion machinery, and electronic devices. Coast Guard policy also leaves critical safety decisions to the discretion of the COTP.

The inspection itself is one of the 18 requirements which the COTP, at his discretion, may place upon LNG transit operations, according to CG 478.[9] In Boston, under the LNG-LPG Operation/Emergency Plan, the COTP has the right to prohibit a ship from entering the port, if there are serious discrepancies in safety systems. If a safety subsystem is not in good working order, it is the COTP who decides whether the condition is serious enough to warrant keeping the ship out of the harbor.

This arrangement is unsatisfactory for three reasons. (1) Since Coast Guard personnel do not have to be trained in LEG properties, hazards, technology, and cargo operations, they may not be fully qualified to judge the significance or consequences of a malfunction. (2) Without specific requirements, there may be a tendency to give undue weight to the large, certain, economic impact of the ship's delayed entry against the uncertain possibility of harm posed by the malfunction. (3) The lack of specific requirements results in confusion in the world shipping industry as to the U.S. Coast Guard's safety standards for admitting LNG ships.

The following two examples illustrate the kind of decision a COTP must make under current regulations. Each involved a fault in one of the major safety subsystems of an LEG carrier.

The LPG carrier Faraday, carrying 27,500 cubic meters of propane, was inspected on March 5, 1977, outside Boston Harbor. The ship uses inert gas consisting of 85 percent nitrogen and 15 percent carbon dioxide in the cargo hold surrounding cargo tanks. The carbon dioxide absorbed infrared light, triggering the ship's gas alarm. This problem was discovered on a previous trip to the United States by the Faraday. With a crew member visually monitoring the gas detector dial, the ship was allowed to enter the port. This decision involved some risk. If propane did begin leaking into the hold, the gas indication could have been difficult to separate from the "false" reading caused by carbon dioxide. A sufficient leak of cargo can cause the hull to crack, thus allowing cargo to spill.

On April 3, the Coast Guard inspected the Lucian, which was carrying 28,000 cubic meters of LNG. Although the seals on two of the ship's relief valves were broken, it was allowed to enter. In such instances, there is a risk, however unlikely, that the relief valves have been tampered with, rather than that the seals were accidentally broken. There is no way to check whether the relief valves have been changed to a higher pressure setting which, as discussed in Section I, could lead to tank rupture and cargo spill. The incident underscores the need for a regulation requiring pressure switches that automatically shut off relevant equipment in case of high differential pressures.

These were both difficult decisions which worked out satisfactorily, but we believe the COTP should not have had to make them. Coast Guard requirements should specify which faults are sufficiently serious to prevent a ship's entry. The COTP should not have to weigh the dollar costs of a delay against the potential risk posed by a safety fault. Although it is true that, if the COTP is undecided, he may request the Commandant to advise him or to furnish a technical representative, a COTP may be reluctant to admit more technically qualified assistance is needed.

As noted, specific requirements would also be to the advantage of the LEG shipping industry. Otherwise the present confusion may increase as more ports are involved in LNG shipping, and ship captains may face the possibility of inconsistent implementation of the guidelines by various COTP's.

Visibility Considerations

According to the Coast Guard's regulations for Boston Harbor, if the visibility is less than 2 miles, an LEG ship is not permitted to enter the harbor. However, if a ship has reached a point east of Fort Point Channel, and the visibility drops below 2 miles, the ship is allowed to continue to the ship's berth. This was the case last winter when the Lucian arrived in a heavy snowfall.

According to the visibility requirements, a vessel must begin transit of the harbor at least 2 hours before sunset. The 10 miles from Broad Sound to the Everett Terminal usually takes 1-1/2 hours. On April 4, the Lucian arrived at the dock at 6:35 p.m. and was moored at 7:15 p.m. Sunset on that day was 6:13 p.m. If the trip took 1-1/2 hours the Lucian would have had to begun transit almost an hour beyond the Coast Guard deadline. Although local port regulations call for a minimum of 3 tugboats, the Lucian was assisted by only two on that transit.

Aircraft Hazard Assessed

While on board one of the LNG carriers, we noted how close the ship was to Boston's Logan Airport. On investigation we found that planes approaching the airport's Runway 4-R fly over the ship channel used by both LNG and LPG tankers. On July 31, 1973, a Delta DC-9 executing an instrument landing approach to this runway crashed into the seawall.[10] We examined the circumstances of this crash to assess the danger of an airplane colliding with a gas tanker in the channel.

In Fig. 6-4 the prescribed flight path and the flight track of the crashing plane are plotted on a nautical chart of Boston Inner Harbor. The numbers given on the map are channel depths. The flight profiles are shown on Fig. 6-5.

Correct flight procedure calls for altitude to be maintained within 100 feet of prescribed altitude during initial approach. This should decrease to approximately 50 feet at decision height (DH), the height at which the pilot should decide whether to continue or abandon his approach.

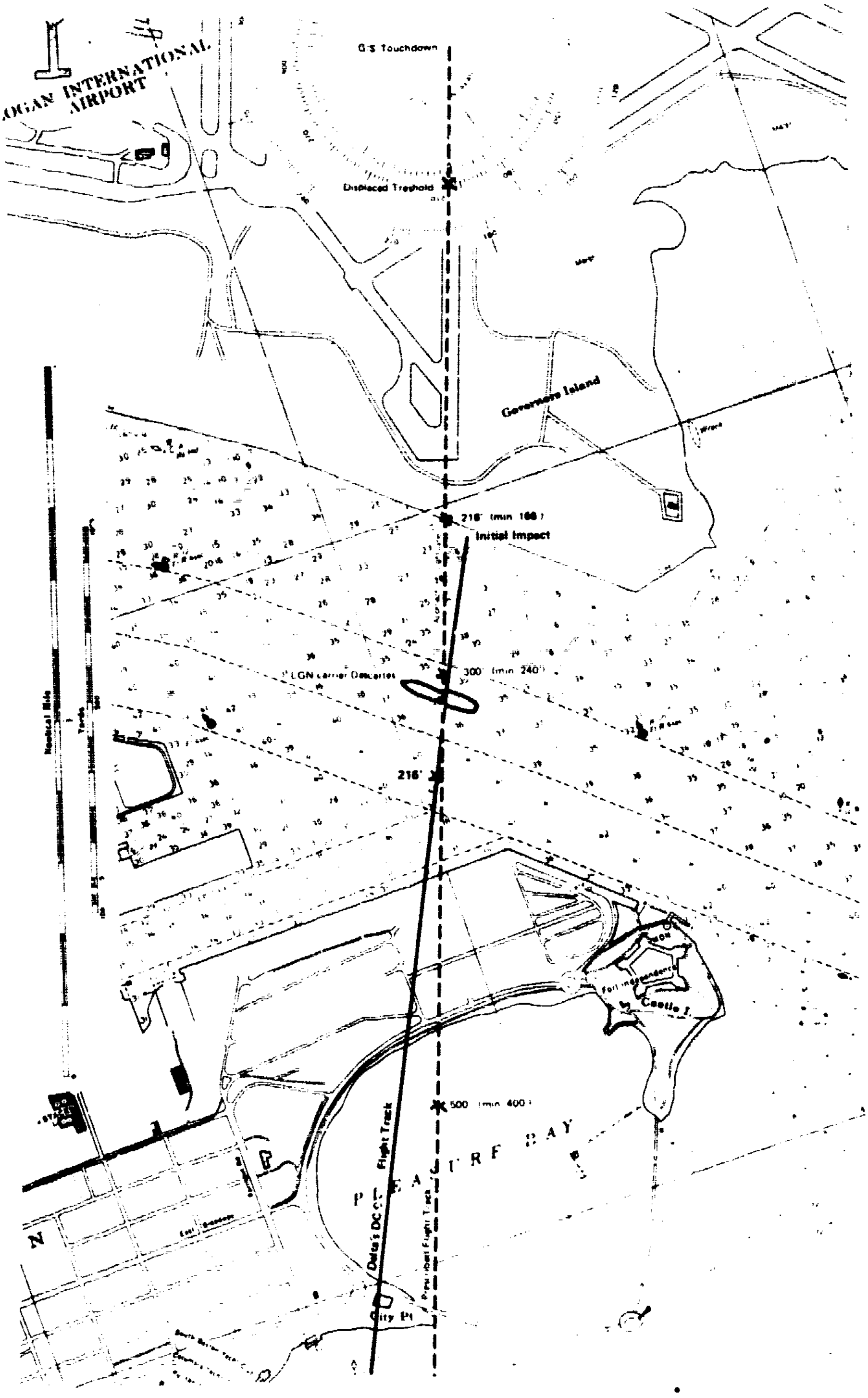
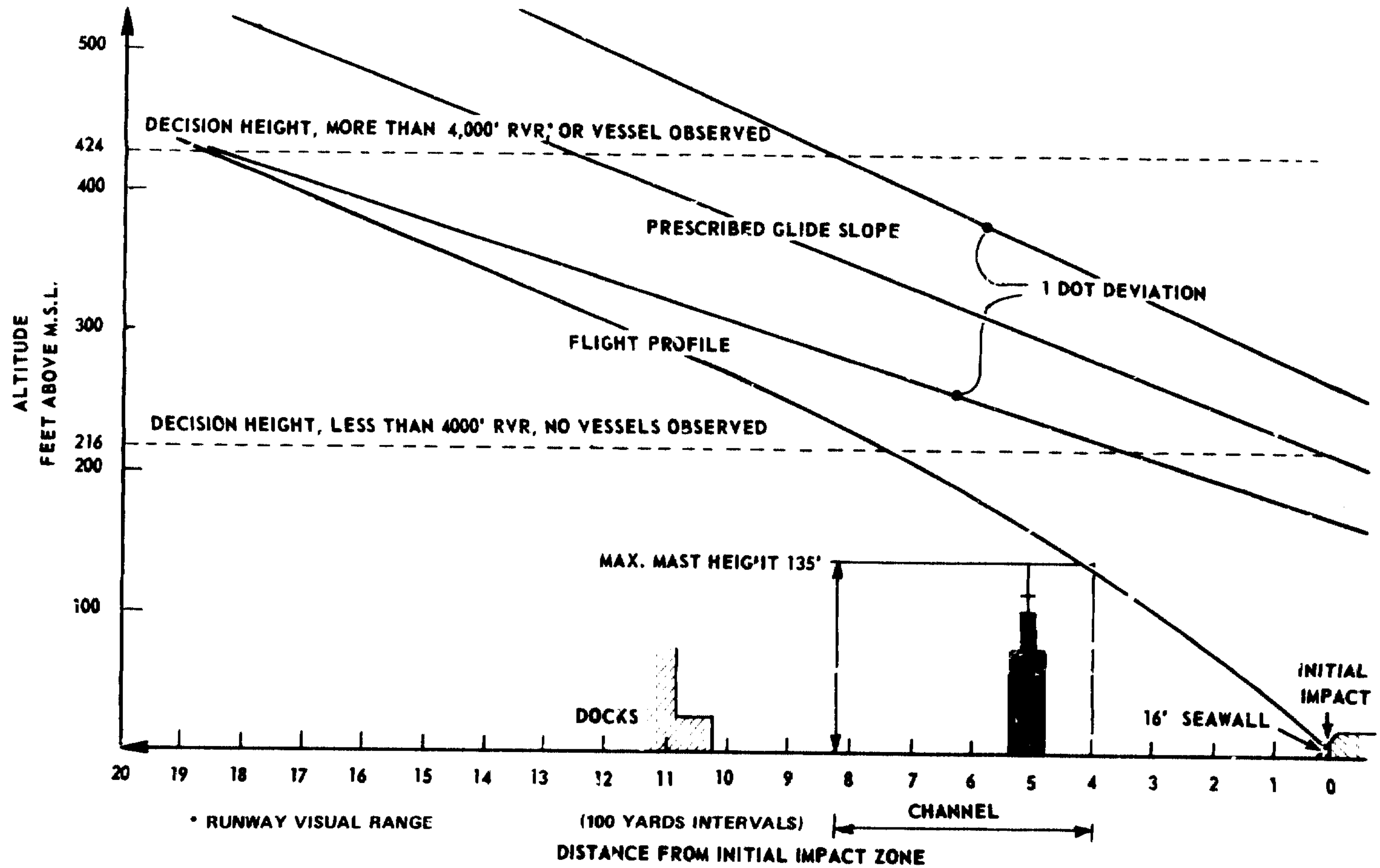


FIG. 6-4

PRECRIBED FLIGHT PATH AND FLIGHT TRACK OF THE PLANE CRASH INTO LEG SHIP CHANNEL SEAWALL.

FIG. 6-5 LANDING APPROACH FOR RUNWAY 4R, LOGAN INTERNATIONAL AIRPORT, AND FLIGHT PROFILE FOR CRASH.[1]



1/IN NOVEMBER 1977, AFTER IMPROVEMENTS TO RUNWAY 4-R, THE FAA LOWERED THE NORMAL DECISION HEIGHT FROM 424 FT. TO 359 FT. WITH MORE THAN 5000 FT. RVR.

The horizontal distance is given from the edge of the seawall, where the crash took place. As can be seen from the diagram, the ship will never be closer than 400 yards from this point.

The maximum mast height is set to 135 feet, which is the vertical clearance under the Mystic River Bridge. Some ships are slightly taller, such as the Charles Tellier (137 feet). These taller ships have to lower their masts and/or be brought under low tide conditions.

If an LEG tanker had been in the channel, would the DC-9 have crashed into it? According to our calculations, probably not, but clearance could have been a matter of only a few feet.

When an LEG ship is scheduled to pass through the channel, the airport will be notified.[11] When visibility is better than 2 miles, however, no advisories to aircraft are issued. A "regular" flight profile could bring a plane in as low as 100 feet above the mast of an LEG ship. This clearance seems to be in accordance with our visual observations. It is interesting to note that the airport considers vessel height of 132 feet or greater to constitute a hazard,[12] indicating it is aware of the danger posed by ships to aviation traffic.

Flights approaching Runway 33-L also go over the ship channel, further east. These flights do not seem to represent a hazard to LEG ships in transit.

There is no planning or coordination with the Federal Aviation Administration or the Department of Defense to minimize the chance of a disaster resulting from the crash of an aircraft into an LEG ship or facility.

OFFLOADING GROUNDED LEG TANKERS

There are no contingency plans or pre-positioned equipment to partially offload and thus lighten an LEG ship that has gone hard aground in inland waters. Because LNG is extremely cold, special cryogenic equipment and ships must be used to offload it. LPG also requires special equipment for offloading. They must be planned for and positioned in advance if they are to be available on short notice.

COMPARATIVE RISKS IN SELECTED PORTS

Based on our examination of local harbor conditions, traffic density, and navigational features, we believe that the potential for the collision or grounding of LEG ships varies for each port. A detailed summary of port characteristics is given in Appendix VI-5. Here are our findings in brief:

- Because of the depth and wide expanse of Chesapeake Bay the approach to the terminal at Cove Point, Md., appears to be the safest of the ports we examined from a navigational standpoint. The transit of the lower Chesapeake Bay, with its large volume of commercial and naval traffic in and out of the Hampton Roads area, may be more of a problem.

- The Savannah River Channel's record of collisions and groundings is excellent to outstanding, but because the channel is serpentine, special precaution should be taken for the passage of LNG ships.

- The harbor depths and minimal current conditions indicate that the ports of Boston, Mass., and Staten Island, N.Y., are low to medium navigational risks.

- The proposed sites in Los Angeles Harbor and Oxnard, Calif., seem to have a relatively low navigational risk.

- Ports with long, narrow, or winding channels and dense shipping present high risks of collisons and groundings, as shown by the recent accident history of the Houston and Philadelphia channels.

- The Houston Ship Channel is one of the ports for which the Coast Guard has installed a Vessel Traffic Service (VTS). The service—manned by Coast Guard personnel—utilizes radar, radio, closed circuit television, and a computer information system for monitoring traffic in the 55-mile ship channel. VTS appears to be a valuable and effective aid in support of safe navigation, not only for LEG shipping but for all sea-going ships. Its use is not mandatory. However, Coast Guard personnel in Houston say that 95 percent of the ships do use it. Coast Guard personnel also told us that there are so many LPG barges operating in the port that the Coast Guard does not attempt to introduce all of them into the service.

- There is no specific requirement which spells out the conditions under which an LEG ship with a malfunctioning safety system should not be allowed to enter a port.

- Local COTP regulations are not necessarily reviewed by or approved by the Commandant, U.S. Coast Guard.

FINDINGS

Ship Design

- Cargo containment systems for LPG ships are not built to the same safety standard as LNG carriers. A double hull is not required.

- The critical speed and/or the displacement of the striking vessel would have to be much higher to penetrate an LNG vessel than to penetrate an oil tanker.

- To our knowledge, the only collision resistance analysis for LNG ships has dealt with spherical tanks. Yet the size and shape of these tanks, and the greater average transverse distance between the tank and the ship's side suggest that they are the least vulnerable of all designs in the event of a collision.

- Other designs, although presumably less collision-resistant, offer other safety advantages. The Conch II's self-supporting design, with its internal bulkheads, reduces free surface effects as well as the amount of LNG spill in case of a tank rupture. The membrane designs provide good stability, good hull utilization, good visibility from the bridge, and a reduced windage area.

- The Coast Guard's proposed rules for LEG ship design do not require that tank design load calculations for membrane tanks include data on buckling. A relatively low overpressure of the cargo hold could cause buckling and possibly rupture of the primary barrier.

- LNG ships are vulnerable to sabotage through tampering with their safety relief valves and pressure control systems.

- Research suggests that a large fire on an LNG ship exposes present cargo tank insulation to temperatures that cause it to partly deteriorate or to melt.

Crew Training

- LEG ships need highly skilled operators for safe operation. Data collected on general marine casualties show that human error was a contributing factor in 85 percent of all casualties and operating problems.

- The CTIAC proposal being considered by the Coast Guard for Waterfront Facility Regulations for LNG in Bulk (which would revise 33 CFR Part 126) do not meet two of the criteria we believe necessary: team work training, and training in trouble-shooting and emergency decision making.

- The rules for LNG terminal facilities proposed by the Office of Pipeline Safety Operations (49 CFR Part 193) cover operations only to a limited extent. They omit the same criteria as the CTIAC proposal, do not include training to provide a basic understanding of LEG behavior under all conditions, and do not specifically provide for hands-on training in fighting fires.

- Both sets of proposed rules will lack effectiveness, because neither the Coast Guard nor the Office of Pipeline Safety Operations plans to require that training programs for waterfront facilities be submitted for approval.

- Regulations for personnel qualifications of LPG waterfront facilities have not yet been proposed.

- The U.S. Coast Guard's proposed tankerman regulations will require training only for one or two crew members responsible for cargo handling, and will concentrate on loading and discharging operations. Instruction in emergency procedures is not required, and requirements for practical experience are inadequate. The proposed rules do not satisfactorily meet four of our eight criteria.

- Private training of both ship and shore personnel is characterized by the lack of regulatory guidelines and the wide variety of training approaches.

- All of our criteria are satisfied collectively by the training programs of the Cove Point and Elba Island terminals. Some ship companies have designed training programs that far exceed the present and proposed requirements of regulatory bodies.

- Because of the variety of LEG ships and ports and because crew training depends so heavily on the company operating the ship and the flag under which it sails, we believe that studies done for one port, ship design, and flag cannot be used to judge the safety of any other combination of port, type of ship, and flag.

Ship Operations

- To effectively supervise LEG cargo transfer operations in U.S. waters and ports, the Coast Guard will need more money and manpower, revised regulations, and new plans and policies.

- Existing procedures for handling LPG need more attention. The Coast Guard has not issued any document, similar to CG-478, as guidance for the movement and transfer of LPG.

- LPG vapor has significantly different density, vaporization temperature, detonatability, and burning characteristics than LNG vapor. Current Coast Guard operating procedures do not reflect these differences.

- No COTP has used his authority under 33 CFR Parts 125 to 127 to require that guards provided by the owner or operator of an LEG facility be in such numbers and of such qualifications as to assure adequate surveillance and to prevent unlawful entrance, nor to designate an LEG facility as a security zone.

- The Coast Guard does not require the officers and enlisted personnel who are involved in LEG ship operations to attend any specialized LEG courses. Although some Hazardous Materials Officers are well-qualified by experience or education, most have had little training in the hazards of LEG.

- The Coast Guard carries out a lengthy inspection before an LNG ship is permitted to enter Boston Harbor, but the inspection does not include the operating condition of ship control equipment such as steering engines, propulsion machinery, and electronic devices.

- If a safety subsystem is not in good working order, it is the COTP who decides whether the condition is serious enough to warrant keeping the ship out of the harbor. This arrangement is unsatisfactory for three reasons. (1) Since Coast Guard personnel do not have to be adequately trained in LEG properties, hazards, technology, and cargo operations, they may not be fully qualified to judge the significance or consequences of a malfunction. (2) Without specific requirements, there may be a tendency to give undue weight to the large, certain, economic impact of the ship's delayed entry against the uncertain possibility of harm posed by a malfunction. (3) The lack of specific requirements results in confusion in the world shipping industry as to the U.S. Coast Guard's safety standards for admitting LNG ships.

- There are no contingency plans or pre-positioned equipment to partially offload and thus lighten an LEG ship that has gone hard aground in inland waters. Both LNG and LPG require special equipment.

- No specific plans exist for coping with a major LEG spill, and there appears to be little agreement among responsible officials as to what should be done, if one occurs.

- The Coast Guard's operational readiness inspections are not actual tests of the training and performance of LEG personnel and the efficiency of equipment.

- The Delta Airlines DC-9 which crashed into the seawall of Boston's Logan Airport on July 31, 1973 would probably have cleared an LNG tanker in the adjacent channel by only a few feet. We believe this represents an unnecessary and unacceptable risk.

- There is no planning or coordination with the Federal Aviation Administration or the Department of Defense to minimize the chance of a disaster resulting from the crash of aircraft into an LEG ship or facility.

RECOMMENDATIONS

Ship Design

To the Commandant, U.S. Coast Guard

We recommend that the Commandant, U.S. Coast Guard:

- require calculations on collision resistance for all vessels carrying hazardous cargoes.

- require an analytic and accurate determination of tank stresses be made on all types of LEG carriers to provide a better understanding of fatigue life and tank bursting and buckling pressures.

- require a double-hull for all LEG carriers.

- conduct a study of the different ways a tank might be ruptured by pressure. This could lead to development of protection systems, such as pressure switches that would automatically shut off relevant equipment in case of high differential pressures, in addition to existing safety relief valves.

- require precision position fixing equipment, bridge control of main engine, and collision avoidance systems as a means of improving the maneuverability of gas carriers, many of which already have this kind of equipment.

- require that cargo containment systems be able to contain the cargo during and after a specified fire, and that insulation in critical places be able to withstand high temperatures; the Coast Guard should sponsor research if necessary to meet this goal.

Crew Training

To The Commandant, U.S. Coast Guard

We recommend that the Commandant, U.S. Coast Guard:

- expand the Coast Guard's proposed tankerman requirements to include a wider scope of training for all personnel involved in cargo handling, and enforce the expanded requirements.

- include in the Coast Guard's training requirements for LEG marine terminals and ships the 8 criteria we list in the Training Criteria section.

- continue to require that the deck officer and engineer in charge of cargo operations aboard U.S. flag LNG ships be non-watchstanding, and work through IMCO for similar requirement for foreign flag LNG ships.

- assure that licensed officers are in compliance with codes which limit their working hours (46 USC 235 and 46 USC 673).

- assure that employees and advisers who write and those who enforce training regulations have a thorough understanding of LEG ship operations and LEG properties.

- assure that any LEG safety analyses of a particular port be based on studies of that specific port and the type and nationality of ships used.

- continue the Coast Guard's efforts to bring about the adoption of new IMCO training standards for ship personnel.

To the Secretary of Transportation

We recommend that the Secretary of Transportation through the Office of Pipeline Safety Operations:

- require and enforce for LEG terminal personnel the same 8 training requirements we have recommended for LEG ship personnel, possibly including the licensing of supervisory personnel.

- consult with the U.S. Coast Guard about the means both agencies could employ to familiarize terminal and ship personnel with each other's LEG operations.

To the Secretary of State

We recommend that the Secretary of State:

- give strong support to the Coast Guard's efforts to bring about the adoption of new IMCO training standards for ship personnel.

Ship Operations

To the Commandant, U.S. Coast Guard

We recommend that the Commandant, U.S. Coast Guard:

- issue a policy document for LPG, similar to CG-478 for LNG. The document should clearly reflect the differences between LPG and LNG in density, vaporization rate, detonatability, and burning characteristics. The policy should be mandatory except where differences in port conditions clearly make flexibility desirable.

- vigorously exercise the Coast Guard's authority, pursuant to 33 CFR Parts 125 to 127, to improve security at LEG facilities adjacent to navigable waters. In particular, it should enforce subsection 126.15(a) and require owners and operators of waterfront LEG facilities to have guards in such numbers and of such qualifications as to assure adequate surveillance and to prevent unlawful entrance.

- make the guidance in CG-478 mandatory, except where differences in port conditions clearly make flexibility desirable.

- establish a formal, mandatory training and qualifications program for officers and enlisted personnel involved in LEG ship operations.

- require an examination of the operating condition of ship control equipment such as steering engines, propulsion machinery, and electronic devices as part of its inspection of LEG ships before they enter a U.S. port.

- issue specific requirements that spell out which faults are sufficiently serious to prevent a ship's entry into a U.S. port.

- require the preparation of contingency plans and the pre-positioning of equipment to partially offload an LEG ship that has gone aground in inland waters.

- require the preparation of specific plans for coping with a major LEG spill, both when the vapor ignites at the ship and when it does not.

- require that surprise operational readiness inspections be conducted, including simulating serious problems, to evaluate the LEG personnel and resources assigned to COTP's.

- review local port regulations to assess their adequacy.

- arrange with the Federal Aviation Administration and the Department of Defense to prohibit landing and taking off planes from flying low over LEG tankers and storage tanks.

- require pressure-activated switches on LEG ships entering U.S. waters that automatically shut off relevant equipment in case there is too high a differential pressure between the cargo tanks and the atmosphere, or between the cargo holds and the atmosphere.

- improve control of ships carrying hazardous cargo in U.S. coastal waters and harbors through selective implementation of Vessel Traffic Services, and use both Notices to Mariners and local security broadcasts when LEG ships are in transit.

To the Administrator, Federal Aviation Administration

We recommend that the Administrator, Federal Aviation Administration:

- halt landing approaches to Runway 4-R of Logan International Airport in Boston during the time an LEG ship is in transit in the ship channel beneath the flight path. (Following our recommendation, the Federal Aviation Administration plans to prohibit aircraft from flying directly over large LEG vessels to land on Runway 4-R.)

AGENCY COMMENTS AND OUR EVALUATION

The detailed comments of the Departments of Commerce and Transportation on this chapter deal principally with regulations and the hazards of overpressure, fire, and collisions.

Regulations

1. Commerce states:

> ". . .The thrust of the GAO report on directives is that hard and fast rules need to be established and that these safety rules must be applied rigidly in all instances. We disagree. We believe that a more flexible approach with the Coast Guard's Captain of the Port having the final decision based on regulations, guidelines, experience and the events at hand is proper and has proven effective in the past. . ."

DOT makes a similar comment.

GAO response:

We do not suggest totally rigid regulations. We suggest, rather, that the Coast Guard guidelines on LNG be made mandatory except in instances where flexibility is clearly desirable. In those instances the Captain of the Port would be the controlling authority.

2. DOT makes the following comments on our recommendations that the Commandant of the Coast Guard issue a similar guideline statement on LPG:

> ". . .The report emphasizes the fact that CG-478 addresses only LNG and not LPG. The reason for

this is the inordinate public, Congressional, and news media interest in LNG. The Coast Guard found it beneficial to publish this information to satisfy repeated inquiries. The Coast Guard is aware of the hazards of LPG and many other liquefied gases, but because there has not been the same overwhelming cry for information, it has not been deemed necessary to publish a pamphlet for each liquefied gas carried in bulk marine shipments. . ."

". . .The Coast Guard is revising CG-478 and will include a chapter on LPG. . ."

GAO response:

DOT seems to be of a divided mind on this issue. In these comments DOT argues that there is no present need for publishing LPG guidelines, but it announces that it also plans to publish them.

3. DOT states:

". . .Since Coast Guard regulations and operating procedures are all directed at preventing the release of liquefied gases, it is unclear how the properties of LPG in the vapor phase (i.e., after release) should influence these procedures. . ."

GAO response:

This is not true. Part II of the Coast Guard, Port of Boston LNG-LPG Operation/Emergency Plan concerns procedures to be followed after an LNG/LPG incident has taken place.

4. DOT states:

> ". . .{The} instruction, training, experience {of key Coast Guard personnel} combine to provide a COTP with sufficient expertise to make rational decisions concerning vessel and facility safety. . ."

GAO response:

This is contradicted by our interview with the Hazardous Materials Officer stationed at a major LNG port, which is included in this chapter.

5. In another comment DOT does not contradict our statement that, although local port regulations call for a minimum of 3 tugboats, the Lucian was assisted by only two on the transit we observed. DOT does say, however, that:

> ". . .Perhaps the fact that LUCIAN is a much smaller vessel (29,000 m^3 compared to the 50,000 m^3 DESCARTES) was considered when allowing two tugs {instead of} three. . ."

GAO response:

The Coast Guard's LNG-LPG Operation/Emergency Plan for the Port of Boston requires that "<u>a minimum of (3) tugs</u> of suitable horsepower will attend the needs of each LNG ship regardless of size." (The words are underlined in the Operation Plan.)

Overpressure

6. Commerce states:

> ". . .Even where the safety valves were locked closed, a tank would not rupture anywhere from a few days to a couple of weeks depending on the type of containment system. . ."

GAO response:

This is true only if pressure is built up solely by normal evaporation. It does not contradict our suggestion that saboteurs could manipulate the pressure control system to overpressurize the cargo tanks or cargo holds.

7. DOT states:

> "The Coast Guard does not directly require bursting pressure calculations for LNG tanks or pressure vessels. The design of an LNG tank (or pressure vessel) inherently limits the maximum allowable stress experienced by the tank to a specified percentage of the ultimate strength of the tank material, leading to a safety factor of at least four on tank bursting pressure. Requiring the submission of a calculation for the actual bursting pressure would be superfluous."

The issue is not the maximum allowable stress experienced under normal conditions but the stress that could be produced by someone purposely misusing the pressure control systems to overpressurize the cargo tanks or cargo holds. It is necessary to know the bursting pressure in order to tell how long it would take a saboteur to rupture a tank by such means and to devise appropriate protective measures.

8. DOT also states:

> ". . .There are high pressure alarms on the ship to indicate excessive tank pressure. There is no 'relevant equipment' to be shut down in the event of high pressure on the LUCIAN. The only equipment affecting tank pressure on the LUCIAN serves to lower tank pressure; therefore why shut it down?. . ."

> ". . .Finding 6 is oversimplified and indicates a basic minunderstanding of liquefied gas ship design. There are many ways that a gas ship could be sabotaged--just as there are many ways that any ship could be sabotaged. The method indicated is probably one of the most unlikely. It is very difficult to tamper with relief valves to the extent necessary to cause catastrophic destruction of the ship. Pressure alarms are available to alert the crew that something is wrong. Pressure control systems on gas ships are installed to reduce pressure, not increase it. . ."

GAO response:

High pressure alarms can be disabled. The statement that the only equipment affecting tank pressures serves to lower it is not true. Two systems raise pressure. The system for purging cargo tanks sends vaporized LNG into the tanks, and the emergency cargo discharge system uses a compressor to overpressurize the tanks after the safety valves are manually closed.

Fire

9. Commerce states:

> "It is unlikely that insulation, except for that on the tank dome, would be exposed to fire except where the hold was already breached."

DOT states:

> ". . .a cargo fire around an LNG ship is described while the findings mentioned a fire on the LNG ship. Only the tank dome extends above the deck and the safety valve calculations consider the fire situation. . ."

GAO response:

As ship drawings in Appendix VI-1 illustrate, the statement that "only the tank dome extends above the decks" is not true for three of the four types of LNG ships -- Moss-Rosenberg, Technigaz, and Gaz Transport.

10. DOT states:

> ". . .Cargo containment systems are required to be able to withstand fire exposure without failure. Cargo vapors, however, will be vented by relief valves. Insulation is normally protected by steel sheathing or the vessel's hull. The scenario the recommendation envisions apparently is one where fire is surrounding the ship, the inner and outer hulls have been breached, and the tank insulation is exposed. To design to such criteria is not practical. . ."

GAO response:

We did not suggest that insulation would be exposed directly to fire. We suggested that it might be exposed to high temperatures that could cause it to deteriorate. The Det Norske Veritas analyses discussed in the "Fire Hazard" section show that in a fire where neither the outer nor inner hulls has been breached, the insulation might still be subjected to temperatures far higher than those needed to decompose it completely.

Collision

11. Commerce states:

> "Presently, there are no requirements or criteria for determining what {collision} resistance is needed. . .The assumptions concerning the structural configuration, speed, angle of incidence, and a number of other factors make such calculations largely an academic exercise. . ."

GAO response:

We do not agree. We are disturbed by the lack of requirements or criteria for determining what resistance is needed, and we believe collision analyses can be done with sufficient precision to aid rulemaking and design.

12. DOT states:

> ". . .It is not clear what would be achieved with similar studies on other designs. The minimum distances between outer hull and tank boundaries are, by regulation, the same for all types. The difference lies in some variation in

probability that a tank boundary will be involved with certain penetrations onto the LEG vessel. . ."

GAO response:

The comment is not relevant. We recommend that the Coast Guard calculate collision resistance for all vessels carrying hazardous materials. Vessels of different design have different tank suspension systems, and these affect their collision resistance. Det Norske Veritas calculated the resistance of LNG ships with spherical tanks. We believe the Coast Guard should develop similar data for all ships carrying highly hazardous cargoes.

13. DOT states:

". . .Delete the sentence, 'However, data on buckling of membrane designs are not required.' Membranes by definition cannot withstand compressive loads. . ."

GAO response:

The buckling of the Polar Alaska's membrane suggest that it would be worthwhile to know what pressures will buckle particular tank construction.

OTHER COMMENTS

LEG Crew Training

14. Commerce states:

". . .The draft report stresses the need for formal training of all shipboard personnel having LEG responsibilities and in this we concur. Eight criteria for training are given. While the majority of the criteria are acceptable and reasonable, we find that the references to 'simulator' and 'simulated environment' to be vague with regard to meaning. Simulators can be extremely costly, both to create and to operate. . ."

GAO response:

Several simulators are in operation, and we believe their cost is justified by their value in training key personnel in critical areas of safety. The value of simulators has long been recognized in training aircraft pilots.

Aircraft Collision Hazard

15. Commerce states:

> ". . .The extent of control of air traffic alluded to in the report is excessive. The fact that one aircraft crashed in making a landing should not lead to the conclusion that it can be expected that additional crashes will happen further from the airport in the ship's channel. . ."

GAO response:

The Federal Aviation Administration, on the other hand, agrees with our recommendation. FAA states:

> "We agree that there is a potential for widespread disaster in the event of an accident involving an aircraft landing on Runway 4R at Boston and a Liquefied Energy Gases (LEG) ship in transit through the shipping channel.

"The air traffic control tower at Logan International Airport has a program for detection of ships in Boston Harbor. The system makes use of radar, closed circuit television, and verbal communications to detect, track, and identify ships with tall masts. Such vessels can be an obstruction to aircraft making instrument approaches to Runway 4R. We will expand our tall mast detection program and clear aircraft landing on Runway 4R at Logan Airport so that the aircraft will not fly directly over large LEG vessels operating within the boundaries of the instrument landing system protected airspace trapezoid. The Captain of the Port, U.S. Coast Guard, has assured us the U.S. Coast Guard will provide sufficient advance warning of the LEG vessels with cargo. Implementation of the service will require at least two months for completion of procedural arrangements and controller training.

"We are confident that establishment of this additional service will meet the GAO safety recommendations and reduce to the minimum any chance of incident between aircraft and surface vessels."

LNG Vapor Boiloff

16. DOT states:

". . .the cited value of 12,000 cubic meters of liquid per hour is much larger than any reasonable estimate. . ."

GAO response:

The final report refers to the 12,000 cubic meters of LNG vapor that can be generated by a ship's vaporizer. This value is from the specifications for General Dynamics' LNG ships.

REFERENCES

1. Several blueprints and operation manuals for gas carriers.

2. "Whither the LNG Ship," W. B. Thomas; paper given at Royal Institution of Naval Architects, October 1974, London.

3. Update: Domestic LNG Vessel Construction, T. G. Conners; Maritime Administration, May 1977.

4. U.S. Gas Shipbuilding—Present and Future Prospects, E. M. Hood, F. P. Eisenbiegler, A. O. Winall and M. Lee Rice; a panel discussion at GasTech Conference, October 1976, New York City.

5. Risks Associated with an LNG Ship Operation, P.S. Allan, A.A. Brown and P. Athens; paper given at Fourth International Symposium on Transport of Hazardous Cargoes, October 1975, Jacksonville.

6. LNG Ship Safety Enhanced by Research and Development, J. L. Howard and R. Kvamsdal; paper given at SNAME Spring Meeting, May 1977, San Francisco.

7. Analysis of LNG Marine Transportation for the Maritime Administration, Booz-Allen Applied Research, Inc., November 1973, COM-74-11684.

8. Gas Carriers—Effects of Fire on the Cargo Containment System, T. K. Authen, E. Skramstad and J. Nylund, GasTech 1976, New York City.

9. The Coast Guard's authority to require these safety measures by an LNG vessel or waterfront facility owner or operator comes from 33 CFR 6.04 and 6.14.

10. Aircraft Accident Report, National Transportation Safety Board (NTSB-AAR-74-3), Delta Airlines DC-9, Boston, July 31, 1973.

11. Prior to and during an LEG ship's harbor transit a security broadcast will have been issued by the Coast Guard on Channel 16 FM. The Coast Guard will also notify Logan (Massport) Fire Department of each LEG vessel transit. Logan Fire Department is responsible for notifying the flight tower of any incident that possibly could affect flight patterns. In addition to these communication channels, the airport uses radar and closed circuit television to detect, track, and identify ships with tall masts.

12. Letter to Airmen 77-3, Subject: Boston Tower Advisories of Tall Masted Vessels.

ADDITIONAL REFERENCES

Section I

Algeria I. An El Paso Information Booklet, April 1977.
LPG and Chemical Gas Carriers. A Fairplay Report, London, 1976.

The LNG ship and Changing Energy Environment, W.B. Thomas, paper given at SNAME Spring Meeting, May 1977, San Francisco.

BIBLIOGRAPHY

Section II

Fire Safety Aboard LNG Vessels, University Engineers, Inc., January 1976, AD-A030-619.

Handbook for the Development of Qualifications for Personnel in New Technology Systems, Operations Research, Inc., February 1976, AD-A027-525.

Manpower Analysis in Transportation Safety, Florida Technological University, May 1977, DOT-TST-77-40.

Recommendations for Qualifications of Liquefied Natural Gas Cargo Personnel, Engineering Computer Optecnomics, Inc., April 1976, AD-A027-108, 109, 110.

CHAPTER 7

TRUCK SHIPMENTS

CONTENTS PAGE

LNG trucks that move routinely through highly populated cities are vulnerable to accidents and sabotage that could cause major damage. The far more extensive trucking of LPG, in single-walled trucks under pressure, is also vulnerable to major accidents and sabotage. The main features of the trucks are shown in Figures 7-1a and 7-1b.

LNG TRUCKING

Each LNG truck working out of the Distrigas terminal in Everett, Massachusetts, carries 40 cubic meters of LNG in a vacuum insulated tank at -260°F. More than 90 such truckloads may come out of the Everett terminal in a single day. The gas companies which purchase LNG from Distrigas Corporation transport it from the Everett terminal to their own satellite tanks which tie into their distribution systems. When an LNG ship arrives at the terminal, the gas companies notify their truckers who usually run every available LNG trailer on a 24-hour schedule until the transfer is completed. The Distrigas contracts call for customers to remove half of their allotment within the first 10 days after the LNG ship's arrival and to remove the second half before the ship returns with another cargo (approximately one month).

LNG can be hauled by companies which have Interstate Commerce Commission (ICC) authority for the bulk transport of petroleum products or liquid chemicals. These companies can lease the trucks and drivers of other companies which do not have such authority. The ICC also certifies companies specifically for LNG transport.

The ICC has granted specific LNG rights in the Northeast to three companies: Gas Incorporated,[1,2]

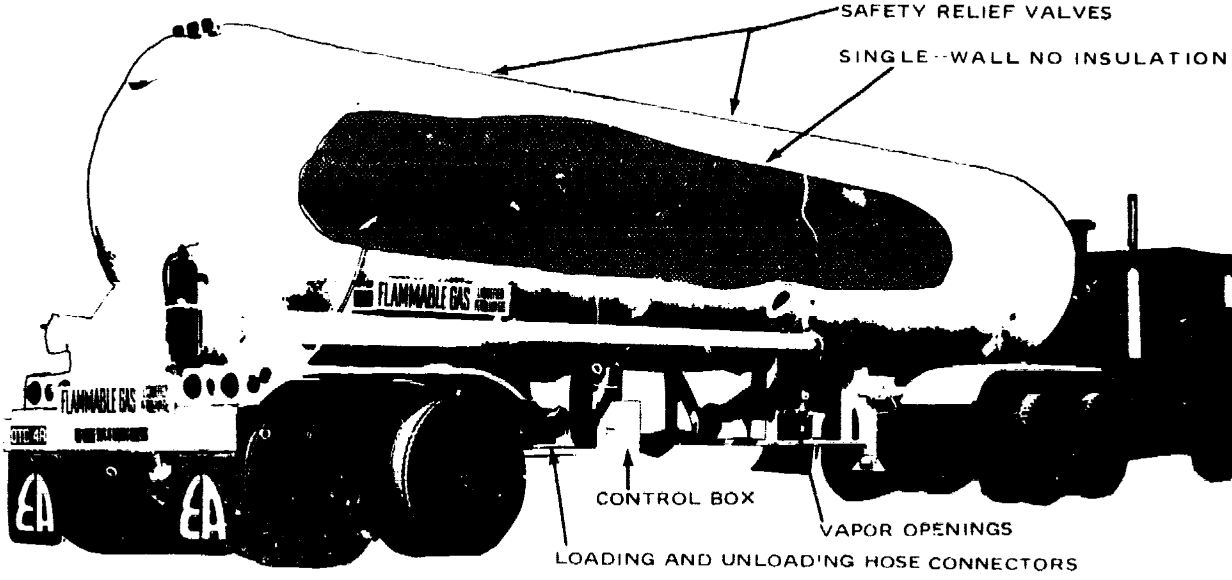


Fig. 7–1a

CROSS–SECTION OF AN LPG TRUCK TRAILER

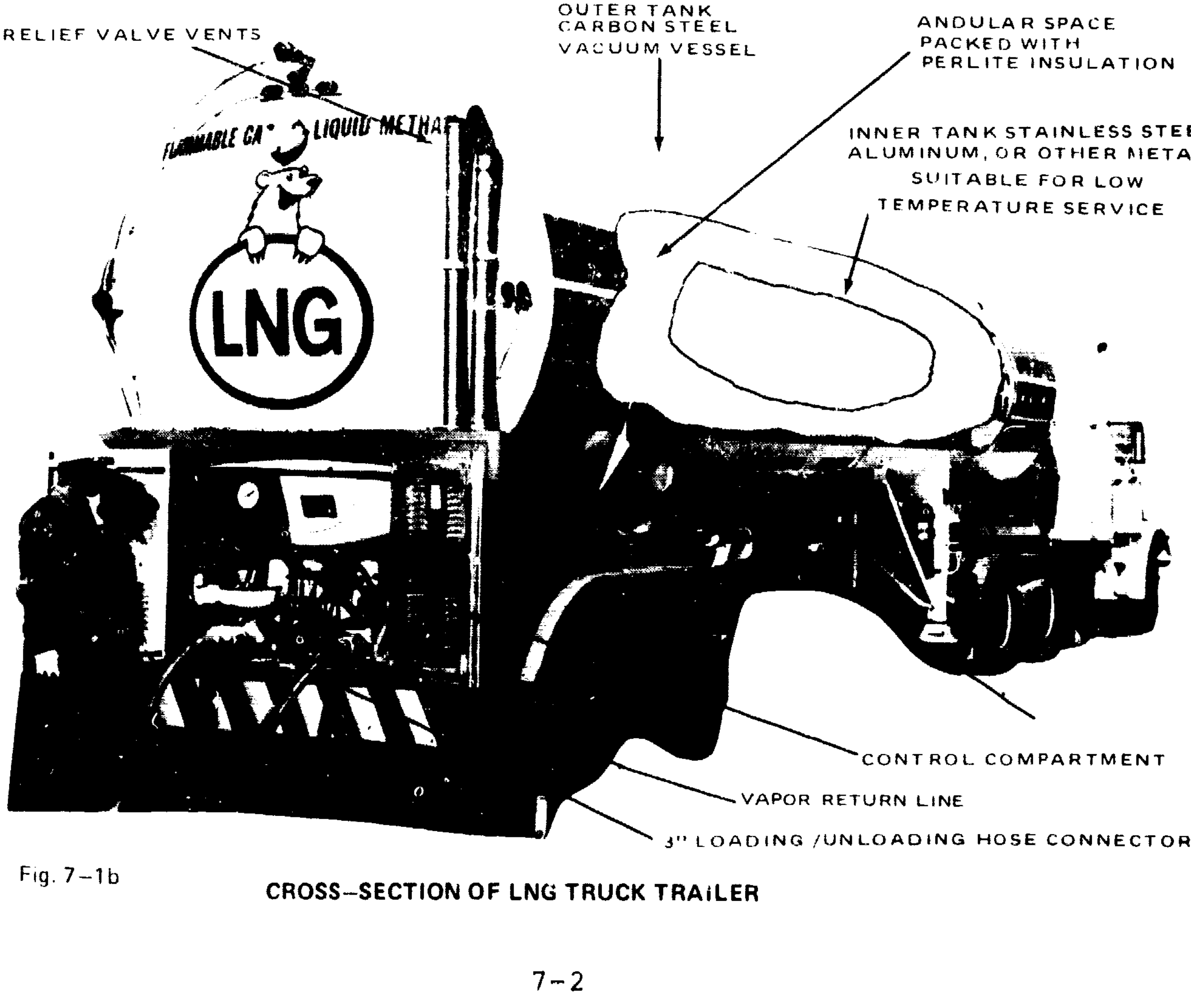


Fig. 7–1b

CROSS–SECTION OF LNG TRUCK TRAILER

Indianhead, and Capitol Truck Lines. They all own their own trailers. Most LNG trucking in the Northeast under ICC authority for bulk transport of petroleum products is done by either Chemical Leaman or Gault Transportation. Chemical Leaman[3] for the most part uses its own tractors and specially trained drivers, but supplements its small fleet of cryogenic trailers by lease arrangements. While it does subcontract some business to "leased operators", Chemical Leaman deals directly with the gas companies in making arrangements for LNG transportation.

Gault Transportation Company[4] owns no LNG trailers and does all LNG business through "leased operator" arrangements with other trucking companies. In these cases, the gas company makes arrangements with a trucking company[5] which will operate under Gault's ICC certification. Gault assumes major financial responsibility in the case of an accident, provides liability insurance for injuries, fatalities, and property damages, and receives 10-15 percent of the trucking revenues. It is also Gault's duty to ensure that drivers are familiar with the Motor Carrier Safety Regulations of the Federal Highway Administration. In most cases, these "leased operators" have no LNG trailers but lease them from the gas company for which they are moving the LNG.[6,7] With this arrangement, the lessee is responsible for all aspects of the trailer including operation, maintenance, and vehicle insurance.

LNG trailers are far more resistant to ruptures than those carrying fuel oil or gasoline, but the potential danger from an LNG accident is far greater than from one involving a less volatile petroleum product. We believe that LNG should be hauled exclusively under a certificate specifically for LNG.

An LNG trucker usually carries about one million dollars in liability insurance.[4,5,6,8] These policies name the gas company for which the gas is hauled as co-insured. The gas company also requires that the trucker, or the company holding the ICC certificate, carry additional liability insurance of $10-30 million.[1,3,4] The gas company may have additional liability insurance to cover the losses in a major catastrophe.[8,9]

The ICC does not allow companies transporting LPG to ship it by trucking subsidiaries. Such subsidiaries are considered separate entities in terms of accident liability. If a company does ship LPG by a subsidiary, the subsidiary automatically becomes a contract carrier which must meet full ICC financial and disclosure requirements.

In Massachusetts the tariff for LNG trucking is set by the State's Department of Public Utilities. Half of this revenue goes to the truck driver as salary, and another 10-15 percent passes to the common carrier. The remaining 35-40 percent goes to the trucking company.

<u>Vulnerability to Human Error</u>

Many trucking companies in the Northeast have viewed LNG transport as an auxiliary enterprise to keep men and equipment in use during the slower winter months. The erratic nature of this business has made drivers prefer the more regular hours and income of gasoline tank trucking.[1] Trained dependable drivers have therefore been hard to keep in the LNG business.

LNG truck drivers may be better trained and supervised if companies licensed by the ICC to carry LNG are not allowed to lease drivers and trucks from companies which do not have such a license.

It may be that the drivers' lack of experience was responsible for some highway accidents, since the high center of gravity of LNG trailers makes them difficult to handle and prone to rolling over.[1,10] With the increased availability of LNG in recent years, many companies have found LNG transport to be a full-year dependable business. This may improve the LNG trucking safety record.

Vulnerability to Accidents

Because LNG trailers have an inner and an outer tank with insulation in between, they are quite resistant to puncture and cargo loss. In several accidents they have withstood rollovers, head-on collisions, and fires which have destroyed the tractors. The trucks are also equipped with heavy rear bumpers which can withstand considerable impact.

Nevertheless, two accidents in 1971 which did involve cargo loss point up two vulnerable features. (1) While the tractor provides considerable protection in a head-on collision, a portion of the trailer face remains unprotected and vulnerable. (2) Even if the tank does not rupture, rear piping may be punctured. One of the accidents also demonstrates the role of human error.

The accidents occurred in Vermont[11] and New Hampshire.[12] In the Vermont countryside a tractor tire blew out at 50 mph. The driver lost control and the head of the trailer hit a rock ledge on the side of the road. This tore a hole in the head of the trailer, which lost approximately 8 cubic meters of LNG. The remaining cargo could not be pumped out because the punctured tank could not hold pressure. The remaining LNG had to be slowly drained through several connected hoses into a nearby gully, where it vaporized and eventually dissipated. Fortunately, there was no ignition source and no nearby city sewers. An industry official involved in this emergency operation recently said that, while each accident had to be dealt with individually, an urban accident like this might best be handled in the same way by slowly dumping the LNG into the streets. He stated that pumps were neither safe nor available in most locations.[13] An industry group is currently looking at this problem.

The New Hampshire accident occurred a few months later when the driver "either fell asleep or blacked out for reasons unknown". His LNG truck ran off the side of the road, rolled over down an embankment, and finally landed on its wheels. The rolling apparently twisted the rear bumper and loosened some fittings in the control section at the rear of the trailer. The resulting LNG leak never ignited and was sealed off when representatives from the trucking company arrived. A DOT investigator found that the driver had been on duty 60 hours in 6 days, and had probably been driving 10½-11½ hours at the time of the accident.[12] The DOT report noted that the driver had falsified the Driver Log, and that other LNG truck drivers were also violating limits on hours of service.

A similar (insulated, double-wall) cryogenic trailer carrying ethylene crashed into a brick house in Spain in 1974. The small amount of material that escaped eventually caught fire, causing the tank and remaining cargo to explode. A similar accident involving an LNG trailer is possible.[14]

Since LNG has a low density, LNG trailers can be built higher than most tank trucks to provide extra volume, without violating the legal limits on length, width, and cargo weight. The resulting high center of gravity[10] makes them particularly susceptible to rolling over in high-speed turns, when swerving to avoid other vehicles, or when struck from the rear.

An ammonia tractor trailer which rolled over a bridge barrier in Houston (1976) had a center of gravity of 68.5 inches high.[15] A typical propane tractor trailer's center of gravity is 84 inches high.[16] An LNG tractor trailer has a center of gravity 93 inches high.[12] There have been at least 12 LNG trailer accidents, as described in Appendix VII-1.

While the LNG trailers have been able to withstand the few rollovers that have occurred so far, tank rupture is still quite possible in such accidents. If a rolled LNG truck was struck by a fast moving car or truck it might cause cargo loss and fire. If a truck went over the barrier of an elevated roadway and fell to the street below it would almost certainly rupture. This is particularly significant since the majority of LNG trucked out of the Everett facility travels through Boston on the elevated Southeast Expressway.[13] These trucks pass within a few blocks of the crowded Government Center area, which is laced with sewer and subway tunnels as well as other subterranean structures. Since very cold natural gas is heavier than air, both the LNG and the vapor will go down into sewers, subways, and basements through any opening available. Due to its very low boiling point, the LNG will quickly vaporize, generating a pressure that will spread the invisible, odorless gas throughout the structure. In enclosed spaces, appropriate mixtures of natural gas and air are explosive.

In the first 6 months of 1977, there were four serious accidents involving tractor-trailer trucks on the Southeast Expressway.[17] One of these trucks went over the guard rail, plunged to the streets below, and overturned. Although none of these trucks were carrying hazardous cargoes, they could have been. If the truck which fell had been carrying LNG instead of paper products, the consequences could have been very serious.

Trucking LNG over expressways is not unique to Boston. In New York City during February, 1977, for example, LNG was trucked across the Goethals and Verranzano-Narrows bridges and the Staten Island Expressway. A Brooklyn Union Gas spokesman noted that although the trucking of LNG may be somewhat unusual for New York City, it is common throughout the country.[18]

Vulnerability to Sabotage

LNG trucks are highly vulnerable to mischief and sabotage. A large unlocked cabinet houses the control piping and valves. Inside, a large, clearly labeled main valve is attached to an exit pipe which is loosely capped by an easily removed dust cover. Opening the main valve allows the entire contents of the trailer to run out on the ground. A remote controlled shut off valve is also built into this line. Regulations (49 CFR 177.840 (9)) require that the valve be closed during transportation, but we were told that it is routinely left in the open position. If the "pressure building valve" (a smaller but well-labeled valve) were opened, the tank would empty at a rate of 350 gallons per minute (total tank load in 1/2 hour). Some trailers also carry flexible hoses to connect to the exit pipe and use of these hoses can direct the LNG flow into any nearby opening. However, since most storage areas have hoses, many trucks do not bother to carry them.

No special effort is made to prevent LNG trucks from being hijacked. When a driver leaves the Distrigas terminal, for example, he is entirely on his own. There is no surveillance, scheduling, or communication system associated with his trip. Drivers are given no protective equipment or instructions to deal with a hijacking. LNG trucking firms believe that the LNG cargo is not marketable and therefore not attractive to hijackers.

If two trained drivers were required for each tractor, safety would be improved. One could remain with the trailer at all times in the event of an accident or maintenance problem.

There have been no cases of LNG hijacking, but vandalism and sabotage of energy and petrochemical facilities is common. LNG is an increasingly publicized commodity. It would not take great scientific knowledge to realize that a great deal of damage could result from dumping a 40 cubic meter truckload of LNG into sewer lines or subways. LEG truck sabotage is also discussed in Chapter 9.

Hazards of Spills into Sewers

The National Fire Protection Association in 1975 published a list of recent accidents involving explosions in underground structures. These accidents are described in Appendix VII-2.

The accident on the list involving the most casualties is the one in Cleveland, Ohio, in 1953. One person was killed and 58 were hospitalized after a tremendous underground explosion in a combination storm and sanitation sewer.[19,20]

The Cleveland disaster of October, 1944, in which LNG spilled into sewers and basements, was not on the list. The Bureau of Mines investigation[21] found that the gas from the LNG "mixed with the air in the storm sewer system and formed an explosive mixture which subsequently ignited." One-hundred thirty people were killed and millions of dollars of damage was done. The Bureau of Mines report concluded that: "Extreme precaution should be taken to prevent spilled liquefied gas from entering storm sewers or other underground conduits."

An LNG truck carries 40 cubic meters. Vaporized and mixed with air in flammable proportions, the resulting mixture could fill a 6-foot diameter sewer line for a distance of 110 miles.

The subway system of Boston consists of 16-foot diameter tunnels.[22] A flammable air-gas mixture from one LNG truck could fill such tunnels for 16 miles, virtually the entire subway system of Boston. In practice the vapor would leak out of openings and would not go this far.

Since some methane is normally found in sanitary sewers, all buildings are required to have a trap in their sewer lines leading to the sewer system.[23] The trap is a U-shaped pipe which normally contains a few inches of water as a seal to prevent the backup of gas into the building. An LNG spill into a sanitary sewer would vaporize very quickly, generating high gas pressures which might blow out the water seal and lead to easy gas access into basements.

The entrances to Boston's Sumner and Callahan tunnels are only a few hundred feet downhill from the elevated Southeast Expressway. Although LNG trucks are not allowed in these tunnels, a major spill could lead to the flow of LNG or cold vapor into both of these openings.

LPG TRUCKING

Pipelines handle most long-distance transportation of LPG, but in 1976, 3.4 percent of long-distance LPG movement (2.6 million cubic meters) was completed solely by trucks. The average haul was 122 miles.[24,25] Trucks carry at some time over 90 percent of the LPG produced in the U.S., and most local distribution is by truck. Truck shipment is the only practical means of delivery for many LPG users, especially small ones.

Since 1963, about 4,600 LPG tank trucks with capacities between 28 and 46 cubic meters have been manufactured.[24] These are mostly class MC 331 tanks, as specified by 49 CFR 178.337, and most of them are still active today. There are also many smaller tank trucks.

Accidents

In 1976 there were 25,666 commercial motor carrier accidents; of these, 1,427 involved hazardous materials and led to 168 deaths, 1,385 injuries, and 14.1 million dollars worth of damage. In 475 accidents, some hazardous material was released. LPG is one of these hazardous materials and is involved in about one percent of all hazardous materials accidents. Statistics for previous years are very similar.[26]

The dangers inherent in LPG truck accidents are illustrated by the following two examples.

At 2:30 p.m., May 24, 1973, an MC 331 tractor-semitrailer carrying 34 cubic meters of LPG was traveling north on U.S. Route 501, a winding, two lane mountain road above Lynchburg, Virginia.[27] While rounding a 48 degree curve to the left at 25 miles per hour, the driver moved the truck into the opposite lane in order to maximize the turning radius. However, the driver soon saw a car approaching in this lane, and, in a violent maneuver to return to the proper lane, the truck overturned and slid twenty-five feet into a rock outcropping. The impact ruptured the tank and the LPG began to evaporate, the vapor spreading along the road and down the hill adjacent to the roadway. Approximately two minutes later, the vapor cloud was ignited and formed a fireball about 135 yards in diameter, enveloping the fleeing driver and three occupants of a house down the hill from the accident. Radiant heat burned three more people who had stopped on the road because of the mishap. The house, several outbuildings, and about twelve acres of wood also burned down.

A much more destructive accident occurred near Eagle Pass, Texas, on April 29, 1975.[28] At 4:20 p.m., a 36 cubic meter, MC 330 tractor-semitrailer, filled with 33 cubic meters of LPG, heading west at 55 miles per hour on U.S. Route 277, swerved to avoid a slowing car. The tank separated from the tractor during the evasive maneuvers, overturned, crashed into the concrete headwall of an irrigation canal, and split open. Two explosions quickly followed: the front section of the tank rocketed 1,650 feet and demolished three mobile homes; the aft section broke into three pieces which each flew about 800 feet. The resulting fireballs destroyed a nearby used car facility and fifty cars. In all, 16 people were killed and 35 were injured.

LPG trucks are subject to many of the hazards which can affect LNG trucking. For example, LPG trucks have a destabilizing high center of gravity, though not as high as LNG trucks. LPG trucks have exterior valves which are vulnerable in accidents. Furthermore, LPG tanks are pressurized, have single wall construction, and have no insulation. This makes them more vulnerable to cracks and punctures than LNG trucks, and more likely to explode in fires.

In addition to traffic accidents, many incidents happen during deliveries or during repair work to trucks.[29] Drivers sometimes pull the truck away after making a delivery without disconnecting the supply hose.[30] Often an accident of this sort releases only a few gallons of LPG which harmlessly disperse. However, the conjuntion of a spill and an ignition source can be disasterous. Valves are sometimes accidently or mistakenly opened, with similar results.

LPG is often delivered to populated areas. An accident in West St. Paul, Minnesota, on January 11, 1974, illustrates how residential areas can be affected.[31] Around midnight a tank truck carrying 36 cubic meters of LPG was transferring its load into a 42 cubic meter storage tank serving an apartment complex. Auxiliary equipment to the tank included three vaporizers. After twenty minutes of pumping, a leak developed. LPG vaporized and was ignited by one of the vaporizers. Firemen responded to the resulting fire and attempted to shut off the flow of LPG. Before they could stop the flow, a connecting hose burned through and created a torch directed on the storage tank. The firefighters worked to establish cooling sprays on the tank and to evacuate nearby apartment buildings. Thirteen minutes later, a BLEVE (Boiling Liquid Expanding Vapor Explosion) occurred. Sections of the storage tank demolished apartments and fire vehicles. Four people were killed, ten injured, and large sections of three apartment buildings were destroyed. The local fire department had detailed plans to deal with an LPG fire at this location, but snow conditions prevented carrying them out.

<u>Sabotage</u>

LPG trucks are even more vulnerable to sabotage than LNG trucks because they have a single wall and are under high pressure. LPG is heavier than air at ambient temperatures, thus it will flow down into sewers, subways, basements, or any other opening below ground. The gas is odorless and colorless, and can detonate.

Misleading Odorization Labels

At a California LPG storage terminal we observed trailer trucks, carrying non-odorized propane, that were painted with large signs saying "ODORIZED". We were told by one driver that this was common practice in California, because the signs have to be painted on the trucks, although the trucks carry odorized or non-odorized propane at random. The implications of this are serious. Firemen approaching an accident which had caused a leak from such a truck would not be able to see the extent of the invisible, explosive cloud. Seeing the sign "ODORIZED" they would assume that they could smell any cloud that was concentrated enough to burn or explode. Such misinformation might cause a large number of unnecessary deaths. All signs should indicate that the LPG might not be odorized.

LEG TRUCK MOVEMENT

LEG truck movement is not generally restricted. Local officials can prohibit LEG movement through tunnels, but further restriction is governed by Federal regulation 49 CFR 397.9, which states:

> "Unless there is no practicable alternative, a motor vehicle which contains hazardous materials must be operated over routes which do not go through or near heavily populated areas, places where crowds are assembled, tunnels, narrow streets, or alleys. Operating convenience is not a basis for determining whether it is practicable to operate a motor vehicle in accordance with this paragraph."

Local Federal Highway Administration officials apply this regulation in negotiating an agreement with trucking companies and local governments on satisfactory routes for regular truck movement. Enforcement, as such, or legislation specifically prohibiting certain routes is usually left to local governments.

It is virtually impossible for action to be taken on irregular or infrequent truck shipments. Furthermore, the above regulation is limited by the tacit recognition that once a need for LPG or LNG has been established, it has to be delivered. The safest possible route is not necessarily a safe one.

The ICC regulates entry into the interstate trucking industry. Certificates issued by it have not restricted LEG truck routes. Instead, ICC has granted "irregular" route authority.

FINDINGS

- LNG truck trailers have a higher center of gravity than most tank trucks, which makes them particularly susceptible to rolling over. This leaves the tank vulnerable to collisions with other traffic.

- Because LNG trailers have an inner and outer tank with insulation in between, they are quite resistant to puncture and cargo loss.

- A portion of an LNG trailer face is not protected by the tractor and is vulnerable to head-on collisions with other traffic or fixed objects.

- LPG trucks have a high center of gravity, although not as high an LNG trucks.

- LPG trucks are more vulnerable to cracks and punctures and more likely to explode in fires than LNG trucks.

- Many LPG accidents occur during transfer operations.

- LPG trucks in California sometimes carry painted signs saying "ODORIZED", when their LPG is not odorized. In the event of an accident, this misinformation could lead to many otherwise avoidable casualties.

- By opening a few valves in an unlocked cabinet at the back of an LNG trailer, anyone can empty the tank at a rate of 350 gallons per minute. Using the flexible hose that some trailers carry, one can direct the LNG into any nearby opening. LPG trucks are equally easy to empty.

- LNG trucks are vulnerable to sabotage. LPG trucks are more vulnerable than LNG trucks.

- LEG trucking companies take no precautions to prevent hijacking or sabotage.

- The intentional urban release of LEG from one or more trucks by terrorists could cause a catastrophe.

- LEG truck accidents occur frequently and often involve losses of life and property.

- Driving LEG trucks on elevated urban highways is very dangerous because one might go through the guard rail and split open on the street below. This could fill sewers, highway tunnels, subways, and basements with invisible, odorless, explosive gas. The LNG traffic on the Southeast Expressway through Boston is an example.

- The 40 cubic meters of LNG in one truck, vaporized and mixed with air in flammable proportions, could fill 110 miles of 6-foot diameter sewer line, or 15 miles of a 16-foot diameter subway system.

- ICC certificates for LEG trucking have not restricted truck routes.

- LEG trucks move routinely through large cities.

CONCLUSION

- The dangers present in trucking LEG are far greater than those involved in trucking petroleum products such as fuel oil, naphtha, and gasoline. The trucks are highly vulnerable to sabotage, hijacking, and certain types of accidents. LEG trucking in densely populated areas is very dangerous.

RECOMMENDATIONS

We recommend that the Interstate Commerce Commission:

- not allow LEG to be carried under a certificate for petroleum products. ICC should require a special certificate for LNG and a separate special certificate for LPG. This would limit LEG transportation to fewer carriers with more experience.

- not allow trucking companies which are licensed to carry LNG to lease trucks and drivers of other companies which have not demonstrated their competence to the ICC.

We recommend that the Secretary of Transportation:

- prohibit trucking of LEG through densely populated areas and any areas that have features which are very vulnerable to a major LEG spill (e.g., sewer systems, tunnel openings, subways) unless delivery is otherwise impossible. DOT should also give particular attention to restricting travel on routes with highway configurations which make tank rupture accidents likely (e.g., elevated roadways, overpasses, high-speed traffic, roadside abutments).

- require that the relatively vulnerable front end of LEG trailers be protected with heavier steel, and cushioning material or shock absorbing equipment. Similarly protecting the entire tank should be considered.

- require that the cabinet housing the control valves of LEG trucks and the valves themselves be kept locked.

- forbid LNG trucks to carry hoses. The hoses should remain attached to the storage facilities.

- require LEG hoses to have positive coupling devices which would override a required check valve in the exit line. The check valve would prevent the outflow of the fluid into anything other than the special coupline hoses.

- develop emergency procedures, teams, and equipment to deal with LEG trailer rollovers and spills. Equipment should include empty trailers and portable pumps suitable for transferring LEG from a ruptured vessel. Different equipment will be needed for LNG and LPG.

- require LEG truck drivers to receive more extensive instruction on the properties of LEG, proper handling of LEG trucks, proper transfer procedures, and appropriate damage and fire control procedures.

- require LPG trailer tanks to be insulated to help prevent explosions.

- require all LPG trailers to have an easily visible sign on each side indicating that the LPG may not be odorized.

- require that all LEG trucks have a radio communications system.

- require that all long-distance LEG truck shipments be made with two drivers.

AGENCY COMMENTS AND OUR EVALUATION

The Department of Commerce comments that, before describing the effects of LNG truck spills into sewers, GAO should present evidence that such accidents could occur. We have presented such evidence. LNG truck rollovers are described in this chapter and in Appendix VII-1. One incident of a large trailer-truck falling off an elevated roadway is mentioned in this chapter, and other accidents of this type have occurred on roads where LNG trucks are known to travel. Spills into sewers and their effects are described in Chapter 9 and Appendix VII-2.

Commerce says further that "the record seems to indicate that present construction of trailers is rather good and seems sufficient for the service," and that "no fires or explosions resulted" from the accidents listed in Appendix VII-1. We agree that LNG truck trailers are sturdy, but rollovers and spills have occurred, and LNG trailers are vulnerable to more serious accidents. Because of the potential consequences of an accident, we believe our recommendations are warranted.

We recommend that the Secretary of Transportation prohibit LEG traffic in densely populated areas, unless delivery is otherwise impossible. Both the Materials Transportation Bureau and the Federal Highway Administration suggest that this type of routing be done by local jurisdictions. We agree that local governments should take an active role in this area, but local power is limited by Federal prerogatives in interstate commerce. For this reason it is important that DOT impose the restrictions we suggest.

MTB claims that our recommendation that hoses remain attached to LNG storage facilities could be financially burdensome to small facilities and could aggravate vandalism problems at unattended facilities. We do not think that the cost of a hose would represent a major expenditure in relation to any LNG facility. Securely stored hoses at unattended facilities would be no more vulnerable to vandalism than other equipment at the facilities.

MTB says that requiring LEG hoses and truck valves to have positive coupling devices would be carrying sabotage protection to an extreme, because the other measures we recommend should be enough to discourage vandalism. Although removing the hoses from the trucks would be a step in the right direction, LEG could still be released from a truck just by opening the valves, unless positive coupling devices are installed.

The cost of insulating LPG trailer tanks would not be justified when compared to the "good safety record of these vehicles," according to FHWA. We do not believe the safety record has been that good, as the accidents discussed in the chapter indicate. FHWA itself points out the benefits of insulation: longer exposure to fires necessary to produce BLEVE's and less severe explosions when they do occur. It is for the same reasons that the Federal Railroad Administration is requiring insulation of LPG railcars on an accelerated schedule.

The Interstate Commerce Commission, in its comments, questions the need for requiring LEG haulers to have a specific certificate to do so. The ICC notes that companies hauling chemicals and petroleum products have extensive experience with specialized carriers carrying dangerous commodities. We do not believe this is sufficient. Expertise in handling gasoline, for example, is not proof of expertise in handling LNG, which involves unique problems. If a company does have special competence, it can qualify for an ICC certificate for LNG.

The ICC also comments that, because more than half of the trucks carrying petroleum products are in private or exempt operations, these companies would be unaffected by such a restriction. Further, according to the ICC, leasing arrangements for trucks and drivers are necessary to provide flexible operations, to meet urgent demands for equipment, and to eliminate deadhead mileage.

We do not believe these points are relevant to LNG trucking. Most LNG trucking is not private nor exempt from ICC regulation. The LNG trailers, however, are often owned by the gas companies, rather than by the truckers, which allows the flexible use of the equipment.

The ICC suggests that safety regulations should focus on the driver-equipment level. We have recommended improvements in the training of LEG truck drivers and in the equipment, but supervision of drivers has proven to be difficult. We believe that LNG truck drivers are likely to be better trained and supervised if they are employed by companies certified by the ICC specifically to carry LNG.

The ICC also urges greater emphasis on DOT's participation in safety fitness proceedings before the ICC. We agree.

REFERENCES

1. Statement of official, Gas Incorporated, in interview, April 1977, in telephone conversation, May 1977, in letter, May 1977.

2. Interstate Commerce Commission Initial Decision No. MC-13884 (Sub. No. 1), Gas Incorporated Common Carrier Application.

3. Statement of official, Chemical Leaman Tank Lines, Inc., in telephone conversation, June 1977.

4. Statement of official, Gault Transportation Co., in telephone conversation, May 1977.

5. Statement of official, Fairside Trucking Co., in interview, May 1977.

6. Statement of official, Andrews and Pierce, in interview, April 1977.

7. Statement of official, Boston Gas Company, in telephone conversation, April 1977, and letter, May 1977.

8. Statement of official, Northeast Utilities, in telephone conversation, April 1977.

9. Statement of official, Bay State Gas Col, in telephone conversation, April 1977.

10. Statement of official, Russell Engineering Works, in telephone conversation, May 1977.

11. Hazardous Materials Incident Report DOT #1080070.

12. DOT Accident Investigation Report No. 228.

13. Statement of official, Distrigas of Massachusetts, in telephone conversation, April 1977.

14. Statement of official, National Fire Protection Association, in interview, April 1977, in telephone conversation, May 1977.

15. NTSB Report #HAR 77-1.

16. NTSB Report #HAR 73-4.

17. Statement of official, Metropolitan District Police, in telephone conversation, April 1977, in letter, April 1977.

18. Staten Island Advance, February 2, 1977.

19. Report on the Investigation of the West 117th Street Sewer Explosion of September 10, 1953.

20. "Blast Rips Cleveland Streets," NFPS Quarterly, October, 1953, pp 1535. NFPA #328 Flammable Combustible Liquids and Gases in Manholes, Sewers, 1975.

21. Report on the Investigation of the Fire at the Liquefaction, Storage and Regasification Plant of the East Ohio Gas Company, Cleveland, Ohio, October 20, 1944. U.S. Department of the Interior, Bureau of Mines.

22. Statement of official, Civil and Design Engineering Division, Massachusetts Bay Transportation Authority, in telephone conversation, April 1977.

23. Statement of official, Public Works Department, Boston, Mass., in interview, April 1977, in telephone conversation, April 1977.

24. "1976 LP-Gas Market Facts", National LP-Gas Association

25. "Energy Required to Supply Propane" and "Propane Transportation, 1974" by O.N. McClanahan for Texas LP-Gas Association, June 1976.

26. Annual Reports on Hazardous Material Control, 1970-1976, Department of Transportation; 1976 Accidents of Motor Carriers of Property, Department of Transportation.

27. Highway Accident Report 73-3, National Transportation Safety Board, May 24, 1973.

28. Highway Accident Report 76-4, National Transportation Safety Board, May 5, 1976.

29. "Fires Involving LP-Gas Tank Trucks in Repair Garages," Fire Journal, Sept., 1974, p. 18-20.

30. Risk Assessment of Storage and Transport of LNG and LPG, Science Applications, Inc., Nov. 25, 1974, p. 68-73.

31. "The Terrible Blast of a Bleve," Fire Command, May 1974, p. 14-17.

CHAPTER 8

TRAIN SHIPMENTS

CONTENTS | PAGE

INTRODUCTION

Railroads handle about 5 percent of the primary long-distance LPG transportation in the United States, approximately 4 million cubic meters annually.[1] Total railroad movement in 1977 involved about 100,000 carloads of LPG.[2] The percentage carried by railroad and truck has been decreasing as LPG pipeline systems have been expanded and extended. Nevertheless, railroads continue to have a part in LPG movement because of easy access to some locations and the convenience of using tank cars for on-site storage.

Ten percent of America's 1.7 million freight cars are hazardous materials tank cars.[3] About 16,000 of these, each with a capacity of approximately 115 cubic meters, carry most of the railroad LPG. The movement of hazardous materials is the most dangerous aspect of railroad cargo transportation.

All LPG railroad traffic is part of interstate commerce and not subject to local regulation. Federal regulations[4] (see Chapter 17) are enforced by the Hazardous Materials Division (HMD) of the Federal Railroad Administration, (FRA), of the Department of Transportation. HMD has eighteen full-time inspectors and uses the 180 general railroad inspectors employed by the FRA on a part-time basis.

HMD works closely with the Association of American Railroads (AAR), an industry organization which is given large oversight responsibilities by 49 CFR 179.3. Under this regulation, the AAR's Tank Car Committee approves all designs of tank cars to ensure that they conform to Federal and industry standards. The Railway Progress Institute, an organization established by railroad equipment manufacturers, also cooperates with the FRA in testing tank cars and developing better regulations and designs.

ACCIDENTS

In 1976 there were 10,248 railroad accidents, which caused 158 deaths and 1,282 injuries—a rate of 1.54 deaths and 12.52 injuries per hundred accidents. There were 1,368 collisions and 7,934 derailments. Human error led to 2,360 accidents, while 6,434 resulted from defects in railroad equipment or in the track and roadbed. These statistics are representative of the past several years.[5]

In the six years, 1971-1976, an average of 129 accidents occurred annually involving one or more hazardous materials tank cars, which led to a yearly average of 2.5 deaths, 250 injuries, and 10,750 persons evacuated—a rate of 1.7 deaths and 166 injuries per hundred accidents.[6] Many other hazardous materials incidents produced spillage or leakage of material without further damage. The following two examples show the danger of LPG railroad accidents.

On February 12, 1974, at 1:55 p.m., freight train NWB-4, consisting of three locomotives and 122 railcars, left Binghamton, N.Y., bound for Mechanicville, N.Y. Cars 20 through 27 were 115 cubic meter tank cars filled with LPG. At 4:20 p.m. while rounding a $3^{\circ}30'$ curve near Oneonta, N.Y., at 32 mph, the fourth car, a grain hopper, fell over and derailed. The locomotives and first three cars proceeded down the track, but the cars behind the hopper derailed and piled up. Car 21 was crushed and split open, releasing LPG which quickly ignited and formed a fireball. Firemen from local departments moved in to try to cool down the remaining LPG cars, but fire officials decided that the situation was dangerous and thirty minutes after the fire began, ordered them to withdraw.

The absence of an efficient communications system caused the order to come too late. As the firemen began to pull back, one of the LPG tanks exploded: 54 men were injured in the blast. Three more explosions occurred in the next half-hour. Some tank car halves were propelled a quarter-mile away from the fire site. One ruptured tank car continued burning for seven days.[7]

The second accident took place in a railyard in Decatur, Illinois, on July 19, 1974. At 4:50 a.m., 5 freely-rolling 115 cubic meter LPG cars were switched onto a track where the lead car collided with an empty, freestanding box car, punching a 22" x 26" hole in the LPG car. For 13 minutes LPG vaporized. Then the cloud ignited and exploded over an area one-half by three-quarters of a mile. The explosion was felt 45 miles away. Fire fighters' efforts to control the yard fire were largely successful; more tank car explosions were prevented. There were 7 deaths, 349 injuries, and $24 million of damage. Litter and debris from the fire and explosions covered 20 blocks of the city.[8]

THE RAILROAD TANK CAR

The Code of Federal Regulations specifies the various classes of tank cars and their permitted cargo. LPG is mostly carried in 15,000 Class 112 and 114 cars and sometimes in 1,000 Class 105 cars. The 112 cars and the 114 cars, which differ only in their loading and unloading apparatus, were not required to be insulated until recently. Class 105 cars have been so required.

All LPG cars are cylindrical and made from 9/16- or 11/16-inch thick steel. They are designed to hold pressures of 500-1000 psi, although safety relief valves generally release at 250-300 psi, depending on the sub-class. The maximum volume is 130 cubic meters, but most cars hold only 115 cubic meters. The maximum loaded gross weight is 263,000 pounds. All cars carrying LPG are required to carry diamond-shaped placards 10-3/4" on a side saying "Flammable Gas," and to be labelled on both sides with 4" lettering identifying the gas.[9]

Originally, all LPG tanks were required to have insulation to keep the gas cool under ordinary conditions. However, it was shown that in normal circumstances insulation is superfluous, which led to the creation of the uninsulated 112/114 Class in 1959. The absence of insulation permitted bigger and cheaper cars to be built, but has led to serious problems after accidents.

The following is a typical scenario of an LPG railroad accident, fire, and explosion. In a collision or derailment a tank car is crushed or punctured by a disengaged coupler, and the LPG begins to vaporize. If ignition of the LPG cloud is delayed for several minutes, the initial explosion can cover an extensive area, such as occurred in Decatur. If ignition is immediate, there is usually no imminent danger from the first car alone. The danger arises if the fire impinges on a second, unpunctured LPG car, which is not unlikely since the cars often run in groups of more than ten. The heat raises the pressure inside the second car; after some time the safety valve will release, but, if the fire continues, the second tank will rupture and cause a "Boiling Liquid Expanding Vapor Explosion," or BLEVE.[10] Each explosion contributes to the heating and weakening of neighboring tanks and makes additional explosions more likely. As noted previously, a BLEVE can rocket a 45,000 pound steel section of the tank for a quarter of a mile.

It is not a massive build-up of internal pressure which causes a BLEVE. Tests have shown that the required safety valves are generally adequate to maintain the pressure close to some threshold value, usually 250 psi, in most LPG fires. Indeed, prior to explosions, observers have seen safety valves close during fires, indicating that the internal pressure had dropped below the threshold value. Rather, the weakening of the steel wall as the temperature rises is the immediate cause of the explosion. The steel attains its maximum strength near 400°F, but the wall weakens as the temperature rises, and at $900\text{-}1100^{\circ}$F it is not able to contain the pressure maintained by the relief valve, and the BLEVE occurs.

When the tank does begin to fracture, no matter what the orientation of the initial crack, the internal structure of the rolled steel forces the rupture to propagate circumferentially.[11] This makes the end of the tank car rocket forward.

ACCIDENT RESPONSE

Firefighting at LPG accidents is directed toward c[illegible]ng undamaged tanks, since an LPG-fed fire is virtually impossible to extinguish. Several factors inhibit the safe and efficient application of cooling water streams:

accidents often occur far from adequate water supply; many fire departments have not been trained to recognize and respond appropriately to LPG fires; and the timing of a BLEVE is unpredictable. Explosions have taken place from several minutes to several hours after a fire's commencement. Misjudgment can be fatal. For the past several years, the National Fire Prevention Association has sponsored a program to teach fire fighters how to handle LPG fires, alerting them to the danger of BLEVE's and demonstrating the most effective cooling maneuvers.[12]

Explosions can occur without the presence of a fire, as demonstrated by an accident in Waverly, Tennessee, on February 22-24, 1978. There, two LPG cars were scraped and dented in a derailment, but there was no leak and no fire. Two days later, a few hours before transfer operations to empty the damaged cars were scheduled to begin, one of the tanks ruptured. The vaporizing gas ignited and the resulting fireball caused 15 deaths and more than 40 injuries. Prompt and courageous action by the volunteer fire department (which was trained in LPG fire fighting procedures) helped to prevent a BLEVE of the second tank car.

The probable cause of the rupture was an internal crack produced by the derailment. When the ambient temperature at Waverly reached 52°F, 20° higher than the previous day's, the weakened tank shell was unable to withstand the 50 percent rise in internal pressure and exploded.

The apparent stability of the LPG tank cars and the absence of a leak had persuaded officials at the accident scene, including local firemen, Tennessee Civil Defense personnel, and railroad employees, that there was no immediate danger from the derailed LPG cars. As a result, there was no water deluge of the tanks (which would have had little effect, in any case); evacuation limits were relaxed; and equipment to transfer LPG with pressure pumps was brought in. Even if the temperature had remained low, the increase in pressure during transfer might have split the tank.

The Waverly incident points up several deficiencies in emergency response to LPG train accidents. First, there is no way to test quickly the structural integrity of a derailed tank car. A technique for this purpose would also be a valuable adjunct to the regular static pressure tests which may not reveal small cracks or weaknesses that could be dangerous in extreme conditions. Second, there is no safe and efficient method for quickly unloading a tank car, without moving it and without pressure. Strategically-placed, quick-connecting fittings and valves and easily transported, temporary tanks could provide an alternative to permitting damaged cars to remain full for several days. Finally, with a large number of independent organizations present at railroad accidents, it is not always clear how lines of authority run and who has final responsibility for directing an operation. These problems suggest the need for Railroad Disaster Control Response Teams, which would be capable of reacting immediately to hazardous materials accidents with the special expertise and equipment necessary to prevent disasters.

Several sources of information are currently available for firefighters approaching hazardous materials accidents. The NFPA's Fire Protection Handbook and the Coast Guard's Chemical Hazards Response Information System both detail the properties and dangers of, and recommended emergency responses to, hundreds of hazardous materials. Additionally, several groups, such as the Manufacturing Chemists Association, maintain 24-hour emergency response centers, which can be called for immediate information.

NEW SAFETY REQUIREMENTS

The LPG industry, HMD, and the railroads recognize the danger in LPG movement and have collaborated in identifying and correcting deficiencies in tank car design. On September 9, 1977, as a result of a long inquiry, HMD, through the Materials Transportation Bureau (MTB), amended the specifications for 112/114 LPG tank cars (Docket No. HM-144). The new regulations require all LPG tank cars to have a three-part safety system—consisting of shelf couplers, a tank head puncture resistance system, and thermal protection—designed to prevent accidents and leaks, and to prevent explosions if a fire does occur.[13]

The new regulations specify a schedule for the retrofitting of older tank cars, which requires shelf couplers to be installed by June 30, 1979, and the tank head and thermal protection by December 31, 1981. However, after the Waverly accident, subsequent recommendations from the National Transportation Safety Board, and congressional inquiries, MTB has proposed to shorten the retrofit schedule to require shelf couplers by December 31, 1978, and the other equipment by December 31, 1980. A complete retrofit will cost $9-12,000, and new cars—current price about $50,000—will cost $4-8,000 more.

Shelf couplers inhibit the vertical separation of railroad cars more effectively than standard couplers.

Since most punctures are made by free couplers, the use of shelf couplers should help prevent releases. The tank head puncture resistance system will generally be a head shield, a steel plate mounted on either end of a tank car in a position to resist most coupler thrusts. If an LPG railcar is in a fire, thermal protection, such as insulation, can prevent BLEVE's by retarding the heating of the steel walls. This allows more time to extinguish the fire and to vent the tank before the steel is weakened enough to fail. All the new features must meet strict performance standards. HMD expects these measures to reduce significantly tank car accidents and LPG spills.

Shelf couplers and thermal protection systems are already used by railroads and are proven technologies. HMD has listed four commercially available thermal protection systems as conforming to the new standards. The LPG and railroad industries favored the standards for shelf couplers and insulation, but had reservations about the head shield requirement. They believed that head shields were not proven and could break or fall off and themselves cause tank car accidents. Tests run by the FRA and the AAR-RPI suggest that these fears are unfounded.[14]

There are several problems which the new regulations do not address. No actions have been taken to improve the strength or fracturing properties of the steel used, or to protect the sides of a tank car from punctures. Present regulations requiring static pressure testing of tank cars every 10 years, and safety valves every 5 years, do not ensure that tank cars are safe in extreme conditions.

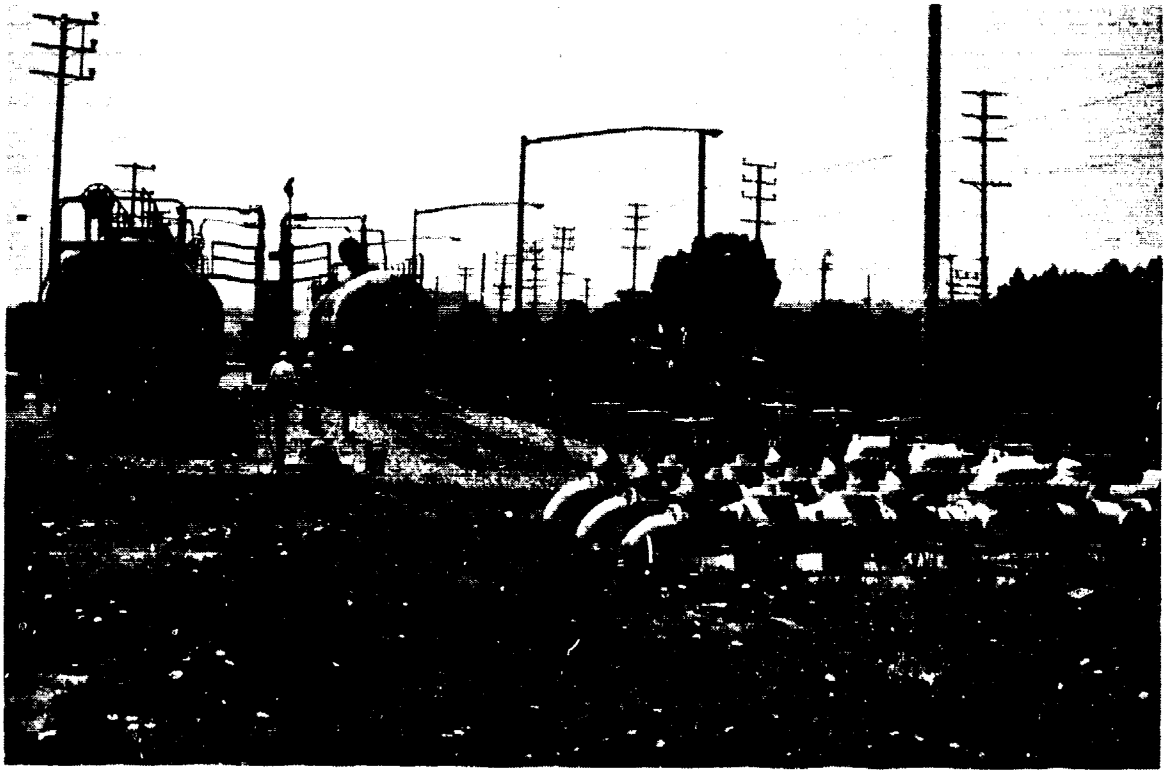
TANK CAR MAINTENANCE

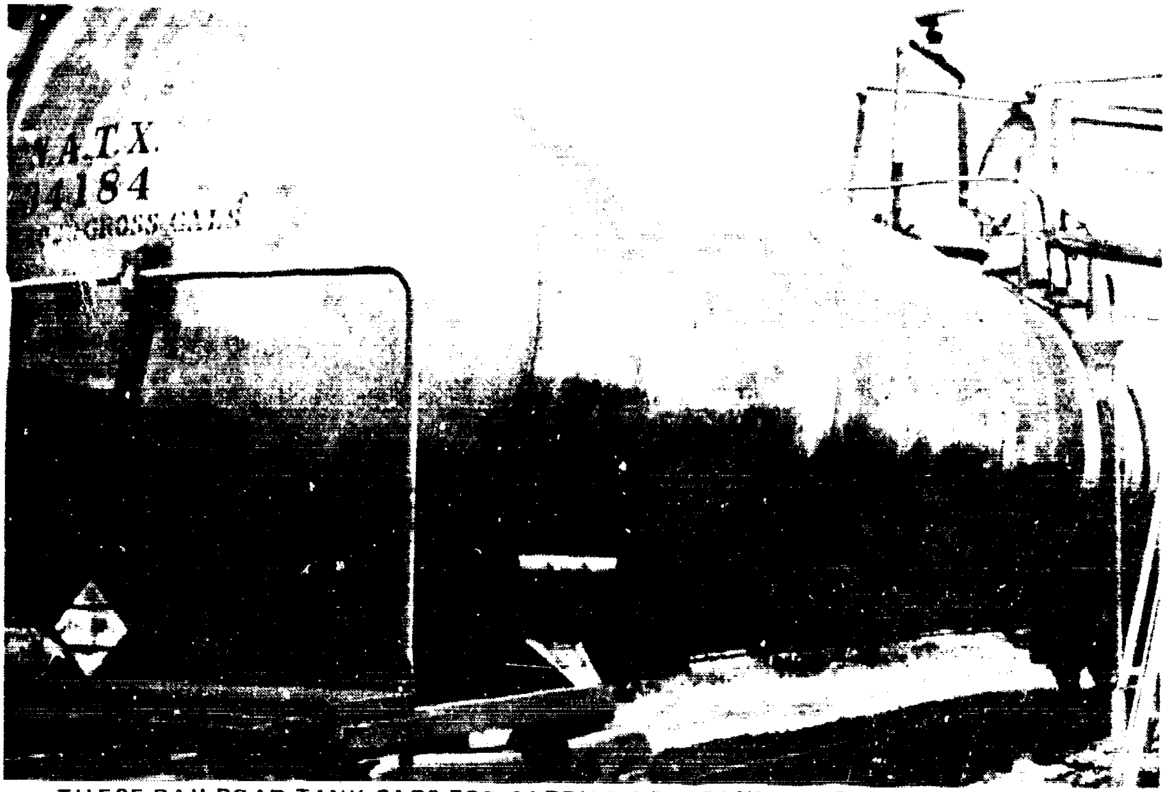
If tank cars receive proper maintenance and are not in an accident, the tank shell should easily last 40 years. Tank cars are not necessarily maintained well, however. At one site we found rusted propane cars waiting to be loaded. See the photographs on the next page. We were told by the management that since the cars had arrived they would have to be loaded, but that the company would ask never to have those particular cars sent again. They could, of course, be sent elsewhere. We did not determine the depth of the rust. Improperly maintained tank cars holding hazardous materials under high pressure are a sizable and unnecessary danger to the public.

TANK CAR MOVEMENT

Most freight cars are owned by the railroads, but tank cars are owned by shippers or tank car companies which lease the cars to shippers. Railroads charge the shippers for hauling the loaded cars on a per ton-mile basis. Once a tank car meets the design and loading specifications set out in Title 49 of the Code of Federal Regulations, there are few restrictions on its actual movement. Therefore, the most direct route is usually chosen, although both the shipper and the carrier have some discretion in specifying alternatives. The average distance of an LPG railroad shipment is 276 miles.[15]

The free movement of LPG is sometimes in apparent conflict with local restrictions. For example, with one exception, the New York City Fire Department (NYCFD) prohibits storage of LPG in the City. Nevertheless, as shown in the photographs, LPG cars have traveled through





THESE RAILROAD TANK CARS FOR CARRYING PROPANE WERE PHOTOGRAPHED ON GAO'S SITE VISIT IN JULY 1977. NOTE THE RUST ON BOTH CARS.

TWO VIEWS OF DENSELY POPULATED AREAS IN THE QUEENS THROUGH WHICH LPG TANK CARS HAVE TRAVELED. THE TOP PICTURE SHOWS THE THROGS NECK BRIDGE AND MANHATTAN IN THE BACKGROUND. THE APARTMENTS IN THE BOTTOM PICTURE ARE LESS THEN 50 YARDS FROM THE TRACKS.

densely populated areas of the city, over bridges and elevated railways. The NYCFD is not alerted to the passage of these cars and only becomes aware of a specific movement if there is an accident. There have been LPG incidents, including derailments, to which the Fire Department has had to respond. The Fire Department has objected to LPG transportation through New York City, but has been unable to prevent it because that would be interference with interstate commerce. Although there apparently has been no LPG rail traffic through New York City in the past year, the Fire Department is still concerned. There is nothing to prevent such traffic from resuming at any time.

The danger from an LPG spill would be particularly acute in a densely populated area, such as New York City: propagation of explosions in urban canyons, sewers, or subways, and the impossibility of quickly evacuating thousands of people multiply the hazards. It is fortunate that most large accidents have occurred in relatively unpopulated areas; that they do not always do so is shown by the Decatur fire.

As shown in Chapter 9, sabotage of LPG cars would not be difficult. Youth gangs frequently place obstacles on tracks which delay freight trains in New York City just to harass the trainmen. The potential danger from moving LPG through urban areas is very great.

HMD has jurisdiction in this area, but opposes restrictions on LPG movement for several reasons with which the industry generally agrees: it is simpler and more economical to regulate tank car design than tank car movement; trains move more slowly in congested areas, decreasing the chance of an accident; there is an accident rate associated with handling and switching cars, more of which would be necessary in circuitous routing. For similar reasons, there is little regulation of the position of LPG cars in a train. Although LPG cars cannot be placed next to explosives, radioactive materials, or poison gas, LPG cars are shipped consecutively, which has frequently caused a domino effect in accidents. HMD believes that the new regulations for tank car construction are sufficient for their safe operation. We believe restriction of routes is also necessary.

FINDINGS

- Boiling Liquid Expanding Vapor Explosions (BLEVE's) are not caused by overpressurized LPG tanks, but by the steel of the uninsulated, single-wall tanks weakening from intense heat to the point where it can no longer hold the normal tank pressure.

- By December 31, 1981, all 112/114 LPG cars will be required to have shelf couplers, tank head resistance systems, and thermal protection. DOT has proposed to shorten this schedule.

- DOT has taken no action to improve the strength or fracturing properties of the steel used in tank cars, or to protect the sides of tank cars from punctures.

- The static pressure tests required of tank cars every 10 years and of safety valves every 5 years are not adequate to ensure that the cars are safe in extreme conditions.

- Rusted tank cars holding propane under high pressure are currently being used.

- LPG cars travel through densely populated areas of cities, even cities which prohibit LPG storage. If large amounts of LPG or its vapor get into the sewers, subways, and other subterranean ducts in a big city, it could lead to a catastrophe.

- Sabotage of LPG cars or the trains they are part of would not be difficult.

- Current practices of emergency response to railroad LPG accidents are inadequate to protect the public.

RECOMMENDATIONS

We recommend that the Secretary of Transportation:

- require a large increase in the size of the placards saying "Flammable Gas" so that they can be more easily read from a considerable distance in the jumble and possible fire of a train wreck.

- require that all LPG cars be prominently labeled "Insulated" or "Non-Insulated" until thermal protection is required on all of them. This information will be of great help to firemen confronted with a train wreck involving LPG cars and may save many lives.

- consider requiring tougher steel in tank cars, or additional puncture protection for the sides of tank cars.

- take immediate action to inspect hazardous materials tank cars and remove from service those that are obviously not being maintained properly.

- require more frequent inspection and testing of all safety-related features of LEG tank trucks and railcars.

- prohibit the travel of LPG railroad cars to or through densely populated areas unless it is impossible to deliver it without going through densely populated areas.

- require that the Bills of Lading on any train containing hazardous materials have detailed instructions on fire fighting and other emergency measures which should be taken in the event of a wreck. The telephone numbers of 24-hour emergency response centers, such as the Manufacturing Chemists Association "Chemtrec", should also be shown. If the train is to go through any densely populated areas, the instructions should explicitly address the dangers peculiar to such areas.

- establish Railroad Disaster Control Response teams, capable of quickly responding to railroad hazardous materials accidents with the knowledge and equipment necessary to prevent disasters.

- investigate methods of quickly determining the structured integrity of damaged tank cars and methods of emergency transfer of material.

AGENCY COMMENTS AND OUR EVALUATION

We recommend that the size of identifying placards on LPG tank cars be increased. The Materials Transportation Bureau in DOT comments that "because of the unique shape and current size of the placard, it is recognizable from a distance sufficient, in most cases, to provide safety to the viewer." On the other hand, the Federal Railroad Administration, also in DOT, comments that "there is no practical size placard that can be read safely in an accident," and that the placard is for other purposes.

We stand by our original recommendation. Enough train accidents involving LPG cars have occurred in just the last few months to underline the importance of being able to identify quickly and clearly derailed LPG cars.

Both MTB and FRA comment that a requirement for tougher steel in tank cars would not be cost-effective. The accidents we have noted, especially the one in Waverly, Tennessee, demonstrate that improving steel properties could be an important step in reducing injuries and deaths. We have made no attempt to calculate the value of reducing injuries and deaths.

FRA states that our recommendation—requiring immediate action to inspect hazardous materials tank cars and remove those not being maintained properly—is not needed since such action is already being taken.

FRA also says that "firefighters would receive no useful information" if LPG cars were labeled 'Insulated' and 'Non-insulated', and that they "do not believe there need be special information for handling accidents in densely populated areas."

We disagree. MTB's new regulations point out the advantages of insulated tank cars, and firefighters should be aware of the conditions of railcars they approach. We have also shown that populated areas present especially hazardous situations (e.g., sewers), and special precautions do need to be taken to prevent catastrophes.

FRA disagrees with the recommendation to prohibit LPG rail traffic through densely populated areas unless it cannot be delivered by another route. MTB also notes that we have not defined precisely "densely populated area."

In this report we identify movements and storage of LEG through major urban areas. In implementing our recommendation, the responsible Federal agency will have to define densely populated areas.

REFERENCES

1. 1976 LP-Gas Market Facts, National LP-Gas Association.

2. Association of American Railroads.

3. Yearbook of Railroad Facts - 1977, Association of American Railroads.

4. 49 Code of Federal Regulations, Transportation, Parts 100 to 199, Dec. 31, 1976, Office of the Federal Register, General Services Administration.

5. Accident Bulletin, 1973, 1974, 1975, and 1976, Federal Railroad Administration, Department of Transportation.

6. Annual Reports on the Hazardous Materials Control, 1970-1976, Secretary of Transportation, Department of Transportation.

7. "Railroad Accident Report: Derailment and Subsequent Burning of Delaware and Hudson Railway Freight Train at Oneonta, New York - February 12, 1974," National Transportation Safety Board, October 17, 1974, Report Number: NTS13-RAR-74-4.

8. "Hazardous Materials Incident Report #4080869" to the Department of Transportation; 'Coordinated Attack' in Fire Command!, July 1975, p. 14-17.

9. 49 CFR Parts 172, 173, and 179.

10. "Lessons - An NFPA Staff Report" in Fire Command!, April, 1972, p. 18-25.

11. "Analysis of Findings of Four Tank-Car Accident Reports," Report Number FRA-OR&D 75-50, C. Interrante, G. Hicho, D. Harne, January, 1975.

12. Fire Protection Handbook, NFPA, Boston, 1976, p. 3-40-3-47.

13. Docket Number HM-144; Amendment Numbers 173-108, 179-19, September 9, 1977.

14. "Phase 5 Report on June 9, 1974, Accident Involving Head Shields," August 29, 1974, RA-05-2-29; "Phase 5 Report on Head Shield Fatigue Tests," November 10,

1975, RA-05-3-35; Railroad Tank Car Safety Research and Test Project, RPI-AAR.

15. "Energy Required to Supply Propane" and "Propane Transportation, 1974," by D.N. McClanahan for Texas LP-Gas Association, June, 1976.

CHAPTER 9

VULNERABILITY OF LEG FACILITIES TO SABOTAGE

CONTENTS | PAGE

INTRODUCTION

We have tried in this chapter to discuss the possible effects of sabotage on LEG and naphtha transportation and storage facilities in a way which does not substantially contribute to the ability of malicious persons to carry out such acts.

To consider the possible effects of sabotage on LEG and naphtha transportation and storage facilities we:

a. Assessed the current security levels of trucks, tank cars, terminals, storage sites, and processing facilities.

b. Evaluated the sabotage vulnerability of ships, trucks, tank cars, pipelines, terminals, and storage sites.

c. Determined what weapons, explosives, and other materials are available to potential saboteurs.

d. Assessed possible effects on ships, trucks, tank cars, pipelines, terminals, and storage sites of various sabotage scenarios.

e. Conducted charge calculations for ships, trucks, tank cars, pipelines, and storage tanks to determine the type, configuration, and amount of explosive materials/weapons required to accomplish the necessary penetration.

f. Conducted experiments with munitions known to be in the hands of terrorist organizations to validate certain of our calculations and evaluations.

To collect the data for this chapter, we made a comprehensive literature review, visited sites and facilities, studied detailed company plans and blueprints, and held discussions with industry, government, and other personnel.

THE THREAT TO LEG FACILITIES

A typical sabotage threat analysis would characterize potential saboteurs according to their attributes, capabilities, and motivations. Although the potential threateners to LEG facilities have not been previously studied, there is no reason to believe they would constitute a very different group than those for nuclear or other large facilities. Detailed threat studies have been done for nuclear facilities.[1] In addition, there are many documents available which discuss typical perpetrators of malicious actions. Thus, we have concentrated our efforts on assessing the resources available to saboteurs and the vulnerability of LEG transportation and facilities to sabotage.

Groups which might try to sabotage LEG transportation or facilities can be divided into four categories: foreign governments, foreign subnational groups, domestic criminal groups, and domestic political dissident groups. There are elements in each category which have the necessary capabilities and might have the motivation.[1,2] In addition, an isolated, knowledgeable, capable psychotic might try LEG sabotage.

Appendix IX is a compilation of recent bombing incidents obtained from the FBI Bomb Data Program Incident Summaries for the period 1974 through 1977, including a selected list of incidents which occurred on public utility and oil company properties. The number of attempted and actual bombing incidents reached a peak of 2,074 in 1975 and then dropped to 1,314 in 1977, the lowest number in several years.

Availability of Weapons

In addition to commercially available weapons and explosives, an impressive array of weaponry has been stolen from military installations and National Guard armories. The losses include small arms, automatic weapons, recoilless rifles, anti-tank weapons, mortars, rocket launchers, and demolition charges.

A large number of commercially available publications provide detailed instructions on the home manufacture of explosives, incediaries, bombs, shaped charges, and various other destructive devices. All the required material can be bought at hardward stores, drug stores, and agricultural supply outlets. Many of the manuals also discuss tactics and techniques for sabotage operations. These types of books are readily available at libraries across the country, including the Library of Congress.

It is not unusual for international terrorist groups to be armed with the latest military versions of fully automatic firearms, anti-aircraft or anti-tank rockets, and sophisticated explosive devices.

The mobility of international terrorists and the ease with which they acquire and transport weapons is a matter of serious concern. Our inability to control the cross-border drug traffic, and the continuing large inflow of illegal aliens indicate that weapons and small terrorist units could also be infiltrated into the United States.

The Introduction of LEG or Naphtha into Underground Conduits

LEG could be used as an ignition material for fires. A hijacking of one or more tanker trucks would provide a significant, uncontrollable source of ignition and explosions. If LEG were released into a sewer system or subway, a disaster could result. Even naphtha, a much less dangerous material, can cause extensive damage, as a recent incident in Akron, Ohio showed.

Around 2:30 a.m. on June 23, 1977, a major sewer line running beneath Akron's Glendale Cemetary exploded. The street outside the entrance to the cemetary collapsed. (The photograph shows the resulting damage.) Water from a ruptured pipe enlarged the crater into a huge trench. As the blast rolled through nearly 7,000 feet of sewer main, other sections of pavement buckled and caved in. Cast-iron manhole covers were hurled into the air. Storm drains were cracked. Fortunately, much of the force of the explosion was vented through the manholes and storm drains or absorbed by the old-fashioned 13-inch brick walls of the sewer. Otherwise, the explosive mixture would have detonated, according to the City's investigators.[3] As it was, there was little damage to nearby homes except for some broken windows. If the explosion had occurred at a busier time, such as during rush hour traffic, damage would

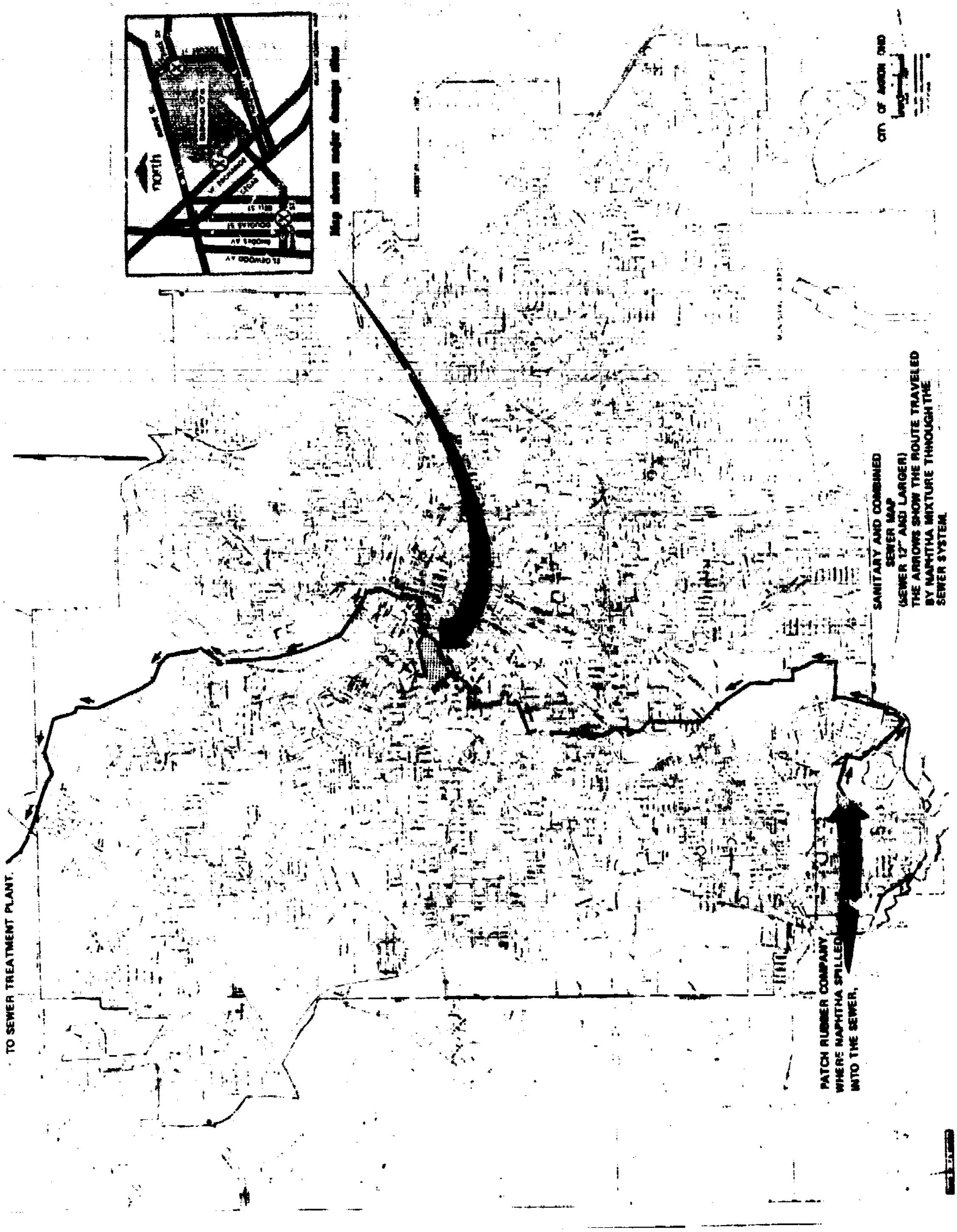
DAMAGE AT ENTRANCE TO GLENDALE CEMETARY AFTER THE NAPHTHA EXPLOSION IN THE SEWER SYSTEM JUNE 22, 1977.

have been greater, and injuries may have resulted. A sewer explosion in Cleveland in 1953 killed one person and hospitalized 58 others.[4]

The Akron blast was caused by naphtha. At approximately 8 o'clock the previous night, a disgruntled former employee broke into the Patch Rubber Company and opened several storage tanks. In all, 11 cubic meters (3,000 gallons) of naphtha and 3.5 cubic meters (900 gallons) of other volatile liquids spilled on the plant floor.

The naphtha poured down a drain in the floor and flowed into the sanitary sewer system at the rate of 64 liters (17 gallons) a minute. After about 3-1/2 miles, this line widens into the main bricklined storm and sanitary sewer. As the naphtha passed through this 10-foot diameter main line, there was enough air to dilute the rich vapor to the flammable range. The explosion came six hours after the naphtha was dumped, and eight miles from the point of entry. The route of the spill is shown on the map. The inset indicates the site of major damage.

Investigators suspect that the hot catalytic converter of a police car that had stopped close to a manhole opening set off the explosion. The engineers estimated that only 2.2 cubic meters of naphtha was required to fill the 6625 foot section of the main line involved in the explosion. Akron officials estimate that complete repairs of the streets and the sewer line will take at least a year and cost more than $10 million.


TO SEWER TREATMENT PLANT.
north
PATCH RUBBER COMPANY
WHERE NAPHTHA SPILLED
INTO THE SEWER.
SANITARY AND COMBINED
SEWER MAP
(SEWER 12" AND LARGER)
THE ARROWS SHOW THE ROUTE TRAVELED
BY NAPHTHA MIXTURE THROUGH THE
SEWER SYSTEM.
CITY OF AKRON OHIO

An investigation of the 1953 Cleveland blast[4] concluded that the most probable cause was either industrial wastes, or gasoline leaking into the sewer, or a combination of these. The investigators found that the rate of vaporization of flammables and the length of time they remain in the sewer are critical factors in explosions of this kind. They also found that volatile flammable liquids in surprisingly small quantities may produce devastatingly destructive effects if the structures are not suitably drained or ventilated. They said that gasoline leakage of five gallons per day into the sewer for about a month, a total leakage of about one-half cubic meter, would have provided an explosive mixture sufficient to cause the disaster.

VULNERABILITY OF FACILITIES TO SABOTAGE

All our findings on the vulnerabilities of LEG and naphtha facilities to sabotage have been thoroughly corroborated by reference data, calculations on individual components, or actual test. The assessments are presented to provide a better understanding of the potential vulnerabilities of LEG system components. To avoid increasing the danger, none of the systems is identified with a specific site.

Our vulnerability assessment considers malicious acts by an individual or groups of individuals which could threaten offsite lives and property. The assessment was limited to the damage that might be caused by a sabotage group of no more than six outside individuals with the assistance of two insiders. The group's resources were limited to those known to be available, as discussed earlier. The actual threat could be considerably greater.

There are two basic types of LEG facilities: base load plants, including import terminals; and peakshaving plants. The storage and processing facilities of both types are similar in physical layout. The design of individual components (e.g.. storage tanks, piping, processing equipment, dikes), however, varies with location and manufacturer, as shown in Appendix XVI-2. Peakshaving plants can be located in any area with access to transmission lines or truck transportation. Import terminals must have onshore pier facilities or offshore terminals with connecting pipeline trestles or tunnels.

Urban Area Facilities

Urban LEG facilities are usually located in heavy industrial developments predominantly occupied by petroleum product storage and processing. LEG storage facilities are often adjacent to other facilities which store very large quantities of LEG or other volatile liquids. Some are next to sewer plants which store large amounts of deadly chlorine gas. This proximity means that a single cause, such as an earthquake or an attack might simultaneously destroy many tanks, thus increasing the damage and casualties many times. A major incident at one facility might cause further failure at adjacent facilities and set off a chain reaction. For example, a detonation in a propane cloud might initiate a detonation in a natural gas cloud.

Urban area facilities are attractive targets for saboteurs, particularly terrorists, because of the immediate impact of any significant incident on large numbers of people. The normal workday congestion and confusion provide excellent cover for daytime infiltration, observation, selection of targets and determination of access and escape routes. One possible form of sabotage involves selectively disabling critical components. Thus, it is important to carefully screen site personnel who have access to plant monitoring and control equipment. If insiders disable key components at the same time that outsiders breach a pipeline, a major spill could result. Certain tank designs and piping configurations we examined would facilitate causing a spill outside the containment area.

At one terminal we visited, police and Coast Guard security are routinely provided during LNG unloading operations, but this is not the practice at most LEG terminals.

We observed a salvage yard crane operating close to the pier-to-plant pipeline at this plant during the unloading of an LNG ship there. An error by the crane operator could have caused a large amount of metal scrap to drop on the pipeline. This could have released a significant quantity of LNG outside the diked area.

The extensive tank truck and rail car traffic between import terminals and other storage facilities provides a malicious group with three options. It can:

- Hijack one or more trucks and use the contents for malicious action.

- Conceal a time-delay device on a truck or rail car set to detonate at a critical time and location.

- Use a truck as a means of plant entry or possible extortion.

Storage Tanks and Dikes

The primary considerations in determining LEG container vulnerability are:

a. Tank design and materials.

b. The size and depth of penetration required to cause massive release of the contents.

The predominant materials used in tank construction are steel, aluminum and concrete. However, as shown in Appendix XVI-2, container designs and dimensions vary considerably between sites. Although none of the tanks we examined are impervious to sabotage, some designs do provide a greater degree of protection against explosive penetration than others. Stronger designs also complicate the sabotage operation by requiring specially designed charges, more explosive materials, and more onsite preparation time. Concrete tanks have much more resistance to penetration than single wall LPG tanks; double wall metallic tanks fall in between.

Concrete LNG Tanks

The depth of the concrete berm around a typical concrete tank provides fairly effective protection against explosive breaching of the tank walls. It would require close to 1,500 pounds of explosive placed in direct contact with the outside wall, to cause significant damage to a concrete tank of this size. If the walls were constructed entirely of reinforced concrete, the explosive requirements would be increased by a factor of 1.5. The depth of the concrete berm also makes these tanks highly resistant to shaped charge penetration. There are currently no known weapons in the terrorist arsenal that are capable of one shot penetration of a concrete tank. The addition of a high contiguous sloped earthen berm around these tanks provides an almost impenetrable barrier against sabotage.

Double-Wall Metal Tanks

Because limited data are available on explosive effects against typical metal double-wall LNG tanks we conducted live firing tests against a full scale tank section with an inner tank of cryogenic aluminum. The tests confirmed that the double-wall structure of these tanks affords limited protection even against non-military small arms projectiles, and that devices used by terrorists could cause a catastrophic failure of the inner wall. The rapid release of LNG (at -260°F) against the outer carbon steel wall could result in extensive crack propagation and possible collapse of that wall as well.

Double-wall tanks which permit access to the insulation space through near ground level manholes are particularly vulnerable to explosive damage. Interior placement of charges would more than double their effectiveness.

Single-Wall Metal Tanks

The single-wall metal tank is the most vulnerable to sabotage. The critical crack length (see Chapter 4) for typical large single-walled tanks is small enough so that properly placed charges could cause their complete catastrophic collapse. This would cause a large amount of the contained fluid to escape the dike (see Chapter 5).

Tanks Built on Piles

Some large storage tanks are supported on pile foundations. We observed one design with about 1.5 feet of air space between the bottom of the tank and the ground surface. This design can reduce by 67 percent the amount of explosives required for extensive rupture of the tank floor. Ground wave reflection and the tamping effect of a partially enclosed space significantly increase the peak pressure of the blast wave. The partial confinement of the resulting gases sustains the pressure on the tank bottom, which can cause more damage than the initial blast wave.

There is also a danger of LEG and LEG vapor accumulating under the tank in the event of a spill. The gases, if ignited, might explode and cause an extensive rupture of the tank floor. No one has looked into this possibility.

Underground Storage

The pipes connected to mined caverns are vulnerable to both accidental and malicious actions, but redundant automatic safety devices provide an almost instantaneous water seal to control vapor release to the atmosphere. Liquid hydrocarbons can be released by overfilling, however, as has happened in Marcus Hook on January 28, 1978.

Close High Dikes

A typical thin high dike wall can be easily breached by a small amount of explosives and properly placed charges would blow out a very large section of the bottom of the wall.

Earthen dikes are much more resistant to sabotage than thin, high concrete dikes. Even the smaller earthen dikes are relatively difficult to breach unless boreholing techniques are used.

Piping

The liquid pipelines which fill and empty LEG tanks are extremely vulnerable, but there are few circumstances in which their rupture would result in offsite damage. To cause offsite damage would require careful planning, timing, and execution, and the assistance of at least one employee with a thorough knowledge of control panel operations and automatic safety valves. To avert such an incident, tank connections and pipeline routing should be examined to determine the possibility of:

- Inducing, from the head in the tank, a self-sustaining flow through the bottom draw-off lines to a point outside the diked area.

- Intentional pumping of LEG or naphtha to the same point.

In many facilities fluid can be sent beyond the dikes both ways. This is particularly critical in plants with concrete tanks and no containment area, or those with close high dikes.

SECURITY EVALUATION OF LEG TERMINALS

The most effective deterrent to sabotage is a well organized physical security program. In addition to a security plan which details responsibilities, procedures, and countermeasures, the need for the following factors should be determined for each facility:

- Physical barriers, guards, guard dogs, random roving patrols, and alarm systems.
- Area surveillance devices and intrusion detection systems; including terrestrial, in-water, and waterfront sensors.
- Specialized and redundant communications and lighting systems.
- Hardening of specific structures to reduce the ease of damage and control forceful entry.
- Security escorts for ships, trucks, and tank cars.
- Traffic control, air and underwater surveillance, unique security procedures and countermeasures for waterfront and shore facilities.
- Special damage control equipment and procedures.

- Personnel screening procedures.
- Visitor clearance and control.
- Special training requirements.
- Authority for guards to carry and use weapons.
- Training staff to avoid loose talk and to report suspicious persons.

Access to all of the facilities we visited would be easy, even for untrained personnel. At the LPG facilities, in particular, there was an apparent sense of complacency about security. The only special precaution we observed during our visits was the use of local police support for traffic control while the Descartes was offloading at the Everett LNG terminal. Only one site provided a detailed security plan in writing. The rules for LNG facilities under consideration by the Office of Pipeline Safety Operations, however, require that each LNG operator prepare and follow written security procedures.[5]

All of the 16 LEG storage facilities we visited are fenced and most of the plants have gate guards and routine visitor check-in procedures during daylight hours, but none of the guards are armed. Two sites use closed-circuit TV to monitor traffic at the main gate. There appears to be heavy reliance on the closed-circuit Low Light Level TV system on those sites where it is installed. Procedures for internal patrols seem to depend on the individual initiative of the crew foreman or night watch, particularly during plant "idle-time" periods. On one night neither we nor company personnel were able to establish phone contact with anyone at an urban, operating LNG plant. There is no intrusion/detection alarm system at any of the installations.

The lack of redundancy of certain facility installations and equipment contributes to overall plant vulnerability. Emergency power supplies and communications are two critical areas. Because even untrained saboteurs recognize the importance of severing all communications and power supply lines, battery operated radios with a 24-hour emergency channel to police should be available at key locations throughout plant areas. Emergency generators should be located away from hazardous areas, with a fuel supply that is well protected from fire and explosions.

Security procedures for truck trailer and railcar operations are inadequate. Drivers are not identified nor are vehicles and railcars inspected, before loading or offloading. This is of particular concern because trucks are vulnerable to hijacking and unguarded railcars are attractive targets for terrorist groups.

VULNERABILITY OF LEG TRUCK TRAILERS AND RAIL TANK CARS TO SABOTAGE

Truck trailers are used to transport both LNG and LPG; rail tank cars are used only for LPG.

The extended exposure of these mobile LEG containers increases their vulnerability to sabotage. A truck or rail car which operates over an established route between fixed points is an easy target for a saboteur. A truck can be hijacked for extortion, or for malicious use of the cargo; a group of tank cars can be derailed at a predetermined time and place. Both are very vulnerable to improvised explosive devices and other weapons commonly used by terrorists, including high-powered small arms. Truck trailers are particularly dangerous because they allow the easy capture, delivery, and discharge of a large amount of explosive substance to a point or points of the hijacker's choosing.

Container design is a critical factor in determining the vulnerability of a vehicle to destruction.

LPG Vehicle Tanks

The LPG containers used on tank cars and truck trailers are single wall, cylindrical, steel pressure vessels, mounted horizontally. The standard railroad tank cars hold 115 cubic meters, while the truck trailers hold 40 cubic meters. Tank car fittings and liquid lines are top mounted at the tank center, while trailers have bottom rear lines.

The same techniques can be used to penetrate or rupture LPG trailers or tank cars. The 5/8 inch steel wall can be easily cut with pocket size explosive devices, and many other weapons commonly used by terrorists would also be effective.

LPG vehicle tanks are especially hazardous because the LPG is stored under pressure, 255 psig at 115^{o}F for propane. Any tank penetration causes an LPG discharge and an associated fire hazard. LPG tanks frequently explode when exposed to fire. The pressurized storage also causes LPG to discharge if any tank valve is opened, including the top mounted valves on tank cars.

LNG Trailer Trucks

LNG is currently carried overland only by trailer trucks. The tanks are slightly less vulnerable than LPG tanks because they are double-walled. The walls are relatively thin, however, and can be penetrated by a fairly small improvised shaped charge. Properly placed, such a charge would cause LNG to discharge into the insulation space, causing the outer jacket to fracture and disintegrate.

VULNERABILITY OF LEG AND NAPHTHA SHIPS TO SABOTAGE

External Attacks

There are very few alternatives available to a saboteur of an LEG ship if he is denied on-board access to vulnerable areas. The placement of explosive charges on a ship's hull requires diver training and specially designed devices or significant amounts of military type explosives to be effective. The sabotage operation would have to be conducted while the ship is anchored or alongside the pier. Improvised limpet mines can cause critical damage and flooding in single hull ships, including many LPG carriers. Several single hulled merchant ships were sunk in Vietnam with crude home-made limpet devices. Improvised limpet mines could cause extensive, but not critical damage to a double hull LNG ship.

Effective port surveillance during LEG carrier operations can minimize the threat. The Coast Guard should also be prepared to take appropriate action in the event of a suspected attack. This includes a ship bottom and pier area search by qualified explosive ordnance disposal experts.

Boarding a ship in a roadstead or even at anchor is very difficult without crew assistance. However, saboteurs might use various ruses, such as feigning injury or distress, to gain this assistance. Unless pier access is restricted, a saboteur might be able to board a ship at the pier under some guise. Effective surveillance and awareness of the dangers by the ship's crew could prevent these unauthorized boardings.

Another potential sabotage threat comes from the crew. Only an expert would recognize some types of explosive material as explosives. One LNG ship crew member, trained in the use of explosives, could cause simultaneous tank and hull damage below the water line, with proper charge placement. In the absence of effective damage control, this might initiate an extremely hazardous sequence of events. A crew member of a single hull LPG tanker could do even more damage to the ship.

Vulnerability

The double hull of the LNG tanker provides a higher degree of resistance to external blast damage than the single hull of a LPG ship or a conventional tanker. It also provides reserve buoyancy and stability control in the event of extensive damage and flooding. We believe that an LNG tanker would survive a swimmer sapper attack by a terrorist group without significant tank damage. The spherical tank configuration appears to be the least vulnerable to this type of attack because of the hull stand-off distance and skirt support structure.

All four tank designs allow for internal access below the storage containers. The pipeline tunnels or duct keels run the entire length of the cargo area with open trunks at both ends. (See Appendix VI-2.) These tunnels might become liquid distribution systems in the event of deliberate explosive rupture of a tank.

FINDINGS

THE THREAT

- Public utilities and petroleum companies have been often targeted by terrorist groups and individuals.

- A large range of firearms, ammunition, and explosives is available in this country to potential saboteurs. Instructions for the construction and use of appropriate explosives from easily available materials are widely available in open literature.

- The existence of highly trained, international terrorist groups armed with sophisticated weapons and explosive devices, combined with the openness of our borders, poses a serious threat to the safety of LEG and naphtha facilities.

- Recent and future technological advancements in weaponry will eventually increase the threat to LEG and naphtha facilities.

STORAGE FACILITIES AND DIKES

- Except during ship unloading at one site, the security procedures and physical barriers at LEG and naphtha facilities we visited are not adequate to deter even an untrained saboteur.

- Most LEG and naphtha storage tanks are highly vulnerable to sabotage. Metal tanks are the most vulnerable. Underground storage or concrete tanks with a sloped earthen berm from ground level to tank top provide the most protection against explosive penetration.

- Sabotage of single or double wall metal tanks could lead to complete catastrophic failure of the wall(s) and subsequent massive spilling of the contents. The level of sabotage needed is within the capabilities of terrorist groups.

- Properly placed charges would blow out a very large section of the bottom of a high, thin concrete dike. Properly designed earthen dikes are extremely difficult to breach.

- In many facilities, through manipulation of equipment, it is possible to spill a large amount of fluid outside the diked areas through the draw off lines.

ADJACENT ACTIVITIES

- Even a few cubic meters of LEG or naphtha in a sewer system can cause many casualties and do a great deal of damage.

- LEG storage facilities in cities are often adjacent to sites which store very large quantities of chlorine, LEG, or other volatile liquids. Thus, a single cause might simultaneously destroy many tanks, or an incident at one facility might cause further failures at adjacent facilities.

LEG VEHICLES

- LEG trucks are highly vulnerable to sabotage and hijacking; tank cars are also highly vulnerable to sabotage.

- Small charges can penetrate the one or two walls of LEG vehicle tanks, as can other weapons.

- LEG can easily be discharged from vehicles, just by opening unlocked valves.

- LNG vehicle tanks are slightly less vulnerable to sabotage than LPG vehicle tanks.

LEG AND NAPHTHA SHIPS

- LNG ships are vulnerable to sabotage, but unless explosives are used on-board or the ship is hijacked, massive spillage into the water is unlikely.

- Improvised limpet mines placed on a single hull LPG ship, while it is anchored or alongside the pier, could result in a massive LPG release and the sinking of the ship. On-board explosives could sink the ship even more easily.

- No governmental body has made a comprehensive effort to determine critical shipboard vulnerabilities to malicious action.

GENERAL CONCLUSION

- The vulnerability to sabotage of LEG facilities and transportation in urban areas is a serious danger to offsite lives and property.

RECOMMENDATIONS

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation:

- enforce the requirement, stated in 33 CFR Part 126.15(a), that guards provided by the owner or operator of an LEG facility be in such numbers and of such qualifications as to assure adequate surveillance and to prevent unlawful entrance. In particular we recommend that the Secretary make and enforce regulations requiring:

  1) - that every truck and train car is carefully checked for weapons and explosives before it enters the facility.

  2) - that every driver and passenger in a vehicle is positively identified before they enter the facility. Picture badges should be issued to all frequent visitors.

3) - surveillance of site boundaries and key components on a 24-hour basis.

4) - that devices be installed which can immediately detect unauthorized entry. These should include completely lighted fences, intrusion alarm systems which can detect if the fence is damaged or crossed, and low light television cameras which can see any area of the boundary.

5) - battery powered redundant communications through which security personnel at any point on the facility can communicate to each other and to local law enforcement officials.

6) - employee screening and training procedures. The training should include threat awareness, recognition of hazardous devices, special safety precautions, and preventive actions that can be taken.

7) - a written security plan which details appropriate procedures for all of the above and is routinely promulgated to all employees.

- require that loaded LEG trucks and loaded, stationary railroad cars not be left unattended outside the plant area.

- determine what security procedures are necessary to prevent LEG trucks from being sabotaged or hijacked and used for destruction. Particular attention should be paid to unavoidable movements of LEG through densely populated areas.

- identify all the specific design vulnerabilities to sabotage at each facility and determine the amount of hardening of key components that is needed to reduce facility vulnerability to sabotage and to control forceful entry.

- require that emergency generators be located away from hazardous areas, with a fuel supply that is well protected from fire and explosions.

- require that automatic shut-off or isolation valves be placed along pipelines which run from piers to storage tanks.

- prohibit the transmission of LEG through pipelines whose integrity is threatened by nearby offsite industrial activity.

- examine the total handling and storage system at each facility to see if an external pipeline breach in conjunction with the misuse or disabling of appropriate system components could cause a major spill outside the containment area. DOT should require whatever modifications are needed to make this impossible.

- examine all facilities near LEG storage sites to see the consequences of simultaneous failures at several sites from a single cause and whether failures at one facility could cause failures at others.

- determine whether LEG or LEG vapor accumulating under a tank elevated on piles could cause an explosion that could rupture the tank bottom.

- systematically determine the critical vulnerabilities to sabotage of ships carrying hazardous materials in U.S. ports and require appropriate preventive and mitigating measures.

- implement effective port surveillance during LEG carrier operations.

- be prepared to take appropriate action in the event of a suspected attack including a ship bottom and pier search by qualified explosive ordnance disposal experts.

- develop contingency plans and emergency procedures for individual ports in the event of a ship hijacking.

TO THE SECRETARY OF ENERGY

We recommend that the Secretary of Energy:

- establish a comprehensive program to determine the vulnerability of LEG tanks to sabotage. This program should include the effect of:

  - o External explosives, including shaped charges.

  - o Internal explosives.

  - o Firearms and light anti-tank weapons.

  - o Introduction of other chemicals.

TO THE CONGRESS

We recommend that the Congress:

- enact legislation requiring that facility guards carry weapons and be authorized to use them if necessary to prevent sabotage. This recommendation is similar to one that GAO made in 1977 for commercial nuclear fuel facilities.[6]

AGENCY COMMENTS AND OUR EVALUATION

The Departments of Transportation and Commerce question the need for much of the material in this chapter. They express concern that the chapter could provide material for potential saboteurs. Many industry comments reflected similar concerns.

Unfortunately, instances of sabotage and terrorism occur so frequently in today's world that the potential cannot be ignored in any serious treatment of the safety of highly dangerous substances such as liquefied energy gases. Nor would it be sufficient merely to say that LEG facilities are vulnerable to sabotage. In making a realistic assessment of this vulnerability, we have attempted to show that malicious groups could sabotage LEG facilities and that current safeguards should be upgraded substantially. We have been careful not to give any information which would significantly increase the ability of potential saboteurs.

Notwithstanding its overall concern, the Department of Transportation agrees with many of GAO's recommendations and points to several comparable provisions for LNG facilities in an Advance Notice of Proposed Rulemaking (ANPR) published by OPSO on April 21, 1977.

In several instances the ANPR addresses generally, but not specifically, an issue dealt with in our recommendations. They would require, for example, a written security plan, employee screening and training procedures, locating emergency generators away from hazardous areas, and written procedures for dealing with possible damage effects. DOT agrees that more specific requirements can reasonably be included in its regulations. We believe the specific requirements we recommend are necessary.

One section of the ANPR partially satisfies our recommendation that DOT prohibit the transmission of LEG through pipelines whose integrity is threatened by nearby, offsite industrial activity. Only new LNG facilities connected to natural gas pipelines are covered, however. We believe that existing LNG facilities and new and existing LPG sites should also be covered.

ANPR provisions would also require 24-hour surveillance of site boundaries and key components, battery-powered redundant communications, and, at facilities storing 250,000 barrels (40,000 cubic meters) or more, intrusion devices. DOT's comment, however, notes that alternate provisions for small, remote sites may be needed or appropriate. We agree that it may be appropriate to consider special provisions for remote sites, but such provisions are not included in the ANPR.

Even though DOT agrees in general with a number of our recommendations and points to its ANPR as corrective action already underway, we should point out that the ANPR was issued over one year ago and is just that, an advance notice. No proposed rules have been issued, and DOT officials could not tell us when they may be.

DOT disagrees with our recommendation that it determine whether LEG or LEG vapor accumulating under a tank elevated on piles could cause an explosion that could rupture the tank bottom. DOT states that ". . .safety is more effectively and efficiently served by prohibiting such designs of new facilities, as provided in the ANPR."

Even if the building of new LNG tanks on piles is prohibited, it still is necessary, in our opinion, to determine the vulnerability of existing tanks built on piles. DOT states that such research would be "extremely costly". Experts we consulted indicate that the kind of structural analysis and explosion effect calculations needed to carry out our recommendations would not require a sizeable expenditure of money or time.

DOT objects to our recommendation that it require modifications in facilities to prevent a major spill from a combination of an external pipeline break and the misuse or disabling of appropriate system components. DOT states that: ". . .in the absence of any showing of an imminent hazard, we believe the intended retrofitting of existing facilities is unjustified, and short of shutting down a large number of facilities, implementation is not possible. Such action could have a dire impact on public welfare with associated greater risk than continued operation of the facility. . ." They agree that such modifications should be made for new facilities, however.

We believe the existing facilities would need to be shut down only a short time, at most, in order to implement this recommendation. This could be done during a period of low demand. The grave danger which could be caused from a major spill generated in this manner is the same for existing and new facilities, and greatly outweighs any inconvenience involved.

DOT disagrees with our recommendation that it require every truck and train car to be carefully checked for weapons and explosives before entering a facility. DOT questioned whether such a check would be effective in light of the potential for concealment and resulting lost time and cost.

In some ways such checks would be similar to baggage and passenger checks at airports. Once LEG checks are standardized, they would require relatively little time and should prove to be very effective.

DOT states that some efficient steps can be taken to reduce the risks to LEG trucks of sabotage, hijacking, and destructive use. These include requiring vehicles to be attended, use of driver-initiated engine breakdown controls, manual reset wheel locks, locked valves, the installation of tire pressure release devices, gas tank water injectors, "on only" visual audible alarms, and automatic emergency signal transmitters. We agree that these measures should be required.

In a general comment on this chapter, DOT states: "The security measures proposed for LEG facilities, if imposed continually, are a classic example of an 'overkill' approach to protect one possible terrorist target while leaving other equally desirable targets unguarded. Furthermore, the recommended security measures would not deter the effective use of the mortar and rocket weapons which the report states are in the hands of potential saboteurs. Neither would these precautions at LEG facilities in any way affect the availability to saboteurs of gasoline or their access to drains for introducing many times the required 1/2 cubic meter into every sewer system in this country." Some industries made similar comments.

We do not agree for these reasons:

(1) Gasoline, because it is a liquid under normal conditions, is much less dangerous in sewers and elsewhere than LEG.

(2) Adequate security measures would offer great protection against the worst sort of sabotage—which requires entry to the site.

(3) Our work was directed to liquefied energy gases. The dangers are clear, and the measures needed are effective and appear to cost relatively little. If there are other equally grave dangers to public safety, corrective measures for them should also be considered.

REFERENCES

1. Mitre Corporation, "The Threat to Licensed Nuclear Facilities" MTR 7022, September 1975.

2. LEAA National Advisory Committee on Criminal Justice Standards and Goals, "Disorders and Terrorism" Washington, DC 1976.

3. "Investigation of June 23, 1977 Willow Run Sewer Explosion," HRC Report 3876, Hazards Research Corporation, Denville, N.J.

4. Investigation conducted by a committee of Case Institute of Technology professors, retained as consultants by the cities of Cleveland and Lakeland, Ohio.

5. Department of Transportation (OPSO), Advance Notice of Proposed Rulemaking, "Liquefied Natural Gas Facilities (LNG); Federal Safety Standards", Development of New Standards. Federal Register, Vol. 42, No. 77, April 21, 1977.

6. An Unclassified Digest of a Classified Report Entitled "Commercial Nuclear Fuel Facilities Need Better Security." EMD-77-40a. May 2, 1977.

CHAPTER 10

THE CLEVELAND LNG ACCIDENT OF 1944

CONTENTS | PAGE

INTRODUCTION

The accident in the liquefaction, storage, and regasification plant of the East Ohio Gas Company on October 20, 1944, was the first and only LNG accident in this country to cause off-site damage and injury. Several major investigations were therefore undertaken.

This chapter reviews the circumstances of the accident and the principal findings of the investigations. There are still lessons to be learned. LNG technology has changed since 1944, but it has not changed radically. The people who planned, built, and operated the Cleveland facility were trained, experienced, and reputable. They believed their plant was safe enough to be located in a populated area.

On October 23, the Mayor of Cleveland established a Board of Inquiry which produced the "REPORT OF THE TECHNICAL CONSULTANTS BOARD OF INQUIRY FOR THE MAYOR OF CLEVELAND ON THE EAST OHIO GAS COMPANY FIRE". This report, submitted in July 1945, addressed a broad range of questions relating to the design, construction, and operation of the plant. It included a narrative of the disaster that incorporated several eyewitness accounts of the early sequence of events.

In addition, the Federal Government's Bureau of Mines had a responsibility to obtain technical information on the causes of such disasters.[1] Its investigations produced "BUREAU OF MINES REPORT OF INVESTIGATIONS 3867".

The Coroner of Cuyahoga County also prepared a report whose recommendations and conclusions were included in the Mayor's Board Report.

The synopsis of the report of the Mayor's Board said: ". . .partly owing to the fact that there is no evidence of warning or irregularity in the behavior of the plant up to the moment of failure, the specific and direct cause of the failure may never be known exactly." It also noted that a number of possibilities were developed in the inquiry which, separately or in combination, could be the cause of the disaster.

BACKGROUND

The East Ohio Gas Company (EOG) supplied fuel to the growing Cleveland metropolitan area. The company examined ways to meet the increasing peak demand for gas, including the large requirements of war industries, and ultimately selected liquefied natural gas as the best solution. It built a new plant on the site of an older one that had been used for 50 years as a conventional gas plant with water-sealed compressed gas tanks. The new plant received natural gas from fields in West Virginia, liquefied it for storage, and regasified it for distribution through the regular gas distribution system when needed.

The commercial liquefaction process for natural gas they used was patented by a California inventor in 1937. The Hope Natural Gas Company initiated intensive laboratory study of the process and constructed a small pilot plant in the summer of 1939. Its operation led to the definition and solution of a number of technical problems. During six months of operation, the pilot plant produced about 22,600 cubic meters of LNG which was temporarily stored in a horizontal cylinder eight feet in diameter and 18 feet long holding about 26 cubic meters.[2] The EOG Cleveland plant was the first large operation anywhere.

The EOG plant, completed in January, 1941, had three spherical tanks. A fourth cylindrical tank was built two years later. The collapse of this cylindrical tank caused the disaster.

DESIGN, CONSTRUCTION, AND OPERATION

The people involved in planning, designing, constructing, and operating the EOG LNG plant were competent and reputable. Mr. H.C. Cooper, President of the Hope Natural Gas Company, testifying before the Mayor's Board, said that the extent to which engineering skill could prevent such disasters was an open question.

Site Selection

The site for the LNG plant was selected because it was already EOG property and was appropriately located on the gas distribution system. The storage tanks were placed on a small site in the middle of a densely populated and highly industrialized section. Mr. W.G. Hagan, Vice-President and General Manager of the EOG, told the Mayor's Board that the company felt it was building a safe plant that could be located anywhere. Ground tremors generated by activities within and outside the plant were not considered significant. Although the bearing capacity of the ground was low, the foundations of the tanks were built to compensate for this and remained stable throughout the disaster. No action was taken to prevent any material spilled over the dikes from entering sewers.[3] During the October 20 incident, LNG was seen flowing in gutters, and several structures exploded or burned from the inside out. This suggests very strongly that sizeable amounts of LNG went into sewers and basements.

Tank Design

The original plant, with three 2,359 cubic meter spherical LNG tanks, produced its first LNG on February 7, 1941. By April 1942, EOG found it necessary to expand the storage capacity. Designs and bids for spherical and cylindrical storage vessels were called for. The Pittsburgh Des Moines Steel Company (PDM) told the gas company that a cylinder was as satisfactory as a sphere and cheaper. Mr. J.O. Jackson, Chief Engineer of PDM, later said that he had not recommended a cylinder over a sphere because of cost, but because a stress analysis of a cylinder could be made with greater certainty.[4] Appendix X contains a detailed discussion of the tank designs and testing.

The building permit for Tank 4, a cylinder of 70 foot diameter with a working depth of 43 feet and a capacity of 4,248 cubic meters, was issued in August 1942. It was put into service in the fall of 1943.

In both the spherical and cylindrical designs the inner tanks were made of a nickel alloy steel having at least 3.5% nickel and less than .09% carbon. Present day tanks are built of 9% nickel alloy steel. The spherical tanks were insulated with cork; the cylindrical tank, with rock wool. Present day tanks are insulated with perlite or polyurethane foam.

External Tank Frosting

Frost spots appeared on the bottom of Tank 4 several months before the failure. Mr. Jackson suggested ventilating the tank bottoms with heated air. This did away with the frost, but not, of course, with the cause of the frost. The spots returned when the air flow was stopped. Frost spots also appeared on the top of Tank 4, but disappeared when rock wool was added. Frost spots had previously appeared on the top of one of the spheres, but disappeared when granular cork was added.

Provisions for Spills

A failure of the metal during initial testing of Tank 4 (see Appendix X) led EOG to consider the possibility and effects of leaks or spills. It was decided to use an idle pit as a sump with drains running to it from all tanks.[5] Dike walls were also built around each tank, but their capacity was not adequate to contain and carry off to the sump a sudden large flow from one or more tanks. Little thought was given to massive spills because PDM said they were installing a tank that could not leak.[6] Thus, provisions were made only for relatively slow leaks. (Current LNG storage site dikes are also designed to contain only relatively slow leaks (see Chapter 5).

The spillage sump was covered by a steel top, grouted in around its circumference, and topped with a forty-foot stack. There was no burning taper, no flashback screen, and no provision for purging the sump with inert gas. The top collapsed inward in the disaster.

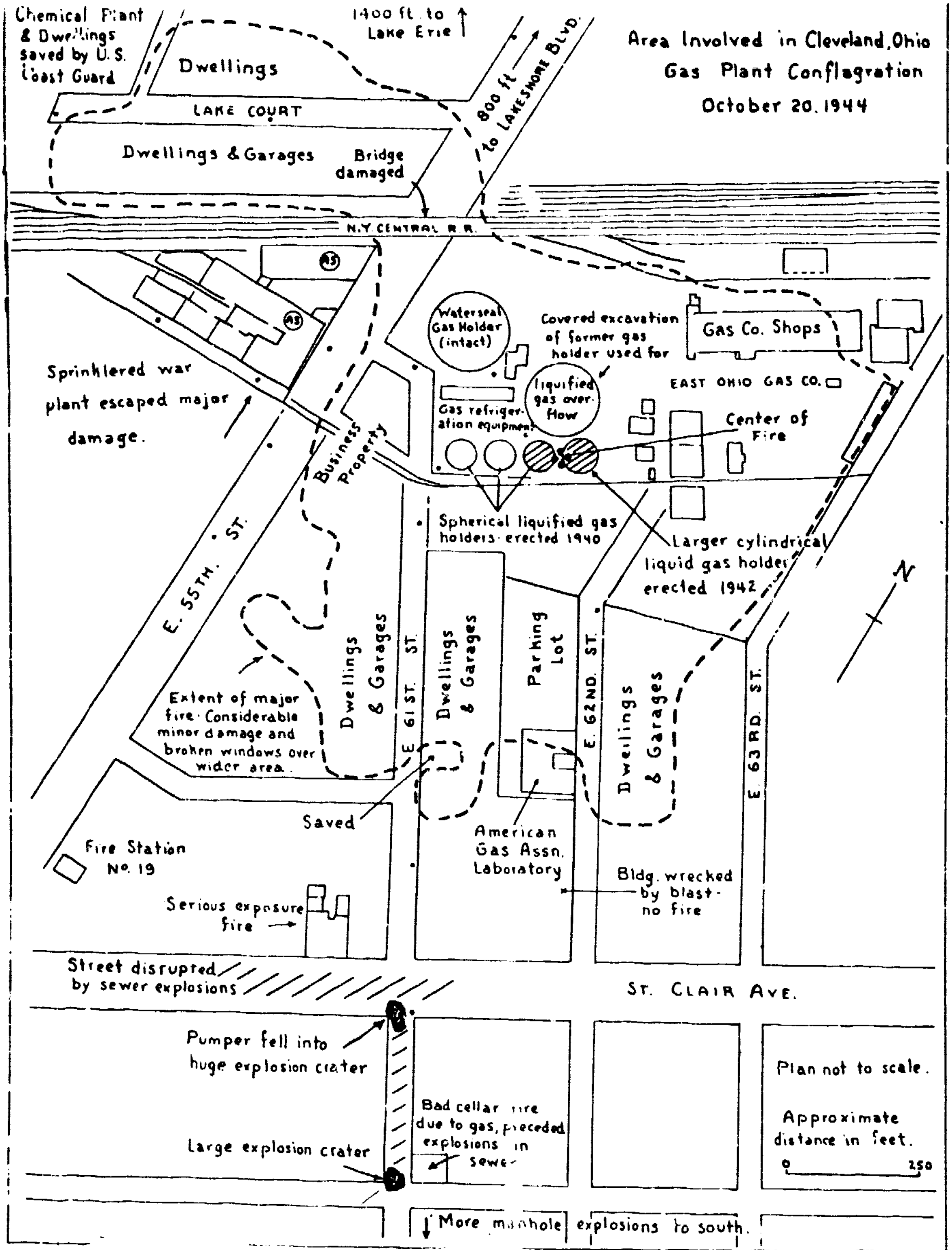
AN ACCOUNT OF THE SPILLS

In the afternoon of October 20, when Tank 4 failed, employees were performing their normal duties in shutting down the plant. They appear to have been well-trained and conscientious. No unusual conditions or causes for alarm came to their attention.

When the catastrophe began, the wind was from the north and northeast at 12 to 16 mph. The temperature was around 50°F.

First vapor and liquid came from the south side of the cylindrical tank.[7] Then it collapsed. There was a "whoosh," a dull red glow, and a slight earth shock. The vapor clouds spread in all directions, some hugging the ground while others rose above it. The clouds suddenly ignited with orange-yellow flashes. Then a great rush of flames generated waves of heat powerful enough to blister buildings half a mile away.

When Tank 4 failed, it released about 4,200 cubic meters of LNG at -260°F.[8] Vaporization began at once, but the lay of the land caused most of the liquid to flow south and southeast. The map shows the area involved in the accident. The plant was in a slight depression, but the general slope of the ground was downward from north to south with about a four-foot drop from the north side of the plant proper to a point 100 yards from the Gas Association Building. The liquid moved down East 62nd Street where some entered the storm sewer, vaporized, and exploded. The vapor moved along 62nd Street and ignited.



Source: NFPA Newsletter, November 1944.

About 20 minutes after Tank 4 failed, the legs holding Tank 3 collapsed from the heat, releasing another 2,100 cubic meters of LNG.[9] The subsequent explosion shot flames more than half a mile into the air. The temperature in some areas reached 3000°F.[10]

Some 10 minutes later another huge blast in the yard area began a series of explosions in sewers, underground conduits, and basements. Streets were blown up, manhole covers hurled into the air, water lines broken, and windows shattered. One explosion opened a crater 25 feet deep, 30 feet wide, and 60 feet long swallowing a fire department pumper and ripping a hole in one of the main intercept sewers. Smaller blasts continued for several hours.

FIRE BEHAVIOR AND FIREFIGHTING

The LNG spills produced explosions and rapid burning in gas clouds, large gas flames, and the burning of gas which evaporated as the liquid ran over the ground and found ignition points. There were fires and explosions in confined spaces, ignition of materials by radiant heat, and secondary fires started by LNG-soaked rock wool. Drops of liquid gas fell on roofs and ignited. Some buildings in the middle of areas of intense fire escaped almost undamaged while their immediate neighbors were almost totally destroyed. The photographs on the next two pages show the damage done.

The first fire alarm sounded almost immediately. The fire spread rapidly and eventually 8 alarms were struck. Before fire trucks arrived houses on both sides of East 61st and East 62nd Streets were burning. Those nearest the

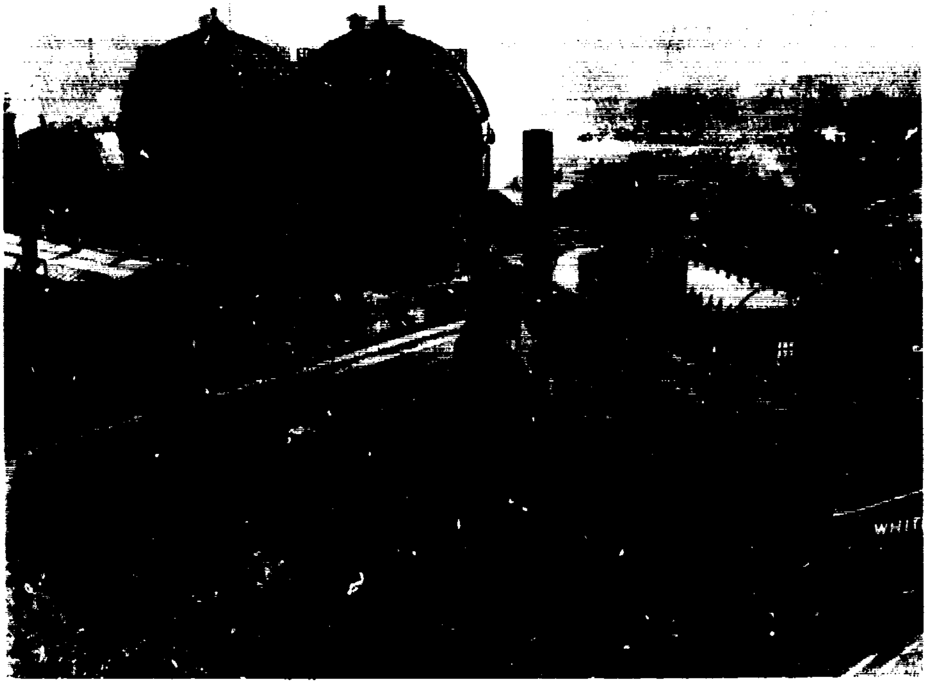
AERIAL VIEW OF DESTRUCTION CAUSED BY EXPLOSIONS AND FIRE AFTER LNG SPILL IN CLEVELAND, OHIO, OCTOBER, 20, 1944.

gas plant on 62nd Street were burning from the inside out. Flames ran along the curbing and disappeared into sewers.

A total of 35 firefighting companies, two rescue squads, a Coast Guard fireboat, and the arson squad were on the scene. Fire and explosions destroyed or damaged parts of the fire communication system, putting 230 boxes out of commission. Despite damage to some water mains, there was adequate supply. At some places fallen high-tension lines blocked streets and forced the fire department to lay very long lines for water.

CORONER'S REPORT[11]

Two factories, eight mercantile establishments, and the laboratories of the American Gas Association suffered



VIEW OF THE REMAINS OF THE PLANT AND LNG STORAGE TANKS.

REMAINS OF MAIN BUILDING OF EAST OHIO GAS COMPANY'S LNG FACILITY, AFTER 1944 DISASTER.

critical damage. The Cleveland Fire Chief gave these figures:[12]

Totally Destroyed	Partially Destroyed
79 houses	35 houses
2 factories	13 factories
217 automobiles	
7 trailers	
1 tractor	

The area directly involved was about one-half-mile square, of which about 30 acres were completely devastated; everything combustible burned. Some nearby dwellings suffered little damage while some farther away were destroyed.

At least 14 of 39 large industrial users of gas were temporarily shut down. Rail services passing through the area were rerouted. City transit services were halted by street damage and destruction of track. Electric cables serving the area were burned and poles destroyed. Some underground cables were damaged, and power was cut off as a safety measure. Telephone circuits were damaged and 878 telephones were put out of commission.

A thorough survey was made to locate and examine the parts and fittings from Tanks 3 and 4. The violence and speed with which Tank 4 collapsed was demonstrated by the fact that it broke up into hundreds of fragments, varying in size from 38' x 16' to pieces the size of a man's hand, which were distributed over thousands of square feet. One piece weighing several hundred pounds was thrown about 200 feet and smaller pieces traveled twice that distance.

Consultants to the Mayor's Board suggested that the initial failure of Tank 4 took place at the top center of the inner shell and that the possibilities of shock or stress in that part of the tank required particular examination.[13] The Bureau of Mines said that fragments from Tank 4 appeared to be of the type induced by embrittlement.[14]

According to early reports, 136 people were listed as dead and an additional 77 as missing.[15] The coroner's final tally was 130 deaths, and 225 injuries.[16]

The National Fire Protection Association (NFPA) Newsletter of November 1944 said that ". . .there might have been much more extensive loss of life had the explosion occurred an hour later". At the time of the fire most children were in school and most men were at work. The NFPA Newsletter also said: "The fact that the wind was blowing away from the congested part of the area is believed to have been a major factor in prevention of an even more devastating conflagration which could have destroyed a very large part of the East Side."

FINDINGS

- It is not certain what factor or combination of factors caused the collapse of Tank 4.

- Before the East Ohio Gas Company facility was constructed extensive research had been carried out and a pilot plant was built and operated.

- Before cylindrical Tank 4 was built, three spherical tanks had been operating without difficulty at the facility for more than two years.

- There is no reason to believe that the choice of a cylindrical shape for Tank 4 had any connection with the accident. All large LNG tanks today are cylinders.

- The staff and management of the East Ohio Gas Company who operated the facility, and the Pittsburgh Des Moines Steel Company (PDM) who built it were trained, experienced, and reputable.

- The East Ohio Gas Company took precautions to control small and moderate rates of LNG spillage. They assumed that a sudden massive spill was not credible. The same assumption is made today in designing dikes around LNG facilities. In fact, it is made in designing dikes around most facilities which store large amounts of all dangerous fluids.

- Both PDM and the East Ohio Gas Company assumed that a small leak would precede a catastrophic collapse. They also assumed that the small leak would be noticed and corrected before it became serious.

- Frost spots were noticed on the top and bottom of Tank 4 and had previously appeared at the top of one of the spherical tanks. The frost spots at the top of the tanks were caused by the settling of the insulation and disappeared when more insulation was added. Mr. J.O. Jackson, Chief Engineer of PDM, advised the East Ohio Gas Company to eliminate the frost spot at the bottom of Tank 4 by continuously ventilating it with warm air. It disappeared whenever this was done and reappeared when the ventilating was stopped.

- No thought was given to the nearby presence of other industrial facilities, residences, storm sewers, or other conduits. Little thought is given to similar neighbors in planning some facilities today.

- Less than 6,300 cubic meters of LNG spilled and a large part of that remained on Gas Company property. This is a very small amount compared to the capacity of today's facilities, which often store more than 100,000 cubic meters.

- The final death toll was 130. There were 225 injuries.

- The National Fire Protection Association (NFPA) said that casualties could have been much higher if the explosion had taken place at a different time of day. At the time of the fire most children were in school, and most men were at work.

- The NFPA also said that, if the wind had been blowing in the opposite direction, a very large part of the East Side of Cleveland could have been destroyed.

- Among the conclusions and recommendations of the Mayor's Board of Inquiry were the following:

  o "The obvious teaching of the. . .disaster is that insufficient attention was given by the public authorities and by the industry alike to the restrictions that were necessary for safety in the storage of this material; and that a false sense of security had been engendered. . ."

- An application for construction should include a full statement of the energy content and maximum possible rate of energy dissipation.

- The application should show proof that the design provides for the contingency of failure of each and every component, and for the consequences of failure.

- The owner should be required to prove that he offers no hazard to the surroundings and that firefighting and emergency provisions are adequate.

\- Among the recommendations of the Bureau of Mines were the following:

- Plants dealing with large quantities of liquefied inflammable gases should be isolated at considerable distance from inhabited areas.

- Containers for the liquefied gas should be isolated from other parts of the plant and provided with dikes large enough to contain the entire contents of the tank.

- Extreme caution should be taken to prevent spilled gas from entering storm sewers or other underground conduits.

\- The Coroner's final conclusion was:

"In view of the destruction by this disaster, the Coroner must come to the conclusion that no plant or structure of any kind which, by reason of its inherent nature may be explosive or inflammable, or which may present any hazard which would endanger life and property in its vicinity, should be permitted to be built in a residential, semi-residential, business or congested factory district."

AGENCY COMMENTS AND OUR EVALUATION

The Departments of Commerce and Transportation and the Federal Preparedness Agency of the General Services Administration comment that cryogenics technology, storage tank fabrication, and construction techniques have substantially improved since the Cleveland accident. DOT states: "The inclusion of an account of the 1944 Cleveland LNG incident in this report without stressing the fact that the apparent causes of this mishap do not exist at today's LNG facilities is misleading."

The actual cause of the Cleveland accident has never been determined. There is no reason to believe that cryogenics was the primary problem. LNG technology in use today is still relatively new. We are not sure what effect many years of exposure to very cold temperatures will have on modern LNG tanks. The industry did not discover the "rollover effect" of combining different LNG mixtures in a storage tank until after an August, 1971 incident in La Spezia, Italy in which about 220 cubic meters of LNG were released through safety valves. There is still much that needs to be learned about LEG properties and behavior. For example, much uncertainty still exists on the distance an LNG cloud may travel in a flammable state, as we discuss in Chapter 12.

Both Commerce and DOT emphasize the more recent LEG safety record. Commerce says that our analysis of an accident that took place 34 years ago points out the recent safety record of LEG facilities. Commerce also says that the serious oversights that contributed to the Cleveland accident could not happen with modern technology, strict construction safety codes, and sophisticated and redundant monitoring equipment. They said, for example, that any facility would be immediately shut down if frost developed on the outer tank walls, and the defect corrected.

The LEG industry's safety record has not been perfect over the last 34 years. There is a long history of accidents in all aspects of LPG use. Although there have been no major LNG accidents since the one in Cleveland, there have been documented incidents in LNG production, storage, and distribution in the United States and abroad.

There is no evidence that present day technology, stricter construction safety codes, and sophisticated and redundant monitoring equipment can certainly prevent another major catastrophe. Present safety codes will not necessarily prevent flows over dikes, as we have shown in Chapter 5. Two major LEG storage facilities overseas have blown up as a result of accidents, including one in Qatar, in 1977.

In January, 1978, a 40,000 cubic meter butane storage cavern at the Sun Oil refinery in Marcus Hook, Pa., was overfilled despite three monitoring methods and a safety relief valve.

The cavern was excavated in granite more than 300 feet underground. The main device to measure the butane level in the cavern, a manometer, malfunctioned and indicated that the cavern contained only 10,000 cubic meters of butane. A vapor pressure gauge at the wellhead also malfunctioned, and company bookkeeping records, showing how much butane was pumped into and out of the cavern, were very inaccurate. The safety relief valve, set at 175 pounds per square inch, never operated because the cavern pressure never reached that level.

The escaping butane caused fires that destroyed five houses only 100 feet from the outer wall of the cavern. Since 1956 there have been at least four other overspills from mined caverns.

The conclusions of those who investigated the Cleveland accident are still highly relevant: that plants dealing with large quantities of liquefied flammable gases should be isolated at considerable distance from inhabited areas, and that extreme caution should be taken to prevent spilled gas from entering storm sewers or other underground conduits.

REFERENCES

1. 30 U.S.C. 1.

2. Report of the Technical Consultants Board of Inquiry for the Mayor of Cleveland on the East Ohio Gas Company Fire, Cleveland, Ohio, July 1945, (Hereafter Mayor's Board) p.10.

3. Mayor's Board, p. 94.

4. Bureau of Mines Report of Investigations 3867, May 30, 1945, (Hereafter BuMines) p. 13.

5. BuMines, p. 18-19.

6. Mayor's Board, pp. 43-44.

7. BuMines, p. 24.

8. BuMines, p. 24.

9. BuMines, p. 25.

10. Coroner's Report on East Ohio Gas Company Disaster, Cuyahoga County, Cleveland, Ohio, July 1945, p.8.

11. Coroner's Report, p. 11.

12. Mayor's Board, p. 31.

13. Mayor's Board, p. 7, 62, and 62-a.

14. BuMines, p. 28.

15. National Fire Protection Association Newsletter, Boston, Mass., November 1944.

16. Coroner's Report, p. 7.

CHAPTER 11

LIABILITY AND COMPENSATION

CONTENTS

CONTENTS	PAGE

INTRODUCTION

A major LNG accident in a densely populated area could cause damage of such severity that injured parties could not be fully compensated under current insurance arrangements.

Claimants would face a complicated legal and financial situation. In some instances liability would be limited by statute. The long and complex litigation necessary would be burdensome and perhaps futile since neither the insurance nor the reachable assets of the corporation may cover the damages.

Companies that transport and store LNG are typically part of intricate corporate structures, which sharply limit the liability of the parent corporations for offsite damage. Most of the assets of the frontline company (the company actually owning or operating the facility or vessel) may be destroyed in a major accident. Moreover, the insurance policies the companies carry are inadequate to cover the claims that could result from a major accident in a densely populated area.

Although highly destructive materials are transported by ship or barge through city harbors and rivers, stored in tank complexes in or near densely populated cities, and carried by truck and train through large cities, the Federal Government has neglected the issue of offsite liability of hazardous enterprises. No Federal agency assumes responsibility for assuring adequate compensation of victims.

THE OWNERSHIP STRUCTURE AND FINANCING OF LNG COMPANIES

Import Facilities

LNG is imported and stored by wholly owned, separately capitalize subsidiaries of larger firms. The structure places "corporate veils" between parent firms and those subsidiaries most vulnerable to liability. The most thinly capitalized level in this structure is usually the subsidiary most directly involved in LNG operations, and most vulnerable to liability. To the extent that debt to equity ratios increase, claimants have fewer assets to proceed against, assuming the assets of corporate parents are out of reach.

Table 11-1 shows the ownership structure and financing of LNG import facilities. Figure 11-1 illustrates typical corporate structures. Meaningful financial figures are not available for some companies whose facilities are far from start-up.

If the insurance coverage and surviving assets of a company are inadequate, claimants would have to obtain any additional recovery from the assets of a parent firm. This would be difficult, because claimants would have to persuade a court to hold the parent company accountable for acts of its subsidiary. Courts do so only if they find: a) the primary firm has not been run as a separate entity, but is completely controlled and financed by the parent; b) it has been so thinly capitalized that it cannot withstand normal business risks; c) it has substantially no business except with the parent corporation, or no assets except those received from the parent.

TABLE 11-1 LNG TERMINAL COMPANY DATA RELEVANT TO LIABILITY AND COMPENSATION[1]

MARINE TERMINAL AND STATUS	CORPORATE STRUCTURE		CAPITALIZATION ($ MILLIONS) ASSETS	LONG TERM LIABILITY	EQUITY[2]	LIABILITY INSURANCE COVERAGE PER INCIDENT ($ MILLION)	CLEARLY AMENABLE SERVICE OF PROCESS[3]
Everett, MA (near Boston) currently operating	Primary Cos.:	Distrigas of Massachusetts Corp. (owner/operator)	33.1	14.9	18.3	*	Massachusetts, Delaware
		Distrigas Corp. (importer)	2.6	0	2.6	*	Massachusetts, Delaware
	Parent:	Eastern Energy Corp. owned by	19.6	13.4	6.9	*	Massachusetts, Delaware
		Cabot Corp.	477.3	129.2	240.4	*	Massachusetts, Delaware
Providence, RI	Primary Co.:	Algonquin LNG, Inc. (lessee,[4] operator)	+	+	+	+	Rhode Island
	Parent Cos.:	Algonquin Gas Transmission Co. owned	+	101.9	69.9	+	Delaware, Massachusetts
		by Algonquin Energy, Inc. owned by	+	+	+	+	Delaware
		Eastern Gas & Fuels Assoc. (36.8%)	675.0	202.9	283.9	+	Massachusetts
		New England Gas & Electric Assn. (34.5%)	160.8	29.4	128.1	+	Massachusetts
		Texas Eastern Transmission Corp. (28%)	2,725.7	1,019.1	900.9	(5)	Delaware
		Providence Gas Co. (0.7%)	65.1	23.5	18.2	+	Rhode Island
Staten Island, NY (Rossville) proposed	Primary Cos.:	Energy Terminal Services Corp. (owner/operator)	*	127.7(est)	46.7(est)	100.0	Delaware, New York
		EASCOGAS LNG, Inc. (importer)	N/A	N/A	N/A	*	*
	Parent:	Public Service Electric and Gas Co.	4,532.1	1,958.2	1,932.5	*	New Jersey
West Deptford, NJ (near Philadelphia) proposed	Primary Cos.:	Tenneco LNG Inc. (owner/operator)	N/A	N/A	N/A	*	New Jersey, Delaware
		Tennessee Gas Pipeline Co. (importer)	*	*	*	*	Tennessee
	Parent:	Tenneco Inc.	6,584.2	2,280.3	2,400.0	100.0 of excess liability coverage	Delaware, Texas
Cove Point, MD currently operating	Primary Co.:	Consolidated System LNG Co. (50%)	121.1[6]	54.0	65.1	140.0	Delaware, Maryland, Virginia
	Parent:	Consolidated Natural Gas Co.	1,798.4	639.3	755.7	*	Delaware
	Primary Co.:	Columbia LNG Corp. (50%)	220.5	94.0	95.6	50.4 Columbia Gas System and affiliates	Delaware, Maryland Virginia, Ohio
	Parent:	Columbia Gas System Inc.	3,202.6	1,352.1	1,062.8		Delaware
Elba Island, GA (near Savannah) operational in 1978	Primary Co.:	Southern Energy Co. (owner, operator, importer)	150.0	*	*	100.0 affiliates of Southern Energy Co.	Georgia, Delaware
	Parent:	Southern Natural Gas Co. owned by	787.8	278.4	293.6		Georgia, Delaware
		Southern Natural Resources, Inc.	1,189.6	428.1	419.7		Delaware
Lake Charles, LA application approved by FPC in mid-1977	Primary Co.:	Trunkline LNG Co.	190.0	145.0	50.0	"to the fullest extent possible"	Louisiana, Delaware

TABLE 11-1 LNG TERMINAL COMPANY DATA RELEVANT TO LIABILITY AND COMPENSATION (CONTINUED)

MARINE TERMINAL AND STATUS	CORPORATE STRUCTURE		CAPITALIZATION ($ MILLIONS) ASSETS	LONG TERM LIABILITY	EQUITY[2]	LIABILITY INSURANCE COVERAGE PER INCIDENT ($ MILLION)	CLEARLY AMENABLE SERVICE OF PROCESS[3]
	Parent:	Trunkline Gas Co. owned by	628.2	284.4	222.5	planned	Texas, Delaware[7]
		Panhandle Eastern Pipe Line Co.	1,694.6	798.7	490.7	*	Texas, Delaware[7]
Port O'Connor, TX	Primary Cos.:	El Paso LNG Terminal Co. (owner/operator)	Expects $457 million capital investment, 75% long term debt and 25% equity			*	Texas, Delaware
		El Paso Atlantic Co. (importer)	N/A	N/A	N/A	*	Delaware
	Parent:	El Paso LNG Co. owned by	*	*	*	*	*
		The El Paso Co.	2,410.1	1,201.8	529.5	*	Texas, Delaware
Ingleside, TX (near Corpus Christi) proposed	Primary Cos.:	NGP-LNG Inc. (owner/operator)	N/A	N/A	N/A	*	Texas, Delaware
		Natural Gas Pipeline Co. of America (proposed importer)	1,410.7	586.9	526.1	*	Illinois
	Parent:	Peoples Gas Company	2,198.8	973.2	1,368.1	*	Illinois
Southern California[8] Oxnard Los Angeles Point Conception proposed	Primary Co.:	Western LNG Terminal Associates (owner/operator)	379.4 (75% debt with project revenues as the chief security to lenders)	284.6	94.8	50 minimum for third party and property	California
	Parent Co.:	Western LNG Terminal Co.	16.2	-	-	*	California
		(50%) owned by Pacific Lighting Corp.	1,662.8	697.1	614.4	*	California
		Pacific Gas LNG Terminal Co.	+	+	+	+	California
		(50%) owned by Pacific Gas & Electric Co.	6,620.9	3,[illegible]5.6	2,993.3	+	California

1. Sources: Company letters, FERC records, Moody's Public Utility and Industrial Manuals for 1976.
2. Common and preferred stock and retained earnings.
3. This column indicates states in which the company in column 2 is incorporated or doing business, or maintaining agents to receive service of summons and complaint.
4. The property is owned by Providence Gas Co.
5. Texas Eastern maintains $75 million property damage coverage and $100.5 million general liability coverage per incident.
6. Capitalization is expected to be $200 million when the facility begins operation.
7. Trunkline Gas is also subject to process service in Louisiana, Arkansas, Tennessee, Kentucky, Illinois, and Indiana. Panhandle Eastern is also subject to process service in Oklahoma, Wyoming, Kansas, Missouri, Illinois, Indiana, Ohio, and Michigan.
8. In September 1977, the State of California enacted a law authorizing only one LNG terminal site in the State.

* Company would not disclose this information.
\+ No letter was sent to the company.
N/A Not appropriate.

FIGURE 11-1 TYPICAL CORPORATE STRUCTURE FOR LNG IMPORT TERMINALS

Everett, Massachusetts

Cabot Corporation

Eastern Energy Corporation

Distrigas of Massachusetts Corporation (terminal owner/operator)

Distrigas Corporation (importer)

Cove Point, Maryland

Columbia Gas System, Inc.

Consolidated Natural Gas Co.

Columbia LNG Corporation (50%) and Consolidated System LNG Company, (50%)

(joint terminal owners/operators)

Elba Island, Georgia

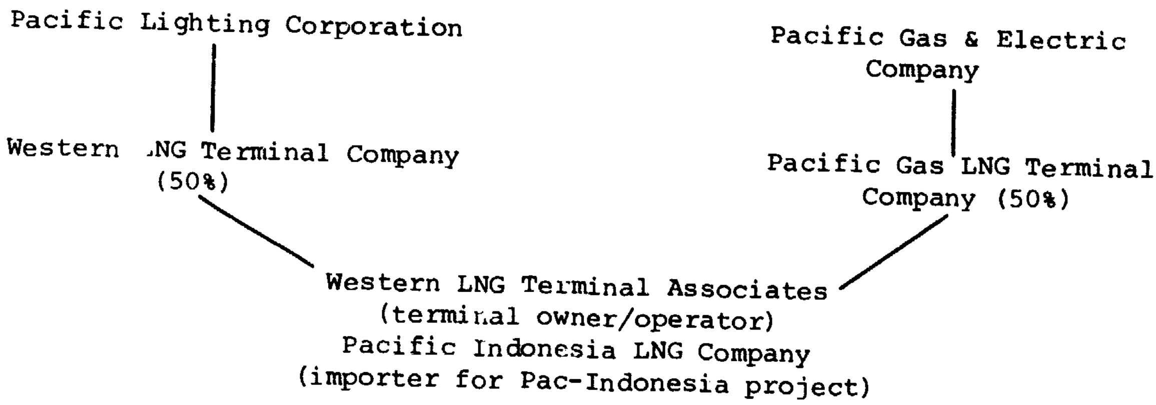
Southern Natural Resources, Inc.

Southern Natural Gas Company

Southern Energy Company (terminal owner/operator/importer)

FIGURE 11-1 (continued)

Southern California



If the defendant frontline firm has independent assets and/or insurance, even though these may be inadequate to satisfy the judgment, a court may not be convinced that it should pierce the corporate veil. In any case, the question may require extensive litigation.

Claimants who can convince a court to pierce the corporate veil still face stiff and extended litigation to prove the liability of the frontline and parent companies.

LNG Carriers

Each U.S. and foreign flag LNG vessel is ordinarily owned, leased, or chartered by a separate subsidiary company of a larger firm, as shown in Table 11-2. This structure is designed to limit liability exposure to the subsidiary company's assets. There is a statutory limitation (46 U.S.C. 183) on the liability that can be imposed on the owners and bareboat charterers* of ships and barges. The limitation, enacted in 1851, was intended to promote national fleets and international commerce. Many precedents date from a period when shipping was more simply organized than today's LNG trade, with its multi-layered, multi-national corporations.

Under the 1851 statute, the liability of both owners and bareboat charterers is limited to the salvage value of the vessel plus the amount owing for freight, if they can prove that they did not know about the causes of an accident. If injuries or deaths occur, however, the limit

*A bareboat charterer charters the hull, and mans and victuals the vessel. A time charterer hires the services of a vessel for a period of time, leaving its operation to others.

TABLE 11-2 LNG SHIPPING COMPANY DATA RELEVANT TO LIABILITY AND COMPENSATION[1]

MARINE TERMINAL & LNG SOURCE	SHIPPING ARRANGEMENTS	CORPORATE STRUCTURE	CAPITALIZATION ($ MILLION)	PROTECTION AND INDEMNITY INSURANCE COVERAGE[2]	CLEARLY AMENABLE SERVICE OF PROCESS[3]
Everett, MA from Algeria	Transportation in ships owned by	Gazocean USA, Inc. or Sonatrach (Algerian National company)	* *	*	Louisiana, Texas Texas
Staten Island, NY (Rossville) project being restructured[4]	Originally, 3 ships owned by EASCO, a subsidiary of Citicorp., the First Chicago Corporation and GATX, were to be	Bareboat chartered to separate subsidiaries of Energy Corp. They would time charter to subsidiaries of Burmah Oil Shipping Co.[5]	Nominal-required to maintain working capital by Maritime Administration	* $100 million	* Burmah, Delaware
Cove Point, MD and Elba Island, GA from Algeria, 1978	6 ships, each owned by a	Separate subsidiary of the	For each subsidiary, minimum working capital levels of $10.1 million up to aggregate of $42 million $168.1 aggregate net worth[6]	in excess of $100 million	Delaware, Maryland Georgia
		El Paso LNG Co., which is owned by The El Paso Co.	* $2,410.1 assets	* *	* Texas, Delaware
	3 ships, each owned by a	Separate subsidiary of the	$314 aggregate capital. Net worth and working capital similar to above.	in excess of $100 million	*
		El Paso Maritime Co., a wholly-owned Liberian subsidiary of El Paso Natural Gas Co., which is owned by The El Paso Co.	The net worth and working capital maintained at a lower level than its subsidiaries $2,410.1 assets	* * *	Delaware Delaware Texas, Delaware
Lake Charles, LA from Algeria	2 ships to be furnished by	Lachmar, a 3-way partnership of subsidiaries of:	$332 estimated total capital costs[7]	*	*
		Panhandle Eastern Pipe Line Co. (40%)	$1,694.6 assets	*	Delaware, Texas
		General Dynamics Corp. (40%)	$1,338.1 assets	+	Delaware
		Moore McCormack Bulk Transport, Inc. (20%)	+	+	+
	3 ships to be chartered by the Algerian National Shipping Co. to	Sonatrach	*	*	*
Port O'Connor, TX from Algeria	6 ships to be furnished[8] by	El Paso Atlantic Co., owned by El Paso LNG Co.	N/A *	*	* * *
	6 ships to be furnished by	Sonatrach	*	*	*

TABLE 11-2 LNG SHIPPING COMPANY DATA RELEVANT TO LIABILITY AND COMPENSATION (CONTINUED)

MARINE TERMINAL & LNG SOURCE	SHIPPING ARRANGEMENTS	CORPORATE STRUCTURE	CAPITALIZATION ($ MILLION)	PROTECTION AND INDEMNITY INSURANCE COVERAGE	CLEARLY AMENABLE SERVICE OF PROCESS[2]
Southern California from Indonesia	9 ships to be time-chartered by	Pacific Indonesia LNG Co.	0.6 assets	Value of vessel	California
		owned by Pacific Lighting	1,662.8 assets	*	California
		Corp. and by Pacific Gas and Electric Co.	6,620.9 assets	+	California
	3 ships from	Ogden Marine Indonesia, Inc., owned by	+	+	Delaware
		Ogden Marine, Inc.,	+	+	*
		owned by Ogden Corp.	926.0 assets	+	Delaware
	3 ships from	Zapata Western LNG, Inc.	+	+	Delaware
		owned by Zapata Corp.	796.6 assets	+	Delaware
	1 ship from	Zodiac Shipping Co., N.V.	+	+	Netherlands
		owned by N.V. Nederlandsthe Scheepvaart Unie.	+	+	Netherlands
	1 ship from	Gazocean S.A.	+	+	France
	1 ship from	Odessey Trading Co., Ltd.	+	+	Bermuda
		owned by Ocean Transport and Trading, Ltd.	+	+	United Kingdom
from South Alaska	2 ships built for	Pacific Marine Associates	*	*	*
		owned 50% by Pacific Lighting Marine Co. owned by	12.8 assets	*	California
		Pacific Lighting Corp. and	1662.8 assets	*	California
		50% by Pacific Gas Marine Co.	+	+	California
		owned by Pacific Gas and Electric Co.	6620.9 assets	+	California

1. Sources: Company letters, FERC records, Moody's Public Utilities and Industrial Manuals, 1976.
2. Insurance clubs place no fixed limit on the protection and indemnity coverage available to foreign flag ships, but until a recent change owners of U. S. flag LNG vessels could get this insurance only up to $200 million. British insurance clubs announced in February 1978 that they would offer unlimited protection and indemnity insurance to U. S. flag entries without regard to the value of the hull.
3. This column indicates states in which the company in Column 3 is incorporated or doing business, or maintains agents to receive service of summons and complaint.
4. In May 1977, EASCOGAS withdrew from its contract with Burmah Oil Shipping Company because its Gas Sales Contract with Sonatrach was terminated (the contract required EASCOGAS to obtain FPC approval by May 31, 1977).
5. A bareboat charterer not only charters the hull but also mans and victuals the vessel. Time-charterers hire the services of a vessel for a period of time, leaving its operation to others. Time charterers do not have to carry protection and indemnity insurance because they are not liable for faulty operations.
6. Each ship-owning subsidiary is required by MarAd to have these minimum levels of capitalization.
7. Anticipated sources of capital are: $50 million MarAd construction differential subsidy, $211.5 million from sale of long term debt, and $70.5 million from equity. The debt carries a MarAd guarantee.
8. The El Paso Atlantic Co. will either contract with affiliates or make arrangements with third parties.

* Company would not disclose this information
\+ No letter was sent to the company
N/A Not appropriate.

is raised to $60 per ton of cargo. The 1851 limitation might not be applicable if LEG shipping were declared an abnormally hazardous activity, enabling recovery by injured parties on the basis of strict liability. For a large LEG ship this would be about $3,500,000.

Commerce's Assistant Secretary for Maritime Affairs, in an April 29, 1977, letter to us, described how the ownership structure of LNG vessels is utilized:

> ". . .In general, the ownership of LNG's {ships}, whether they be leased or owned, is by a trust or single-purpose corporation with only one vessel in each trust or corporation. If the vessels are subsequently bareboat or time chartered, they are likewise chartered to single purpose corporations. This structure is specifically utilized to attempt to limit third party liability to the value of the asset {vessel} with no recourse to any other assets. Usually, the obligations of these corporations are not guaranteed by any other party. Guarantees of charter hire or of freights payable under a transportation agreement may be guaranteed by a parent corporation to induce lenders. However, the limit of liability {of parent firms under these agreements} is only to the amount of hire or freights payable and would not in any way guarantee any third party as a result of a casualty. In theory, an injured third party would only have recourse to the value of the vessel and insurance carried by the owner or bareboat charterer. . ."

An LNG ship corporation's major asset is the ship itself. Most of these corporations are not required to carry specified amounts of net worth and working capital. Such requirements are, however, among the conditions imposed under Title XI of the Merchant Marine Act of 1936, as amended, under which a qualified candidate may have the U.S. Government guarantee loans up to 87½ percent of a ship's costs for construction, reconstruction, or reconditioning. The program is administered by the

Maritime Administration in the Department of Commerce. Sixteen U.S. flag LNG carriers are being constructed under this program.

Under this program, the El Paso Company (parent of the El Paso LNG Company) has committed itself to cause each of its LNG ship-owning subsidiaries to have a specified net worth on the delivery date of its tanker, and, if called upon, to make additional specified contributions of capital to each subsidiary for working capital purposes. The aggregate amount of the first of these commitments for all six subsidiaries is approximately $168.1 million, including minimum working capital requirements of $16.1 million. The aggregate maximum amount of the second of these commitments for all six subsidiaries is $42.1 million.

The mortgages on these six tankers will be in favor of the United States, as collateral for the government guarantees. Similar arrangements are required for ships being built for other companies.

When shipowners are required to have substantial net worth, as they are under the Title XI program, injured parties enjoy better prospects of finding assets from which claims might be paid. However, if claims exceed the level of assets required by the Maritime Administration, a court might be less likely to assert jurisdiction over the parent company than it would if no government regulation was involved. A court might seriously consider and defer to that agency's judgment on the adequacy of capitalization of the subsidiary.

Recovery can be difficult if the defendant is a foreign corporation. Foreign nations or nationals own, or expect to own, LNG ships for use in conjunction with terminals in Everett, Staten Island, Cove Point, Elba Island, Lake Charles, and Southern California. Unless a liable corporation has other assets in this country, the ability to recover will depend on whether a U.S. court decree is honored in a foreign court. This may be less likely if the liable corporation is owned by a foreign government.

In order to recover damages, a plaintiff must first locate assets here or abroad. Such a wide-ranging search for proof of assets might be beyond the resources of many plaintiffs.

Findings

- LNG is imported on ships, each owned or leased by a separate subsidiary corporation, and stored in terminals owned by subsidiaries. Parent firms are, in many cases, wholly-owned subsidiaries of still larger firms, which may themselves be wholly-owned or under another firm's corporate control.

- The level most vulnerable to liability is usually the most thinly capitalized. LEG terminal companies generally have no limit on their ratio of debt to equity, and only those ship-owning subsidiaries whose ships are being built under the Title XI program are required to carry specified minimum amounts of net worth and working capital.

- In many cases the major assets may be the ship or terminal itself, which may not survive an accident which does extensive offsite harm.

- Most of the assets in the system are protected by the corporate layers. It would be difficult for claimants to litigate the liability of parent firms for damage caused by an LNG accident. If they did, the litigation would be a long and expensive process, which many litigants could not afford.

- The ownership structure of LNG carriers is designed to protect the assets of owners and bareboat charterers. The statutory limitation on liability further benefits these single-ship corporations or trusts. Even if personal liability is established, available assets may not be sufficient to satisfy claims.

- Claimants attempting to recover damages through foreign assets of foreign corporations will encounter special difficulties, particularly if the foreign corporations are government owned.

LNG LIABILITY COVERAGE

Import Terminal Coverage

Table 11-1 includes data on insurance coverage provided by companies at our request. Among those which responded fully, present or planned terminal coverage ranges from $50 million per incident for Pacific Lighting Corporation's proposed Western LNG Company terminal, to $190.4 million total coverage per incident carried by the co-owners of the Cove Point, Maryland terminal. The $100 million insurance coverage for the Elba Island, Georgia terminal is carried by affiliates of Southern Energy Company, the terminal owner. Southern plans to obtain additional liability coverage before operations begin in 1978.

We could not obtain detailed insurance information for the Everett, Massachusetts terminal, which has been operating since 1971. The terminal is owned and operated by Distrigas Corporation of Massachusetts. The president of Eastern Energy Corporation, Distrigas' corporate parent, replied to our letter to Eastern's corporate parent, Cabot Corporation.

> "The insurance coverage carried by the Cabot LNG companies is in layers, and different policies would respond, depending on the specific circumstances of any particular claim. It is not corporate policy to disclose details or limits of insurance coverage, but we do carry amounts of insurance representing what we believe reasonably prudent management requires."

None of the 50 states requires proof of public liability insurance as a prerequisite to obtaining a permit for dealing, storing, or handling LNG. Ten states do require such proof from LPG companies, but the amount required may be as low as $10,000 per incident; the maximum required anywhere is only $100,000 for any one incident.

LNG Carrier Coverage

Insurance clubs place no fixed limit on the protection and indemnity (liability) coverage available to foreign flag vessels, but until a recent change owners of U.S. flag LNG vessels could get this insurance only up to

$200 million. British insurance clubs announced in February 1978 that they would offer unlimited protection and indemnity insurance to U.S. flag entries without regard to the value of the hull. The insurance data in Table 11-2 were provided in 1977. El Paso LNG informed us that all of its ships are insured against accidents to the maximum extent available in the market, and that in every case this is "in excess of $100 million." Pacific Lighting plans carrier coverage "at least equal to the value of the vessel."

In states which have "direct action" statutes, injured parties can sue the insurers directly, prior to the rendering of a judgment against the owner or charterer. In Independent Towing Company, 242 F. Supp. 950 (E.D. La. 1965), the court held that liability limitation proceedings do not exclude direct action against an insurance company as permitted by Louisiana state law. It held further that insurers, unlike vessel owners and bareboat charterers, cannot claim the protection of the limited liability statute. In states without a direct action statute (for example, Maryland, Massachusetts, and New York) injured parties do not have this recourse.

Shipbuilding Insurance

Prior to navigation, shipyard risks are imposed upon builders, subject to normal contract exoneration terms. Ship-building contractors give a six-month to one-year warranty that does not cover design defects. Design defect liability might be imposed upon marine architects, who are insured independently.

Liability Coverage of LNG Trucking Companies

Under Interstate Commerce Commission (ICC) regulations, LNG trucking companies are required to carry only minimal amounts of liability insurance, but they ordinarily carry much more than the required amount. The ICC regulations call for policies of $100,000 (maximum liability for any one person), $300,000 (maximum liability for one incident), and $50,000 (property damage for one incident). This subject is discussed in more detail in Chapter 7.

Findings

- Present and planned liability coverage for LNG import terminals ranges from $50 million to $190 million per incident. Ten states require proof of liability insurance for LPG facilities, but the maximum required is $100,000 per incident.

- Where there have been no injuries or deaths, the liability of shipowners and bareboat charterers may be limited to the post-accident value of the vessel plus the freight then pending, if they can prove that they did not know of the factors that caused the accident. If there are injuries or deaths the limit is raised to $60 per ton of cargo. For a large LEG ship this would be about $3,500,000.

- The amount of liability insurance coverage the ICC requires trucks under its jurisdiction to carry (up to a total of $350,000 for one incident) is much lower than the amount some gas companies require LNG trucking firms to carry ($10-30 million). A trucker may also be covered under the gas company's liability policies, but if a liable trucker is not acting as the agent of the gas company, claimants may not have access to this coverage.

- A major accident could cause damage of such severity that injured parties could not be fully compensated under existing insurance policies.

SUPPLEMENTAL LIABILITY COVERAGE FOR HAZARDOUS OPERATIONS

The Nuclear Power Experience

The question of how to handle the potentially large but unpredictable liability from public utility installations using new technology confronted Congress in the 1950's with the advent of commercial nuclear power. Congress found that the size of the liability which could result from a nuclear accident and the lack of available, adequate commercial liability insurance were major obstacles to the commercial development of nuclear power.

The Price-Anderson Act, Section 170 of the Atomic Energy Act of 1954, as amended (42 U.S.C. 2210), was enacted in 1957 to solve this problem. It established a combination of private financial protection and government indemnity amounting to a maximum $560 million to cover liability claims that might arise from a nuclear accident at a commercial nuclear facility.

The objectives were (1) to assure the availability of funds to satisfy liability claims in the event of a catastrophic nuclear accident and (2) to remove the deterrent to private investment of possibly enormous liability claims.

The 1957 Price-Anderson Act was regarded as temporary legislation and was written for only a 10-year term. In 1965 the Act was extended an additional 10 years by P.L. 89-210. A second 10-year extension, until August 1, 1987, was enacted by P.L. 94-197.

P.L. 94-197 continues to limit the amount of liability protection (and the liability that may be imposed) to $560 million, even though estimates of economic losses alone range as high as $14 billion.[1] The new amendments spell out for the first time, however, that in the event of a nuclear incident involving damages in excess of $560 million, "the Congress will thoroughly review the particular incident and will take whatever action is deemed necessary and appropriate to protect the public from the consequences of a disaster of such magnitude."

Nuclear power plants must be licensed by the Nuclear Regulatory Commission (NRC). Owners of power reactors are required (10 CFR 140) to have and maintain financial protection in the amount of $125 million for each nuclear reactor with a rated capacity of 100 electrical megawatts or more. Liability insurance is available from two insurance pools: the Nuclear Energy Liability-Property Insurance Association and the Mutual Atomic Energy Liability Underwriters. The amount of financial protection required of reactors of less than 100 megawatts is established with a formula that takes into account the population near the reactor. The amount cannot be less than $4.5 million nor more than $74 million.

The first $140 million of damages from a nuclear incident would be paid out of insurance pool funds. To cover additional damages, the pools could collect up to $5 million for each licensed reactor. With 65 reactors presently operating, these "retrospective premiums" could total $325 million.[2] The Act requires owners to maintain proof of their ability to pay these retrospective premiums.

The Price-Anderson Act requires that the reactor owners must execute and maintain an indemnity agreement with NRC, under which NRC will indemnify the owner for all public liability claims exceeding these two levels of financial protection, up to $560 million per nuclear accident. The Act authorizes the NRC to collect indemnity fees of $30 per year per thousand kilowatts of thermal energy authorized in the reactor's license, with a minimum fee of $100 per year. The annual fee for a 1,000 megawatt (electric) power plant would be about $104,000.

The Supreme Court, in a June 26, 1978 decision, upheld the constitutionality of the Price-Anderson ceiling on nuclear liability. The court reversed a district court ruling that the limitation violates due process.[3]

Hazardous Materials Compensation Fund

We believe that a more adequate liability insurance system is needed for non-nuclear hazardous operations, and that the arrangements should be considered from the viewpoints of both accident prevention and equity. Accident prevention requires that the system provide maximum incentives for safe operations. Equity requires that those harmed are fairly and promptly compensated.

We propose a system somewhat similar to that created by the Price-Anderson Act for nuclear power. Corporations transporting, storing, or using significant quantities of flammable hazardous materials would be required to: (1) carry the maximum liability insurance available from the private sector, and (2) contribute a fixed sum per BTU to a Federal Hazardous Materials Compensation Fund (HMCF). The Fund would pay claims (beyond those paid by private liability insurance) up to a fixed ceiling for any one incident. Non-energy hazardous materials corporations could contribute to the Fund on a different basis.

All the consumers of the gas that goes through a particular facility would bear the costs of private insurance for that facility. All those receiving service from an operation would pay to cover the risks incurred by those near the operation.

All LEG users (and eventually, perhaps, all users of other hazardous materials) would share the cost of building and maintaining the Fund. This is not completely equitable, since customers of safer facilities would be subsidizing customers of less safe facilities. We feel, however, that only through such a Fund will those harmed in an accident, particularly those without large intact resources, be able to get [illegible], fair compensation for claims against very large corporations and insurance companies. The Fund's only task after an accident is to assure that all monies paid out are warranted by the damage done.

In order to make the implicit subsidy involved in the Fund more equitable, we propose that the United States be subrogated to the rights of injured persons compensated by the Fund so that the Attorney General of the United States can sue the companies or persons responsible for the accident for whatever monies the Fund has paid out. The Attorney General will have many more resources available to him for such a suit than will a shopkeeper or homeowner.

The problem with the Price-Anderson Act is that, if an incident causes more than $560 million dollars of damage, there is no assurance that all legitimate claimants will be fully compensated. This is clearly inequitable, and since the costs of their liability insurance and their contributions to the Fund will be passed on to their customers, this provides no incentive for public utilities to improve the safety of their operations.

In order to remedy this concern, we propose that Congress consider legislation which would allow injured parties in a hazardous materials accident to sue individually, or as a class, when permitted by the jurisdiction's rules of civil procedure, for damages beyond those covered by insurance and the Fund, all the companies in the corporate chain back to the beneficial corporate owners (but not including individuals who are stockholders).

In a typical LEG corporate chain the "benefited corporation" at the top controls the lower companies and receives all the profits. An LEG disaster in which the claims exceed the limit that the Fund can pay, would probably destroy most or all of the assets of the frontline company. Thus the benefited corporation, which receives all the profits, may have little more to lose from a disaster that does enormous damage to the general public than from one that only destroys the facilities of the frontline company. This gives it little extra incentive to prevent such a disaster. We think this shows up in the fact that facility components such as dikes are built under standards which are adequate to control small accidents, but are not adequate to stop offsite damage from very large ones.

No expense or administrative burden will be placed on anyone by this provision unless a disaster involving very large damage to the general public occurs. Every company we have talked to considers the possibility of such a disaster to be extremely small. Thus they should have little objection to a requirement that the assets of a benefited corporation be on the line in the event one does occur. Such a provision would improve the equity of the situation and give benefited corporations a strong incentive to prevent such disasters. It would help to remove the burden of possible uncompensated risk from segments of the general public. Some of the risk would be placed directly on the benefited corporations, whose officials could lower the risk by ordering their frontline subsidiaries to build and locate facilities prudently.

Findings

- A more adequate liability insurance system is needed for non-nuclear hazardous operations. The system should include incentives for safe operation and prompt, fair compensation for anyone injured.

LIABILITY LITIGATION

Most of the problems we have discussed have been those that claimants might face once a company's liability had been established in court and a judgment awarded. Claimants' problems in reaching that point are often much greater. It is often difficult to establish the primary cause of a major accident because critical evidence is destroyed. This type of litigation is usually long, complex, and expensive; plaintiffs may encounter jurisdictional problems and hostile legal precedents.

Securing Jurisdiction

The process begins with securing a court's jurisdiction. If the defendant is incorporated or doing business in the state in which a suit is brought, this can be done by serving a summons and complaint. Owners/operators of LNG terminals, for example, must maintain agents to receive such documents in the state where their terminals are located (see Table 11-1), and U.S. flag LNG tanker subsidiaries must also maintain such agents. El Paso LNG Company noted that its various LNG tanker subsidiaries could be sued as a matter of course in Delaware, Maryland, and Georgia, and that, if such companies commit a tort in any other coastal state, they could be sued in that state also. It may not be possible to serve legal documents on some foreign flag vessel owners. Sonatrach, Algeria's national company, does maintain agents in Texas. As noted earlier, foreign assets of foreign corporations are difficult to reach, especially if the foreign corporation is government owned.

If a defendant is not doing business within the state in which a suit is brought, the service necessary to secure jurisdiction must be made under state "long-arm" statutes. To legally extend such an arm, the defendant must be deemed under state law to have "sufficient" contact with the state in which suit is brought.

If the defendant is reached by serving documents on his legal agent, the resulting judgment can be enforced so as to reach all the defendant's assets to satisfy claims. When jurisdiction is secured by attaching an object such as a ship, however, the court is only empowered to dispose of the ship to satisfy claims.

Plaintiffs could face a spectrum of state, and maritime and other Federal laws. Jurisdiction would be complicated if an incident affected persons and property in more than one state: New York and New Jersey, for example, or Maryland and Virginia. Separate trials in both states might be necessary. Some claimants might be able to sue in Federal court, while others could not.

When an administrative agency—for instance, the Federal Energy Regulatory Commission—has jurisdiction over some aspects of a facility at which an accident has occurred, a court may defer judicial proceedings pending the outcome of administrative proceedings. This deferral arises from employment of the doctrine of "primary jurisdiction," so called because the agency originally certified the facility as necessary and reasonable. The doctrine is used because the administrative agency may have the capacity to provide expert insights to the court. However, the delay of judicial proceedings and the need to participate in agency proceedings may work great hardship on a plaintiff because it delays his ultimate recovery and forces him to retain additional counsel, fund additional litigation, and assume additional burdens of proof. If a plaintiff's case is to benefit from a showing that defendant failed to adhere to regulatory requirements, it must also be shown that those requirements were intended to protect persons in the plaintiff's position.

Legal Theories of Recovery

A plaintiff must establish a legal theory permitting recovery which is recognized by the court in which the suit is filed. These include: (1) the attribution of negligence on the part of an LNG operator and (2) strict liability—the assertion that the risk factor in LNG operations is so great that liability for any accident that may occur, regardless of fault, must be accepted by the operator. The availability of non-negligence causes of action (theories of recovery) varies among the states.

A plaintiff may assert that a defendant is liable irrespective of fault because an LNG operation is an ultra-hazardous undertaking, as in McLane v. Northwest Natural Gas Co., 467 P. 2d 635 (Or., 1970), a case arising from the death of a workman at an LNG site. In this case the court held that the storage of natural gas in a populated area is abnormally dangerous because of the inherent risk and not the frequency of harm. The fact that the defendant held a certificate or franchise for the activity was not allowed to bar liability. Similarly, in Yommer v. McKenzie, 257 A. 2d 138 (Md., 1969) the court imposed strict liability in consequence of damages resulting from the leakage of a gasoline tank located near a residential well.

The decision in Doundoulakis v. Town of Hempstead, 381 N.Y.S. 2d 287 (App. Div., 1976) supports imposition of strict liability upon those who engage in an activity which poses a great danger of invasion of the land of others. The court held that it matters little whether the force used is dynamite, gunpowder, or pressure created by accumulating, massing, and diverting large amounts of water, or whether the invasion is by objects projected by explosion. It was noted that a deliberate manipulation of natural forces or resources—frequently on a massive scale—often underlies these invasion-causing activities.

The State of New York has recently enacted legislation which applies strict liability to LNG and LPG operations. The Liquefied Natural and Petroleum Gas Act, 1976 Laws, Chapter 892, determines the storage, transportation, and conversion of LNG and LPG within the state to be hazardous, entailing strict liability on the part of any person who undertakes such activities. Neither regulatory compliance nor the exercise of due care can prevent recovery for personal or property damage caused by the accidental release of LNG or LPG. In addition, Maine imposes strict liability for damages resulting from natural gas operations generally, without specifying any applicability to LNG.

A variant of the theory of inherent risk is the theory of enterprise liability in which a defendant is found to have created, in the course of a profit-seeking undertaking, an unavoidable risk to a plaintiff, and thus to be responsible for the cost of damages that result when that risk materializes.

According to the Restatement of Torts (Second), risks requiring the imposition of strict liability due to abnormally dangerous activity on the site, arise from a meld of factors (Sec. 520): high degree of risk of harm, gravity of potential harm, risk not eliminated by reasonable care, activity not a matter of common usage, activity inappropriate to its location and its value to the community is outweighed by its dangerous attributes.

The 1851 statutory limitation on the liability of shipowners and bareboat charterers might not apply if LEG shipping were declared an abnormally hazardous activity, enabling recovery by injured parties on the basis of strict liability.

The doctrine of <u>res</u> <u>ipsa</u> <u>loquitur</u> (the thing speaks for itself) may be available to help a plaintiff establish liability for negligence. Under this theory, liability for negligence is imputed in the event of an occurrence which would not have happened under normal circumstances without negligence on the part of defendant, to which plaintiff did not contribute, and concerning which defendants are likely to have more information or access to information than is available to the plaintiff. If there are multiple defendants, application of this doctrine requires that defendants jointly control the instrumentality which caused the accident.

For purposes of determining negligence, it may be stated that:

- A shipowner is not liable for the negligence of a harbour pilot if the use of such a pilot is mandatory, but the ship is liable in rem. 2 Benedict on Admiralty §11 (7th Ed. revised).

- Should an accident result from negligence by a ship's master, claims for damage may be brought against him, against the vessel involved, or against the ship's owner personally. (Supra.)

Liability for Damages Caused by Sabotage

Damages resulting from sabotage of an LNG operation constitute a special category. Assignment of liability in such cases would have to be premised on the existence of a duty of care owed to the injured plaintiff. A duty to maintain adequate security is owed to employees and invitees on the premises of a facility or vessel, and may be owed to others offsite. Of course, in the absence of other evidence, a duty of reasonable care would not necessarily be breached by an incident. Even where security measures were less than "adequate," an owner might not be held liable if it appeared that "adequate" security would not have afforded protection. This line of reasoning assumes, of course, that the defendant is not liable under the enterprise theory simply because he caused the dangerous facility to be placed in the community.

Neither the Congress nor the courts have viewed the risk of harm being inflicted intentionally upon a facility or vessel as properly assignable to the owner or operator, unless one or the other is negligent.

Liability for "Acts of God"

Companies are not liable for damages resulting solely from lightning, earthquakes, and other "acts of God." Injured parties would not be compensated.

Findings

- There is no simple procedure for claimants to recover damages from a major LNG accident. Instead, claimants face long, complex, and expensive litigation involving potential complications at every step in the legal process.

- If the defendant corporation is foreign-owned, the corporation may be out of reach.

- Even when it is possible to summon defendants, claimants may encounter a spectrum of state, and maritime and other Federal laws.

- In some states claimants may be able to establish a non-negligence legal theory such as that the operation was an ultra-hazardous undertaking, or created an unavoidable risk to the plaintiff. In other states where such theories are not available, plaintiffs will have to prove that the accident was due to want of care on the part of defendants.

- If damages result from an act of sabotage, liability will be difficult to prove.

- Companies are not liable for damage caused by lightning, earthquakes, or other "acts of God." Injured parties would not be compensated.

- It is not always possible to prove the primary cause of a major accident. Critical evidence may be destroyed in the accident itself.

FAILURE OF AGENCIES TO EXERT FEDERAL JURISDICTION OVER LNG OFFSITE LIABILITY

No Federal agency considers the issue of offsite liability in dealing with LNG operations.

The Federal Power Commission, which had jurisdiction over LNG imports and import facilities, informed us: "No studies have been done by this commission on legal liability of owners and operators. We believe the Courts have the responsibility to decide the liability issue."

We do not agree. Under Section 7 of the Natural Gas Act, projects approved for certification by the Commission must comport with "the public convenience and necessity". We believe the availability of adequate compensation for offsite damage is as much a matter of public convenience and necessity as other safety and environmental issues which the courts and the Federal Power Commission have recognized as the Commission's responsibility.

The courts have construed Section 7 broadly. Among the issues raised in relevant decisions:

1. The Commission may consider the impact a proposed project would have on air quality. See <u>FPC</u> v. <u>Transcontinental Gas Pipeline</u>, 365 U.S. 1 (1961). With the passage of the National Environmental Policy Act, a project's impact on the human environment has become an even clearer element of public convenience and necessity.

2. The Commission is authorized to require that a proposed project be financially feasible and

reliable, and that the applicant be sufficiently financially responsible to support the undertaking. See Kansas Pipeline and Gas Co., 2 FPC 29(1939). The existence or absence of liability can materially affect all of these factors, although the Commission has not yet so viewed it. A liable company with inadequate insurance or resources could be forced into bankruptcy or reorganization, to the detriment of its level of service.

The Commission itself has recognized that it has an obligation to consider the safety of projects coming before it. See, for example, recent decisions in Trunkline LNG Company, Docket No. CP 74-138 (February 18, 1977) and in the Initial Decision in El Paso Alaska Co., et al., Docket No. CP 75-96, et al., (February 1, 1977).

The possibility of public exposure to uncompensated risk is a matter affecting the safety practices and plans of an applicant. It appears that the Commission has not so much rejected, as overlooked, the relevance of compensation for offsite damage. The subject was raised in one interrogatory to the Commission, from the Honorable John Murphy, Member of Congress, regarding LNG imports into New York and Boston. See Distrigas Corporation et al., FPC Docket No. 73-78 et al., and Eascogas LNG, Inc., FPC Docket No. CP 73-47 et al., interrogatory filed June 16, 1976. Representative Murphy asked detailed questions about the kinds of issues examined in our analysis. We believe that such questions should be answered in testimony before the Commission under oath for every LNG facility and terminal. In addition the Commission could require that: (1) a project's Environmental Impact Statement include information about the applicant's ability to compensate for offsite damage; (2) LNG applicants post liability bonds as a condition of certification.

The Commission also has jurisdiction over the LNG importer, who may be a separate entity from the terminal owner or operator. Under Section 3 of the Natural Gas Act, persons wishing to import natural gas must obtain the Commission's permission on such conditions as it finds consistent with the public interest. The Commission has not asserted jurisdiction over the parent corporations of importers. This means that the Commission might require an importer to maintain an agent for receipt of service in a state, but not the importer's parent company.

We believe the Commission could require that LNG applications include all of the real parties at interest (including owners of tankers) and that it should condition the permits upon all parties assuming liability for damages resulting from accidents they cause. This would not be unreasonable; banks which finance ships and terminals require parent corporations up the line to co-sign notes.

{FPC's Section 3 authority over imports was transferred to DOE. The Secretary may assign these functions to either the Federal Energy Regulatory Commission or to the Economic Regulatory Administration. The final distribution of responsibilities within DOE has not been completed. The substance of the discussion above remains valid.}

Findings

- No Federal agency considers the question of offsite liability of LNG operations. This includes the

Federal Energy Regulatory Commission which is responsible for granting Certificates of Public Convenience and Necessity or licenses for LNG facilities. The Commission's position is that the liability issue is solely for the courts to decide.

- The courts have not precluded the Federal Power Commission from considering environmental and safety issues under Section 7 of the Natural Gas Act. We believe the availability of adequate compensation for offsite LNG damage falls within this range.

- The DOE agency with Section 3 responsibilities could require importers to maintain agents for the receipt of legal documents in all states in which they operate. We believe Section 3 also confers sufficient authority on the agency to assert jurisdiction over LNG tanker companies transporting imported natural gas.

RECOMMENDATIONS

TO THE SECRETARY OF ENERGY AND THE FEDERAL ENERGY REGULATORY COMMISSION

We recommend that the Secretary of Energy and the Federal Energy Regulatory Commission take steps to:

- ensure that adequate compensation for offsite damage is available before permitting LNG projects to proceed.

- use their authority to require that importers and LNG tanker companies maintain agents for the receipt of legal documents in all states in which they operate.

- consider their possible authority to require the parent corporations of LNG tanker companies, which apply to transport imported natural gas, to assume joint liability with the applicant for damages resulting from accidents they cause.

TO THE CONGRESS

We recommend that the Congress:

- enact legislation which requires that strict liability be applied in all accidents involving LNG and LPG.

- amend the 1851 Act (46 U.S.C. 183) which limits the liability of owners and bareboat charterers of ships and barges by substantially raising the statutory limit for vessels carrying hazardous materials.

- enact legislation creating a more adequate liability insurance system for non-nuclear hazardous material operations that would:

1) - Require corporations transporting, storing, or using significant quantities of flammable hazardous materials to

   -carry the maximum liability insurance available from the private sector.

   -contribute a fixed sum per BTU to a Federal Hazardous Materials Compensation Fund (HMCF).

2) - Provide that the United States be subrogated to the rights of injured persons compensated by the Fund, to allow the Attorney General of the United States to sue the companies or persons responsible for an LEG accident to recover whatever monies the Fund has paid out.

3) - Allow injured parties in a hazardous materials accident to sue individually, or as a class when permitted by the jurisdiction's rules of civil procedure, for all damages beyond those covered by insurance and the Fund, all of the companies in the corporate chain.

AGENCY COMMENTS AND OUR EVALUATION

The Department of Commerce states:

". . .The conclusions and recommendations with respect to statements requiring that the companies involved in supplying LNG and LPG be liable to the full extent of the assets of their parent corporations would be totally unacceptable to any corporate board of directors. If the liability conditions suggested by the GAO were to be imposed on the industry, the effect would surely be the total withdrawal and disinvolvement of private enterprise with LEG projects or any project that has unlimited risk. No private corporation could assume that type of exposure in any one element of its overall business activities. Such a requirement would have the same effect on the industry as the Cleveland disaster in 1944, which as the report indicates virtually halted the use of LNG for 20-years. . ."

Commerce also states:

". . .it is illogical to believe that government officials from the many agencies that are involved in regulating liquefied energy gases would permit participating companies to engage in unsafe operating procedures that would prove ultimately inadequate and unsafe to the public. . ."

If the risk of an accident involving extensive offsite damage and injury is negligible, it is difficult to see why extending liability to the corporations which get all the profits would make a profitable venture "totally unacceptable to any corporate board of directors". Corporate boards frequently take very substantial risks for profit. It is at the heart of the free enterprise system. If, on the other hand, the risk of extensive offsite damage and injury is not negligible, it seems unfair that those who happen to live or work near a facility and get no profits should have to risk their lives and property, while the corporations which receive guaranteed profits do not even have to assume the financial risk of liability for the damage.

The Federal Preparedness Agency states:

> "We agree with GAO that there is insufficient liability protection on LNG facilities. The recommendations appear well founded with an urgent requirement that they be acted on to assure adequate protection for this public. . ."

The Department of Transportation states:

> ". . .A number of statements concerning liability are inaccurate or overly broad. However, it is likely that there is a need for a new liability and compensation system. Such a system should be established by a comprehensive Federal statute addressing preemption, liability, liability limits, creation of a compensation fund, and other necessary legal issues. . ."

REFERENCES

1. Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants. U.S. Nuclear Regulatory Commission, WASH-1400, October 1975.

2. Telephone conversation with an official of the Nuclear Regulatory Commission, April 5, 1978.

3. Carolina Environmental Study Group v. United States, 431 F. Supp. 203 (W.D.N.C. 1977), prob. juris. noted, 434 U.S. 937 (Nos. 77-262 and 77-735, argued March 20, 1978. Duke Power Company v. Carolina Environmental Study Group, Inc., Nos. 77-262 and 77-375, U.S.L.W. 2845 (June 26, 1978).

CHAPTER 12

SAFETY RESEARCH AND DISPERSION MODELS

CONTENTS

CONTENTS

INTRODUCTION

This chapter gives a methodology for LEG safety research, discusses important past Federal and private studies, and evaluates current Federal programs and proposals. The next chapter reviews past work in two related critical areas: detonation and flame propagation in LEG clouds. The highly technical parts of both chapters are printed in italics. Non-technical readers may omit them.

Because we are critical of the direction, level, and duration of Federal research plans, and because the time when the result will be most useful is short, we make detailed suggestions in this and the following chapter for a program that would cost much less, take less time, and get more useful results. This research needs to be undertaken as soon as possible.

BRIEF OUTLINE OF RESEARCH ACTIVITIES

A number of civilian government agencies have been involved with LEG safety research. These include the Federal Power Commission (FPC), the National Bureau of Standards (NBS), the Energy Research and Development Administration (ERDA), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and several offices of the Department of Transportation (DOT), including the Office of Pipeline Safety Operations (OPSO) and the U.S. Coast Guard. See Appendix XII.

NBS has been primarily concerned with properties of materials, literature surveys, and data retrieval. NASA has maintained a bibliography of relevant published material. OPSO has sponsored state of the art studies and analyses of incidents. Studies of vehicle accidents have been made elsewhere in DOT. The Coast Guard has sponsored a considerable body of LEG research as part of its responsibilities for marine transportation. For some time they have been funding studies of dispersion, flame propagation, and detonation, at the U.S. Naval Weapons Center at China Lake, California. NSF has sponsored research, and the Department of Energy (DOE) is currently planning a program of LNG research evaluated below.

In addition, a large amount of research has been carried out under private sponsorship, and in the preparation of Environmental Impact Statements by FPC.

AIMS

In order to assess the worth of past and projected research activities, it is necessary to consider the purposes they are intended to serve.

The primary goals of Federal research in this area should be:

- To clarify the hazards, risks, and consequences of LEG operations so that appropriate regulations can protect the public, i.e., as an aid in formulating or modifying regulations.

- To aid in assuring that the plans and practices of operating facilities are adequate to satisfy the regulations.

NATURE OF THE PROBLEM

It is convenient to divide safety research problems into three categories: hazard assessment, risk assessment, and damage assessment. These respectively address the questions:

1. What hazards could lead to a disaster?

2. a) In what ways can each disaster occur?
   b) What is the chance of each of these ways occurring?

3. What damage can be expected from various levels of disaster?

In addition to these questions, research can directly address such questions as:

4. Will current or planned safety systems provide the safety expected of them?

5. Do current regulations and procedures adequately ensure safety in specific areas?

6. What steps can be taken to reduce risks and what are the relative costs of such steps?

Comments on the status of each of these areas follow.

HAZARD ASSESSMENT

If an evaporating LNG spill does not catch fire, the resulting cloud of vapor will eventually dissipate. Four key questions are:

1. How long will it take for an LNG spill to disperse harmlessly?

2. How far can a cloud of vapor travel before it becomes harmless?

3. Under what circumstances can such a cloud detonate?

4. What sort of combustion takes place if the cloud ignites at various stages?

There has been some research effort and controversy over these questions. In particular, there is considerable disagreement over the distance a cloud might move and still be flammable,[1-12] and uncertainty as to the behavior of very large clouds. Detonation is discussed in detail in Chapter 13.

Flame Propagation Models

Most discussions of hazards from LNG-air clouds assume that a flame ignited on the downwind edge of the cloud will burn back to the source. A flame propagates in a natural gas-air cloud at 6-12 miles per hour. High wind speeds increase air turbulence and thus flame propagation speeds. But it is not possible from present knowledge to tell whether a flame front ignited on the downwind edge of a cloud in a high wind would burn back to the source or be carried forward by the wind. In a recent test at China Lake, the cloud from a small spill on the pond spread onto the land in a light wind. After ignition on the land, the flame front burned back to the shoreline and then stayed burning there until almost all the vapor was consumed. It then burned back to the source. This totally unexpected effect has not yet been explained. In another test, a spill on the pond was ignited at its center and the flame remained there without spreading. The explanation for this is also unknown. The appearance of these unexpected phenomena during relatively few, quite small tests further illustrates how little is understood about flame propagation in such clouds.

Much less research has been done on dispersion and flame propagation in LPG clouds than in LNG clouds. Thus, these phenomena are even less understood for LPG than for LNG.

Finding

- Very little reliance should be placed on present models of flame propagation in LEG-air clouds in evaluating the dangers of possible spills during operations.

Large Pool Fires

Most discussions of the consequences of an LEG ship tank rupture assume that a large pool fire will result. It is not presently known, however, whether a very large pool of burning LNG on the water could produce a large fireball in the air. A large cloud of LPG might produce a fireball or detonate. A fireball or a detonation would be much more dangerous than a pool fire.

Finding

- It is not prudent to assume that a very large pool fire cannot form a fireball.

Land Spill Hazards

While there has been some research done on cloud dispersion and flame propagation from water spills, there are hazards associated with land spills from storage tanks, railcars, or trucks on which almost no research has been done. For example:

1. Spillage of LEG into sewers, subway tunnels, or other conduits. In the previously discussed 1944 Cleveland incident, much of the destruction was caused by LNG and cold natural gas entering sewers and basements where it produced explosions and fires. Among the questions associated with LEG hazards of this kind are:

   a) Assuming a spill into a sewer system, how far can LEG flow before vaporizing?

   b) Under what circumstances will the gas enter buildings and explode?

   c) What are the consequences of a spill into a subway, railroad, or highway tunnel? In particular, how wide an area would be affected? What would the effects be?

   d) What are the effects of LEG or gas in the basement of a modern multi-story structure?

e) What configurations or environments are particularly vulnerable to spills of this kind?

f) What is the credible damage from an accident in each of several possible environments?

2. Secondary fires and explosions. Under what circumstances will secondary effects amplify the hazards from a fire caused by a spill? Will the secondary effects feed back and enhance the direct destructive effect of the spill?

Questions of this kind depend on the site involved. The danger of secondary fires and explosions is greater if the surrounding area contains flammable materials and structures. Junk yards, for example, present this kind of hazard. An important question is whether or not LEG poses a significantly higher danger than gasoline or petrochemicals in generating secondary effects.

3. Neighboring facilities containing hazardous materials. LEG facilities are sometimes located near other tank storage sites, sewer plants, or other places that store hazardous materials. An earthquake, sabotage, or some other cause could result in a combined spill and conflagration involving several facilities. Also, fire or a shock wave from one facility could spread to another, producing a higher level of hazard than from any one alone. The existence and nature of

the augmented hazard from different types of neighboring sites should be investigated.

4. Sabotage. An individual or group intent on causing public damage may be able to create hazards at LEG facilities that might otherwise be so unlikely as to be ignored. It is important to explore such potential hazards.

Finding

- There has been no effort in recent years by the Federal Government to answer questions of the kind described in 1-4 above, nor is any contemplated as far as we can tell.

Federal Plans for Hazard Assessment

DOE is presently planning a $50 million program of research over the next 5 years which will be focused primarily on LNG hazard assessment.[13] The major expenditure ($35 million) is for building storage tanks and facilities at a testing ground in order to produce and analyze very large (1,000 cubic meter) spills.

Investigations of vapor dispersion and flame propagation characteristics, and of potential control techniques are also planned. There have already been a number of conflicting studies of vapor dispersion, and specific recommendations for future research have been published. Vapor dispersion and flame propagation problems are important, and clearly deserve further study. Unfortunately, however, large scale experimentation is not scheduled until FY-1982. By the time the results are available, the questions may be moot since most facilities will have already been approved. Further, it is not clear how the experiments will produce useful information. (Will large-scale releases be sudden? Will they be allowed to drift? Will they be over land or water? What wind conditions will be tested?)

Current fluid dynamical modeling of LNG spills has little sophistication. The magnitude of the potential hazard requires much better effort than various current estimates of downstream methane concentration, which differ by more than a thousand percent. The credibility of predictions from future models will depend on successful scaling tests comparing numerical experiments with laboratory and field experiments. To establish the validity of the scale dependence and hypotheses contained in the models, extensive small scale studies of all parameters are needed, followed by a few critical larger scale (350 cubic meter) tests.

DOE's program uses an unnecessarily long time to develop credible models for spills, vapor dispersion, and flame propagation. We believe that all needed small scale experiments could be finished by mid-1979, leading to a highly plausible prediction scheme for the few large scale field tests in late 1979.

The differences in the predictions of the vaporization rate of spills are perhaps the easiest factor in previous calculations to improve upon, with a more complete parameterization of convective heat flux from ocean and air into the spreading LNG layer.

Finding

- DOE's research plans will take too long to carry out to have much impact on the siting or design of most facilities. Its research program aims to subsidize the general development of LNG use and increase basic scientific knowledge rather than quickly attack specific safety issues. The necessary development of accurate spill models could be completed by late 1979.

RISK ASSESSMENT

Research on the risk of LNG spillage from tankers has been carried out under Coast Guard sponsorship. Studies of the risks of LNG shipping and storage tanks at proposed terminals at Los Angeles, Point Conception, and Oxnard, all in California, were done by Science Applications, Inc. (SAI) under sponsorship of the proposers of the projects. The FPC has studied the risk at several facilities. These and similar studies are summarized in Reference 1.

Risk assessment first lists all possible sequences of events that can produce disaster, and then attempts to assign probabilities to each element of these sequences and thus to entire sequences.

The validity of risk assessment depends on the following factors:

- Have all significant disaster paths been identified?

- Have the probabilities of all the sequence elements been accurately assigned?

- Have the couplings and interactions among these sequence elements been correctly analyzed?

Typically, a poor risk assessment study underestimates risks because it overlooks disaster paths and underestimates couplings among elements.

SAI Risk Studies

The most comprehensive risk studies to appear so far are the SAI studies of Los Angeles, Oxnard, and Point Conception.

The SAI study of the proposed Los Angeles LNG facility finds that the probability of a tank rupture on a ship is rather high, approximately one in ten over the twenty year lifetime of the facility.[3] SAI, however, uses a model in which vapor typically spreads 1.2 miles in a flammable state. Thus, they find the onshore risk from such spills to be small since they claim the likely collision region is 2 to 7 miles offshore.

J. Havens assessed SAI's estimate of flammable cloud dispersion distance and comparable estimates made by other investigators: .75 miles (Federal Power Commission); 5.2 miles (American Petroleum Institute); 11.5 miles (Cabot Corporation); 16.3 miles (U.S. Coast Guard CHRIS); 17.4 miles (Professor James Fay); and 25.2-50.3 miles (U.S. Bureau of Mines).[2] According to Havens: "The FPC estimate, in the author's opinion, is not justified. . .In the author's opinion, the predicted maximum distances of about 5 miles by Feldbauer and about 1 mile by SAI. . .cannot be rationalized on the basis of any argument thus far advanced except that of gravity spread/air entrainment effects and experimental verification of those effects has not been adequately demonstrated."

SAI's Dispersion Model

A spill from a ship tank rupture has three phases.

1. The spilling out of liquid over the water, and its spread and evaporation.

2. Propagation of the vapor when the liquid has all evaporated, but the resulting cloud of vapor is still heavier than air.

3. The subsequent spreading and dispersion of the vapor when, through increase in temperature, it has become no more dense than air.

There is not much controversy about the first phase; the liquid would be heated very rapidly by the water and would evaporate at a rate of roughly an inch per minute, according to most experts. The FPC model, however, uses a much lower evaporation rate which causes its very small distance to nonflammability.

The third phase represents a phenomenon that is less understood, but there are vapor dispersion models that apply to similar phenomena. Models such as SAI's can be checked and calibrated for behavior in this phase.

Models of the second phase, however, are controversial. There is a cloud or fog of heavy vapor above the water, undergoing rapid heating from the 32°F water below and gravitational slumping. The vapor mixes with the atmosphere, which is cooled and stratified by it.

In describing the second and third phases, SAI uses numerical computations based upon conservation laws and empirical eddy transport equations in the average concentration of vapor. SAI's calculations involve average quantities only.

The crucial assumption in SAI's approach which results in a short distance to the lower flammable limit is probably wrong. *In their model the rate of vertical mixing of concentration is related by a "vertical eddy diffusivity" to the rate of change of concentration with height. A similar model is used for momentum diffusion. As defined, these diffusivities are complicated functions of the entire system. SAI models the momentum diffusivity at a point as a function of height above the ground and the computed temperature gradient. The diffusivity for momentum is chosen to match normal atmospheric experiments. The normal atmosphere value is also chosen to calibrate the concentration diffusivity.* The consequence of these assumptions is that there is no clear boundary between the vapor cloud and the air, and enormous mixing is predicted at the edge of the vapor cloud.

This phenomenon is not suggested by any experiment. It stems, rather, from the use of a mathematically simple model for diffusivity in a range where it has not been tested. One would, on the basis of physical intuition, rather assume that the local wind shear at the top of the dense vapor cloud determines the magnitude of vertical mixing.

California's Energy Resources Conservation and Development Commission, in its August, 1977 draft report, "LNG Siting: An Assessment of Risks", also was skeptical of the manner in which entrainment and mixing are modeled in SAI's code.

There are alternate simple diffusivity models. An opposite extreme from SAI's would be a model in which the diffusivity is related to the distance from the top of the cloud rather than from the sea. Such a model for phase two would have very different consequences than SAI's.

As a result of the large amount of mixing predicted by SAI's diffusivity model, vapor concentration falls rapidly from vertical mixing and there is comparatively little spreading before it is diluted.

Data from small scale confined spills suggests that the diffusivity assumptions in the SAI model could be modified empirically to deal adequately with large scale spills. However, careful scaling from a series of different size spills is needed. It should be possible to determine the validity of these assumptions instead of guessing about them.

Estimates made by our consultants indicate that SAI's results for distance to flammability (1.2 miles) are likely to be five to ten times too low, i.e., the distance to flammability is probably 6 to 12 miles.

Finding

- SAI's dispersion distance computations are based on models chosen for mathematical simplicity and have no experimental basis. Because of their models' short distance to the lower flammability limit, SAI may have seriously underestimated the onshore risk of tank rupture at sea. Testing of models and suitable improvements to them can be made by small scale experiments along with larger size tests of scaling. Results should be obtainable in one to two years.

At Oxnard and Point Conception, SAI's calculation of risk does not take into account possible collisions in the shipping channels. Ignoring this risk may be unjustified in light of the previous discussion. On the basis of its computations, SAI finds that no more than 97,000 fatalities would occur in an incident and this number has a probability of only 5×10^{-50} per year. (Apparently SAI considers the probability that its dispersion computations are wrong and one of the others right to be less than 10^{-40}.) On the other hand, T. Needels[2] of FPC agrees that FPC dispersion calculations may be wrong, but suggests that the chance of a major tank rupture is very small. In reference to Havens' report he writes, "Your otherwise fine report may therefore permit misleading information because it analyzes essentially impossible events."

Finding

- The short SAI dispersion distance is crucial to the low risk reported by SAI. A substitution of 6 or 12 miles for the 1.2 miles used would dramatically increase estimates of LNG risks at Los Angeles.

Storage Tank Rupture

SAI essentially rules out storage tank rupture from normal use by the following reasoning. Since critical crack length greatly exceeds tank thickness, cracks will leak long before they pose a danger of rupture. There is a one in a thousand chance per year of a leaking crack, but only a one in a million chance that the leak will fail to be detected and the crack repaired before rupture. Earthquakes are assumed to reduce critical crack length, but could, according to SAI, shatter a tank only if the quake reduced critical crack length to tank thickness. This would require an extraordinary earthquake. However, this reasoning does not apply to outer tanks which do not leak if cracked, and which have the potential to damage or crack the inner tank if they collapse. SAI does not consider this possibility. What is more, as is shown in Chapter 3, if a tank fails in an earthquake, the most likely mode of failure is for the tank walls to lift off and separate from the tank bottom, spilling the contents. SAI also ignores the possibility that a crack of critical length might be induced by sabotage, as discussed in Chapter 9.

Another difficulty in SAI's risk analysis is that it was made before the proposed facilities were fully designed. Thus, flaws in design, construction, or operation that would lead to safety problems were ignored.

The SAI studies conclude, therefore, that the primary means by which a land facility can fail and cause a disaster is by being hit by an airplane. Such an event could rupture inner and outer tanks and dikes as well. Many other possible disasters are considered, but all are calculated to have very much smaller chances of occurring than a plane hitting a facility (which is estimated to occur once in a million years).

In part, the small probability calculated for most disaster sequences in LNG risk analyses stems from the fact that at least two simultaneous unlikely events are required for them to occur.

Unfortunately, it is possible for a single initiating event to produce simultaneous failures. Indeed, it is typical that failure of one component or system produces failures of others, and one cause may produce several failures. SAI's assumption that a disaster requires a number of independent occurrences is questionable, because several systems can fail from one source.

For example, in the 1944 Cleveland incident (see Chapter 10), shocks of some sort apparently produced a small crack in one inner tank. It may be that leakage through this crack over a relatively long time eventually led to exposure of the outer tank and a massive spill. Fire from this spill then produced rupture of another inner and outer tank. Thus four tanks, two inner and two outer, probably ruptured from a sequence started by one cause.

If 1944 data and the SAI study methods were used to compute the probabilities of a tank rupture, the probability associated with four tanks rupturing at roughly the same time (even including the "common mode" computations used) would be less than one in ten million. Yet four tanks did rupture at roughly the same time probably as a result of a perfectly natural and not unlikely sequence of events, starting from not very improbable small cracks. Even though for a long time there was substantial evidence of a small leak, which was investigated by the gas company and the tank builders, the leak was not repaired. In the light of what happened in

Cleveland, it is hard to justify SAI's probability of one in a million for leaks not being detected and repaired before rupture.

The low dikes used in many facilities will not hold all the LEG that would emerge in a sudden massive tank rupture. As shown in Chapter 5, a high percentage of the fluid could surge over the dike. All the risk assessments so far have assumed that such spills would be confined to the enclosed diked area, unless the dike also failed.

None of the probabilities calculated in any of the LNG risk assessments consider sabotage. Thus, the chance of failure from malicious action has to be added to the calculation. We do not think that this can be done with present knowledge, but without sabotage probabilities, any total risk calculation lacks much usefulness.

DAMAGE ASSESSMENT

Damage assessment has been examined under contract to the Coast Guard and as part of several risk assessment studies.

Among the major problems not adequately addressed in these assessments are the following:

- Secondary fires.
- Dike overflows.
- Presence of other hazardous materials nearby.
- Problems associated with sewers and other underground structures.
- Effects of sabotage.

EFFECTIVENESS OF SAFETY SYSTEMS

In the past, OPSO and the Coast Guard have studied the effectiveness of proposed procedures, equipment, and safety devices, but their research budgets are no longer adequate for them to pursue such research effectively. It is important that these studies be done by the agencies involved in regulating the areas. Only they have the direct hands-on knowledge that makes such research to the point.

ADEQUACY OF SAFETY REGULATIONS

Provisions in OPSO's Advance Notice of Proposed Rulemaking would strengthen the previous LNG safety standards in many respects and may be controversial. Neither OPSO nor the Coast Guard have enough research funds to evaluate the adequacy of the existing industry codes or the proposed standards.

LONGEVITY OF LNG OPERATIONS

Large-scale LNG operations will probably be over by the end of this century. Most large LNG facilities have already been planned, licensed, or built. Five years from now there will be few, if any, left to build. A very expensive research plan such as DOE's, which aims at increasing basic knowledge over a five year period (to start sometime in the future) instead of concentrating on answers in the next two years, is a misuse of resources. DOE has already spent one critical year planning such a program. It is unlikely to publish substantial results much before 1980. Most results will probably come after that. These will have little effect on what is actually built.

In several chapters of this report we have suggested other specific research items and programs. Most of these can be carried out in the next two years.

CONCLUSIONS

- The present plan to channel the bulk of LNG safety research through DOE is faulty and will not produce timely or useful safety results. DOE plans to support LNG research in a manner analogous to its support of research in other areas. This is entirely inappropriate in relation to the safety of facilities now under development, under construction, or in use. The research needed for current, temporary technology is different from that which is needed for long-term and not yet perfected technologies. At the same time, the organizations directly responsible for safety have inadequate budgets and personnel to make informed technical judgments on safety.

- Good quality hazard analysis has been carried on primarily by the Coast Guard. Its emphasis, however, has been on the effects of a spill on water. There is a need for much more thorough hazard analysis of the interaction of LEG spills with man-made structures such as buildings, subways, sewers, and ships.

- Building expensive, new facilities for very large (1,000 cubic meter) experimental spills is not a sensible way to spend LNG safety research funds. It is unlikely that any results can be obtained in this manner soon enough to affect the design of most facilities.

- LEG risk assessment studies have not reached a stage where they give confidence in their conclusions. Therefore, safety decisions cannot logically be based on them. Regulatory agencies will have to make timely, prudent decisions with the realization that many important questions cannot presently be answered with confidence.

RECOMMENDATIONS

TO THE CONGRESS

We recommend that the Congress provide to the organizations directly responsible for LEG safety (OPSO, FERC, ERA, NHTSA, OHMO, Coast Guard, etc.) adequate budgets and personnel to make informed technical judgments and do research on safety procedures and equipment to be used under their jurisdiction. Adequate funding should eliminate the need for agencies to share costs of hazard studies with private industry.

TO THE SECRETARY OF ENERGY AND THE SECRETARY OF TRANSPORTATION

We recommend to the Secretary of Energy and the Secretary of Transportation that:

- The primary goals of Federal research on hazardous materials be to: (1) clarify the hazards, risks, and consequences of their use, so that appropriate regulations can protect the public; (2) aid in assuring that the plans and practices of operating facilities are adequate to satisfy the regulations; and (3) investigate techniques to reduce the risk of their storage and transportation.

- An immediate, significant research program be focused on the interaction of spills of hazardous substances with man-made structures such as buildings, subways, sewers, and ships.

- An immediate program be started to investigate the possibility of preventing or mitigating the effects of sabotage on the storage and transportation of hazardous materials in populated areas.

TO THE SECRETARY OF ENERGY

We recommend that the Secretary of Energy replace immediately the department's present LEG safety research plans with a less costly, two-year effort focused on the sort of studies of detonation, fire characteristics, flame propagation, vapor dispersion, crack propagation, and interaction with man-made structures that we have outlined in this and other chapters. The research program should also seek to determine the best remedial measures for dealing with fires from LEG spills.

NOTE: Agency comments on LEG research and our evaluation of the comments follow the recommendations in Chapter 13.

REFERENCES

1. "Draft LNG Siting: An Assessment of Risks," State of California Energy Resources Conservation and Development Commission, Facility Siting Division (August 1977).

2. Havens, J., "Predictability of LNG Vapor Dispersion from Catastrophic Spills into Water: An Assessment," U.S. Coast Guard (April 1977).

3. "LNG Terminal Risk Assessment Study for Los Angeles, California," SAI-75-616-LJ (January 1976).

4. "LNG Terminal Risk Assessment Study for Oxnard, California," SAI-75-615-LJ (December 1975).

5. "LNG Terminal Risk Assessment Study for Point Conception, California," SAI-75-616-LJ (January 1976).

6. Burgess, D.S., J.N. Murphy, and M.G. Zabetakis, "Hazards of LNG Spillage in Marine Transportation," U.S. Bureau of Mines, performed for the U.S. Coast Guard (NTIS AD-705078) (1970).

7. Burgess, D.S., J. Biordi, and J. Murphy, "Hazards of Spillage of LNG into Water," U.S. Bureau of Mines, performed for the U.S. Coast Guard (NTIS AD-754498) (1972).

8. Feldbauer, G.F., J.J. Heigl, W. McQueen, R.H. Whipp, and W.G. May, "Spills of LNG on Water - Vaporization and Downwind Drift of Combustible Mixtures," Esso Research and Engineering Company Report No. EE61E-72 (performed for the American Petroleum Institute 24 November 1972).

9. Germeles, A.E. and E.M. Drake. "Gravity Spreading and Atmospheric Dispersion of LNG Vapor Clouds," Fourth International Symposium on Transport of Hazardous Cargoes by Sea and Inland Waterways, sponsored by U.S. Department of Transportation (U.S. Coast Guard), Jacksonville, Florida, 26-30 October 1975.

10. Raj, P.P.K. and A.S. Kalelkar, "Assessment Models in Support of the Hazards Assessment Handbook (CG-446-3)," prepared for DOT, U.S. Coast Guard January 1974 (NTIS AD-776617).

11. Fay, James A. and David H. Lewis, Jr., "The Inflammability and Dispersion of LNG Vapor Clouds," Fourth International Symposium on Transport of Hazardous Cargoes by Sea and Inland Waterways, sponsored by U.S. Coast Guard, Jacksonville, Florida 26-30 October 1975.

12. "Draft Environmental Impact Statement for the Construction and Operation of an LNG Receiving Terminal at Los Angeles, California, Volume II," Federal Power Commission, Western LNG Terminal Associates Docket No. CP 75-83-2 (September 1976).

13. Draft ERDA LNG Safety and Environment Control Program.

CHAPTER 13

DETONATION AND FLAME PROPAGATION RESEARCH

CONTENTS PAGE

INTRODUCTION

The purpose of this chapter is to review the most pertinent experimental research that has been performed on the detonatability of LNG and LPG vapor-air mixtures, to suggest the critical unanswered questions, and to recommend research which would answer these questions within the next 1 to 2 years. Certain recent theoretical models are also briefly reviewed. In the closing section we analyze the possibility of a flame propagating upwind through an LEG vapor-air cloud. The highly technical parts are italicized. Non-technical readers may omit them.

A detonation is a combustion (burning) wave moving supersonically. The combustion is so rapid that a high temperature is reached before the mixture has much chance to expand, thus producing a high pressure that is essentially independent of the presence of confining walls. (The maximum detonation pressure is 250 pounds per square inch (psi).) In contrast, a deflagration is a flame front which moves at subsonic speed, generally building up little pressure unless the mixture is confined in a closed or nearly-closed structure. The more general term explosion usually denotes any sudden gaseous expansion which produces a loud noise. Explosions include detonations as well as milder events such as the bursting of buildings due to deflagrations inside, or pressurized gas bottles blowing up.

The planned rapid increase in the domestic shipment and storage of LEG makes urgent the question of whether destructive detonations are possible. Very large amounts, 150,000 cubic meters or more, will be shipped or stored in one place. If even a small part of this amount were spilled and the ensuing vapor-air cloud detonated, the resulting blast wave could injure people and damage structures miles from the cloud center.

LNG is primarily methane (65 to 99% by volume), with smaller amounts of the heavier hydrocarbons ethane and propane.[1] Methane burns when mixed with air within the flammability limits (5.3 to 15.0% methane[2]), but methane-air mixtures are very difficult to detonate. This is supported by laboratory and field experiments[3,4,5] and by the fact that no accidental detonations are known to have occurred over decades of commercial and residential usage of natural gas. However, experiments have shown that methane-air mixtures in large pipes can be made to detonate.[3,6] And very recently it has been shown that even unconfined homogeneous mixtures will detonate, if they are large enough in volume and initiated with several kilograms of high explosive.[5,7] Moreover, in contrast to natural gas at room temperature, the cold vapor from an LNG spill is denser than air. Thus, a large cloud may be formed near the ground. A large cloud may be detonatable. Finally, boil-off of spilled LNG may result in fractional distillation,[8] so that the last part of the vapor cloud to be formed contains principally ethane and propane, which are considerably easier to detonate than methane.[9]

LPG is composed primarily of propane and butane, in relative proportions that may vary widely.[10] These gases have similar detonation properties, when concentrations are measured relative to the stoichiometric* value for each mixture,[9,11] and both are significantly easier to detonate

*A stoichiometric mixture is one that has exactly the amount of oxygen needed for complete burning.

than methane.[9] There has been at least one well-investigated accidental detonation of an unconfined propane-air cloud, which was released by a break in a pressurized propane pipe. The detonation was apparently initiated by the explosion of a concrete warehouse.[12] There is no doubt that for comparable amounts LPG presents a greater detonation hazard than LNG.

STATEMENT OF THE PROBLEM

The general problem addressed in this chapter is whether large releases of LNG or LPG can lead to detonations, initiated by sources that might be present in the vicinity of LEG storage facilities or transportation routes, and if so, what fraction of the total fuel spilled would contribute to the detonation. This general problem can be subdivided into the following technical questions:

1. If LNG is spilled on water or land, is there significant separation of the hydrocarbon components during the boiloff?

2. What are the spatial and temporal variations of the fuel vapor concentration in the vapor-air cloud formed when LNG or LPG is spilled and the variations in the hydrocarbon composition for LNG if differential boil-off occurs?

3. What types of sources could initiate detonation in the vapor-air cloud formed by an LNG or LPG spill, or in the aerosol cloud of liquid droplets formed by the violent disruption of an LNG or LPG container? For experimental

convenience in preliminary investigations, this question may be replaced by the question: Will any of these sources detonate homogeneous vapor-air or uniform liquid droplet-air mixtures? Such homogeneous situations represent "worst cases", and the large vapor clouds from actual releases may contain nearly uniform regions, at least part of the time. Two other important questions are:

a. Since it is well established that explosive gases can be detonated more readily in large tubes than in unconfined regions, is it possible that in an LEG release a detonation might be started in a storm drain, tunnel, or similar structure and propagate from there to the unconfined cloud?

b. Since mixtures of air with LEG vapor are much easier to ignite than to detonate, and since many explosive mixtures are known to make a transition from a deflagration to a detonation if a long enough burning path is available, can such a transition also occur after a large LNG or LPG release, either in the unconfined cloud or in a storm drain or tunnel?

4. If a detonation occurs, what fraction of the vapor cloud (or aerosol cloud) actually detonates and contributes to the explosive yield? This depends on the spatial and temporal

variations of the fuel concentration in the cloud and on the characteristics of a detonation in an inhomogenous mixture (the answer to Question 2). Clearly, there will always be a cloud "fringe region" where the fuel is too diluted to detonate, and, if detonation initiation occurs before considerable mixing with air has taken place, there will be an inner region too rich to detonate. In the intermediate region, where the fuel concentration may vary back and forth across the nominal detonation limits due to incomplete mixing, the situation is more complex.

PAST INVESTIGATIONS RELEVANT TO LEG CLOUD DETONATIONS

Detonation of Essentially Unconfined Mixtures of LEG Vapor with Air

The experiments most relevant to the present problem are those on completely unconfined (and therefore inhomogeneous) hydrocarbon-air clouds released in the open, but very few such experiments have been carried out. Benedick et al.[11] produced propane-air clouds by releasing gaseous propane on calm days. They successfully detonated the clouds using 0.8 kilograms (kg) of sheet explosive as initiator, but they made no quantitative measurements. Also, propane aerosol clouds produced by explosive disruption of a liquid propane container have been detonated by an explosive charge, but again no measurements were made.[13]

Another relevant observation comes from an accident that occurred in 1970 near Port Hudson, Missouri.[12] A pipeline carrying liquid propane under pressure broke and about 90 cubic meters escaped into the open in the next 24 minutes. A large detonation then occurred, probably initiated by pressure build-up after ignition in a concrete warehouse about 300 meters downwind and downhill from the pipe break. An analysis of the blast damage indicated that the explosive yield corresponded to detonation of about 7.5% of the total propane which had escaped.[12] Similar analyses of the accidental detonation of other large vapor clouds (most of them not LEG) give explosive yields less than 10% of the total fuel energy.[14] All these clouds were very small compared to the contents of modern storage tanks or ships. Much larger clouds might give substantially greater percentage explosive yields if initiated near the time when the maximum volume of the cloud lies within the explosive limits.

A pertinent "negative" observation is that a number of small test spills of LNG on land and water have been deliberately ignited and none of them detonated.

In the majority of "unconfined" detonation experiments, the fuel-air mixture was contained in a thin rubber or plastic balloon or bag. Usually the mixture was initiated by high-explosive charges of varying sizes. In such an arrangement, theory and observations show that if the bag is large enough the detonation will either propagate or die out before any disturbance reaches the container walls. Accordingly, the results are the same as for a completely unconfined fuel-air mixture, except that the mixture is more uniform than one resulting from an LEG release in the open.

Early investigations of essentially unconfined fuel-air detonations were carried out in the USSR by

Kogarko, Adushkin and Lyamin[4] on stoichiometric mixtures of methane, propane, and acetylene with air, in spherical rubber balloons up to 3 meters (m) in diameter. As initiators, they used TNT charges of various sizes placed in the balloon center, and they determined the progress of the detonation by means of photographs and pressure sensors at various distances from the center. They concluded that propane-air mixtures could be detonated by a 155 gram (gm) TNT charge, but methane-air mixtures required a 1 kg charge (the largest they tried). Their result for propane appears to be reasonably accurate, but their result for methane is questionable. The 1 kg initiator needed to detonate the methane-air mixture contained 8% as much energy as that in the entire balloon, and this energy may have been enough to detonate the gas locally without producing a self-propagating detonation.

During the years since Kogarko's work there have been a number of investigations of gas detonations in spherical geometry using as initiators high explosives of only a few grams, or electric sparks of even less energy. Most involved hydrogen-oxygen or hydrocarbon-oxygen mixtures, although in some cases increasing amounts of nitrogen diluent were added. With these small initiators some investigators obtained detonations in propane-oxygen mixtures, but, as expected from Kogarko's results, detonations were no longer obtained after addition of only a moderate amount of nitrogen (much less than that in a propane-air mixture).

The next relevant investigation was carried out by TRW under sponsorship of the American Gas Association.[15] In 6.1 m diameter balloons filled with a stoichiometric mixture of air and natural gas (88.4% methane, 8.2% ethane *and 1.2% propane), they were unable to produce propagating detonations with a 0.48 kg charge of C-4 explosive placed either in the balloon center or 15 centimeters (cm) above the ground. Since in the latter geometry reflections from the ground should roughly double the effective initiator energy, and since C-4 has about 30% more energy than the same mass of TNT, the TRW results tend to confirm the conclusion that Kogarko did not actually obtain a propagating detonation in his methane-air mixture with 1 kg of TNT.*

Results of large-scale experiments on propane and butane, conducted at Albuquerque, New Mexico, were published in 1970 by Benedick, Kennedy and Morosin.[11] Using long rectangular plastic bags (1.8 m x 1.8 m x 7.6 m or 1.2 m x 1.2 m x 6.1 m) and an initiator of up to 0.8 kg of Dupont EL 506-A.5 sheet explosive at one end, they were able to detonate propane-air mixtures with fuel concentrations between 3% and 7%, and butane-air mixtures with fuel concentrations between 2.5% and 5.2%.

A few years later similar tests were made at Eglin AFB, Florida by Vanta, Foster and Parsons[15] on natural gas-air mixtures in bags 1.2 m x 1.2 m x 6 m and 2.4 m x 2.4 m x 2.4 m. They observed "erratic" detonations for near-stoichiometric mixtures initiated by sheet explosives of about 1 kg. It is not necessary to discuss the validity of their conclusions, since their work has been superseded by very recent unpublished experiments by Benedick and colleagues,[7] who definitely observed a propagating detonation in a stoichiometric methane-air mixture contained in a 2.4 m x 2.4 m x 12 m bag and initiated by 4 kg of sheet explosive backed by a large plywood sheet and placed over one end. This is the first known propagation *of a sustained detonation in an "unconfined" (bagged) cloud of methane/air. While active instrumentation was limited to high-speed photography, we believe the quality of the data to be excellent. Benedick also produced a detonation over about three-fourths the length of a 1.7 m x 1.7 m x 9.5 m bag containing a slightly richer mixture using 2 to 4 kg of sheet explosive; however, it appeared that the 1.7 m dimension was marginal to support a sustained detonation.*

A more extensive investigation, using compact rather than sheet explosive charges, has recently been carried out by Bull et al. in Great Britain.[5] They exposed stoichiometric hydrocarbon-oxygen-nitrogen mixtures in thin plastic bags 1 m diameter x 3 m long to shock waves from square cylinders of high explosive (Tetryl) of several sizes ranging up to 0.52 kg. By interpolation or extrapolation against the nitrogen concentration, the minimum charges necessary to detonate stoichiometric mixtures of air with methane, ethane, propane and butane were determined to be 22, 0.04, 0.08 and 0.08 kg, respectively. The minimum charge for mixtures of methane and ethane fell between the values of the two pure gases; for 65% methane and 35% ethane (within the possible LNG range, if the differences between ethane and the heavier hydrocarbons are neglected) the minimum charge was about 0.3 kg. Deviations from a stoichiometric mixture by 20% toward the lean side or 50% toward the rich side increased the minimum charge by about a factor of 3. These experiments were well instrumented and carefully performed. The results appear to be quite reliable.

Very recently, Lind has investigated detonation initiation in hemispherical balloons of 10 m diameter at China Lake, California.[16] Using a hemispheric Composition

B charge placed in the center on top of a steel plate (which should approximately double its effective energy), with 1.4 and 2 kilogram charges he did not obtain detonation in stoichiometric mixtures of air with natural gas (96% methane, 3% ethane, 1% propane), or with 86% methane/3% ethane/11% propane (1.4 kg charge). He did obtain detonation with an 81% methane/3% ethane/16% propane mixture (1.4 kg charge). His results, though less complete, are consistent with those of Bull et al.[5,9]

Lind also ignited methane-air and propane-air mixtures in the center of the hemisphere with a spark, but he did not observe any transition from deflagration to detonation in 5 m or 10 m paths. In such slow flame experiments the plastic container may have a significant influence by temporarily holding in the pressures built up by the flame, but this can only assist in the transition to detonation. Lind's work appears to be of high quality and reliable.

Some recent theoretical papers pertinent to unconfined vapor-air explosions are worth mentioning. Kuhl, Kamel, and Oppenheim[17] analyzed the pressure waves that would be produced by a steadily expanding spherical deflagration front. Their results show that for the usual flame speed the pressure waves would be quite weak, but if the flame speed could be considerably increased (by turbulence, for example), destructive pressure waves would be produced even without a true detonation. The immediate usefulness of this work is limited by our lack of knowledge of what flame velocities might be attained in realistic situations.

Williams,[18] Strehlow,[19] Oppenheim et al.,[20] and others have developed simplified models which also show a *strong dependence of the overpressure produced by a non-ideal explosion on flame speed and combustible cloud shape. These models indicate that if flame speeds of about 35 m/sec or more are present, damaging overpressures can be produced even though such speeds are far below those associated with a detonation.*

Very recently Boni et al.[21] *calculated the tendency of flames in unconfined methane-air mixtures to accelerate and make a transition to detonation. They used a simplified chemical kinetics scheme and assumed various values of the turbulent eddy diffusivity. These numerical calculations indicate that such a transition will occur only if unreasonably high levels of turbulence are initially present or are generated by the flame. Similar calculations with a more complete chemical kinetics scheme might suggest whether ethane-air or propane-air mixtures would make the deflagration to detonation transition. However, because of the simplified and parametric treatment of turbulence, the results could not be relied upon without experimental confirmation.*

In a recent theoretical analysis, Sichel[22] *has expressed the minimum energy required for the blast initiation of detonation in planar, cylindrical and spherical geometry in terms of a parameter which can be evaluated for any fuel/air ratio of a given hydrocarbon if the minimum initiation energy is known for any one geometry and fuel/air ratio of the same hydrocarbon. Most of the results pertinent to LEG detonations that his theory could give have already been obtained experimentally by Bull et al.*[5,9] *However, Sichel's equations, with the parameter evaluated from the data of Bull et al., can be used to show that lightning bolts must have energy densities of 4 x* 10^7

and 4 x 10^5 Joules/m in order to detonate stoichiometric methane-air and ethane-air mixtures, respectively. The ethane-air value falls within the upper range of typical lightning bolts[23], but the methane-air value is almost as large as that for lightning "superbolts", which occur about once in every two million strokes.[24]

Detonation of Confined Mixtures of LEG and Air

Essentially all quantitative investigations of detonations in confined hydrocarbon-air mixtures have dealt with the mixtures in pipes and tubes. These investigations are pertinent to LEG cloud detonations because the heavy vapor may seep into storm drains, sewers, tunnels, or similar structures, and a detonation started there may propagate out into the free cloud.

In early work, Henderson[25] determined that in a 10 cm diameter pipe 75 m long, closed at both ends and filled with a stoichiometric mixture of air and natural gas (91% methane, 8.5% ethane), deflagrations made transitions to detonations in a distance of 100 to 200 pipe diameters, but only when the fuel-air mixture was initially flowing at over 1.3 m/sec (apparently creating the required turbulence). Later, Gerstein, Carlson and Hill[6] observed that a similar mixture (90% methane, 8% ethane) in a 61 cm diameter closed pipe 93 m long made such a transition in 50 to 150 pipe diameters when the mixture was initially stationary, but the detonation velocity oscillated about the theoretical value, a "galloping" detonation. This work was actually carried out at initial pressures of 0.2 to 0.4 atmosphere, but the results were rather insensitive to pressure variations.

Kogarko[3] determined that a stoichiometric methane-air mixture in a 30.5 cm diameter pipe could be initiated by a 0.05 kg high-explosive charge inside the closed end, while a 0.07 kg charge detonated considerably leaner and richer mixtures (almost to the flammability limits). N detonations could be obtained in a pipe of only 2 cm diameter. Similar experiments with propane-oxygen-nitrogen mixtures by Manson et al.[26] in tubes up to 5.2 cm diameter gave detonations only for mixtures with slightly less nitrogen than in propane-air mixtures, but a short extrapolation indicated that propane-air detonations could be produced in tubes of 6 cm diameter or larger.

Benedick obtained detonation of stoichiometric methane-air mixtures over the entire length of open-ended wooden boxes about 0.6 m x 0.6 m x 9.8 m by detonating 250 gm of sheet explosive inside the fuel-air mixture, but about 0.5 m outside of one end of the box.[7] He did not, however, get a detonation in similar tests with the mixture ignited by either 32 gm of explosive or by a glowing filament placed at the end of the box.

Observations on an accidental explosion that occurred near Port Huron, Michigan are also pertinent. Methane gas seeped into a 4.9 m diameter water tunnel that was under construction. Apparently the gas was accidentally ignited near the closed end. This produced a "galloping" detonation with regions of high pressure occurring about every 60 tunnel diameters (along a 5 km length of tunnel), where it blew holes in the 30 cm thick concrete tunnel liner.[27]

Apparently no studies of the deflagration to detonation transition for ethane-air and propane-air *mixtures in tubes have been published. However, numerous laboratory experiments, using more easily detonated gases in small tubes, have shown that such transitions generally occur if the tube is wide enough to allow a detonation, long enough to permit a complete transition, and if the gases are ignited either near a closed end or a long distance from both ends.[28] Ignition with a weak source near an open end does not yield a detonation.*

Distribution of Detonatable Mixtures in an LEG Vapor Cloud

An important consideration for estimating the effects of an unconfined LEG vapor cloud fire or explosion is the mass fraction and location of that portion of the cloud between the flammable or detonatable concentration limits (the detonatable limits are presumably close to the flammable limits when a sufficiently large initiator is involved). Although a number of methane concentration measurements were made during a series of small LNG test spills in earthen dikes,[29] and also in wind tunnel vapor dispersion simulation studies,[30,31] the data are not extensive enough to provide good estimates of vapor cloud concentration contours.

If it is assumed, as many of the available vapor cloud dispersion models do[32], that the concentration structure of these vapor clouds can be described as a gaussian distribution in space, one can easily demonstrate that, regardless of the form of the gaussian dispersion coefficients, the maximum mass fraction of the methane cloud between the 5 and 15 percent concentration contours is approximately 45%,[14] whereas for propane a maximum of approximately 65% of the cloud mass can lie between the 2 and 10% flammability limits. The maximum flammable *mass fraction occurs approximately when the maximum concentration in the cloud reaches the upper flammability limit. Thus, the maximum mass fraction occurs at only one instant in time; at both earlier and later times, the flammable mass fraction is less. We emphasize, however, the the gaussian assumption ignores smaller-scale concentration variations due to irregular turbulent mixing, and, even as an approximation to the mean concentration profile, it has not been verified by adequate measurements on a large, negatively-buoyant vapor cloud.*

FLAME PROPAGATION

It has often been stated that if an LEG vapor cloud is ignited at its edge, the flame will burn back to the site of the spill. This may not be true if the cloud is ignited on the downwind edge in a strong wind.

Relevant observations have recently been made by Lind, who spilled 5.7 cubic meters of LNG in 1-1/2 minutes on a 50 m x 50 m pond, and ignited the vapor a short distance outside and downwind of the pond, in winds of 2.5 to 5 m/s (5.5-11 mph). The fire burned back to the edge of the pond (a 2-1/2 foot drop), paused, and then burned more slowly back across the water. Most of the LNG had been consumed before the flame left the edge of the pond. LPG spills gave similar results, but the pause was shorter.

Laboratory measurements give laminar flame speeds for these mixtures of only 0.5 m/s (1 mph) or less, but in turbulent flows the flame speeds often reach 5 to 10 m/s (11 to 22 mph) and occasionally faster. On a windy day the atmosphere is quite turbulent, so flame propagation in a combustible mixture against a moderate wind may be *possible. However, the flame plume formed initially near the ignition point produces an updraft which draws in air from the sides, giving a velocity which adds to the wind velocity and makes upwind flame propagation more difficult. Near the water or land, friction prevents the gases from moving with the full wind speed, so upwind propagation may occur. However, when ignition occurs before the bulk of the vapor has mixed much with air (which is generally true while the liquid is still boiling off, as in these test spills), the vapor near the ground is too rich to burn. An exception is the fringe region where the edge of the cloud touches the ground.*

For a considerably larger spill, the flame plume formed near the ignition point may be so large that it will create its own strong inward winds, pulling almost all of the flammable vapor to it without the plume moving much.

If ignition is delayed until most of the vapor is diluted into the flammability region (which has not been attempted in any of the test spill ignitions that we know of), upwind propagation should be easier. There is also a chance of a propagating detonation as discussed earlier. It is also possible that a sufficiently strong wind will carry the flame front away from the spill.

Finding

- Current knowledge of flame propagation in an LEG vapor/air cloud is insufficient to determine whether the flame will burn back to its source if a large cloud is ignited on its downwind edge in a strong wind. It is possible that the flame will stay at the ignition point, or that it will be carried downwind. In a recent test in a low wind at China Lake, LEG vapor/air clouds generated on the water were ignited on land and burned back to the water's edge. They stopped and burned there for some time before continuing across the water. This unexpected result shows again how little is understood about such problems.

GENERAL CONCLUSIONS

Flame Propagation

- Little reliance should be placed on statements that if an LEG vapor/air cloud is ignited on its perimeter the flame front will burn back to the source, regardless of the wind conditions.

LEG Vapor-Air Detonations

- In a large release of LEG, it is possible that the resulting vapor-air cloud will detonate and produce a blast wave that could injure people and damage structures out to a large distance. Experiments have demonstrated that essentially unconfined mixtures of air with the LNG and LPG hydrocarbons will detonate if initiated by a large enough charge of high explosive. Moreover, at least one carefully analyzed accident involved the detonation of a medium-sized cloud of propane (a major LPG and minor LNG constituent). What has not yet been determined is what sources are sufficient to cause detonation of an LEG vapor cloud (either directly or indirectly by a multiple-stage process, such as starting a detonation in a confined region, or in a region enriched with the more easily detonatable hydrocarbons from the spill, and then propagating through the main cloud). In addition, the maximum fraction of the cloud which is properly mixed and detonatable at one time is not well established. In accidental detonations this fraction is not believed to have exceeded about 10%, but dispersion theory suggests that it could reach 45% or more.

- The critical questions concerning LEG detonation can be answered in 1 to 2 years if a vigorous research program is undertaken. The emphasis of the program must be on experimental studies, since the physical problems involve the interaction of turbulent fluid mechanics with complex chemical kinetics. These problems cannot, with high confidence, be solved theoretically at any time in the near future. Moreover, most of the experiments must be done on a size scale of meters to tens of meters because they must be much larger than the detonation induction length, which is relatively long for hydrocarbon-air mixtures (especially for methane).

SPECIFIC TECHNICAL CONCLUSIONS

LEG Vapor-Air Detonations

- Theory suggests and preliminary laboratory experiments support the idea that considerable fractionation occurs when spilled LNG boils off, with methane primarily boiling off first, then ethane, then propane. This result is important because the latter two hydrocarbons are considerably easier to detonate than methane; accordingly, it needs confirmation by further laboratory and field tests. If it is confirmed, wind tunnel and field tests are needed to determine if the components remain separate during cloud dispersion and mixing with air.

- An explosive source too weak to start a detonation in an unconfined hydrocarbon-air mixture might initiate detonation in a large pipe or tunnel, and the detonation then might propagate from the pipe to the unconfined cloud. Such a process has been observed in small-scale experiments using fuel-oxygen mixtures, but not in fuel-air mixtures. Experiments on the latter are needed.

- Information is not readily available on the presence near possible LEG release areas of stored high explosives, acetylene or other compressed gas bottles, sewers, subways, storm drains, subsurface conduits, vulnerable high voltage lines, tall structures where lightning is likely to strike, and other objects that might contribute to detonation initiation. Such information is critical for safety evaluations and Federal agencies should require it before they make any determination of the safety of a proposed facility.

- Very few experiments have been carried out on the detonation of mixtures of air with methane, ethane, and propane, either unconfined or in large pipes, by the weaker sources mentioned above (sparks, exploding bottles, etc.). A more complete matrix of measurements is needed.

- Practically nothing is known about the propagation of detonations through inhomogeneous regions, where either the fuel/air ratio, or the proportions of the different fuels, vary. Relevant experiments are badly needed, especially on mixtures containing small regions where the concentrations lie outside the detonation limits.

- No information is available on the ease of detonation of LEG aerosols; a quick experimental survey is needed.

- Information on the spatial and temporal variation of the fuel/air ratio in a large LNG or LPG vapor cloud is inadequate to predict with confidence what fraction of the cloud is detonatable. Wind tunnel and field tests are required to answer this question.

RECOMMENDATIONS

LEG DETONATION RESEARCH

TO THE SECRETARY OF ENERGY

We recommend to the Secretary of Energy that his department focus its LEG detonation research to answer critical questions on LNG cloud detonation as quickly as possible and to provide important information on the initiation of detonation in LPG clouds. The physics associated with these questions is so complex that to obtain a complete, quantitative understanding of the phenomena both detailed theoretical modeling and extensive laboratory and field experiments are necessary. But complete, quantitative understanding is not needed for the policy decisions about LEG use that have to be made. For near-term results on detonatability (obtainable over the next 1 to 2 years), we recommend that emphasis be placed on relatively large-scale (350 cubic meters) field experiments supplemented by wind tunnel investigations. Continuation of some of the laboratory experiments and approximate theoretical modeling currently being pursued, however, can be useful to help plan the field experiments and interpret their results.

We believe that such a program could be conducted within two years and would involve less than a fifth of the $50 million DOE is planning to spend on LNG research. A suggested program devised by us is presented below, including rough cost estimates. DOE has questioned whether the program can be carried out at these cost levels. We have reviewed our estimates carefully and believe that, with prudent use of public funds, the estimates are valid.

See the section on Agency Comments below.

The ultimate scope and extent of the experiments described will depend upon what is learned as each part of the work is completed. If, for example, it is found from early experiments that differential boiloff of the liquid does not occur under field conditions with LNG spills, then detonation experiments might be limited to three fuels: methane, methane with 35% ethane, and pure propane (for LPG applications). Should the converse prove to be the case, then testing of a larger range of fuel mixtures with various initiation sources might be necessary, substantially expanding the test matrix.

The first four research tasks described and the preliminary two-phase cloud experiments would provide answers to critical questions on LEG vapor cloud detonation within about one year, provided the work is well coordinated and conducted in parallel where possible. The estimated cost for these tasks is $1.5 million.

In one additional year, at an estimated cost of $3 million, 350 cubic meter field tests could provide increased confidence in the answers obtained during the first year. They would also provide information on downwind combustible vapor cloud travel and possibly fireball radiation. (If an initial set of explosively dispersed LEG experiments were conducted, add roughly $800,000 to the second year's cost.)

<u>Differential Boiloff of LNG Constituents</u>

Perform field experiments spilling LNG on unconfined areas of salt water and measuring spatial and *temporal concentrations of methane, ethane, and propane in the vapor above the evaporating liquid. Perform similar experiments for spills on soil.*

This work, some of which has begun at the Naval Weapons Center, China Lake, California, with 6 cubic meter spills, will provide a check of MIT laboratory work to determine if a strong fractionation process also occurs under field conditions. Tests should be run in the size range of 1 to 35 cubic meters (1 truckload) to provide as wide a range as can be obtained relatively rapidly and inexpensively. If enrichment in ethane or propane is found, the large vapor cloud field tests should also be instrumented to give measurements of differential boiloff over an experimental range of 3 orders of magnitude.

We estimate that these differential boiloff tests would require about $300,000 and eight months time. Conducted early, the output could have a substantial influence on the type and scope of further detonation experiments.

Detonation Initiation Sources

Survey, compile, and physically describe all current and foreseeable sources of rapid energy release which might be located up to about 5 km from LEG marine terminals and major storage areas. Determine through analysis and screening experiments which of these energy sources are potentially capable of detonating methane-, propane-, and perhaps ethane-air mixtures. Select those potential initiation sources believed most likely to produce a detonation in LEG vapor clouds for use in cloud detonation experiments.

These potential initiation sources should include electrical discharge sources (including lightning), high pressure gas containers, highly flammable stored gases and stored oxygen, machinery capable of exploding, condensed explosives, etc. The study should evaluate the effects of confining structures such as large metal and concrete pipes open to the atmosphere (storm drains), and underground conduits and shafts into which gas might flow. Whether ethane is considered should depend on the findings of this work and that of the preceding experiment.

About six months and $100,000 are required for this effort.

<u>Wind Tunnel Vapor Plume Tests</u>

> *Conduct vapor dispersion experiments in a meteorological wind tunnel to define the existence and distribution of detonatable hydrocarbon concentrations in the dispersing LEG vapor cloud.*

If the LNG boiloff tests show that little fractional distillation occurs, these experiments need to simulate only methane and propane clouds. If fractional distillation does occur, the tests should also include releases that simulate the fractional distillation found in the experiment on boiloff, using downstream sensors that can distinguish the different gases. The results would determine whether high concentrations of the heavier hydrocarbons persist in sizeable regions of the cloud as it disperses downwind, in time to provide inputs to the field detonation experiments discussed below. They would also provide a measure of the possibly detonatable fraction of the cloud as a function of time after spill, whether or not strong species separation persists. Finally, the results would be useful for planning and evaluating the large-scale field tests discussed below.

We estimate that the wind tunnel experiments can be conducted in eight months for $200,000, with useful data produced as early as four months from the beginning of testing.

<u>Detonation Initiation and Propagation Experiments Using Plastic Bags</u>

> *Perform experiments to determine if the sources selected in the ignition source study produce detonations in a range of methane/ethane mixtures contained in large plastic bags, and in mixtures of air with methane, 65% methane/35% ethane, and propane.*

These experiments should include a range of ethane-air mixtures only if the boiloff and wind tunnel investigations show that LNG boiloff produced hydrocarbon fractionation that persisted while the fractions were mixed with air to detonatable concentrations. Although some of these bag experiments, using high explosive initiators, have already been carried out by investigators at China Lake, Albuquerque, and in Great Britain, more are required using other types of initiators that might be present near LEG releases, including multiple stage processes such as propagation from a pipe to a bag, and from a bag of ethane to one of methane. Both stoichiometric and off-stoichiometric mixtures should be included in the investigation. If carried out in rectilinear bags, the experiment will provide a measure of the lateral dimensions required to propagate a detonation in a geometry similar to that of the cloud from a spill. Bags of dimensions up to 3 or more meters on a side and 30 meters long should be used. The experiments should also investigate propagation in inhomogeneous fuel/air mixtures by use of partitioned or multiple bags, with adjacent compartments filled with mixtures having different fuel/air ratios.

In addition to direct-initiation experiments, a number of tests should be conducted to determine if transition from deflagration to detonation (or to a near-detonation that produces destructive overpressures) can occur when the mixture is ignited with a weak source. The effects of turbulence, dust, and partial confinement should be included. The linear dimensions of the bags required for the tests might be three or more times greater than those for the direct-initiation experiments.

The cost of these "bag" experiments is difficult to estimate accurately because of uncertainties in the number and sizes of tests ultimately required. However, if 100 separate tests are assumed, about $750,000 and 8 to 12 months would be required.

These bag experiments, together with the wind tunnel tests, will be the culmination of the first year's effort and should provide initial answers to the basic detonation questions. An assessment should be made of the results at this juncture and a decision made as to whether large spill detonation tests are essential to provide answers with higher confidence. If deemed so, the following experimental program should be undertaken (for which planning would have been completed during the first year).

Large Vapor Cloud Field Experiments

Conduct a set of experiments in which about 350 cubic meters of LNG and about 150 cubic meters of propane are spilled on water and soil, and attempt to detonate them with appropriately chosen initiators.

These experiments would integrate all the phenomena tested separately in the earlier experiments. Detonation would not be attempted in the first tests for water or for soil spills, but measurements would be made to describe the spatial and temporal concentrations and hydrocarbon composition. These first tests would serve to check the differential boiloff and wind-tunnel experiments, thereby increasing confidence in the description of dispersing vapor clouds. They would also help determine the maximum distance at which a non-detonated cloud could initiate fires.

Attempts would be made to detonate the cloud in subsequent tests using initiators selected from the first year's work. Since the tests would be expensive and since a large number of detonation attempts are needed for high confidence, perhaps 10 to 20 initiators would be activated simultaneously in each test cloud. With careful initiator spacing and monitoring, one could establish which initiators produced detonation and whether a given detonation propagated through several pockets of the combustible mixture. Repeat tests would be performed to provide an adequate statistical base.

The results of these experiments should provide high-confidence answers to the question of LNG and LPG vapor cloud detonatability as well as a measure of the extent and pattern of possible blast damage should detonation occur. In addition, such tests could provide valuable data on fireball and flame radiation.

Since the cost of these tests will be substantial, careful planning will be required to establish the minimum acceptable spill sizes; results should be analyzed after each test to minimize the number of tests required. We estimate that a program of twelve tests would cost about $3 million. If detailed test planning is accomplished during the first-year effort described above, most if not all of the twelve-test program could be completed in the second year.

Two-Phase Cloud Detonation

> *Perform experiments in plastic bags to determine whether a cloud formed by a spray of LNG or LPG droplets in air is more or less easily detonated than gas/air mixtures of the same fuels at ambient temperature.*

These experiments would be conducted in a manner similar to those on detonations using plastic bags, so that a direct comparison could be made with those results. They would serve to establish whether the cloud produced by an exploding container of the cryogenic liquids has the potential for posing a special explosive hazard. Performed as part of the plastic bag experiments discussed above, a few tests should cost an additional $100,000 and take about one or two additional months. Should these tests indicate that a special hazard might exist, tests with the fuel explosively dispersed should be considered. An initial set of 10 such tests, using the techniques applied to the

Fuel-Air-Explosive (FAE) weapon development and about one to two cubic meters of liquid fuel, would cost about $800,000 and take about nine months to one year to perform.

AGENCY COMMENTS AND OUR EVALUATION

The Departments of Energy, Transportation, and Commerce all comment that GAO's research suggestions are well-founded, but that they are inadequate to provide a thorough understanding of LEG hazards and that they will cost more and require more time than is projected.

We agree that our research program would not answer all questions of LEG behavior. However, we believe that this relatively brief and inexpensive effort could provide more useful information for the decisions to be made in the next few years than DOE's longer, more expensive program.

The major source of the difference between DOE's and GAO's estimates of the time and money needed to carry out an adequate research program is DOE's proposal to build a new facility for intermediate and large-scale test spills. This facility would cost $18 million and require two years to build. We do not believe that a new, permanent facility is needed to proceed with our program. A natural body of water could be used for water spills; surplus liquid hydrogen tanks (currently available for $0.2 million) could be used for test site storage; mobile instrumentation vans (of which DOE has several) and temporary sensors could replace permanent sensor networks and instrumentation buildings.

DOE currently plans spills of up to 1,000 cubic meters, an arbitrarily chosen number. Our calculations indicate that spills of 350 cubic meters are sufficient.

DOE plans a large number of experimental tests; we believe that multiple sampling and careful analysis would drastically reduce the number needed. DOE believes that 240 detonation and initiation tests would be necessary; we expect that 100 tests would provide sufficient information, and that each test would cost only half of DOE's estimate. DOE recommends 100 large-scale tests; we believe that twelve tests, each testing 10 to 20 detonation initiators, would be adequate.

DOE and DOT comment that a major obstacle to accurate experiments is the lack of a rapid response particle detector. We agree that such an instrument is needed. The Coast Guard says that they will have developed a detector for total hydrocarbon vapor concentration by the first quarter of 1979. We believe that using existing technology a suitable particle-separator and detector could be developed by then.

In addition to this general research plan, we also recommend that Congress provide adequate research budgets to the Federal agencies with regulatory responsibility. DOT comments that "LEG research to date has been fragmented and often duplicative because of the interrelated needs of the responsible agencies." We agree. The research program we suggest would provide information valuable to all agencies. However, problems peculiar to each segment of the LEG industry (e.g., ships, trains) can best be investigated by the agency with specific jurisdiction. This research could investigate specific technological problems, evaluate existing codes, and develop adequate new standards.

DOE comments that this "supports the notion that regulatory agencies should perform research (on a cost sharing basis with industry)." We oppose such cost-sharing. It is for this reason that we stress that Congress should provide adequate research budgets for the appropriate agencies.

REFERENCES

1. E. I. Shaheen and M. K. Vora, "Worldwide LNG Survey Cites Existing, Planned Projects," Oil and Gas J. 75, 59, June 20, 1977.

2. B. Lewis and G. von Elbe, Combustion, Flames and Explosions of Gases, 2nd Edition, (New York: Academic Press, 1961).

3. S. M. Kogarko, "Detonation of Methane-Air Mixtures and the Detonation Limits of Hydrocarbon-Air Mixtures in a Large Diameter Pipe," Zh. Tekh. Fiz. 28, 2072, 1958, translated in Soviet Phys.-Tech. Phys. 3, 1904, 1958.

4. S. M. Kogarko, V. V. Adushkin and A. G. Lyamin, "An Investigation of Spherical Detonations of Gas Mixtures," Nauchno-Tekhn. Prob. Goreniya i Vzryza 1, 22, 1965, translated in International Chem. Eng. 6, 393, 1966.

5. D. C. Bull, et al., "A Study of Spherical Detonation in Mixtures of Methane and Oxygen Diluted by Nitrogen," J. Phys. D. 9 , 199, 1976.

6. M. Gerstein, E. R. Carlson and F. U. Hill, "Natural Gas-Air Explosions at Reduced Pressure," Ind. Eng. Chem. 46, 2558, 1954.

7. W. B. Benedick, Sandia Laboratories, private communication, 1977.

8. J. Valencia, MIT, private communication, 1977.

9. D. C. Bull and J. A. Martin, "Explosion of Unconfined Clouds of Natural Gas," paper presented at the American Gas Association Transmission Conference, St. Louis, May 1977.

10. Gas Engineers Handbook, (New York: The Industrial Press, 1966).

11. W. B. Bendick, J. D. Kennedy, and B. Morosin, "Detonation Limits of Unconfined Hydrocarbon-Air Mixtures," Combustion and Flame 15, 83, 1970.

12. D. S. Burgess and M. G. Zabetakis, Detonation of a Flammable Cloud Following a Propane Pipeline Break. The December 9, 1970 Explosion in Port Hudson, Mo., Bureau of Mines, RI 7752, 1973.

13. James Bowen, Naval Weapons Center, private communication, 1977.

14. D. Burgess et al., "Volume of Flammable Mixture Resulting From Atmospheric Dispersion of a Leak or Spill," Fifteenth Symposium (International) on Combustion, The Combustion Institute, 1975, p. 289.

15. Thermal Radiation and Overpressures from Instantaneous LNG Release into the Atmosphere, TRW Systems Group, Report No. 08072-4, April 26, 1968.

16. C. D. Lind, Naval Weapons Center, private communication, 1977.

17 A. L. Kuhl, M. M. Kamel, A. K. Oppenheim, "Pressure Waves Generated by Steady Flames," Fourteenth Symposium (International) on Combustion, the Combustion Institute, 1973, p. 1201.

18. F. A. Williams, "Qualitative Theory of Nonideal Explosions," Combustion Science and Technology 12, 1976, pp. 199-206.

19. R. A. Strehlow, "Blast Waves Generated by Constant Velocity Flames," Combustion and Flame 24, 1975, pp. 257-261.

20. A. K. Oppenheim et al., "Blast Waves Generated by Exploding Clouds," University of California, Berkeley, California, July 1977.

21. A. A. Boni et al., "On Combustion-generated Turbulence and Transition to Detonation," paper presented at the AIAA Fifteenth Aerospace Sciences Meeting, Los Angeles, California, January 24-26, 1977.

22. M. Sichel, "A Simple Analysis of the Blast Initiation of Detonation," Acta Astronautica 4, 409, 1977.

23. M. A. Uman, Lightning, McGraw-Hill Co., 1969, p. 165.

24. B. N. Turman, "Detection of Lightning Superbolts," J. Geophys. Res. 82, 1977, pp. 2566-68.

25. E. Henderson, "Combustible Gas Mixtures in Pipe Lines," P.C.G.A. Proc., 1941, p. 98.

26. N. Manson et al., "Vibratory Phenomena and Instability of Self-Sustained Detonations in Gases," Ninth Symposium (International) on Combustion, Academic Press, 1963, p. 461.

27. J. A. Nicholls, Testimony on the Port Huron Water Tunnel Explosion Case, Wayne County Circuit Court, June 16-17, 1975.

28. S. R. Brinkley, Jr. and B. Lewis, "On the Transition from Deflagration to Detonation," Seventh Symposium (International) on Combustion, The Combustion Institute, 1959, p. 807.

29. LNG Safety Program Phase II, Consequences of LNG Spills on Land, American Gas Association Project IS-3-1, Battelle Columbus Laboratories, November 1973.

30. LNG Wind Tunnel Simulation and Instrumentation Assessments, R & D Associates staff and Fluid Mechanics and Wind Engineering Programs staff, Colorado State University, RDA-TR-105700-003, April 1977 (Draft).

31. D. J. Hall et al., Experiments on a Model of an Escape of Heavy Gas, Warren Springs Laboratory Report No. CR 882 (AP), Department of Trade and Industry (U.K.), 1975.

32. J. Havens, Predictability of LNG Vapor Dispersion from Catastrophic Spills Onto Water, Cargo and Hazardous Materials Division, Office of Merchant Marine Safety, United States Coast Guard, April 1977.

CHAPTER 14

THE CAPABILITY OF NON-URBAN SITES TO MEET TOTAL U.S. IMPORT REQUIREMENTS FOR LPG

CONTENTS | PAGE

INTRODUCTION

Liquefied petroleum gas (LPG) is the nation's fourth largest source of energy, supplying some 13 million customers. Most of these customers are in rural areas, including approximately 1.4 million farms. Farmers use LPG, principally in the form of propane, for agricultural purposes and home heating.

In addition, LPG can be used to supplement or substitute for natural gas. Recent curtailment of natural gas supplies to industrial users has led many independent energy consultants and governmental agencies to predict a new, high level of demand for LPG. (See Appendix XIV-1 for a breakdown of LPG demand.) At the same time, domestic production of LPG is declining along with that of the two basic products from which it is derived—natural gas and refined oil.

As a result, the United States has begun to import LPG through marine terminals in large quantities, and analysts forecast a sharp rise in LPG imports over the next decade. The import terminals have been built as near as possible to LPG customers in order to reduce transportation costs. Most are on urban sites.

As analyzed in earlier chapters, LPG ships and storage tanks pose hazards to the areas near the terminals. Increased LPG imports at urban terminals will increase those hazards. Presently, there is only one non-urban LPG terminal; however, four new import projects using non-urban terminals have been proposed. By 1985, non-urban terminals will have the capacity to receive all of the projected LPG imports. Whether the LPG could then be distributed to the final consumers through the existing distribution system, or what additions would be necessary to make this possible, is unclear.

Part of the demand for LPG as a supplement to natural gas can be met by linking natural gas pipelines to non-urban LPG import terminals on the Gulf Coast and injecting liquid or vaporized LPG into the passing gas stream.

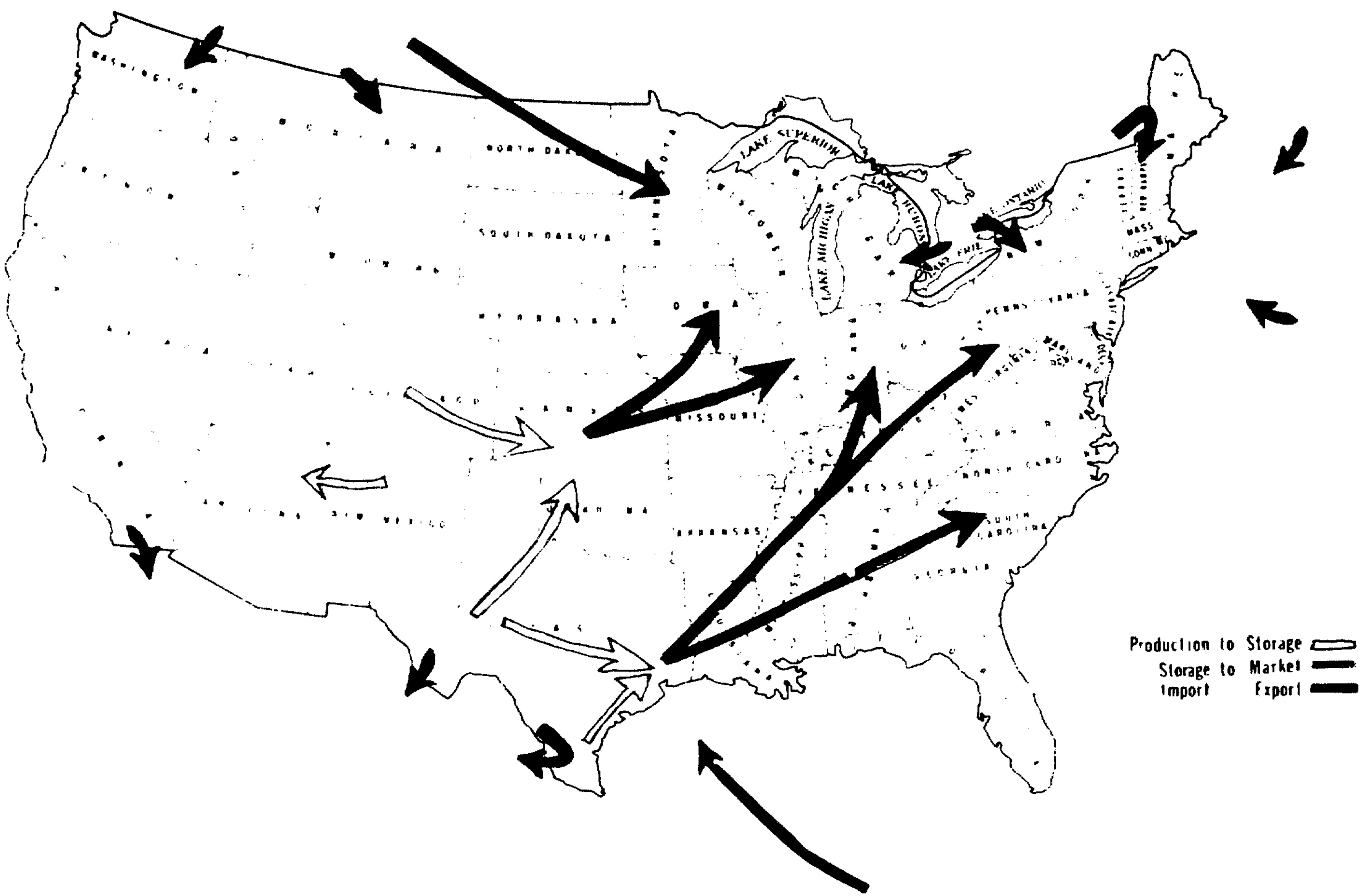
DISTRIBUTION

LPG products travel from production sources and major storage centers through a complex distribution system. Domestically produced LPG moves from a production site by pipeline, truck, or rail into a storage complex or an interstate pipeline and then to a local storage terminal. From there the LPG is shipped by truck or rail to the final consumer. The sequence for imported LPG is the same, with an import terminal substituted for the production site.

The domestic LPG logistical system consists of 16 existing import terminals, 56 million cubic meters of primary storage space, 70,000 miles of cross country pipelines, 16,300 rail tank cars, 25,000 transport and delivery trucks and more than 8,000 bulk storage and final distribution points. (Figs. 14-1 and 14-2, Table 14-1.)

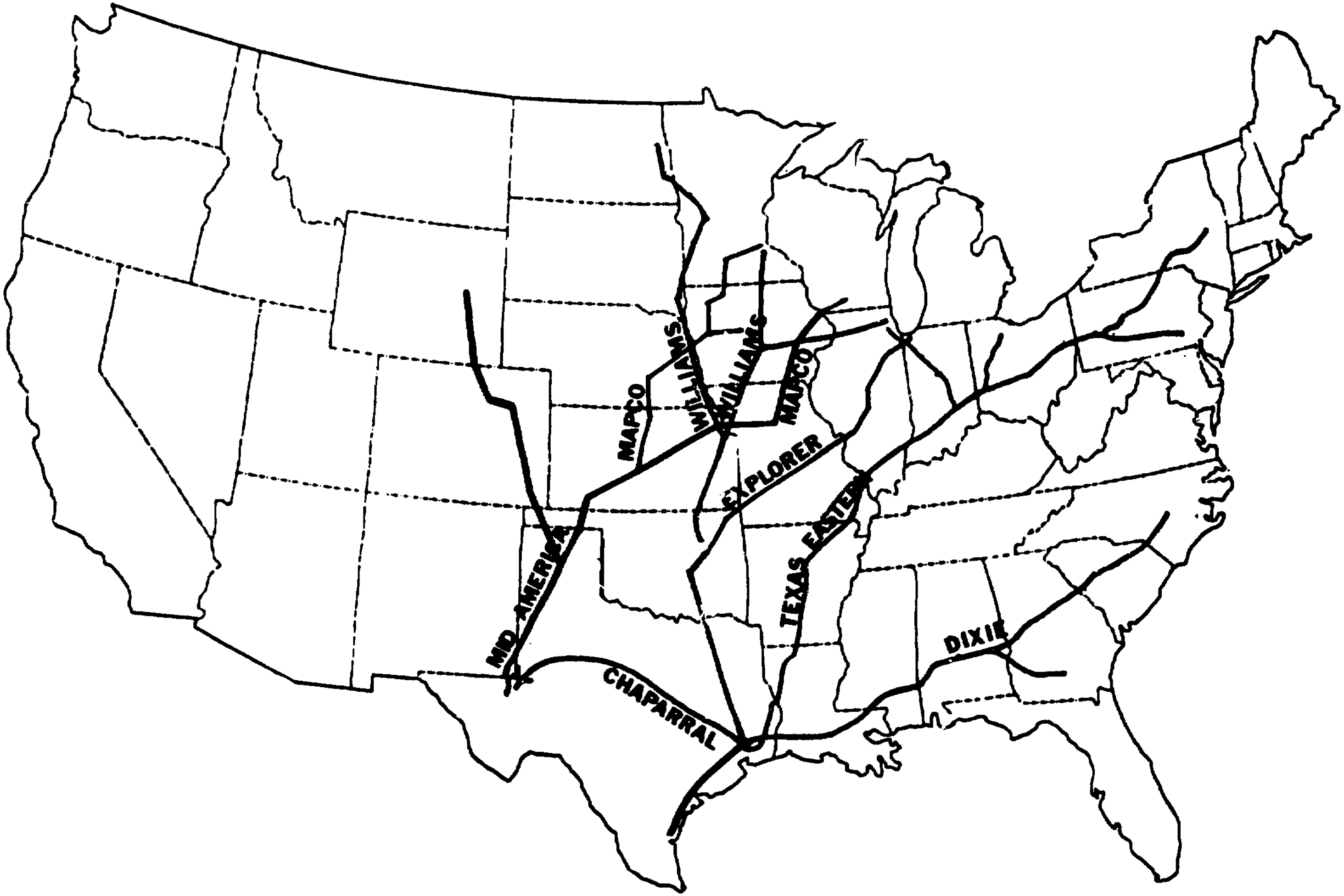
The system is flexible because of the location of the import terminals and major pipelines and the availability of railcars and truck-trailers. During the winter of 1976-77, however, LPG demand in the Northeast exceeded the

FIG. 14-1 LPG PRODUCTION FLOW



DERIVED FROM INTERVIEWS WITH LPG INDUSTRY PRODUCER/MARKETING GROUP.

FIGURE 14-2 – MAJOR PIPELINES WITH CURRENT OR POTENTIAL LPG CAPACITY



DERIVED FROM COMPANY PIPELINE MAPS AND INTERVIEWS.

TABLE 14-1 DOMESTIC BULK TRANSPORTATION OF LPG, 1975 AND 1976
(In units of 1,000 cubic meters)

	1976	Percent of Total	1975	Percent of Total
Truck	2,565	3.4	2,823	3.8
Rail	683	0.9	1,095	1.5
Pipeline-Truck	67,679	90.6	68,975	91.9
Pipeline-Rail	3,404	4.6	1,9[illegible]	2.6
Tanker or Barge*	406	0.5	168	.2
Total	74,737	100%	74,986	100%

*Approximately 90% of the volume in this category is transported by pipelines prior to tanker or barge movement.

Source: National LP-Gas Association, "1976 LP-Gas Market Facts" system's ability to move LPG from storage centers to markets. The situation could have been alleviated if more storage had been available in the Northeast.

AGRICULTURE

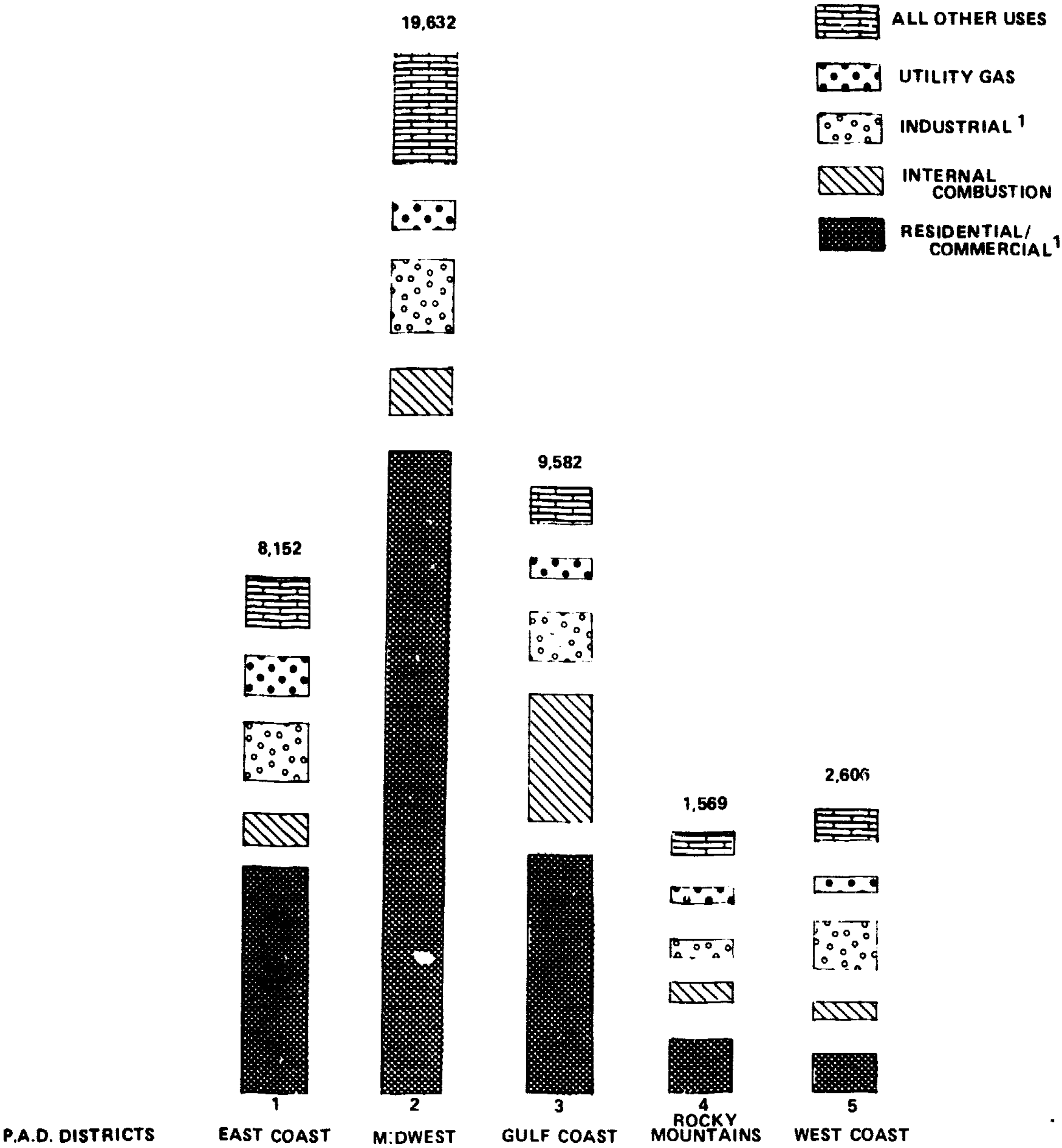
The regional consumption of LPG according to end use is shown in Fig. 14-3. Agriculture is a major user of LPG (see the tables in Appendix XIV-1). Fifty-one percent (1.4 million) of all farms in the United States use LPG for a variety of purposes including crop drying and powering poultry brooders, stock heaters, tractors, and irrigation pumps.

Agricultural consumers along the eastern seaboard will be the most severely affected by the decline in domestically produced LPG unless additional supplies are imported into the area. Historically, LPG for this region has been transported from the major producing and storage areas in the Midwest and Gulf Coast.

It would be cheaper to satisfy any excess Eastern demand by importing LPG through East Coast, rather than Gulf Coast, marine terminals.

Because existing LPG pipelines are full much of the year, import terminals and adequate storage in consuming areas are important. Certain underutilized natural gas transmission lines, however, could be converted to carry LPG. This would lessen the need for import terminals and local storage.

FIG. 14-3- SALE OF LPG BY PRINCIPAL USES: 1975**
(IN UNITS OF 1,000 CUBIC METERS)



**EXCLUDING CHEMICAL & SYNTHETIC RUBBER,AND REFINERY FUELS AND FEEDSTOCKS.

1 AGRICULTURAL USE IS USUALLY AGGREGATED INTO THE INDUSTRIAL OR COMMERCIAL TOTALS.

DERIVED FROM NATIONAL LP—GAS ASSOCIATION (NLPGA) DATA IN "1975 LP—GAS MARKET FACTS "NLPGA SOURCE: BUREAU OF MINES.

USE AS A SUPPLEMENT TO NATURAL GAS

An increase in demand for LPG may come from industrial consumers whose supply of natural gas has been curtailed. LPG can be furnished to these consumers through the existing natural gas pipeline system by injecting it into the pipelines at or reasonably close to import terminals. The LPG can be introduced into the gas flow by one of three methods: (1) by first mixing it with air, (2) by breaking it down into methane and thus creating a synthetic natural gas (SNG), or (3) by injecting it in its liquid form. The first two methods are currently in use at many utility sites (see Appendix XIV-1).

LPG-Air

LPG is consumed as a gas although it is produced, stored, and transported as a liquid. The gas has 2.5 to 3 times greater energy density (energy per unit volume) than methane, the largest component of natural gas. The vaporization of the liquid and injection of air by natural aspiration or mechanical compression dilutes LPG to an energy density equal to that of natural gas. Several hundred domestic gas-air plants exist for standby and full-time use at industrial and utility sites.

Synthetic Natural Gas

SNG is currently being produced to augment declining natural gas supplies by changing LPG or other petroleum based fuels to methane. Thirteen SNG plants ranging in size from 16 MMcf/d (million cubic feet per day) to 250

MMcf/d are currently operating. Five of these use LPG as a feedstock component and one uses propane to raise the energy density of the output gas.

LPG Liquid Injection

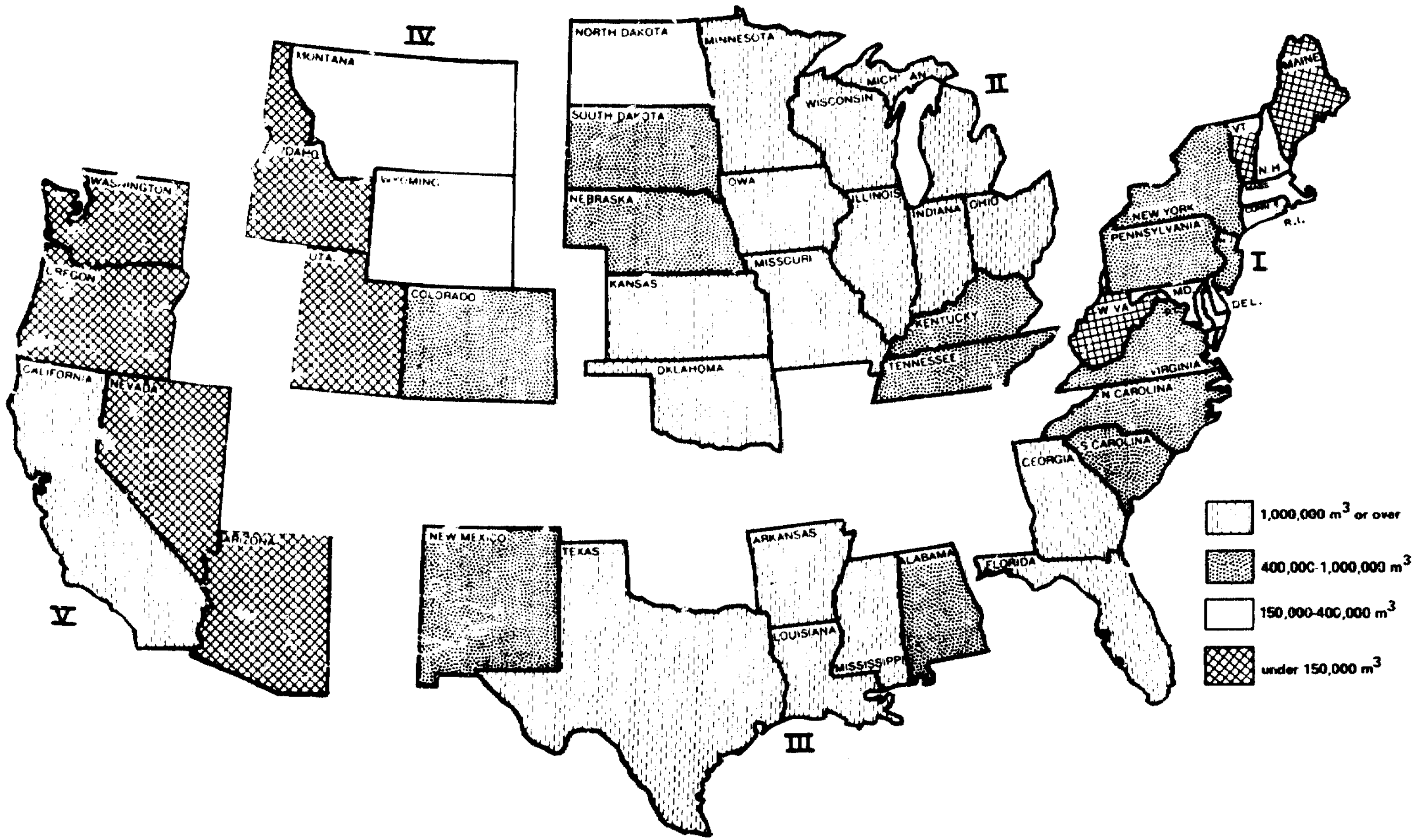
A new method injects liquid LPG directly into a natural gas pipeline. The injection must be into a substantial flow of natural gas, such as the main transmission lines in the Gulf Coast region. The liquid propane is heated to help it vaporize and blend completely into the passing gas stream. A transmission line with 1.5 MMMcf/d (billion cubic feet per day) can receive up to 8,000 cubic meters per day of propane, or smaller amounts of butane. The need for high volume gas lines and large LPG storage currently limits this method to the Gulf Coast where imports can be stored in large salt domes.

SUPPLY AND DEMAND

The demand for LPG in the United States varies by region. (Figs. 14-4 and 14-5.) Demand is high in rural areas because supplying natural gas to these areas by pipelines would be too expensive. The demand may be met by locally produced supplies or by bringing it in from other sources. Particularly remote locations are limited to locally produced LPG supplies because of the high cost of moving LPG from distant sources. (See Fig. 14-6.)

In the northern states, the principal demand for LPG is in winter. The interstate pipeline system cannot fully meet this peak demand. Consequently, inventories are built up during the summer to help meet winter requirements.

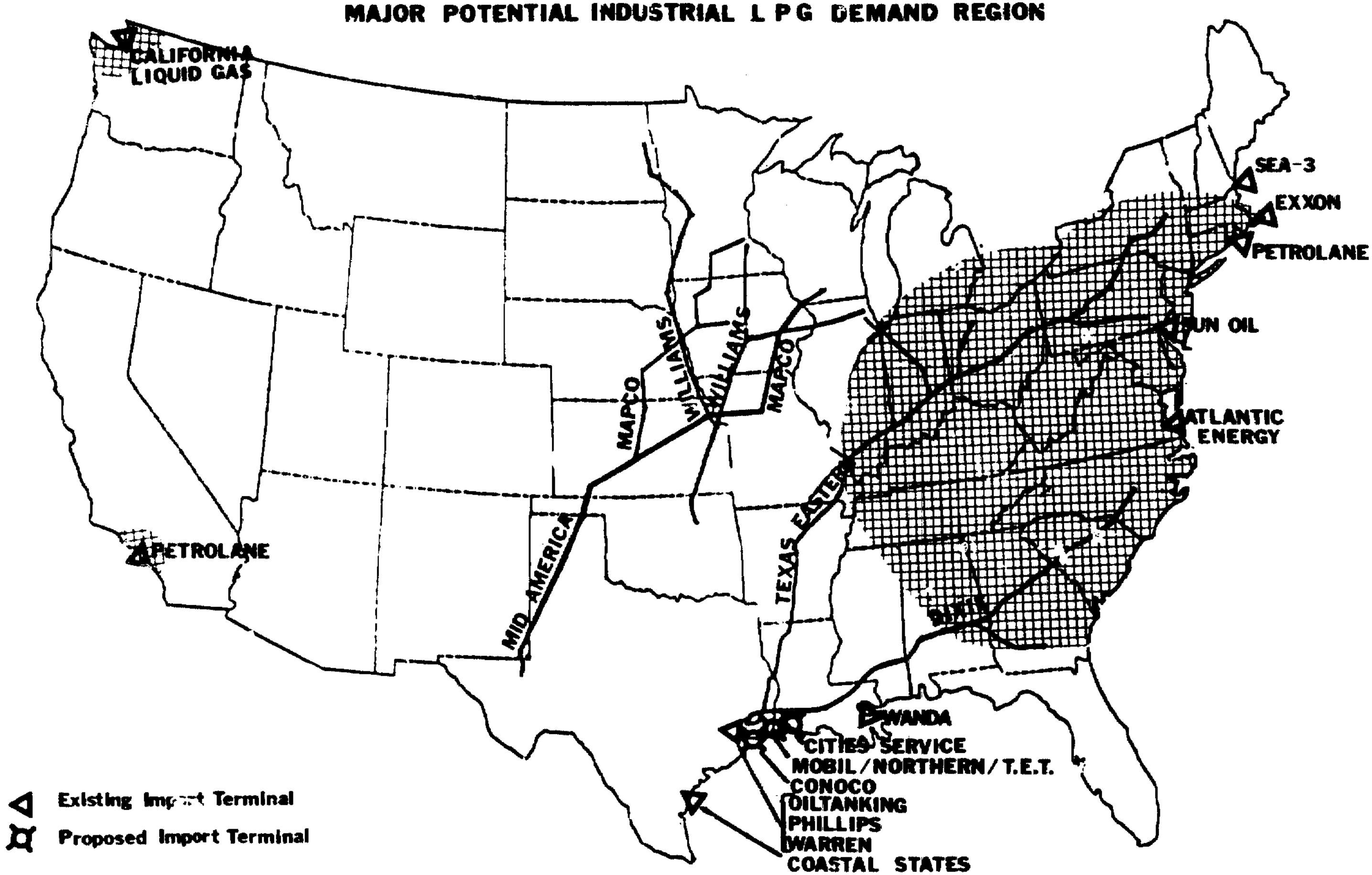
FIG. 14-4- LPG SALES WITHIN P.A.D. DISTRICTS



NATIONAL LP—GAS ASSOCIATION, "GAS FACTS—1975," AND BUREAU OF MINES

FIG. 14-5

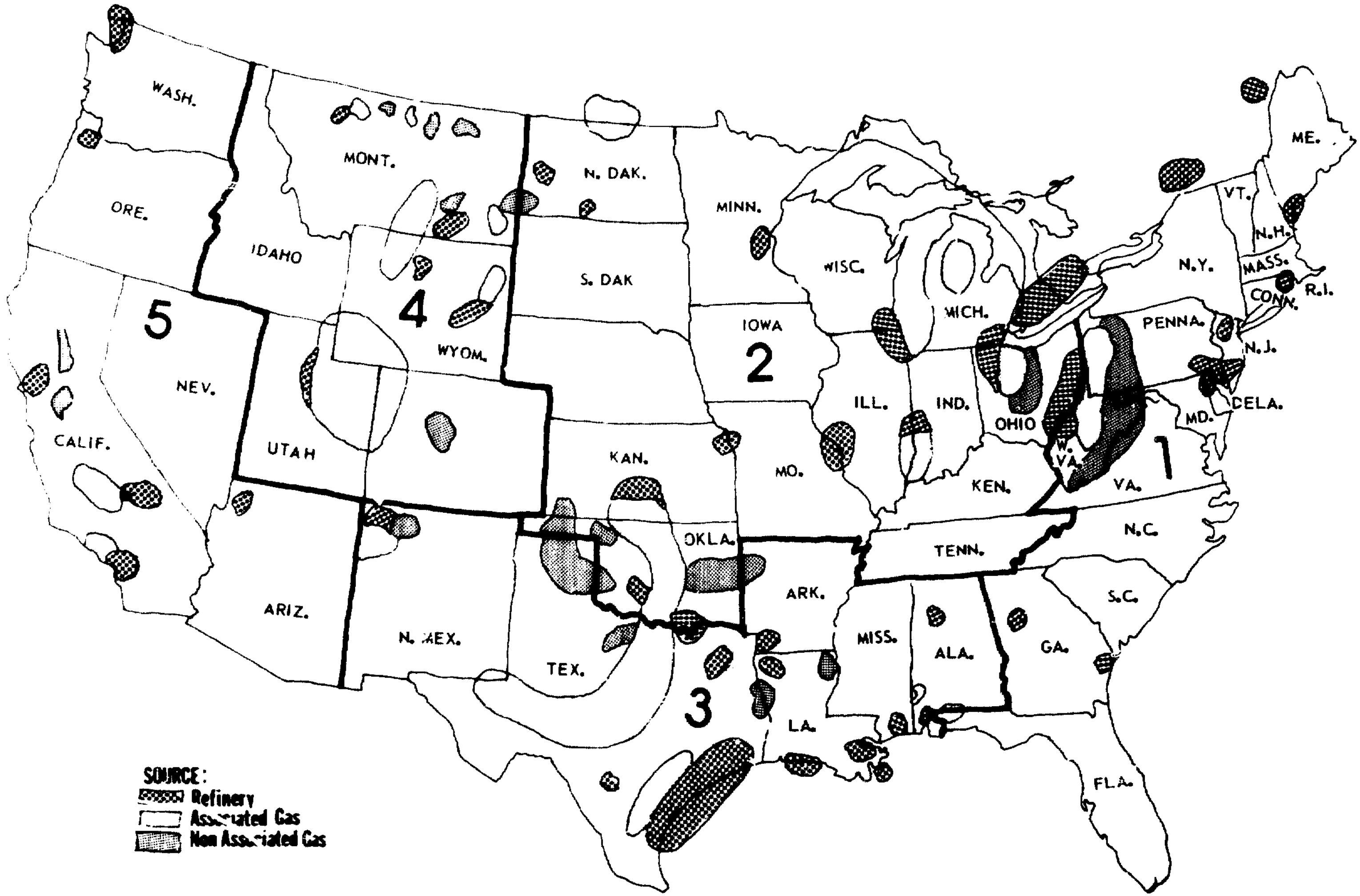
MAJOR POTENTIAL INDUSTRIAL L P G DEMAND REGION



DERIVED FROM VARIOUS PIPELINE COMPANY OWNERS MAPS.

FIG. 14-6

LPG PRODUCTION AREAS



DERIVED FROM INTERNATIONAL PETROLEUM ENCYCLOPEDIA — 1977

Analyzing LPG supply and demand by P.A.D. (Petroleum Administration for Defense) District, the following picture emerges:

The eastern seaboard states in P.A.D. District 1 have found it increasingly difficult in recent years to acquire enough domestically produced LPG. Existing marine terminals supply that portion of demand not met by inter-district pipeline movement, minor indigenous production, and rail car imports from Canada. Natural gas curtailments to industry in this district have increased the need for imports. Bureau of Mines figures indicate that 7.7% of P.A.D. District 1 demand was met by overwater imports.

The Midwest region (P.A.D. District 2) is the highest LPG consuming area in the United States. Local production supplies 47% of demand and most of the rest is met by inter-district pipeline. Canadian imports supply 11%.

The Gulf Coast area (P.A.D. District 3) produces more LPG than it consumes, and most (52%) of the nation's overwater imports come into District 3. The surplus is piped to other Districts.

The Rocky Mountain area (P.A.D. District 4) moves its excess summer production to the large underground storage complex in Kansas (P.A.D. District 2). Winter demand exceeds the District's LPG production capability and shortages are met by rail from Canada.

In the West Coast region (P.A.D. District 5), California and Washington have substantial production, but the District imports 38% of its LPG from other P.A.D. districts and from Canada.

LPG supply and demand by P.A.D. District for 1975 is shown in Appendix XIV-1. As U.S. and Canadian LPG production declines, more overwater imports will be required to fill the increasing demand.

MARINE IMPORT TERMINALS

The first domestic LPG marine terminals were built in the 1950's to receive vessels carrying no more than 30,000 cubic meters. The LPG was shipped between coastal ports or exported. Pipelines from storage sites to terminals were also designed for small volume movements. Subsequently, these terminals were adapted to import LPG, but most cannot handle the much larger ships often used now.

Many present northeastern terminal sites have little room to expand. When space is available, expansion often is resisted by political, environmental, and safety oriented groups. Partly because of these problems, most new LPG import terminals are being planned for the Gulf Coast. The low priced salt dome storage in the area is also attractive to potential LPG importers.

Appendix XIV-2 describes the 16 existing import terminals, the five proposed terminals, and six potential sites. Six of the existing terminals have physical limitations that restrict their importation levels. The 15 major existing or proposed terminals will be capable of receiving 35.5 million cubic meters per year by 1980 and

61.4 million cubic meters per year by 1985. We estimate overwater LPG imports of 13.5 million cubic meters in 1980 and 26.9 million cubic meters in 1985.

Four major terminals, including two proposed terminals, are on the Houston Ship Channel. (In addition, Petro-Tex Chemical Corporation will receive smaller quantities of LPG.) According to our estimates, there will be 133 LPG ship arrivals in the Houston Ship Channel in 1980 and 188 in 1985. An average of one LPG ship per day will be moving into or out of the Channel in 1985.

When the Federal Power Commission (FPC) staff was assessing the proposed El Paso LNG marine terminal at Port O'Connor, Texas, it developed criteria for suitable navigational conditions. According to one of these criteria, "existing ship traffic should not be so heavy that closing down the approach channel for 2-4 hours every 2-2.5 days would impose excessive economic hardship on other shipping activities."[1]

The Final Environmental Impact Statement rejected three possible sites on the Houston Ship Channel, citing the density of ship traffic in the channel and navigational hazards including currents, obstructed areas in the channel, a turn of almost 90 degrees at Pelican Island, and a seaplane landing area located less than 0.5 miles from one portion of the channel.

Ships are permitted, however, to routinely deliver LPG and other highly hazardous materials to sites on the Houston Ship Channel. This makes no sense.

Because of drafting and storage restrictions, 75,000-cubic meter LPG vessels can currently offload only in the Gulf of Mexico and at the Sun Oil terminal at Marcus Hook, Pa.

The East and Gulf Coasts now have about equal offloading capacity, but if all announced terminal construction and expansion plans occur, the Gulf Coast offloading capacity will increase to 78% of the national total by 1980 and will continue at that level.

Table 14-2 classifies major existing and proposed import terminal sites by their location in relation to the edge of a densely populated area of at least 25,000 people: URBAN is defined as a site that is within four miles; SEMI-URBAN as a site that is between four and twelve miles; and RURAL as a site that is more than twelve miles. The table also indicates whether ships enroute to a site must pass by an urban area.

STORAGE

LPG is stored in large aboveground refrigerated storage tanks or, under pressure, in large underground salt domes and mined granite caverns or in small pressurized "bullet" storage tanks. About 86 percent of the LPG in bulk storage is stored underground, particularly in the excavated natural salt deposits in Texas, Louisiana, and Kansas.

TABLE 14-2 LPG IMPORT TERMINAL SITES

Urban Sites	Company	Distance to the Edge of a Densely Populated Area Miles	City	Population	Requires Ships To Pass By An Urban Area
San Pedro, Cal.	Petrolane	0.3	Los Angeles, Cal.	2,800,000	No
Providence, RI	Petrolane	0.6	Providence, R.I.	179,000	Yes
Everett, Mass.	Exxon	0.7 0.9	Boston, Mass. Everett, Mass.	641,000 42,000	Yes
Corpus Christi, Tex.	Coastal States	1.3	Corpus Christi, Tex.	204,000	No
Houston, Tex.	Warren Petroleum	1.8	Pasadena, Tex.	89,000	Yes
Marcus Hook, Pa.	Sun Oil	-0- 1.9 2.9	Marcus Hook, Pa. Chester, Pa. Claymont, Del.	3,000 56,000 7,000	Yes
Houston Tex.	Phillips Petroleum	2.1	Pasadena, Tex.	89,000	Yes
Chesapeake, Va.	Atlantic Energy	2.2 2.9	Portsmouth, Va. Chesapeake (South Norfolk) Va.	67,000 17,000	Yes
Houston, Tex.*	Oil Tanking of Texas	3.0	Pasadena, Tex.	89,000	Yes
Newington, N.H.	Sea 3	3.1	Portsmouth, N.H. Kittery, Me.	26,000 11,000	Yes
Semi-Urban Sites					
Plaquemine, La.*	Dow Chemical	1.4 7.0	Plaquemine, La. Baton Rouge, La.	7,800 166,000	Yes
Atkinson Island, Tex.*	Continental Oil	2.0 7.2	La Porte, Tex., Baytown, Tex.	7,000 44,000	Yes

Rural Sites	Company	Distance to the Edge of a Densely Populated Area Miles	City	Population	Requires Ships To Pass By An Urban Area
Hackberry, La.*	Cities	3.0	Hackberry, La.	< 5,000	No
	Service	3.0	Grand Lake, La.	< 5,000	
		12.0	Lake Charles, La.	79,000	
Sabine Pass, Tex.*	Mobil, NNG	5.0	Sabine Pass, Tex.	< 5,000	No
	TET, Texaco	12.0	Port Arthur, Tex.	57,000	
Ferndale, Wash.	California	6.0	Ferndale, Wash.	< 5,000	Yes
	Liquid Gas	12.0	Bellingham, Wash.	39,000	

*Under construction or proposed.

The major storage centers in the United States help to integrate imports of LPG with domestic production and to match winter demand with summer production. They also boost supply to regions whose rate of pipeline deliveries is inadequate during heavy demand periods.

Insufficient on-site or nearby storage often limits the through-put capacity of import terminals. Import terminals that have only enough on-site refrigerated storage space for about one shipload (56,000-95,000 cubic meters) must either adjust receiving schedules to ensure storage space for a full cargo, or arrange for delivery to more than one marine terminal, which substantially increases transportation and handling costs.

The import terminals with the largest through-put capacity have access to large underground storage complexes. The large capacity permits more timely receipt of vessels, and may offer greater flexibility to receive mixed or non-specification products. Underground storage is also much more economical than refrigerated tanks to construct and operate. Storage construction costs per cubic meter are: washed from salt, $12.50 to $31.50; mined (usually in granite), $41 to $88; refrigerated, $94 to $126; pressure tanks, $200 to $226.

The problem of inadequate storage at some facilities is compounded by insufficient pipeline capacity to deliver the LPG from the ship to on-site or off-site storage and then to the distribution network.

Table 14-3 shows the amount of storage available at each of the major existing and planned import terminals. It can be seen that almost all of the nation's connected storage capacity (94 percent) is in the Gulf Coast area,* with only 4 percent on the East and West Coasts.

This enormous concentration of LPG storage capacity reduces the flexibility of the domestic LPG distribution system.

Figures 14-7 and 14-8 show potential areas for underground storage complexes. Finding locations in the Northeast and on the West Coast for import terminals that are near potential underground storage areas is difficult.

*This does not give full weight to the terminals connected to the large storage complex at Mt. Belvieu, Texas, because some of the storage is used for domestically produced LPG. Only the storage directly connected to or owned in conjunction with each individual facility is considered.

TABLE 14-3 STORAGE AVAILABLE FOR LPG MARINE IMPORT TERMINALS IN 1977

(In units of 1,000 cubic meters)

TERMINAL LOCATION	OWNER	STORAGE CAPACITY	ON-SITE STORAGE
Newington, N.H.	Sea-3, Inc.	64	64 (aboveground)
Everett, Mass.	Exxon Company U.S.A.	64	64 (aboveground)
Providence, R.I.	Petrolane Inc.	64	64 (aboveground)
Marcus Hook, Pa.	Sun Oil Co.	333	333 (underground)
Chesapeake, Va.	Atlantic Energy Co.	76	76 (aboveground)
*Plaquemine, La.	Dow Chemical Co.	3,044	-
*Hackberry, La.	Cities Service Co.	1,350	-
*Sabine Pass, Tex.	Mobil/NNG/T.E.T./Texaco	1,700	-
*Houston, Tex.	Continental Oil Co.	**	-
*Houston, Tex.	Oiltanking of Texas, Inc.	**	-
Houston, Tex.	Phillips Petroleum Co.	916**	27 (aboveground)
Houston, Tex.	Warren Petroleum Co.	5,187**†	57 (aboveground)
Corpus Christi, Tex.	Coastal States Marketing, Inc.	1,493**	2 (aboveground)
San Pedro, Cal.	Petrolane Inc.	96	96 (aboveground)
Ferndale, Wash.	California Liquid Gas Corp.	56	56 (aboveground)
TOTAL STORAGE AVAILABLE		14,442	

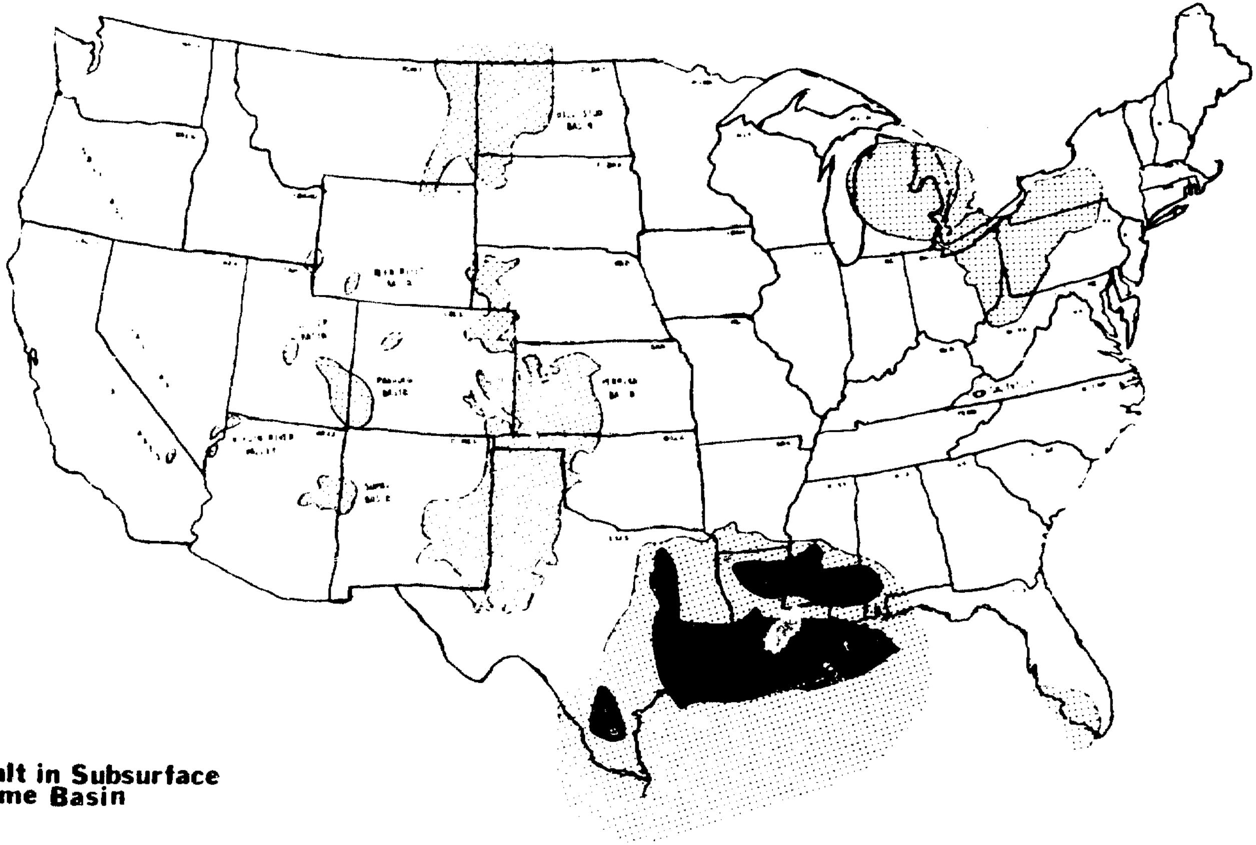
*LPG terminals under construction or proposed

**Connected to existing 14.3 million cubic meters storage at Mt. Belvieu, Texas

†Includes dedicated Warren storage at Mt. Belvieu

FIG. 14-7

MAJOR SUBSURFACE SALT DEPOSITS



FENIX + SCISSON ENGINEERING COMPANY.

FIG. 14-8 **POTENTIAL MINED STORAGE AREAS**

FENIX + S SON EN GINEERING COMPANY.

FINDINGS

- In 1976 the United States imported over water about 1.9 million cubic meters of LPG.

- Almost all of the existing LPG marine import terminals have been built on urban sites. To reach most of the terminals, LPG ships must pass by urban areas. Many terminals have large aboveground refrigerated storage tanks on-site.

- Existing and announced non-urban terminals will have the capacity to receive 111 percent of projected LPG imports in 1985.

- Several non-urban terminal sites could inject LPG directly into natural gas pipelines to supplement domestic supplies. On the Gulf Coast, where natural gas transmission lines originate, volume through the potential Pascagoula, Miss. site could approach 3 million cubic meters annually. Smaller amounts (0.8 million to 1.6 million cubic meters) could be injected from each of the potential non-urban terminals on the East and West Coasts.

RECOMMENDATION

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation develop a computer program able to analyze the capability of the national LPG storage and distribution system. Such a program should be able to determine the rate at which LPG can be delivered - as LPG or as synthetic natural gas - from any point to any other point and the cost to increase this capability by any desired amount.

REFERENCE

1. Final Environmental Impact Statement for the Matagorda Bay Project, FPC, Docket No. CP77-330 et al., September, 1977.

CHAPTER 15

THE CAPACITY OF NON-URBAN SITES TO MEET TOTAL U.S. IMPORT REQUIREMENTS FOR LNG

CONTENTS | PAGE

INTRODUCTION

As analyzed in Chapters 3, 4, 5, and 9, LNG terminals in densely populated areas pose risks to public safety. If LNG imports through these areas could be reduced or eliminated, the public would be exposed to far less risk. This brief chapter assesses the capacity of terminals in non-urban locations to handle all the LNG imports required by the United States through 1990.

DISCUSSION

The Federal Energy Administration projected U.S. LNG imports to expand from about 19 million cubic meters (.4 trillion cubic feet) in 1980 to a maximum of 142 million cubic meters (3 trillion cubic feet) in 1990.[1] The 1980 total is based on projects at Everett, Massachusetts; Cove Point, Maryland; and Elba Island, Georgia. The 1990 total is based on the import projects approved or currently before the Federal Energy Regulatory Commission (FERC) or the Economic Regulatory Administration (ERA), Department of Energy, and an assumed 4 to 6 new projects. In addition, Western LNG Terminal Associates has applied for a permit to receive 6.9 million cubic meters of LNG from southern Alaska.

These LNG projects are based on long-term contracts between subsidiaries of U.S. energy corporations and exporting countries, in order to protect the large investments required by both importers and exporters. For instance, the El Paso "Algeria II" project proposal to import 16 million cubic meters at Port O'Connor, Texas is estimated to cost $4.5 billion (1976 dollars). This includes an estimated $2.3 billion for drilling, pipeline, and marine terminal facilities in Algeria and $856 million for six LNG carriers by subsidiaries of Sonatrach (the Algerian National Oil and Gas Corporation). The subsidiaries of the El Paso Company would invest $896 million for six LNG carriers and $456 million for marine terminal facilities at Port O'Connor.[2]

There are 11 applications approved or presently before FERC and ERA for permits to build LNG marine terminal facilities. Table 15-1 classifies the existing and proposed terminal sites by their location in relation to the edge of a densely populated area of at least 25,000 people: URBAN is defined as a site that is within four miles; SEMI-URBAN as a site that is between four and twelve miles; and RURAL as a site that is more than twelve miles. The table also indicates whether ships approaching each site must pass by an urban area.

Table 15-2 shows the handling capacity of urban and non-urban marine terminals. The import data were provided by the terminal companies. The table indicates that the non-urban projects propose to import more than two times as much LNG as the urban projects. With additional ship berths, storage tanks, regasification equipment and natural gas pipelines, the non-urban terminals could easily handle all of the LNG imports projected for 1990.

TABLE 15-1 LNG MARINE TERMINAL SITES

Urban Sites	Company	Distance to the Edge of a Densely Populated Area Miles	City	Population	Requires Ships To Pass By An Urban Area
Providence, RI	Algonquin	0.6	Providence, RI	179,000	Yes
Everett, Mass.	Distrigas	0.6	Boston, Mass.	641,000	Yes
			Everett, Mass.	42,000	
Oxnard, Cal.	Western LNG	0.9	Oxnard, Cal.	71,000	No
Los Angeles, Cal.	Western LNG	1.1	Los Angeles, Cal.	2,800,000	No
Staten Island, NY	Public Service Electric & Gas	1.5	Staten Island (Eltingville, Annandale Princess Bay), N.Y.	295,00	Yes
		1.5	Carteret, N.J.	23,000	
		2.5	Woodbridge, N.J.	99,000	
West Deptford, N.J.	Tenn[illegible]	1.8	Woodbury, N.J.	12,000	Yes
		3.6	Philadelphia, Pa.	1,950,000	
Elba Island, Ga.	Southern Energy	3.6	Savannah, Ga.	118,000	No
Semi-Urban Sites					
Lake Charles, La.	Trunkline	6.0	Lake Charles, La.	79,000	No
Rural Sites					
Ingleside, Tex.	Natural Gas Pipeline	3.3	Ingleside, Tex.	<5,000	No
		7.6	Portland, Tex.	7,000	
		12.0	Corpus Christi, Tex.	204,000	
Port O'Connor, Tex.	El Paso	3.5	Port O'Connor, Tex.	<5,000	No
Cove Point, Md.	Columbia/ Consolidated	7.0	Solomons, Md.	<5,000	No
		11.0	Lexington Park, Md.	9,000	
Point Conception, Cal.	Western LNG		no towns in vicinity		No

TABLE 15-2. LNG MARINE TERMINAL HANDLING CAPACITY: URBAN SITES vs. NON-URBAN SITES[1]

Urban Sites	Proposed (million cubic meters/year landed)	Potential (million cubic meters/year landed)	Non-Urban Sites	Proposed (million cubic meters/year landed)	Potential (million cubic meters/year landed)
Everett, Mass.	2.0	2.0	Cove Point, Md.	11.2	25.8
			Lake Charles, La.	8.4	16.8
Providence, RI[2]	3.0	4.2	Port O'Connor, Tex	16.0	48.1
Staten Island, N.Y.[3]	6.4	12.4	Ingleside, Tex.	6.9	20.7
West Deptford, N.J.	8.6	34.4	Point Conception, Cal.[4]	15.5	68.9
Elba Island, Ga.	6.0	17.2		58.0	180.3
	26.0	70.2			

1. Data provided by the companies. Proposed quantities are based on the companies' applications to FPC. Potential quantities reflect the amount of LNG that could be received through the terminal with additional ship berths, in some cases, storage tanks, regasification equipment, and natural gas pipeline capacity.

2. The "Proposed" quantity reflects the original filing with the FPC by Eascogas LNG, Inc. Algonquin plans to develop a new import project.

3. Public Service Electric and Gas plans to import 60% of the original filing with the FPC by Eascogas LNG, Inc.

4. In September 1977, the State of California enacted a law authorizing the construction of one non-urban LNG marine terminal. In November 1977 Western LNG Terminal Associates amended its applications to the ERA and the FERC shifting the receiving terminal sites from Oxnard and Los Angeles, California to Point Conception.

If the inherent danger of living near an LEG terminal is insufficient to keep large numbers of people from moving nearby, a non-urban site might become an urban site over the lifetime of a facility. Thus, it is necessary to predict the population pattern of the site area for the projected lifetime of the facility. The Nuclear Regulatory Commission requires such predictions for nuclear facilities, and they have proved to be accurate.

Table 15-3 shows a regional breakdown of the existing and proposed LNG marine terminals. The five non-urban terminals are located in the Northeast, the Gulf Coast, and the West Coast.

FINDING

- The Federal Energy Administration projected maximum U.S. LNG imports in 1990 to be 142 million cubic meters. In addition, Western LNG Terminal Associates has applied to receive 6.9 million cubic meters from southern Alaska. Non-urban LNG marine terminals have the potential capacity to receive 180.3 million cubic meters. Thus, non-urban LNG terminals could easily handle all of the LNG imports projected for 1990. We have not looked at the capacity of the main gas transmission lines to distribute these quantities.

TABLE 15-3. LNG MARINE TERMINAL HANDLING CAPACITY: BY REGION

	Proposed	Potential
	million cubic meters/year landed	
Northeast		
Everett, Massachusetts	2.0	2.0
Providence, Rhode Island	3.0	4.2
Staten Island, New York	6.4	12.4
West Deptford, New Jersey	8.6	34.4
Cove Point, Maryland	11.2	25.8
	31.2	78.8
Southeast		
Elba Island, Georgia	6.0	17.2
Gulf Coast		
Lake Charles, Louisiana	8.4	16.8
Port O'Connor, Texas	16.0	48.1
Ingleside, Texas	6.9	20.7
	31.3	85.6
West Coast		
Point Conception, California	15.5	68.9
	15.5	68.9

AGENCY COMMENTS AND OUR EVALUATION

The Department of Energy suggests that we should ". . .fully document the conclusion that LNG supplies projected for 1990 could be handled in non-urban sites. The volumes are so substantial that absent of a discussion of ship requirements, berth facilities, etc., the statements per se are inconclusive." Several companies make similar comments.

We obtained our estimates for the potential LNG imports that could be received through the marine terminals, shown in Table 15-2, from the terminal companies involved. We mention several ways in which existing facilities and pipelines might have to be expanded. We have not analyzed the possible costs.

REFERENCES

1. Statement of an official of the Office of Oil and Gas, Department of Energy, in a telephone conversation on October 13, 1977.

2. Federal Energy Regulatory Commission "Initial Decision upon Applications to Import LNG from Algeria," Administrative Law Judge Southworth Presiding, October 25, 1977, pp. 4-5.

CHAPTER 16

FEDERAL, STATE, AND LOCAL REGULATIONS

CONTENTS	PAGE

CONTENTS

INTRODUCTION

This chapter evaluates and compares safety laws and regulations for large LEG and naphtha storage facilities, focusing on 12 special issues. It gives an overview of transportation regulations which are discussed more fully in Chapters 6 and 17. Our review covered the Federal Government, the 50 states, and 30 representative localities listed in Table 16-1.

The survey shows that substantive regulation of the storage and handling of bulk LNG, LPG, and naphtha remains under the jurisdiction of the states.

Except for a few municipalities that have their own codes, city and county authorities follow state regulations for enforcement and inspection purposes.

Federal regulations are similar to those of the states and municipalities because they all rely heavily on National Fire Protection Association (NFPA) standards.

Appendix XVI-1 lists all U. S. facilities having LNG, LPG, or naphtha storage in excess of 23,000 cubic meters (m^3), or a monthly throughput greater than that figure. Appendix XVI-2 describes 12 large LEG facilities that we visited.

THE EVOLUTION OF SAFETY STANDARDS

Most regulations governing the siting, design, testing, inspection, and operation of LNG, LPG, and naphtha facilities evolved within the industry. The first major LNG facility, constructed in Cleveland in the early

TABLE 16-1 LOCALITIES WHOSE LEG AND NAPHTHA SAFETY REGULATIONS WERE REVIEWED

State	City	Fuel(s)
California	Chula Vista	LNG, naphtha
	Los Angeles	LNG*, LPG, naphtha
	Oxnard	LNG*
Connecticut	Rocky Hill	LNG
Delaware	Claymont	naphtha
Georgia	Elba Island	LNG*
Idaho	Boise	LNG
Illinois	Fisher	naphtha (SNG), LNG
Kentucky	Calvert City	LPG (cavern)
Louisiana	Lake Charles	LNG*
Maryland	Cove Point	LNG
Massachusetts	Dorchester	LNG
	Everett	LNG, LPG
	Boston	naphtha
	Lowell	LNG
Michigan	Marysville	naphtha (SNG)
Minnesota	Burnsville	LNG
Nebraska	Omaha	LNG
New Jersey	Linden	naphtha (SNG)

New York	New York:	
	Brooklyn	LNG, naphtha (SNG)
	Astoria	LNG
	Staten Island	LNG*
	Jamaica	naphtha
	Queens	naphtha
Ohio	Green Springs	naphtha (SNG)
Oregon	Newport	LNG
Pennsylvania	Marcus Hook	naphtha, LPG
	Philadelphia	LNG
Puerto Rico	Puneulas	naphtha
Rhode Island	Providence	LNG, LPG
Tennessee	Memphis	LNG
Texas	Houston	naphtha, LPG
	Ingleside	LNG*
Virginia	Tidewater	LNG
Washington	Plymouth	LNG

---

* not operating

1940's, was designed on the assumption that credible accidents would involve leaks that were no faster than those from a major piping accident. Present LEG codes and standards are more stringent than those used at Cleveland, but they are still designed to handle only the same limited leakage.

Regulations governing LEG and naphtha storage are based on NFPA and other professional group standards. LPG and naphtha have been in widespread use for many years, and the regulations controlling them are more nearly uniform than those for LNG. The American Petroleum Institute (API), the NFPA, and some localities have special rules covering bulk storage of refrigerated LPG.

NFPA Standard 58, "Storage and Handling of Liquefied Petroleum Gases," was first adopted in 1932. Between 1932 and 1940 the rapidly growing use of LPG led to several separate NFPA standards for different LPG applications. In 1940 these were combined into Standard 58. The Standard has been revised about every two years since. The current version is the 1974 edition. This standard is accepted by nearly all state and local fire agencies.

NFPA Standard 59, "Storage and Handling of Liquefied Petroleum Gases at Utility Gas Plants," was originally developed in 1949. The 1974 version was the product of a cooperative effort between the American Gas Association and the NFPA. This standard is usually adopted by utility regulatory bodies because of its specific application to utility plants.

NFPA Standard 59A, "Storage and Handling of Liquefied Natural Gas," as revised in 1972, is the common minimum standard for LNG. The 1975 revision is now being adopted by states and localities.

NFPA Standard 30, "Flammable and Combustible Liquids Code," is used for naphtha. It was originally developed in 1913 as a suggested ordinance for the storage and handling of flammable liquids, and it has been the basis for most subsequent regulations for liquid fuels such as naphtha. The text was expanded over the years, and in 1957 was changed to a recommended Code in recognition of the tendency toward statewide regulation. The current edition was published in November, 1976.

API Standard 2510 is sometimes adopted by regulatory groups. It does not apply to LPG installations covered by NFPA 58 or 59, but rather to those at marine and pipeline terminals, refineries, or tank farms. In some criteria API 2510 is more stringent than NFPA 58, in others less.

API Standard 620 is entitled "Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks." The sixth edition, released on July 15, 1977, has an appendix which applies specifically to LNG tanks.

API Standard 650 (1977 ed.), "Welded Steel Tank for Oil Storage," applies to naphtha tanks. Pressure vessels such as non-refrigerated LPG tanks are designed to American Society of Mechanical Engineers (ASME) pressure vessel codes.

FEDERAL REGULATION OF LEG AND NAPHTHA SAFETY

Federal regulations covering land storage facilities are not well coordinated for LNG and are minimal for LPG or naphtha. The LNG regulations incorporate NFPA 59A. There are no specific Federal laws or regulations covering minimum liability insurance requirements for LEG or naphtha facilities.

In the Federal regulation of LNG storage facilities, there have been areas where jurisdiction among agencies has been unclear. Two DOT agencies—the Office of Pipeline Safety Operations (OPSO), in the Materials Transportation Bureau (MTB), and the U.S. Coast Guard—have each exercised authority over LNG facilities adjoining the navigable waters of the United States. The former Federal Power Commission (FPC) also had certain responsibilities for the safety of LNG import terminals and some peakshaving plants.

On February 7, 1978, the MTB and the Coast Guard signed a two-page Memorandum of Understanding which specifies the responsibilities to be carried out by each agency. This action, which took more than three years of negotiations, should reduce the duplication of effort and speed the promulgation of needed regulations.

The Coast Guard will be responsible for establishing regulatory requirements for:

(1) Facility site selection as it relates to management of vessel traffic in and around a facility;

(2) Fire prevention and fire protection equipment, systems, and methods for use at a facility;

(3) Security of a facility; and

(4) All other matters pertaining to the facility between the vessel and the last manifold (or valve) immediately before the receiving tank(s).

Except as provided in those paragraphs, the MTB (through OPSO) will be responsible for site selection and all other matters pertaining to the facility. This division of responsibilities appears to be appropriate. The two agencies agreed to cooperate in carrying out their enforcement activities and to consult with each other before issuing proposed and final regulations.

Appendix XVI-3 includes the full memorandum and a discussion of the statutory authority of the two agencies. This appendix also includes an analysis of the relationship between OPSO and the FPC.

Several DOT offices are also responsible for setting and maintaining safety standards for interstate trucks and railcars carrying LEG. This chapter discusses only the regulations issued by MTB and its Office of Hazardous Materials Operations (OHMO). The Interstate Commerce Commission (ICC) is also involved in LEG transportation, since only it can revoke or suspend the certificates of interstate carriers found to be unsafe. The Coast Guard has Federal jurisdiction over LEG and naphtha shipping.

Office of Pipeline Safety Operations

Responsibilities for LNG Facilities

OPSO is responsible for prescribing and enforcing Federal safety regulations for LNG storage facilities connecting with a pipeline in or affecting interstate commerce. See 49 CFR Parts 191 and 192. These regulations incorporate the 1972 version of NFPA Standard 59A. The facility design regulations apply only to LNG pipeline-connected facilities for which construction began after January 1, 1973, but the operating and modification provisions apply to all facilities. Currently, OPSO has an Advance Notice of Proposed Rulemaking on "Liquefied Natural Gas Facilities, Federal Safety Standards," which could add a new Part 193 to Title 49, CFR (42 Fed. Reg. 20776, dated April 21, 1977). It expands on the 1975 edition of NFPA 59A, uses safety performance standards, and includes some specific new technical requirements. The new design standards will apply to existing facilities only if they are modified in the future.

OPSO carries out its pipeline safety program across the United States through its five regional offices, each staffed by two professionals and a secretary. OPSO plans to increase the number of professionals in the field offices to 45, but eight will be assigned to the Alaska gas pipeline project.

OPSO mainly relies on certified state agencies for the inspection of LNG storage facilities. (This certification program is described below.) In 1977, OPSO made three inspections, including the Cove Point, Md. marine terminal. State agencies made 242 inspections of

74 LNG storage facilities in 1977. OPSO records do not indicate the extent of the state inspections.

A more comprehensive review of OPSO's authority, regulations, and performance is presented in GAO's report, "Pipeline Safety--Need for a Stronger Federal Effort" (CED-78-99). One of its conclusions is that OPSO's staffing, particularly in the regional offices, is not adequate for carrying out its present mandated responsibilities in a comprehensive, effective, and timely manner.

OPSO regulations require LNG storage facilities to report at the earliest practicable moment by telephone any leak that causes death or injury, property damage of more than $5,000, or gas ignition. No written follow-up report is required if the facility serves fewer than 100,000 customers. For example, the owners of the Cove Point import terminal, whose only customers are other pipeline companies, would not have to file a written report.

In the annual report required of all gas transmission companies, all leaks must be described. There is no requirement, however, by OPSO or any other Federal agency, for the reporting of other unusual occurrences, such as the venting of vapor from storage tanks or the breakdown of vital machinery. Gas utility companies do not have to identify the type of facility where a leak occurred. It would not be clear, for example, whether a leak occurred at an LNG peakshaving facility or in the natural gas pipeline.

Responsibilities for LPG and Naphtha Facilities

OPSO's regulation of LPG and naphtha pipelines is authorized under the Transportation of Explosives Act of 1908, 18 U.S.C. 831-835, and the Hazardous Materials Transportation Act, 49 U.S.C. 1801 et seq. The Explosives Act gives OPSO responsibility over interstate and foreign commerce by these pipelines, but it does not cover interstate pipelines and facilities that merely affect interstate commerce. The Hazardous Materials Transportation Act excludes interstate liquid pipelines covered under the Explosives Act from its provisions. OPSO further interprets the Act to exclude jurisdiction over intrastate liquid pipelines affecting interstate commerce. We disagree. We believe that intrastate LPG and naphtha pipelines, including connecting import terminals and storage complexes, affecting interstate commerce are under OPSO's jurisdiction and that OPSO should extend its regulations to cover these pipelines.

Under the Explosives Act, the Director of OPSO cannot levy civil penalties for violations. In order to penalize violators, he must initiate criminal charges. If no death or serious injury resulted from the violation, the maximum penalty is $1,000 and one year imprisonment.

According to OPSO regulations, 49 CFR 195.264, LPG and naphtha storage tanks under its jurisdiction are only required to provide a means to contain liquid in the event of a spill or tank failure, to protect against unauthorized entry, and to provide normal and emergency relief venting. These regulations do not require a particular percentage of the liquids spilled to be contained, or say what constitutes adequate protection against unauthorized entry.

U.S. Coast Guard

The U.S. Coast Guard regulates various aspects of the design, construction, and harbor movements of seagoing vessels and cargo tanks for LEG and naphtha (46 U.S.C. 391a). It has issued regulations on the design and operation of tank vessels transporting LEG and naphtha, in 46 CFR Parts 30 to 40; and for the transportation of liquefied flammable gases in portable containers stored on deck for use as ships' stores and supplies, in 46 CFR Part 147. It has regulations on hull and tank construction for liquefied gases, 46 CFR Parts 151 and 152, and for the maintenance of standards on foreign vessels, 46 CFR Part 154. Coal tar naphtha is regulated under 46 CFR Part 153 as a bulk liquid chemical.

In October, 1976, the Coast Guard published proposed standards for new self-propelled vessels carrying bulk liquefied gases. The Coast Guard has not promulgated regulations directly relating to LNG land facilities but had announced an intention to do so. Under the new Memorandum of Understanding, the Coast Guard's rule-making will be coordinated with OPSO's.

The Coast Guard is responsible for designating security zones on land to guard against sabotage, and it issues permits and maintains precautions relevant to the handling of dangerous cargo in or contiguous to waterfront facilities, pursuant to 33 CFR Parts 6 and 124-127.

Materials Transportation Bureau

MTB has promulgated detailed regulations on the transportation by rail, highway, air, or water, of hazardous materials in commerce. These, set forth in 49 CFR Parts 171-179, identify hazardous materials by classes (LNG and LPG are flammable gases) and require specific design standards for hazardous materials containers, including railcars and tank trucks. At present, however, no regulations for the design of cryogenic tank trucks exist, and MTB (through OHMO) approves LNG tank truck designs by exemption. The regulations in 49 CFR Parts 171-179 incorporate parts of NFPA Standard 58 and other standards of private organizations.

Federal Power Commission

The Natural Gas Act of 1938, 15 U.S.C. Section 717 et seq., authorized the Federal Power Commission to regulate the transportation and sale for resale of natural gas in interstate commerce, including, under Section 717f, the regulation of facilities. In addition, the Commission has exercised jurisdiction over import facilities under its authority to regulate imports of natural gas (15 U.S.C. 717b). Regulations in 18 CFR Part 3 Appendix B, Guideline 9.4.1., which were adopted pursuant to the National Environmental Protection Act, require that Environmental Impact Statements be prepared for LNG transport, storage, and regasification facilities. These must include a description of compliance with the relevant OPSO and Coast Guard safety regulations.

U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers has the authority under 33 U.S.C. Section 401 to regulate the construction of bridges and wharves, and other activity or construction which affects navigable waters. In this capacity, the Corps issues permits relevant to the construction of waterfront LNG terminals, but lacks authority to otherwise regulate either LNG ships or terminal facilities. Permit regulations are found in 33 CFR Part 209.

Interstate Commerce Commission

The ICC, under its basic grant of authority in 49 U.S.C. Section 1 et seq., has general authority over interstate surface transportation. Its control over the safety aspects of different modes of transportation and its specific powers to regulate the transportation of dangerous materials was transferred to DOT by the DOT Act of 1966, as amended (49 U.S.C. 1651 et seq.).

Federal Aviation Administration

The Federal Aviation Administration has the authority to certify airports and set standards for the storage and inspection of fuel storage (14 CFR 139.1 et seq. and 139.51). This includes naphtha, but not LNG or LPG, since they are not used for aircraft fuel.

Environmental Protection Agency; Council on Environmental Quality

The Environmental Protection Agency has several regulations which potentially affect LEG and naphtha facilities. They are somewhat removed, however, from the issues which are the subject of this inquiry. Some examples are regulations on Ambient Air Quality Standards, 40 CFR Part 50; Registration of Fuels and Fuel Additives, 40 CFR Part 79; Energy Related Authority, 40 CFR Part 55; and Hazardous Substances, 40 CFR Parts 116-119. The regulations of the Council of Environmental Quality pertinent to the National Oil and Hazardous Substances Contingency Plan, 40 CFR Part 1510, fall in this same category.

The Coastal Zone Management Act

The Coastal Zone Management Act of 1972, under 16 U.S.C. 1451 et seq., encourages state regulation of coastal land use. This could have an impact on LEG import facilities, since no license or permit shall be granted by a Federal agency for such an area unless the state concurs with the applicant's certification that the proposed activity complies with the state's approved coastal zone management program. There is provision, however, for the Secretary of Commerce to find, after providing a reasonable opportunity for detailed comments from the Federal agency involved and the state, that the proposed activity is consistent with the objectives of the Act or is otherwise necessary in the interest of the national security. See 16 U.S.C. 1456(c).

Findings

- Federal regulation of LNG storage facilities has not been well coordinated. The February 1978 Memorandum of Understanding between the U.S. Coast Guard and MTB should reduce the duplication of effort and speed the promulgation of needed regulation of waterfront LNG facilities.

- Prompt reporting of all unusual occurrences at LNG facilities is needed. OPSO requires gas transmission companies to report all spills in the annual reports submitted to OPSO, but only major spills must be reported by telephone immediately. A company with fewer than 100,000 customers, such as an LNG importing company, does not have to submit a written, follow-up report. No Federal agency requires companies to report other unusual occurrences such as the venting of gas or the breakdown of vital machinery at LNG storage facilities.

- There are no Federal regulations for intrastate LPG pipelines and connecting storage facilities that affect interstate commerce. OPSO interprets the Hazardous Materials Transportation Act as excluding jurisdiction over these pipelines and storage facilities. Under the Transportation of Explosives Act of 1908, OPSO may initiate only criminal charges in court against violators of LPG interstate pipeline regulations. No civil penalties are available.

STATE AND LOCAL REGULATIONS

State Regulations

Enabling legislation usually delegates a state's responsibility for developing LEG and naphtha regulations to a specific agency, which promulgates standards. Most state agencies incorporate or follow NFPA Standards. Appendix XVI-4 contains summaries of the state regulations. Appendix XVI-6 includes a list of state agencies with LEG and naphtha regulatory responsibilities.

Section 5 of the Natural Gas Pipeline Safety Act (49 U.S.C. Section 1674) authorizes OPSO to establish a voluntary program for state agencies to assume Federal inspection and enforcement responsibilities for intrastate gas pipelines and connecting facilities. Agencies, typically public service or utilities commissions, from all 50 states, the District of Columbia, and Puerto Rico are currently participating. Almost all LNG peakshaving facilities are regulated by the state agencies through the OPSO program. A few states, including New York and Massachusetts, have regulations which exceed OPSO's requirements in some respects.

In more than half the states, the State Fire Marshal's Office regulates liquid fuels, including LPG. This office often is part of a larger agency charged with overall law enforcement, policy, or public safety responsibilities. Historically, these state offices dealt with naphtha and other nonpressurized, usually petroleum-based, combustible or flammable fuels. Subsequently, regulations were developed for pressurized LPG.

State public service or utilities commissions participate in the OPSO certification program because they regulate natural gas. Occasionally they have regulations for LPG handling and storage, but only rarely for naphtha.

Other state agencies with regulations applicable to the transportation, storage, or handling of LEG or naphtha include Departments of Labor and Industry (or Industrial Relations, or the like). The regulations of such agencies are often heavily oriented toward the protection of workmen. Their safety concerns encompass only the areas of labeling, packaging, and related requirements associated with small amounts of fuel. In New Jersey, the Department of Labor and Industry is the primary regulatory body for LEG and naphtha. Many states also [illegible] motor vehicle transportation regulations, such as requiring trucks transporting LNG to come to a full halt at railroad crossings. Kentucky and Louisiana have LPG Commissions whose regulations extend to bulk storage of LPG in salt dome cavities. None of these regulations, however, covers the seismic design of LPG caverns. Illinois covers the same subject area under the State Environmental Protection Agency.

In the last three years, there has been a trend at the state level toward the formation of Energy Departments, Energy Facilities Siting Councils or Commissions, and Environmental Protection Agencies. With few exceptions, New York for example, offices of this kind show an interest only in the location of LNG facilities. A similar interest is shown by the Coastal Zone Management Councils which have been formed as the result of the Federal Coastal Zone Management Act in states including California, Delaware, Massachusetts, and Oregon.

The central concern of agencies of this type is in locating facilities in harmony with energy resource planning, or other land use patterns. Thus, while safety is a matter of concern, it appears at a generalized level rather than in the context of specific requirements affecting construction and management. These agencies have generally deferred to the specific standards established by other state agencies.

Local Regulations

Except for a few large cities that have detailed fire codes, city and county authorities follow state regulations for enforcement and inspection purposes. State-imposed standards are usually followed even in those cases where independent rulemaking authority clearly exists at the local level. Like the state agencies, local authorities often adopt NFPA Standards on a de facto basis without the trappings of official promulgation. This is important, since local officials play a more significant role than state officials in overseeing the construction of facilities and in periodically inspecting them for compliance with operational requirements.

Some cities have adopted official facility standards because of a void in state and Federal law, as in the case of Houston, or because of the pressure for greater safety scrutiny arising from high population densities and the concentration of bulk storage facilities for many hazardous substances in a small area.

New York is the only city with comprehensive local LNG standards. When the first LNG peakshaving facility in the New York metropolitan area was proposed in the 1960's, the New York City Fire Department (NYCFD) became concerned about the siting of such a facility in a congested urban area and developed informal requirements for it. These were later translated into a detailed set of written regulations which exceed those of NFPA in a number of ways. The New York State Public Service Commission later adopted its own standards for LNG facilities, drawing on and somewhat modifying both the NFPA standards and the NYCFD requirements. In June, 1976, New York State enacted the Liquefied Natural and Petroleum Gas Act making the safety of LNG facilities the responsibility of the State Department of Environmental Conservation.

Local building and zoning codes do not focus on LEG facilities, as such, but building codes are used to set design criteria for the construction of storage tanks. Building codes are usually adopted at the state level. These codes are fashioned after models provided by professional organizations, such as the International Conference of Building Officials, whose codes incorporate some NFPA regulations. Zoning codes are primarily land-use oriented and do not provide specific safety criteria applicable to fuel facilities of any kind.

Permit Granting Agencies

At both state and local levels the authorization of many governmental organizations may be required before an LEG facility can be constructed. At the local level, zoning boards present the most common example. At the state level, there has recently been a proliferation of agencies whose permits must also be obtained, causing an overlap of authority with more traditional regulatory bodies. For example, a proposed LNG facility might require the permit or certification of an Environmental Protection Agency, the Energy Facilities Siting Council and/or a Coastal Zone Management group, as well as that of a Fire Marshal and a Public Utilities body, and appropriate local agencies.

The more recently created bodies tend to be primarily concerned with land use and/or energy resource planning. In general, specific safety issues are not an abiding or primary concern. As a result, those agencies have few regulations that are directly relevant to this study. Their authority is sufficiently broad, however, to allow issues such as compliance with NFPA or other standards to become a part of their decision-making on a given application. However, this pattern at the state level is too recent to have given rise to a body of legal precedent. At least one state, Alaska, is attempting to consolidate the permitting structure for LNG facilities into a single agency process.

It is not clear whether a facility plan approved by the FPC or the Department of Energy could be blocked by state land use groups, such as Coastal Commissions or Energy Facilities Siting Councils. Historically, the FPC has respected the decisions of local and state authorities and avoided any conflict. State agencies have generally been granted final authority over land use issues. This point has not yet been tested in the courts since a significant conflict has not yet arisen.

Airports

LEG bulk storage facilities are not generally located at airports. Naphtha, however, because it is a common component of jet fuel, is stored at airports.

Since airports are typically under both state and local jurisdiction, any fuel facilities constructed on them are subject to the regulatory patterns described above. In addition, airports are subject to requirements imposed by the FAA. However, as discussed earlier in the context of Federal standards, these requirements are not directly relevant to this study. Aviation or aeronautics agencies take a similar regulatory approach. The tendency of airport regulatory bodies is to informally adopt NFPA standards, or to defer to the specific requirements of other state agencies for fuel facilities.

Insurance and Liability Standards

With the exception of New York State, which imposes strict liability for LNG and LPG, we found no specific state or local requirements concerning insurance or the imposition of special liability standards which have any applicability to LNG facilities. Ten states have insurance requirements for LPG transportation. However, the required coverage is small, ranging from $10,000 per person injured to a maximum of $100,000 per accident. This leads us to believe that the basic concern of these requirements is with storage, transportation, and handling of relatively small containers of LPG rather than bulk quantities.

Findings

- Almost all state and local regulations are based on NFPA standards. The exceptions include somewhat more stringent regulations developed by the New York State Public Service Commission and the New York City Fire Department.

- Most responsibility for the safety of LEG and naphtha has traditionally been under state and/or local fire marshals. LEG at public utilities is also regulated by State Public Service or Utilities Commissions. Energy Facilities Siting Councils and Coastal Commissions have recently been given jurisdiction over the development of new large energy facilities. However, such groups are too new to have established much state law precedent.

- Permit requirements are becoming increasingly cumbersome as agencies proliferate. Some states are attempting to simplify this problem for LNG facilities by consolidating the process under a single agency.

- New York State imposes strict liability for LNG and LPG facilities. In other states, LNG storage is not subject to specific regulatory provisions imposing liability for injury to persons or property, or requiring that insurance be carried against whatever liability would be imposed by courts under general tort law.

FINDINGS OF SPECIAL ISSUES ANALYSIS

This section lists our findings for the following 12 special issues for LNG, LPG, and naphtha:

1. The Minimum Distance Required Between the Tanks or Dike and Residential, Social, Business, and Government Facilities.

2. The Minimum Distances Required Between LNG, LPG, or Naphtha Tanks and Tanks Holding Other Flammable, Explosive, Poisonous, or Toxic Materials.

3. Security Requirements.

4. Diking Requirements.

5. Requirements For Resistance to Natural Phenomena.

6. Requirements For Operating Procedures and Personnel Training.

7. Materials Specifications For Storage Tanks.

8. Materials Specifications For Truck Trailers and Rail Cars.

9. Requirements For Harbor Movements and Unloading of LEG and Naphtha Tankers.

10. Requirements For Tanker Construction.

11. Liability.

12. Liability Insurance Requirements.

Our detailed analyses are in Appendix XVI-5. Only those state and local regulations which supplement or modify the Federal regulations applying to a particular issue are cited.

1. <u>The Minimum Distance Required Between Tanks or Dikes and Residential, Social, Business, and Government Facilities</u>.

One concern in siting a major energy facility is to protect the people living and working in surrounding areas from the consequences of credible major accidents at the facility.

Basic protection is provided by requiring adequate separation between the fuel storage area and any property line that abuts other property which is in use. Additional requirements are imposed in a few jurisdictions if the site is located near critical occupancy buildings such as schools, hospitals, and places of public assembly.

To obtain some idea of the range of distance requirements, an example may be helpful. If a 25,000 cubic meter (m^3) capacity storage tank with a diameter of 120 ft and a 80 ft liquid height were surrounded with a 100% capacity square dike 20 ft high, the length of one side of a square dike would be about 210 ft. A tank with twice that volume (50,000 m^3) and with the same liquid height and dike height would require a tank diameter of 170 ft and a dike side of 300 ft; a 100,000 m^3 tank would have a 240 ft diameter and dike sides of 420 ft.

For these three size tanks, Table 16-2 shows the exclusions distances required for LNG, LPG, and naphtha by different codes and jurisdictions.

Findings

- There is a considerable variation in buffer zone requirements. The NFPA 59A - 49 CFR Part 192.12 standards for LNG require smaller exclusion distances for the smaller tanks than those recommended by NFPA 59 for LPG and NFPA 30 for fixed roof tanks with emergency relief vents. (All LNG tanks have fixed roofs and emergency relief valves.) The LNG buffer zones set by New York State and the New York City Fire Department are more consistent with the distances required for LPG and naphtha. Buffer zones for LPG are close to those for naphtha.

- A very few jurisdictions recognize certain critical occupancy buildings (such as schools, hospitals, places of public assembly, etc.), and require additional separation ranging from 300 ft for naphtha (Connecticut) to 1,000 ft for LNG (NYCFD). No consistent criteria have yet been published relating to flammable vapor travel. Flammable vapor cloud migration offsite is not considered per se in LPG siting regulations. It is mentioned for LNG in the 1975 NFPA 59A, but the criteria for assessing acceptable safety are vague and the suggested computational methods are inappropriate. The NYCFD requires submission of vapor travel analyses for LNG facilities but does not state methodology or criteria.

TABLE 16-2 EXCLUSION DISTANCES FROM THE TANKS TO THE PROPERTY LINE

Agency Regulation	Exclusion Distance to Property Line 25,000 m^3	50,000 m^3	100,000 m^3
LNG			
49 CFR 192.12 (NFPA 59A)			
from dike	160'	228'	320'
from tank	200'	285'	400'
New York State			
from dike	400'	570'	800'
from tank	440'	627'	880'
NYCFD			
umbermed	400'	570'	800'
bermed	250'	250'	300'
from critical occupancy	1,000'	1,000'	1,000'
Massachusetts			
from dike	160'	228'	320'
from tank	100'	100'	100'
LPG (Refrigerated)			
NFPA 59			
from tank	400'	400'	400'
API 2510			
from tank	200'	200'	200'
California-PUC			
to schools	500'	500'	500'
from tank	50'	50'	50'
Pennsylvania			
from tank	50'	50'	50'
NAPHTHA			
NFPA 30			
float roof	120'	170'	175'
fixed roof	350'	350'	350'

Agency Regulation	Exclusion Distance to Property Line 25,000 m^3	50,000 m^3	100,000 m^3
Connecticut			
float roof or extinguishing system	120'	120'	120'
Florida			
float roof	120'	170'	175'
fixed roof	350'	350'	350'
Indiana			
float roof	120'	170'	175'
fixed roof	350'	350'	350'
Michigan			
float roof or extinguishing system	120'	120'	120'
Pennsylvania			
float roof	120'	170'	175'
fixed roof	350'	350'	350'

- In most situations, for a given volume, LPG is more dangerous than LNG and LNG is more dangerous than naphtha. The minimum exclusion distances imposed by NFPA standards and states and localities do not reflect this. Buffer zones for naphtha are often close to or even greater than those for LPG, and buffer zones for LNG are often substantially less than those for naphtha.

2. The Minimum Distances Required Between LNG, LPG, and Naphtha Tanks, and Tanks Holding Other Flammable, Explosive, Poisonous, or Toxic Materials.

The following table presents separation distances for the same three sizes of tanks discussed in Issue One. The separation distance applies to two tanks of the size indicated.

TABLE 16-3 EXCLUSION DISTANCES BETWEEN STORAGE TANKS

Agency Regulation	Inter-tank Exclusion Distance 25,000 m^3	50,000 m^3	100,000 m^3
LNG			
49 CFR 192.12 (NFPA 59A)	60'	85'	120'
California	60'	85'	120'
New York State	250'	357'	500'
NYCFD	250'	357'	500'
Massachusetts	60'	85'	120'
LPG*			
NFPA 59 (1976)	60'	85'	120'
NFPA 58 (1976)	60'	85'	120'
API 2510 (1970)	60'	85'	120'
California	18"	18"	18"
Kansas	60'	85'	120'
Mississippi	60'	85'	120'
New Jersey	60'	85'	120'
Pennsylvania	3'	3'	3'
Wisconsin	60'	85'	120'
NAPHTHA**			
NFPA 30 (1976)	60'	85'	120'
California	18"	18"	18"
Connecticut	60'	85'	120'
Florida	40'	57'	80'
Indiana	40'	57'	80'
Michigan	60'	85'	120'
Pennsylvania	40'	57'	80'

* Refrigerated Containers

** Floating Roof Tank

Findings

- Basic NFPA standards give inter-tank separation distances of one-fourth the sum of the diameters of adjacent tanks for LNG and LPG tanks. For naphtha tanks the separation distance generally is one-sixth this sum except for very large naphtha tanks with fixed roof design and large impounding areas. API 2510 has spacing requirements for LPG tanks that are in some cases less stringent than those of NFPA 58 and 59. State requirements generally are the same as or less stringent than NFPA standards. The NYCFD, however, requires spacing between two LNG tanks to be the greater of 250 ft or 1.25 tank diameters.

- The NFPA 59A LNG container spacing requirement does not take into account the dike design or the location of the tanks within the dikes.

- Requirements for inter-tank spacing are not logically related to the different hazards presented by the different fuels and are frequently no more stringent for LEG than for naphtha. They usually are no more stringent for LPG than for LNG. They are sometimes more stringent for naphtha than for LPG.

3. Security Requirements.

Findings

- In light of the potentially severe consequences of sabotage, the required deterrents are weak. Most of the codes require only fencing, without mentioning locks, and none of the codes mentions additional perimeter security measures. NFPA 59 requires that any locks used be breakable (to ease the entrance of firemen). The NYCFD requires locked gates at LNG facilities.

4. Diking Requirements.

An important aspect of energy facility safety is to assure that any accidental fuel releases will be contained in limited areas on-site, preferably in impounding areas of adequate capacity and minimum surface area. Also, facilities should be designed so that an impounding area fire does not jeopardize other critical parts of the facility or its environs.

Findings

- Diking is required for LNG, refrigerated LPG, and naphtha. Pressurized LPG is not considered under either NFPA 58 or API 2510 to need diking, although the API Standard suggests area grading so that any spills will flow away from the storage area to a safe impounding location.

- For LNG, refrigerated LPG, and naphtha, NFPA standards require that dike volumes be at least equal to the maximum storage volume of the tank they protect. If a dike protects more than one tank, the dike volume must at least equal that of the largest tank contained in the dike. Any LEG outer tank walls that might be wetted in a spill must be able to withstand low temperature exposure.

- Dike design requirements are more comprehensive in the NFPA standard covering naphtha than in the NFPA standards for LNG and LPG.

- New York State and the New York City Fire Department require 150% capacity diking for LNG and prohibit multiple tanks in a single dike.

- The NYCFD now allows only bermed LNG tanks surrounded by an additional dike with height at least half the maximum tank liquid level height. Most other codes treat bermed tanks as tanks with integral dikes and do not require secondary diking.

5. Requirements for Resistance to Natural Phenomena.

Hazardous facilities should be designed to withstand any severe environmental conditions which might occc during the lifetime of the facility. Such conditions include high winds, tornadoes, earthquakes, floods, rapid atmospheric temperature and pressure changes, snow loads, etc. Building codes usually specify a design event for these natural phenomena. Most petrochemical facilities have been designed to meet normal building code standards. Frequently, the design event (the event the facility is designed to withstand without endangering the public) is the worst occurrence in the area for the period in which catastrophic events are documented. This amounts to a 200 - 300 year data base in most of the United States. Often it is only the worst event in the area in the past 50 years. NRC imposes much stricter requirements on nuclear plants.

Current OPSO standards are based on NFPA 59A (1972) and thus do not include certain changes made in NFPA 59A (1975) such as the need for a detailed geotechnical site investigation in seismic areas. There is no such requirement for equally large tanks of LPG.

The draft LNG regulations developed for comment by OPSO suggest a design event for each natural phenomena for which there is only a 0.5% probability of a more severe event occurring during a 50 year period. This is equivalent to an average repeat interval of about 10,000 years, which seems adequate. However, if there are 50 LNG facilities, there is a 22% chance that a larger than design event will occur at the site of one or more of them during a 50 year period. For 100 facilities the chance is

39%. For 100 facilities and three independent phenomena, such as earthquakes, winds, and floods, the chance is 78%. There are already more than 100 LEG aboveground storage facilities, including 68 with at least 23,000 cubic meters of storage. What is more, most of these are built to the much lower standards of the building code.

The probability that one of the design events of the facilities will be exceeded can be characterized by a parameter L. L is defined as the number of sites (s), multiplied by the number of years an average site is expected to operate (y), multiplied by the number of independent natural phenomena the site is designed to resist (p), divided by the repeat interval of the phenomena (r). In equation form we have:

$$L = syp/r$$

If we have three phenomena, such as earthquakes, winds, and floods, and floods tend to be correlated with high winds, then instead of p being 3 it would be between 2 and 3. If design event floods only occurred at the same time as design event winds, then p would be 2.

Figure 16-1 gives the probability (in percent) of having N or more events which exceed the design event, for various values of L. For L = 100, for example, there is a 51 percent chance of at least 100 greater than design events occurring and a 99 percent chance of having at least 79.

L=(NUMBER OF SITES) x (NUMBER OF YEARS) x (NUMBER OF INDEPLNDENT PHENOMENA)/(REPEAΓ INTERVAL)

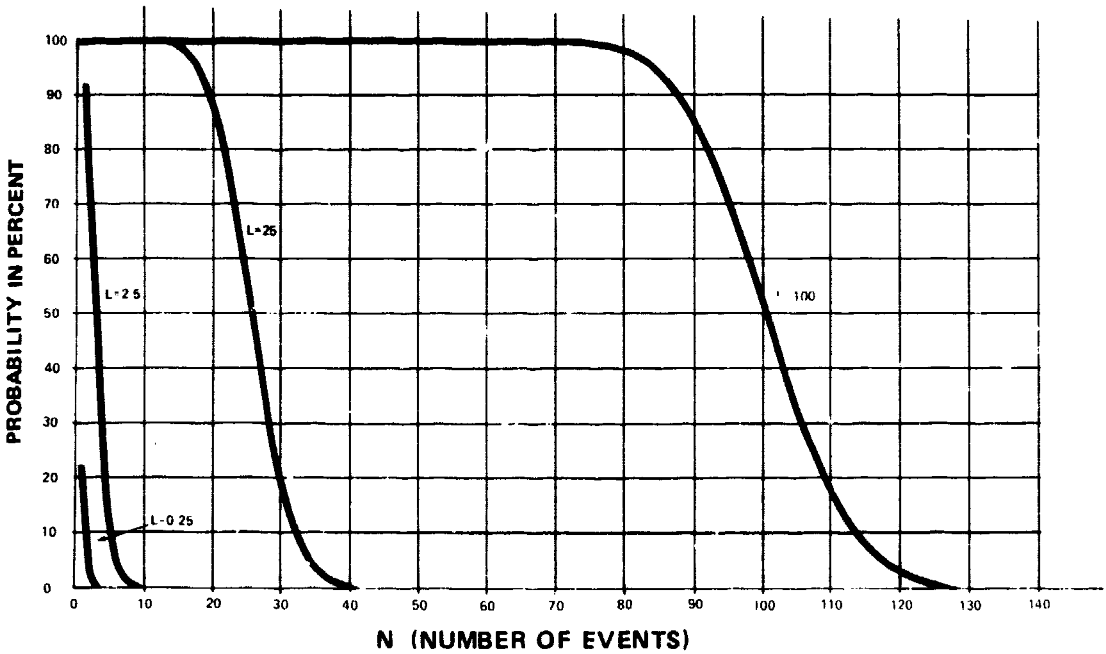


FIG. 16-1 THE PROBABILITY (IN PERCENT) OF HAVING N OR MORE EVENTS WHICH EXCEED THE DESIGN EVENT, FOR VARIOUS VALUES OF L.

In general, structures can survive stresses greater than design load stresses (those generated by design events). The safety factor is the ratio of the allowable stress (the maximum stress in a structure allowed by building codes) to the design load stress (the maximum stress in a structure produced by the loads that the codes require the equipment to withstand). In Chapter 3 we show that the natural phenomena safety factors for many large LEG tanks are quite low. This is even more disturbing since even during the lifetime of present large LEG facilities the design events are certain to be exceeded many times.

The design requirements discussed above apply to critical structures such as LNG storage and dike systems. OPSO, for example, proposes that less important components be designed for events with a 475 year repeat interval. For three phenomena this gives an L close to 25.

Findings

- Most LEG and naphtha facilities have been designed to meet normal building code standards; thus, design standards for naphtha are essentially as strong as those for LEG.

- The design event (the event the facility is designed to withstand without endangering the public) for each type of phenomenon (earthquakes, winds, floods, etc.) is usually the worst occurrence in the area in some past period. The period is 50 years for some jurisdictions and 100-300 years in others. In a few areas it is longer. OPSO's draft LNG regulations use 10,000 years. NRC usually imposes even stricter requirements on nuclear plants.

- There are more than 100 LEG aboveground storage facilities, including 68 with at least 23,000 cubic meters of storage.

- It is virtually certain that design events will be exceeded a large number of times during the lifetime of present large LEG facilities. This is particularly serious because of the low safety factors of many large LEG tanks. (See Chapter 3.)

- Large scale urban area storage of hazardous materials in facilities built according to normal building code standards is common and highly dangerous. Even if OPSO's guidelines are adopted and precisely implemented, they are still not strict enough to allow urban area siting.

6. Requirements For Operating Procedures and Personnel Training.

Detailed operating procedures and competent and well-trained personnel are important factors in facility safety. All facilities have operating procedures, but there is considerable variation in their completeness and whether they are strictly enforced or just intended as recommended guidelines for operating personnel.

Findings

- Outside of some specific technical operating requirements scattered through the various regulations, there are only quite general references to the desirability of operator qualification and training. The NYCFD certifies LNG plant operators. A few states certify operators at LPG facilities. There are no comprehensive requirements for the development of formal operating procedures and training programs or for the review of such procedures by jurisdictional agencies.

7. Materials Specifications for Storage Tanks.

Findings

- Materials standards for a high level of structural integrity appear to be well defined and documented in the relevant codes. Materials standards for metal and concrete tanks are generally well standardized and documented in ASME and ACI Codes. Testing and inspection procedures are also included in the codes to verify materials performance.

- Insulation for storage tanks should be non-flammable. Where insulation is used to protect LPG or naphtha tanks from external fires, the insulation should be designed to maintain its integrity during prolonged exposure to impinging flames.

- Some states have developed extensive requirements for corrosion control (such as coating, cathodic protection, etc.) which supplement the basic requirements of the design codes.

8. Materials Specifications for Truck Trailers and Railcars.

Large quantities of LNG are moved by truck. Trucks and railcars transport LPG and naphtha. The mobility of such vehicles often brings them into areas of high population density and increases their chance of being in an accident.

Findings

- Tank vehicle safety is largely regulated by DOT regulations on brakes, lights, etc., and by Federal, state, and local standards for tank design. Naphtha transport, like gasoline transport, is considered routine.

- A standard developed by the Compressed Gas Association which requires 3/32-inch steel insulation jackets for LNG carriers and other requirements is generally followed. To date, OHMO has been extremely slow in promulgating similar Federal standards for LNG tank vehicle design, and approves designs on an individual basis through a special permit or exemption process.

NOTE: LEG truck and train transportation is discussed in detail in Chapters 7 and 8. The regulations governing this transportation are discussed in Chapter 17.

9. Requirements for Harbor Movements and Unloading of LEG and Naphtha Tankers, and

10. Requirements for Tanker Construction.

Findings

- Coast Guard regulations are quite comprehensive, covering vessel design, operation, and inspection. At present, however, many of the detailed operating requirements are at the discretion of the Commandant or the Captain of the Port(COTP). (See Chapter 6.) It is Coast Guard policy to follow unofficial regulations which have been published (October 1976) as proposed rules.

- Naphtha is included in the general category of flammable liquid cargoes for which there are weaker standards for ship survivability in the event of stranding or collision. Some cargo loss under such conditions is not unlikely.

- LEG carriers are designed to a higher standard of survivability and are designed to contain cargo in case of stranding or minor side damage. Refrigerated LPG ships, however, can be single-hulled.

- The operational requirements for LEG carriers entering U.S. ports are under the jurisdiction of the Captain of the Port concerned. Although Coast Guard position papers have outlined comprehensive typical requirements for COTP's, these are discretionary.

11. Liability.

Findings.

- New York State imposes strict liability for offsite damages against persons engaged in the storage, handling, and transportation of both LNG and LPG, but not naphtha. Maine has adopted strict liability for injuries arising from natural gas operations generally without specifying its applicability to LEG or naphtha. There are no other regulatory provisions that deal specifically with liability for handling these fuels. As a result, the extent to which responsible persons will be liable for offsite damages is determined by judicial case law standards in the various states.

12. Liability Insurance Requirements

Findings

- Ten states require proof of public liability insurance in amounts varying from $10,000 to $100,000 for any single accident involving LPG. There are currently no specific requirements for liability insurance for owners of LPG facilities in the remaining 40 states. There are no insurance requirements applicable to owners of LNG or naphtha facilities in any of the states.

RECOMMENDATIONS

TO THE CONGRESS

We recommend that the Congress:

- enact legislation which prohibits, except in remote areas, the construction of new—or the expansion in size or use of existing—facilities for the storage of highly dangerous materials (including LEG) unless the storage tanks are inground with the highest level of fluid below ground level, or built to standards similar to those demanded for licensed nuclear installations in remote areas.

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation:

- require companies handling hazardous materials to file routine operation summaries annually and to report any unusual occurrences within 48 hours to the Department of Transportation in a manner analogous to the reports required by the Nuclear Regulatory Commission. Reportable occurrences should include any venting or leakage of hazardous material; any overpressuring of tanks; any transportation breakdown; any vital machinery breakdown; and any attempt by unauthorized persons to enter company premises. These reports should be available to the public in Washington, D.C. and at an appropriate office near the site of the unusual occurrence.

- form a central analysis group which would have the staff and resources to discover patterns in the data reported by companies handling hazardous materials. It makes no sense to require companies to go through the expense and trouble to submit annual operations reports and unusual occurrence reports if they are not going to be analyzed in sufficient depth so that serious malfunctions can be prevented. The Accident Analysis Branch in OHMO does not operate in this fashion. (See Chapter 17.)

- require OPSO to issue detailed standards for operating procedures and for operator qualification and training at LEG facilities. It should periodically review the operation of LEG facilities to see that they are meeting those standards.

- require OPSO to extend its regulations to cover intrastate LPG and naphtha pipelines, including connecting import terminals and storage complexes, affecting interstate commerce. GAO made this recommendation in its earlier report on pipeline safety, "Pipeline Safety—Need for a Stronger Federal Effort" (CED-78-99).

- require OHMO to promulgate standards for LNG vehicle design.

AGENCY COMMENTS AND OUR EVALUATION

Comment on Special Issue 5

The Department of Transportation asks:

> "How does one get from a 78 percent chance that one of three phenomena will occur at 1 of 100 facilities in 50 years to virtually certain (i.e., 100 percent chance) that design events will be exceeded a "large number" of times?"

Our finding that it is virtually certain that design events will be exceeded a large number of times during the lifetime of present large LEG facilities is based on our analysis in Chapter 3 of Uniform Building Code design standards, as discussed elsewhere in Special Issue 5. The 78 percent chance that one of three phenomena will occur at 1 of 100 facilities in 50 years applies to the stronger design standards in OPSO's Advance Notice of Proposed Rulemaking.

Comment on Special Issue 9 and 10

The Department of Transportation suggests that we delete the sentence, "Refrigerated LPG ships, however, can be single-hulled," because they say it implies that LPG ships are similar to conventional tankers and are somehow less protected than LNG ships.

We disagree. The sentence is accurate, and the implication that single-hulled vessels are less strong than those with double hulls is justified.

Comments on Recommendations

The Department of Transportation says that our recommendation--that OPSO issue standards specifying operating procedures, operator qualifications, and OPSO inspections of LEG pipeline facilities--is included in OPSO April 1977 Advance Notice of Proposed Rulemaking for LNG Facilities. DOT notes that additional detail may be appropriate and will be considered.

Our recommendation addresses LEG facilities, LPG as well as LNG. DOT does not describe any plans to promulgate similar standards for LPG pipeline facilities. We believe DOT should do so.

The Department of Transportation, commenting on our recommendation that OHMO promulgate standards for LNG vehicle design, states that these standards currently are being developed.

The standards (HM115 "Cryogenic Liquids") were originally published in the Federal Register as a Proposed Notice of Rulemaking in March 1974. Because of the volumes of comments, MTB revised the proposed notice to an Advance Notice of Proposed Rulemaking in September of 1974. MTB has not issued a new proposed notice since then.

REFERENCES

GENERAL CODES

NBC

The National Building Code—Recommended by the American Insurance Association, 1976 Edition.

UBC

Uniform Building Code—Enacted by the International Conference of Building Officials, 1973 Edition.

ASME

Section VIII of the American Society of Mechanical Engineers, "Rules for Construction of Pressure Vessels," Division I and II, 1974 Edition.

Section II of the American Society of Mechanical Engineers, "Material Specifications," Parts A, B, and C, 1974 Edition.

ACI

American Concrete Institute 311-64, "Recommended Practice for Concrete Inspection," 1964 Edition.

LNG CODES AND STANDARDS

NFPA 59A

National Fire Protection Association 59A, "Liquefied Natural Gas Storage and Handling," 1972 and 1975 Editions.

API 620

American Petroleum Institute 620—"Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks," (1977). Appendix Q - LNG.

NY STATE PSC

State of New York Public Service Commission, Case 26180—"Liquefied Natural Gas," 16 NYCRR, Part 259 and revised draft.

NY—1976 LAWS

New York Liquefied Natural and Petroleum Gas Act of 1976.

MASS DPU

Massachusetts Gas Distribution Code, Section 5, Department of Public Utilities, 1972 Edition.

NYCFD

New York City Fire Department, "Rules and Regulations Governing the Manufacture, Storage, Transportation, Delivery, and Processing of Liquefied Natural Gas," 1977 Edition.

API 2510A

API 2510A, "Design and Construction of LNG Installations at Petroleum Terminals, Natural Gas Processing Plants, Refineries and Other Industrial Plants."

LPG CODES AND STANDARDS

NFPA 58

NFPA 58, "Liquefied Petroleum Gases, Storage, and Handling," 1976 Edition.

NFPA 59

NFPA 59, "Liquefied Petroleum Gases at Utility Gas Plants," 1976 Edition.

API 2510

API 2510, "Design and Construction of LP-Gas Installations at Marine and Pipeline Terminals, Natural Gas Processing Plants, Refineries and Tank Farms," 1970 Edition.

CAL-PUC

California Public Utilities Commission Order 94-B.

FLA-FIREM

Florida Rules of the State Fire Marshal - LPG.

GA-FIREM

Georgia Rules of the Safety Fire Commissioner - LPG.

ILL-LPG

Illinois Liquefied Petroleum Gases - Rules and Regulations.

LA-LPG

Louisiana Liquefied Petroleum Gas Commission.

MASS-DPU

Massachusetts Department of Public Utilities.

MISS-MV

Mississippi Motor Vehicle Comptroller Liquefied Gas Division.

NM-LPG

New Mexico Liquefied Petroleum Gas Rules and Regulations.

SD-DPS

South Dakota Rules of the Department of Public Safety LPG.

NJ-AC

New Jersey Administrative Code-Liquefied Petroleum Gas.

NY - 1976 LAWS

New York Liquefied Natural and Petroleum Gas Act of 1976.

PA-DLI

Pennsylvania Department of Labor and Industry Liquefied Petroleum Gas.

TX-RRC

Texas Railroad Commission Rules and Regulations Division II.

WI?C-AC

W?sconsin Administrative Code Liquefied Petroleum Gases.

NAPHTHA CODES AND STANDARDS

NFPA 30

NFPA 30 - "Flammable and Combustible Liquids Code," 1976 Edition.

CAL-PUC

California Public Utilities Commission Order 94-B

CONN-SP

Connecticut Commission of State Police Flammable Liquid Regulations.

FLA-FIREM

Florida Rules of the State Fire Marshal Flammable or Combustible Liquids.

IND-FIREM

Indiana Rules of the State Fire Marshal Flammable Liquids.

MASS-DPU

Massachusetts Department of Public Utilities Fire Protection Regulations.

MICH-FLAM

Michigan Flammable Liquids Regulations.

PA-SP

Pennsylvania State Police Regulations - Flammable Liquids

PR-FS

Puerto Rico Fire Service: Storage and Handling of Flammable Liquids.

CHAPTER 17

FEDERAL REGULATION OF LEG TRUCKS AND RAILCARS

CONTENTS | PAGE

TRUCK REGULATIONS

Introduction

Several offices in the Department of Transportation (DOT) are responsible for setting and maintaining safety standards for interstate trucks carrying liquefied energy gases. The Interstate Commerce Commission (ICC) is also involved, since only it can revoke or suspend the certificates of interstate carriers found to be unsafe.

The diffusion of responsibility among several agencies and a lack of effective administration have hampered the formulation of uniform safety standards and have made enforcement difficult in three significant areas:

- the design and reliability of equipment;

- the safeguarding and control of LEG as it is loaded, transported, and unloaded; and

- the qualifications of LEG truck drivers.

Three DOT organizations are concerned with interstate LEG trucking.

- The Federal Highway Administration (FHWA) administers the provisions of the Motor Carrier Act of 1935 (49 U.S.C. 304) regulating qualifications and maximum hours of service of employees, and safety of operation and equipment.

- The National Highway Traffic Safety Administration (NHTSA) administers the National Traffic and Motor Vehicle Safety Act of 1966 (15 U.S.C. 1381 et seq.), under which safety standards for trucks and trailers are promulgated.

- The Materials Transportation Bureau's (MTB) Office of Hazardous Materials Operations (OHMO) prescribes regulations under the Transportation of Explosives Act of 1908 (18 U.S.C. 831-835) and the Hazardous Materials Transportation Act (49 U.S.C. 1801 et seq.), regulating the packaging, handling, and routing of hazardous materials.

By successive delegations from the Administrator of the FHWA, the Director of the Bureau of Motor Carrier Safety (BMCS) issues federal motor carrier safety regulations and enforces those of the MTB relating to transportation of hazardous materials by highway.

Federal Highway Administration,
Bureau of Motor Carrier Safety

The FHWA is responsible for reducing interstate commercial vehicle accidents, fatalities, injuries, and property losses. The Administrator has delegated responsibility to the BMCS to issue regulations applying to drivers, facilities, and the operational safety of motor carriers used in interstate transportation.

The Regulations Division of BMCS makes new safety regulations and modifies old ones. Its Compliance Division may intervene before the ICC, asking for the revocation or suspension of the certificates of carriers violating regulations.

BMCS and FHWA share responsibility for the 128 BMCS inspectors who monitor more than 160,000 carriers and 3,000,000 motor carrier vehicles. They work under the supervision of Directors of Regional Motor Carrier Safety Offices and make inspections only at terminals or at highway inspection stations, checking trucks which look or sound faulty. In 1974, 21 percent of the vehicles inspected were so unsafe that they were declared out-of-service.[1]

Of 4,112 violations reported in 1976, only 41 involved trucks carrying "flammable compressed gases", a category which includes LPG but not LNG.

The Regional Motor Carrier Safety Directors who supervise the inspectors have qualified as "hazardous materials specialists" through in-house programs. Most inspectors were formerly truck drivers or police officers, and some have formal training in transportation, business administration, or public administration. None have science or engineering degrees or formal training in the properties of cryogenic materials.

Carriers found in violation of safety regulations are fined. Those with repeated violations, about 20 carriers per year, are required by the FHWA to set up internal safety organizations. Inspectors check on compliance the next time they visit a terminal of the carrier involved.

The ultimate sanction on carriers is revocation of their permanent ICC certificates. The FHWA has recommended revocation eight times in five years, but none of the eight certificates were revoked by the ICC. At the FHWA's request, the ICC did refuse to renew "temporary authority" or "emergency temporary authority" certificates for 140 carriers between July 1, 1975 and June 1, 1977, on the basis of "unsatisfactory reports" filed by the BMCS.

In March 1973, the BMCS sent out an Advance Notice of Proposed Rule Making on repair and maintenance of motor carrier vehicles. These proposed rules would require pre-trip and post-trip equipment inspections for all interstate trucks, written records of inspections, retention of such records in the vehicles for 30 days, and correction of any safety-related deficiencies prior to operation.[2] The BMCS then hired the University of Michigan's Highway Safety Research Institute to study the effectiveness of preventive maintenance. The study concluded that interstate motor carrier vehicle inspection and preventive maintenance can reduce accidents.[3] The BMCS issued the Notice of Proposed Rule Making on April 5, 1977. After nearly five years, BMCS still has not incorporated these requirements into final rules on motor carrier repair and maintenance.

National Highway Transportation Safety Administration

NHTSA has jurisdiction over safety performance standards for trucks and trailers. Its Office of Crash Avoidance (OCA) has issued standards for tires and brakes. However, these were tested only on trucks carrying the maximum allowed loads, and their effectiveness on overloaded trucks is not known. Our examination of bills of lading indicates that propane trucks are sometimes overloaded during seasons of high demand.

The brake regulations authorize anti-skid and anti-locking "121" systems, but BMCS has not been able to inspect for compliance because it has not published its procedures for such inspections. Only "courtesy" inspections of the NHTSA brake regulations are planned through 1978.

NHTSA has not:

- Set standards for under-ride protection to prevent automobiles from going under trailers.

- Crash-tested tank trailers.

Office of Hazardous Materials Operations

The Office of Hazardous Materials Operations (OHMO), in DOT's Materials Transportation Bureau (MTB), has authority to issue regulations governing the manufacture and use of LEG shipping containers. OHMO sets standards for packaging, handling, and routing, and for personnel qualifications and training requirements. It establishes criteria for inspections and for equipment for the detection, warning, and control of hazardous materials. Through the Secretary of Transportation, it may conduct investigations and hearings, issue subpoenas, and compel disclosure of documents.

Section 109(d) of the Hazardous Materials Transportation Act requires the Secretary to maintain facilities and staff to provide, within the Federal

Government, the capability to evaluate risks involved in the transportation of hazardous materials, and to conduct a "continuing review" to determine procedures necessary for the safe transportation of hazardous materials.

The standards for LPG trailers, however, were developed before OHMO was established and no LNG trailer standards have been issued. Instead of permits, OHMO issues "exemptions" to LNG trailer manufacturers and transporters. Manufacturers' applications for exemptions contain engineering drawings, but transporters do not state proposed routes, even though OHMO has the power to regulate routing. The engineering drawings are considered trade secrets and are not available to the public. Renewal of exemptions appears to be almost automatic. No application for renewal has ever been denied, but modifications have sometimes been imposed as a condition of renewal.

Each transporter applicant must instruct its drivers in procedures to prevent or control overpressurization during prolonged shipping delays, but the transporters themselves decide the procedures.

OHMO's compliance staff has only three professionals and a secretary. Three lawyers from the DOT General Counsel's Office have recently been assigned to help, permitting OHMO to begin enforcement efforts for the first time. Occasionally it inspects plants manufacturing pressurized cylinders.

OHMO's Accident Analysis Branch has five professionals and one secretary. It receives, processes, and stores reports on the "release of hazardous materials." Such incidents range from the spilling of hot fluid concrete to the release of poisonous or explosive gases. The branch spends most of its time responding to requests for routine information from DOT personnel and from carriers settling damage claims.

About 1,500 reports of hazardous material releases are received monthly, very few of which involve LEG. Reports are required by regulation, but the branch head estimated that only one-tenth of the actual instances are reported. (See Chapter 7.)

OHMO has only three persons with technical competence in cryogenic areas. Only one of them is available for monitoring work. Only 250 inspections of trucks carrying hazardous materials were conducted in 1976.

Driver Qualifications

FHWA regulations require road tests and physical examinations for all interstate truck drivers. Each driver must furnish the carrier with a written history of his driving, and the carrier must investigate it within 30 days of his employment. Thorough physical examinations are given at 2 year intervals.

Drivers must either take a road test or have a state license for the category of vehicle to be driven. The requirement that drivers also take a written examination is misleading. The Federal Motor Carrier Safety Regulations state that:

> The objective of the written examination is to instruct prospective drivers in the rules and regulations established by the Federal Highway Administration pertaining to commercial vehicle safety. It is an instructional tool only, and a person's qualifications to drive a motor vehicle under the rules in this part are not affected by his performance on the examination. . .

In other words, even if a driver answers every question wrong, he is issued a license.

Intermittent or temporary drivers are excused from the written test, road test, and background test, but they must meet the physical requirements.

The limited data available suggest that drivers of hazardous materials trucks may work longer hours than those handling general cargo.[4]

RAILCAR REGULATIONS

Safety regulation of LPG rail transportation is the responsibility of DOT, acting through the Federal Railroad Administration (FRA) and through OHMO within MTB. Economic regulation and certification for entry into the interstate railroad industry remains with the ICC. LNG is not moved by rail.

OHMO - Federal Railroad Administration

The FRA has general authority to investigate the safety compliance of any applicant seeking railroad carrier operating authority from the ICC. The FRA's safety regulatory authority covers: safety appliances and equipment, safety methods and systems, and hours of service of employees. The FRA administers the Federal Railroad Safety Act of 1970 (45 U.S.C. 421 et seq.) to reduce accidents, deaths, injuries, and property damage by prescribing railroad safety rules and standards to supplement existing laws. The Act declares that laws, rules, regulations, and orders shall be nationally uniform to the extent practicable.

The FRA's own safety regulations cover locomotive inspection, hours of service of employees, operating rules, accident reporting, and standards for safety appliances, power brakes, track safety, and freight car safety.

OHMO prescribes rules under the Transportation of Explosives Act of 1908 and the Hazardous Materials Transportation Act. These acts authorize regulation of the shippers and manufacturers of containers used in or affecting interstate transportation of hazardous materials, including their packaging, labeling, handling, and routing. There are regulations that specifically address LPG railroad tank car design and operation requirements.

Hazardous Materials Division

The Federal Railroad Safety Authorization Act of 1976 divides the FRA on a geographical basis into no fewer than 8 safety offices to administer all federal railroad safety laws. The FRA has authority to issue an order prohibiting further use of any facility or piece of equipment in an unsafe condition involving a hazard of death or injury. For enforcement, the FRA has established a Hazardous Materials Division (HMD) which has 18 full-time inspectors and also uses the FRA's 180 general railroad inspectors on a part-time basis. Pursuant to Federal regulations (49 CFR

179.3-179.5), HMD and the Association of American Railroads (AAR) work closely together on tank designs and testing, and on developing regulations.

Chapter 8 deals with the hazards of LPG rail shipments and the effectiveness of regulations.

FINDINGS

TRUCK REGULATIONS

- The Interstate Commerce Commission has never revoked a permanent certificate because of a Federal Highway Administration request.

- Nearly five years after its Advance Notice of Proposed Rule Making on repair and maintenance of commercial vehicles, the Bureau of Motor Carrier Safety has not promulgated final rules.

- The National Highway Transportation Safety Administration has not:

  - o been able to inspect for compliance with its anti-skid and anti-locking brake systems regulations, because it has not published its procedures for such inspections.

  - o set standards for under-ride protection.

  - o crash tested tank trailers.

- The standards for LPG trailers were developed before the Office of Hazardous Materials Operations was established and no LNG trailer standards have been issued.

- The Office of Hazardous Materials Operations:

- issues "exemptions" instead of permits to LNG trailer manufacturers and transporters. No application for renewal of an exemption has ever been denied, although modifications have sometimes been imposed as a condition of renewal.

- receives about 1,500 reports of hazardous material releases monthly, very few of which involve LEG. Reports are required by regulation, but the head of the Accident Analysis Branch estimated that only one-tenth of the actual instances are reported.

RECOMMENDATIONS

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation:

- Develop standards for hazardous material trailer manufacturers which would complement the standards for shippers and enforce both with the same inspection and compliance apparatus.

- Impose harsh penalties on companies that fail to report hazardous material releases.

TO THE CONGRESS

We recommend that the Congress enact legislation to protect drivers from discharge or discrimination on account of information or complaints they provide DOT. Drivers are now largely excluded from protection under the Occupational Safety and Health Act of 1970 (29 U.S.C. 660(c)).

AGENCY COMMENTS AND OUR EVALUATION

The Department of Transportation says:

> "As noted in this chapter and in Chapter 7, there are very few inspectors for hazardous materials tank cars and trucks. Considering the number of Coast Guard inspectors per ship carrying hazardous materials, it is strange that Chapter 6 calls for more Coast Guard personnel, but Chapter 17 does not do likewise for the other modes. Similarly, more training of Coast Guard inspectors is called for. yet no recommendation is made for FHWA or FRA."

LNG ships carry 3,000 times more liquefied gas than LNG trucks, and the new LPG ships carry 650 times more L[illegible] than railcars and 1,800 times more LPG than trailer trucks.

REFERENCES

1. BMCS Notice of Proposed Rule Making, April 5, 1977.

2. Docket MC-48, 39 Federal Register 7127.

3. Effect of Commercial Vehicle Systematic Preventive Maintenance on Specific Causes of Accidents, University of Michigan Highway Safety Research Institute; July 1975.

4. Canyon Research Group, Inc. "A Nationwide Survey of Truck and Bus Drivers," BMCS Contract NO-DOT FH-11-8817.

CHAPTER 18

THE FEDERAL POWER COMMISSION

CONTENTS

INTRODUCTION

This chapter discusses the former Federal Power Commission's (FPC) role in assessing the safety of proposed LNG projects. The FPC has inadequately assessed the hazards of LNG shipping and storage. Safety issues have been considered on a case-by-case basis and have often been overshadowed by economic considerations. Decisions are based on evidence presented at formal hearings, at which the FPC staff testifies. The staff's testimony has often been based on insufficient independent investigation. The FPC has been disbanded, and its functions have been assumed by the Federal Energy Regulatory Commission (FERC) and other par' of the Department of Energy (DOE). This chapter is written in the present tense, as if the FPC still existed, to make it easier to read.

The FPC has statutory jurisdiction over the sale of natural gas in interstate commerce for resale. It also has statutory jurisdiction over interstate pipeline transportation and importation of natural gas. This includes authority over the site, design, construction, and operation of liquefied natural gas import and export terminals, storage facilities, and pipelines in interstate commerce.

FPC's authority to assess the safety of proposed projects is derived from provisions in the Natural Gas Act and the National Environmental Policy Act. See Chapter 11. This authority was not diminished by the Natural Gas Pipeline Safety Act of 1968, Public Law 90-481, 49 U.S.C. 1671, et seq. That Act led to the creation of the Office of Pipeline Safety Operations in the Department of Transportation. The legislative history includes the statement that:

> ". . .The Federal Power Commission presently has exercised certain safety regulatory authority over interstate transmission lines under the Natural Gas Act. The Commission considers and takes action on some elements of the safety of transmission proposals in acting on applications for new or extended authority and it is not intended that the passage of this act will diminish that authority and responsibility of the Commission. In order, however, that the Commission not be placed in the position of having to determine whether the construction and operation details of a proposed service conform to the {DOT} Secretary's standards, an applicant may certify to this effect and the certification will be conclusive on the Commission. . . .It is not intended by the committee that this process of certification of compliance with the Secretary's standards will bar the Commission from continuing to consider safety in the same fashion it presently does in connection with awarding certificates of public convenience and necessity."[1]

Later amendments to the Act left the FPC's safety responsibilities intact. (See conference report on Natural Gas Pipeline Safety Act Amendments of 1976, H.R. Rep. No. 1660, 94th Cong. 2nd Sess. 7.)

The Commission's control is limited, both in law and practice. It has no authority over intrastate facilities, including most peakshaving and satellite storage facilities. LPG facilities do not come under FPC jurisdiction, and only those LPG facilities that are part of an interstate pipeline are regulated by OPSO. Thus, many large LEG facilities are not regulated by either agency. Large LPG import terminals have been built without any Federal assessment of siting and safety, even though in most situations, for a given volume, LPG is more dangerous than LNG.

The Commission's major concern in LNG commerce has been economic, in accordance with its statutory mandate. It has focused on rate questions and on the certification of large, import facilities, built for deepwater shipping.

It has not prepared Environmental Impact Statements for all peakshaving facilities under its jurisdiction. Further, it has not considered the public risks from trucking LNG to and from the storage sites it licenses and it has not fully considered shipping hazards.

Until March 1978, the only LNG import facility in operation was at Everett, Mass. It has operated for seven years without final certification. An Administrative Law Judge has ruled that its design and operation are safe, but the Commission has never made a final safety finding.

The FPC has issued certificates for new major import terminals at Cove Point, Md.; Elba Island, Ga.; and Lake Charles, La. The Cove Point terminal began operating in March, 1978, and the Elba Island terminal is expected to begin operating later in 1978. Applications are pending for facilities at Everett, Mass.; Providence, R.I.; Staten Island, N.Y.; West Deptford, N.J.; Port O'Connor, Tex.; Ingleside, Tex.; and Point Conception, Cal. In November, 1977, Western LNG Terminal Associates amended its applications, shifting all its proposed receiving terminal sites to Point Conception, Cal.

HEARINGS

Under 18 CFR 1.4(d), the Commission staff is not allowed to privately discuss a case with persons who are parties to proceedings before the Commission. This precludes private discussions with intervenors such as states, local governments, and citizen groups. On March 11, 1977, the FPC amended its rules to allow ex parte communications between the staff and intervenors and applicants, but these are limited to requests for data and information. The staff may discuss a case in a technical conference, but only upon notice to all parties.

The limitations on staff contacts do not apply until a formal application has been filed. The staff often discusses possible applications for a year or more before they are filed. The staff justifies such pre-filing conferences on the ground that they ensure the filing of a more complete application, minimize piecemeal staff review of often interconnected issues, and avoid regulatory delays. During this period, however, outside parties have no notice that a project is being planned. They learn of an application only when it is announced in the Federal Register. As a result, they may not have enough time to adequately prepare for hearings.

The time and expense necessary for public participation is further increased because:

"It is the Commission's practice to hold formal hearings under the Natural Gas Act in Washington, D.C. Occasionally the Commission has, upon motion of a party, decided to add local hearing sessions," in communities in which LNG facilities are planned, but most witnesses who appear at them make "statements of position" which are not "evidence of the facts asserted" under the Commission's rules and "cannot be used by the Commission in arriving at its decision." The Commission has said that the purpose of such hearings generally is to allow "local citizens to express their views by statements of position or to present sworn testimony if they so desire."[2] Such local hearings were held on the Everett, Staten Island, and Racoon Island projects.

THE FPC STAFF

Despite the complex and highly technical issues which must be considered in LNG applications, the primary responsibility for these cases is carried out by only four professionals in the Bureau of Natural Gas (BNG) and five lawyers from the Office of the General Counsel. There is also input from the Office of Pipeline and Producer Regulation (OPPR), including its Environmental Evaluation Branch; the Office of Regulatory Analysis, and the Office of Chief Accountant.

The BNG staff and the FPC lawyers prepare and present evidence considered at formal hearings of LNG applications. The two groups are responsible for developing, analyzing, and presenting data in legal, economic, and technical areas, including safety. BNG shapes the presentation. The five lawyers present witnesses, conduct cross-examinations, and write briefs, but have only a small role in the framing of issues and the selection of witnesses.

The small staff often has unreasonable burdens placed upon it. For example, in the Pacific Indonesia hearing on a proposed facility at Oxnard, California, one attorney wrote briefs on all economic and social issues in 45 days. He addressed questions on maritime transportation contracts and rates; financing and costs of service for the proposed facility; the proper rate treatment and market for imported

LNG; FPC jurisdiction over foreign commerce; and environmental impact and public safety.

THE BUREAU OF NATURAL GAS

The BNG Accident Model

BNG first devoted significant attention to LNG in 1973, when Eascogas applied for certification of an LNG import facility on Staten Island, in New York City. A staff physicist and a consultant statistician developed, with some assistance from the Coast Guard, a general concept of a "maximum, credible shipping accident," and that model, with small modification, is still in use. The BNG has not developed models for other types of LNG facility failure because it feels the danger involved in a "maximum, credible shipping accident" is much greater than in any other. As discussed elsewhere in this report, we do not agree.

The BNG model does not consider:

- Accidents involving trucks at the terminal.
- Accidents involving the terminal itself.
- Sabotage.
- The possibility that the gaseous plume could detonate.

- The possibility that the plume density might vary from point to point. The model's plume dispersion component, based on Coast Guard analysis but later modified by the staff, has never been validated in a wind tunnel nor through large-scale experimentation. The Coast Guard does not endorse these models.

By expressing the risk from a shipping accident in terms of the risk per person per year, the BNG model obscures the total number of possible fatalities and the effect of the density of people and structures. These factors are buried in the BNG calculations. This approach makes it difficult to distinguish between the risks to large and small communities. The risk per person per year could be roughly the same, but the total impact of an accident on a highly populated area would be much greater.

The model of a ship accident is too narrow. It assumes that:

- No more than one LNG tank on a ship will rupture.

- The single rupture will not set in motion the release of flammable or poisonous substances from nearby vessels.

- There will be no secondary fires.

The staff has not analyzed the sensitivity of its model to variations in input and assumptions.

Support from Other Agencies

The Bureau of Natural Gas has relied on the Coast

Guard, the Environmental Protection Agency, the Bureau of Mines, and the National Bureau of Standards for scientific and technical assistance.

The National Bureau of Standards (NBS), a principal source of support, depends in its reviews on plans submitted by applicants and the application of relevant codes and specifications. The NBS review assumes all standards, codes, and regulations are adequate and will be complied with and that the plant will be properly operated.

NBS reviews do not consider plume dispersion, sabotage, or very large spill containment. No explicit fault-tree analysis is made.

The NBS reviews we have read are competent, but far too limited in scope to be a substitute for adequate FPC staff work and procedures. NBS recommends that semi-annual reports be made to FPC after operations begin. While routine operations summaries are probably not needed more than once a year, a system should be set up which requires companies to report any unusual occurrences within 48 hours to the Office of Pipeline Safety Operations. (See Chapter 16.)

Criticism from Other Agencies

BNG's technical work has been criticized by other agencies as inadequate. In one case BNG first favored construction of a terminal facility in the Delaware Valley[3] and then reversed itself after other Federal agencies sharply criticized its draft Environmental Impact Statement (EIS). The Energy Research and Development Administration (ERDA) said the BNG study on vapor cloud plume dispersion "failed to evaluate the hazard realistically and to consider the characteristics of the terrain."[4] The Nuclear Regulatory Commission (NRC) said the draft EIS 'neglected impacts on nearby nuclear power stations and inadequately considered possible alternatives in design and site." The NRC criticized the evaporation rates as "much lower than those reported by the American Petroleum Institute for smaller test LNG spills." It said BNG's risk analysis "obscures the obvious fact that it is safer to conduct LNG traffic in areas of low population than in cities."[5] The Environmental Protection Agency (EPA) said the BNG's final EIS "seriously underestimates the hazards of LNG shipping on the Delaware River" and did not consider the possible effects on a nearby oil refinery nor on the ship traffic to another proposed LNG terminal nearby. EPA said the final EIS ignored local accident histories, low channel depths, the possibility that the LNG ship itself might catch fire, tanker explosions, and the differences between spilled oil and spilled LNG.[6]

The Navy filed major criticisms of the BNG draft EIS on the Oxnard site. It noted that since no ship plans were available the "determination of the safety of the proposed operation. . .with any exactness" is difficult. It expressed the hope that the Commission would be "conservative in evaluating opinions and information not clearly supported by factual data." It pointed out that the Commission's vapor cloud propagation and thermal radiation models appeared to be less conservative than other models, such as the one used in the Coast Guard LNG/LPG Contingency Plan for the Port of Boston. (The Commission's predicted flammable vapor dispersion range was a tenth to a hundredth of other model ranges.)

The Navy also pointed out that by BNG's own figures, "8.5 times as many people could be killed as the result of a major accident at Oxnard. . .(as at). . .Point Conception." It also noted that the possibility of sabotage had not been considered.

In the Pacific Indonesia case BNG rejected a State of California study which concluded that an LNG accident at Oxnard could result in a great number of deaths.[7]

The staff argued that the study should be ignored since it had not been introduced into evidence.

Under the hearing rules the staff could have asked the Administrative Law Judge to reopen the hearing to admit the study as evidence. Instead they argued that he should not, and he didn't. In a matter involving human safety, we have reservations whether the staff's action evidenced disinterested concern for the protection of the public.

Examples of Inadequate Technical Work

On September 17, 1974, the Western LNG Terminal Company applied for a certificate to build receiving, storage, revaporization, and send-out facilities at Point Conception, Los Angeles, and Oxnard, California. The Oxnard and Los Angeles sites are near heavily populated areas. Point Conception is in an area of very low population density. An FPC staff brief recommended, in consonance with the California Coastal Act of 1976, that only one of the three facilities be built initially. It selected Oxnard, contending that safety risks there were "of an acceptable level." Although the final EIS also noted that the facility would be tied to the Oxnard

Municipal Sewer System[8], it did not consider that the site is adjacent to the city's sewer plant where large quantities of chlorine are stored, or that LNG might flow into the system after an accident. Every building in Oxnard is connected to the sewer system, and since natural gas is highly explosive in sewers and houses, a large quantity of LNG or natural gas in the system could cause a disaster.

The final EIS dismissed the possibility of two on-shore tank failures at the same time as "out of the realm of possibility" although for some causes, such as earthquake, flood, high winds, or sabotage, the probability of multiple tank failure is not much less than the probability of a single tank failure.

In the hearing on the Eascogas Staten Island facility BNG concluded that an oil tanker spill was twenty-five times as likely as an LNG spill.[9] They decided this on the basis that LNG tankers were five times more carefully constructed and that LNG ship spill risks could be reduced by another factor of five because LNG tanker crews exercised "extra navigational care and safety precautions."[10] These factors of five were chosen arbitrarily, without consultation with the Coast Guard, for example, and cannot be rigorously supported. In Chapter 6 we discussed many needed improvements in LNG ship design research, training requirements, and operational controls.

BNG has not adopted uniform site selection and facility operation criteria, in spite of a petition from several state governments that they do so. The petition, which asked the Commission for a rule-making proceeding to "promulgate and adopt uniform site selection and facility operation criteria standards for Liquefied Natural Gas marine storage terminals", was signed by the Attorney General of the State of New Jersey, the Public Advocate of New Jersey, the Attorney General of the State of New York, the Attorney General of the Commonwealth of Pennsylvania, the Attorney General of the State of Delaware, the Township of Woodbridge, New Jersey, and U.S. Representative John M. Murphy. The Commission has failed to rule on the petition.

Without uniform standards, terminal site safety is determined on a case-by-case basis. In the final EIS on the Everett facility, which is already constructed in an urban area, BNG concluded that since the facility has already been built (before FPC certification was required), a discussion of alternatives "would be fruitless to pursue."

In this regard, we are not aware that the FPC staff has ever considered the alternative of using only non-urban sites to receive all LNG imports and developing a gas exchange program using existing pipelines to ensure appropriate distribution of gas supplies. In Chapter 15 we show that non-urban terminals have the capacity to handle the needed quantities.

Under present law the FPC (and its successors in DOE) have no power to require operating LNG terminals to expand to handle new LNG supplies. This prevents the complete consideration of alternative sites for new LNG imports.

For example, in the final EIS for the El Paso Matagorda Bay Project, FPC said that the terminals at Cove Point, Maryland and Elba Island, Georgia "would be well suited to expansion because more than enough land would be available and disruption to other shipping caused by the additional LNG carrier traffic would be minimal." The possibility of bringing the LNG into Cove Point or Elba Island instead of into Matagorda Bay was rejected, however, because ". . .barriers could exist since El Paso owns neither these terminals nor the gas distribution systems to which they are connected".[11]

Such barriers would be insufficient to bar the use of suitable sites if DOE had the power to require certificated sites to expand to handle new material—as long as expanded use could be carried out economically and with adequate safety.

The nation's ability to pick the best sites for LEG imports, and to avoid storing and transporting large quantities of LEG in densely populated areas, is seriously impaired because already chosen sites cannot be required to serve new customers. This requirement is one that all common carriers must observe.

ADMINISTRATIVE LAW JUDGES

The key figure in LNG safety matters is the Administrative Law Judge (ALJ) who writes the Initial Decision recommending approval or disapproval of an application. None of the safety findings in Initial Decisions on LNG facilities has been questioned in Final Decisions issued by the Commission.

ALJ's rely on the staff for technical assistance. At any stage of a hearing an ALJ may call for further evidence from any parties involved or from the staff, but the record shows that in the FPC this prerogative is seldom used in LNG cases.

Adequate resolution of complex safety issues requires a process which insures that adequate evaluation and input is obtained from technically qualified persons. ALJ's are not expected to have such a background themselves and our review of published decisions indicates that serious questions exist regarding the adequacy of technical input under the current FPC process.

We have discussed the need for technical input and background with some of the ALJ's. We believe their opinion can best be summarized by a statement in the Initial Decision handed down on June 28, 1977, in the Distrigas hearing. After noting that it had been suggested that "scientists are more able to make decisions, assumedly even in areas outside their expertise, than others," the ALJ responds:

> "Even granting that a number of scientists may begin the effort ahead of the decision-maker due to their previous scientific training, the record, including the scientific evidence, made for decision purposes is explicated in common English and the scientists' advantage, no matter what it may have been at the commencement of the exercise, rapidly fades. Moreover, the decision-maker calls upon all parties to supply that information necessary for a complete record and relies upon the entire record."

Unfortunately, our review of FPC's published Initial Decisions show that adequate information to resolve inconsistencies and to provide a complete record is not always obtained. Many important questions are not raised by any party, and intervenors often do not have the time or money to do the research needed to question an applicant properly. In an area of new technology such as LNG where there is little previous practical experience, it is difficult to make logical safety findings, even with a clear understanding of the evidence presented. If the evidence is misunderstood or misconstrued, accurate findings are impossible.

The demonstration of safety in LNG cases is usually done on the basis of probabilistic arguments. What may seem obvious, or "common English," to an untrained person may be incorrect or imprecise or both. The uncritical acceptance by the ALJ of the LNG fatality probabilities estimated for the proposed Oxnard terminal illustrates this.

In a report prepared for the Western LNG Co.'s application, Science Applications, Inc. (SAI) stated that: "The probability of electric shock fatalities in electrically wired residences is 1 chance in 1 million per person, per year for the residential population served by electricity. Thus the fatality probability per person, per year, within 5/8th of a mile of the site (Oxnard) due to possible LNG accidents is only 15 percent of that for electric customers throughout the country from electric shock fatalities."[12]

In Chapter 12 we have shown that SAI's fatality probability estimate for persons living within 5/8th of a mile of the proposed site is not supported by the SAI's own analysis. Because neither the FPC staff nor the ALJ realized this, the evidence went unchallenged. What is more, the ALJ, in paraphrasing SAI's estimate in his Initial Decision, misconstrued it. He said that the fatality probability per person, per year, for those within the 5/8th mile radius "was about 7 times less than the risk to the same person of being electrocuted by faulty wiring when flicking a light switch in his residence." This distorts SAI's accurate estimation of the probability of electrical shock fatality and is completely wrong. Most shock victims in homes are children who are electrocuted while playing with plugs or electric toasters and persons doing their own electrical repairs. We have been unable to find a single case of a person killed "by faulty wiring when flicking a light switch in his residence."

The need for independent analysis by the FPC is illustrated by the following examples. The Initial Decision on the application for the facility at Everett, Mass., which has metal tanks, found that "the possibility of the type of accidental spill which would result in the formation of a vapor cloud capable of catastrophic destruction is extremely remote." The El Paso Alaska Initial Decision found that:

> "In order to achieve the large size vapor cloud necessary to create even measurable risks for people located some distance away, an assumption has to be made that a huge volume of LNG be released instantaneously, but that it be done by force which causes no spark to ignite the escaping vapor. The instantaneous spill can be envisaged as a Dixie cup filled with 10,000 cubic meters (a room about 70 feet wide x 70 feet long x 70 feet deep) suspended over the ocean. A large hand now removes the Dixie cup and the LNG whooshes of a sudden into the ocean. In other words, the risk analysis is not realistic; it is a textbook analysis since only in textbooks can one envisage the removal of the container, such as a ship's hold or the contents of a storage tank, in the manner proposed."

Since the staff did no independent analysis, it did not discover that the most likely mode of failure for many metal tanks in the event of an earthquake, is tipping the inner tank, breaking the welds which seal the sides to the bottom, and spilling the contents as discussed in Chapter 3. Moreover, there is no evidence that LEG in a large spill would ignite on site, confining most damage there. Spilled LNG, as in Cleveland, may flow into sewers and basements before igniting and exploding. We have also shown in Chapter 9 that sabotage could cause a massive release of fluid. There is no evidence that the sabotage itself would necessarily ignite LEG vapors.

We are not aware that the staff or any ALJ has ever questioned whether any NFPA codes used in LNG facility design might be mistaken or inadequate, as we have shown them to be in Chapter 5.

The danger of sabotage has not been seriously considered by the FPC. The Initial Decision on importation of LNG from Indonesia commenting on the California Public Utility Commission's (CPUC) point that "risk assessment studies have not taken into consideration the possibility of sabotage or terrorist intervention," said:

> "SAI does not believe these risks can be quantified and no evidence was presented by any party, the CPUC or the Commission Staff on the matter. . .Applicants, aided no doubt by the appropriate authorities, will take all practicable measures to safeguard against sabotage and terrorist intervention. In any event, these risks which are probably miniscule, must not be permitted to defeat energy projects which are in the public interest and required by the public convenience and necessity."

We agree that these risks cannot be quantified, but the ALJ presented no argument and cited no evidence to justify his conclusion that the risks are "probably miniscule." In response to a GAO inquiry about the basis for this and other conclusions in initial decisions, the FPC Chief Administrative Law Judge stated that ". . .our policy has always been that the initial decisions of the Administrative Law Judges speak for themselves."[9] We have not been able to find a logical basis for the assertion that the risks of sabotage are "probably miniscule". In Chapters 6, 7, 8, 9, and 16, we have shown that applicants, aided by appropriate authorities, do not take all practicable measures to safeguard against sabotage and terrorist intervention. To say that "in any event" the risks must not be "permitted to defeat energy projects which are in the public interest and required by public convenience and necessity" seems unreasonable. Since (1) alternative, non-urban sites are available, (2) the risk from sabotage cannot be even approximately quantified, and (3) the consequences are so great, it is unwise to build susceptible facilities in populated areas.

The threat to public safety from LNG ship accidents and from sabotage was similarly discounted in the Initial Decision on the Everett terminal:

> "Giant can openers do not rip open ship bottoms when docked, and if they do, they are not likely to do so without sparks that would ignite the fuel at its source. Nor do forces blow up facilities quietly or with spark-free explosives. . .whether from natural causes or sabotage."

We believe that if the FPC had developed a better system for assessing LNG safety, the problems we have raised would have been addressed and considered, rather than dismissed as impossible or unlikely.

FINDINGS

- The FPC has:

    - allowed LNG facilities to operate in large cities without adequately assessing the threat to the public from such facilities.

    - not sufficiently investigated the possibility that gas exchange programs would minimize the number of urban LNG terminals.

    - not considered the public risks from the trucks and not fully considered those of ships which make or take deliveries at LNG storage sites it licenses.

    - not prepared Environmental Impact Statements and safety analyses on all peakshaving LNG facilities under its jurisdiction.

    - not set uniform criteria for site selection and has failed to rule on a petition by the Attorney General of the State of New Jersey, the Public Advocate of New Jersey, the Attorney General of the State of New York, the Attorney General of the Commonwealth of Pennsylvania, the Attorney General of the State of Delaware, the Township of Woodbridge, New Jersey, and U.S. Representative John M. Murphy for a rule-making proceeding to "promulgate and adopt uniform site selection and facility operation criteria standards for Liquefied Natural Gas marine storage terminals."

- never questioned a safety finding in an Initial Decision.

- held almost all formal hearings in Washington, D.C., making it costly for affected local interests to participate fully. It is important for hearings to be held at a place which is convenient for the public in the area concerned rather than at one that is convenient for the Commission and its applicants. It is the public that will suffer the risk and is paying for the process and the results.

- The first public notice of applications for LNG terminals is the formal notice in the Federal Register, after applicants and the Commission staff may have discussed the proposed application at length. Interested outside parties do not have the opportunity during this period to prepare their positions on the project.

- Many large LEG facilities are not regulated by either the FPC or OPSO.

- The nation's ability to pick the best sites for LEG imports, and to avoid storing and transporting large quantities of LEG in densely populated areas, is seriously impaired because already chosen sites cannot be required to serve new customers. This requirement is one that all common carriers must observe.

CONCLUSIONS

The FPC system for approving LNG projects is clearly inadequate to protect the public health and safety. Some Initial Decisions on LNG projects have been based on safety findings which our research indicates are inaccurate. Where these Initial Decisions have been acted upon by the Commission, none of these safety findings has been questioned by the Commission in its opinions.

Judgments on public safety in an area of new, complex technology involve questions and answers which cannot be found in the published literature. The record indicates that such issues cannot be adequately handled with the level of knowledge, experience, and effort involved in the FPC process. The extent to which there will be any differences in regulation under DOE is unclear. If economic questions are included in the same process as safety questions, as in the case of LNG, fuzzy trade-offs between the two are inevitable.

Improvement in LNG regulation must be considered in the context of the nation's overall approach to energy regulation. In March 1977, GAO issued a report to the Congress on "Energy Policy Decisionmaking, Organization and National Energy Goals" (EMD-77-31, March 24, 1977).

In that report we stated our skepticism as to whether health and safety regulation could any longer be construed as truly "not economic" in nature. In LNG as in other areas, health and safety regulators decisions are likely to affect the cost and timing of facilities and to have significant impact on the options available to energy policy makers. We also pointed out the problems involved in having regulation focus narrowly on the health and safety aspects of individual energy sources. We supported the idea of bringing together all energy health and safety regulatory functions so that the trade-offs of developing one form of energy as opposed to another could be considered. In the years ahead, such trade-offs will become increasingly important since almost all forms of energy development appear to have some form of adverse environmental and/or health and safety impacts.

In our earlier report, we provided three options for Congressional consideration in the reorganization of Federal energy regulation activities:

- Include energy regulatory functions--both economic and health and safety related--in the Department of Energy. Under this approach, economic and health and safety regulation could be separate entities, but both would fall under a single Assistant Secretary. Statutory provisions should be included to assure maximum insulation of regulatory decisions from the policy process.

- Include only economic regulation in the Department of Energy because of the perceived importance of establishing energy price regulatory policies which are consistent with other energy goals and consolidate health and safety regulation of energy in a separate independent Energy Health and Safety Regulatory Agency (EHSRA). Statutory provisions should be included to assure maximum insulation of economic regulation from the policy process.

- Continue to separate energy regulation—both economic and health and safety related—from energy policy formulation. Should this be done, we believe that the creation of a single energy regulatory agency is desirable. Such an agency could provide a forum for more carefully considering the trade-offs among problems involved in different forms of energy development.

Since our earlier report, the Department of Energy Organization Act transferred FPC's responsibilities to the new Department. No action was taken to consolidate energy health and safety regulatory activities.

The shortcomings in FPC's treatment of LNG safety questions point to the need for a single regulatory agency to consider the complex technical issues in energy health and safety and to balance the health and safety trade-offs among different energy sources.

Given the inadequate consideration of such issues under the administrative law process used by FPC, we believe the current NRC model would more likely ensure adequate and competent technical coverage of health and safety questions. A typical regulatory action in NRC with respect to a construction permit or operating license for a facility involves interaction among the Commissioners, the staff, Advisory Committee on Reactor Safeguards, Atomic Safety and Licensing Board (ASLB), and Atomic Safety and Licensing Appeal Board (ASLAB).

The ASLB and ASLAB work with three-man boards whose members have a variety of legal and technical skills relevant to the safety problems which come before them. No individual Administrative Law Judge can have such breadth—and he must cover complicated economic issues as well.

With a mandate to adequately protect the public health and safety, EHSRA could assemble a technical staff competent to investigate complicated questions raised by others and to raise important new questions itself. It should be able to develop a higher technical level than the industries it regulates.

RECOMMENDATIONS

TO THE CONGRESS

We recommend that Congress consider creating an Energy Health and Safety Regulatory Agency (EHSRA) which could include the Nuclear Regulatory Commission; the pipeline safety aspects of transporting fuel on land, now handled by the Department of Transportation; the safety aspects of importing energy, now handled in the Department of Energy; and all safety responsibilities carried out in the past by the Federal Power Commission. For reasons discussed in Chapters 7, 8, 16, and 17, additional consideration should be given to including the safety regulation of liquefied energy gases transported by truck and train. (The Nuclear Regulatory Commission already has responsibility for the safe transportation of nuclear materials.) The Department of Transportation would continue to be responsible for all other safety regulation of motor carriers and railroads except those transporting nuclear materials and liquefied energy gases. The Environmental Protection Agency should retain the responsibility for setting air and water quality standards, including those impacting energy development and use, and waste disposal.

The new agency could be completely independent of the Department of Energy (DOE), or included in DOE with strong statutory provisions to ensure its independence.

The recommendations in Chapters 7, 8, 16, and 17 should be carried out by the Secretary of Transportation and the Interstate Commerce Commission, if liquefied energy gases transportation safety is not included in an Energy Health and Safety Regulatory Agency, or if the agency is not formed.

OTHER RECOMMENDATIONS TO THE CONGRESS

We also recommend that the Congress:

- enact legislation to require all large LNG and LPG facilities to get certificates of public convenience and necessity from the Federal Energy Regulatory Commission.

- enact legislation that allows the Department of Energy to require certificated sites to serve new customers—as long as the expanded use can be accomplished safely and economically.

NOTE: The following recommendations are intended only if an Energy Health and Safety Regulatory Agency is not formed, or until it is formed. The suggestions should be carried out by EHSRA if it comes in existence.

TO THE SECRETARY OF ENERGY AND
THE FEDERAL ENERGY REGULATORY COMMISSION

We recommend that the Department of Energy and the Federal Energy Regulatory Commission:

- hold most formal hearings for LNG facilities near the site of the proposed facility, rather than in Washington, D.C.

- announce in the Federal Register that they have held discussions on a possible LNG site, the first time such a discussion occurs, so that other interested parties can also talk to them early in the process. Such a notice should also be placed in newspapers in the locality involved.

- consider the public risks from the trucks and ships which make or take deliveries at LNG storage sites in considering applications for such sites.

- require a staff study of the feasibility of using only non-urban sites to receive all LNG imports and developing a gas exchange program using existing pipelines to ensure appropriate distribution of gas supplies.

AGENCY COMMENTS AND OUR EVALUATION

Department of Energy Comments

1. DOE states:

"The draft report indicates, in several places, that economic considerations have overshadowed safety issues in FPC proceedings. The relative emphasis given to various issues depends, in part, on the project. In all cases, both environmental, including safety, and economic factors have, in the past, been given independent and major weight in FPC proceedings. . ."

GAO response:

Our statement that "safety issues. . .have often been overshadowed by economic considerations", is supported throughout the chapter:

- The FPC, like all Federal agencies, considers safety as part of its responsibilities under the National Environmental Protection Act. The courts have stated, however, that FPC's main responsibility under the Natural Gas Act of 1938, 15 U.S.C. 717 et seq., is economic. (Atlantic Refining Co. v. P.S.C. of N.Y., 360 U.S. 378 (1959).)

- Although the FPC frequently reverses economic findings in its Initial Decisions, it has never even questioned the safety finding in an Initial Decision.

- With regard to the dangers from possible sabotage of the facility, the Initial Decision on LNG from Indonesia says:

> "Applicants, aided no doubt by the appropriate authorities, will take all practicable measures to safeguard against sabotage and terrorist intervention. In any event, these risks. . .must not be permitted to defeat energy projects which are in the public interest and required by the public convenience and necessity."

  To say that "in any event these risks. . .must not be permitted to defeat energy projects. . ." is an example of safety issues being overshadowed by economic considerations. The quote is discussed at greater length in the chapter.

- Safety issues are hardly mentioned in FPC Final Decisions. Even Initial Decisions typically devote only a small percentage of their discussion to safety problems.

2. DOE states:

> "Staff does not believe that the publication of notices is appropriate when an LNG site is discussed for the first time with staff (page 23). Notice would be premature because an application for a certificate might never be filed.

GAO response:

The public is paying for the FPC and the gas company. We believe the public has a right to know about any discussions the FPC is having with companies about possible

LNG sites. The fact that "an application for a certificate might never be filed" does not bear on the public's right to know.

3. DOE states:

> "Staff has advocated combined LNG terminal projects in a number of proceedings and has investigated the possibility that gas exchange programs would minimize the number of urban LNG terminals (also page 16). Three terminals have been proposed on the East Coast in urban areas. Since Everett, Massachusetts was the first urban terminal to be built, no exchange program with other LNG terminals was possible. The Providence, Rhode Island terminal is no longer a viable application; and the Staten Island, New York terminal is still in hearing and still under staff investigation."

GAO response:

The type of exchange program we have in mind would not be restricted to exchanging gas between LNG terminals, but rather among all companies in the interstate system. The FPC comment clearly shows that such general applications are not considered in evaluating LNG termina applications.

4. DOE states:

> "The draft report asserts that the FPC has allowed LNG facilities to operate in large cities without adequately assessing the threat to the public from such facilities. Only one LNG import terminal has been allowed to operate in or near a large city—Everett, Massachusetts. . ."

GAO response:

Only two LNG import terminals are operating in the United States. Only one, Everett, was operating when the FPC sent its comments to GAO. More importantly, our statement was about all LNG facilities—most of which are peakshaving plants—not just about marine terminals. Our statement is true as it stands.

5. DOE states:

> "Staff has testified that the 'maximum credible shipping accident' for an LNG vessel is the rupture of one cargo tank. On numerous occasions the Coast Guard has also testified that the rupture of one cargo tank is the major credible accident for the LNG vessel. Staten Island LNG project (Docket Nos. CP73-47, et. al.). While staff presently believes that the rupture of one cargo tank remains the maximum credible shipping accident, it will continue to assess the probability of shipping accidents. . ."

GAO response:

We believe that LNG shipping is the strongest link in the entire LNG storage and transportation system. BNG's position is that non-shipping accidents are not even worth including in their risk assessment model. The whole report supports our position.

6. DOE states:

> ". . .Staff's general conclusion is that spills from equipment and/or storage tanks spills into diked areas pose little or no significant hazard off-site. . ."

GAO response:

At five of the six sites we examined, more than 50 percent of the fluid in the tanks can vault over the dikes if there is a sudden collapse or major rupture of the tank wall. See Chapter 5.

7. DOE states:

"With respect to safety analyses at specific sites, the draft report notes that the EIS on the Pacific Indonesia LNG Company project (Docket Nos. CP-74-160, et. al.) at Oxnard, California did not consider that the site is adjacent to the city's sewer plant where chlorine is stored or that LNG could flow into the system after an accident (page 10). The staff was aware of the location of the Oxnard sewage plant about 4,000 feet to the northwest of the proposed LNG facility area. The staff was also aware that only sanitary wastes from the LNG terminal would be pumped to the treatment plant through a closed pipeline system. No open sewers are involved. Further, the staff was aware that the LNG storage tanks would be enclosed by individual high-walled concrete dikes and that the perimeter service road around the LNG plant would provide a secondary means of diking. The staff recommended diking around the LNG unloading transfer lines. For these reasons, spills into the sewer system were not considered credible."

GAO response:

The following points are relevant:

- There are many entrances on the site to the closed pipe system leading to the sewer plant.

- An explosion or fire in or above the closed pipe system could lead to further large openings.

- Pleasant Valley Road runs only 4,600 feet from the tanks, and it has open storm sewers connected to the sewer plant and the entire city sewer system.

- The high-walled concrete dikes enclosing the storage tanks will be built to the same standards as the tanks, and thus would be vulnerable to failure from the same manmade or natural events. See Chapters 3 and 9.

- The nominal diking provided by the perimeter service road would have little effect on stopping any flow of LNG. See Chapter 5.

- We have no way to tell what the staff was aware of, but it is a fact that the EIS did not consider the nearby presence of storm sewers or the city sewer plant.

8. DOE states:

". . .the probability of ignition of the cloud approaches unity at a finite distance downstream. . ."

GAO response:

Since every distance is finite, FPC's comment seems true. It isn't, however, since the cloud may disperse below the flammable limit without igniting. More important, however, is the possibility that in a fairly strong onshore wind, the flame front may be blown through a city rather than burn back to the site of the spill. See Chapter 13.

9. DOT states:

> "We oppose the recommendation in the report for inclusion of the safety aspects of transporting energy fuels in a new Energy Health and Safety Regulatory Agency to be established in the Department of Energy (DOE). These safety functions are now carried cut in the Department of Transportation (DOT) as part of an overall safety program devoted to the transportation of hazardous materials in general, including transportation by marine vessel. The risks posed by energy fuels are, in many cases, not dissimilar from other hazardous materials regulated by DOT which move in volume in interstate and foreign commerce. To separate and transfer the fuel aspects of the hazardous material program, when there are many benefits of a consolidated hazardous materials program in terms of regulatory and enforcement actions and R&D, would be inimical to an efficient, comprehensive and well coordinated national safety program."

GAO response:

Health and safety problems connected with the transportation of fuels can be considered under the categories of "health and safety", "energy", or "transportation". Because energy is currently one of our most critical problems, we suggest the creation of an Energy Health and Safety Regulatory Agency (EHSRA).

LNG importation and storage is largely regulated by DOE already and most R&D programs in energy—including many for energy transportation—are conducted by DOE or the Nuclear Regulatory Commission.

REFERENCES

1. H.R. Rep. No. 1390, 90th Cong., 2d Sess. 34,35 (1968). Similar language may be found in S. Rep. No. 733, 90th Cong., 1st Sess. 12(1967).

2. September 1, 1977 letter from the Secretary of the Federal Power Commission.

3. Applications to the FPC for an LNG terminal on Racoon Island, Delaware: Tenneco LNG Inc., CP 76-16, and Transco Terminal Co., CP 73-258.

4. ERDA Comments on the Federal Power Commission's Draft Environmental Impact Statement (DEIS), for proposed Racoon Island site, September 8, 1975.

5. NRC comments on the FPC's DEIS for proposed Racoon Island site.

6. Letter dated August 8, 1976, to the FPC from EPA, Region II.

7. Staff brief, p. 29.

8. Final Environmental Impact Statement, Pacific Indonesia Project, FPC Docket 74-160, December 1976.

9. Eascogas Hearing, 37 Tr. 4360.

10. Eascogas Hearing, 37 Tr. 4697 and 4709-10.

11. Final Environmental Impact Statement for the Matagorda Bay Project, FPC Docket CP 77-330, September, 1977.

12. SAI 75615LJ, December 22, 1975: LNG Terminal Risk Assessment for Oxnard.

CHAPTER 19

LNG USE IN JAPAN

CONTENTS | PAGE

INTRODUCTION

While the United States is shifting from natural gas to coal, Japan, which imports almost all its energy, is moving from coal to LNG. Of all energy sources, only nuclear is projected to grow faster than imported LNG. LNG, which provided only .8 percent of Japan's total energy in 1973, will supply 5.2 percent in 1980 and 7.9 percent in 1985. Meanwhile, the use of coal and naphtha as natural gas feedstocks will drop sharply. By 1979, 44.3 million cubic meters of LNG will be imported annually, two-thirds by electric utilities and about one-third by gas utilities. The number of LNG storage tanks will increase from 46 in 1977 to 58 by 1979, with a total capacity of 3.5 million cubic meters. Appendix XIX gives statistical data on Japan's LNG receiving terminals, importation projects, and long-range energy supply and demand program.

While surveying Japan's facilities for importing, handling, and storing LNG, we visited major LNG import terminals and an LNG shipbuilding yard, and interviewed government and industry officials.

LNG TANKERS

Japan's imported LNG is now carried by foreign-built ships. For example, Cold Gas Trading Ltd. charters seven French-built, 75,000 cubic meter capacity tankers to haul LNG from Brunei. Kawasaki Heavy Industries is currently completing construction of Japan's first LNG carrier, a 128,000 cubic meter Moss Rosenberg design, the type produced by General Dynamics in Quincy, Mass. Kawasaki already builds semi-membrane LPG tankers which typically carry 60,770 cubic meters of propane and 15,188 cubic meters of butane.

Harbor Safety

Before an LEG carrier over 25,000 gross tons can operate in Japanese ports, the ship's plans and a "Safety Assurance Statement" must be submitted to the Maritime Safety Agency (MSA). On its first trip, the tanker is inspected by MSA officials. Only the vessel's papers are checked on subsequent trips unless officials receive information warranting further examination. Smaller tankers require no inspection.

In some ports, pilots are not legally required. In the others, private harbor pilots, used at the captain's discretion, must be on board all LEG ships above a certain size.

LEG tankers coming into Tokyo Bay are met at the mouth by an escort boat, a fireboat, and tugboats. A 125,000 cubic meter LNG carrier requires three or four 3,000 horsepower tugboats. Smaller tugboats are often used for docking. A moving ship-free pocket system was dropped because as the number of LEG carriers increased, it began to disrupt the normal, congested ship traffic. Once a tanker is docked, the terminal managers decide whether a fireboat remains. Fireboats are equipped with powder and foam. In Tokyo Bay they are privately owned and licensed by MSA. MSA's own fireboats are stationed at Japan's six LNG ports, and operate jointly with the required private fireboats. The agency is responsible for all firefighting in smaller ports, but it lacks enough equipment to protect every harbor.

LPG has occasionally leaked from tankers, the spills in some cases igniting. When a spill does not ignite, safety officials keep traffic away until the LPG disperses. One striking incident occurred off the west coast of Japan in March 1976, when a 550 ton LPG tanker cracked open. Two essurized tanks separated from the ship and floated away. A man climbed down a rope ladder from a hovering MSA helicopter and opened valves on both tanks so the LPG would evaporate before they could drift ashore.

Unloading Precautions

At the Tokyo Gas Company's Negishi Bay Terminal, an unloading LNG ship is connected to a control air duct that runs parallel to the LNG unloading arm. If the tanker moves more than 2 meters from the dock, this air duct will tear. Emergency cut-off valves at both ends of the unloading arm immediately close and the pump on the tanker stops.

The system seems simple, reliable, and effective, but questions have been raised. The automatic shutdown may put stress on the equipment because of liquid hammering in pipes and valves. Some LNG would be spilled in the shutdown since there would not be time to drain pipes and hoses. After such a shutdown, it would take a long time to resume unloading.

LNG STORAGE TANKS

Aboveground Tanks and Dikes

LNG storage tank systems in Japan are safer in some ways than American systems. For example, the Japanese require X-ray inspection of all welds in LNG tanks. Each aboveground LNG tank in Japan must be enclosed by a separate dike. (There is no such requirement in the United States.) All Japanese dikes are low, vertical, made of reinforced concrete, and hold at least 80 percent of the tank's capacity. Those at Tokyo Gas Company's Semboku Terminal are typical. They are double walled, three meters high, and enclose an area 110 by 120 meters. An LNG storage tank must be at least 120 meters away from the nearest house. In practice, the distance is often 1 or 2 miles.

At Semboku water sprayers are installed on the dike perimeter to speed the upward diffusion of LNG vapors in case of a spill. High foaming firefighting equipment (designed by Walter Kidde Co. of the U.S.) can fill the dike with foam in 10 minutes. Dry chemical fire extinguishers and fire trucks are stationed in and around the plant. The trucks carry 1,300 liters of air-foam chemical and 1,000 kilograms of dry chemical. This firefighting equipment is more elaborate than at a typical U.S. installation, but still could only extinguish fires from small spills.

Inground Tanks

For greater safety, many Japanese LNG storage tanks are built in the ground. In part, this trend stems from concern over several recent incidents in which flammable liquids leaked from storage tanks.

For example, on December 18, 1974, the wall of a crude oil tank at the Mitsubishi Petroleum Company's Mizashima refinery collapsed and much of the oil escaped the surrounding dike. The fire which followed caused considerable damage. The tank wall collapse was caused by an undetected oil leak into the soil beneath the side wall of the tank. The oil weakened the soil foundation, and that portion of the sidewall gave way. A ladder on the side of the wall fell against the dike causing a breach.

Japanese engineering companies told us they believe inground tanks are intrinsically safer than aboveground systems because liquid spills are nearly impossible. Moreover, they feel seismic forces will be less on inground tanks.

Inground LNG tanks have proved completely satisfactory in operation and cost about the same in Japan as aboveground tank and dike installations. Inground LPG tanks, however, are considerably more expensive than aboveground LPG installations. Nevertheless, Japanese construction and utility companies told us that inground tanks are likely to be increasingly used to store higher temperature dangerous liquids such as LPG. This prediction was also included in a paper presented by Japanese gas company and construction company officials at the 1976 Winter Annual Meeting in New York of the American Society of Mechanical Engineers.[1]

Most of the underground LNG storage systems in Japan were built by the Ishikawajima-Harima Heavy Industries Company (IHI). The company's first inground tank has been in use since 1970. The tanks range in size from 10,000 to 95,000 cubic meters. IHI's basic system consists of a stainless steel (Austenite, SUS 304) inner tank surrounded by polyurethane foam insulation and an outer wall of reinforced concrete up to 3 meters thick. The 2 mm. to 2.5

mm. inner liner cannot be any thinner because of pressure and thermal contraction.

Reliable welding procedures also require a certain thickness of material. The welds must be able to withstand the cyclic expansion and contraction as LNG is pumped into and out of the tank. If there are two cycles monthly, the welds will have to undergo 720 cycles over the 30 year life of a tank.

There have been no problems with outer wall pressures generated by the expansion of frozen soil. The Japanese have found that as the freezing of the soil progresses, the pressure reaches a maximum and then remains at that level or decreases. It is important, however, to maintain the temperature differential across the wall within 35^{o}F to keep thermal stresses from growing too great. The thermal stress on the outer concrete wall reaches its maximum about six months after the tank is first filled with LNG.

IHI uses three types of bases for its underground tanks, depending on soil conditions. If the soil is impermeable it acts as the tank floor, and the reinforced concrete outer wall is sunk six to eight meters into the impermeable layer. When sand is found above the impermeable soil, a concrete shell is first sunk down into the impermeable layer and then all water is pumped out of the sand. Finally, a stainless steel membrane is laid on top of the compacted sand. The polyurethane insulation between the steel liner and outer concrete shell extends through the sand to the impermeable soil. In sandy soil, the bottom of the tank is made of reinforced concrete. Either the water beneath is continuously pumped out or the soil is heated to prevent freezing by pumping 175^{o}F brine through tubes installed below the tank. When soil conditions prohibit the tank from being sunk deep enough to keep the maximum liquid level below ground level, the ground level is raised.

IHI inground tanks are sealed at the top by a cone-shaped steel roof which supports a suspended aluminum ceiling. Mineral wool is laid on top of the ceiling for insulation. The initial boil-off rate is less than .2 percent per day. This drops to .15 percent or less a day as the soil around the tank freezes and insulates the tank.

Mitsubishi Heavy Industries (MHI) has developed its own LNG storage systems and has been operating a 75,000 cubic meter experimental tank filled with liquid nitrogen since early 1971. It is also a licensee for the Conch International Methane Ltd. inground frozen soil LNG tank system and the Whessoe Ltd. aboveground double wall system. The MHI inground tank is similar to the one developed by IHI, but uses a much thicker reinforced concrete bottom slab. In addition, the connection between the side wall and the bottom slab has an unusual hinge to reduce any bending moments. IHI tanks are designed to "float" upward or downward to a certain extent. An outside gauge measures the rise and fall.

The inground tanks developed by the Japanese have no similarity to an earlier type which proved unsatisfactory wherever it was used. This type of tank was built by simply excavating a hole in the ground, freezing the sides, and attaching a roof. Invariably, cracks appeared in the sides of the tank when it was filled with LNG. For example, such a tank was built in granite by the Philadelphia Gas Company after Battelle Memorial Institute tests indicated that only minor cracking would occur. Unfortunately, major cracks developed in a tree-like fashion. The tank had to be pumped out and abandoned.

The Japanese attitude toward handling of LNG involves more than technology. We were told repeatedly that inground LNG storage tanks are "natural". The Japanese say that natural gas comes from under the ground and it is only proper to store it there so that if gas spills, it will go back to its origins. This typical Japanese stress on harmony with nature contains a great deal of technological wisdom.

FINDINGS

- While the United States is shifting from natural gas to coal, Japan is moving from coal to LNG.

- The Japanese handling of LEG differs in several respects from U.S. practices:

  - A fireboat escorts all large LEG tankers in Tokyo Bay.

  - All welds in Japanese LNG tanks are inspected with X-rays.

  - Each aboveground LNG tank is enclosed by a separate, vertical, reinforced concrete dike.

  - Many Japanese LNG storage tanks are built in the ground.

- Japanese engineering companies told us they believe that inground tanks are intrinsically safer than aboveground systems because liquid spills are nearly impossible.

- Many Japanese engineers believe that seismic forces will be less on inground tanks.

- Inground LNG tanks have proven completely satisfactory in operation and cost about the same in Japan as aboveground tank and dike installations.

- Although inground LPG tanks are considerably more expensive than aboveground installations, many

Japanese gas company and construction company executives believe that inground LPG tanks will be increasingly used.

REFERENCE

1. Experimental Study of LNG Underground Tank, by A. Kobayashi, General Manager, and T. Yamada, Senior Project Engineer, Ishikawojima-Harima Heavy Industries Co., Ltd., and T. Asada, General Manager, Tokyo Gas Co., Ltd. Contributed by the Process Industries Division of the American Society of Mechanical Engineers for presentation at the Winter Annual Meeting, New York, N.Y., December 5, 1976.

CHAPTER 20

OVERALL CONCLUSIONS AND RECOMMENDATIONS

CONTENTS | PAGE

CONTENTS | PAGE

INTRODUCTION

This chapter draws overall conclusions and recommendations from the other chapters and appendixes. While certain important conclusions and recommendations are also on the chapters, it is not meant to be a general summary of all the previous material.

The burden that the Atomic Energy Act imposes on the Nuclear Regulatory Commission is to "adequately protect the public health and safety". This basic burden of government is implicitly laid upon every agency regulating or approving potentially dangerous activity. Since the risks associated with the large scale use of any dangerous, modern technology cannot be rigorously quantified, the requirement is essentially one of prudence in the face of potential danger and uncertainty. Such prudence must be based on skepticism of material presented by interested parties, and a vigorous, timely, independent investigation of the critical issues. The evidence must be evaluated by people with the time, resources, and training to understand it. Most important, the government must adequately and truthfully inform the public of the benefits and dangers involved in different choices.

Unfortunately, the Federal Government has not acquired sufficient knowledge or competence before making LEG decisions, and thus has been unable to adequately communicate with the public, or to act prudently. It has not adequately protected the public health and safety.

STORAGE FACILITIES

Storage Tanks

Natural Phenomena

Most LEG and naphtha storage tanks have metal walls—double walls for LNG and single walls for LPG and naphtha. They are adequately designed to meet the requirements of the Uniform Building Code (UBC) for the area in which they are built. These standards essentially require that the tanks be able to withstand the largest earthquake, wind, flood, etc., experienced in the area in the last 50, 100, or 200 years. This means that the probability that these "design events" will be exceeded at a particular site in a given year is low, but that it is virtually certain that design events will be exceeded many times during the lifetime of the 100 LEG facilities currently operating. Because there are already many large LEG facilities, it is virtually certain that design events will be exceeded at many places and many times during the lifetime of these facilities.

Because structures have safety margins beyond their required strength, a tank will not necessarily fail when it is subjected to a load greater than UBC standards demand it withstand.

Although all six LEG tanks and dikes we evaluated were adequately designed for the UBC earthquake and the 100-year maximum wind design criteria, tanks at three of the five sites had earthquake safety margins less than 25 percent. Two of these sites (a total of three tanks), the

Distrigas LNG import terminal and the Exxon propane import terminal are next to each other in Boston Harbor.

The outer steel walls of LNG tanks are not made of cryogenic material. Thus, if the inner tank fails for any reason, it is almost certain that the outer tank will rupture from the resulting pressure and thermal shock. Large LEG tanks made of prestressed concrete are usually much more resistant to natural forces than those made of steel.

Because many large LEG tanks with small safety margins will be impacted by winds, floods, or earthquakes greater than those they are required to withstand, it is likely that some of them will fail. The walls of these tanks will probably separate from the bottoms, spilling their contents.

Sabotage

Public utilities and petroleum companies have been targets of sabotage. Many domestic and foreign groups have the weapons, explosives, and ability to sabotage LEG and naphtha facilities. Instructions for the construction and use of appropriate explosives from easily available materials are widely published in the open literature. Recent advances in weaponry will eventually increase the threat to LEG and naphtha facilities.

Security procedures and physical barriers at LEG and naphtha facilities are generally not adequate to deter even an untrained amateur saboteur. Most LEG and naphtha storage tanks are highly vulnerable to sabotage which could lead to complete catastrophic failure of the tank walls and subsequent massive spilling of the contents. The level of sabotage needed is within the capabilities of terrorists groups.

Dikes

Natural Phenomena and Sabotage

Earthen dikes are normally made of selected, engineered backfill designed for optimum density and slope stability, which make them highly resistant to natural phenomena and sabotage. High, thin, concrete dikes, on the other hand, are often designed to the same building code standards as tanks and are highly vulnerable to sabotage.

Containment

Dikes constructed to National Fire Protection Association safety criteria generally would not contain the surge of liquid from a massive rupture or collapse of a tank wall, or the spigot flows from punctures high up on the tank. We calculated how much LEG could escape from the dikes in six actual facilities. The figures range from 13 to 64 percent in case of a massive rupture or collapse of a tank wall. Five of the facilities could allow more than 54 percent of the fluid to escape. The facility where only 13 percent could escape has a close, high, concrete dike which might be brought down by the same force which destroyed the tank that it contains. For the reasons given in the text we believe these estimates to be conservative, with the possible exception of the facility with the high, concrete dike.

For the same six facilities we calculated that between 0 and 46 percent could arc over the dike from a hole in the tank if there was no friction in the hole. The actual amount would be less, however, since any hole has some friction.

Overall Conclusions

Both natural phenomena and sabotage can lead to the failure of large LEG and naphtha storage tanks and massive spilling of their contents.

Dikes for LEG and naphtha are designed to handle only small spills, and are generally incapable of containing large, rapid ones. The dikes at most LEG facilities could allow more than half the fluid in the tanks they surround to escape containment if the tank walls collapse, or suffer a massive rupture.

Thus, many large LEG storage facilities are a very serious hazard to the surrounding area.

TRANSPORTATION

Ships

Collisions

LNG ships are probably the least vulnerable of all the systems involved in LNG transportation and storage. Nevertheless, if an LNG ship is struck by a sufficiently large vessel going fast enough, a very large spill could result.

Unlike LNG ships, LPG and naphtha ships are not required to have double hulls, and the stress analysis performed is also much less than for LNG ships. Thus, LPG and naphtha ships are much more vulnerable in collisions than LNG ships.

Sabotage

To cause a massive spill from an LNG ship by sabotage, it is probably necessary to use explosives onboard, or to manipulate the ship's controls and valves to cause overpressuring of the tanks.

LPG and naphtha ships with single hulls are much more vulnerable to sabotage. Improvised limpet mines placed on one while it is anchored or alongside a pier could result in a massive fluid release and the sinking of the ship. Onboard explosives could sink the ship even more easily.

Crew Training

Human error is a contributing factor in 85 percent of all marine casualties and operating problems, and LEG ships need particularly skilled operators for safe operation. We do not believe the Coast Guard's contemplated Waterfront Facility Regulations for LNG in Bulk are entirely adequate, and the rules for LNG terminals proposed by the Office of Pipeline Safety Operations cover operations only to a limited extent. Both sets of proposed rules require companies to have training programs, but these would not be reviewed by the agencies. No personnel qualification regulation of LPG waterfront facilities have been proposed.

Operations

The Coast Guard does not require the officers and enlisted personnel who are involved in LEG ship operations to attend any specialized LEG courses. Most Hazardous Material Officers have had little training in the hazards of LEG, and the Coast Guard has not yet even issued a guidance document for the movement and transfer of LPG.

Coast Guard inspections of entering LNG ships do not include the operating condition of ship control equipment.

There are no specific Coast Guard requirements to guide a local Captain of the Port in deciding whether the condition of an LEG ship is serious enough to warrant keeping the ship out of the harbor.

No specific plans or equipment exist to cope with a major LEG spill, or to partially offload and thus lighten an LEG ship that has gone hard aground in inland waters.

Security

The Coast Guard has not used its authority to require adequate security at LEG harbor facilities.

Overall Conclusion

LNG ships are probably the least vulnerable part of the LNG transportation and storage system. LPG and naphtha ships are far more vulnerable to collisions and sabotage. LEG ship crews, terminal staff, and Coast Guard personnel all need more training. The Coast Guard needs to carry out better inspections, give better directions to Captains of the Port, make much better plans to cope with potential emergencies, and exercise its dormant authority to require adequate security at LEG harbor facilities. To effectively supervise LEG cargo transfer operations in U.S. waters and ports, the Coast Guard will need more money and manpower, revised regulations, and new plans and policies.

Trucks

Accidents

LNG truck trailers have a higher center of gravity than most tank trucks, which makes them particularly susceptible to rolling over; but they have an inner and outer tank with insulation in between and thus are quite resistant to puncture and cargo loss. LPG trucks also have a high center of gravity, although not as high as LNG trucks, but they are single-walled and under pressure, and thus are more vulnerable to cracks and punctures and more likely to explode in fires.

Sabotage and Hijacking

LNG trucks are highly vulnerable to sabotage, and LPG trucks are even more vulnerable. It would also be easy for terrorists to hijack one or many LEG trucks. Nevertheless, LEG trucking companies take no precautions to prevent hijacking or sabotage. The intentional urban release of LEG from one or more trucks by terrorists could cause a catastrophe.

Routing

Interstate Commerce Commission LEG trucking certificates do not restrict truck routes, and LEG trucks move routinely through large cities. Driving LEG trucks on elevated urban highways is particularly dangerous because one might go through the guard rail and split open on the street below. This could fill sewers, highways, tunnels, subways and basements with invisible, odorless explosive gas. The 40 cubic meters of LNG from one truck, vaporized and mixed with air in flammable proportions, are enough to fill 110 miles of 6-foot diameter sewer line, or 15 miles of a 16-foot diameter subway system.

Overall Conclusion

The dangers present in trucking LEG are far greater than those involved in trucking less volatile petroleum products such as fuel oil, naphtha, and gasoline. The trucks are highly vulnerable to sabotage, hijacking, and certain types of accidents. LEG trucking in densely populated areas is very dangerous.

Trains

Accidents

Accidents involving LPG railcars are not infrequent and often lead to deaths and injuries. In September, 1977, the Department of Transportation (DOT) issued regulations requiring all LPG cars to make certain modifications by December 31, 1981, which will make them less susceptible to fires and explosions. After Congressional hearings on a series of derailments of hazardous materials railcars in early 1978, and recommendations by the National Transportation Safety Board, DOT announced in May, 1978, that it proposes to shorten the retrofit schedule--to require shelf couplers by December 31, 1978, and to require a tank head puncture resistance system and thermal protection by December 31, 1980.

An adequate inspection program for LPG railcars does not exist, and rusted tank cars holding propane under high pressure are currently being used.

Sabotage

Sabotage of LPG railcars or the trains they are part of would not be difficult. The improvements which DOT has mandated for future LPG cars do not significantly increase their resistance to sabotage although they might mitigate the consequences.

Routing

LPG railcars travel through densely populated areas of cities, even cities which prohibit LPG storage. If the contents of one or more of these cars were released in a city by accident or through sabotage, it could lead to a catastrophe.

Overall Conclusion

Although LPG railcars are vulnerable in accidents and to sabotage, and sometimes run in rusted condition, they travel through densely populated areas of cities even cities which prohibit LPG storage. If the contents of one or more LPG cars were released in a city, it could lead to a catastrophe.

DOT officials believe that the new modificat s on railcars are sufficient for their safe operation. We believe restriction of routes is also necessary.

EFFECTS

It is difficult to estimate the effect of a large LEG spill in a city. The only such spill, in Cleveland in 1944, was quite small compared to the quantities stored in urban areas today. Nevertheless, it killed 130 people and injured 225 more. According to the National Fire Protection Association, if the wind had been blowing in the opposite direction the fire "could have destroyed a very large part of the East Side". A spill today could involve 10 to 20 times as much material.

Some insight can be gotten from the June, 1977 spill of naphtha into the sewers of Akron, Ohio. Although naphtha is much less dangerous than LNG or LPG and less than 15 cubic meters was spilled, the incident caused violent explosions more than 8 miles from the point of the spill.

LNG and LPG vapors are highly explosive in confinement, and propane from a pipeline break in Port Hudson, Missouri, in 1970 caused a large detonation in the open air. If LEG spreads across a city in sewers, subways, or other underground conduits, or if a massive burning cloud is blown along by a strong wind, a city may be faced with a very large number of ignitions and explosions across a wide area.

Overall Conclusion

Although the effect of a large spill of LEG in a big city is uncertain, the damage might be much larger than that caused by the Cleveland spill.

LIABILITY AND COMPENSATION

Liability

LNG is imported on ships, each owned or leased by a separate subsidiary corporation, and stored in terminals owned by other subsidiaries. In many cases, the parent firms are wholly-owned subsidiaries of still larger firms. Most of the assets in the system are protected by these corporate chains, and the top corporations, which derive all of the profits, would generally not be liable for the consequences of an accident. The frontline companies most vulnerable to liability are usually the most thinly capitalized. Most of their assets may be the ship or terminal itself, which is unlikely to survive an accident which does extensive offsite damage. The banks and insurance companies which finance these ships and terminals insist that all the companies in the corporate chain co-sign the notes, so that in the event of a catastrophic accident they will be protected by the assets of the whole corporate chain. The public whose lives and property are at risk deserves no less protection.

Insurance

Present and planned liability coverage for LNG import terminals ranges from $50 million to $190 million per incident. Ten states require proof of liability insurance for LPG facilities, but the maximum required is $100,000 per incident.

The liability of shipowners and bareboat charterers is limited by statute to the post-accident value of the vessel plus any amounts owing for freight, if they can prove that they did not know about the causes of the accident. If injuries or deaths occur, however, the limit is raised to $60 per ton of cargo. For a large LEG ship this would be about $3,500,000.

Recovery

Claimants after a major LNG accident face long, complex, and expensive litigation involving potential complications at every step in the legal process. If the defendant corporation is foreign owned, it and its assets may be out of reach. If the accident resulted from an act of sabotage, or from an "act of God" such as an earthquake, flood, or tornado, the company may not be liable at all. In any case, it is not always possible to prove the primary cause of a major accident, since critical evidence may be destroyed in the accident itself.

Federal Action

No Federal agency considers the question of offsite liability of LNG operations. We believe the Federal Energy Regulatory Commission and the Economic Regulatory Administration have an obligation to do so.

Overall Conclusion

A major LEG accident could cause damage of such severity that injured parties could not be fully compensated under existing arrangements. Present corporate structures and legal limits on liability offer great protection to the parent corporations which reap the profits. This may diminish their incentives for safety.

RESEARCH

Present Results

The Coast Guard has been responsible for some good quality hazard analyses, primarily on the effects of small spills on water. Isolated pieces of research of varying quality have been done by other government and private laboratories around the world. All of the research has been on a very small scale compared to present day hazards.

Among the topics which have been insufficiently explored are: the interaction of spilled LEG with man-made structures such as buildings, subways, sewers, and ships; under what conditions a large LEG cloud ignited on its downwind edge will burn back to its source; under what conditions LNG and LPG clouds can detonate; how far a large LEG could can travel, under varying atmospheric conditions, before reaching its lower flammable limit.

Overall Conclusion

LEG risk assessment studies have not reached a stage where they give confidence in their conclusions. Therefore, safety decisions can not logically be based on them. Federal agencies will have to make timely, prudent decisions with the realization that many important questions cannot presently be answered with confidence.

Future Plans

The Federal Government's present plan is to channel the bulk of LNG safety research through the Department of Energy (DOE). DOE plans to support LNG research in a manner analogous to its support of research in other areas. This is entirely inappropriate because of the number of facilities now under development, under construction, or in use. The research needed for current, temporary technology is different from that which is needed for long-term and not yet perfected technologies. At the same time, the organizations directly responsible for safety have inadequate budgets and personnel to make informed technical judgments.

DOE plans large expenditures to create facilities for very large (1000 cubic meter) experimental spills. This is not an appropriate way to spend LNG safety research funds. It is unlikely that any results can be obtained in this manner soon enough to affect the design of most facilities.

Overall Conclusion

The present plan to channel the bulk of LNG safety research through the Department of Energy is faulty and will not produce timely or useful safety results. Much more thought and resources should be devoted to LPG research.

THE FEDERAL POWER COMMISSION

The level of technical knowledge and experience found at the Federal Power Commission was inadequate to deal with questions of new and high technology such as LNG. In addition, since economic questions were included in the same process as safety questions, fuzzy trade-offs between the two were inevitable. The extent to which procedures will be changed under DOE is unclear. The Initial Decisions on LNG projects have been based on safety findings some of which our research indicates are inaccurate. None has been questioned by the Commission.

Overall Conclusion

The Federal Power Commission's system for approving LNG projects was clearly inadequate to protect the public.

CAPABILITY OF NON-URBAN SITES TO MEET TOTAL U.S. IMPORT REQUIREMENTS OF LPG

Overall Conclusions

Existing and announced non-urban terminals will have the capacity to receive 111 percent of projected LPG imports in 1985.

Non-urban LNG terminals could easily handle all of the LNG imports projected between now and 1990. We have not looked at the capacity of the main gas transmission lines to distribute these quantities.

The nation's ability to pick the best sites for LEG imports, and to avoid storing and transporting large quantities of LEG in densely populated areas, is seriously impaired because already chosen sites cannot be required to serve new customers.

JAPAN

Japan is the world's largest importer of LNG. While the United States is shifting from natural gas to coal, Japan is moving from coal to LNG.

Aboveground Tanks

Japanese LNG storage areas with aboveground tanks are in many ways designed to higher standards than similar installations in the United States. For example, every weld in Japanese LNG tank is inspected with X-rays. Also, each tank is surrounded by a separate, vertical, reinforced concrete dike. Similar low dikes in the United States are usually made of earth and are sloped.

Inground Tanks

In spite of the high quality of Japanese aboveground tanks, many LNG tanks in Japan are built in the ground for greater safety. Japanese engineering companies told us they believe that seismic forces will be less on inground tanks and that these tanks are intrinsically safer than aboveground systems because liquid spills are nearly impossible.

Overall Conclusion

According to industry officials in Japan, inground tanks have proved completely satisfactory in operation and cost about the same there as aboveground tank and dike installations. If inground tanks, instead of aboveground tanks, were used in the United States, large spills would be far less likely.

FEDERAL, STATE, AND LOCAL REGULATIONS

Almost all state and local regulations for LEG are based on National Fire Protection Association (NFPA) standards some of which we have shown to be inadequate. (See Chapter 5.) The exceptions include somewhat more stringent regulations developed by the New York State Public Service Commission and the New York City Fire Department. Most responsibility for the safety of LEG and naphtha has traditionally been under state and local fire marshals. At public utilities, LEG and naphtha are also regulated by state utility commissions.

Federal safety responsibilities for LEG are shared by many departments and agencies. Federal regulation of LNG has not been well coordinated, and there is little Federal regulation of LPG or naphtha.

In most situations, for a given volume, LPG is more dangerous than LNG, and LNG is more dangerous than naphtha. Many of the regulations imposed by NFPA standards, states, and localities do not reflect this. Buffer zones for naphtha, for example, are often close to or even greater than those for LPG, and buffer zones for LNG are often substantially less than those for naphtha. The same inconsistencies arise in the requirements for intertank spacing. Dike design requirements are more comprehensive in the NFPA code covering naphtha than in the NFPA standards for LNG and LPG. In addition, since most LEG and naphtha facilities have been designed to meet normal building code standards, design standards for naphtha tanks are essentially as strong as those for LEG tanks.

The requirements for security at LEG and naphtha facilities are so slight as to provide virtually no deterrent to potential saboteurs.

Outside of some specific operating requirements scattered through the various regulations, there are only quite general references to the desirability of operator qualifications and training. New York City certifies LNG plant operators and a few states certify operators at LPG facilities, but there are no comprehensive requirements for the development of formal operating procedures and training programs, or for the review of such procedures by jurisdictional agencies.

Overall Conclusion

The mixture of Federal, state, local, and NFPA codes for LNG, LPG, and naphtha reflect neither the relative dangers from the fuels nor much consistency among themselves. Most of the regulations are based on an uncritical acceptance of NFPA standards.

Federal regulation and inspection of LEG importation, transportation, and storage have not been adequate to ensure the public safety.

GENERAL OVERALL CONCLUSIONS

- No construction of new, large LEG storage facilities - or expansion in size or use of existing ones - should be permitted except in remote areas.

- If any new, large LEG storage facilities are built in other than remote areas, all tanks should either be inground, with the highest level of fluid below ground level, or be built and operated to standards similar to those applied to the construction and operation of nuclear plants.

- Existing LEG facilities in other than remote areas need to be evaluated and any necessary steps taken to protect the public.

- LEG should not be moved through densely populated areas if there is any other way to deliver the material.

- The safest way to move LPG is by pipeline, and railcars are preferable to trucks.

- Dikes for LEG and naphtha are designed to handle only small spills and are incapable of containing large, rapid ones.

- No present or foreseeable equipment can put out a very large LEG fire.

- LEG and naphtha facilities have virtually no protection against saboteurs.

- More careful and comprehensive Federal regulations for LEG storage and transportation are needed, as are more inspectors.

- It is virtually certain that the level of natural phenomena that LEG facilities are designed to withstand will be exceeded at a large number of facilities in the next 50 years. One or more of them will probably fail by the walls lifting from the foundation, spilling the contents.

- At most facilities, most of the fluid released in a large, rapid spill will go over the dike. If this sequence of events happens in a densely populated area, a catastrophe may take place. The same train of events could be started by sabotage.

- A much more equitable system is needed to assign liability and compensate victims after an LEG accident.

- Many energy health and safety responsibilities should be placed in a Federal Energy Health and Safety Regulatory Agency.

GENERAL OVERALL RECOMMENDATIONS

Recommendations to Federal Agencies

1. We recommend that the Secretaries of Transportation and Energy and the Federal Energy Regulatory Commission take whatever steps are necessary to ensure that

- All new, large LEG storage facilities are built in remote areas.
- No existing, large LEG storage facilities in other than remote areas are expanded in size or in use.

2. If, despite our recommendation, new, large LEG storage facilities are built in other than remote areas, or existing ones are expanded in size or use, we recommend that:

- All storage tanks be in the ground with the highest level of fluid below ground level, or
- All storage tanks be built and operated to standards similar to those applied to the construction and operation of nuclear plants.

3. We recommend that the Secretary of Energy evaluate each existing, large LEG storage facility and recommend to the President and the Congress the actions necessary to protect the public from the hazards associated with them.

CHAPTER 21

GAO TREATMENT OF AGENCY AND COMPANY COMMENTS

INTRODUCTION

Because of the wide interest in this report, it has undergone several reviews to ensure its accuracy and objectivity.

Prior to furnishing the draft of this report to concerned Federal agencies and the LEG industry, we asked a group of past and present leaders in industry, labor, science, law, consumer affairs, security, and government to comment on the material developed before GAO's findings, conclusions, and recommendations were prepared. Their comments were received in writing and at an all-day meeting.

Eight Federal agencies which have jurisdiction or a direct interest in LEG safety received a complete draft of the report. At the same time, we sent to companies and private organizations those chapters of the report in which they were mentioned, minus GAO's findings, conclusions, and recommendations.

We received more than 500 pages of comments from companies, organizations, and Federal agencies. The official comments received from six Federal agencies are reprinted in Volume 3 of this report. The comments from private organizations and companies are available for public review at the U.S. General Accounting Office, 441 G Street, N.W., Washington, DC.

Many changes have been made in the report since the initial draft - some as a result of the comments, some as a result of further staff work.

Most of the Federal agency comments with which we disagreed are answered at the back of the appropriate chapters. We did not have time to comment on every such industry comment, but many industry comments were similar to those received from agencies.

Where comments correctly disputed the accuracy of specific statements, we made the appropriate corrections. The suggestions we adopted are not commented upon. General comments on more general issues—such as the report's procedures, motivation, tone, presentation, use of certain types of analyses—are discussed in this chapter.

THE REVIEW PROCESS

Several companies objected to our removal of preliminary findings, conclusions, and recommendations from the chapters they were sent. Others asked to review the entire draft, not just the portions they were mentioned in. We also received requests for copies from many state and local agencies and private organizations which were not mentioned in, and not sent, the draft.

GAO recognized the wide public interest in this study, but it is GAO's policy to send to private organizations only those parts of studies in which they are discussed. The purpose of sending those parts is to allow companies to review the accuracy of statements made about them. Federal agencies, which are required by law to respond to GAO recommendations, are always sent the entire report.

MOTIVATION OF THE REPORT

Many comments complained that we had singled out LEG for scrutiny. They named other dangerous substances which are used in much greater quantities than LEG, such as gasoline and fuel oil, and others which may be more hazardous, such as chlorine.

There are other hazardous materials used, stored, and transported in the United States, and we do not mean to imply that LEG is the only one worthy of public attention. We chose LEG for examination because of its widespread and possibly growing use, and its storage and transportation in very large quantities in urban areas. GAO has examined the storage and transportation of other hazardous materials in the past—for example, nuclear materials—and may do similar studies in the future.

Although LEG is very dangerous, we believe it can be used in a way that does not pose undue risk to the public. Our recommendations are pointed toward making its use adequately safe. Many of our conclusions and recommendations may be applicable to other hazardous materials.

LEG BENEFITS

Some comments suggested that we failed to adequately bring out the benefits of LEG. They correctly point out that liquefying energy gases makes overseas imports possible and often makes storage and transportation cheaper. They also point out that its use may increase and that a moratorium on LEG could impose hardships on parts of the country.

This report was not intended to evaluate the advantages and disadvantages of LEG as an energy source. Rather, because LEG use is substantial and may greatly increase, we believe it is important to examine the adequacy of current practices for handling LEG.

TONE

Some comments criticized the report for being "unobjective" and for attempting to "discredit the industry." We have attempted to present the material in the report in a logical clear manner without inflammatory language. We demanded that the consultants who worked on the report have the highest qualifications and have no financial or intellectual stake in the results. We believe that we have carefully backed up our findings and conclusions, even conducting our own basic research where necessary.

THE LEG SAFETY RECORD

Some comments accuse GAO of ignoring the "excellent" safety record of the LNG industry. They say that, since the Cleveland accident in 1944, there has been no major accident, either at storage facilities or in land or sea transportation. They also claim that the Cleveland accident is no longer relevant because advances in cryogenic technology and engineering practices make it "impossible" for such an accident to re-occur.

Since no cause for the Cleveland catastrophe was ever officially determined, it is impossible to say whether the cause has been eliminated by the somewhat higher percentage of nickel in the tank steel and the other changes made. However, the same assurances of safety that were given before the Cleveland accident are given now, and many of the same design assumptions are still being made. Most important, although the quantities spilled in Cleveland are much smaller than those at storage sites today, the accident illustrates the kind of phenomena that can take place in an urban spill. And very large quantities of LEG are still stored in urban areas.

The LNG safety record has been less than perfect since Cleveland. Although no other catastrophes have occurred, accidents—including uncontrolled spills of material—have happened at LNG storage facilities around the world and from ships and trucks. There have also been many serious accidents in all aspects of the much older and more widespread LPG industry. Some of the ones that happened in the United States are recounted in the chapters on truck and train transportation, but accidents have also occurred at storage facilities and on ships.

USE OF NUCLEAR ANALOGY

In Chapter 3 we examined the extent to which typical LEG facilities meet the requirements of the Uniform Building Code (UBC), the least stringent code to which buildings are built, and the requirements for nuclear plants, the most stringent criteria applied to commercial buildings. Many commentators condemned this juxtaposition, saying that the short-term dangers from an LEG spill are much less than the short- and long-term effects of a nuclear accident. Some comments also suggested that reevaluations of nuclear standards have implied that they may be overly stringent.

It is not obvious to us that the risk to the public from a remotely located nuclear power plant is less than that from a large LEG installation in an urban area, and we are not aware of any analysis which would lead to this conclusion. This study does not address the issue of whether nuclear standards need to be more or less stringent but, as we conclude in the report, it makes little sense to allow LEG facilities in urban areas to use much weaker standards than nuclear facilities in rural areas.

A few companies pointed out that the UBC is the minimum level earthquake and wind loading required for many industrial facilities which store other types of hazardous materials. They also suggested that experience with LNG storage tanks shows that large LEG tanks designed to the UBC standards can be safely built in urban areas.

Chapter 3 shows that many LEG tanks will experience natural forces greater than the UBC standards require, and some of these have very low safety factors.

Only in the last several years have many large LNG tanks been built, and some have had serious operating problems. A few have been closed because of them.

LPG storage tanks have also had serious problems as indicated by the following examples. In 1977, the wall of a 50,000 cubic meter propane storage tank in Qatar, designed by Shell International, suddenly collapsed. The fluid went over the dikes. The resultant explosion killed many people and destroyed the natural gas liquids facility in which it was located.

At the Rhone-Alpes Refinery, one of France's most modern, eight butane and propane storage tanks exploded. The original explosion was caused when the vapor from a leaking butane tank was ignited by a truck passing on a road 175 yards from the tank. Eleven people died and another 70 were injured.

We believe that this report supports the need for substantial strengthening of the design and operation standards for LEG facilities, and for site-by-site evaluations of existing LEG facilities in urban areas to determine actions needed to adequately protect the public.

7379

BY THE COMPTROLLER GENERAL

Report To The Congress

OF THE UNITED STATES

Liquefied Energy Gases Safety: Appendixes

VOLUME 2 OF THREE VOLUMES

UNITED STATES GENERAL ACCOUNTING OFFICE

EMD-78-28

PREFACE

This is Volume 2 of a three-volume report. Volume 1 contains the Executive Summary and report chapters. Volume 3 contains the formal comments provided on this report by Federal agencies.

This volume contains the appendixes that support and supplement the report chapters. There are 14 appendixes, some consisting of more than one part.

Appendix I contains listings of (1) the contractors and consultants who contributed to this study, and (2) the facilities and organizations that we visited during the study. The remaining appendixes are numbered to correspond with the chapters that they support or supplement.

Some of the appendixes contain detailed discussions of the calculations and experiments we performed to verify certain assumptions or to obtain answers where none were previously available. Of necessity, these are highly technical and complex.

<u>CONTENTS</u>

VOLUME 2

APPENDIX

NOTE: For ease of reference the appendixes are numbered to correspond with the chapters they support or expand. There are no Appendixes VIII, XI, XIII, XV, XVII, XX, or XXI.

APPENDIX

APPENDIX I

CONTENTS

APPENDIX I-1

MAJOR CONTRIBUTORS TO THE LIQUEFIED ENERGY GASES SAFETY REPORT

Contractors	Location
S. L. Lindsey	Houston, Texas
Arthur D. Little, Inc.	Cambridge, Massachusetts
Marinco Ltd.	Falls Church, Virginia
Maritime Institute of Technology and Graduate Studies	Linthicum Heights, Maryland
R&D Associates	Los Angeles, California
J.D. Stevenson, Consultants	Cleveland, Ohio
S. Ross and Company	Boston, Massachusetts
Whitfield Russell and Associates, P.C.	Washington, D.C.

Individuals	Affiliation
Mr. Petter Aarrestad	Maritime Institute of Technology and Graduate Studies
Dr. James Austin	MIT
Mr. Sheldon Bierman	Attorney
Dr. Bernard Budiansky	Harvard University
Mr. Angus Fraser	USMC (ret.)
Ms. Irene Gordon	Editorial Consultant
Dr. Harvey Greenspan	MIT
Mr. Samuel Iker	Editorial Consultant
Mr. Thomas Kelly	Editorial Consultant
Dr. Daniel Kleitman	MIT
Dr. Willem Malkus	MIT
Ms. Patricia Nield	Legal Consultant
Mr. Daniel Rapoport	Editorial Consultant
Mr. Michael Ricinak	USN (ret.)
Mr. Richard Royston	R.H. Royston Co.

Individuals (cont.)	Affiliation (cont.)
Mr. Whitfield Russell	Whitfield Russell and Associates, P.C.
Mr. Wendell Webber	Marinco Ltd.
Dr. Hilton Weiss	Bard College

Review Consultants	Affiliation
Mr. Murray Comarow	Vom Baur, Coburn, Simmons, and Turtle Law Firm
Mr. Alan Grospiron	President Oil, Chemical, and Atomic Workers International Union
Dr. Paul Martin	Dean of Engineering and Applied Sciences Harvard University
Mr. S. Sterling Munro, Jr.	Independent Consultant; formerly Administrative Assistant to Senator Henry Jackson
Mr. Ralph Nader	Consumer Advocate and Lawyer
Mr. William Sullivan	Independent Consultant; formerly Assistant to the Director of the FBI in charge of investigations
Mr. Ardell Tiedeman	President California Liquid Gas Company

APPENDIX I-2

SITE VISITS

LNG Marine Terminals

Owner	Site
Algonquin LNG	Providence, R.I.
Columbia LNG/Consolidated System LNG	Cove Point, Md.
Distrigas of Massachusetts	Everett, Mass.
El Paso LNG Terminal	Port O'Connor, Tex.
Public Service Electric & Gas	Staten Island, N.Y.
Southern Energy	Elba Island, Ga.
Tenneco LNG	West Deptford, N.J.
Trunkline LNG	Lake Charles, La.
Western LNG Terminal Associates	Los Angeles, Cal. Oxnard, Cal. Point Conception, Cal.

LNG Peakshaving Facilities

East Ohio Gas	Cleveland, Ohio (site of 1944 accident)
Northwest Pipeline	Plymouth, Wash.
Philadelphia Electric	West Conshohocken, Pa.
Philadelphia Gas Works	Philadelphia, Pa.
Texas Eastern Transmission	Staten Island, N.Y.

SNG Plants

Boston Gas	Everett, Mass.

LPG Import Terminals

Atlantic Richfield	Philadelphia, Pa.
Exxon U.S.A.	Everett, Mass.
Gulf Oil	Philadelphia, Pa.

Petrolane	San Pedro, Cal.
Petro-Tex Chemical	Houston, Tex.
Sun Oil	Marcus Hook, Pa.
Warren Petroleum	Houston, Tex.

Shipyards

Avondale Shipyards	New Orleans, La.
General Dynamics	Quincy, Mass.

Storage Tank Construction

Chicago Bridge and Iron	Oak Brook, Ill.
Preload Technologies	Garden City, N.Y.

LPG Distribution Supply Center

Pargas	Fairfax, Va.

LNG Truck Transport Companies

Andrews and Pierce	North Abington, Mass.
Fairside Trucking	Brockton, Mass.
Gas, Inc.	Lowell, Mass.

Organizations

American Gas Association	Arlington, Va.
BLAST (Bring Legal Action to Stop Tanks)	Staten Island, N.Y.
National Fire Procection Association	Boston, Mass.

Federal Government Facilities

U.S. Coast Guard	Washington, D.C. Boston, Mass. New York, N.Y. Philadelphia, Pa. Baltimore, Md. (Cove Point)

U.S. Coast Guard	Savannah, Ga. Houston, Tex.
Naval Weapons Center	China Lake, Cal.
Sandia Corporation	Albuquerque, N.M.

State Government Agencies

California Coastal Zone Conservation Commission

California Energy Commission

California Office of Planning and Research

California Public Utilities Commission

Tennessee Adjutant General

Local Government Agencies

Akron, Ohio city officials

Boston, Mass. city officials

New York City Fire Department

Oxnard Town Council

Waverly, Tenn. city officials

Franklin County, Wash. officials

JAPAN

LNG Marine Terminals

Owner	Site
Osaka Gas Company	Semboku Works, Osaka
Tokyo Gas Company	Negishi Works, Yokohama Sodegaura Works, Chiba

Shipyard

Kawasaki Heavy Industries Sakaide Shipbuilding Division	Kagawa

Storage Tank Construction

Ishikawajima-Harima Heavy Industries	Tokyo
Mitsubishi Heavy Industries	Tokyo

Organization

Japan Gas Association	Tokyo

National Government

Ministry of International Trade and Industry
  Gas Safety Division
  Public Utilities Bureau

Ministry of Transportation
  Maritime Safety Agency

APPENDIX II

U.S. LEG AND NAPHTHA CONSUMPTION, 1976

Table II-1 U.S. Energy Consumption by Fuel

	Quad (10^{15} Btu)	%
Petroleum*	32.9	44
Natural Gas+	20.1	27
Coal	13.7	19
Hydro-electric	3.0	4
LEG and Naphtha	2.2	3
Nuclear	2.0	3
Geothermal	0.1	-
Total, 1976	74.0	100

*Excludes LPG and naphtha used outside refineries and gas plants.

+Excludes natural gas transported or stored as LNG.

Source: United States Statistical Abstract, 1977

Table II-2 LEG and Naphtha Consumption by Fuel*

	Quad (10^{15} Btu)	%
LNG	0.1	5
LPG	1.5	68
Naphtha	0.6	27
	2.2	100

*Excludes plant LPG used at refineries.

Table II-3 LPG Consumption
(in units of 1,000 cubic meters)

	Propane	Butane	Mixture	Total
Total U.S. Production	4,457	1,612	650	6,719
Less Use in Plants	- 72	- 902	- 541	-1,515
Change in Stock	+ 128	+ 89	+ 29	+ 246
U.S. Production for Use Outside Plants	4,513	799	138	5,450
Imports	394	360	0	754
Total Use Outside Plants	4,907	1,159	138	6,204
Btu Equivalent (Quads)	1.17	0.31	0.04	1.52

Source: Bureau of Mines, "Mineral Industry Surveys," December, 1976.

Table II-4 Naphtha Consumption
(in units of 1,000 cubic meters)

	Jet Fuel	Industrial	Total
Production	1,089	519	1,608
Change in Stock	- 20	- 1	- 21
Imports	88	1	89
Total Use Outside Plants	1,157	519	1,676
Btu Equivalent (Quads)	0.39	0.17	0.56

Source: Bureau of Mines, "Mineral Industry Surveys," December, 1976.

APPENDIX III

CONTENTS | PAGE

APPENDIX III-1

LEG STORAGE SITE EVALUATION QUESTIONNAIRE

LIQUEFACTION

A. For the site selected, assuming piles or selected backfill foundation were not used, was the potential for tank foundation liquefaction as a result of earthquake evaluated?

If yes, is evaluation report available?

If no, please provide the following foundation media data within 80 feet of tank bottom if available.

1. Type of foundation media.
2. Profile with depth of foundation media grain sizes.
3. Profile with depth of foundation media density.
4. Surcharge (weight of structure) psf.
5. Profile with depth of relative density of foundation media.
6. Location of water table.
7. Depth to rock.
8. Size of tank.

B. If selected backfill was used, please indicate:

1. Depth of backfill below tank bottom.
2. Same data as requested in A1 through A8.

C. If piles were used:

1. Total depth of piles.
2. Type of pile - wood, concrete, steel.
3. Type - bearing or friction.
4. Driving criteria.
5. Ar ˙ provision for lateral loads on pile system.

FLOODING - COASTAL

A. For the site selected, was potential for coastal flooding or storm surge considered?

B. If yes, what was the flood height determined relative to the bottom of the storage tank?

What probability per year or return cycle is the flood height determined for?

C. If flood height is above storage tank base height:

1. Was tank design evaluated for buoyancy forces?
2. Were any water flow loads considered? If so, how?

FLOODING - RIVER

Same questions as asked for above A through C, plus what is the potential for combined river plus coastal flooding?

TSUNAMI

A. Was any consideration given to tsunami (tidal wave) effects?

B. If yes, is an evaluation report available?

C. If no, please give tank bottom evaluation above mean sea level, and if possible, provide a topographical map of the site in scale large enough to show general shape of site shore line.

APPENDIX III-2

EVALUATION OF 300,000 BARREL PETROLANE, INC., LIQUID PROPANE STORAGE TANK FACILITIES, SAN PEDRO, CALIFORNIA, TO WITHSTAND EARTHQUAKE LOADING WITHOUT RUPTURE

INTRODUCTION

The evaluation performed on the seismic capacity of the Petrolane, Inc., propane storage tank facilities, San Pedro, California, was based on a site visit on July 26, 1977, plus a review of the design calculations performed by Chicago Bridge & Iron Company[1] and CB&I drawings:

1A	Rev. 6	Contract No. 72-4145
1B	Rev. 5	Contract No. 72-4145
42	Rev. 1	Contract No. 72-4145

We also reviewed the California PUC Draft Safety Report,[2] and Soil and Earthquake Engineering Investigation Report prepared by Converse, Davis, and Associates.[3]

The original seismic design analysis performed by CB&I, which used the ground response spectrum provided by Converse, Davis, and Associates, is shown in Fig. III-1. This response spectrum scales to 0.29g at zero period, which is normally equated to the zero period (maximum ground acceleration) at the site. The PUC draft safety report seems to conclude that the tanks were designed to 0.4g (see p. 12-2) and compared this acceleration value directly with accelerations associated with earthquake magnitudes. The correlation of earthquake magnitude with acceleration is normally done on the basis of zero period ground acceleration and not response acceleration which is dependent on the frequency characteristics of the structure being analyzed and the shape of the response spectrum. The 0.4g acceleration level used in design includes the response of the tanks. However, the reference zero period ground acceleration defined for the site and used in design is 0.29g, not 0.4g as indicated in the California PUC Draft Report.

In evaluating the ultimate seismic capacity of the tanks, the same response spectrum as originally defined was used as shown in Figure III-1. In determining seismic loads, the same model representation of the tank as that described by CB&I was used. In our analysis to determine seismic loads, we used higher modes of response, in addition to the fundamental mode, and determined the dynamic characteristics of the tanks by the finite element computer algorithm, ANSYS[4]. A description of the analysis performed is given below. Except as noted, the analytical procedures used to evaluate ultimate seismic capacity of the tank was the same as that used by CB&I in the original design. Final results and comparisons are presented in Table III-1.

DYNAMIC ANALYSIS

The fundamental period (frequency) of the tank is a key parameter in determining seismic loads. The dynamic characteristic analysis performed by CB&I used a proprietary computer program based on the Rayleigh-Ritz procedure and determined a fundamental period of the tank

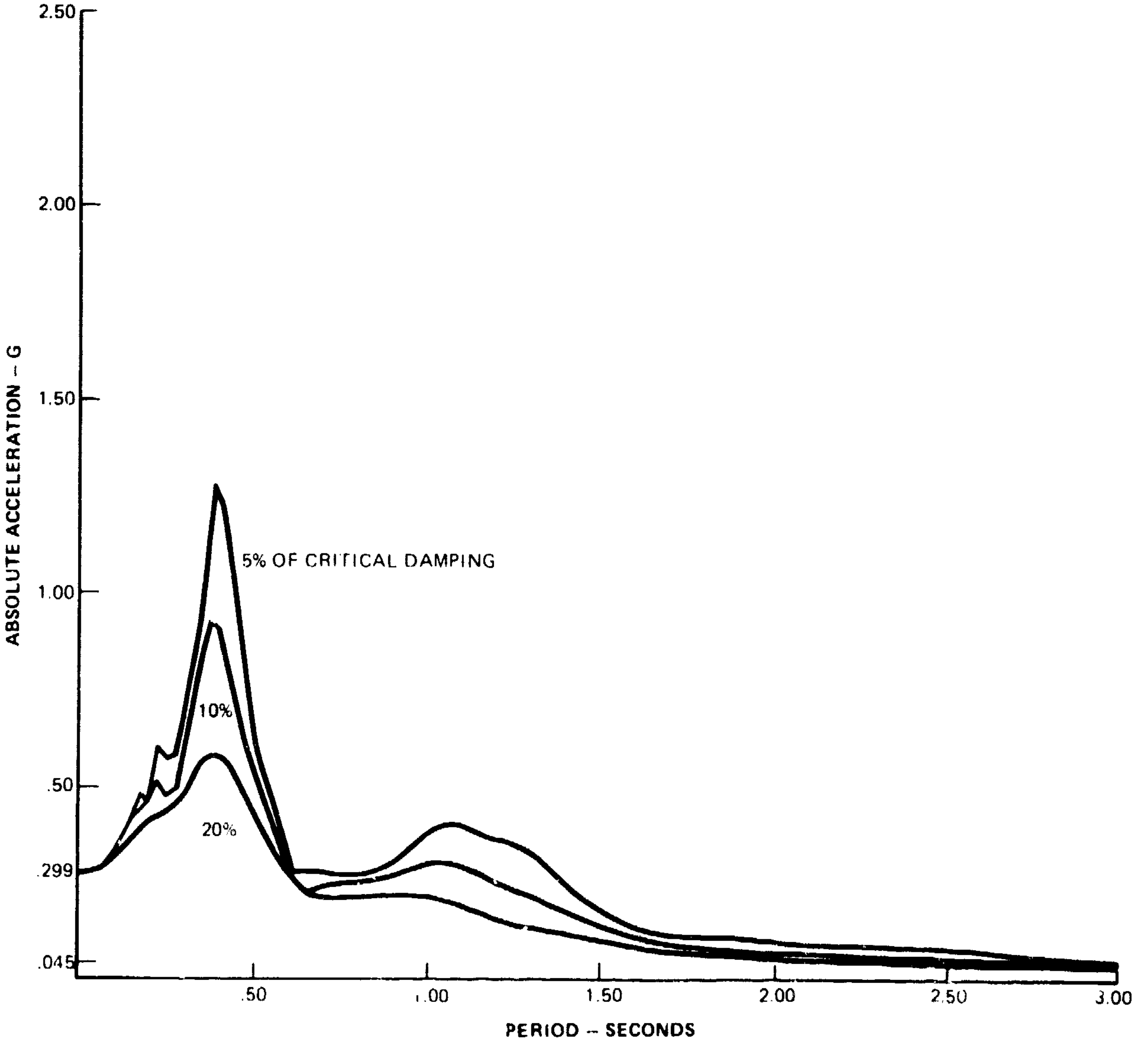


FIG. III-1 ABSOLUTE ACCELERATION RESPONSE SPECTRA FOR A MAGNITUDE 5.5 TO 6.0 EARTHQUAKE ON THE PALOS VERDES FAULT of 0.132 seconds (7.58 Hz). Using the computer program, ANSYS, which used a finite element consistent mass matrix form of solution and the same model as described by CB&I, we determined a fundamental period of 0.210 seconds (4.77 Hz).

The difference in fundamental period between CB&I's and our solutions is larger than can normally be accounted for by usual computer algorithm differences.

In addition to evaluating the natural period of the tanks as cantilever beams on a rigid foundation, the response of the structures was also evaluated using a standard rigid body soil-structure representation as would typically be done for surface located nuclear stations. A comparison of the dynamic characteristics of the three analyses is given in Table III-1.

CONCLUSION

Based on the comparison shown in Table III-1, and assuming the response spectra shown in Fig. III-1 are still valid, the Petrolane, Inc., Liquid Propane Storage Tank Facilities in San Pedro should be able to accommodate an earthquake of zero period ground acceleration in the free field at the foundation base level of at least

$$0.29 \times 2.23 = 0.65g$$

before significant leakage or failure of the tank bottom would be expected.

TABLE III-1

SUMMARY RESULTS OF ANALYSIS OF 300,000 BARREL
PETROLANE, INC., LIQUID PROPANE STORAGE TANK FACILITIES
SAN PEDRO, CALIFORNIA

	Calculated Fundamental Natural Frequency	Response Spectral Value	Over-turning Moment X 10^3 K-ft.	Calculated Stress in Tie Down Straps	Ultimate Strength Capacity	Safety Factor[3]	Remarks
1. CB&I Analysis	7.58 Hz .132 sec. period	0.40g	407.3	26,150	62,500[1]	2.39	
2. Reanalysis Using Rigid Base Model	4.77 Hz .210 sec. period	0.48g	488.8	28,450	62,500	2.20	
3. Reanalysis Using Soil Spring Model	0.83 Hz	0.37g	481.4[2]	28,050	62,500	2.23	

(1) Based on Specified Minimum Yield = 50,000 psi

+ 10% Above Yield before significant distortion of the tie down straps, which, it is assumed, would result in rupture of the cylinder to base weld = 5,000 psi

+ 15% Mean of Actual Yield to Specified Minimum = 7,500 psi

Total 62,000 psi

(2) This moment includes higher modes and is within 1.5 percent of Case 2 values.

(3) Safety factor to failure does not consider material parameters, non-linear structural behavior, foundation conditions, or as built condition of tank; hence safety factors given must be considered as approximate values.

REFERENCES

1. Design Calculations, 1710 (300 MB) Propane Tank and Foundation, San Lake City Office, CBI Contract 72-4145, dated 7/17/72 for Petrolane, Inc., San Pedro, California 20 pages.

2. Safety Report on Liquified Propane Storage with Low Temperature Pipeline of Petrclane, Inc., California Public Utilities Commission, Utilities Division, San Francisco, California, (DRAFT) July 1977.

3. Converse, Davis, and Associates, "Soil and Earthquake Engineering Investigation, Proposed Distribution Facility - Gaffey Street Site, Los Angeles, California," for Petrolane, Inc., May 1972.

4. Swanson Analysis Systems, "Computer Algorithm ANSYS - Engineering Analysis System," Elizabeth, Pennsylvania, March 1975.

APPENDIX III-3

DESIGN EVALUATION OF TANKS

Allowable Behavior Criteria

In the evaluation of the storage tanks to withstand wind and earthquake load, two levels of allowable stress behavior criteria were used.

The allowable tensile stress criteria used in the evaluation of UBC and the 100-year wind loads are those given in Supplement No. 3 to API 620, Recommended Rules for Design and Construction of Large Welded, Low-Pressure Storage Tanks, 1975; namely, the normal allowable of $0.3f_u$, as shown in Table 3.05 of API 620, is increased by a factor of 1.33 to $0.4f_u$, per Section 3.05.5, where f_u is defined as the specified minimum tensile strength (ultimate or breaking stress).

For tornado and Safe Shutdown Earthquake loads, the criteria used in the evaluation are those presented in Appendix F, Level D Service Limits, of the ASME Boiler and Pressure Vessel Code, Section III, for Nuclear Components. Appendix F, Level D Service Limits, as defined by the ASME Code, permit gross general deformations with some consequential loss of dimensional stability and damage requiring repair, which may require removal of the component from service. This value was selected as the upper bound stress limit where the leak tight integrity of the component can be reasonably assured. The typical maximum allowable stress used for SSE earthquake and tornado is $0.7f_u$. It should be noted that the $0.7f_u$ stress limit is approximately 2.3 times the normal allowable stress limit for API-620 components, and well beyond the yield point of the material, where significant plastic deformation is anticipated. The actual stress limits for each steel tank evaluated are shown in Table 3-2 for earthquake and Table 3-4 for wind.

Definition of Failure

Failure, as used in Chapter 3, means the significant and uncontrolled leakage of LEG from its primary insulated container. Such a failure does not necessarily result in the catastrophic release of the contained gas to the environment.

The factors of safety shown in Tables 3-2, 3-3, and 3-4 have been determined, according to usual design practice, as a function of the limit on allowable behavior criteria for the load cases considered. The determination of actual failure load is not normally performed as a function of engineering design and analysis, because the load at failure for any real complex structural system, such as a storage tank, cannot be defined with any degree of accuracy. Actual failure load is a function of:

(a) actual material properties, not specified minimums;

(b) actual loads and load paths;

(c) behavior of the structure in the non-linear range—to include non-linear material behavior, instability, large deformation, and changes in geometry; and

(d) "as built" as opposed to "as designed" strength, inertia, and stiffness properties of the structure and its supporting media.

These specific quantities are generally not known, and it would require a very substantial experimental and analytical program to define them for each tank.

In Chapter 3, a judgment is made as to when tank failure might be expected to occur based on the limiting behavior criteria and the nature of the load determination for the various load cases considered.

APPENDIX IV
CRACK-INDUCED FAILURE OF METAL LNG TANKS

INTRODUCTION

This appendix discusses the calculations on which the discussion in Chapter 4 is based.

The figures may be used to estimate some crack sizes that should be sufficient to induce extensive ruptures in spherical, equatorially-supported tanks (Figs. IV-1, IV-2) and in cylindrical storage tanks (Figs. IV-3, IV-4), both fully loaded, but not subjected to the additional design stresses associated with inertial, thermal, or slosh loading. In each abscissa, the crucial parameter K_c, a material property, appears. Unfortunately, the precise magnitude of K_c for both 5083 aluminum and 9% Ni-steel can only be estimated at present. However, plausible estimates can be made, and are used in the numerical examples shown below. The parameter σ_B, the membrane tensile stress at the tank bottom, also appears in the figures. This quantity, under the loading conditions specified, will vary from one design to another, but can be expected to be about 1/2 to 1/3 the design stress of the material. In any event, it can be estimated by

$$\sigma_B = \gamma R^2/t_B \text{ (spheres)}$$

and

$$\sigma_B = \gamma RH/t_B \text{ (cylinders)}$$

where γ is the LNG density, and t_B is the shell thickness at the bottom point B.

A discussion of the figures, together with a numerical example for each, follows. The derivation of numerical results is given in the final section.

SPHERICAL TANK - SUB-EQUATORIAL CIRCUMFERENTIAL CRACK

Probably the most crack damage that can be inflicted on the spherical tank supported equatorially is illustrated in Fig. IV-1. A sufficiently long-circumferential crack, just below the reinforced equatorial region, could conceivably unzip the entire bottom of the tank as it propagates around in both directions. The initial crack sizes needed for such propagation (whether or not total separation actually will occur is beyond calculation) can be estimated as shown by the following example for 5083 aluminum:

$$\left\{\begin{array}{ll} R & = 60' \\ t_B & = 1.60'' \\ t_A & = 1.45'' \\ \sigma_B & \approx 6000 \text{ psi} \end{array}\right.$$

$$K_c \approx 150 \text{ ksi* } \cdot\sqrt{\text{in}}$$

where t_A is the shell thickness at the start of the crack.

$$R/t_A \approx 500; \quad \left(\frac{t_A}{t_B}\right) \quad \frac{K_c}{\sigma_B\sqrt{R}} \approx .84$$

*kips per square inch (kip = 1000 pounds)

From Fig. IV-1, this gives $L/R \approx .14$, so that the crack length L needed to burst the tank is approximately 8-1/2 feet long.

SPHERICAL TANK - BOTTOM CRACK

Critical-sized bottom cracks can be expected to propagate at least to the equator. Using the numbers in the above example with Fig. IV-2 we have $R/t_B \approx 480$ and $K_c/\sigma_B \cdot R \approx .93$. This gives $L/R \approx .13$, $L \approx$ 7-3/4'.

CYLINDRICAL TANK - VERTICAL BOTTOM CRACK

Here a vertical crack of length given by the solid curves can be expected to propagate up to the final length shown by the point on a dotted curve on Fig. IV-3 at the same value of $K_c/\sigma_B\sqrt{H}$. (For simplicity, the tank wall thickness is assumed constant.) An example for 9% Ni-steel follows.

$$\left\{\begin{array}{lcl} H & = & 56' \\ R & = & 120' \\ t & = & .44'' \\ \sigma_B & \approx & 20{,}000 \text{ psi} \end{array}\right.$$
$$K_c \approx 285 \text{ ksi } \sqrt{in}$$

$$\frac{H^2}{Rt} \sim 710; \quad \frac{K}{\sigma_B\sqrt{H}} \approx .55$$

Hence L/N ≈ .08, critical crack length ≈ 4-1/2', and the crack should propagate almost to the top of the rank.

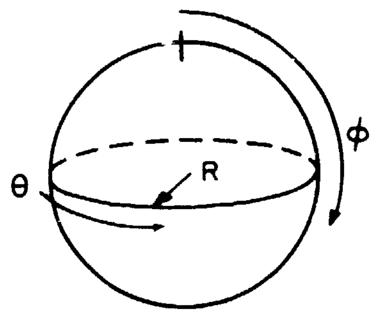
CYLINDRICAL TANK - MID-HEIGHT VERTICAL CRACK

In this case (Fig. IV-4), the crack of critical length will propagate to the bottom, and also reach to the upper limit given in Fig. IV-3. With the same data, L/H ≈ .14, or L ≈ 8' is needed.

The curves in the figures are based on simplified analyses involving several approximations. Also, there is considerable uncertainty about the value of K_c. For the reasons given in Chapter 4 we believe our calculations are conservative.

The estimates used for K_c are based on the extrapolation in Ref. 1 (pages 147 and 312) and on the burst test of Ref. 2. More large-scale testing (difficult and expensive) would be needed to refine these highly uncertain estimates.

DERIVATION OF FIGURES



In the lower hemisphere, the meridional stresses σ_ϕ and the circumferential stresses σ_θ are approximately (based on membrane theory, ignoring bending)

$$\sigma_\phi = \frac{\gamma R^2}{t}\left[\frac{1}{2} - \frac{1}{3}\cos\phi + \frac{1}{3(1-\cos\phi)}\right] \equiv \frac{\gamma R^2}{t} g_1(\phi)$$

$$\sigma_\theta = \frac{\gamma R^2}{t}\left[\frac{1}{2} - \frac{2}{3}\cos\phi - \frac{1}{3(1-\cos\phi)}\right] \equiv \frac{\gamma R^2}{t} g_2(\phi)$$

$$\left(\frac{\pi}{2} \leq \phi \leq \pi\right)$$

where t is the thickness.

The K for a meridional crack of length L is approximately

$$K = \sigma_\theta \sqrt{\frac{\pi L}{2}}\; f\left(\frac{L}{2\sqrt{Rt}}\right)$$

where f is the curvature correction function given on page 328 of Ref. 1. This equation ignores the influence of bending stresses on K. Then the equation on which Fig. IV-1 is based (assuming the crack is almost equatorial) is

$$\frac{t_A}{t_B}\;\frac{K}{\sigma_B\sqrt{R}} = \frac{5}{6}\sqrt{\frac{\pi L}{2R}}\; f\left(\frac{1}{2}\,\frac{L}{R}\sqrt{\frac{R}{t}}\right)$$

where $g_1(\frac{\pi}{2}) = \frac{5}{6}$ has been used.

For Fig.IV-2 we use (assuming constant thickness)

$$\frac{K}{\sigma_B\sqrt{R}} = g_2(\phi_A)\sqrt{\frac{\pi L}{2R}}\; f\left(\frac{1}{2}\,\frac{L}{R}\sqrt{\frac{R}{t_A}}\right)$$

The curvature correction used to prepare Figs. IV-3 and IV-4 was $h\left(\frac{L}{2\sqrt{Rt}}\right)$ shown on page 321 of Ref. 3, and the circumferential stress is just $\frac{\gamma x R}{t}$ where x is the distance down to the appropriate crack tip.

Hence, Fig. IV-3 is based on

$$\frac{K}{\bar{\sigma}_B\sqrt{H}} = \left(1 - \frac{L}{H}\right)\sqrt{\frac{\pi L}{2H}} \quad h\left(\frac{\pi L}{2H}\frac{H}{\sqrt{Rt}}\right)$$

and Fig. IV-4 was based on

$$\frac{K}{\sigma_B\sqrt{H}} = \frac{1}{2}\sqrt{\frac{\pi L}{2H}} \quad h\left(\frac{L}{2H}\frac{H}{\sqrt{Rt}}\right)$$

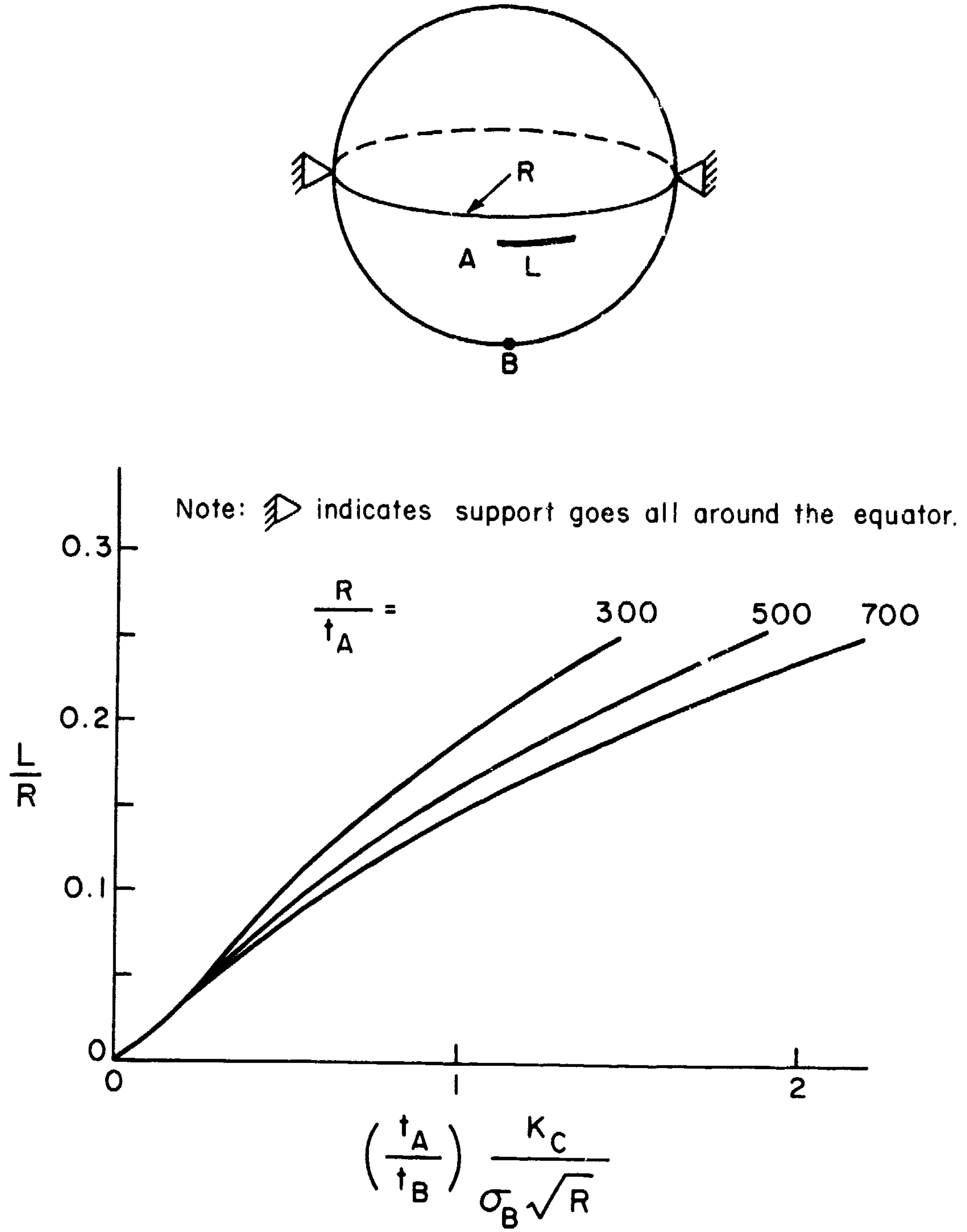


FIG. IV-1 CRITICAL LENGTH OF SUB-EQUATORIAL CIRCUMFERENTIAL CRACK.

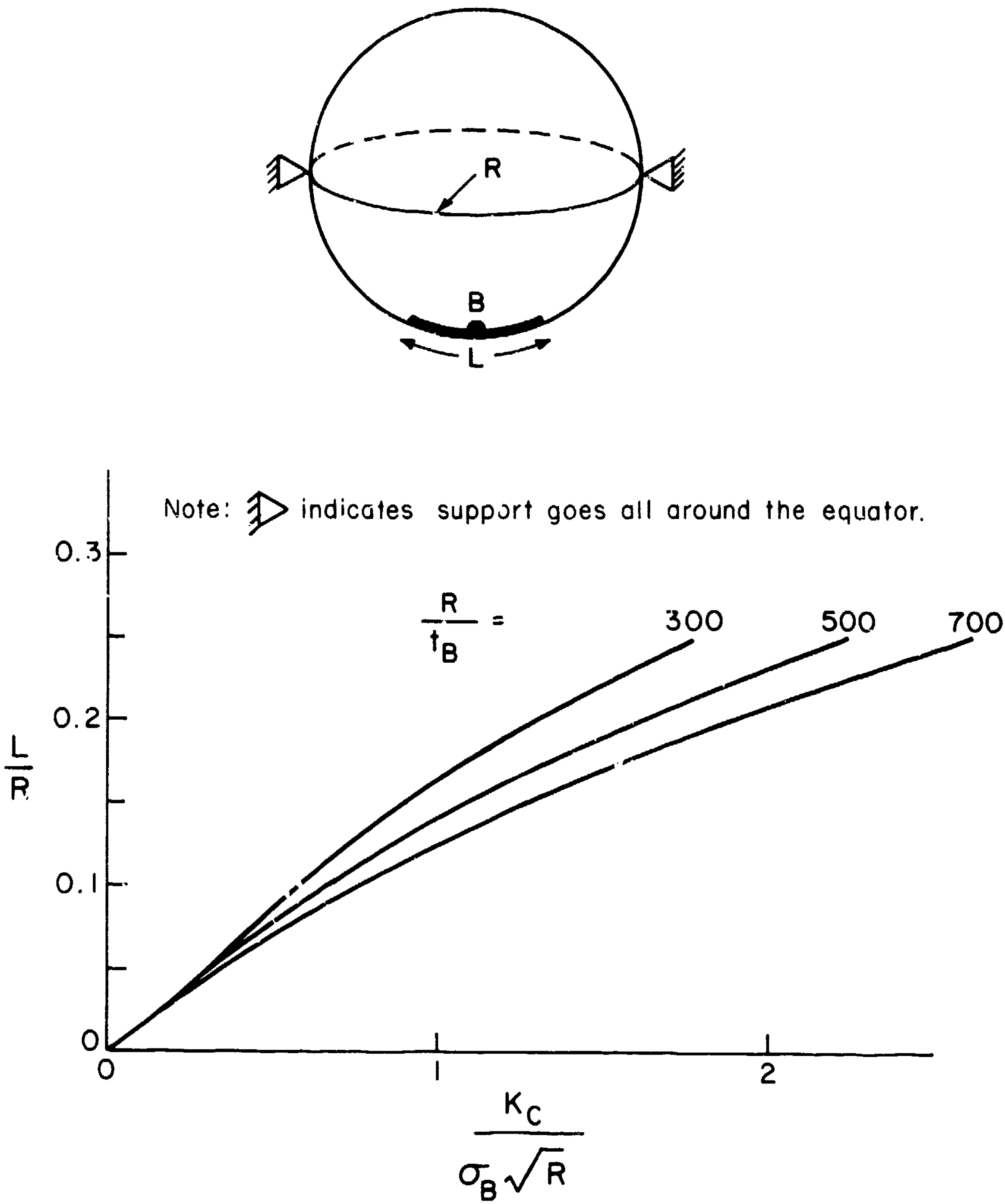


FIG. IV-2 CRITICAL LENGTH OF MERIDIANAL BOTTOM CRACK.

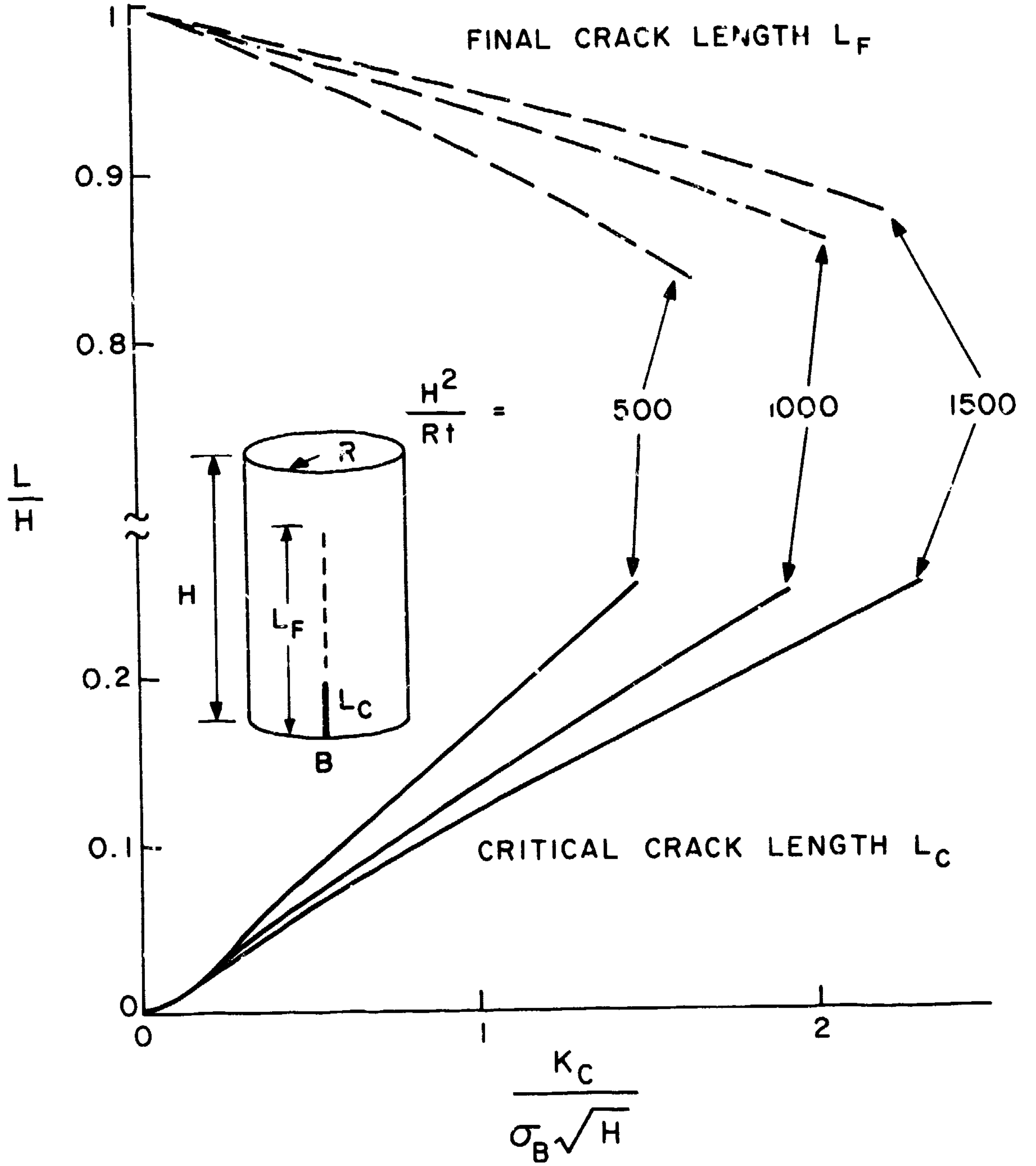


FIG. IV-3 CRITICAL AND FINAL LENGTHS OF VERTICAL BOTTOM CRACKS.

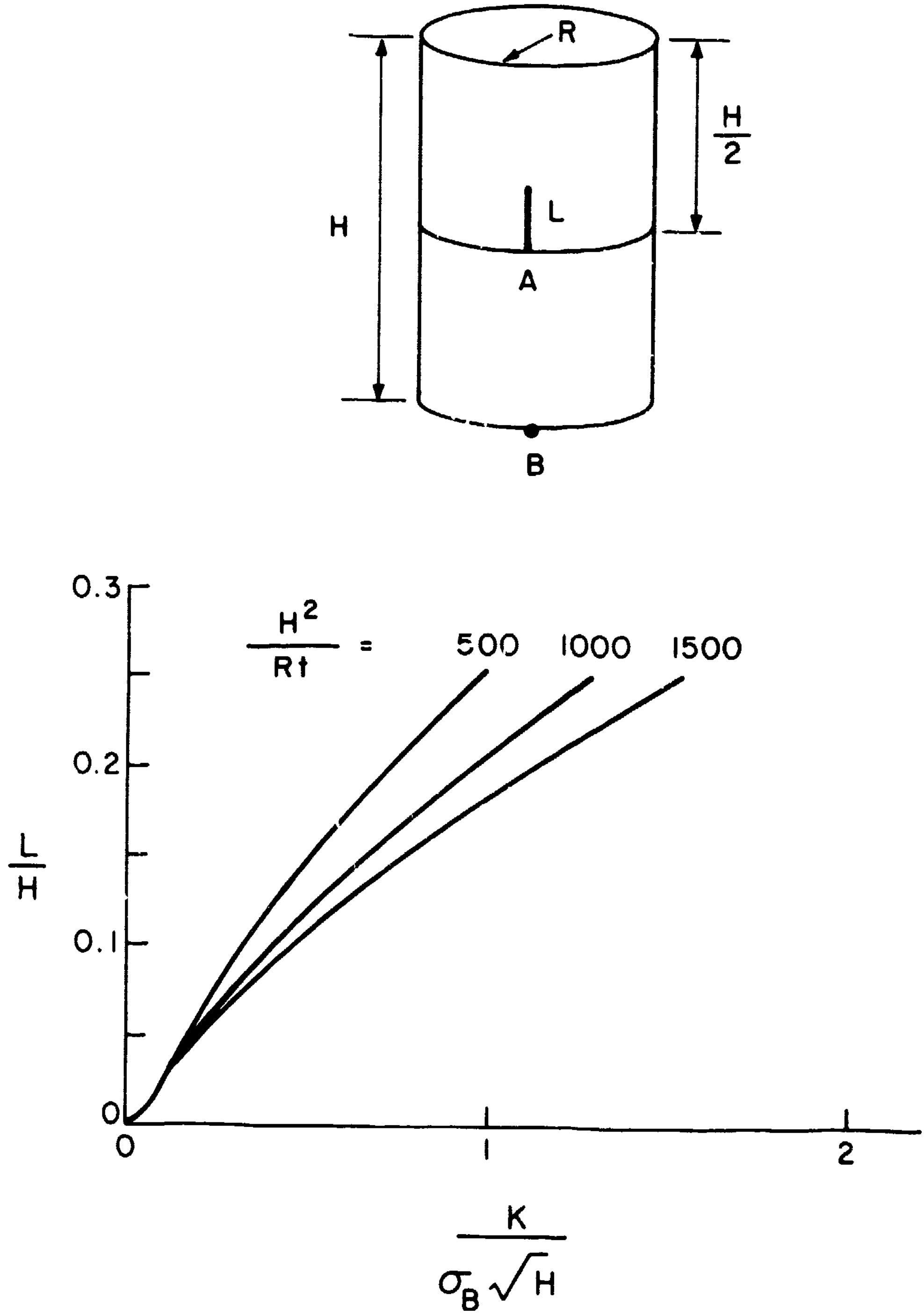


FIG. IV-4 CRITICAL LENGTH OF MID–HEIGHT VERTICAL CRACK.

REFERENCES

1. "Properties of Materials for Liquified Natural Gas Tankage", ASTM STP 579, 1975.

2. Lake, Eiber, & DeMoney, Advances in Cryogenic Engineering, Vol. 13, 1968, pp. 278-293.

3. Rooke & Cartwright, "Stress Intensity Factors", Her Majesty's Stationery Office, London, 1976.

APPENDIX V

CONTENTS

APPENDIX V-1
OVERFLOW

VERTICAL DIKES

This section gives a one-dimensional treatment of overflow. For this reason the tank width is $-R \leq x \leq 0$, rather than $-2R \leq x \leq 0$. One effect left out is the lateral spreading of the wave as it heads for the dike. The importance of this effect depends on the relative distance to the dike.

The non-linear shallow water equations are in essence depth-averaged versions of the conservation laws of mass and momentum in which the dependent variables are free surface height h(x,t), and mean horizontal velocity u(x,t):

$$((h-h_G)u)_x = -h_t, \tag{V.1}$$

$$u_t + uu_x = -g\,h_x. \tag{V.2}$$

The quantity

$$c = \sqrt{g(h-h_G)}\ , \tag{V.3}$$

which is the wave speed of disturbances in the flow, plays a fundamental role in the theory. Here g is the acceleration of gravity and $h_G(x)$ is the elevation of the dry ground above some reference level; $h-h_G$ then measures the depth of the fluid. The subscripts x and t refer to partial derivatives. It is assumed that the terrain between tank and vertical dike is level so that $h_G=0$ (but in more complicated geometries including inclined dike problems, topographic variations are important and must be included).

The maximum fluid height in the tank H and time $\sqrt{H/g}$ are characteristic scales which are used to make the problem dimensionless by the following transformations:

$$x \to Hx; \quad t \to \sqrt{H/g}\ t; \quad h \to Hh; \quad u \to u\sqrt{gH}; \quad c \to c\sqrt{gH}.$$

Equations (V.1) and (V.2) can then be written as

$$2(c_t+uc_x) + cu_x = 0, \qquad (V.4)$$

$$u_t + uu_x + 2cc_x = 0. \qquad (V.5)\ .$$

For $t<0$ the quiescent fluid fills the tank, that is $u=0$, $c=1$, in $-R/H \leq x \leq 0$. At $t=0$, the wall of the tank at $x=0$ is suddenly removed and the water rushes towards the vertical dike at $x=x_W=L/H$. During this phase, the solution of equations (V.4) and (V.5) is

$$\left.\begin{aligned} u &= \frac{2}{3}\ (1 + \frac{x}{t}), \\ c &= \frac{1}{3}\ (2 - \frac{x}{t}). \end{aligned}\right\} \qquad (V.6)$$

when

$$-\frac{R}{H} \leq -t \leq x \leq 2t \leq x_W.$$

The free surface is as shown in Fig. V-1. (The water is still at rest in the region $-R/H<x<-t$.) The leading edge of the fluid, which corresponds to $c=0$, moves with the constant dimensionless speed 2 (i.e., twice the

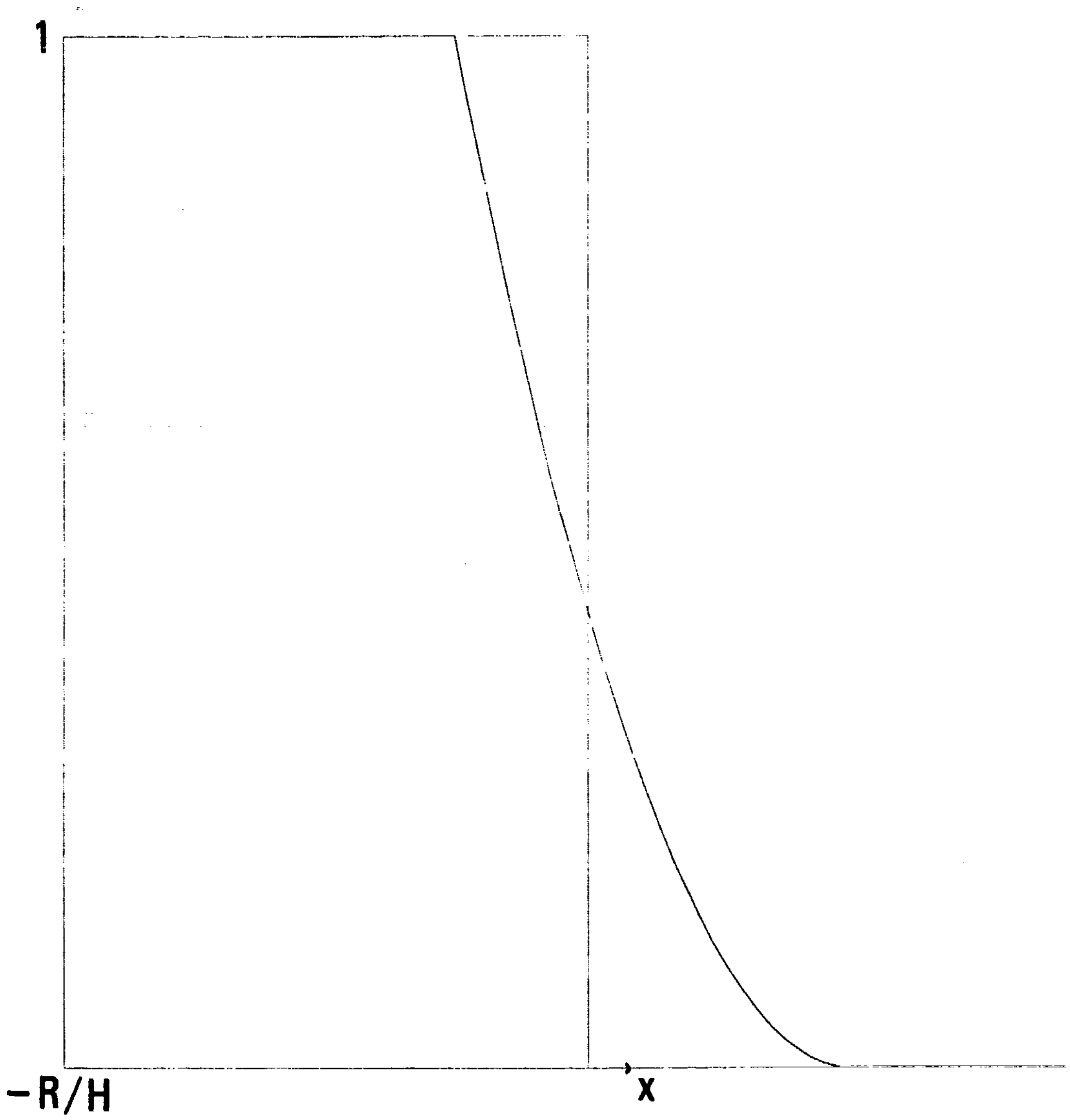


FIG. V-1

THEORETICAL PROFILE OF FREE SURFACE HEIGHT FOLLOWING THE COLLAPSE OF THE TANK WALL. COMPARE WITH THE FIRST PHOTO INSET IN FIG. 5-3.

natural propagation speed $\sqrt{gH}$) and reaches the dike at the time $t_W=x_W/2$. Meanwhile, a rarefaction wave propagates through the tank and reflects off the wall $x=-R/H$ when $t=R/H$. Friction and ground resistance modify this result[3] so that the liquid actually hits the dike somewhat later than predicted. (Our experimental results on arrival time are consistent with the data of Dressler[2].) Upon collision with the vertical wall, water accumulates rapidly and to great height; a strong shock forms and propagates, slowly at first, back towards the tank.

Since the edge of the fluid front has zero thickness in the inviscid theory, impact must be examined analytically, and with care, in order to provide the data to initialize a numerical program. To this end, the shock locus is described by $x_s(t)$ for $t \geq t_W$ with $x_s(t_W)=x_W$ and $x_s'(t) < 0$. For some time after impact the flow between the shock and the wall of the tank is given by equation (V.6). A solution of the basic equations is then sought in the domain between the shock and the dike $x_s \leq x \leq x_W$ which satisfies the shock conditions

$$u_+ = u_- - \frac{c_-}{\sqrt{2}} (M^2-1)(1 + \frac{1}{M^2})^{1/2}, \qquad (V.7)$$

$$U = x_s'(t) = u_- - \frac{c_-}{\sqrt{2}} M^2 (1 + \frac{1}{M^2})^{1/2}. \qquad (V.8)$$

Here subscripts -(+) **refer to the region into (from) which** the shock moves in the next instant of time; U is the shock velocity and

$$M = \frac{c_+}{c_-} \tag{V.9}$$

is a measure of shock strength. The fluid velocity at the barrier is zero until the water level exceeds the height of the dike, i.e., $u(x_W, t) = 0$ for $h \le a$.

It is convenient to define space and time variables centered at the impact position $x_W = 2t_W$, given by

$$\eta = \frac{x_W - x}{t_W}, \quad \tau = \frac{t - t_W}{t_W}, \quad \zeta = \eta/\tau^2, \tag{V.10}$$

for then the flow variables in the region between shock and the barrier,

$$0 \le \zeta \le \zeta_s = \eta_s/\tau^2 \tag{V.11}$$

can be represented as the power series

$$\left.\begin{aligned} u &= \tau\zeta + \tau^2 f_1(\zeta) + \cdots \quad, \\ c &= \tau^{1/2}(k + \tau g_1(\zeta) + \cdots). \end{aligned}\right\} \tag{V.12}$$

The shock locus is written as

$$\zeta_s = z(\tau) = z_0 + z_1\tau + \cdots \tag{V.13}$$

and the shock velocity becomes

$$U = -\frac{d}{d\tau}\eta_s = -\frac{d}{d\tau}(\tau^2 z(\tau)) = -(2z_0\tau + 3z_1\tau^2 + \cdots). \tag{V.14}$$

The substitution of these series into the equations of motion and boundary condition yields

$$k = 2^{5/4}\, 3^{-1/2}; \qquad k_1 = -\frac{5}{9}\frac{3^{1/2}}{2^{1/4}}\left(2^{1/2} - \frac{1}{9}\right);$$

$$g_1 = -\frac{\zeta^2}{2k} + k_1; \qquad f_1 = \frac{5}{3}\frac{\zeta^2}{k^2} + \frac{2k_1\zeta}{k}; \qquad \text{(V.15)}$$

$$z_0 = \frac{8}{27k^2}; \qquad z_1 = -\frac{1}{4}\left[f_1(z_0) + \frac{6z_0}{k}g_1(z_0) + 8z_0 - 6z_0^2\right];$$

or simply

$$\begin{aligned} k &= 1.373178, \\ k_1 &= -1.054409, \\ z_0 &= 0.157135, \\ z_1 &= -0.035232, \\ g_1(z_0) &= -1.063400, \\ f_1(z_0) &= -0.237886. \end{aligned} \qquad \text{(V.16)}$$

Examination of these formulas for $x_s(t)$ and c^2 shows that water accumulates rapidly at the dike because the shock is very slow in starting. Moreover, the free surface height behind the bore is nearly uniform at any instant of time. This is the basis of an analytical approximation which enables the motion to be determined when the wall of the dike is too high to allow any overflow. But discussion of this aspect of theory is omitted here because the results merely confirm the numerical calculations.

Equations (V.6), (V.12), and (V.14) give the entire solution through impact and a short period there-after. At this time, water is rapidly piling up at the dike behind the shock that moves towards the tank. Soon fluid will begin to flow over the barrier and the reflected waves and propagating shock will interact as they reverberate between boundaries. In these later stages, the equations are solved numerically using as initial data the known values of all variables at time $t_W+\Delta t$ following impact. Only the proper boundary condition to describe overflow must still be formulated.

If the dimensional height of the fluid at the barrier wall is h_w, then the water level atop the dike at $x=x_W$ is h_W-a, and the local wave speed there is

$$\tilde{c} = \sqrt{g(h_w-a)}. \qquad (V.17)$$

We assume that fluid which passes over the impounding wall ceases to influence the main body of water still within the containment area. This is assured by setting

$$\tilde{u} = \tilde{c}$$

where $\tilde{u}$ is the velocity atop the dike. (The convected propagation velocities are then positive and no "signal" can travel backwards.) However, the conservation of mass requires

$$u_w h_w = \tilde{u}(h_w-a). \qquad (V.18)$$

With $c_0^2=ga$, the last relationship can be expressed as

$$u = \frac{(c^2-c_0^2)^{3/2}}{c^2} H(c-c_0) \quad \text{at } x = x_W, \qquad (V.19)$$

which is also the proper dimensionless form. The Heaviside function

$$H(x) = 1, \quad x > 0$$
$$= 0, \quad x < 0$$

is used to incorporate all the conditions at this boundary into one succinct formula. Therefore, for $c_w < c_0$, (no overflow) the velocity is zero, $u_w = 0$; spillage occurs after the water level exceeds the height of the barrier.

Numerical computation makes use of the characteristic forms of the basic equations

$$\left.\begin{aligned} u + 2c &= \text{constant along the ray, } \frac{dx}{dt} = u+c \\ u - 2c &= \text{constant along the ray, } \frac{dx}{dt} = u-c \end{aligned}\right\}. \qquad (V.20)$$

The numerical program based in part on this mode of description is presented in the following section.

Although there is no explicit vertical velocity in the shallow water theory the law of conservation of mass enables the theory to account for the actual rise of fluid after it hits the wall. The height attained by the main body of fluid indicated by arrows in Fig. V-2 exceeds theoretical prediction by about 15%. The model cannot describe the flight of particles from the leading edge of the surge. Droplets reach a height three times that of the tank but the amount of fluid involved is small.

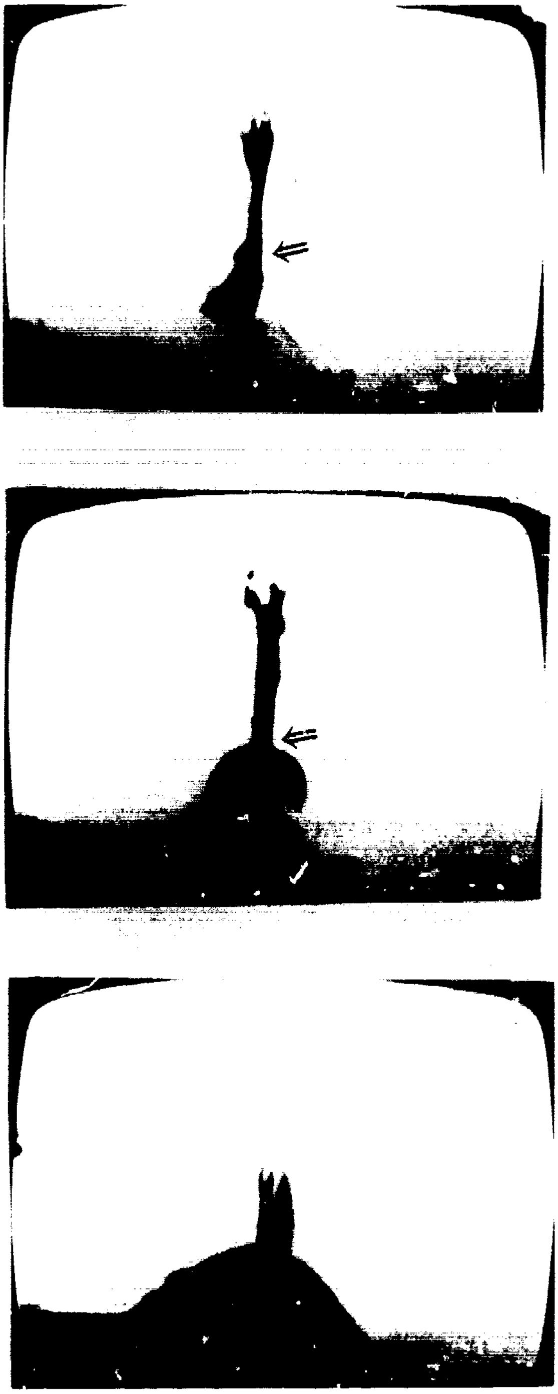


FIG. V-2

IMPACT SEQUENCE SHOWING THE OVERFLOW AND FORMATION OF A SHOCK. THEORY ACCOUNTS WELL FOR FLUID MOTION BELOW THE HEIGHT INDICATED BY THE ARROWS. PARTICLES IN THE LIQUID JET ABOVE THIS ARE ESSENTIALLY IN FREE FLIGHT AND REACH A HEIGHT ABOUT THREE TIMES THAT OF THE TANK.

Shallow water theory, despite obvious limitations, does remarkably well in predicting the main features of motion and spillage. Presumably the results could be improved by including ground friction and turbulence in the model or by modifying the overflow condition.

INCLINED DIKES

A very simple model for the flow over an inclined dike leads to surprisingly accurate predictions of the spillage fraction shown in Figs. 5-10, 5-11, and 5-12.

The run-up of the liquid on the incline is a very complicated process marked by strong vertical acceleration and overturning, but the motion can be described in an approximate manner by applying the conservation laws in the large (much like the treatment of shocks). A theoretical estimation of the progress of the surge on the slope until spill-over, provides the initial data for subsequent numerical calculation.

The ground elevation with a sloping dike of inclination angle θ is given by

$$h_G(x) = (x-x_W)H(x-x_W)\tan\theta \quad \text{for } x \le x_T \qquad (V.21)$$

where

$$a = (x_T-x_W)\tan\theta$$

is the height of the barrier (at $x=x_T$). For $x<x_W$, $h_G=0$, indicating level ground.

At time $t=t_w=\frac{x_w}{2}$, the liquid reaches the dike and begins to move up the slope; a shock develops at the discontinuity in ground slope. At time t=T, the fluid overflows the barrier; during the interim, the leading edge of the rushing liquid is at $x_F(t)$. For a strong surge, the shock is swept back along with the flow and in this case, the velocity and free surface height at the break in elevation are assumed to be nearly the same as for the incoming flow described by equation (V.6):

$$u_w = \frac{2}{3}\left(1 + \frac{x_w}{t}\right),$$
$$c_w = \frac{1}{3}\left(2 - \frac{x_w}{t}\right). \tag{V.22}$$

The (dimensionless) conservation laws of mass and momentum applied to the region on the slope $x_w \leq x \leq x_F(t)$ for $t \leq T$ imply that

$$\int_{x_w}^{x_F} c^2 dx = \int_{x_w}^{2t} c_w^2 dx \tag{V.23}$$

and

$$\frac{d}{dt} \int_{x_w}^{x_F(t)} uc^2 dx = u_w^2 c_w^2 + \frac{1}{2} c_w^4 - \int_{x_w}^{x_F} c^2 \sin\theta dx. \tag{V.24}$$

On the dike, the variables c^2, u are approximated as linear functions of distance for $t \leq T$:

$$c^2 \approx c_w^2 \frac{x_F(t) - x}{x_F(t) - x_w}$$
$$u \approx u_w + \frac{u_F(t) - u_w}{x_F(t) - x_w}(x - x_F(t)) \tag{V.25}$$

where $u_F = x_F'(t)$. The substitution of these expressions in equation (V.23) or (V.26) leads to an equation for $x_F(t)$. (Since we have eliminated the shock and shock locus from consideration in this simple treatment based on linear profiles, only one of the conservation equations is required to determine the position of the edge and the approximate formulas in equation (V.25).)

Use of equation (V.23) (conservation of mass) implies that

$$x_F(t) = \frac{1}{3}x_w + \frac{4}{3}t \qquad (V.26)$$

which indicates that the dimensionless velocity of the advancing edge on the dike is $u_F = \frac{4}{3}$ as compared with the value 2 on the level plane. We anticipate that equation (V.26) is a reasonably accurate approximation for a strong surge when the barrier is easily surmounted. In other cases, when there is substantial conversion of kinetic energy to potential energy, use of the momentum law might be preferable and the substitution of equation (V.25) in equation (V.24) yields

$$\frac{d}{d\tau}\left[c_w^2\xi\left(\frac{d\xi}{d\tau} + 2u_w\right)\right] = 6c_w^2\left(u_w^2 + \frac{1}{2}c_w^2 - \beta\xi\right) \qquad (V.27)$$

where

$$\xi = \frac{x_F - x_w}{t_w}, \quad \tau = \frac{t - t_w}{t_w}, \quad \beta = \frac{t_w}{2}\sin\theta. \qquad (V.28)$$

For small τ, we find that

$$\xi = \alpha_1\tau + \alpha_2\tau^2 + \cdots$$

with $\alpha_1 = 2(\sqrt{3}-1)$, $\alpha_2 = \dfrac{-4 + \alpha_1(\frac{2}{3} - \frac{3}{2}\beta)}{3\alpha_1 + 4}$

and this expression at τ=.01 is used to integrate the differential equation forward in time. Here the velocity of the front for small τ is $u_F \approx 1.464$ which is very similar to the value obtained from mass conservation. As long as the surge is strong enough to surmount the barrier and the time $T-t_w$ is short, both approximations provide similar starting conditions at t=T when $x_F=x_T$ to initiate the numerical integration of the full equations. In the former case by mass conservation, $T=t_w+\frac{3}{4}a \cot \theta$; in the latter, T must be determined by integrating equation (V.27). It turns out that since there is only a small amount of water on the slope to start, the spillage factors calculated by either of these approaches agree in all cases to three decimal places. Spillage is rather insensitive to the particular initial conditions on the dike. Accordingly the more elaborate approximation theory in which both conservation equations are employed to determine frontal position and locus and strength of a shock will not be presented here.

At time T, approximations of the flow variables c^2, u are given by equation (V.6) for $x \leq x_w$ and equation (V.25) for $x_w \leq x \leq x_T$. These expressions constitute the initial data for a numerical solution of the nonlinear shallow water equations (V.1), (V.2) which in characteristic form appropriate both to the inclined dike and the level plane are

$$u + 2c + tH(x-x_w)\tan\theta = \text{constant on } \frac{dx}{dt} = u + c$$

(V.27)

$$u - 2c + tH(x-x_w)\tan\theta = \text{constant on } \frac{dx}{dt} = u - c$$

where $0 \leq x \leq x_T$ and $H(x)$ is the Heaviside function. Continuity of both u and c at x_w is required in the absence of a shock at that exact location. For $u>c$ at $x=x_T$, no overflow condition is required since both characteristics at that position pass out of the region of physical interest. Otherwise, we require $u=c$ as the proper boundary condition to describe spill over the edge. The computation described in Section 2 proceeds forward in time. Shock development is properly accounted for and the spillage fraction, Q, calculated by

$$Q = \frac{1}{R} \int_T^t u_T c_T^2 dt. \qquad \text{(V.28)}$$

The experimental results are given in Figs. 5-10, 5-11, and 5-12. Spillage factors calculated from the starting conditions obtained from either conservation of mass or momentum agree to three decimal places in all cases.

APPENDIX V-2

COMPUTATIONAL METHOD

VERTICAL DIKES

The hyperbolic nature of the mathematical model allows distinct computational regions to be defined. Fig. V-3 depicts the regions of interest in solving the initial value problem between $x=-R/H$ (rear wall of tank) and $x=L/H$ (dike position). The face of the tank at $x=0$ is assumed to vanish instantaneously at $t=0$.

The fluid is undisturbed in Region I, i.e., $c=1$, $u=0$; Region II does not yet have fluid, i.e., $c=0$. In Region III the motion is described by the exact solution $c=(2-x/t)/3$, $u=2(1+x/t)/3$. On the line $x=-R/H$, $u=0$.

Regions III and IV are bounded by the line $x=2t-3(R/H)^{2/3}t^{1/3}$ on which $c=(R/Ht)^{2/3}$, $u=2(1-(R/Ht)^{2/3})$.

Region IV in front of the shock shows the effect of the finiteness of the tank. Here the equations, in characteristic form, are solved numerically by integrating forward in time from the boundary conditions at $x=-R/H$ and $x=2t-3(\frac{R}{H})^{2/3}t^{1/3}$. The method of characteristics is also used in Region V which lies behind the shock. However, the boundary conditions differ from those used in Region IV.

The shock locus forms the boundary between III and V and between IV and V; the condition on u across this discontinuity is given in equation (V.7)

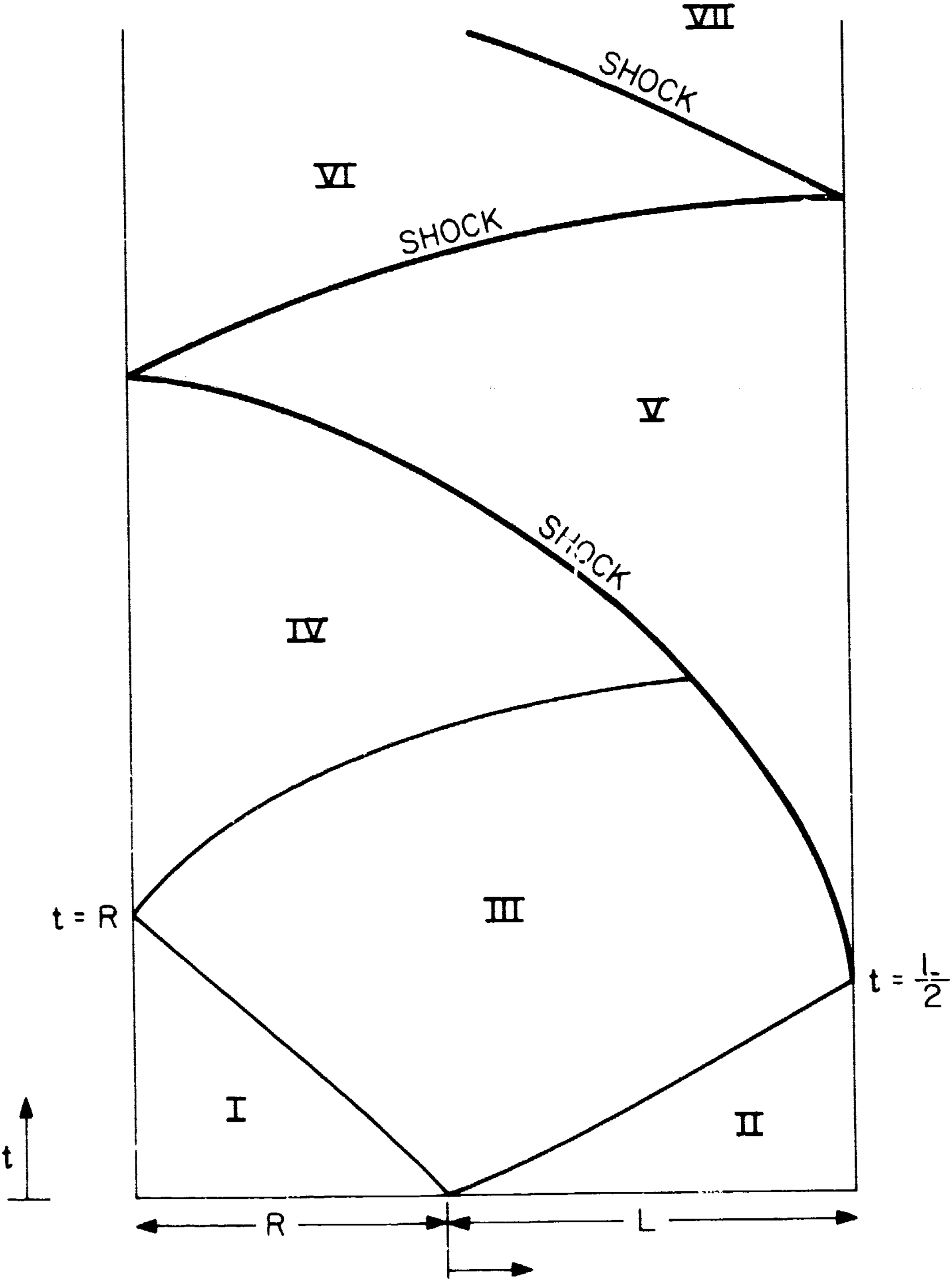


FIG. V-3

REGIONS OF X,T SPACE AS DELINEATED BY THE LOCI OF THE SHOCK AND THE PRINCIPAL RAYS.

$$u_+ = u_- - \frac{c_-}{\sqrt{2}} (M^2-1)(1 + \frac{1}{M^2})^{1/2}; \quad M = \frac{c_+}{c_-}; \qquad \text{(VII.29)}$$

and the values of u and c ahead of the shock (u_-,c_-) are determined from information interior to region III or IV. The above equation for u_+ as a function of c_- is solved simultaneously with the constraint from the minus characteristic ($u-2c$=constant along $u-c=\frac{dx}{dt}$) which passes through the shock boundary point of interest back into the previously solved portion of Region V.

The shock position is updated each time-step using the shock velocity formula

$$U = u_- - \frac{c_+^2}{\sqrt{2}c_-} \sqrt{1 + \left(\frac{c_-}{c_+}\right)^2} \qquad \text{(V.30)}$$

The initial shock position and conditions behind the shock are taken from the theoretical development discussed earlier, equations (V.12) - (V.15).

The boundary condition on the line x=L/H (the dike) which describes flow over the dike is from equation (V.19)

$$u = \frac{(c^2-c_0^2)^{3/2}}{c^2} H(c-c_0) \quad \text{at } x = x_w.$$

The shock (i.e., the boundary between regions IV and V) eventually reaches the back of the tank at x=-R/H. At this point the bore reflects off the rear wall and proceeds in the positive x direction until it reflects off the dike. These reverberations continue until fully dissipated, or as long as one cares to continue the computation.

The reflection of the shock from the rear wall of the tank is determined from the shock conditions using the known values of c_- and u_- in Region V and $u_+=0$. The velocity U and c_+ are then given by

$$\left.\begin{aligned} c_+^2 &= z\,c_-^2 \\ U &= -\frac{u_-}{z-1} \end{aligned}\right\} \qquad (V.31)$$

and

where $z=M^2$ is the solution of

$$(z^2-1)(z-1) = 2\frac{u_-^2}{c_-^2}z, \qquad z \geq 1. \qquad (V.32)$$

Similarly in the shock reflection off the dike, c_- and u_- in Region VI are known, and we must determine U, the shock velocity, and c_+ and u_+ in Region VII. With z obtained from

$$\frac{u_-}{c_-} - \frac{1}{\sqrt{2}}(z-1)(1+\frac{1}{z})^{1/2} = \frac{1}{z}(z-\frac{c_0^2}{c_-^2})^{3/2}H(c-c_0) \qquad (V.33)$$

it follows that

$$U = u_- - \frac{c_-}{\sqrt{2}}z(1+\frac{1}{z})^{1/2}, \qquad (V.34)$$

$$u_+ = u_- - \frac{c_-}{\sqrt{2}}(z-1)(1+\frac{1}{z})^{1/2}. \qquad (V.35)$$

Note that Regions VI, VIII, X, XII, etc., are similar to Region IV; Regions VII, IX, XI, XIII, etc., are similar to Region V.

We now discuss details of the computation based on the method of characteristics, and the technique for advancing the shock position.

The calculations at time t proceed from the known values of u and c at an earlier time and at the physical boundaries x=-R/H and x=L/H. The boundary value problem which consists of these initial and boundary conditions, and the non-linear system of hyperbolic partial differential equations:

$$\left.\begin{aligned} u_t + uu_x + 2cc_x &= 0, \\ 2(c_t + uc_x) + cu_x &= 0, \end{aligned}\right\} \qquad (V.36)$$

is then well-posed. The dependent variables are represented by values at a grid along the x-axis, using linear interpolation to define points between nodes. The physical positions of these node points differ at successive times in order that the shock position is always between two nodes, at which the values of the dependent variables satisfy the shock conditions. The nodes within each region are uniformly spaced; their number depends on the relative lengths of the regions separated by the shock, and on the total number of nodes allocated. Calculations are advanced in time using the method of characteristics and in this format the basic equations are

$$u + 2c = \text{constant on } \frac{dx}{dt} = u + c \quad \text{(a plus-characteristic)}$$

$$u - 2c = \text{constant on } \frac{dx}{dt} = u - c \quad \text{(a minus-characteristic).}$$

(V.37)

Thus, to determine u_{in} and c_{in} at the position x_{in} and at the new time t_n using forward differences (Fig. V-4a) the following algorithm is applied:

(1) Calculate u_i and c_i at the same x position, x_i, but at the old time t.

(2) Determine x_p, the x position at the old time whose plus-characteristic passes through x_{in}:

$$\frac{x_{in}-x_p}{t_n-t} = u_i + c_i. \tag{V.38}$$

(3) Obtain u_p and c_p at x_p.

(4) Similarly, evaluate x_m using the minus-characteristic, u_i and c_i and interpolate to find u_m and c_m.

(5) Calculate u_{in} and c_{in} from the simultaneous equations:

$$u_p + 2c_p = u_{in} + 2c_{in} \tag{V.39}$$

and

$$u_m - 2c_m = u_{in} - 2c_{in}. \tag{V.40}$$

These results are used as starting conditions for determining u_{in} and c_{in} from central difference formulas. We then recalculate x_p and x_m using the average of u and c at the old and new time endpoints of the characteristics obtained in the previous iteration. We can then redetermine u_p, c_p, u_m, c_m, u_{in}, and c_{in}. The process continues until the successive x_p's and x_m's differ insignificantly from previous values.

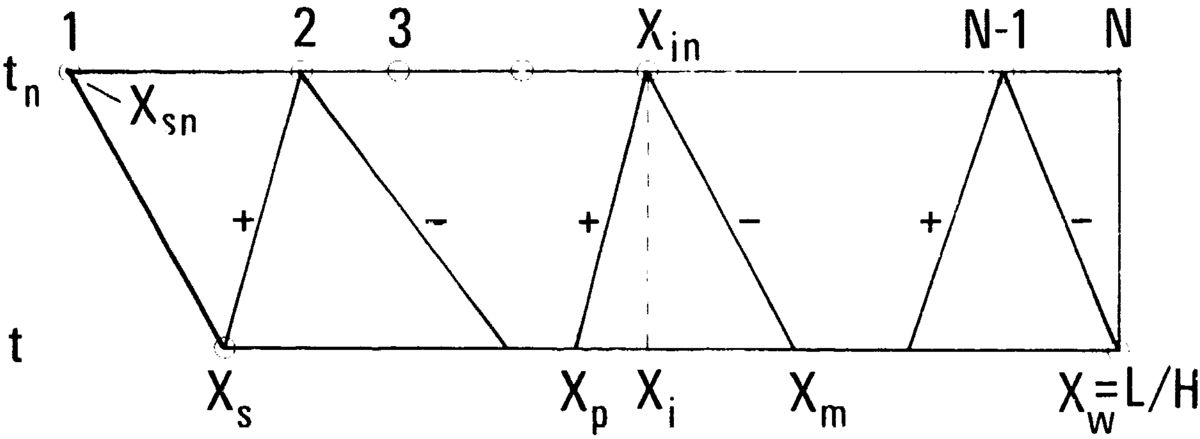


FIG. V-4a

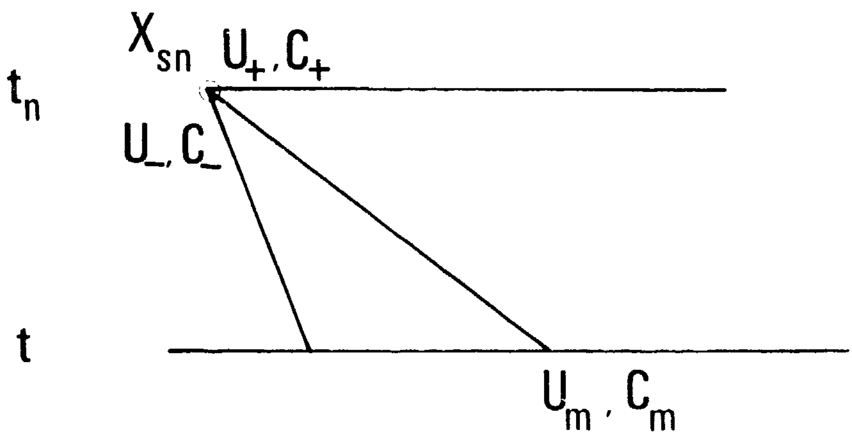


FIG. V-4b

DEFINING DIAGRAMS FOR NUMERICAL GRIDS.

At the dike $x=x_w$, we require that t_n-t be sufficiently small that all interior nodes at t_n lie between the plus-characteristic through the shock position at t and the minus-characteristic through x_w. In this way, problems of interpolating along the wall or the shock are avoided. Linear interpolations are employed using data defined at node points along the segment between x_s and x_w to determine u and c at points not coinciding with nodal values from the two adjacent nodes (Fig. V-4b)

At the shock, the shock condition, equation (V.29), is invoked along with the minus-characteristic equation

$$u_m - 2c_m = u_+ - 2c_+, \tag{V.41}$$

to solve for u_+ and c_+, using a Newton-Raphson iteration with c_+ at the previous time as a starting condition. The values of u_- and c_- in the undisturbed side of the shock are given by

$$\left.\begin{aligned} u_- &= \frac{2}{3}\left(1 + \frac{x_{sn}}{t_n}\right) \\ \text{and} \qquad c_- &= \frac{1}{3}\left(2 - \frac{x_{sn}}{t_n}\right). \end{aligned}\right\} \tag{V.42}$$

The shock velocity is then obtained using equation (V.30). Initially, we locate the shock at time t_n, using forward differences

$$x_{sn} = x_s + U(t_n-t),$$

where the shock velocity at time t is used. The new shock location is recomputed using central differences and the average of the shock velocities; the shock conditions are recomputed as well. This process is repeated until the change in shock position is insignificantly small.

It should be noted that using forward differences sometimes introduces numerical instabilities; we adopted central differences for our computations. Few individual computations required more than three or four iterations to converge to the central difference.

Results were relatively insensitive to the number of x-position nodes employed; we generally used 50 or 100. Time steps were interpolated as necessary to insure that the plus- and minus-characteristics to interior nodes of the new time depend only on information at the previous time.

For various values of L/H and R/H, computations were made to determine the percentage of original tank fluid spilled over the dike. This is

$$Q = \frac{H}{R} \int_0^T u_d(t)\, c_d^2(t)\, dt \qquad (V.43)$$

where u_d and c_d are values at the dike. The numerical results were discussed earlier.

INCLINED DIKES

The numerical solution for the flow over an inclined dike was based on the method of characteristics and the equations of motion (V.27). The starting conditions at t=T are given by equation (V.6) for $x \le x_w$ and equations (V.25) and (V.26) for $x_w \le x \le x_w + a \cot\theta$. If the conservation of mass equations are used to determine the initial setting, then $T = t_w + \frac{3}{4} a \cot\theta$. Use of the conservation of momentum necessitates integration of equation (V.27) until $x_F(t) = x_T = x_w + a \cot\theta$. This was done by two different methods from the IBM Scientific Subroutine Package, a Runge Kutta Method (Subroutine RKGS) and a Hammings Modified Predictor Corrector Method (Subroutine HPCG). The results were in good agreement. We generally used Subroutine HPCG.

Over the flat bed, we have, as before,

$$u + 2c = \text{constant along the ray, } \frac{dx}{dt} = u + c$$

$$u - 2c = \text{constant along the ray. } \frac{dx}{dt} = u - c.$$

Over the inclined dike we have

$$u + 2c + t \tan\theta = \text{constant along the ray, } \frac{dx}{dt} = u + c$$

$$u - 2c + t \tan\theta = \text{constant along the ray, } \frac{dx}{dt} = u - c.$$

For a ray that crosses the line $x = x_w$ between the two regions, we take the intermediate step of solving for conditions at the intermediate time where the ray crosses the boundary so that the proper characteristic equations are used. We accumulate the spill as before

$$Q = \frac{H}{R} \int_{t_T}^{T} u_T(t)\, c_T^2(t)\, dt$$

using values at the top of the dike. The calculation continues normally as long as $u_T > c_T$. We then use the condition $u_T = c_T$ along with the condition along the ray $\frac{dx}{dt} = u+c$, disregarding the condition along the minus-characteristic.

Sometime after the $u_T = c_T$ condition is enforced, a shock forms and proceeds back towards the tank. The shock conditions given earlier are then enforced, and the shock velocity is used to update the shock position at the next time.

The calculation then proceeds until $u_T = c_T = 0$ at which time the total spill is known. The computed spillage is very insensitive to the initial setting at time T, and use of starting conditions based either on mass or momentum conservation yields values which agree to three decimal places.

APPENDIX V-3

SPIGOT FLOW

RESULTS

A cylindrical tank of radius R and maximum fluid height H on a circular pedestal of height P and radius R+K is surrounded by a circular dike of height $a(=a_p)$ at radius R+L, as shown in Fig. V-5. The volume contained by the dike is equal to the volume of the tank:

$$HR^2 = a(R + L)^2 - P(R + K)^2 \qquad (V.44)$$

Liquid is presumed to flow from a relatively small hole in the tank located at height z above the pedestal.

If

$$a + L \geq H + P \qquad (V.45)$$

or, if a satisfies equation (V.44) and

$$H \leq \frac{(R + L)^2}{(2R + L)} - \frac{P(2R + L + K)}{(2R + L)} \frac{(L - K)}{L}, \qquad (V.46)$$

then the dike is adequate to contain all spigot flows. Otherwise, it is possible for such flows to clear the containing wall, and the conditions necessary are specified.

For a tank with no pedestal, P=0, the specifications for an adequate dike are:

$$HR^2 = a(L + R)^2; \qquad (V.44a)$$

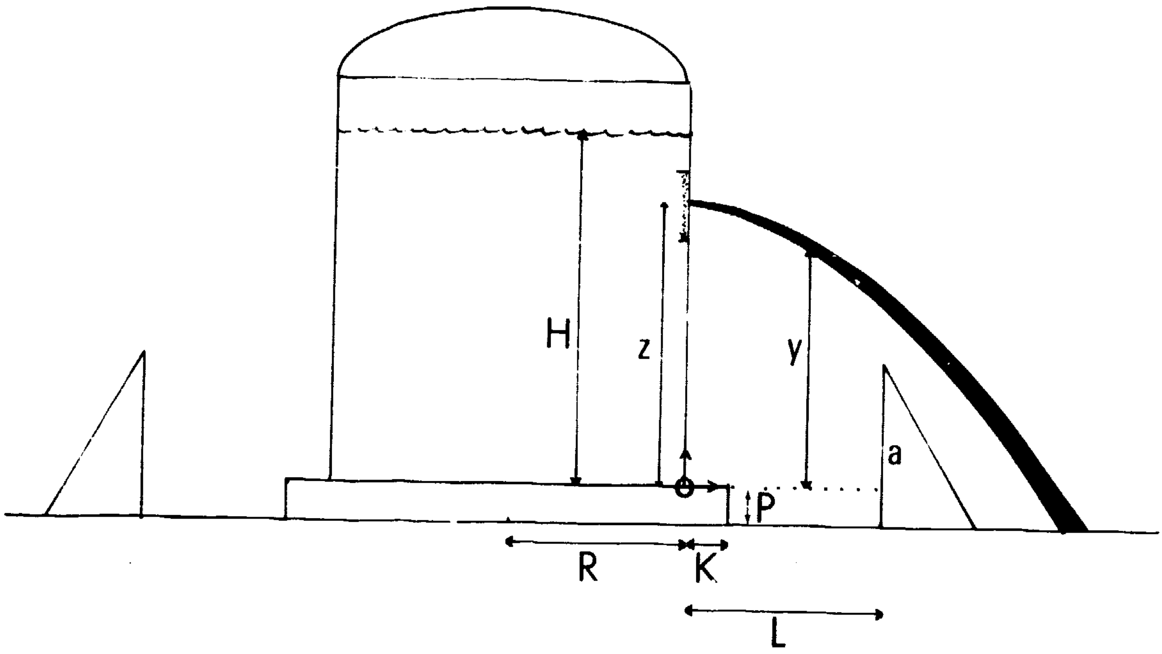


FIG. V-5

DEFINING DIAGRAM AND NOMENCLATURE FOR SPIGOT FLOWS. FLOW FROM A PUNCTURE CANNOT CLEAR ANY DIKE IN THE REGION X≥H. FLOW FROM ANY PUNCTURE IN THE STIPPLED ZONE OF THE TANK WALL LANDS BEYOND THE DIKE AT X=L.

$$L + a \geq H; \qquad (V.45a)$$

$$H \leq \frac{(R + L)^2}{(2R + L)}, \qquad (V.46a)$$

and these are the results stated earlier.

CALCULATIONS

If h is the height of the liquid within the tank, then Bernoulli's theorem implies that the fluid velocity at the spigot is approximately

$$V = \sqrt{2g(h - z)}, \qquad (V.47)$$

where g is the gravitational acceleration. The trajectory from the hole is parabolic:

$$y = z - \frac{x^2}{4(h - z)}, \qquad (V.48)$$

where x is the distance from the tank and y+P is the height above level ground. The maximum range for the spigot, $x=H+P$, occurs for $h=H$ and $z=(H-P)/2$. Therefore,

$$L \geq H + P \qquad (V.49)$$

provides an absolute safety criterion for spigot flow.

For a given L, a spigot at $z_{max}=H-L/2$ passes over the barrier with maximum elevation,

$$y_{max} = H - L \qquad (V.50)$$

A wall height that is greater than the maximum spigot height at the wall is sufficient to contain the flow, i.e.,

$$a_m \geq H + P - L$$

or, incorporating equation (V.44)

$$a \geq \max \left(H+P-L, \ \frac{HR^2 + (R+K)^2 P}{(R+L)^2} \right) \qquad (V.51)$$

and

$$H \leq \frac{(R + L)^2}{(2R + L)} - \frac{P(2R + L + K)}{(2R + L)} \frac{(L - K)}{L} \qquad (V.52)$$

For x=L<H+P, the spigot trajectory will clear the barrier if y>a-P. This can occur for holes located in the range

$$\frac{h+a-P-\sqrt{(h-a+P)^2 - L^2}}{2} \leq z \leq \frac{h+a-P+\sqrt{(h-a+P)^2 - L^2}}{2} \qquad (V.53)$$

when

$$a + L \leq h + p \qquad (V.54)$$

Initially $h=h_0=H$. Flow over the dike will cease when $h=h_f$, for which y=a-P at x=L, i.e.,

$$h_f = z + \frac{L^2}{4(z - a + P)}. \qquad (V.55)$$

The spillage fraction over the dike is then

$$Q = \frac{V_{spill}}{V_{tank}} = 1 - \frac{h_f}{H} \qquad (V.56)$$

For fixed a, L, and P, the maximum spillage occurs at z_{max}=a-P+L/2, and

$$Q = \frac{(H + P) - (a + L)}{H} \qquad (V.57)$$

However, treating L also as an independent variable, with a given by equation (VII.44), the conditions for maximum spillage,

$$\frac{\partial Q}{\partial z} = \frac{\partial Q}{\partial L} = 0, \qquad (V.58)$$

imply

$$h_f = L + a - P = 3\left(\frac{HR^2 + (R+K)^2 P}{4}\right)^{1/3} - (R + P) \qquad (V.59)$$

so that

$$Q_{max} = 1 + \frac{(R + P)}{H} - \frac{3}{H}\left(\frac{HR^2 + (R+K)^2 P}{4}\right) \qquad (V.60)$$

In the case where there is no pedestal, P=K=0,

$$Q_{max} = 1 + \lambda - 3\left(\frac{\lambda}{2}\right)^{2/3}, \qquad (V.61)$$

where λ=(R/H). The graph of Q_{max} versus λ is shown in Fig. 5-11. The spillage is small for $\lambda \approx 2$ and there is none for $\lambda \geq 2$. Spillage is large when the aspect ratio, λ, is small, which corresponds to a tank whose height is much greater than its radius. Under the worst spillage conditions, $L=(2HR^2)^{1/3}-R$, the NFPA safety condition,

$$L \geq .6\ (H - a) \qquad (V.62)$$

implies

$$2.6\left(\frac{\lambda}{2}\right)^{2/3} - \lambda - .6 \geq 0 \qquad \text{(V.63)}$$

This criterion is satisfied for $.74 \leq \lambda \leq 2$. Since for $0 \leq \lambda \leq 2$ the spigot effect can carry fluid over the dike from some holes, equation (V.61), this NFPA safety formula is basically irrelevant because it still permits facilities to be built from which fluid can escape over the dike by the spigot effect.

The effect of a pedestal is partially determined by the method of compensating for the extra volume. If a pedestal is introduced and L is held constant while a is increased to compensate for the pedestal's volume, then,

$$\left.\frac{\partial Q}{\partial P}\right|_L = \frac{L^2}{4H(z-a+P)^2}\left[1 - \frac{(R+K)^2}{(R+L)^2}\right] \geq 0 \qquad \text{(V.64)}$$

In this case, the amount of spillage is always increased. If a is held fixed, while L is increased, then,

$$\left.\frac{\partial Q}{\partial P}\right|_a = \frac{L^2}{4H(z-a+P)^2}\left[1 - \frac{(R+L)(R+K)^2 \quad (z-a+P)}{L\left[HR^2 + (K+R)^2 P\right]}\right] \qquad \text{(V.65)}$$

For P=K=0 and z-a=L/2, this yields

$$\frac{\partial Q}{\partial P} \propto 1 - \frac{(R + L)}{2H} \qquad \text{(V.66)}$$

Depending upon whether this quantity is positive or negative, the spillage will increase or decrease. Using the maximum NFPA standard, L=.6(h-a), and assuming R<H, this quantity is positive. However, for non-zero values of P and K, the sign of $\partial Q/\partial P$ is not determined.

REFERENCES

1. Henderson, F.M. (1966), Open Channel Flow, MacMillan, NY.
2. Dressler, R.F. (1950), J. Res. Nat. Bur. Stud. 49, 217.
3. G.B. Whitham (1955), Proc. Roy. Soc. 227, 399.

APPENDIX VI

CONTENTS | PAGE

APPENDIX VI-1

REACTIVE SAFETY EQUIPMENT ON LNG TANKERS

A typical LNG tanker carries the following safety equipment:

Fire Fighting and Damage Control

- 45 main fire stations, each equipped with a minimum 50-foot water hose, a fog nozzle, and a spanner wrench.

- 12 fixed fire monitors on the main deck.

- 14 dry chemical hoses using nitrogen as a propellant.

- Portable dry chemical extinguishers.

- Fixed CO_2 systems for machinery space, diesel generator room, ballast pump room, paint room, and cargo compressor room.

- A water spray system covering the forward side of main superstructure, cargo tank domes, and pipes on deck.

- Emergency Shut Down System (ESDS), which can be automatically activated by a number of alarm conditions and thermal fuses, or manually controlled from several locations on deck and in the cargo control room. This device shuts down all pumps and compressors immediately, closing valves in 30 seconds to prevent shock.

Explosion Hazard Suppression Equipment

- Equipment to maintain an inert atmosphere in the cargo holds containing LNG tanks. (This is specified in the Energy Transportation Corporation's Safety Manual for its LNG Ships.)

- Infrared gas detection systems which take continuous suction from all areas which gas could enter, analyzing one point at a time.

- Combustible gas detection systems which continuously monitor all test areas.

- Pressure relief valves on pipes, cargo tanks, and cargo holds.

- Explosion-proof or intrinsically safe electrical equipment installed in hazardous locations.

- Cargo vent system and accommodations ventilation systems, so designed that LNG vapor will be prevented from entering accommodations and interior working spaces.

Additional Safety Equipment

- Insulated drip pans under shore connections.

- Temperature sensors in critical portions of hull structure, warning of possible insulation failures or leaks.

- Numerous alarms indicating abnormal operating conditions, some of which provide automatic shut-off.

- Portable safety equipment, such as protective clothing, dry chemical and CO_2 fire extinguishers, breathing apparatus, portable gas detection equipment, and oxygen analyzers.

APPENDIX VI-2

LEG CONTAINMENT SYSTEMS

LNG SHIPS

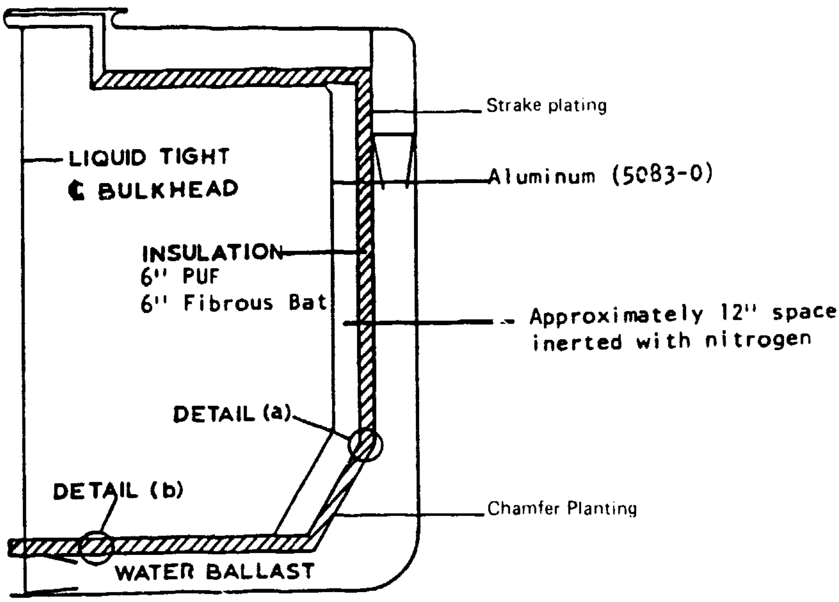
Following are specific characteristics of the four LNG containment systems of ships that will transport LNG to the United States.

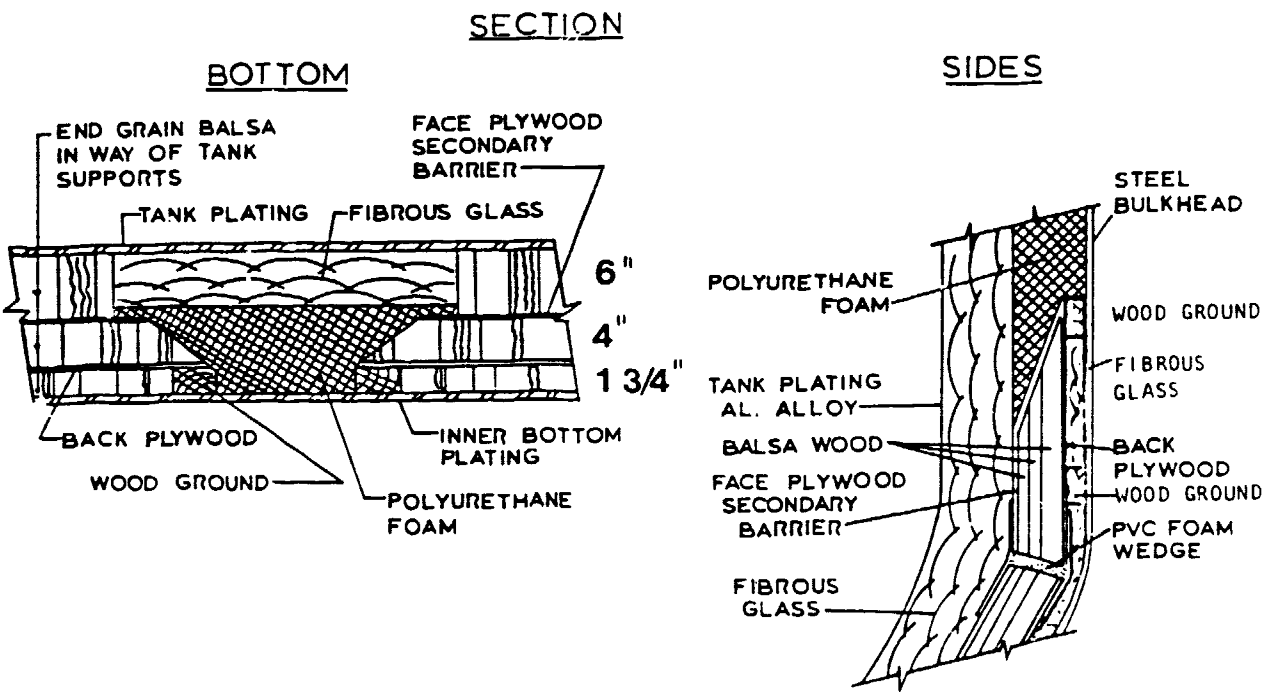
CONCH II DESIGN

This is a self-supporting design in which the five single-walled prismatic cargo tanks are made of an aluminum alloy (5083-0). Among the structural details are: longitudinal centerline liquid-tight bulkheads, transverse bulkheads, vertical stiffeners, and horizontal girders. The bulkheads provide structural strength, and reduce the forces generated by the free-surface effect of the cargo at sea. The tank thickness at the top near the upper strake is one-half inch. This increases to 1-1/2" at the chamfer panels. The three middle tanks are approximately 76 feet deep, 123 feet wide, and 124 feet long. The two end tanks are somewhat shorter. The tanks are located by keys and keyways at the bottom and top, allowing the necessary contraction and expansion. The keys are made of permali, a reinforced hardwood.

The insulation system consists of balsa/plywood frame panels along the corners, with a sprayed-in-place high density polyurethane covering the inner hull between the frames. See Fig. VI-1. The frames are 10' long with 2' legs and 4" thick. The foam is applied in layers with two

CONCH II





CONCH TANK AND INSULATION DETAILS

FIG. VI-1
Source: Footnote Reference 3.

partial and one full nylon reinforced nets integrated into the foam, acting as crack arrestors. The foam is 6" thick. On top of this, 6" of fiberglass is draped as additional insulation. The 12" void space between the wall insulation and the cargo tank is maintained inert by N_2.

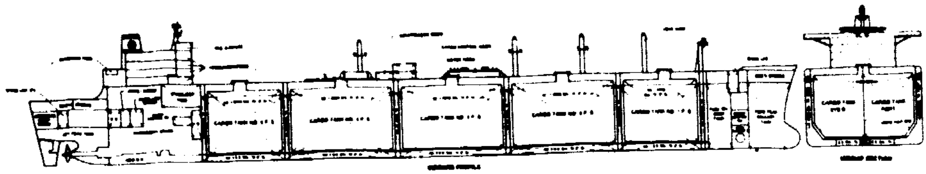
The tanks are supported by balsa/plywood insulation panels which are uniformly distributed under 30% of the tank bottom. In general, the support panels are 5' by 10' and 11-3/4" thick, with polyurethane foam and a fibrous glass bat between the panels. The secondary barrier is made of plywood and polyurethane foam.

The principal dimensions of this design are given in Fig. VI-2. It is characterized by its complex cargo tank construction. The many internal stiffening members make it very difficult to get an accurate analytical determination of stresses. The stiffening members also introduce possible sources of crack initiation. However, a secondary barrier is provided. The tank structure also has some advantages. The tight centerline bulkhead reduces free surface effects, as well as the amount of LNG spill in case of a tank rupture. The tank is easily inspected internally, but the facilities for insulation inspection are very limited, particularly for the load bearing insulation.

Some additional data are given below:

Safety Cargo Relief Valves:	2 on each tank 2 on each cargo hold
Safety Cargo Tank Relief Valve Setting:	2.6 psig positive

AVONDALE CONCH II



PRINICPAL CHARACTERISTICS

	Metric	English
HULL		
LENGTH OVERALL	283.9 m	931.5 ft
LENGTH BETWEEN PERPENDICULARS	270.3 m	887.0 ft
BEAM	42.8 m	140.5 ft
DEPTH, AT SHIP'S SIDE	28.7 m	94.0 ft
DRAFT, LOADED	11.0 m	36.0 ft
BLOCK COEFFICIENT, AT LOADED DRAFT	0.740	0.740
WETTED SURFACE, AT LOADED DRAFT	14,150 m²	152,310 ft²
MACHINERY		
PROPULSION PLANT	Steam turbine Cross-compound-type Delaval	Steam turbine Cross-compound-type Delaval
BOILERS (TWO PER SHIP)	Top fired Dual fuel Foster Wheeler	Top fired Dual fuel Foster Wheeler
SHP @ MAXIMUM CONTINUOUS POWER	41,570 CV	41,000 HP
RPM @ MAXIMUM CONTINUOUS POWER	117	117
PROPELLER DIAMETER	7.62 m	25.0 ft
WEIGHTS AND (EXCLUDING CARGO TANK VOLUME) CAPACITIES		
GROSS TONNAGE	72,000T	72,000 T
NET TONNAGE	56,000 T	56,000 T
DISPLACEMENT, AT LOADED DRAFT	96,596 MT	95,075 LT
LIGHT SHIP WEIGHT	31,365 MT	30,871 LT
BALLAST CAPACITY, 98% SALT WATER	53,899 MT	53,051 LT
FUEL OIL CAPACITY, 98% 15 API FUEL	6,202 MT	6,104 LT
CARGO CONTAINMENT AND HANDLING		
TYPE LNG CONTAINMENT SYSTEM	Conch	Conch
NUMBER CARGO TANKS	5 large	5 large
TOTAL CARGO TANK CAPACITY, 100% COLD	127,807 m³	803,906 Bbl
TOTAL LNG PUMP CAPACITY	12,038 m³/hr	53,000 gpm
NUMBER AND SIZE LOADING/DISCHARGE LINES	5-406.4 mm	5-16 in
OPERATING SPEEDS		
DESIGN SERVICE SPEED	18.5 kts	18.5 kts
TRIAL SPEED AT 90% SHP	20.45 kts	20.45 kts
SERVICE SPEED AT 90% SHP	19.55 kts	19.55 kts

FIG. VI-2
SOURCE: "ALGERIA I," AN EL PASO INFORMATION BOOKLET.

		-0.15 psig negative
	Flow:	9684 SCFM (standard cubic feet per min.)
Cargo Hold, Setting:		2.0 psig positive
	Flow:	6700 SCFM
Boil-off Compressor Capacity:		(2) 1160m^3/hr.
at a discharge pressure of:		34.0 psia
High Duty Compressor Capacity:		12800m^3/hr.
at a discharge pressure of:		20.0 psia
Vaporizer Capacity:		16000 kg/hr.

This design is presently being used by Avondale Shipyard, but we expect that this yard will switch to the Moss Rosenberg design when the 3 El Paso ships are completed. If this happens, these 3 ships will probably be the only Conch II ships in the U.S. trade.

MOSS ROSENBERG DESIGN

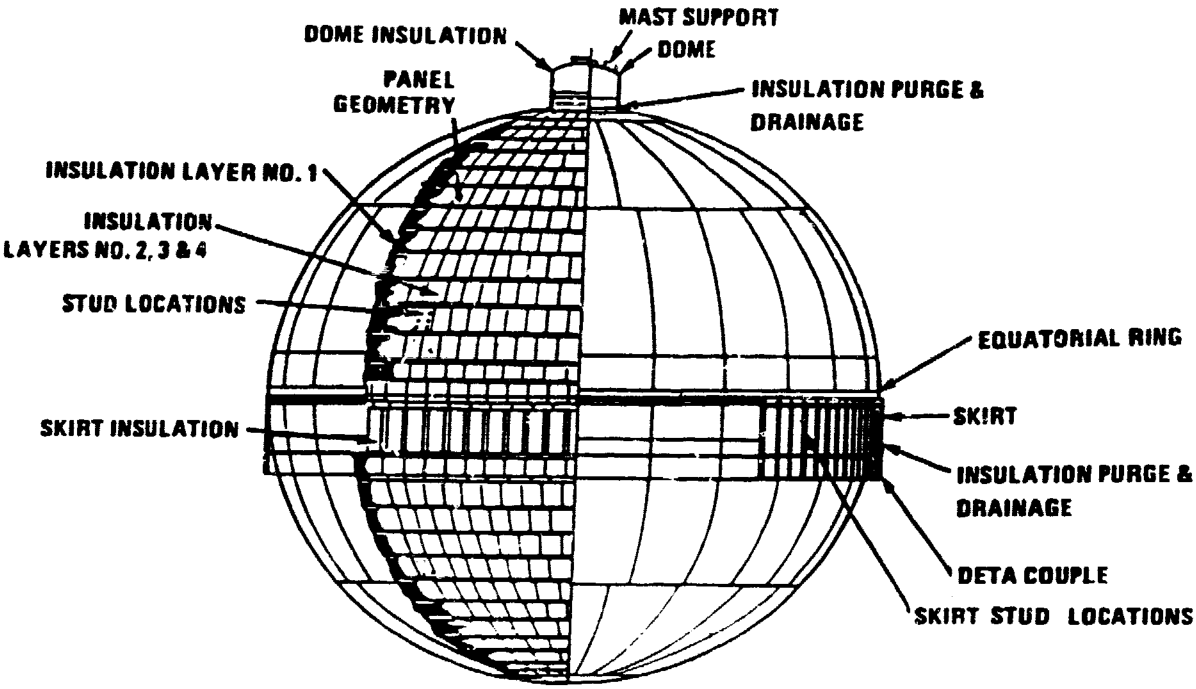
The five spherical self-supporting aluminum alloy (5083-0) tanks are supported by a cylindrical skirt at the equator of the tank. See Fig. VI-3. The skirt's upper part is made of 2-1/4" thick aluminum; the lower part is made of modified grade A steel (8537), 1-3/8" thick and welded to the ship's structure at the skirt-table. The tankwall is 1.57" thick, at equator it is 7.68" thick. The skirt is equipped with vertical stiffeners. The tank has no stiffeners or internal bulkheads.

The insulation incorporates four layers of 2" thick polyurethane installed in prefabricated panels of 4' by 6'. All panels are faced with aluminum paper on both of the surfaces and attached to the cargo tanks by means of a total of 13,000 stud fasteners. Foam is sprayed into the joints to fill the gaps and bind the panels together. The entire surface is finally sprayed with a butyl rubber compound which acts as a vapor barrier.

No secondary barrier is required for this design, but the cargo holds are equipped with a partial secondary barrier consisting of a splash sheet made of stainless steel and an insulated catch basin made of polyvinyl chloride (PVC) closed cell foam, covered with a stainless steel lining.

Principal dimensions are given in Fig. VI-4. The design is characterized by the spherical tanks, which make stress analysis easier, and provides good internal tank and insulation inspection capabilities. The tanks' shape and strength give them a higher collision resistance than other designs. There are also disadvantages with this

GENERAL DYNAMICS



DETAIL AT STUD FASTENER

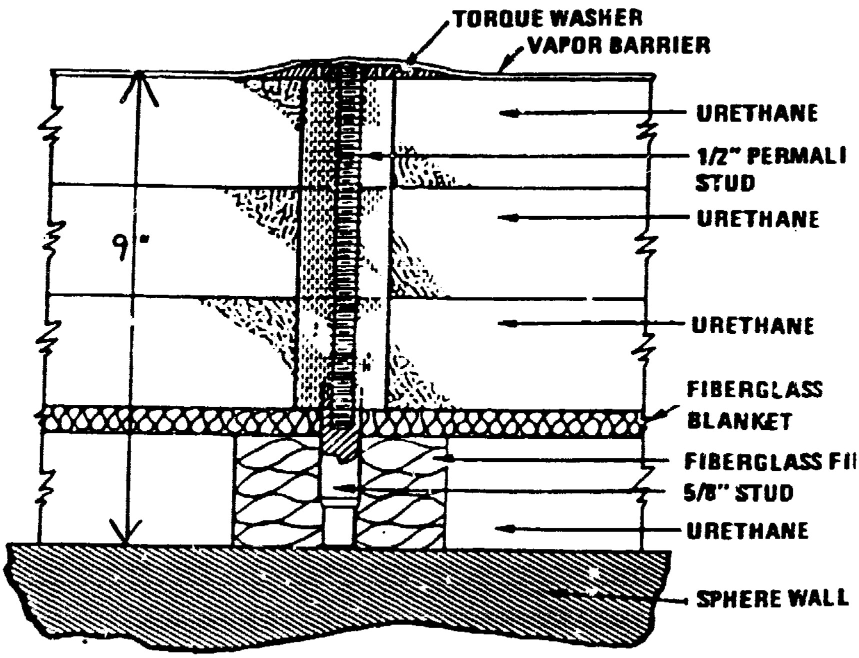
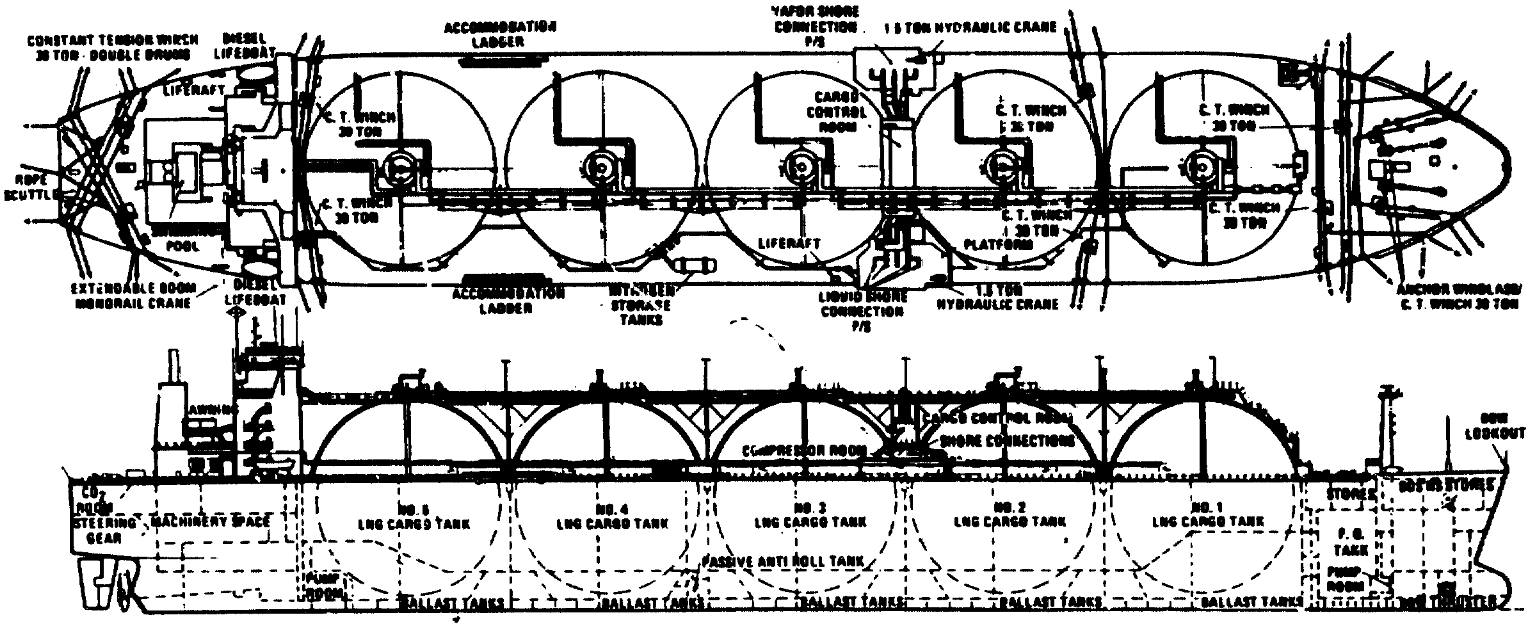


FIG. VI-3
SOURCE: "TOTAL LNG SYSTEM," GENERAL DYNAMICS INFORMATION BOOKLET.

MOSS ROSENBERG DESIGN
General Dynamics



PRINCIPAL CHARACTERISTICS

LENGTH OVERALL	936'-6"	285.3 M
LENGTH BETWEEN PERPENDICULARS	897'-0"	273.4 M
BREADTH, MOLDED	143'-6"	43.7 M
DEPTH, MOLDED TO UPPER DECK AT SIDE AMIDSHIPS	82'-0"	25.0 M
DRAFT, DESIGN WATERLINE	36'-0"	11.0 M
TOTAL DEADWEIGHT	63,000 L. TONS	64,620 M. TONS
DISPLACEMENT	95,000 L. TONS	96,514 M. TONS
CRUISING RADIUS BURNING OIL ONLY (APPROX.)	10,500 N. MILES	19,500 KM
SHAFT HORSEPOWER, MAX. CONTINUOUS	43,000 HP	43,000 M. HP
DESIGN SPEED, TRIAL CONDITIONS, KNOTS	20.4	
SPECIFIC FUEL CONSUMPTION RATE (APPROX.)	0.477 LBS/SHP-HR	0.213 KG/SHP-HR

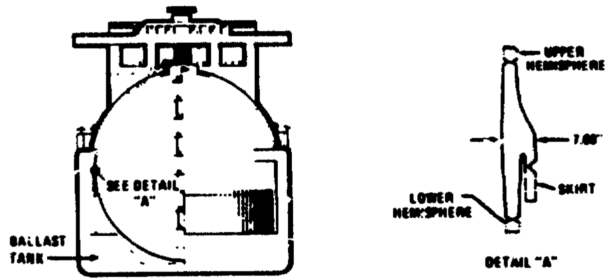


FIG. VI-4
SOURCE: UNITED STATES NAVAL INSTITUTE, "PROCEEDINGS," APRIL 1977.

design. The higher center of gravity provides less initial stability and a more restricted view from the bridge. Forward blind range from the wheelhouse is 2244 feet and from the bridge wing 971 feet.

The tanks penetrate the main deck, providing less protection for them and adding substantially to the windage area.

A special feature of the spherical design is the capability of emergency discharge by overpressurizing the tanks in case of pump failures. To do so requires closing the safety relief valves allowing vaporized LNG to build up a pressure of approximately 30 psig.

Some additional operating data are given below:

Safety Relief Valves:	2 on each tank
	2 on each cargo hold
Cargo Tank, Setting:	2.9 psig positive
	-1.9 psig negative
Flow:	24000 SCFM at 4.73 psig
Cargo Hold, Setting:	1.2 psig positive
	-0.4 psig negative
Flow:	2727 SCFM at 1.43 psig
Boil-off Compressor	
Capacity:	(2) 5100m^3/hr.
at a discharge pressure of:	29 psia
High Duty Compressor	
Capacity:	(1) 20388m^3/hr.
at a discharge pressure of:	26.6 psia

Vaporizer Capacity:	(1) 24800 kg/hr.
Cargo Pump Capacity:	(10) $1100m^3$/hr. each
LN_2 Storage Tank:	$24.8m^3$
LN_2 Vaporizer:	$764m^3$/hr.
Bow Thruster:	2200 HP

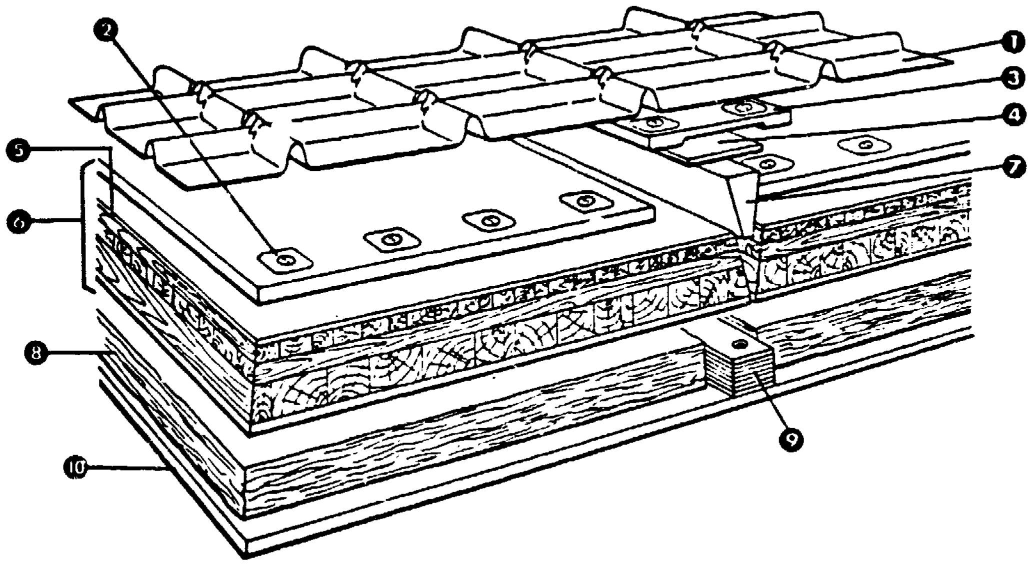
About one third of the American LNG fleet will probably be of spherical design, constructed by General Dynamics (126,750 cubic meter capacity) and Avondale (130,600 cubic meter capacity). The latter will have a length of 943', beam of 144', depth 82', and a draft of 37'3". The insulation on the Avondale ships will be like the original Moss Rosenberg concept: approximately 10" thick expanded polystyrene plastic foam with a vapor barrier of aluminum foil.

TECHNIGAZ DESIGN

This is an integrated containment system, sometimes called membrane, in which the primary barrier is made of 1.2mm thick, waffled or corrugated stainless steel membrane. The tank sheets have two sets of orthogonal corrugations to allow for contraction and expansion. These ogival shaped corrugations cross each other by means of special geometrical surfaces called "knots." The distance between the corrugations measures 34 by 34cm on all vertical and horizontal sheets and 24 by 34cm on all 45° angles or chamfer sheets. The overlapping sheets are welded to each other to form the membrane, which in turn is welded to stainless steel pieces embedded in the insulation. The tank, having no internal bulkheads or stiffening, departs in its upper area from a general prismatic shape into a long trunk which serves to reduce the free surface effect of the cargo. The tanks are uniformly supported by a load bearing balsa/plywood insulation system.

Working inward from the inner hull of the vessel, the system is made up of wood grounds (75mm thick), fastened to the hull structure. See Fig. VI-5. The space between these grounds is filled with fiberglass bats. The insulation panels, consisting of laminated balsa layers totalling 165mm, are faced with 1/2" fir plywood on the warm side and 1/8" sugar maple plywood on the cold side. The panels are attached to the grounds, and the joints between them filled with PVC. Finally, a 55mm balsa padding with embedded stainless steel anchor points provides the necessary surface for the membrane. The secondary barrier is the 1/8" sugar maple plywood. Principal dimensions are given in Fig. VI-6. This system

TECHNIGAZ



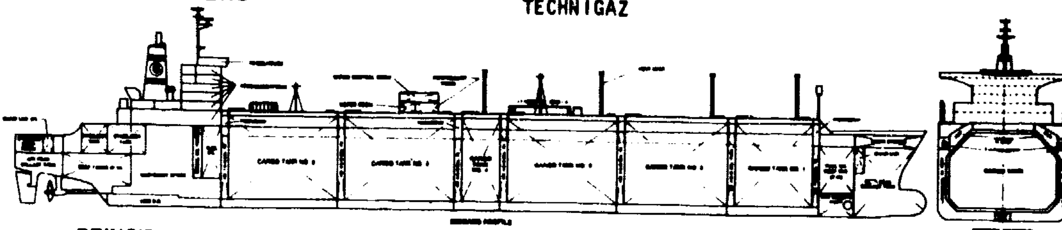
1 Stainless steel primary barrier
2 Anchor points for primary barrier
3 Balsa bridge pad
4 Secondary barrier plywood splice
5 Secondary barrier plywood
6 Balsa/plywood insulation panel
7 PVC foam wedge
8 Fiberglass bat
9 Grounds
10 Inner hull of ship

EXPLODED VIEW OF TECHNIGAZ CONTAINMENT SYSTEM

FIG. VI-5
Source: Footnote reference 3.

NEWPORT NEWS

TECHNIGAZ



PRINCIPAL CHARACTERISTICS

	Metric	English
HULL		
LENGTH OVERALL	289.1 m	948.5 ft
LENGTH BETWEEN PERPENDICULARS	276.1 m	906.0 ft
BEAM	41.2 m	135.0 ft
DEPTH, AT SHIP'S SIDE	25.9 m	85.0 ft
DRAFT, LOADED	11.0 m	36.0 ft
BLOCK COEFFICIENT, AT LOADED DRAFT	0.770	0.770
WETTED SURFACE, AT LOADED DRAFT	14,504 m²	156,128 ft²
MACHINERY		
PROPULSION PLANT	Steam turbine Cross-compound-type Delaval	Steam turbine Cross-compound-type Delaval
BOILERS (TWO PER SHIP)	Top fired Dual fuel Foster Wheeler	Top fired Dual fuel Foster Wheeler
SHP @ MAXIMUM CONTINUOUS POWER	40,560 CV	40,000 HP
RPM @ MAXIMUM CONTINUOUS POWER	105	105
PROPELLER DIAMETER	7.62 m	25.0 ft
WEIGHTS AND (EXCLUDING CARGO TANK VOLUME) CAPACITIES		
GROSS TONNAGE	56,800 T	56,800 T
NET TONNAGE	35,300 T	35,300 T
DISPLACEMENT, AT LOADED DRAFT	98,770 MT	97,215 LT
LIGHT SHIP WEIGHT	33,196 MT	32,675 LT
BALLAST CAPACITY, 98% SALT WATER	70,799 MT	69,681 LT
FUEL OIL CAPACITY, 98% 15 API FUEL	5,945 MT	5,851 LT
CARGO CONTAINMENT AND HANDLING		
TYPE LNG CONTAINMENT SYSTEM	Technigaz	Technigaz
NUMBER CARGO TANKS	5 large & 1 small	5 large & 1 small
TOTAL CARGO TANK CAPACITY, 100% COLD	126,020 m³	792,866 Bbl
TOTAL LNG PUMP CAPACITY	12,280 m³/hr	54,200 gpm
NUMBER AND SIZE LOADING/DISCHARGE LINES	5-406.44 mm	5-16 in
OPERATING SPEEDS		
DESIGN SERVICE SPEED	18.5 kts	18.5 kts
TRIAL SPEED AT 90% SHP	19.90 kts	19.90 kts
SERVICE SPEED AT 90% SHP	19.15 kts	19.15 kts

FIG. VI-6

SOURCE: "ALGERIA I," AN EL PASO INFORMATION BOOKLET.

is characterized by its lower center of gravity; the primary barrier is much thinner and closer to the hull. This provides better stability, better hull utilization, better visibility from the bridge, and a reduced windage area.

The disadvantages with this system are (1) the higher possibility of tank damage in a collision or grounding, (2) difficulty in accurately calculating stresses, which makes it difficult to calculate the danger of fatigue failure, and (3) great difficulty in inspecting the insulation.

Another characteristic of membrane designs is the low tolerable differential pressure between the cargo tank and the cargo hold (interbarrier space). A relatively low overpressure of the cargo hold could cause buckling and possibly rupture of the primary barrier.

Some additional operational data are given below:

Safety Relief Valves:	2 on each cargo tank
	2 on each cargo hold
Cargo Tank, Setting:	3.5 psig positive
	-0.15 psig negative
Flow:	12850 SCFM
Cargo Hold, Setting:	0.3 psig positive
Flow:	230 SCFM
Boil-off Compressor:	(2) 4000m^3/hr.

High Duty Compressor: (1) $17000 m^3/hr$.

Vaporizer Capacity: 22500 kg/hr.

Newport News is presently building three LNG tankers of this design for El Paso. The yard will probably stay with this design in the future; however, they could modify the insulation by using the General Electric Mark III insulation system. This system makes use of preformed polyurethane panels in place of balsa/plywood.

GAZ TRANSPORT DESIGN

In this membrane design, both the primary and the secondary barriers are constructed from Invar steel (36% nickel iron alloy). This alloy has such a low coefficient of thermal expansion (1/10 of stainless steel) that corrugations in the barrier are unnecessary. The sheets, which are 0.5mm thick, are welded along upturned edges around the periphery of the tank. Otherwise, the membranes are flat, without any internal stiffening.

The loads imposed by the cargo are transmitted to the hull through a supporting insulation made up of 200mm thick plywood boxes filled with perlite. See Fig. VI-7. The boxes prevent compaction of the perlite. A framework of wood joists is installed on the inner hull. The secondary insulation boxes are placed within this framework and attached to the hull plating with studs and bolts. Invar tongue strips are attached to the plywood boxes. The secondary barrier is welded to these strips. Next are fitted vertical channels of 9% nickel-alloy steel, anchored to the wood framework through the secondary barrier. The primary insulation is attached to these vertical channels. Finally, Invar tongue strips, fastened to the primary insulation, provide the connection to the primary barrier. The bent-up edges of these sheets are welded to the tongues. Principal dimensions are shown in Fig. VI-8.

The operational and handling characteristics are similar to the Technigaz design, but the large number of discontinuous pieces in the insulation system makes the long term fatigue life of the system open to question.

GAZ TRANSPORT MEMBRANE TANK

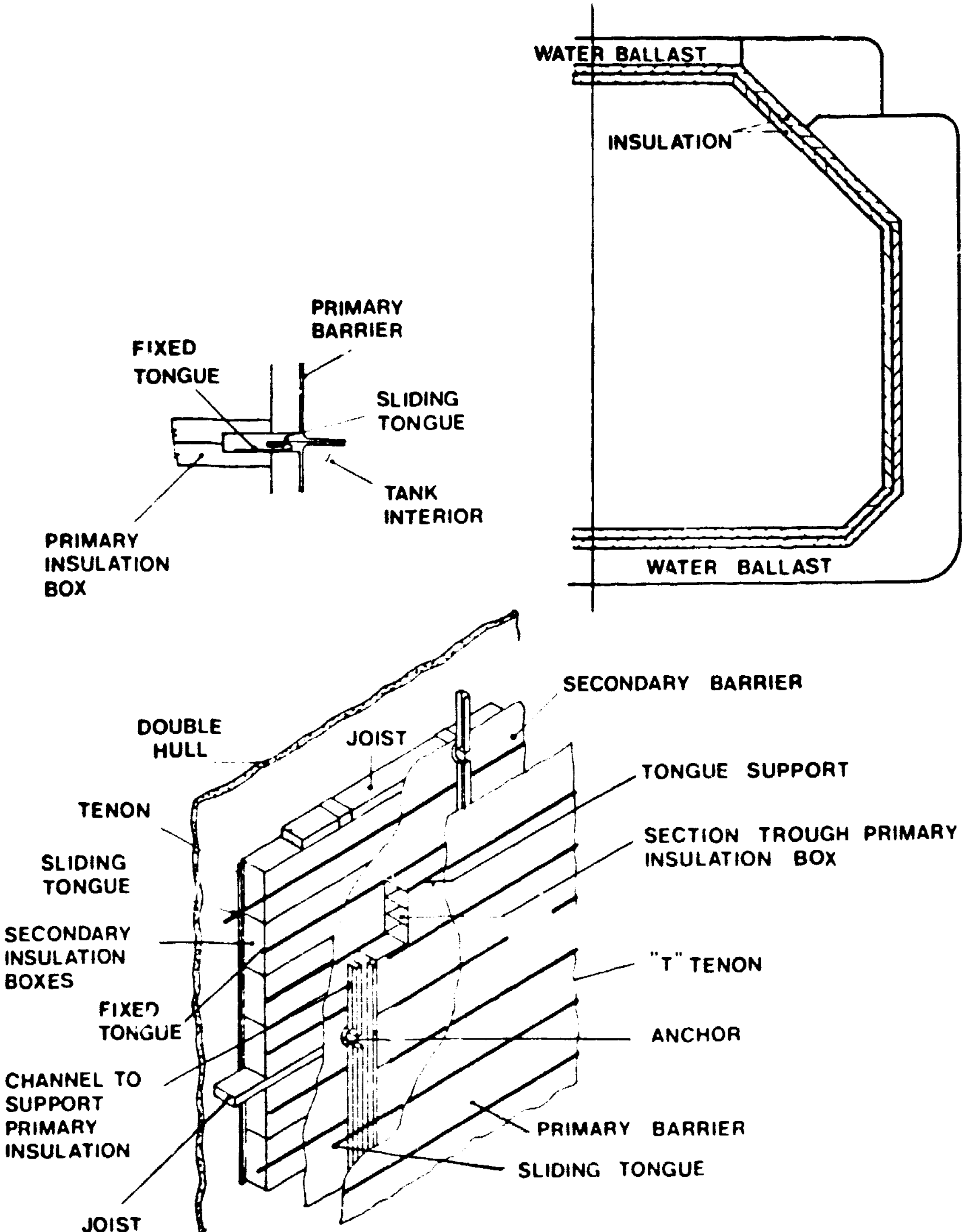
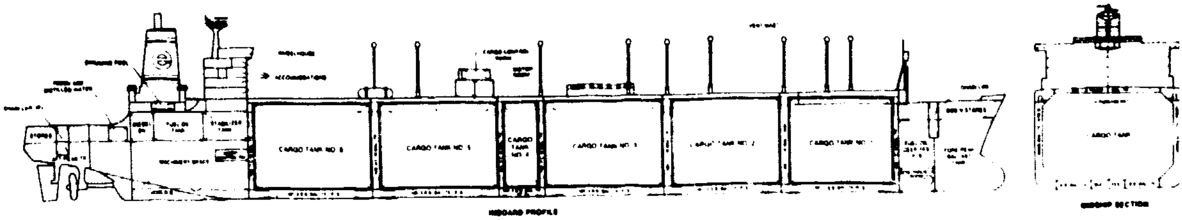


FIG. VI-7

Source: Marine Transportation of LNG and LPG, textbook used by Marine Institute of Technology and Graduate Studies.

FRANCE-DUNKERQUE GAZ TRANSPORT



PRINCIPAL CHARACTERISTICS

	Metric	English
HULL		
LENGTH OVERALL	280.6 m	920.7 ft
LENGTH BETWEEN PERPENDICULARS	266.0 m	872.8 ft
BEAM	41.6 m	136.5 ft
DEPTH, AT SHIP'S SIDE	27.5 m	90.2 ft
DRAFT, LOADED	11.0 m	36.0 ft
BLOCK COEFFICIENT, AT LOADED DRAFT	0.753	0.753
WETTED SURFACE, AT LOADED DRAFT	13,891 m²	149,521 ft²
MACHINERY		
PROPULSION PLANT	Steam turbine Cross-compound-type Stal Laval	Steam turbine Cross-compound-type Stal Laval
BOILERS (TWO PER SHIP)	Front fired Dual fuel Foster Wheeler	Front fired Dual fuel Foster Wheeler
SHP @ MAXIMUM CONTINUOUS POWER	45,000 CV	44,380 HP
RPM @ MAXIMUM CONTINUOUS POWER	108	108
PROPELLER DIAMETER	7.7 m	25.3 ft
WEIGHTS AND (EXCLUDING CARGO TANK VOLUME) CAPACITIES		
GROSS TONNAGE	66,807.64 T	66,807.64 LT
NET TONNAGE	47,420 T	47,420 T
DISPLACEMENT, AT LOADED DRAFT	94,234 MT	92,726 LT
LIGHT SHIP WEIGHT	29,485 MT	29,013 LT
BALLAST CAPACITY, 98% SALT WATER	62,991 MT	61,996 MT
FUEL OIL CAPACITY, 98% 15 API FUEL	4,196 MT	4,130 LT
CARGO CONTAINMENT AND HANDLING		
TYPE LNG CONTAINMENT SYSTEM	Gaz-Transport	Gaz-Transport
NUMBER CARGO TANKS	5 large & 1 small	5 large & 1 small
TOTAL CARGO TANK CAPACITY, 100% COLD	125,011 m³	786,319 Bbl
TOTAL LNG PUMP CAPACITY	11,500 m³/hr	50,750 gpm
NUMBER AND SIZE LOADING/DISCHARGE LINES	5-406.4 mm	5-16 in
OPERATING SPEEDS		
DESIGN SERVICE SPEED	18.5 kts	18.5 kts
TRIAL SPEED AT 90% SHP	20.8 kts	20.8 kts
SERVICE SPEED AT 90% SHP	19.9 kts	19.9 kts

FIG. VI-8

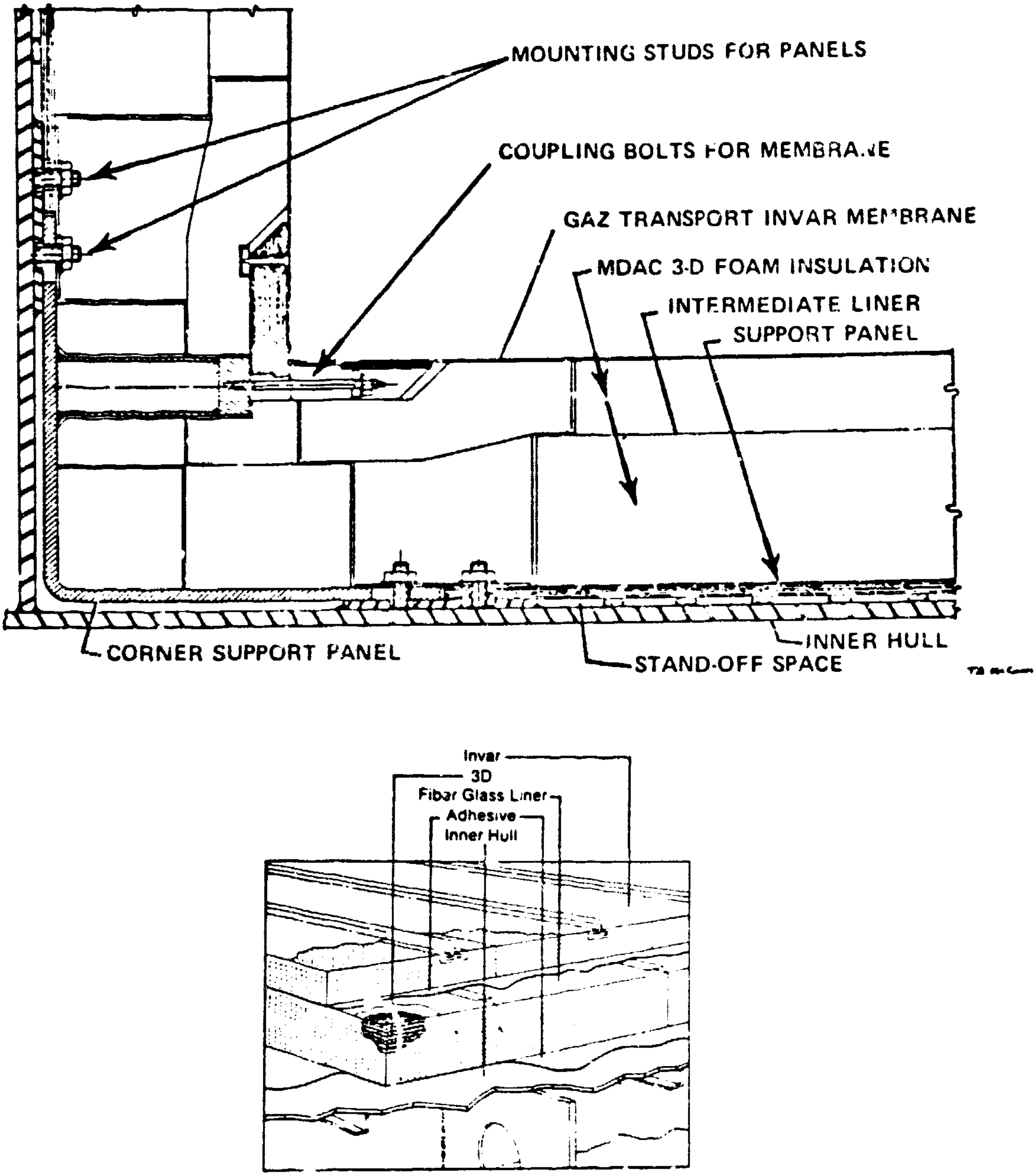
SOURCE: "ALGERIA I," AN EL PASO INFORMATION BOOKLET.

The Gaz Transport system has a substantial amount of service experience. Of particular interest is the bulging of the primary barrier that took place on the Polar Alaska in December 1969. This bulging was caused by overpressurizing the interbarrier space with nitrogen. In September 1971, the Arctic Tokyo had a loss of the primary barrier in tank No. 1. Liquid motion in the tank generated a high sudden pressure on the barrier, causing damage to the plywood boxes and tearing the membrane.

Some additional operational data are given below:

Safety Relief Valves:	2 on each cargo tank 2 on each cargo hold
Cargo Tank, Setting:	3.5 psig positive -0.2 psig negative
Flow:	N.A.
Cargo Hold Setting:	0.2 psig positive
Flow:	$750 m^3$/hr. methane/N_2 vapor
Boil-off Compressor Capacity:	$4600 m^3$/hr.
High-duty Compressor Capacity:	$8200 m^3$/hr.
Vaporizer Capacity:	(2) 8500 kg/hr each at -140°C

Three French built ships for El Paso use this design. See Fig. VI-9.



GAZ-TRANSPORT / McDONNELL DOUGLAS
CONTAINMENT SYSTEM

FIG. VI-9

Gaz Transport and McDonnell Douglas have combined their cryogenic containment systems to produce the GT/MDC system. This system will be used by Sun Shipyard for the two Pacific Lighting Marine ships on order. The primary barrier is still provided by the Gaz Transport flat Invar membrane, but it is increased to 0.7mm in thickness. The insulation system consists of two layers of polyurethane foam panels, reinforced in three directions and separated by a fiberglass reinforced layer which functions as the secondary barrier.

The method of attaching the membrane to the insulation has basically been retained in the new design.

LPG CARRIERS

Avondale Shipyard offers an American designed LPG tanker of 81,500 cubic meter capacity.

As shown in Figs. VI-10 and VI-11, the four tanks are prismatic, self-supporting, and made of 2.5% nickel-iron alloy, capable of withstanding -50°F, sufficient to hold propane, propylene, butane, and ammonia. Tank thickness is 0.4375" at top, increasing to 0.6875" at bottom. The tanks are divided by liquid-tight centerline bulkheads, forming eight compartments, internally stiffened by transverse structure members. Each tank is fitted with roll and pitch keys in very much the same way as the Conch II LNG carrier design.

The insulation is made of 4-10" polyurethane foam, depending on customers' boil-off specifications. The vapor barrier is made of PVC sheeting, joined with PVC H-shaped strips. The insulation is applied on the inner hull, providing a cold cargo hold space. The bottom insulation, providing tank support, is made of balsa/plywood with hardwood grounds.

The inner hull, acting in this design as the secondary barrier, is made of 0.625" thick ARMCO LTM grade T steel, suitable for low temperature service.

Principal characteristics are:

Length Overall:	740'0"
Length between perpendiculars:	705'0"
Beam:	126'0"
Depth:	77'6"

81,500m³ LPG CARRIER
AVONDALE SHIPYARD
Midship Section

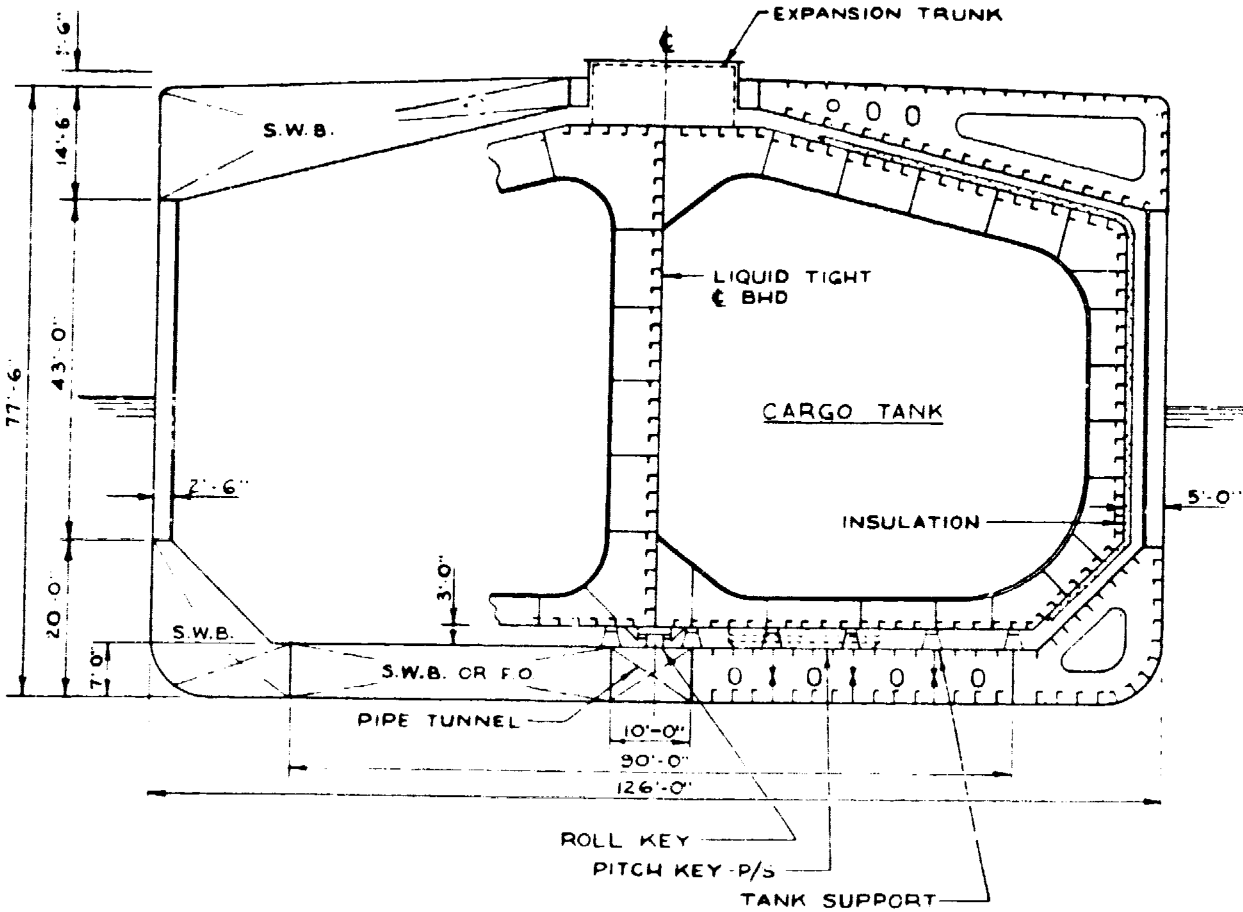
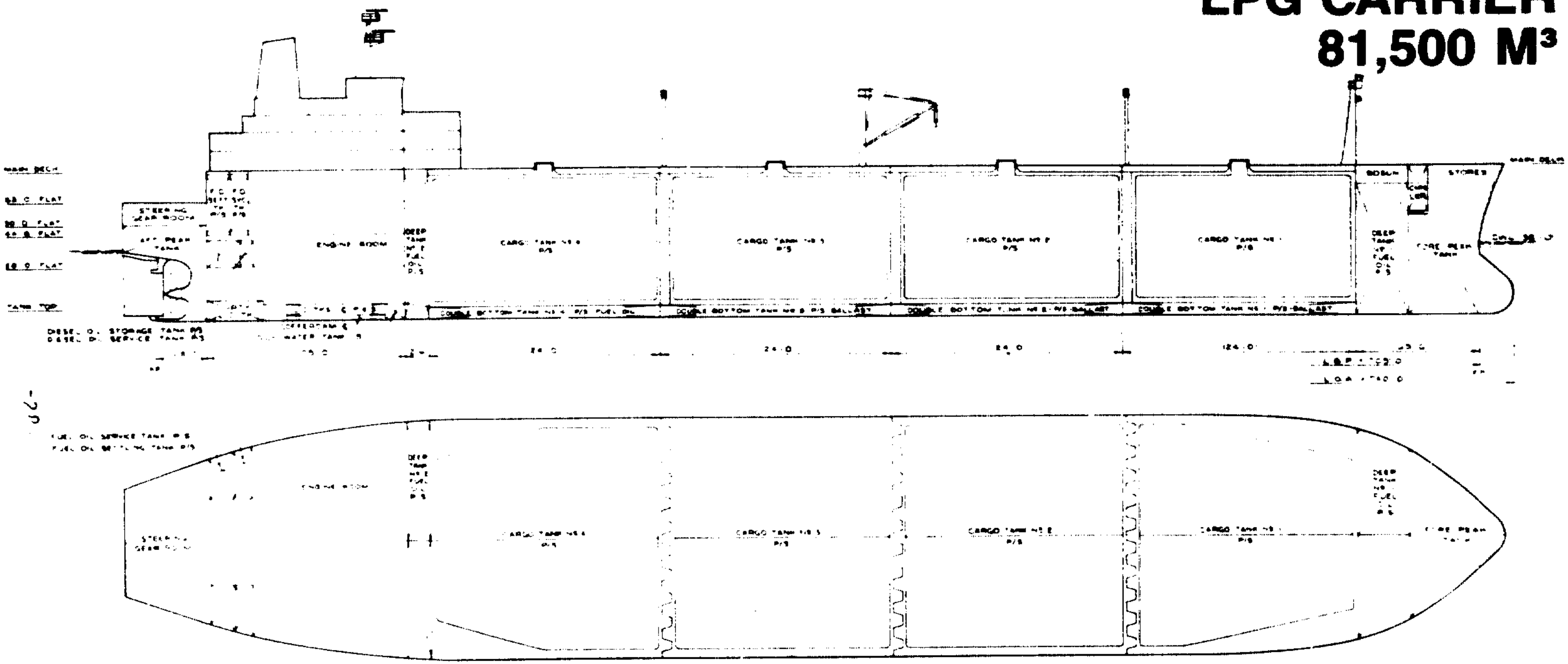


FIG. VI-10
Source: Information Booklet, Avondale Shipyard.

GENERAL ARRANGEMENT LPG CARRIER 81,500 M³



CARGO OIL TANKS		
TANK No	VOLUME CUBIC FEET 100% FULL	VOLUME CUBIC METERS 100% FULL
1 PORT	[illegible]	[illegible]
1 STBD	[illegible]	[illegible]
2 PORT	[illegible]	[illegible]
2 STBD	[illegible]	[illegible]
3 PORT	[illegible]	[illegible]
3 STBD	[illegible]	[illegible]
4 PORT	[illegible]	[illegible]
4 STBD	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]

CLEAN SALT WATER BALLAST		
TANK	VOLUME CUBIC FEET	L. TONS 100% FULL 35 C. F./TON
FOREPEAK	[illegible]	[illegible]
No. 1 UPPER WING P/S	[illegible]	[illegible]
No. 2	[illegible]	[illegible]
No. 3	[illegible]	[illegible]
No. 4	[illegible]	[illegible]
No. 1 D. BOT./WING P/S	[illegible]	[illegible]
No. 2 LOWER WING P/S	[illegible]	[illegible]
No. 3	[illegible]	[illegible]
No. 4	[illegible]	[illegible]
No. 2 DOUBLE BOTTOM P/S	[illegible]	[illegible]
No. 3	[illegible]	[illegible]
AFTPEAK	[illegible]	[illegible]
TOTAL	[illegible]	[illegible]

MISCELLANEOUS TANKS		
TANK	% FULL	L. TONS
FUEL OIL	[illegible]	[illegible]
FRESH WATER	100	[illegible]
DIESEL OIL	[illegible]	[illegible]
LUBE OIL	[illegible]	[illegible]

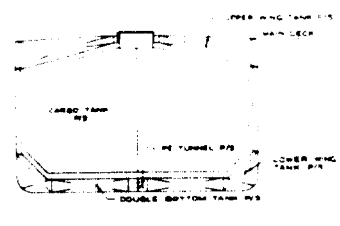


FIG. VI-11

SOURCE: INFORMATION BOOKLET, AVONDALE SHIPYARD.

Design Draft:	38'0"
Displacement:	76,185 long tons
Total Deadweight:	53,500 long tons
Main Propulsion Plant (Diesel):	25,800 HP
Service Speed:	16.7 knots
Cargo Capacity:	81,500 cubic meters
Discharge Capacity (8 Pumps):	650 cubic meters/hr ea.
Safety Relief Valves Setting:	3.85 psig positive

Compressor capacity is up to customers' specifications. Two 150 ton reliquefaction plants are suggested.

This size LPG ship will probably be the largest involved in U.S. trade. None has been ordered.

APPENDIX VI-3

LNG INCIDENT EXPERIENCE TO DATE

(Excerpted from "Fire Safety Aboard LNG Vessels." University Engineers, Inc., January, 1976, Sponsored by U.S. Coast Guard, NTIS #AD-AO30619.)

Contrary to original expectation, detailed information on all liquefied natural gas releases from LNG tankers and barges is currently not available. In the initial planning of this task, it was assumed that the approximately 100 combined years of experience in marine transport of LNG and some 50,000 hours of transfer operations should have produced a considerable number of releases of such consequences as to either require or inspire documentation. The general assumptions posited that some releases would not be documented: releases that might occur during shakedown and those that in continued operations were essentially matters of routine maintenance, such as torquing flanges and packing nuts. It was expected that other releases, however, of less routine nature and of more consequence either in terms of release size or repairability would have been documented, particularly in any cases involving failure caused by material specification or mechanical design.

Interviews and other contacts with 48 domestic and foreign companies involved in or knowledgeable about the marine LNG transportation industry produced information on only six cryogenic liquid spills. All had been previously documented and appear to have been documented only because they produced brittle fracture of decks. All were relatively small spills, under 100 gallons. Three were spills of LNG; three were spills of liquid nitrogen:

1. Methane Progress, Voyage 14, 1 May 1965. At disconnection of loading arms, LNG spilled from ship's crossover line. Seating of the liquid leading valve was prevented by a piece of a failed Teflon valve facing lodging between valve disc and seat. The drip pan overflowed due to water being projected onto it. A minor deck plating crack occurred.

2. Methane Princess, Voyage 182, 30 May 1971. Liquid nitrogen loading line relief valve opened and spilled liquid nitrogen through the combined vent line onto foredeck. Some cracking in deck plating occurred. Relief valve had been improperly reset at annual survey to a lower than specified pressure setting.

3. Methane Progress, Voyage 193, 31 October 1971. A liquid nitrogen storage tank was inadvertently overfilled causing discharge through the tank vent valve and combined vent line onto the foredeck. Main and second deck plating were cracked.

4. Jules Verne, Voyage 2. During loading, LNG tank was overfilled, causing a liquid spill from vent riser. A foreign object jammed in the float track prevented proper indication of liquid level by liquid level gage. The tank cover and a deck stringer plate fractured.

5. Massachusetts, 4 June 1974. A two-inch ordnance coupling on the liquid nitrogen loading hose fractured, spilling approximately ten gallons of liquid nitrogen. The ordnance coupling probably had been mechanically overloaded by repeated attempts to achieve seal by hammering. The main and canopy decks were fractured by the liquid nitrogen.

6. Massachusetts, 16 July 1974. A one-inch globe valve (nitrogen purge valve) was overpressured during cargo loading and spilled approximately 40 gallons of LNG. The sudden pressure rise occurred when the cargo loading valve closed because of a momentary electrical power interruption after generator switchover. The liquefied natural gas cracked the canopy deck.

Since the spills evoking the most concentrated public apprehension appear to be those resulting from failure of the primary barrier, information on any primary barrier failure was also sought. Only four failures have occurred, and again, all have been previously publicized.

1. Descartes, Voyage 2. A gas concentration was observed in the space surrounding the membrane on the aftermost tank during the second loaded voyage. A minor fault was discovered at the connection of the membrane to the tank dome during shipyard examination. There were no secondary effects of this failure and release.

2. Arctic Tokyo, 2 September 1971. The INVAR membrane (primary barrier) of Number 1 Tank was torn during the ballast leg of the voyage due to internal impulse forces generated by motion of slack liquid (LNG). Some of the plywood insulation boxes crushed as a result

of this loading. There were no secondary effects of this failure.

3. _Polar Alaska_, Ballast Voyage 1. A cable tray on the pump support column in Number 1 Tank broke away and perforated the membrane (primary barrier) in several locations. The cable tray failure was attributed to forces generated by motion of slack liquid (LNG). The failure was discovered during loading for Voyage 2. There were no secondary effects of this failure.

4. _Polar Alaska_, Second Loading. During gas freeing operations after discovery of leakage from the primary barriers (no. 3 above), the space between the primary and secondary barriers was inadvertently pressurized with nitrogen. The primary barrier was distorted. There were no secondary effects of this distortion.

Only one fire aboard an LNG cargo vessel was reported. The fire occurred on the Methane Princess at the forward vent riser during loading for Voyage 4. Ignition was caused by lightning. There were no secondary effects of this fire. Reference was made during interviews to random occurrence of fires in vent risers. No information was available on frequency or on causes of ignition, since the fires were all extinguished by automatic systems and were apparently considered operational in nature.

One collision between an LNG vessel and another vessel has been reported. While unloading, the _Methane Princess_ was rammed astern by another vessel. No hull penetration or LNG release resulted from this unusual, but nonetheless minor, incident.

Similarly, occasional mention was made at interviews of small liquid drips or streams and small gas releases. Useful information was not available. Generally, these small and infrequent leaks occurred at valves, flanges, packings, and seals and were eliminated by re-torquing fasteners and pressure nuts. No mechanical failures or blow-out type failures were specified, other than those mentioned above. During personal visits to operating LNG vessels, only one LNG leak was observed. This particular leak occurred during a loading procedure at the connection flange and was estimated at less than 0.01 gpm, essentially a very minor drip which was incapable of creating a hazardous condition.

Because of the scarcity of specific information on incidents in marine shipping of LNG, information on incidents at land-based facilities has been reviewed. The majority of this information has been reviewed previously, particularly in publications from the American Gas Association, and will not be repeated here since the historical approach was not feasible for determination of failure rate probabilities and risks.

APPENDIX VI-4

OPERATING PROBLEMS AND SHIP DELAYS

(Excerpted from "Analysis of LNG Marine Transportation for the Maritime Administration", Booz-Allen Applied Research, Inc., November, 1973, NTIS # COM-74-11684.)

There are insufficient data to predict a continuing favorable out-of-service profile for these ships. In fact, there are indications that it could increase during the last seven contract years. Our analysis shows that 29 percent of the total out-of-service time for these ships has been experienced over the last operating year for which there are data. This last year represents 12.5 percent of the period sampled for the METHANE PRINCESS and 13.3 percent for the METHANE PROGRESS.

It is understood that Conch is updating its out-of-service time and intends to deliver the results to the Maritime Administration.

The POLAR ALASKA and ARCTIC TOKYO have experienced considerably more difficulty during their first 4 years of operation. These ships contrast sharply with other operating LNG ships in the following areas:

--Until the delivery of the GADINIA in the fall of 1972, these ships were 43-percent larger by capacity than the next larger LNG ship (DESCARTES) operating, and 79-percent larger than any LNG ship operating in a continuing long-term charter.

The round-trip distance of 7,000 miles from Cook Inlet, Alaska, to Tokyo Bay is nearly double that of the next largest route length (Algeria to U.K.).

Ships operating in an Alaskan service are subjected to extreme temperature conditions.

The operating history of the POLAR ALASKA and ARCTIC TOKYO is widely known. The apparent causes for the excessive out-of-service time and the corresponding effects are summarized in Table VI-1.

Note: A history of time delays for the Methane Progress, Methane Princess, and Polar Alaska and Arctic Tokyo are given in Tables VI-2, VI-3, and VI-4.

TABLE VI-1

OPERATING PROBLEMS WITH POLAR ALASKA AND ARCTIC TOKYO

General Problem Area	Specific Cause	Impact
Poor design of both cryogenic and conventional systems	Faulty cable tray design	Failure-41 day delay
	Improper calculation of sloshing loads on extreme tank bulkheads during ballast leg	Damage to membrane and insulation-22 day delay
	Insufficient flow of cooling water through main condenser	Severe condenser tube corrosion-15 days of delay to date with retubing planned in late 1973
	Improper design of flue gas scrubber	Soot and seawater carryover to feed system resulting in system corrosion, 20-day delay
	Operating problems with ships service generator	Generator insulation breakdown, 16.5-day delay
	Stand-by feedpump	Feed pump fails after startup, 10-day delay
	Boilers	Boiler casing cracked, 20-day delay
	Poor burner throat refractory design	Cracked and deteriorated, 10-day delay

General Problem Area	Specific Cause	Impact
Adverse characteristics of ports serviced	Unusual corrosion characteristics-Tokyo Bay	Corrosion of sea valves and condenser tubes; sea valves will be replaced
	Icing conditions at Cook Inlet	Severe scraping and grinding of hull; will require more frequent painting and hull protection
Poor performance of ship's crew	Negligence during gas freeing of number 1 tank	Over pressurizing of barrier space, 21-day delay
	Questionable routine Operation of stream plant	See impacts referenced under poor designs above

TABLE VI-2

METHANE PROGRESS TIME DELAYS

Voyage Number	Dates	Delay in Days	Details
4	25 Dec. 1964	.25	Fire at Ford riser (lightening strike); delay in loading
10	21 Mar. 1965	.50	Investigation of cold spots
	5/6 May 1965	0	No delay recorded; repairs to cracked deck (cargo spillage)
32	6 March 1966	.25	Monitor seal bar fracture repairs; no schedule delay
37	11 Apr. 1966	0	Liquid leak; no schedule delay
42	12 July 1966	.25	Inspection of cracks in No. 3 hold steel (Lloyds/ABS)
50	26 Dec. 1966	0	Repairs to monitor seal barrier
68	5 Oct. 1967	.50	Cold spot foaming
70	28 Oct. 1967	.25	Steel repairs No. 2 hold; no schedule delay
71	9/10 Nov. 1967	1.0	Steel repairs No. 2 hold; no schedule delay
73	30 Nov. 1967	.50	Steel repairs No. 2 hold; no schedule delay
74	11 Dec. 1967	.25	Steel repairs No. 2 hold
75	21/22 Dec. 1967	1.25	Steel repairs No. 2 hold
76	1/2 Jan. 1968	1.50	Steel repairs No. 2 hold
83	10/12 Mar. 1968	1.0	Steel repairs No. 2 hold
98	17 Aug/21 Sept. 1968	35.0	Annual docking, Belfast

Voyage Number	Dates	Delay in Days	Details
115	12 Mar. 1969	0	High level capacitance probe shutdown (twice)
120	29 Apr. 1969	0	High level capacitance probe shutdown (twice)
127	28 Jul. 1969	0	Joint leak
171	15 Jan. 1971	.25	Data logger failure delayed loading documents
174	21/23 Feb. 1971	2.25	Steel repairs in No. 2 hold
175	6 Mar. 1971	.50	Steel repairs in No. 2 hold
178	9 Apr. 1971	.75	Gas burning tests for USCG approval application
179	20 Apr. 1971	0	Gas burning tests for USCG approval application
182	26 Apr. 1971	.25	Gas burning tests for USCG approval application
184	Jun/July 1971	34.25	Annual docking (engine room problems main cause of extension)
193	31 Oct. 1971	1.75	Liq. N_2 spillage; deck repairs necessary

TABLE VI-3

METHANE PRINCESS TIME DELAYS

Voyage Number	Dates	Delay in Days	Details
12	8/9 Apr.	1.0	Monitor seal bar fracture, temporary repairs
22	June/July 1966	0	Frosting; insulation repairs; no effective delay
		35.0	Seamen strike
47		2.2	Foaming of cold spots
69	23 Oct. 1967	.75	Foaming of cold spots; schedule not affected
80	13 Feb. 1968	.50	Steelwork crack repairs
83	16/17 Mar. 1968	.25	Monitor seal temporary repair of crack; no schedule delay
84	26/27 Mar. 1968	0	Steelwork crack repair; no schedule delay
93	4 Jul/8 Aug. 1968	34.0	Annual docking due both conventional/cryogenic parts
111	11 Feb. 1969	.75	Cold spot foaming
132	16 Sept. 1969	.25	Ship-to-shore safety trip fault being repaired
134	4 Oct. 1969	0	Data logger printout fault gave documentation delay
152	14 Apr. 1970	0	Ship-to-shore saf ty trip fault being repaired
171	5 Jan. 1971	0	Ship-to-shore safety trip fault being repaired
174	6 Feb. 1971	.25	Liquid valve operating solenoid fault to repair

Voyage Number	Dates	Delay in Days	Details
175	12/19 Feb. 1971	2.75	Water in No. 2 hold-steel fracture inspections in repairs
176	2 Mar. 1971	.50	Cold spot foaming No. 2 hold
178	23 Mar. 1971	.25	Emergency shutdown system fault/repair
180	9 Apr. 1971	.25	Jammed varec gauge delayed loading at Arzew
180	14 Apr. 1971	.25	Cool spot foaming No. 2 hold
182	May/June 1971	25.0	Annual docking
183	16/17 June 1971	1.50	Cold spot foaming No. 2 hold
186	23 Jul/13 Aug. 1971	21.50	Cold spot special repairs
187	17 Aug. 1971	1.0	Cooldown after special repairs
191	Oct./Nov. 1971	20.25	Further special repairs to cold spots
192	13 Nov. 1971	1.25	Cooldown after special repairs
196	11 Jan. 1972	1.50	Cold spot foaming; no schedule delay
197	22 Jan. 1972	3.0	Cold spot foaming continued; no schedule delay
199	17 Feb. 1972	.25	Pump motor burn-out (LeHavre) No. 4 tank
200	28 Feb./2 Mar. 1972	3.25	Replacement of pump in No. 4 tank

TABLE VI-4

POLAR ALASKA AND ARCTIC TOKYO TIME DELAYS

Date	Delay in Days*	Details
November 17, 1969	41 days	Loss of Primary Barrier No. 1 Cargo Tank-Polar Alaska due to faulty design of cable trays. Strength inadequate for the forces generated by slack liquid during heavy weather. Pieces of broken tray perforated primary barrier. Cable trays all tanks beefed up.
December 13, 1969	21 days	Bulging of Primary Membrane No. 1 Cargo Tank on Polar Alaska due to crew negligence during gas freeing operations to repair No. 1 above. Bulging caused by overpressuring the barrier space with nitrogen.
Various 1970	10 days	Burner Throat Refractory in both main boilers cracked and deteriorated (both ships) due to throat design finally changed by reducing length from 18 inches to 13 inches. Problem apparently solved.
Various 1970-1973	10 days to date	Complete failure of the standby boiler feed-water pumps (both ships) due to failure of units shortly after start-up. Supplier is reviewing design.
September 2, 1971	22 days	Loss of Primary Barrier Cargo Tank No. 1. - Arctic Tokyo due to slack liquid carried in No. 1 tank used for ballast leg cooling of cargo tanks. Liquid motion in tank generated high impulse pressures on aft bulkhead causing damage to the plywood boxes containing perlite insulation and tearing INVAR membrane.

Date	Delay in Days*	Details
1972 Annual Docking	20 days	Leaks in Main Boiler Outer Casing (both ships) due to cracks in outer casing causing heavy soot leakage into the engine room. Apparently poor initial fabrication.
1972 Annual Docking	20 days	Heavy corrosion loss to inert Gas System (both ships) due to improper design of the water leg on the flue gas scrubber allowed soot and seawater carry over into the rest of the system causing corrosion problems.
March 21, 1971 to Present	15 days to date	Failure of Condenser Tubes in Main Condenser (both ships) severe corrosion due to marine growth in condenser tubes attributed to inadequate water velocity with scoop injection system. Condensers will be completely retubed in 1973 and a chlorine injection system installed.
February 19, 1973	16-1/2 days	Loss of Main Generator on the Arctic Tokyo due to insulation breakdown on the stator required removal from the ship and rewinding ashore.
February 22, 1973	18 days	Cracks in some deck plates on the Polar Alaska due to cold cracking caused by lack of heating coils in the void space above the pump column in the cargo tanks. Deck plates of C/S quality steel. Cold leak from penetrations for liquid lines in and out of the tanks. Heating coils have been installed after repairs.

*Delays denote impact on both ships

APPENDIX VI-5

SUMMARY OF PORT CHARACTERISTICS

1. Boston, Massachusetts

Boston Harbor has easy deep water access from the sea. Entrance to the main harbor channel is situated at the western end of President Roads where the depth of water is 40 to 50 feet at Mean Low Water (MLW). The channel itself averages 400 yards in width, with an average depth of 35 feet at MLW. The transit from the channel entrance to LEG terminals is approximately 7 nautical miles (NM). Navigational aids are good to excellent. The harbor's excellent geographical features and relatively low shipping traffic density make the danger of collision or grounding minimal. The greatest navigational hazard is the necessary passage of LEG vessels under the Mystic River Bridge on their way to berths at a terminal. However, the requirement for adequate tug services during such passages reduces the possibility of a vessel-to-bridge collision to an acceptable risk. In the past, there has been a risk of an LNG vessel in the channel being struck by a falling aircraft, as analyzed in Chapter 6. Pursuant to GAO's recommendation, the Federal Aviation Administration plans to halt approaches to Runway 4-R at Logan International Airport while these ships are in transit.

2. New York, New York (Staten Island)

As in the case of Boston Harbor, vessels entering New York Harbor have easy access from the sea via Sandy

Hook. The transit to Staten Island (location of a proposed LNG terminal) is normally via Sandy Hook channel, thence other channels to Arthur Kill. Channel depths average 35 feet at MLW with an average channel width of 300 yards. Total distance from Sandy Hook channel to LNG terminals is approximately 18 NM, with the first 12 miles being fairly direct approaches and the remainder of the transit to terminals following a very circuitous route. Navigational aids are good to excellent. Although shipping density for New York Harbor is very high, the passage of vessels to Staten Island avoids the heavy concentration of traffic utilizing the Narrows (Verranzano Bridge) and lower New York Bay. Thus the amount of traffic into Staten Island is relatively light.

3. Philadelphia, Pennsylvania

Access to Philadelphia area berths is attained from Delaware Bay via Cape Henlopen, thence the Delaware River. The main Delaware river channel commences just south of the Smyrna River and is approximately 34 NM to Marcus Hook, Pennsylvania, (site of an LPG terminal). Average depth of channel is 40 feet at MLW with an average width of 250 yards. Navigational aids are good. Initial passage up the river via the Liston, Baker, Reedy, and New Castle ranges is fairly direct and thence becomes very circuitous. Traffic density, particularly tankers serving the port, is high. River current in many cases requires deep draft ships to maintain sufficient speed to maintain steerageway. The junction of the Chesapeake and Delaware Canal at the beginning of the New Castle range of the Delaware River channel raises the potential for collisions, or groundings to avoid collision. The past history of such collisions or groundings confirms this observation. Due to the relatively narrow channel, the length of transit which increases the probability of vessel head-on-head meeting situations, and the existing low margin of safety available for errors in human judgment or mechanical failure, the risk of grounding or collision is high.

4. Cove Point, Maryland

Passage to Cove Point is made from the sea via Cape Henry, Virginia, thence direct via Chesapeake Bay. The Chesapeake Bay Channel is well marked with navigational aids, and has a depth of water varying from 40 to 65 feet at MLW. The approach to the Chesapeake Bay Channel requires crossing the approach to the Thimble Shoals channel, which is the main access to the Hampton Roads area (Norfolk, Newport News, and Portsmouth, Virginia) and which has a very high density of commercial and naval traffic. However, once a vessel bound for Cove Point enters Chesapeake Bay channel, the only deep water ships likely to be encountered will be primarily vessels outbound from Baltimore, Maryland. Because of the density of such shipping and the geographic features of Chesapeake Bay, the risk of collision or grounding is extremely low. Due to the wide expanse of open water at the Cove Point terminals, high winds may sometimes create problems of safely mooring LNG vessels.

5. Savannah, Georgia

The entrance from the sea to Savannah is direct via the Savannah River Channel. The channel is 500 feet wide and has an average depth of 35 to 40 feet at MLW. Navigational aids are good, but the channel is serpentine and from the sea buoy to Elba Island (site of the LNG terminal), approximately 16 NM long. While the past record of groundings and collisions in the channel is excellent to outstanding, the inherent geographic features of the channel indicate that every special precaution should be taken for the passage of LNG vessels.

6. Houston, Texas

Access to LPG and potential LNG terminals in the Houston area from the Gulf of Mexico is via Galveston Bay, thence the Houston Ship channel. The channel is long and circuitous, having a width of approximately 400 feet with an average depth of 40 feet at MLW. Normal navigational aids are good, and, since the installation and operation of a Vessel Traffic Service (VTS) by the U.S. Coast Guard, overall navigation aids are excellent. Channel traffic density (deep water vessels as well as barge traffic) is very high. Due to channel width and configuration and the density of traffic, the potential for collision in head-on-head meeting situationsor for groundings to avoid collision is high. The past record of minor collisions in the channel confirms this.

APPENDIX VII

CONTENTS | PAGE

APPENDIX VII-1

SOME LNG TRUCK ACCIDENTS

Date	Location	Transport Company	Description
6/25/71	Waterbury, Vt.	Capitol	*Blowout, hit rocks by road, hole, 20% spilled, no fire, remainder dumped.
8/28/71	Warner, N.H.	"Lowell Gas" (Gas, Inc.)	Driver fatigue, drove off road. Rollover cracked fittings. Small gas leak, no fire.
10/8/71	N. Whitehall, Wisc.	Indianhead	*Head-on collision with truck, gasoline and tire fire, no cargo loss.
10/73	Raynham, Mass.	"Andrews & Pierce"	Truck side swiped parked car. Brakes locked & trailer overturned. No cargo on board no fire.
1973	Rt. 80 & 95 Jct., N.J.	Chemical Leaman	Driver couldn't negotiate turn off. Rollover demolished tractor; $40,000 damage to trailer; no fire.
2/18/74	Rt. 40, Hamilton Twp., N.J.	Gas, Inc.	*Faulty brakes caused wheel fire. Check valve cracked; 5% leaked out - the

Date	Location	Transport Company	Description
			report is unclear whether the LNG ignited or not.
2/21/74	McKee City, N.J.	Gas, Inc.	*Loose valve leaked LNG during transfer operation.
Winter 1975-76 Jan '76	Chatanooga, Tenn.	LP Transport	Rollover, no fire, caused by oil spill on exit ramp. Truck righted and continued delivery of cargo.
Winter 1975-76 Nov '75	Dalton, Ga.	LP Transport	Rollover, no fire. Driver swerved to avoid pedestrian, hit guard rail, and rolled over & down 80 ft. bank. $18,000 damage to trailer.
9/16/76	Pawtucket, R.I.	"Andrews & Pierce"	Car hit trailer at landing wheels, rollover, no LNG loss or fire.
3 or 4/77	Connecticut Tpk, Conn.	Chemical Leaman	Truck parked (with blowout) hit by a tow truck in rear. No leak or fire.
7/77	Waterbury, Conn.	LP Transport	"Single Wall" Lubbock hit in rear by tractor trailer, axle knocked off. No loss of cargo; in this case controls were

Date	Location	Transport Company	Description
			under the tank. Rollover.

*Accident report obtained from OHMO. Descriptions of other accidents from interviews with LNG trucking industry officials.

APPENDIX VII-2

ANALYSIS OF CAUSES OF SOME UNDERGROUND EXPLOSIONS

(From a list published in Appendix B of NFPA No. 328,1975.)

Location	Description
Savannah, Ga. June 1973 Gas in Manhole	An unknown gas had accumulated in a manhole and was ignited by a welder's torch.
Walthill, New Brunswick, Canada January 24, 1973 LP Gas Leak in Cave	A leak in an underground LP-Gas installation seeped through the ground and into a cave. When a light switch was thrown, an explosion occurred that seriously injured two boys.
Peabody, Mass. May 23, 1972 Flammable Liquids in Sewer	Flammable liquids from an unknown source leaked into the sewerage system and ignited from a welding torch at the sewerage treatment building. The ensuing fire completely destroyed the building.
Nashville, Tenn. January 18, 1970 Gasoline in Sewer	Gasoline that had leaked from a bulk storage plant entered the sewer system and, eventually, the sewerage treatment plant resulting in two explosions. The piping for the roof drain of a floating roof tank, which goes down inside the tank, had frozen and ruptured. Since the valve at the discharge end had been left open, gasoline flowed from that drain valve into the diked area surrounding the tank. The dike drain had also been left open, allowing the gasoline to flow out of the diked area into an open sewer connection nearby. The gasoline eventually made its way to the treatment

	plant, where the explosions occurred. It was estimated that 46,000 gallons of gasoline entered the sewer system.
Joliet, Ill. July 2, 1969 Gasoline in Sewer	A series of sewer explosions in the downtown business district blew out manhole covers and many windows. Exposed buildings were also damaged by fires, and large chunks of concrete were torn from the wall of the Illinois Waterway. The explosions were caused by ignition of gasoline fumes in the sewer lines. The source of the gasoline was a storage tank on the premises of a bottling plant. Vandals had broken into the plant and stolen some motor oil and possibly some gasoline. The pump was found running, and it was estimated that 850 gallons had entered the sewer system through a catch basin in the yard.
Manhattan, N.Y. January 3, 1969 Gas in Tunnel	Explosion of gas leaking from a ruptured 100-foot section of a 16-inch main caused the roadbed of Delaney Street to buckle in many places over a three-block area. The ignition source was not determined. Escaping gas burned along the street, damaging parked cars and exposed buildings. All street and subway traffic was halted, including the Williamsburg Bridge. Occupants were evacuated from 35 five-story tenement buildings. An unknown or forgotten 5-foot-diameter tunnel, two blocks long and containing a narrow-gage railroad track, was discovered under Delaney Street. Apparently the leaking gas has accumulated in the tunnel.
New York, N.Y. October 15, 1968 Gas Leakage in Manhole	Eight firemen and Consolidated Edison workmen were injured when a gas explosion and fireball erupted from a manhole at 42nd Street and

	Eighth Avenue. Subway and street traffic was snarled, and some buildings were evacuated. The accident was caused by ignition of gas leaking from a 2-inch pipe. Ignition source was not definitely established.
Indianapolis, Ind. December 8, 1966 Gasoline in Sewer	After a heavy rainfall, a 6,000-gallon gasoline tank in a service station under construction settled in the trench. The pipe connections broke, allowing about 1,000 gallons of gasoline to flow into the storm sewer. Explosions occurred about 1½ miles downstream, rocketing steel manhole covers high in the air and causing severe damage to the sewer line. Ignition source was not definitely determined but might have been sparking from electric cables in the sewer chambers.
Philadelphia, Pa. August 22, 1962 Vapors in Tunnel	Workmen were digging a 6-foot-diameter tunnel about 40 feet below grade level for an interceptor sewer. At 8:20AM, shortly after four workmen had descended into the tunnel by way of a vertical access shaft, an explosion occurred and flames leaped high into the air from the access shaft. While fire fighters were getting hose lines into operation, another blast occurred, shortly followed by several others. A second alarm was struck. The cause of the explosions is thought to have been ignition of vapor of petroleum products which came from bulk plants along the tunnel during the night.

Long Beach, Cal. December 17, 1959 Gas Leakage into Water Main	Workmen were cleaning a new but uncompleted 24-inch and 30-inch water main which was 2.6 miles in length. When two men did not come out at quitting time, two others entered a nearby manhole and struck a match causing an explosion. It was discovered that another explosion might have occurred several hours before. When firemen tested the manholes with combustible gas indicators, they found flammable mixtures at several locations. Apparently natural gas leaked into the pipe from an unknown source.
Los Angeles, Cal. February 27, 1956 Casinghead Gasoline Pipeline Break	Numerous fires, including 13 in buildings, occurred in an area 2 miles long and ½ mile wide after a contractor's mechanical ditch digger broke a sewer line, then a casinghead gasoline transmission line. An estimated 21,000 gallons of casinghead gasoline (Reid vapor pressure 60 psi) under 325 lbs. pressure escaped from the transmission line and entered the broken sewer. As casinghead gasoline flowed through the sewer it rapidly vaporized and built up sufficient pressure to force its way through water traps in sewer service connections in buildings.
Goldsboro, N.C. April 12, 1954 Leakage in Distribution Piping Systems	An explosion and fire in the business district was followed by a series of secondary lesser explosions at about 5-min. intervals in a nearby street sewer. Gas had entered one building through an abandoned gas pipe protruding into the basement and fire broke out within two or three minutes and burned for about two hours before it was extinguished.

Cleveland, Ohio September 11, 1953 Leakage of Flammable Liquids or Gases into Sewers	A tremendous underground explosion in a combination storm and sanitary sewer demolished 1.2 miles of pavement on West 117th Street killing one person and hospitalizing fifty-eight others. The blast threw manhole covers high into the air and broke out large chunks of concrete pavement some 20 feet by 10 feet in area. Gas mains and water lines were ruptured. A second blast occurred an hour later hurling more manhole covers into the air, but no one was hurt. At least 30 automobiles were heavily damaged or demolished in the blast. (Consultants hired to investigate concluded that the most probable cause was either industrial wastes or gasoline leaking into the sewer, or these in combination. See Chapter 5.)
Brighton, N.Y. September 21, 1951 Gas Accumulation in a Confined Space	Fires and explosions resulted in the loss of nineteen homes and serious damage to twenty-five additional buildings. The initial explosion, resulting from an accumulation of gas, took place in a regulator vault of the gas distribution system. The regulators, damaged by the force of the explosion, opened wide and allowed high pressure gas to pass into a system designed to operate at a lowpressure. This overloading resulted in numerous gas leaks within buildings which caused a series of explosions and fires in the affected area. The exact cause of the initial explosion within the regulator vault was never fully determined.

APPENDIX IX

RECENT BOMBING INCIDENTS

INTRODUCTION

The information contained in this appendix was compiled from the FBI Bomb Data Program Incident Summaries for the period 1974 through 1977.

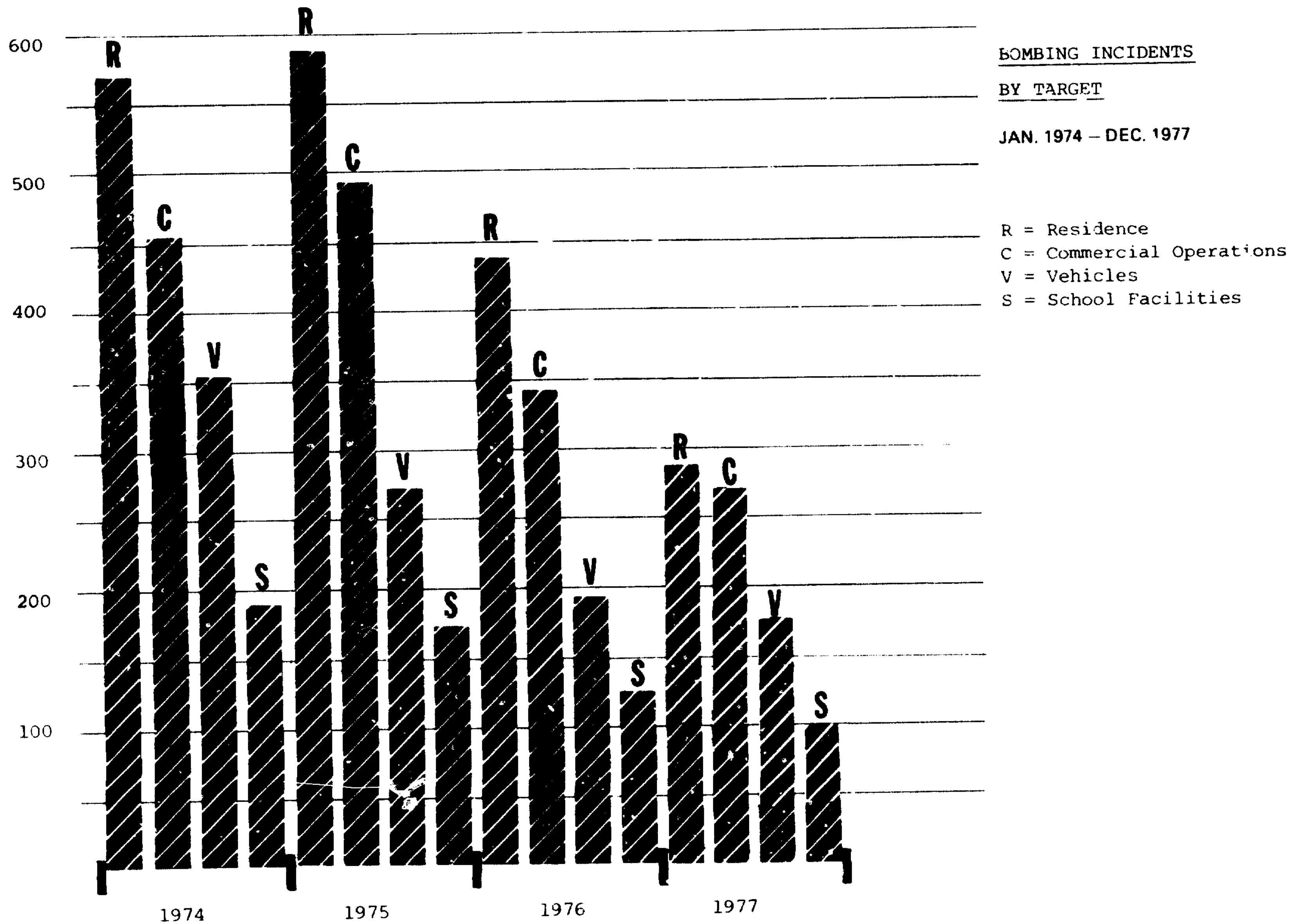
Attempted and actual bombing incidents declined 37 percent from 2,074 reported in 1975 to 1,314 reported in 1977. This is the lowest number of incidents reported since the special survey was first published in 1972. As in prior years, residences led all other categories as targets of these incidents: one of every four. Regionally, the western states reported the highest number of bombing incidents, close to one of every three. Cities of more than 250,000 population were the most frequent site of bombing incidents: one of every three.

There were 50 deaths and 212 injuries resulting from bombing incidents in 1976, 22 deaths and 159 injuries in 1977. Nearly one of every four persons killed or injured in bomb or incendiary explosions was a perpetrator. There is no doubt that these premature explosions spared the lives of many others. Innocent bystanders were the most frequent victims—almost two of every five—as a result of these crimes from 1972 to 1976. Among those killed in 1976 were five law enforcement officers—more than in any prior year since the survey was begun.

Bombings in 1977 caused property damage exceeding $8 million.

Figure IX-1 is a graph of the Bombing Incidents by Target. Figure IX-2 is a graph of the Bombing Incidents by Population Group. Figure IX-3 is a graph illustrating personal injuries due to bombings.

FIGURE IX-1


BOMBING INCIDENTS
BY TARGET
JAN. 1974 – DEC. 1977
R = Residence
C = Commercial Operations
V = Vehicles
S = School Facilities
600
500
400
300
200
100
R
C
V
S
1974
1975
1976
1977

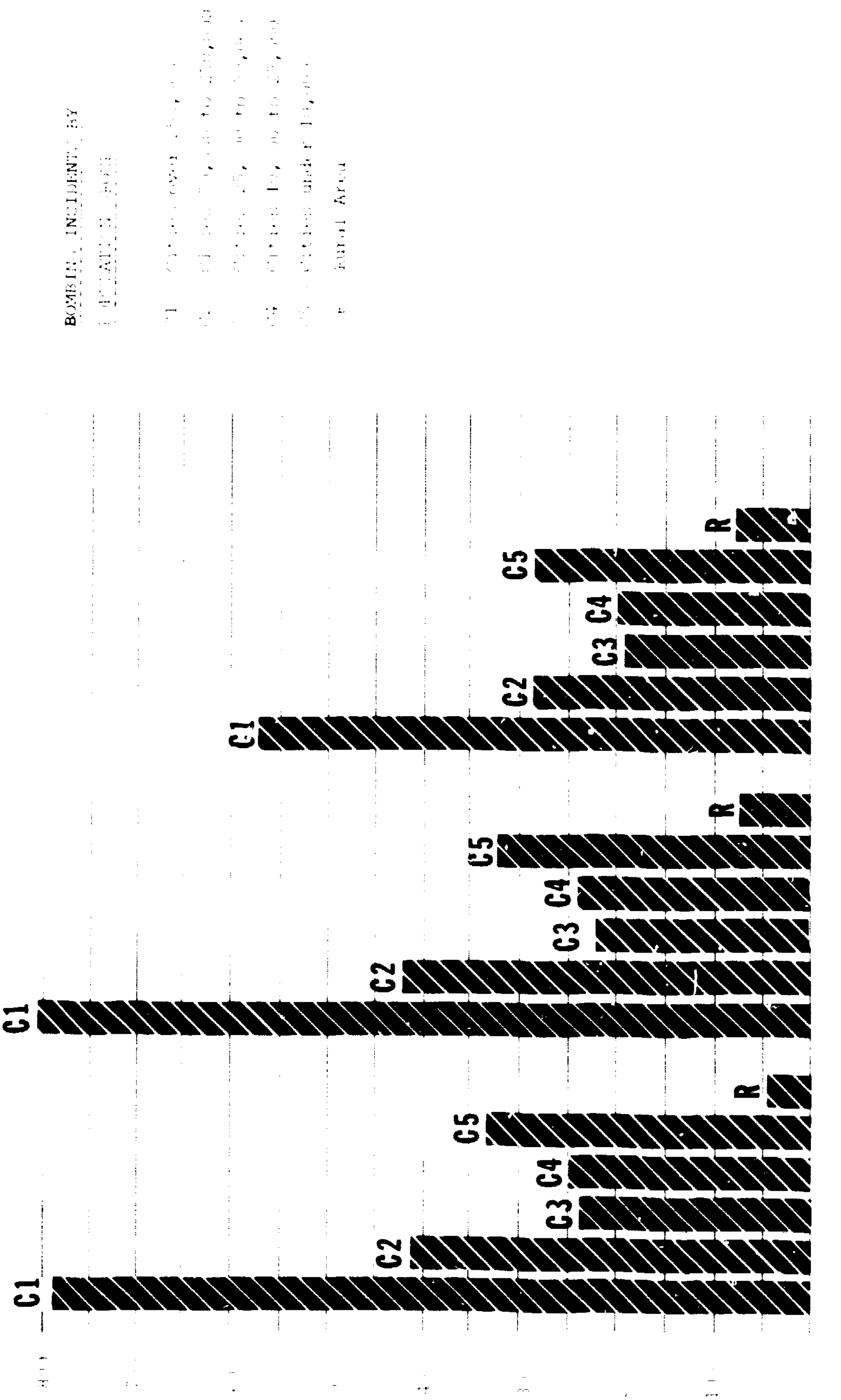
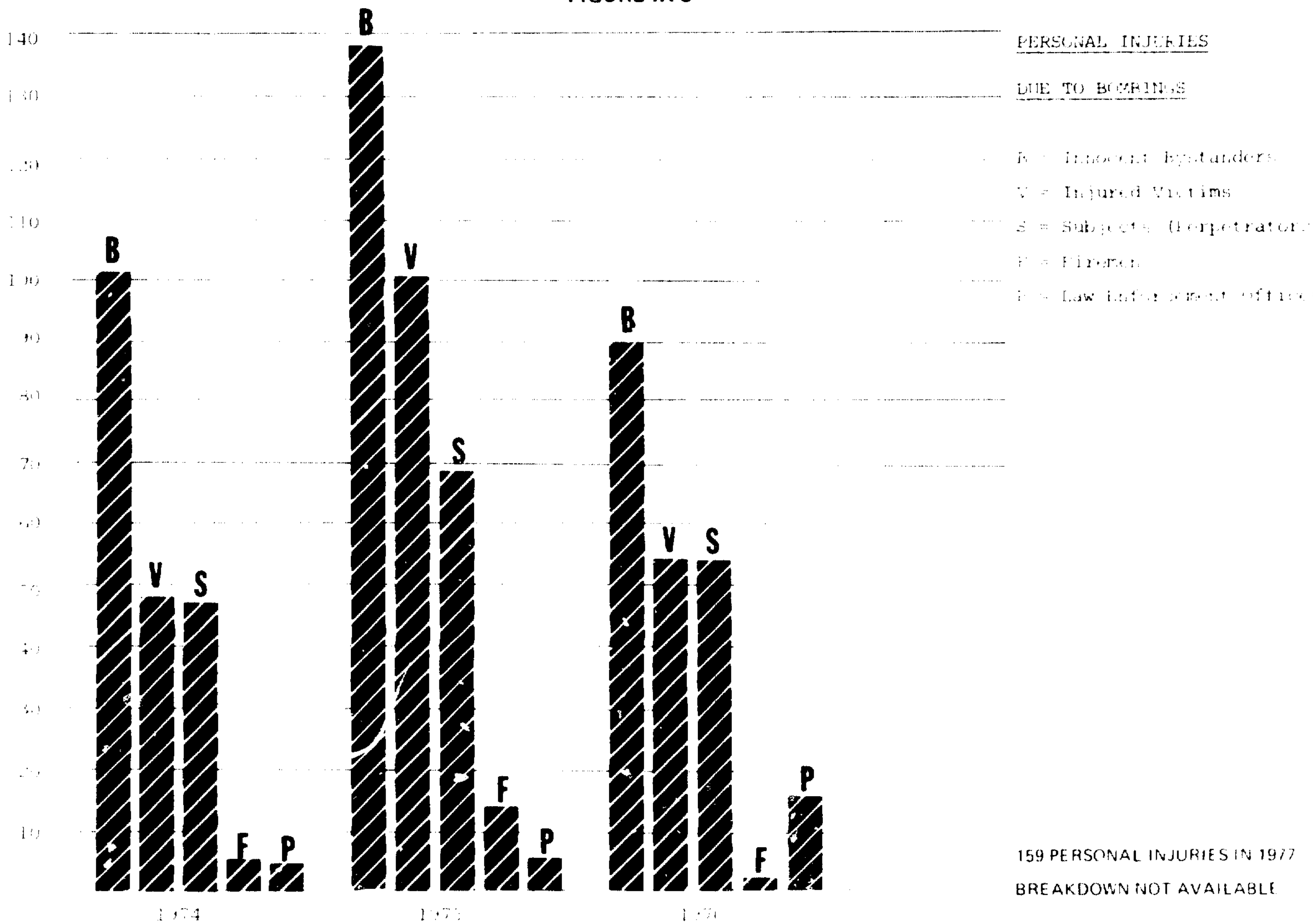


FIGURE IX-2

FIGURE IX-3


140
PERSONAL INJURIES
DUE TO BOMBINGS
B = Innocent Bystanders
V = Injured Victims
S = Subjects (Perpetrators)
F = Firemen
P = Law Enforcement Officers
B
V
S
F
P
1974
159 PERSONAL INJURIES IN 1977
BREAKDOWN NOT AVAILABLE

BOMBING DATA

1. Bombing Incidents

Table IX-1 below covering the period 1972 thru 1977 is a summary of the total actual and attempted bombings, including type of incident, property damage, and injuries and deaths.

Table IX-1
BOMBING INCIDENTS
1972 through 1977

Year	Total, Actual & Attempted Bombings	Actual		Unsuccessful		Property Damage (Dollar Value)	Personal Injury	Death
		Explo.	Incend.	Explo.	Incend.			
1972	1,962	714	793	237	218	7,991,815	176	25
1973	1,955	742	787	253	173	7,261,832	187	22
1974	2,044	893	758	236	157	9,886,563	207	24
1975	2,074	1,088	613	238	135	27,003,981	326	69
1976	1,570	852	405	188	125	11,265,426	212	50
1977 *	1,314	984	330	-	-	8,926,000	159	22

*Actual and attempted incidents not differentiated in the preliminary 1977 Incident Summary

2. Bombing Incidents by Certain Prominent Targets

Table IX-2 is a comparison of bombing incidents by certain prominent targets for the years 1975 and 1976. Although the number of incidents involving public utilities is a small percentage of the total, there were 53 explosion type incidents in the past two years, approximately one every two weeks.

Table IX-2
BOMBING INCIDENTS BY CERTAIN PROMINENT TARGETS
1975 vs 1976

Target	Totals		Actual				Attempt			
			Explo.		Incend.		Explo.		Incend.	
	1975	1976	1975	1976	1975	1976	1975	1976	1975	1976
Residences	582	433	234	189	255	162	42	40	51	42
Commercial Operations	485	335	275	168	127	105	56	36	27	26
Vehicles	273	192	134	102	70	47	47	26	22	17
School Facilities	165	126	87	75	48	31	18	14	12	6
Law Enforcement	76	47	31	16	27	16	12	7	6	8
Government Property	62	38	37	23	13	6	9	6	3	3
Persons	43	82	26	37	4	4	12	32	1	9
Public Utilities	41	28	33	20	1	5	6	3	1	...

3. Bombing Casualties by Apparent Motive

Table IX-3 lists the casualties by category versus the apparent motive of the attacker. By far the largest number of injuries and deaths appears to be motivated by personal animosity.

Table IX-3
BOMBING CASUALTIES BY APPARENT MOTIVE
1976

Motive	Totals		Law Enf. Officers		Firemen		Intended Victims		Innocent Bystanders		Perpetrators	
	Injury	Death	Injury	Death	Injury	Death	Injury	Death	Injury	Death	Injury	Death
TOTALS	212*	50**	14	5	3	-	52	22	90	9	52	13
Anti-"Establishment"	1	-	-	-	-	-	-	-	-	-	1	-
Extremist	11	-	-	-	-	-	-	-	11	-	-	-
Labor Dispute	4	-	1	-	-	-	1	-	2	-	-	-
Malicious Destruction	30	2	-	-	-	-	-	-	14	-	16	2
Monetary Gain	5	2	-	-	-	-	4	-	-	-	1	2
Personal Animosity	63*	24**	7	3	1	-	32	14	20	4	2	2
Political	27	3	4	1	-	-	1	2	22	-	-	-
Racketeering	3	3	-	-	-	-	1	2	2	1	-	-
Unknown	48	14	2	1	2	-	10	4	19	3	15	6
Other	20	2	-	-	-	-	3	-	-	1	17	1

*Includes one State Arson Investigator
**Includes one Army Demolition Expert

SELECTED INCIDENTS

Given below is a selected list of incidents occurring at public utility and petroleum company facilities from 1974 through May 1977.

1. Colorado - March, 1974

The Mapleton Power Substation of the Public Service Company of Colorado in Adams County was the target of a bombing on March 8. A large pipe bomb or similar device was placed next to a transformer at the substation and detonated. Extensive damage, estimated at $250,000, occurred.

2. Pennsylvania - June, 1974

At 9:29 p.m., June 13, the Pittsburgh Police Department was notified of a telephone warning received by the Gulf Oil Corporation that a bomb was in their facility. The caller said that he was with a terrorist group and that a bomb was in the building and would detonate in 17 minutes. An explosion occurred on the 29th floor of the oil company building, resulting in $300,000 to $500,000 damage. A "communique" issued by the same group claimed credit for the bombing as a reprisal for the oil corporation operations in an African country.

3. Oregon - October, 1974

During October, eleven power transmission towers were discovered bombed in four different locations. Three towers were bombed in the Maupin area, three near

Brightwood, three near Parkdale, and two near Sandy. At least three of the towers were toppled as a result of the explosions. Damage has been estimated at over $200,000.

A series of extortion letters, mailed to the Federal Bureau of Investigation at Portland and to a Portland area daily newspaper, demanded payment of $1 million and threatened a "blackout" of Portland if demands were not met.

4. Kentucky - December, 1974

During November and December, twenty natural gas transmission lines and two natural gas cooling towers belonging to a Kentucky-West Virginia gas company were targets of bombing incidents in various areas of Kentucky. The gas pipe lines varied in size from 2 inches to 20 inches in diameter. Dynamite bombs were used in each of the incidents, which caused an estimated $92,650 in damage. In many areas service was disrupted. The motives are believed to stem from labor disputes. There were no injuries or deaths.

5. California - March, 1975

Facilities belonging to a gas and electric company were the targets of bombings on March 20, 27, and 29. During the early morning of March 20, three towers at San Bruno were bombed. Damage was slight, and service was not interrupted.

At approximately 11:05 the same evening three more towers were bombed in Alameda County. Pipe bombs were utilized in these bombings and damage was estimated at $500.

Shortly after midnight on March 27, detonation of five more pipe bombs occurred at utility stations in San Jose. These attacks caused extensive damage to three power transformers and two oil switches. The resulting loss of power affected 35,000 people. Damage was set at $80,000 to $100,000.

On March 29, a transformer at Rancho Cordova was bombed. Twenty thousand dollars in damage resulted.

6. California - April, 1975

On April 4, at 9:00 p.m., a telephone warning was received by a San Francisco television station that a bomb was located in a building owned by Standard Oil of California. A second warning was received at 9:30 p.m. by a telephone operator, during which the caller stated that a bomb would detonate at 10:00 p.m. At approximately 9:34 p.m., an explosion occurred at the building mentioned in the threat. Damage to the building and surrounding area has been estimated at $300,000.

7. California - September, 1975

On September 26, a major oil company was the target of a bombing claimed by an extremist group. An estimated $100,000 damage was done to two 5,000-barrel oil storage tanks at an oil company facility near Coalinga. A crude high explosive device was utilized. The tank which was closest to the bomb contained 3,000 barrels of water.

8. Washington - December, 1975

An anonymous male caller representing an extremist group telephoned the Seattle Police Department at 11:30 p.m., on December 31, and advised that there were bombs at a Seattle power transformer and at a supermarket chain office in Bellevue. At approximately the same time, an explosion occurred at the distribution center office building of the supermarket chain in Bellevue. About fifteen minutes later, a second bomb exploded next to a water tower and pumping station near the same building. In the same time period, an explosive device detonated at a Seattle city light substation. All of the explosions were caused by pipe bombs with timing devices. Total damage at the three locations has been estimated at $102,500. A subsequent communique from the group stated that the attacks were in support of striking city electrical power workers and also in support of farm workers who had been exploited by the supermarket chain.

9. California - May, 1976

One person was killed and one other injured while they alledgedly attempted to place an explosive device inside the locked, fenced area of a hydroelectric power station. At approximately 11:00 p.m. on May 15, the two men entered the unguarded facility with a bomb, which detonated prematurely, resulting in the casualties. A third suspect, who escaped injury, was acting as lookout. Minor property damage has been estimated at $1,500.

10. California - October, 1976

An extremist group's demands for assistance to poor and working class people were demonstrated when they attempted to bomb a gas and electric power facility in Mill Valley on October 1, the management of which the group accused of insensitivity to the needs of underpriviledged persons. Two explosive devices were found and rendered safe by the San Francisco Police.

11. California - January, 1977

On January 19, a bomb exploded at a utility company in Sausalito. A newspaper received a communique from the Eugene Kuhn Unit of the New World Liberation Front (NWLF). The communique claimed that the bombing was a retaliation for the death of an elderly man which had resulted from his electricity being turned off.

12. California - January, 1977

On January 22, in Olema, an improvised explosive device damaged a local utility company. A telephone caller said that the NWLF was responsible.

13. California - January, 1977

On January 27, in Monte Vista, a utility company was the scene of four pipe bombings. The NWLF claimed responsibility.

14. <u>California - February, 1977</u>

On February 2, at Cool, an improvised explosive device caused damage to a utility station.

15. <u>Utah - March, 1977</u>

On March 7, in Dutch John, a small improvised explosive device was found on the roof of a power plant dam.

16. <u>New Mexico - March, 1977</u>

On March 10, at Albuquerque, a newly installed power transformer sustained $2,000 damage in a bombing incident.

17. <u>New York - April, 1977</u>

On April 3, in New York City, a projectile was found at an oil company facility. It was a military mortar round and was dismantled in place by bomb technicians.

18. <u>California - April, 1977</u>

In Oakland, on April 14, transformers at a utility company substation sustained $25,000 damage caused by a bombing. The blast caused a brief power outage.

19. <u>California - April, 1977</u>

In Sonoma, on April 17, four pipe bombs exploded at a utility substation, disrupting power. The Eugene

Kuhn Unit of the NWLF claimed responsibility in an anonymous telephone call.

20. Michigan - May, 1977

At an oil company in Birmingham, on May 2, $100,000 worth of damage was caused by a bombing in the company parking lot. One vehicle was destroyed and several others damaged.

APPENDIX X

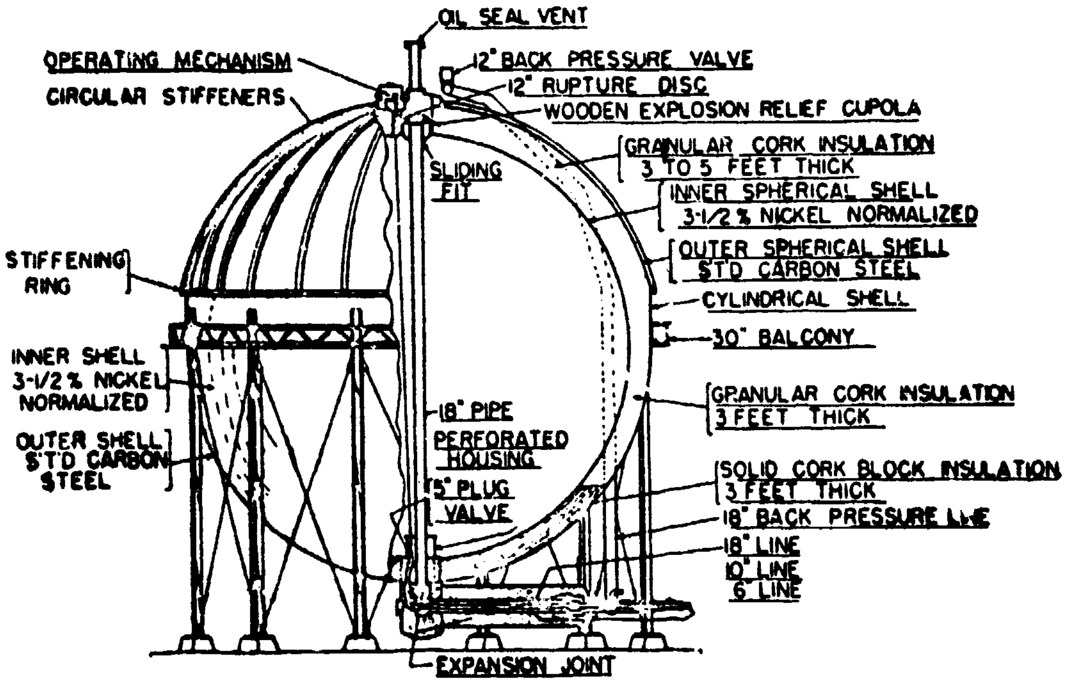
TANK DESIGN AND OPERATING EXPERIENCE, EAST OHIO GAS COMPANY

TANK DESIGN

The construction of the cylindrical LNG tank which the East Ohio Gas Company (EOG) put into service in the fall of 1943 at its Cleveland facility differed from that of the spherical tanks in several ways. The inner shell was supported by two concentric rings of heavy wooden posts, and rock wool was used for insulation because cork was unavailable during the war. (Present day tanks are insulated with perlite or polyurethane foam.) Pittsburgh Des Moines Steel Company (PDM) officials told the gas company that rock wool was a satisfactory substitute and would be used.[1] The decision to use rock wool was based in part on the fact that the inner tank rested on wooden supports rather than directly on the insulation, as in the case of the spheres. Figures X-1 and X-2 show the general features of both types of tanks.

Materials Used

The outer shells of the LNG storage tanks were built of ordinary open hearth steel, using conventional coated mild steel welding rod. The inner tanks, separated from the shells by 3 feet of insulation, had to be able to stand the -260°F temperature of LNG. A nickel alloy steel having at least 3.5% nickel and less than .09% carbon was used in all four inner tanks because it was thought to be satisfactory and was less costly than other materials

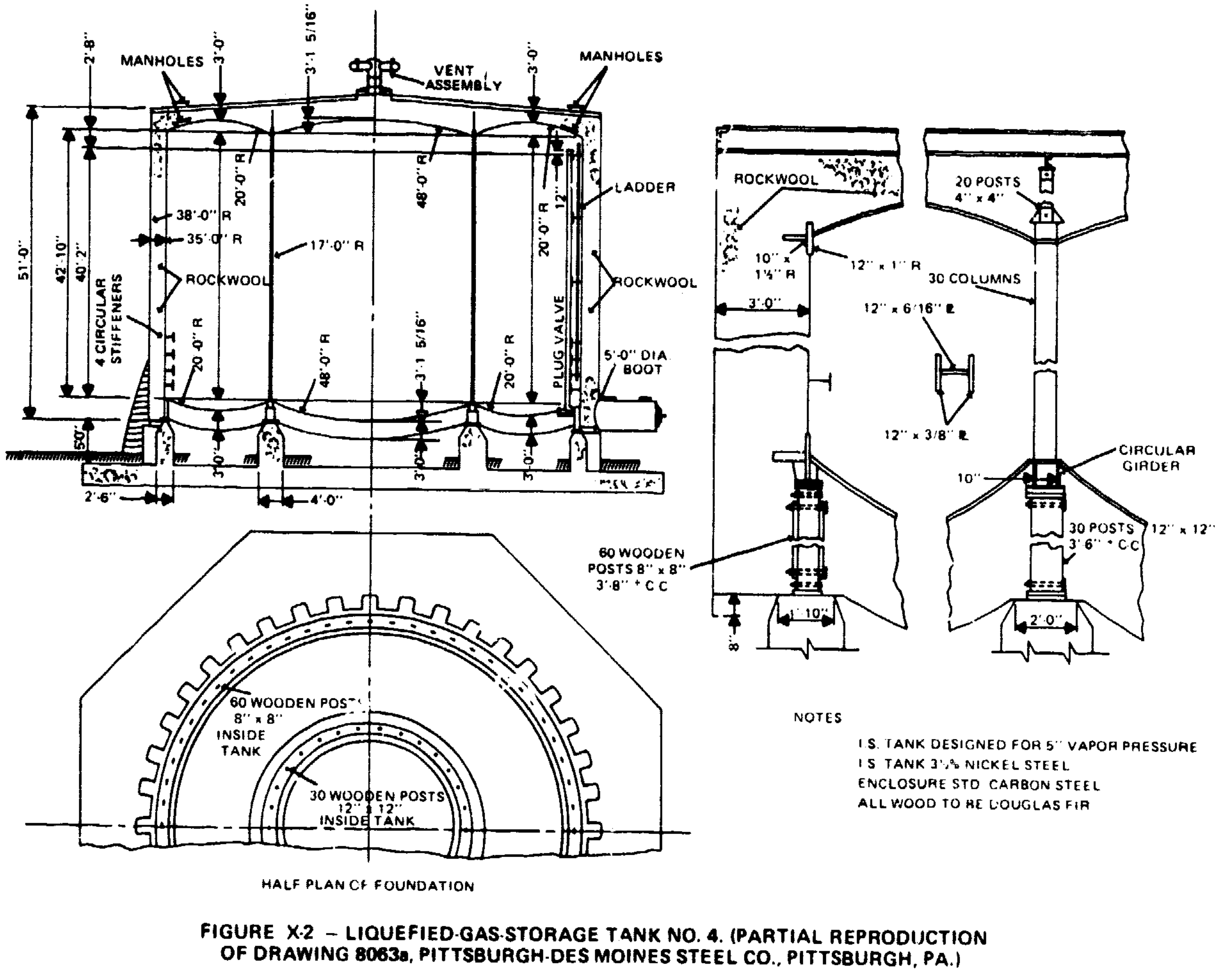


DRAWING NO 1

LIQUID GAS HOLDER

FIG. X-1 —Diagrammatic sketch showing general features of spherical storage tank.

SOURCE: BUREAU OF MINES REPORT OF INVESTIGATIONS 3867, MAY 30, 1945



NOTES

I.S. TANK DESIGNED FOR 5" VAPOR PRESSURE
I.S. TANK 3½% NICKEL STEEL
ENCLOSURE STD CARBON STEEL
ALL WOOD TO BE DOUGLAS FIR

FIGURE X-2 – LIQUEFIED-GAS-STORAGE TANK NO. 4. (PARTIAL REPRODUCTION OF DRAWING 8063a, PITTSBURGH-DES MOINES STEEL CO., PITTSBURGH, PA.)

SOURCE: BUREAU OF MINES REPORT OF INVESTIGATIONS 3867, MAY 30, 1945.

considered. (Present day tanks are built of 9% nickel alloy steel.) Extensive testing had been done at the pilot plant of the Hope Natural Gas Company to find appropriate cryogenic materials. Mr. H. C. Cooper, President of Hope Natural Gas, testified that he thought this steel, although not positively demonstrated as suitable for this specific application, had appropriate properties, including welding suitability. An outside agency inspected the welding in the spherical tanks, but EOG did not have the cylindrical tank welding inspected because it was not an "unfired pressure vessel" of the type requiring such inspection.

J.O. Jackson, Chief Engineer of PDM, was aware that the nickel alloy steel used was brittle at -250°F, but did not think that this should prohibit its use. After the accident in October, 1944 the technical consultants who investigated it for the Mayor (the Mayor's Board) noted that the piping into Tank 4 that would be exposed to temperatures below -50° were of nickel alloy steel, whereas those in the spheres were copper, a superior cryogenic material.

Stress Analysis

According to a consultant to the Mayor's Board, the designer of the cylinder analyzed stresses under assumptions that did not fully match the actual construction of the vessel.[2] The consultant also said:

> "A failure might have occurred due to stress concentration, low temperature brittleness, and shock, as from sudden closing of a heavy vent valve; but such effects cannot be computed mathematically."

He noted that stresses in the lower sidewall of the tank were quite large. It was the Board's opinion that the designers held primary stresses low, for safety, but did not produce calculations of certain secondary stresses. Some were unduly high, producing total stresses much higher than ordinarily allowed.

Support of LNG Storage Vessels

The outer shells of the spherical tanks were supported by steel uprights around their circumference. The three foot layer of cork insulation between inner and outer shells supported and cushioned the inner shell against shocks and stresses from outside the structure while accommodating itself to movements caused by changes in temperature and filling levels. Since this method could not be followed with rock wool insulation, the Tank 4 inner vessel was supported by two concentric rings on 90 heavy wooden posts, fitted with metal shoes at each end. The posts passed through the outer shell and connected the foundation with steel girders attached to the circumference of the inner vessel. The arrangement was designed to permit free movement during the expansion or contraction of the tank. After several woods were tested, Douglas fir was chosen for the posts.

OPERATING EXPERIENCE

The Cracked Plate - An Early Problem

After completion, the cylinder was charged with water to about half the depth of the tank. This equalled the weight of a full tank of LNG. The fill was held to that limit because the soil bearing capacity of the soil had been determined to be only 1400 psi—which left no margin for extra weight.

The first test introduction of LNG caused a crack in a plate at the bottom of the tank. The plate was repaired and another hydrostatic test performed. A second LNG test was then made, preceded this time by provisions for pre-cooling the tank and monitoring the progress of the filling. This time no cracks were found.

Vibrations and Other Problems

Industrial activity in the area, including substantial railway traffic, created discernible vibrations in the earth. J.O. Jackson said that they were noticeable in the engine room and required changes in two of the plant's compressors. The boiler room engineer testified that there were "awful vibrations" when trains passed on the nearby NY Central line. These vibrations were not, however, noticeable on the tank. While tests made during the investigation did not indicate unusually heavy vibrations, constant small vibrations might have caused the rock wool insulation to settle. In fact, it was frequently necessary to add insulation between the inner and outer shells of the cylinder.[3]

Prior planning did not consider the vibrations. The Bureau of Mines Report on the accident suggests that the cylinder was more vulnerable than the spheres to damage from this source because of the way it was supported. The engineer who supervised the post-disaster vibration measurements for the Mayor's Board observed that "the complete investigation will undoubtedly include fatigue stresses of the metal and welds at extremely low temperatures."[4] He also noted the possibility that resonances might have intensified the vibration effects.

The Bureau of Mines Report noted that the evaporation from stored LNG is almost entirely methane. After long storage, the mixture has a large percentage of ethane and propane.[5] The Mayor's Board said that thermal stratification, film stagnation on the surface of the liquid, and lowered molecular activity could ". . .very likely cause 'ebullition lag' or superheating that could be followed by a sudden violent ebullition (almost explosive vaporization), a behavior commonly termed 'bumping.'" The Board thought that this kind of behavior might produce localized cracking in brittle metal. The bumping could be caused by the shock produced in the routine testing of relief valves. While the critical valves were dampened by dashpots, it was demonstrated that their return to position after a test could produce a shock of some magnitude.

REFERENCES

1. Report of the Technical Consult Board of Inquiry for the Mayor of Cleveland on the East Ohio Gas Company Fire, Cleveland, Ohio, July, 1945, p. 45.

2. Mayor's Board, p. 103.

3. Mayor's Board, pp. 51, 54, 65.

4. Mayor's Board, p. 65.

5. Bureau of Mines Report of Investigations 3867, May 30, 1945.

APPENDIX XII

FEDERAL FUNDING OF SAFETY RESEARCH

This appendix consists of seven tables summarizing LEG research programs carried out or sponsored by Federal agencies. The tables are:

TABLE XII-1 - Coast Guard, DOT, Research and Development Relating to LNG, LPG, and Naphtha

TABLE XII-2 - Federal Railroad Administration, DOT, Research and Development Relating to LPG

TABLE XII-3 - Other DOT Research and Development Relating to LNG, LPG, and Naphtha

TABLE XII-4 - Maritime Administration Research and Development Relating to LNG, LPG, and Naphtha

TABLE XII-5 - Federal Power Commission Research and Development Relating to LNG

TABLE XII-6 - NASA Research and Development Relating to LNG

TABLE XII-7 - ERDA Research and Development Relating to LNG and LPG

FEDERAL FUNDING OF SAFETY RESEARCH

TABLE XII-1 COAST GUARD, DOT, RESEARCH AND DEVELOPMENT RELATING TO LNG, LPG, AND NAPHTHA

REPORT TITLE OR PROJECT DESCRIPTION	REPORT DATE (STATUS)	TYPE OF RESEARCH	CONTRACT COST (DOLLARS)	CONTRACTOR	SUMMARY
"Hazards of LNG Spillage in Marine Transportation" (NTIS-AD-705078).	Feb. 1970	Basic	25,000	Bureau of Mines	Provided a basic understanding of LNG behavior on water, including boil off rates, spill spread rates and vapor dispersion. No ice formed and the energy input to the cloud was drawn almost exclusively from the gas/air mixing. Dense cloud layering persisted until below its lower flammable limit.
"Hazards of Spillage of LNG into Water" (NTIS-AD-754498)	Sept. 1972	Basic	75,000	Bureau of Mines	Continued above work in flameless explosions and vapor cloud burning. Consensus that the explosion phenomenon is hydrocarbon concentration sensitive and that the vapor cloud burning evidences a flashback to source.
Vapor Cloud Explosion Study					
Phase I "Explosion Hazards with Spills of Large Quantities of Hazardous Materials" (NTIS-AD-A001242)	Oct. 1974	Basic	C.G.*667,000 ERDA 300,000 OPSO 50,000 AGA 75,000	U.S. Naval Weapons Center at China Lake, California	Developed a theoretical model on non-ideal explosions and calculated the dispersion of a large LNG spill. Hemisphere tests of flame propagation through unconfined vapor clouds of propane were run, and an experimental plan for the future was prepared.
Phase II (NTIS-AD-A047585)	Nov. 1977	Basic	Incl. in Phase I Costs	"	Phase II - Hemisphere tests of various gases were continued. Explosive booster used in attempt to detonate free methane. No detonations observed. Tube investigations also conducted to determine run-up distances to detonation.
Phase III	In Process	Basic	Incl. in Phase I Costs	"	Phase III - Determine the fire hazards of an ignited spreading pool of LNG on water and from the ignition of the vapors of an already spread out vapor cloud. Also included were additional methane and methane/propane detonation tests.
Phase IV	In Process	Basic	180,000	"	Phase IV - Eight spills of 1500 gallons of LPG onto water were made in August, 1977. Four spills had immediate ignition with varying spill rates, and four spills had delayed ignition with varying spill rates.
Phase V	In Process	Basic	AGA 300,000 NASA 50,000 C.G. 125,000	"	Phase V - Four tasks (a) Development of rapid responsive methane sensor (b) Determination of solid explosive booster necessary to cause a steady state detonation in unconfined methane (c) Determination of thermal radiation from the maximum pool fire possible at NWC facility, and (d) Verification of wind-tunnel techniques by conducting vapor dispersion spill tests.

TABLE XII-1 COAST GUARD, DOT, RESEARCH AND DEVELOPMENT RELATING TO LNG, LPG, AND NAPHTHA (CONTINUED)

REPORT TITLE OR PROJECT DESCRIPTION	REPORT DATE (STATUS)	TYPE OF RESEARCH	CONTRACT COST (DOLLARS)	CONTRACTOR	SUMMARY
"Prediction of Lifetime Extreme Accelerations for Design of LNG Cargo Tanks" (NTIS-AD-779635)	March 1974	Applied	260,000	Naval Ship Research and Development Center	Development of a model to predict the extreme accelerations needed for the design of the cargo tanks in LNG vessels. Predicted extremes were compared to the Chemical Transport Industry Advisory Committee (CTIAC) proposed rates.
"Tanker Structural Analysis for Minor Collisions" (NTIS-AD-A031031)	Dec. 1975	Applied	183,000	M. Rosenblatt and Son, Inc.	Evaluated the phenomena that contribute to the ability of a longitudinally framed-ship, particularly a tanker, to withstand a minor collision (cargo tanks remain intact).
"Recommendations for Qualifications of LNG Cargo Personnel" Three Volumes (NTIS-AD-A026108, AD-A026109, and AD-A026110)	April 1976	Applied	95,000	Operations Research, Inc.	Recommended standards for the training and other qualifications of personnel of LNG ships and barges.
"Chemical Hazard Response Information System" (CHRIS) and "Hazard Assessment Computer System" (HACS) Nine Vols.	March 1976 Sept. 1976	Applied	2,000,000	A.D. Little Inc.	Provides information essential for timely decision making during emergencies involving the water transport of hazardous chemicals. Consequent damage to people and property were not assessed.
"Predictability of LNG Vapor Dispersion from Catastrophic Spills onto Water: An Assessment" (NTIS-AD-A040525)	April 1977	Applied	50,000	In-House	Analysis of 6 models of LNG vapor dispersion.
"Fire Safety Aboard Vessels" (NTIS-AD-A030619) and "Small Scale Tests on Control Methods for Some LNG Hazards" (NTIS-AD-A033522)	Jan. 1976 May 1976	Hazard Analysis	249,000	University Engineers, Inc.	Analytical examination of cargo spill and fire hazard potential associated with the marine handling of LNG. (Emphasis on handling operations.) The maximum controllable fire was defined. Tested the effectiveness of water spray on vapor dispersion and pool fire radiation and of dry chemicals on pool fires and obstructed pool fires.
"A Survey of the Effectiveness of Control Methods for Fires in Some Hazardous Chemical Cargoes" (NTIS-AD-A026300)	March 1976	Hazard Analysis	39,999	University Engineers, Inc.	Assessment of fire safety of marine bulk chemical carriers was hampered by lack of data and the inability to confidently scale-up small scale tests of fire extinguishment.
"Vulnerability Model - A Simulation System for Assessing Damage Resulting from Marine Spills" (NTIS-AD-A015245) and "Vulnerability Model User's Guide"	Ongoing May 1975	Hazard Analysis	495,000	Enviro Control, Inc.	Simulation model to predict results of marine spill; i.e., toxic cloud or thermal radiation from a burning pool, and estimated injuries, deaths and property losses for a specific location. Based on CHRIS and HACS models.
	TOTAL CONTRACT FUNDING		5,218,000		

*C.G.: Coast Guard, ERDA: Energy Research and Development Administration, OPSO: Office of Pipeline Safety Operations, AGA: American Gas Association.

TABLE XII-2 FEDERAL RAILROAD ADMINISTRATION, DOT, RESEARCH AND DEVELOPMENT RELATING TO LPG

REPORT TITLE OR PROJECT DESCRIPTION	REPORT DATE (STATUS)	TYPE OF RESEARCH	CONTRACT COST (DOLLARS)	CONTRACTOR	SUMMARY
Hazardous Material Tank Cars - Tank Head Protective "Shield" or "Bumper" Design (NTIS-PB-202624).	Aug. 1971	Applied	30,000	Association of American Railroads	Objective was to design a head shield to reduce the number of railroad tank car puncture accidents. Accident data, full-scale head impact tests, and cost/benefit analysis led to the selection of 3 head shield designs for further study.
RESEARCH BY CALSPAN CORPORATION (FORMERLY CORNELL AERONAUTICAL LABORATORY)					
A Study to Reduce the Hazards of Tank Car Transportation (NTIS-PB-199154).	Sept. 1971	Applied	95,000	Cornell Aeronautical Laboratory	The study found that the liquid feed for tank cars should be the controlling criteria for pressure relief sizing, not the current vapor feed. It also found existing heat flux criteria to be too low. Study recommended a 2 stage relief one for abnormal conditions other than fire and the second, "dump" stage to prevent explosions in fire conditions.
Development of a Computer Program for Modeling the Heat Effects on a Railroad Tank Car (NTIS-PB-241365/6ST).	Jan. 1973	Hazard Analysis		Calspan Corporation	A mathematical model was developed to represent the behavior of a rail tank car loaded with flammable liquid in a fire environment.
Cost/Benefit Analysis of Head Shield Coatings Applied to 112A/114A Series Tank Cars (NTIS-PB-241298/9ST).	March 1974	Applied		Calspan Corporation	A cost/benefit analysis of head shields on new and existing 112A/114A series pressure tank cars was performed based on a redistribution of accident dollar losses. Data and tank head protective designs were obtained from Railway Progress Institute (RPI) - Association of American Railroads (AAR) research program reports.
Cost/Benefit Analysis of Thermal Shield Coatings Applied to 112A/114A Series Tank Cars (NTIS-PB-241295/15ST).	Dec. 1974	Applied		Calspan Corporation	Thermal coatings were applied to tank cars to delay overheating and overpressurization which could cause a BLEVE.* Old accident data was updated to present dollars, and accident losses were re-evaluated.
Rail Hazardous Material Tank Car Design Study	April 1975	Applied		Calspan Corporation	Defined practical and economic safety improvements and identified safety research gaps which need to be closed. Particular attention was given to operational changes, head shields, modified couplers, thermal insulation, tank material changes, and safety relief systems modifications.
ON-GOING RESEARCH BY THE NATIONAL BUREAU OF STANDARDS					
Metallurgical Analysis of Steel Shell Plate Taken from a Tank Car Accident near South Byron, NY (FRA OR&D 5-47).	Oct. 1971	Applied	302,000	National Bureau of Standards	A steel sample was taken from a tank car that had been involved in an accident. The steel reportedly met industry specifications. Testing was done to determine if the sample conformed to the specifications and to determine if the steel was suitable for use in tank cars.

TABLE XII-2 FEDERAL RAILROAD ADMINISTRATION, DOT, RESEARCH AND DEVELOPMENT RELATING TO LPG (CONTINUED)

REPORT TITLE OR PROJECT DESCRIPTION	REPORT DATE (STATUS)	TYPE OF RESEARCH	CONTRACT COST (DOLLARS)	CONTRACTOR	SUMMARY
A Metallurgical Analysis of Five Steel Plates Taken from a Tank Car Accident near Crescent City, Ill. (FRA-OR&D 75-48).	March 1972	Applied		National Bureau of Standards	Five steel samples, of shell plates, head plates, and one combination head and shell plate, were taken from two tank cars which were involved in the accident for a similar analysis as the above.
A Metallurgical Analysis of Eleven Steel Plates Taken from a Tank Car Accident near Callao, Mo. (FRA-OR&D 75-29).	Sept. 1972	Applied		National Bureau of Standards	Eleven steel plate samples were taken from a tank car which was involved in an accident for a similar analysis as the above.
Analysis of Findings of Four Tank Car Accident Reports (NTIS-PB-251097/AS).	Jan. 1975	Applied		National Bureau of Standards	An overview of National Bureau of Standards tests of accident samples is presented. Metallurgical testing included a wide range of chemical, mechanical, and physical tests.
A Metallurgical Investigation of a Full-Scale Insulated Rail Tank Car Filled with LPG Subjected to a Fire Environment (FRA-OR&D 75-52).	Jan. 1975	Applied		National Bureau of Standards	A tank car, filled with 33,000 gallons of LPG, failed after 94 minutes of exposure to a jet fuel fire. The fragments were examined in the field and in the laboratory.
Hazardous Materials Tank Cars - Evaluation of Tank Car Shell Construction Material (FRA-OR&D 75-46).	Sept. 1975	Applied		National Bureau of Standards	A steel sample taken from a tank car accident was metallurgically tested to determine if it met specifications and how the head plate was fractured.
Impact Properties of Steels Taken from Four Failed Tank Cars (FRA-OR&D 75-51).	June 1976	Applied		National Bureau of Standards	An overview is presented of the results and findings of impact tests of tank car materials samples taken from cars involved in tank car accidents.
Mechanical Properties of AAR M128-69-B Steel Plate Samples Taken from Insulation Fire Tested Tank Car RAX 202 (FRA-OR&D 76-74).	June 1976	Applied		National Bureau of Standards	Studies were done to determine the high temperature mechanical properties and fracture behavior of AAR M128-B specification steel plates. The ambient temperature characteristics of the steel were also tested.

TABLE XII-2 FEDERAL RAILROAD ADMINISTRATION, DOT, RESEARCH AND DEVELOPMENT RELATING TO LPG (CONTINUED)

REPORT TITLE OR PROJECT DESCRIPTION	REPORT DATE (STATUS)	TYPE OF RESEARCH	CONTRACT COST (DOLLARS)	CONTRACTOR	SUMMARY
RESEARCH BY THE BALLISTIC RESEARCH LABORATORY (FIRST CONTRACT)					
Railroad Tank Car Fire Test: Test Number 6 (NTIS-PB-241207/OST).	Aug. 1973	Applied	367,000	Ballistic Research Laboratory	Ballistic Research Laboratories conducted a series of field tests using scaled model and standard size railroad tank cars. This test used scaled model tank cars with no thermal protection. The relief valve was turned ninety degrees from the vertical.
Railroad Tank Car Fire Test: Test Number 7 (NTIS-PB-241145).	Dec. 1973	Applied		Ballistic Research Laboratory	A fire test was conducted on a 1/5th scale model pressurized railroad tank car. The model, with a four inch thermal insulation with a .125 inch outer steel jacket, was loaded with propane and engulfed in a JP-4 jet fuel fire.
Fragmentation Metallurgical Analysis of Tank Car RAX201 (NTIS-PB-24125/2ST).	Aug. 1974	Applied		Ballistic Research Laboratory	A full-scale fire test was performed on a 33,000 gallon, DOT 112A340W non-insulated, pressure, rail tank car filled with LPG. After 24.5 minutes of fire exposure the tank car ruptured. The report identified the initial failure point, mapped the location of the fragments, and made a metallurgical analysis of the car.
The Effects of a Fire Environment on a Rail Tank Car Filled with LPG (NTIS-PB-241358/1ST).	Sept. 1974	Applied		Ballistic Research Laboratory	A 33,600 gallon tank car was instrumented and filled with LPG. After 24.5 minutes exposure to a jet fuel fire the car BLEVE'd. Mass flow rates and a discharge coefficient were obtained for the relief valve.
Comparison of Thermally Coated and Uninsulated Rail Tank Cars Filled with LPG Subjected to a Fire Environment (NTIS-PB-241702/OST).	Dec. 1974	Applied		Ballistic Research Laboratory	Two high pressure tank cars, one coated with a .318 cm thermal shield, were exposed to an intense hydrocarbon fire. A comparison of data shows that the thermal shield significantly lengthened the time before the tank car BLEVE'd.
ON-GOING RESEARCH BY THE BALLISTIC RESEARCH LABORATORY (SECOND CONTRACT)					
Preparation of the BRL Tank Car Torch Facility at the DOT Transportation Test Center, Pueblo, CO (NTIS-PB-251151/AS).	Nov. 1975	Applied	1,743,000	Ballistic Research Laboratory	Description of how the new test facility was instrumented and the test procedures that were developed.

TABLE XII-2 FEDERAL RAILROAD ADMINISTRATION, DOT, RESEARCH AND DEVELOPMENT RELATING TO LPG (CONTINUED).

REPORT TITLE OR PROJECT DESCRIPTION	REPORT DATE (STATUS)	TYPE OF RESEARCH	CONTRACT COST (DOLLARS)	CONTRACTOR	SUMMARY
A Comparison of Various Thermal Systems for the Protection of Rail Tank Cars Tested at the FRA/BRL Torching Facility.	Dec. 1975	Applied		Ballistic Research Laboratory	Investigated the thermal responses of steel plates when insulated with various coating systems. All plates were exposed to an LPG torch.
Relative Costs of Installed Coating Systems.	Sept. 1976	Applied		Ballistic Research Laboratory	Compared the relative costs of four coating systems for 112A/114A rail tank cars.
RESEARCH BY WASHINGTON UNIVERSITY					
Computer Simulation of Tank Car Head Puncture Mechanisms (FRA-OR&D 75-23).	Feb. 1975	Applied	420,000	Washington University	The mathematical model attempted to identify puncture mechanisms and quantify the coupler forces in three railroad yard accidents in which the coupler punctured the tank car shell head.
Nondestructive Impact Between Railroad Cars: Experimental and Analytical.	Jan. 1976	Applied		Washington University	Low-speed nondestructive simulated switch yard impacts were conducted to determine the kinematics involved in these impacts.
Theoretical Manual and Users Guide: Longitudinal-Vertical Train Action Model.	June 1976	Applied		Washington University	Described the mathematical model for simulating the longitudinal-vertical motion of railroad cars in impact situations and investigated the pehnomenon of coupler by-pass resulting from impact or squeeze.
Tank Car Head Puncture Mechanisms.	June 1976	Applied		Washington University	Three classification yard and one mainline accident were studied and analyzed using train-to-train collision tests and impact experiments.
	TOTAL CONTRACT FUNDING		2,957,000		

*BLEVE: Boiling Liquid Expanding Vapor Explosion

TABLE XII-3 OTHER DOT RESEARCH AND DEVELOPMENT RELATING TO LNG, LPG, AND NAPHTHA.

REPORT TITLE OR PROJECT DESCRIPTION	REPORT DATE (STATUS)	TYPE OF RESEARCH	CONTRACT COST (DOLLARS)	CONTRACTOR	SUMMARY
OFFICE OF HAZARDOUS MATERIALS OPERATIONS					
Risk Analysis in Hazardous Materials Transportation (NTIS-FB-230 810/4).	March 1973	Risk Assessment	32,500 44,500	Univ. of Southern California	Development of a model, using LPG data and methyl parathion and parathion data, to compare the risks of highway and railroad transportation. The model was subsequently computerized and integrated with the hazardous materials instant reporting system.
"Emergency Services Guide for Selected Hazardous Materials, Spills, Fire, Evacuation Area."	1973	Hazard	4,400	Chemical Propulsion Information Agency	Developed a booklet containing the potential hazards of selected chemicals and the immediate and follow-up actions, including evacuation distances, to be taken. The booklets were distributed to fire departments, police, carriers, and other organizations.
Hazardous Materials Training Course	April 1978	Hazard	180,000	National Fire Protection Association	Development of a training course for amergency services personnel to handle hazardous materials transportation incidents.
FEDERAL HIGHWAY ADMINISTRATION					
Bottom Loading of Flammable Liquids into Cargo Tanks with Vapor Recovery Systems, (DOT-FH-11-9091)	June 1977	Applied	53,400	Dynamic Science, Inc.	Reviewed devices and procedures for loading and unloading flammable liquids and the efficacy of loading lines.
Cargo Tank Integrity In Rollover Accidents. (DOT-FH-11-9193)	June 1977	Applied	69,500	Dynamic Science, Inc.	Physical tests of tank truck rollovers to determine the integrity of valving and piping and the potential for leakage.
Vehicle Handling and Control due to Cargo Shifting.	Final June 1978	Applied	69,000	Dynamic Science, Inc.	Study the effect of surge and high center of gravity cargoes on vehicle control and overturns.
OFFICE OF DEEPWATER PORTS					
Offshore Liquefied Natural Gas Terminals	Oct. 1977	Applied	70,000	Massachusetts Institute of Technology	Forecasted U.S. LNG imports to Y-2000. Identified alternative design and functional configurations of offshore LNG terminals. Based on environmental factors, existing regulations, and DOT policy, the report made recommendations for legislation and departmental policy actions necessary for offshore LNG facilities.
		TOTAL CONTRACT FUNDING	523,300		

TABLE XII-4 MARITIME ADMINISTRATION RESEARCH AND DEVELOPMENT RELATING TO LNG, LPG, AND NAPHTHA.

REPORT TITLE OR PROJECT DESCRIPTION	REPORT DATE (STATUS)	TYPE OF RESEARCH	CONTRACT COST (DOLLARS)	CONTRACTOR	SUMMARY
LNG Cryogenic Program (Progress Reports June and December each year).	On-going	Basic and Applied	FY73 300,000 FY75 150,000 FY76 150,000 FY77 65,000 FY77 35,000 FY77 50,000	National Bureau of Standards Boulder, Colorado	NBS work includes: a. LNG data book based on properties research: Metals - tested 5% and 9% nickel steel and 5083 aluminum for LNG containment systems. Insulation - tested the thermal properties of several insulating materials. Fluids - developed technical data on the properties of various mixtures of LNG. b. Custody transfer systems - assessed the inaccuracy in the photogrammetric tank volume survey consultation. Will provide advisory services to shipbuilders.
LNG Tank Design and Testing Facility Evaluation.	April 1973	Applied	30,000	Todd Shipyards Corp.	Evaluated the plant requirements for the proposed R&D facility at the National Maritime Research Center in Galveston, Texas.
LNG Technology Development	May 1973 July 1973 Oct. 1973	Applied	10,000	Todd Shipyards Corp.	Investigated the codes, standards, and regulations to be followed, and developed a conceptual design for the Galveston research center. Evaluated existing cryogenic containment systems.
A Study of Dynamic Loads Caused by Liquid Sloshing in LNG Tanks Vol. I (NTIS-COM-75-10517/1ST).	May 1974	Applied	142,000	Det Norske Veritas, Oslo, Norway	Investigated the effects of fluid properties on scaling liquid sloshing pressures and forces for both prismatic and spherical tanks.
LNG Test Tanks - Liquid Sloshing	Complete	Applied	20,000 5,000	Southwest Research Institute San Antonio, Texas	Provided technical expertise to MarAd for the evaluation of the Det Norske Veritas calculations and final report. Work included an investigation of the impact loads and dynamic forces on LNG tank walls and structural members by liquid sloshing.
Leakage Through Cracks In LNG Tankage (NTIS-COM-74-11630/25L).	May 1974	Applied	76,000	Versar Corp.	Comparison of experimental and theoretical techniques to investigate leakage through fatigue induced cracks in cylindrical test vessels constructed from aluminum alloys and 9% nickel steel. The generally higher values of leak rate predicted by the theory are explained on the basis of the observed crack geometry.
Closed Cycle Gas Turbine LNG Refrigeration System	June 1974	Applied	250,000	Air Research Phoenix, Ariz.	Investigated the application of closed cycle gas turbine to LNG reliquefication aboard ship.

TABLE XII-4 MARITIME ADMINISTRATION RESEARCH AND DEVELOPMENT RELATING TO LNG, LPG, AND NAPHTHA (CONTINUED)

REPORT TITLE OR PROJECT DESCRIPTION	REPORT DATE (STATUS)	TYPE OF RESEARCH	CONTRACT COST (DOLLARS)	CONTRACTOR	SUMMARY
Single Point Mooring Concept for Cryogenic Service	In Process Final June 1978	Applied	MarAd 55,000 PLMC* 18,000	Donaldson Assoc.	Analyze wave motions to study the effects of various sea states on a single point mooring concept for LNG service, design of concentric swivel, flexible hose, and self-sealing disconnect coupling for LNG.
"Analysis of LNG Marine Transportation for the Maritime Administration" Volumes I and II (Vol. I: NTIS-COM-74-11684/95T) (Vol. II; NTIS-COM-74-11685/65T)	Nov. 1973	Economic	377,000	Booz-Allen Applied Research	Volume I: Analyzed the potential size of the LNG tanker fleet required for projected U.S. LNG imports and the economic risks, such as shipbuilder overruns and the operator's exposure to off-hire, associated with U.S. LNG ship construction and operation and LNG importation. Volume II: Supply/price analysis of natural gas and substitution fuels, especially LNG imports. LNG analysis included the costing of first-generation LNG ship designs, the development of an LNG transportation system evaluation model, and the evaluation of environmental and regulatory considerations.
Nuclear LNG Tanker	March 1975	Economic	97,000	Alexander Marine Assn., New Orleans, Louisiana	Determined economics of nuclear and fossil fueled LNG carriers of 130,000 cubic meter capacity with 100,000 SHP and 160,000 cubic meter with 120,000 SHP on three trade routes: Sumatra to Los Angeles, Ecuador to Los Angeles, and Persian Gulf to Los Angeles.
Alternative Uses for LNG Ships	May 1976	Economic	15,000	National Maritime Research Center Galveston, Tex.	Investigated the possibility of back-hauling cargoes and the design requirements necessary for existing LNG tankers to carry alternative cryogenic cargoes in order to improve the operating economics of LNG tankers.
Management Strategies and Design Philosophies for LNG Ship Operators	In Process: Award Sep. 1977	Economic	80,000	MIT	Determine the economic benefit of incorporating design features prior to construction for carrying alternative cargoes in order to permit greater flexibility of operations and avoid costly lay-ups.
		TOTAL CONTRACT FUNDING	2,325,000		

*PLMC: Pacific Lighting Marine Company

TABLE XII-5 FEDERAL POWER COMMISSION RESEARCH AND DEVELOPMENT RELATING TO LNG

REPORT TITLE OR PROJECT DESCRIPTION	REPORT DATE (STATUS)	TYPE OF RESEARCH	CONTRACT COST (DOLLARS)	CONTRACTOR	SUMMARY
Expected Behavior of in LNG Release Under Specified Conditions.	Aug. 1973	Basic	4,800	Ecosystems, Incorporated	Analyzed the escape and dispersion of LNG vapor for: (1) instantaneous spill on water of the complete contents of a 100,000 cubic meter tanker and (2) accidental removal of the roof of a 900,000 bbl storage tank allowing slow evaporation of vapors. The distance and time to reach the lower flammable limit was determined for both cases and for several wind and weather conditions.
Barge Plume Analysis.	Oct. 1973	Hazard	8,500	Ecosystems, Incorporated	Application of LNG vapor behavior analysis for large-scale spills to a spill of the entire contents of a 5000 cubic meter LNG barge.
Probability Assessment of LNG Ship Accidents in the New York and Providence Harbors.	Feb. 1974	Risk Assessment	3,500	Dr. Theodore W. Horner And Ecosystems, Inc. (Sub)	The study estimated the probability of an "undesirable LNG event" (defined as a massive LNG spill on water from an LNG tanker accident that causes widespread damage) for both the Distrigas Staten Island facility and the Algonquin Providence, Rhode Island facility.
Probability Assessment of LNG Accidents on New York Barge Transits from Staten Island to Newton Creek and Steinway Creek.	May 1974	Risk Assessment	2,800	Dr. Theodore W. Horner	The "undesirable LNG event" probability model is applied to the movements of LNG by barge, from the Staten Island facility (Distrigas) to Brooklyn Union Gas Greenpoint Terminal and to the Consolidated Edison generating station at Astoria, NY. The probabilities calculated are predictions of the possibility that a barge accident will occur and, if so, that it will cause widespread damage.
Behavior of Massive LNG Spills from Storage Tanks at Prince William Sound, Alaska; and Behavior of Massive LNG Spills from Storage Tanks at Point Conception, Oxnard and Los Angeles Harbor, CA (Contract FP 1751).	June 1975	Risk Assessment	37,300	Meteorology Research, Inc.	The study analyzed and described the behavior of a 320,000 cubic meter spill of LNG, assuming a "worst case" spill. The study used a Gaussian vapor dispersion model combined with a population density analysis of the site vicinity to conclude that seven people would be at risk. This study also used the "worst case" spill to determine for each of the three sites the maximum downwind distance to the 5% lower flammable limit (LFL) of the vapor plume. A Gaussian diffusion model and a "real-world" dispersion model were used.
Risk Assessment of LNG Marine Operations for: Racoon Is., NJ Everett, MA Staten Is., NY (Rossville) Providence, RI (Contract FP 1768).	Dec. 1975 (Separate reports for each site)	Risk Assessment	32,400	Science Applications Inc.	The study for each site assessed the risk to the local populace of an LNG ship collision. The probability of occurrence and the effect of the fire were calculated to determine the number of expected fatalities and the annual accident frequency rate.
		TOTAL CONTRACT FUNDING	89,300		

TABLE XII-6 NASA RESEARCH AND DEVELOPMENT RELATING TO LNG

REPORT TITLE OR PROJECT DESCRIPTION	REPORT DATE (STATUS)	TYPE OF RESEARCH	CONTRACT COST (DOLLARS)	CONTRACTOR	SUMMARY
Risk Management Technique for Design & Operation of LNG Facilities & Equipment (NASA-CR-139183).	Dec. 1974	Applied	171,000	Kennedy Space Center and Boeing Aerospace Co.	Work performed for the New York City Fire Department to develop a risk management and facilities certification methodology applicable to LNG facilities.

TABLE XII-7 ERDA RESEARCH AND DEVELOPMENT RELATING TO LNG AND LPG

REPORT TITLE OR PROJECT DESCRIPTION	REPORT DATE (STATUS)	TYPE OF RESEARCH	CONTRACT COST (DOLLARS)	CONTRACTOR	SUMMARY
LNG Safety And Environmental Control Program:	Research Proposal: 1977-1982	Basic		Undesignated	
Vapor Generation and Dispersion			3,500,000		Objective: To develop an adequate validated capability to predict the characteristics of, and to control, vapor generation and dispersion from LNG release.
Fire and Radiation Hazards			2,000,000		Objective: To develop an adequate validated capability to predict the characteristics of, and to control, pool fire from LNG releases.
Flame Propagation			3,500,000		Objective: To develop an adequate validated capability to predict the characteristics of various aspects of vapor cloud deflagration and possible detonation and of flameless (nonchemical) reaction of LNG upon contact with water. (This task includes the so-called "fireball" event, in which a premixed vapor cloud combusts nearly simultaneously in all its parts, potentially emitting radiation at rates significantly higher than normal.
Release Prevention and Control			3,000,000		Objective: To develop an adequate understanding of the processes, phenomena, and other factors that could defeat release preventio or controlled release systems and their regulation.
Instrumentation and Technique Development			3,000,000		Objective: To ensure the capability to obtain high-quality data from experimental studies in this program by development and testing of new instrumentation and measurements techniques where current systems are inadequate.
Scale Effects Experiments			35,000,000		Objective: To conduct medium- and large-scale experiments involving LNG spills on both land and water, in order to establish scaling factors for the results of small-scale experiments and to confirm the accuracy and performance of improved mathematical safety models and control provisions to an acceptable level.
The Boiling Rate of LPG on Water.	Proposed: Final Rpt. in 1980	Basic	46,000 Subject to renewal	MIT	Laboratory-scale investigation of the boiling rate of LPG on water.
		TOTAL CONTRACT FUNDING	50,046,000		

APPENDIX XIV

CONTENTS | PAGE

APPENDIX XIV-1

LPG DEMAND

TABLE XIV-1 PROJECTED OVERLAND AND OVERWATER LPG IMPORTS TO THE U.S.[1]

(Million Cubic Meters)

	Gas Processors Association	FEA Advisory Committee	Poten & Partners Consultants[2]	Texas Eastern Transmission[3]	Pace Consulting Engineers	S.L. Lindsey[4]
1976	7.5	7.3	7.6	8.3		
1978	11.3	17.8	11.7			
1980	16.1	26.7	16.2 to 21.9	26.1	8.9	**13.5**
1985				36.2	15.1	**26.9**
1990					30.2	

1 Includes overland imports of 6.4 million cubic meters from Canada, with declining supply beginning 1981-1982. Generally, more recent projections of LPG imports have been scaled downward because LPG demand has been soft and LPG import projects have been delayed.

2 Poten estimates include a higher import volume if foreign production prices soften.

3 Adjusted to include Canadian imports for comparison purposes.

4 Does not include overland imports from Canada (estimated at 6.0 million cubic meters in 1980 and almost no imports in 1985). S.L. Lindsey estimate was done for GAO. **These projections are more likely to be too large than too small.**

TABLE XIV-2 LPG RETAIL CUSTOMERS, 1976

HOMES	10,772,600
FARMS	1,394,000
COMMERCE AND INDUSTRY	944,400
RECREATION VEHICLES	5,069,800

TABLE XIV-3 LPG APPLICATIONS

Residential & Commercial

- Kitchen Ranges
- Barbeque Grills
- Water Heaters
- Clothes Dryers
- Central Heating Systems
- Central Air Conditioning Systems
- Space Heaters
- Patio and Yard Lamps
- Patio and Pool Deck Heaters
- Recreation: Camp Cookers, Heaters, Lights, Refrigeration
- Infra-Red Heaters
- Laundry Equipment
- Greenhouses
- Incinerators
- Roofing Kettles
- Street Pavers

Internal Combustion

- Farm Tractors
- Industrial Lift Trucks
- Industrial Sweepers
- Stationary Engines
- Bus and Truck
- Automobile
- Portable Engines
- Refrigeration

Synthetic Rubber

Secondary Recovery of Petroleum

Miscellaneous

- Crop Dryers
- Flame Cultivation
- Weed and Insect Control
- Tobacco Curers
- Poultry Brooders
- Stock Tank Heaters
- Pig Farrowers

Industrial

- Standby Fuel
- Flame Cutters
- Metallurgical Furnaces
- Industrial Dryers
- Electric Generation
- Construction Heaters
- Refinery Fuel

Utility Gas

- Propane-Air Systems
- Propane Enrichment

Chemical

- Raw Materials
- Solvents

Source: NLPGA "1976 LP-Gas Market Facts"

TABLE XIV-4 LPG SUPPLY AND DEMAND BY P.A.D. DISTRICT - 1975
(In units of 1,000 cubic meters)

	P.A.D. Districts					
	1	2	3	4	5	Total U.S.A.
Supply	3,649	12,649	46,636	2,198	3,197	68,329
Demand	9,506	26,608	30,129	2,229	5,201	73,673
Excess (Deficit)	(5,857)	(13,959)	16,507	(31)	(2,004)	(5,344)
Imports:						
Canadian	333	2,840	-0-	906	730	4,809
Overwater	733	-0-	855	-0-	67	1,655
Total Imports	1,066	2,840	855	906	797	6,464
*Net Imbalance after imports Excess (Deficit)	(4,792)	(11,119)	17,632	875	(1,207)	1,120**

*Imbalances satisfied by inter-district movements
**Net inventory build-up

Source: Bureau of Mines, Mineral Industry Surveys. Crude Petroleum, Petroleum Products and Natural Gas Liquids: 1975 (final summary), prepared Feb. 24, 1977.

TABLE XIV-5 SALES OF LPG BY PRINCIPAL USES, 1976-1975
(In units of 1,000 cubic meters)

	TOTALS	
	1976	1975
RESIDENTIAL AND COMMERCIAL	27,683	26,574
INTERNAL COMBUSTION	4,428	4,400
INDUSTRIAL	3,981	4,474
UTILITY GAS	1,688	1,525
CHEMICAL & SYN. RUBBER	15,463	15,793
OTHER USES[1]	7,373	5,150
TOTALS	60,616	57,916

(1) Includes secondary recovery of petroleum, agricultural uses, and SNG feedstock.

NOTE: This data does not include LPG for use in the production of gasoline.

Source: NLPGA "1976 LP-Gas Market Facts" and Energy Information Administration.

TABLE XIV-6 SALES OF LPG BY STATES, 1968 and 1976
(In units of 1,000 cubic meters)

	1968	1976
Alabama	833	927
Alaska	18	55
Arizona	173	145
Arkansas	1,279	1,545
California	1,242	2,062
Colorado	703	781
Connecticut	257	361
Delaware	87	135
Florida	1,009	1,289
Georgia	716	1,176
Hawaii	47	165
Idaho	169	203
Illinois	2,112	3,731
Indiana	1,391	2,221
Iowa	1,493	2,626
Kansas	1,122	1,417
Kentucky	593	870
Louisiana	758	994
Maine	94	178
Maryland & D.C.	241	418
Massachusetts	258	403
Michigan	866	1,336
Minnesota	1,223	1,394
Mississippi	1,008	1,262
Missouri	1,790	2,088
Montana	268	226
Nebraska	746	1,042
Nevada	111	70
New Hampshire	114	258
New Jersey	354	473
New Mexico	448	392
New York	587	887
North Carolina	623	997
North Dakota	257	264
Ohio	939	1,247
Oklahoma	1,254	1,396
Oregon	165	113
Pennsylvania	516	888
Rhode Island	37	87
South Carolina	361	573
South Dakota	351	481
Tennessee	427	599
Texas	5,021	4,514
Utah	147	194
Vermont	92	150
Virginia	298	501
Washington	217	129
West Virginia	86	127
Wisconsin	1,127	1,506
Wyoming	265	258

NOTE: State Figures do not include chemical and synthetic rubber.

Source: NLPGA "1976 LP-Gas Market Facts" and Energy Information Administration.

TABLE XIV-7 U.S. FARMS USING LPG, 1976
(In units of 1,000 farms)

	Total Farms	LP-Gas Farms	% LP-Gas Farms		Total Farms	LP-Gas Farms	% LP-Gas Farms
Alabama	77.0	49	64	Nebraska	69.0	48	70
Arizona	6.6	4	61	Nevada	2.1	1	48
Arkansas	69.0	45	65	New Hampshire	3.0	1	33
California	74.0	30	41	New Jersey	8.4	3	36
Colorado	29.3	19	65	New Mexico	12.8	8	63
Connecticut	4.1	1	24	New York	58.0	24	41
Delaware	3.7	2	54	North Carolina	119.0	38	32
Florida	38.5	19	49	North Dakota	42.0	17	40
Georgia	71.0	45	63	Ohio	110.0	31	28
Idaho	27.1	7	26	Oklahoma	86.0	58	67
Illinois	120.0	81	68	Oregon	34.0	5	15
Indiana	98.0	50	51	Pennsylvania	72.0	18	25
Iowa	133.0	100	75	Rhode Island	.7	(1)	--
Kansas	79.0	53	67	South Carolina	45.0	17	38
Kentucky	119.0	55	46	South Dakota	44.0	23	52
Louisiana	45.0	27	60	Tennessee	114.0	27	24
Maine	7.6	3	39	Texas	202.0	135	67
Maryland	17.6	7	40	Utah	13.4	3	22
Massachusetts	5.4	2	37	Vermont	6.7	3	45
Michigan	75.0	26	35	Virginia	64.0	16	25
Minnesota	117.0	60	52	Washington	37.0	4	11
Mississippi	79.0	61	77	West Virginia	26.5	5	19
Missouri	134.0	101	75	Wisconsin	102.0	47	46
Montana	23.7	10	42	Wyoming	8.2	5	61
				TOTAL	2,733.4	1,394	51

(1) Less than 500.

NOTE: Alaska and Hawaii not included.

Source: NLPGA "1976 LP-Gas Market Facts" and Department of Agriculture.

TABLE XIV-8 AGRICULTURAL CROP DRYER SHIPMENTS 1963 - 1976

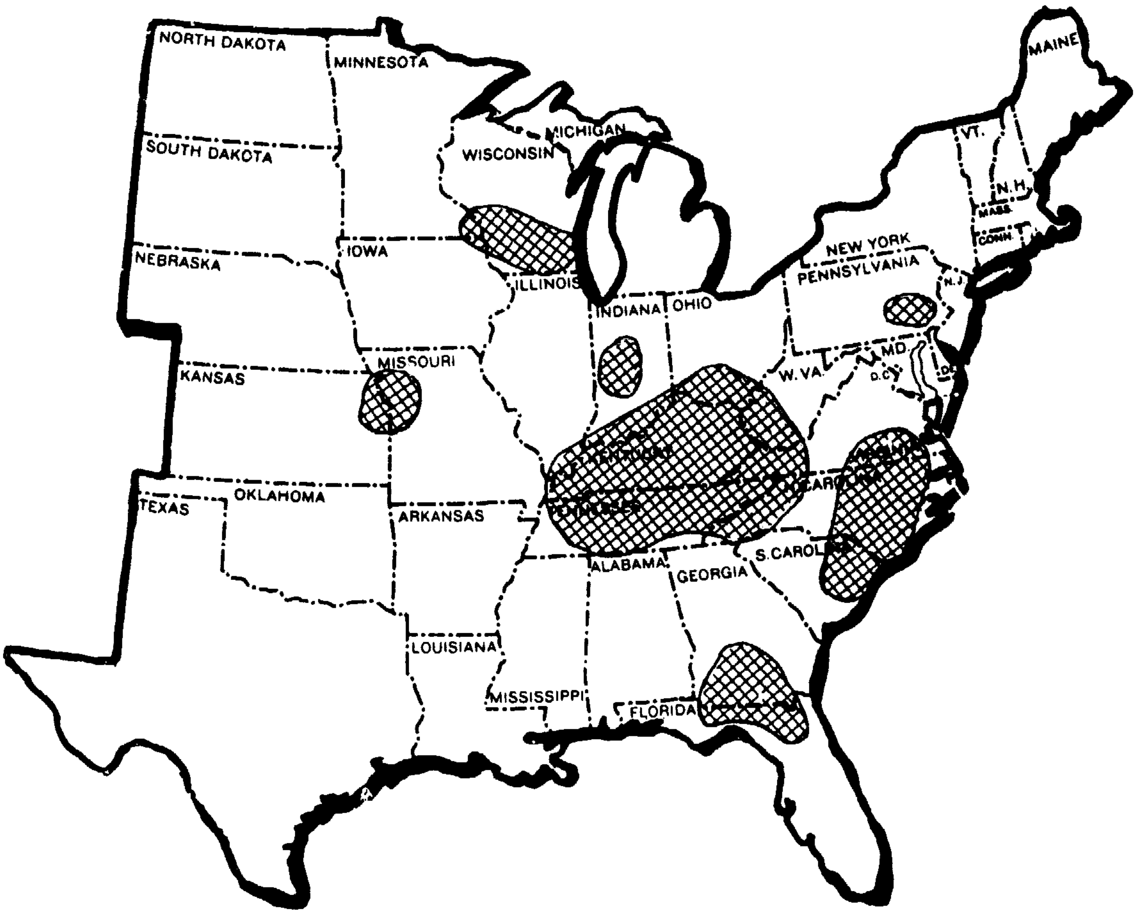
GRAIN, HAY AND SEED DRYERS

YEAR	Heated Types*	Unheated Air Types	Totals
1963	6,161	5,446	11,607
1964	6,061	5,169	11,230
1965	11,801	8,024	19,825
1966	14,904	2,535	17,439
1967	15,278	--	15,278
1968	17,318	925	18,243
1969	10,103	1,519	11,622
1970	7,153	2,019	9,172
1971	13,245	2,279	15,524
1972	16,456	3,358	19,814
1973	23,364	12,140	35,504
1974	34,781	15,936	50,717
1975	24,540	19,586	44,126
1976	25,242	22,429	47,671

*Consist of batch type, continuous flow, heated air and supplemental heater units estimated by manufacturers to be 90% to 95% LPG fueled.

Source: NLPGA "1976 LP-Gas Market Facts" and Bureau of the Census.

FIG. XIV-1 AREAS USING PROPANE TO CURE TOBACCO



COMPILED FROM VARIOUS COMPANY FILES AND INTERVIEWS

TABLE XIV-9 NATURAL GAS UTILITIES WITH PROPANE-AIR FACILITIES IN CLOSE PROXIMITY TO LPG MARINE IMPORT TERMINALS

UTILITY COMPANY	LOCATION	TERMINAL
Northern Utilities	Portsmouth, N.H.	Sea-3, Inc.
Boston Gas Co.	Everett, Mass.	Exxon
Algonquin SNG	Freetown, Mass.	Exxon/Petrolane
Bay State Gas Co.	Brockton, Mass.	Exxon/Petrolane
Commonwealth Gas Co.	Southboro, Mass.	Exxon
Providence Gas Co.	Providence, R.I.	Petrolane
Valley Gas Co.	Cumberland, R.I.	Petrolane
DelMar Va (Delaware Power and Light)	Wilmington, Del.	Sun Oil
Philadelphia Electric	Philadelphia, Pa.	Sun Oil
Philadelphia Gas Works	Philadelphia, Pa.	Sun Oil
Commonwealth Gas Co.	Chesapeake, Va.	Atlantic Energy
Virginia Electric & Power Co.	Norfolk, Va.	Atlantic Energy
Portsmouth Gas Co.	Portsmouth, Va.	Atlantic Energy
Suffolk Gas Corp.	Suffolk, Va.	Atlantic Energy
North Carolina Natural Gas	Fayetteville, N.C.	no existing terminal in area
South Carolina Electric & Gas	Columbia, S.C.	no existing terminal in area

Source: Brown's Directory of North American Gas Companies, 90th Edition, published 1976.

TABLE XIV-10 SYNTHETIC NATURAL GAS PLANTS CONNECTED BY PIPELINE TO LPG MARINE IMPORT TERMINALS

UTILITY COMPANY	LOCATION	TERMINAL
Boston Gas SNG	Everett, Mass.	Exxon (Everett)
Commonwealth SNG Co.	Chesapeake, Va.	Atlantic Energy (Chesapeake)
Columbia LNG Co.	Green Springs, Ohio	Coastal States (Corpus Christi) Warren Petroleum (Houston) Phillips Petroleum (Houston) Oiltanking (Houston)* Conoco (Atkinson Island)* T.E.T./NNG/Mobil/Texaco (Sabine Pass)*

*Planned terminal

APPENDIX XIV-2

LPG MARINE IMPORT TERMINALS

TABLE XIV-11 MARINE TERMINALS IMPORTING SMALL QUANTITIES OF LPG

COMPANY	LOCATION	PHYSICAL LIMITATION
ARCO*	Philadelphia, Pa.	Ship draught is 22 feet
Gulf Oil Corp.	Philadelphia, Pa.	Unloading rate and storage capacity
Tropigas Inc.	Port Everglades, Fla.	Storage capacity and LPG demand in Florida
Warren Petroleum Co.	Port Everglades, Fla.	Storage capacity and LPG demand in Florida
Gulf Oil Corp.	Belle Chasse, La.	Unloading rate; LPG used for captive consumption at the alliance refinery
Petro-Tex Chemical Corporation	Houston, Tex.	Unloading rate

*Presently not in use.

TABLE XIV-12 ANNUAL HANDLING CAPACITY OF MAJOR LPG IMPORT TERMINALS[1]
(In units of one million cubic meters)

LOCATION	OWNER	1977	1980	1985	1990
Newington, N.H.	Sea 3	0.5	1.1	1.1	1.1
Everett, Mass.	Exxon	1.1	1.1	1.1	1.1
Providence, R.I.	Petrolane	0.7	0.7	0.8	0.8
Marcus Hook, Pa.	Sun Oil	0.3	1.0	5.6	5.6
Chesapeake, Va.	Atlantic Energy	1.0	1.0	1.0	1.0
*Plaquemine, La.	Dow Chemical	0	2.9	2.9	2.9
*Hackberry, La.	Cities Service	0.2	4.8	4.8	4.8
*Sabine Pass, Tex.	Mobil/N.N.G./T.E.T./Texaco	0	0	13.5	13.5
*Houston, Tex.	Conoco	0	0	7.9	7.9
*Houston, Tex.	Oiltanking of Texas	0	7.9	7.9	7.9
Houston, Tex.	Phillips Petroleum	1.0	1.2	1.2	1.2
Houston, Tex.	Warren Petroleum	2.4	9.8	9.8	9.8
Corpus Christi, Tex.	Coastal States	1.2	1.2	1.2	1.2
San Pedro, Cal.	Petrolane	1.3	2.1	2.1	2.1
Ferndale, Wash.	California Liquid Gas	0.7	0.7	0.7	0.7
Total		10.4	35.5	61.4	61.4

1. 50% of capacity if unknown

*Planned LPG terminals

TABLE XIV-13 PROJECTED LPG MOVEMENT THROUGH MARINE IMPORT TERMINALS [1]
(In units of one million cubic meters)

Location	Owner	1980	1985
Newington, N.H.	Sea-3	0.5	0.8
Everett, Mass.	Exxon	0.8	1.0
Providence, R.I.	Petrolane	0.5	0.8
Marcus Hook, Pa.	Sun Oil	0.8	1.7
Chesapeake, Va.	Atlantic Energy	0.6	0.9
Plaquemine, La.	Dow Chemical	0.2	1.4
Hackberry, La.	Cities Service	1.2	2.6
Sabine Pass, Tex.	TET/NNG/Mobil/Texaco	-	5.3
Houston, Tex.	Conoco or Oiltanking	2.8	3.8
Houston, Tex.	Phillips Petroleum	0.4	1.2
Houston, Tex.	Warren Petroleum	3.6	4.4
Corpus Christi, Tex.	Coastal States	1.2	1.2
San Pedro, Cal.	Petrolane	0.8	[illegible]
Ferndale, Wash.	California Liquid Gas	0.3	0.7
TOTAL		13.5	26.9

1. We believe these projections are more likely to be too large than too small.

TABLE XIV-14 LPG IMPORT TERMINAL PHYSICAL LIMITATIONS

Location	Owner	Maximum Ship Size (Ft.)		
		Draft	LOA*	Width
Newington, N.H.	Sea-3	34	640	100
Everett, Mass.	Exxon	39	800	---
Providence, R.I.	Petrolane	35	700+	---
Marcus Hook, Pa.	Sun Oil	38	1000	---
Chesapeake, Va.	Atlantic Energy	35	750	110
Plaquemine, La.	Dow Chemical	40	1250	---
Hackberry, La.	Cities Service	38	750	125
Sabine Pass, Tex.	NNG/TET/Mobil/Texaco	40	1000	---
Houston, Tex.	Conoco	39	950	---
Houston, Tex.	Warren	39	750+	116
Houston, Tex.	Phillips	36	750+	110
Houston, Tex.	Oiltanking	39	860	125
Corpus Christi, Tex.	Coastal States	38	775	135
San Pedro, Cal.	Petrolane	35	633+	---
Ferndale, Wash.	Cal Liquid Gas	36	800	---

*Length Overall

NEWINGTON, NEW HAMPSHIRE
Owner: SEA-3 Inc. (GAZOCEAN)

The Newington terminal is the northernmost site currently receiving LPG. Although the facility is non-urban, ships navigating the Piscataqua River pass downtown Portsmouth. The Newington terminal serves the local residential market when domestic supply becomes unavailable during the winter.

There is one 63,600 cubic meter aboveground, refrigerated LPG tank, but there is enough space to construct another tank of the same size. Additional land is available adjacent to the site to construct a 50 MMcf/d SNG plant. Granite State Transmission Company, serving New Hampshire and Maine, has a natural gas pipeline passing within 1,000 feet of the import terminal.

Current restrictions at the terminal and on the waterway to the site exclude ships larger than 40,000 cubic meters.

The terminal is north of most of the New England industrial market, and its imports thus incur an $8.00 per cubic meter charge for truck or rail transportation. This places the facility at a competitive disadvantage with the Exxon and Petrolane terminals for the Boston and Providence markets. Because of location and current winter/summer product use ratio, the current annual capacity is 500,000 cubic meters. Outloading is through three truck spots and six rail tank car spots which normally receive two rail switches per day.*

*"Rail Switch" - "One group of railcars on a train" switched into the receiving terminal at one time; in effect, a "delivery."

If additional storage and either LPG-air or SNG facilities were built, annual LPG capacity could increase to 1 million cubic meters, limited by the number and size of incoming vessels.

EVERETT (BOSTON), MASSACHUSETTS
Owner: Exxon Company U.S.A.

This urban site is close to the pipelines of two major gas transmission companies, Tennessee Gas Transmission and Algonquin.

The outloading capacity of this facility is substantially higher than others of like size because it supplies 1,600 cubic meters per day by pipeline to the Boston Gas SNG plant for feedstock. There are four rail car spots with two switches per day and three truck spots. The maximum daily throughput capacity is 6,900 cubic meters. The annual capacity is dependent upon the number of operational days of the SNG plant. With normal maintenance down time at the SNG plant, the annual handling capacity is about 1.1 million cubic meters. Land and environmental restrictions make it unlikely that additional storage can be added at this site. The existing storage is an aboveground 63,600 cubic meters refrigerated tank. The site is designed to handle ships of up to 40,000 cubic meters, but 52,000 cubic meter ships have offloaded partial cargoes.

PROVIDENCE, RHODE ISLAND

Owner: Petrolane Incorporated

This terminal is located in an urban area and delivers 800 cubic meters per day of propane by pipeline to the Providence Gas Company. No rail car service is available. There are three truck loading spots with daily maximum output of 4,500 cubic meters. The site's maximum annual handling capacity is 730,000 cubic meters. The facility has a single 63,600 cubic meter refrigerated aboveground storage tank. Due to land limitations, there is no possibility of expanding storage facilities.

The largest vessel to offload so far held 52,000 cubic meters, but Petrolane has a general policy restricting incoming vessels to 30,000 cubic meters due to the difficulty of providing adequate storage capacity for the larger vessels on a timely basis.

The terminal serves industrial and residential LPG users when cheaper domestically produced products are not available. The Algonquin SNG plant in Freetown, Mass., which uses naphtha as a feedstock, also gets imported propane from this terminal to upgrade the quality of its pipeline gas.

MARCUS HOOK, PENNSYLVANIA

Owner: Sun Oil Company

This terminal began to receive ships in December 1977. The rest of the facility was already operating in conjunction with the refinery operations. The site serves the eastern industrial fuel market and is near the proposed Transcontinental Pipeline SNG plant at Twin Oaks, Pennsylvania, which could use butane as a feedstock.

The Sun Oil Co. is negotiating with the Texas Eastern Transmission Corp. to use its LPG pipeline system. Reversal of the present LPG flow (from the Pittsburgh area to Marcus Hook) would give the Sun Oil Terminal access to markets in western Pennsylvania, Ohio, and upstate New York. The Marcus Hook leg of the Texas Eastern pipeline has a daily capacity of 3,200 cubic meters. LPG from the Gulf Coast would be displaced to markets in other regions.

The Sun LPG marine terminal has storage capacity of 183,000 cubic meters for propane and 62,500 cubic meters for butane. The oil refinery has storage capacity of 76,300 cubic meters for butane and 12,000 cubic meters for propylene. All LPG is stored in underground mined granite caverns.

Because LPG distribution from the terminal is only by rail and truck, the current handling capability of the facility is limited to 9,200 cubic meters per day and 1 million cubic meters per year. With pipeline connections to the Texas Eastern system and the proposed Transco SNG plant, berthing would become the limiting factor. Handling capability could be eventually increased to 5.6 million cubic meters per year.

CHESAPEAKE (NORFOLK), VIRGINIA

Owner: Atlantic Energy, Inc.

This facility supplies 1,100 cubic meters of butane per day by pipeline to the Commonwealth Natural Gas SNG plant which serves seven industrial companies in the Chesapeake area. Atlantic Energy, Inc., the owner and operator of the terminal, is jointly owned by Tropigas International and Virginia Bottled Gas of Virginia (owned by Commonwealth). The terminal has two 38,200 cubic meter refrigerated storage tanks. One is in butane service for the SNG plant; the other is used for importing propane. The site is located in a non-urban area with little surrounding population. A second 38,200 cubic meter propane tank will probably be in service by 1980. This will allow the facility to be serviced by 52,000 cubic meter ships.

The outloading facilities have seven rail car spots with three switches per day and two truck loading spots.

The daily maximum throughput is 5,100 cubic meters of propane and 1,100 cubic meters of butane. The total annual LPG handling capability is about 950,000 cubic meters. The terminal is connected to the Commonwealth Natural Gas system, which is interconnected to the Transcontinental Transmission line. The area it serves has a greater demand than the Dixie LPG pipeline can supply.

PLAQUEMINE, LOUISIANA
Owner: Dow Chemical Company

This facility is tied by pipeline to the Wanda Petroleum Company (a Dow Chemical subsidiary) storage and fractionation complexes at Napoleonville and Breaux Bridge, Louisiana. Naphtha is now being moved through the pipeline system. An additional line to move LPG is not currently programmed, but is possible in the future.

The Napoleonville/Breaux Bridge complex has a 16,000 cubic meters per day fractionation facility and 827,000 cubic meters of underground salt storage. It currently stores imported naphtha and domestic LPG. The butane is used in local refineries and the propane is sent via the Dixie LPG pipeline for use in the southeastern United States.

Many natural gas transmission lines start in this area and they could use LPG. Among them are lines owned by Southern Natural Gas, United Gas Pipeline, Texas Eastern Transmission, Florida Gas Transmission and others.

HACKBERRY (LAKE CHARLES), LOUISIANA
Owner: Cities Service Company

Cities Service recently announced plans to install by mid-1979 an LPG terminaling facility 17 miles south of Lake Charles on the Calcasieu Ship Channel which flows into the Gulf of Mexico.

Connected underground salt storage will be provided by two new 160,000 cubic meter wells. One will be for propane, the other for mixed butanes. The storage is in addition to an existing 8-well (1,270,000 cubic meter) Cities Service complex located on the West Hackberry salt dome. The storage caverns can receive LPG at an offloading rate of 45,000 cubic meters per day after warmup of the product. The storage complex is connected by pipeline to natural gas liquids plants, refineries, and the Dixie LPG pipeline, and receives product from Mt. Belvieu. The maximum annual offloading volume is limited by the local demand for butane and the ability to inject propane into the Dixie pipeline at Sulphur, Louisiana. The maximum annual volume will increase from an initial 1.9 million cubic meters to 4.75 million cubic meters by 1985. The facility will handle any ship of 75,000 cubic meters or less. Its location in the natural gas producing area gives this facility access to natural gas transmission lines owned by Natural Gas Pipeline Co., Columbia Gulf Transmission, Transcontinental Pipe Line, Tennessee Gas Pipeline and Michigan Wisconsin Pipeline Co.

SABINE PASS, TEXAS

Owner: Mobil Oil/Northern Natural Gas/Texas Eastern Transmission/Texaco

A terminal at the Texas/Louisiana border has been contemplated for some time and the owner consortium has announced that $5 million has been allocated for an analytical engineering study to be completed by mid-1978.

The terminal would be constructed by 1983 at the mouth of Sabine Pass on the Texas side of the river. The vessel offloading rate of 95,000 cubic meters per day would be the highest in the United States. The initial 1.75 million cubic meters of underground salt storage, to be washed from the Big Hill salt dome located near the terminal site, would be increased to 4 million cubic meters.

The terminal would be connected by pipeline to the Texas Eastern LPG pipeline some 40 miles north of the 260 acre Sabine Pass site and approximately 100 miles east of Houston. The terminal is designed to accommodate vessels up to 150,000 cubic meters.

Two gas transmission lines pass through the immediate area. One, owned by Natural Gas Pipeline Co., crosses the terminal property, and the Transcontinental Gas pipeline is close by.

ATKINSON ISLAND (HOUSTON), TEXAS
Owner: Continental Oil Company

A multi-owner terminal near Baytown, Texas, at the mouth of the Houston ship channel, has been proposed by Conoco for ships up to 950 feet long, holding more than 75 00 cubic meters. The facility could receive up to 2,400 cubic meters per hour and deliver it to Mt. Belvieu for storage.

The project has been delayed until 1982. Some 90 acres of the Barbers Hill (Mt. Belvieu) salt dome was purchased by Conoco during 1974; potential storage in the dome is 2.9 million cubic meters. Any injection into natural gas lines would be at the Mt. Belvieu storage area.

HOUSTON, TEXAS
Owner: Oiltanking of Texas, Inc.

This multiple purpose import terminal located on the Houston ship channel plans to include LPG offloading capabilities by 1978. Berthing facilities can now accommodate vessels up to 100,000 cubic meters, but the Houston channel has only 40 feet of water at mean low water and thus cannot transit ships larger than 75,000 cubic meters. The terminal is adjacent to a 1,600 foot turning basin and across the channel from the Shell Oil Petrochemical and Refinery Plant.

The planned offloading rate for propane is 2,100 cubic meters per hour. It will be warmed with seawater at the dockside and pumped to the Mt. Belvieu storage complex. Butane can be simultaneously offloaded into two 20,000 cubic meter shore tanks at the ship's pumping rate and then pumped to Mt. Belvieu or other locations as requested, after the propane is pumped. The annual handling capability of 8 million cubic meters is limited by the pumping capacity to Mt. Belvieu.

Crude, condensate, and dry bult aragonite are also offloaded through the terminal. Three berths are currently used and a finger pier with two berths is available for LPG in the future.

Any natural gas pipeline injection would be done at the Mt. Belvieu underground storage area.

HOUSTON, TEXAS

Owner: Phillips Petroleum Company

Two vessels, whose combined length is less than 750 feet, can be accommodated simultaneously at the Adams Terminals.

Propane is pumped into an aboveground 27,500 cubic meter refrigerated tank at the terminal site and delivered through a warm-up facility to a local Texas Eastern Transmission (TET) pipeline en route to Mt. Belvieu. Butane is pumped directly to TET, as is any mixed stream. Propane and butane can be offloaded simultaneously.

The terminal has been operational since the 1960's when it was originally designed as an export facility. The largest vessel to dock at Phillips so far has been 52,000 cubic meters, but the terminal normally handles ships of 22,000 cubic meters.

Natural gas pipeline injection could take place on site using the refrigerated storage, the warm-up facility and injection pumps.

HOUSTON, TEXAS

Owner: Warren Petroleum Company

The existing berthing facility has two docks, one for butane, the other for propane. It was originally designed for loading small vessels and barges with butane for the Northeast and has been operational for over twenty years.

Currently, 52,000 cubic meter and smaller vessels are using the site which is connected to the Mt. Belvieu underground storage complex.

Warren plans to construct a new dock by mid-1978 to accommodate up to 75,000 cubic meter ships. Existing Houston Ship Channel restrictions will have to be modified slightly from the current 750 feet length, 116 feet beam rule to allow the 75,000 cubic meter ships.

Warren has 57,000 cubic meters of on-site aboveground storage; however, most product is moved directly to Mt. Belvieu as the vessel offloads. Any natural gas pipeline injection would be done at Warren's large underground storage complex at Mt. Belvieu.

CORPUS CHRISTI, TEXAS
Owner: Coastal States Marketing, Inc.

Vessels are offloaded at the Coastal facility through an 8-inch line and a 12-inch line connected directly to Coastal's underground storage and fractionation facility located approximately 200 miles to the northeast at Almeda, near Houston. Five 320 cubic meter tanks are used at the Corpus Christi site to provide surge storage between the vessel and the pipelines. The Coastal facility is capable of offloading vessels at a rate of 560 cubic meters per hour.

The Coastal facility is not equipped with onshore facilities to warm up the LPG product to pipeline temperature. As a result, only butane or propane-butane mixtures are currently being offloaded, unless the vessel is equipped with heat exchangers. However, onshore warm-up facilities could be installed at very minimal cost.

A new import facility is also under consideration by Coastal States. If the venture is undertaken, it would be located on 45 feet of water and have the capability of offloading vessels of prop e c butanes at rates of 2,400 to 4,000 cubic meters per hour. The facility would be designed to handle a minimum daily throughput of 5,500 cubic meters and a maximum of approximately 23,800 cubic meters.

SAN PEDRO (LOS ANGELES), CALIFORNIA
Owner: Petrolane Incorporated

The offloading facility is located at a municipal dock in the West Basin of the Harbor at San Pedro. The propane is pumped 6,000 feet through an underground refrigerated pipeline to two aboveground 48,000 cubic meter refrigerated tanks. Rail and truck loading and unloading facilities are available. Only one ship, in the fall of 1976, has delivered LPG to the terminal. The terminal has been used for storing excess summer product from local refineries.

Under recent contractual agreements, Petrolane will supply Pacific Lighting Service Company with 800,000 cubic meters of imported propane annually. It will be injected as propa e-air. Final approval is pending from the California Public Utility Commission.

FERNDALE, WASHINGTON

Owner: California Liquid Gas Corporation

There is one 55,600 cubic meter aboveground refrigerated storage tank five miles from Ferndale. The docking facil y is owned by a d shared with Intalco Al minum Company.

The facility is able to handle 52,000 cubic meter ships and the corporation expects to use this size when importing product. It has the land available to construct two additional tanks. In the early 1980's, if major imports are necessary, the corporation plans to constru dditional tanks and use 72,000 cubic meter ships.

hwest Pipeline Company has a natural gas transmission line in the area.

POTENTIAL IMPORT SITE

Potential non-urban import terminal sites exist at smaller ports which have enough water (35 feet) to make them feasible for the existing LPG fleet to service. There has not yet been enough demand for LPG in these areas to justify such terminals. With the current decline in domestic LPG production and the increase in demand for imports, however, some of these sites may become economically feasible. To be economical a terminal would have to handle an average of 1,100 cubic meters per day and still be serviced by medium sized (30,000 to 52,000 cubic meter) vessels. Some examples of such potential sites follow.

WILMINGTON, NORTH CAROLINA is an area which has sufficient water and a gas transmission line (North Carolina Natural Gas). This line is supplied by Transcontinental, which is operating under high curtailment conditions. The approaching channel at Wilmington has 38 feet of water.

CHARLESTON, SOUTH CAROLINA has 37 feet of water in the channel well up into the Hog Island area. No large transmission line is in the immediate vicinity, but local lines are available for the induction of LPG-air or SNG. A minimum sized LPG plant could supply part of Charleston's needs.

SAVANNAH, GEORGIA is at the end of a transmission line owned by Southern Natural Gas which has historically had a high natural gas curtailment problem. The channel has water depths over 36 feet well beyond Fig Island Turning Basin, on the edge of the urban area. A terminal sited along the Savannah River, perhaps with the LNG plant on Elba Island, could supply LPG-air or SNG to the Southern Natural Gas system.

PASCAGOULA, MISSISSIPPI has a non-urban area for terminal siting on 38 feet of water. United Gas Pipe Line, which has one of the nation's highest natural gas curtailment ratios, has a main transmission line near Pascagoula. LPG could also be sent by rail or truck from this area.

BENICIA, CALIFORNIA in the upper San Francisco harbor has been the proposed site for an LPG import terminal for some time. Due to several warm winters in succession, there has been little demand for imports and, consequently, the project has been held up. Although located in deep water, the site is restricted by a 38-foot bar in the approach area. Pacific Gas and Electric has several gas mains in the area which could service industry with LPG-air if a natural gas shortage occurs.

LONGVIEW, WASHINGTON is located on the Columbia River near the Northwest Natural Gas main line. A minimum water depth of 37 feet allows access for vessels up to 52,000 cubic meters. Many other non-urban sites are located along the Columbia River near natural gas pipelines.

APPENDIX XVI

CONTENTS PAGE

APPENDIX XVI-1

FACILITY IDENTIFICATION

The following pages contain listings of facilities in the United States having on-site storage of LNG, LPG, or naphtha in excess of 23,000 m or a monthly throughput of one of these fuels in excess of 23,000 m. Naphtha listings do not include storage at military installations nor any naphtha to be used as solvents. The total volumes of constructed storage capacity are indicated for each fuel category, with total planned storage capacity indicated in parentheses.

U.S. LNG PEAK-SHAVING FACILITIES WITH STORAGE IN EXCESS OF 23,000 m

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Alabama Gas Corp.	Pinson Highway Jefferson County, AL	57 (2 tanks)
Alabama Gas Corp.	Coosada, AL	28.5
Atlanta Gas Light Co.	Macon, GA	69
Atlanta Gas Light Co.	Riverdale, GA	115 (2 tanks)
Baltimore Gas & Elec. Co.	Baltimore, MD	23 (2 tanks)
Baltimore Gas & Elec. Co. Plant No. 2	Baltimore, MD	23
Bay State Gas Co.	Ludlow, MA	46
Bay State Gas Co.	Easton, MA	36.8
Boston Gas Co.	Dorchester, MA[1]	98.9 (2 tanks)

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Boston Gas Co.	Lynn, MA	46
Boston Gas Co.	Salem, MA	46
Brooklyn Union Gas Co.	Brooklyn, NY	73.6 (2 tanks)
Chattanooga Gas Co.	Chattanooga, TN	55.2
Citizens Gas & Coke Utility	Beach Grove, IN	46
Commonwealth Natural Gas Corp.	Tidewater, VA	55.2
Connecticut Natural Gas Corp.	Rocky Hill, CT	55.2
Consolidated Edison of New York	Astoria, NY	46
East Tennessee Natural Gas Co.	Fordtown, TN	55.2
Gas Light Co. of Columbus	Columbus, GA	23
Intermountain Gas Co.	Boise, ID	27.6
Iowa Illinois Gas & Electric Co.	Bettendorf, IA	23
Long Island Lighting Co.	Holtsville, NY	27.6
Lowell Gas Co.	Lowell, MA	46
Memphis Light, Gas & Water Division	Memphis, TN	46
Metro Utilities, District	Omaha, NB	46
Minnesota Gas Co.	Burnsville, MN	46
NEGEA Air Products & Chemicals, Inc.	Hopkinton, MA	138 (3 tanks)

COMPANY	LOCATION	CAPACITY (10^3 m^3)
New Bedford Gas & Edison Light Co.	Acushnet, MA	23
Northern Indiana Public Service	La Porte, IN	92
Northern Natural Gas Co.	Wrenshall, MN	100
Northern Natural Gas Co.	Garner, IA	100
Northern States Power Co.	Wescott, MN	92
Northwest Natural Gas Co.	Portland, OR	27.6
Northwest Pipeline Corp.	Plymouth, WA	55.2 (55.2) planned
Peoples Gas, Light & Coke Co.	Fisher, IL	92 (2 tanks)
Philadelphia Electric Co.	West Conshohocken, PA	55.2
Philadelphia Gas Works	Philadelphia, PA	184 (2 tanks)
Piedmont Natural Gas Co.	Charlotte, NC	46
Public Service Co. of North Carolina	Cary, NC	46
San Diego Gas & Electric	Chula Vista, CA	28.8
San Diego Gas & Electric Co. Plant No. 2	Chula Vista, CA	55.2
South Carolina LNG Co.	Bushey Park, SC	46 (2 tanks)
Southern Connecticut Gas Co.	Milford, CT	55.2
Tennessee Natural Gas Lines, Inc.	Nashville, TN	46

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Texas Eastern Cryogenics[2]	Staten Island, NY (destroyed 1973)	(92)
Transcontinental Gas Pipe Line Corp.	Hackensack, NJ	46
Transcontinental Gas Pipe Line Corp.	Carlstadt, NJ	46
	TOTAL	2,635
	Planned	(147)
	Total Built and Planned	2,782

1. In the past ships have delivered LNG to Dorchester, and LNG has been barged from Dorchester to New York City and Providence, R.I. No imports are currently planned.

2. In 1970 the Texas Eastern terminal received two shiploads of LNG.

LNG RECEIVING TERMINALS

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Algonquin LNG, Inc.	Providence, RI	92
Distrigas Corp.	Everett, MA	155 (2 tanks)
Consolidated Systems LNG Co., and Columbia LNG Corp.	Cove Point, MD	240 (4 tanks)
El Paso LNG Terminal Co.	Port O'Connor, TX	(190) planned
Natural Gas Pipeline Co. of America	Ingleside, TX	(275) planned
Public Service Electric & Gas of New Jersey	Staten Is., NY	285 (2 tanks)
Southern Energy Co.	Elba Island, GA	184 (2 tanks)
Tenneco LNG Company	West Deptford, NJ	(580) planned
Trunkline LNG Co.	Lake Charles, LA	(275) planned
Western LNG Terminal Associates	Oxnard, CA	(355) planned
Western LNG Terminal Associates	Point Conception, CA	(355) planned
Western LNG Terminal Associates	Los Angeles Harbor, CA	(355) planned
	TOTAL	956
	Planned	(2,385)
	Total Built and Planned	3,341

LNG BASELOAD LIQUEFACTION PLANTS

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Phillips Petroleum Co. and Marathon Oil Co.	Kenai, AK	129
Pacific Alaska	Cook Inlet, AK	(175) planned
	TOTAL	129
	Planned	(175)
	Total LNG Storage Capacity	3,720
	Total LNG Built and Planned Storage Capacity	6,427

LPG FACILITIES - ABOVEGROUND STORAGE AT IMPORT TERMINALS

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Atlantic Energy Corp.	Chesapeake, VA	76
California Liquid Gas Corp	Ferndale, WA	56
Exxon Company, U.S.A.	Everett, MA	64
Gulf Oil Co., U.S.A.	Belle Chasse, LA	39
Gulf Oil Co., U.S.A.	Philadelphia, PA	32
Petrolare, Inc.	Providence, RI	64
Petrolane, Inc.	San Pedro, CA	96
Phillips Petroleum Co.	Houston, TX	27
Sea 3	Newington, NH	64
Warren Petroleum Co.	Houston, TX	57
	Total Aboveground Storage at Import Terminals	575

LPG - OTHER ABOVEGROUND STORAGE

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Baltimore Gas & Electric Co.	Essex, MD	24
Dixie Pipeline Company	Wake County, NC	64
Exxon Company, U.S.A.	Solano County, CA	48
Florida Hydrocarbons Co.	Bradford County, FL	28
Getty Oil Company	Newcastle County, DE	80 (frozen pit)
Northern States Power Co.	Wescott, MN	45 (ethane)
Phillips Petroleum Co.	Salt Lake County, UT	26
Phillips Petroleum Co.	St. Clair County, IL	80
Phillips Petroleum Co.	Crittenen County, AK	25
Vangas, Inc.	Sacramento, CA	40
Vangas, Inc.	Elk Grove, CA	40
	TOTAL Other Aboveground Storage	500
	TOTAL LPG Aboveground Storage	1,075

LPG FACILITIES - UNDERGROUND STORAGE

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Alto Underground Storage	Kent County, MI	127
Aminoil USA, Inc.	Polk County, MN	56
Amoco Oil Company	Marengo County, AL	28.5
Amoco Oil Company	Madison County, IL	30.7
Amoco Oil Company	Reno County, KA	132
Amoco Oil Company	Grant County, KS	44
Amoco Oil Company	Bienville County, LA	97
Amoco Oil Company	St. Clair County, MI	46
Amoco Oil Company	Hockly County, TX	95
Amoco Oil Company	Ector County, TX	86
Amoco Oil Company	Brozoria County, TX	159
Arco Chemical Company	Chambers County, TX	387 (4 caverns)
Arrow Gas Company	Eddy County, NM	27
Atlantic Richfield Co.	Reno County, KS	154
Atlantic Richfield Co.	Cortland County, NY	65
Atlantic Richfield Co.	Ector County, TX	25
Atlantic Richfield Co.	Ector County, TX	32
Baltimore Gas & Electric Co.	Baltimore County, MD	24
Butane Suppliers, Inc.	Wood County, TX	209
California Liquid Gas Corp.	Maricopa County, AZ	191
Carolina Pipeline Co.	York County, SC	64
Cincinnati Gas & Electric	Kenton County, KY	27
Cincinnati Gas & Electric	Buter County, OH	57
Cincinnati Gas & Electric	Hamilton County, OH	30
Cities Service Co.	Reno County, KS	1,042
Cities Service Co.	Cameron County, LA	297
Cities Service Co.	Cameron County, LA	297
Cities Service Co.	Cameron County, LA	297
Cities Service Co.	Lake Charles, LA	(unlimited) (planned)
Cities Service Co.	Kent County, MI	160

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Cities Service Co.	Gray County, TX	108 (3 caverns)
Cities Service Co.	Chambers County, TX	107
Coastal State Gathering Crude Company	Harris County, TX	122 (3 caverns)
Coastal States Marketing, Inc.	Corpus Christi, TX	1,829
Columbia HydrocarbonCorp.	Greenup County, KY	45
Columbia Hydrocarbon Corp.	Lake County, OH	95
Consolidated Storage, Inc.	Reno County, KS	954
Consumers Power Company	St. Clair County, MI	51
Continental Oil Company	Lake County, IN	40
Continental Oil Company	Evangeline Co., LA	113
Continental Oil Company	Grant County, OK	121
Continental Oil Company	Kay County, OK	41
Cosden Oil & Chemical	Howard County, TX	36 (3 caverns)
Dayton Power & Light Co.	Butler County, OH	30
Diamond Shamrock Oil & Gas Company	Chambers County, TX	1,591
Diamond Shamrock Oil & Gas Company	Moore County, TX	64
Dixie Pipeline Co.	Lamor County, GA	35
Dorchester Gas Producing Co.	Carson County, TX	32
El Paso Natural Gas Co.	Reagon County, TX	155 (2 caverns)
El Paso Natural Gas Co.	Ector County, TX	58
El Paso Natural Gas Co.	Lea County, TX	37 (2 caverns)
El Paso Products	Ector County, TX	119

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Empire Underground Storage, Inc.	Reno County, KA	318
Enterprise Products Co.	Bienville County, LA	207
Enterprise Products Co.	Forrest County, MS	72
Exxon Company, U.S.A.	Ascension County, LA	269
Exxon Company, U.S.A.	Union County, NJ	81
Exxon Company, U.S.A.	Chambers County, TX	156
Getty Oil Company	McPherson County, KS	350
Getty Oil Company	Lea County, NM	51
Getty Oil Company	Carson County, TX	56
B.F. Goodrich Company	Marshall County, KY	35
Hillside Underground Storage	Reno County, KS	286
Home Petroleum Corp.	McPherson County, KS	1,509
Hydrocarbon Transportation Inc.	Will County, IL	40
Hydrocarbon Transportation Inc.	Polk County, IA	44
Koch Oil Company	Grant County, OK	39
Laclide Gas Company	St. Louis County, MO	124
Lake Underground Storage, Inc.	Lake County, OH	557
Marathon Oil Company	Wayne County, MI	254 (3 caverns)
Metropolitan Utilities Dist. of Omaha	Douglas County, NB	61 (2 caverns)
Mid American Pipeline	Peoria County, IL	65
Mid American Pipeline	Johnson County, IA	93
Mid American Pipeline	McPherson County, KS	586
Mid American Pipeline	Lancaster County, NB	60
Mid American Pipeline	Gaines County, TX	106 (2 caverns)

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Mid-West Underground Storage	McPherson County, KS	477
Mobil Oil Corporation	Assumption Co. LA	151
Mobil Oil Corporation	Steuben County NY	120
Mobil Oil Corporation	Martin County, TX	792
Mobil Oil Corporation	Liberty County, TX	253
Mobil Oil Corporation	Wayne County, MI	60
Monsanto	Scurry County, TX	62
National Coop. Refinery Association	McPherson County, KS	514
Northwest Development Inc.	Kent County	127
Phillips Petroleum Co.	Kankakee County, IL	32
Phillips Petroleum Co.	Kingman County, KS	127
Phillips Petroleum Co.	Wayne County, MI	29
Phillips Petroleum Co.	Brazoria County, TX	852
Phillips Petroleum Co.	Hutchinson County, TX	668
Seadrift Pipeline Co.	Matagorda County, TX	405
Sentry Underground Storage Company	Rice County, KS	318
Shell Oil Company	Ascension County, LA	409
Shell Oil Company	Ector County, TX	109
Shell Oil Company	Yoakum County, TX	56
Shell Oil Company	Madison County, IL	116
Sid Richardson Carbon & Gas Company	Winkler County, TX	25
Solar Gas, Inc.	Polk County, MN	53
Standard Oil Company	Allen County, OH	52
Sun Gas Company	Tulsa County, OK	37
Sun Gas Company	Delaware County, PA	183
Sun Gas Company	Delaware County, PA	76
Sun Gas Company	wayne County, MI	124
Tenneco Oil Company	Chambers County, TX	978 (3 caverns)

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Texaco, Inc.	Hardin County, TX	1,186
Texaco, Inc.	Potter County, TX	27
Texaco, Inc.	St. Martin County LA	119
Texaco, Inc.	Ascension County, LA	345
Texaco, Inc.	Scurry County, TX	30
Texas Brine Corporation	Harris County, TX	1,357 (6 caverns)
Texas Brine Corporation	Matagorda County, TX	540 (3 caverns)
Texas Eastern Products Pipeline Company	Will County, IL	48
Texas Eastern Products Pipeline Company	Gibson County, IN	25
Texas Eastern Products Pipeline Company	Jackson County, IN	33
Texas Eastern Products Pipeline Company	Schuyler County, NY	606
Texas Eastern Products Pipeline Company	Butler County, OH	293
Texas Eastern Products Pipeline Company	Westmoreland Co. PA	45
Texas Eastern Products Pipeline Company	Chambers County, TX	3,264 (4 caverns)
Texas Eastman Company	Smith County, TX	318
Union Oil of California	Andrews County, CA	56
Union Texas Petroleum	Ikerville, LA	751
Union Texas Petroleum	Upton County, TX	249
Union Texas Petroleum	St. Martin County, LA	576
UPG, Inc.	Ellsworth County, KS	1,122
U.S. Industrial Chemicals Company	Douglas County, IL	132
Wanda Petroleum Co.	Harris County, TX	532
Wanda Petroleum Co.	Napoleonville, LA	3,180
Wanda Petroleum Co.	Breaux Bridge, LA	1,000

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Warren Petroleum Co.	Bienville County, LA	106
Warren Petroleum Co.	Plaquemine County, LA	792
Warren Petroleum Co.	Forrest County, MS	477
Warren Petroleum Co.	Lea County, NM	48
Warren Petroleum Co.	Chambers County, TX	3,031 (4 caverns)
Warren Petroleum Co.	Jefferson County, TX	117
Washington Gas Light Company	Fairfax County, VA	45
Williams Energy Co.	Apache County, AZ	143
Williams Energy Co.	Apache County, AZ	87
Williams Energy Co.	Grand County, UT	38
Williams Pipe Line Co.	Jasper County, MO	31
Xral Storage and Terminaling Company	Chambers County, TX	477

TOTAL LPG Underground Storage 43,919

SNG PLANTS

(Note: None of these facilities have on-site storage in excess of 23,000 m^3.)

COMPANY AND LOCATION	FEEDSTOCK	MONTHLY THROUGHPUT (10^3 m^3)
Algonquin SNG, Inc. Freetown, MA	Naphtha	124
Ashland Oil, Inc. Tonawanda, NY	Naphtha	52
Baltimore Gas & Electric Co. Stollers Point, MD	Naphtha	57
Boston Gas Co. Everett, MA	Propane	48
Brooklyn Union Gas Co. Brooklyn, NY	Naphtha	63
Columbia LNG Corp. Green Springs, OH	Propane/Butane/NGL*	330
Consumers Power Co. Marysville, MI	NGL*	240
Gasco, Inc. Barbers Point, Oahu, HI	Naphtha	14
Indiana Gas Co., Inc. Indianapolis, IN	Naphtha	(50) (planned)
Northern Illinois Gas Co. Minooka, IL	NGL* Naphtha	158 76
Peoples Gas Light & Coke Co. Elwood, IL	Naphtha	157
Philadelphia Gas Works Philadelphia, PA	Naphtha	(62) (planned)

COMPANY AND LOCATION	FEEDSTOCK	MONTHLY THROUGHPUT (10^3 m^3)
Public Service Electric and Gas Co. Linden, NJ	Naphtha	119
Transco Energy Co. Twin Oaks, PA	Naphtha	(267) (planned)
TOTAL		1,438
Planned		379
Total Built and Planned		1,817

*Natural Gas Liquids

NAPHTHA - ETHYLENE PLANTS

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Amoco	Chocolate Bayou, TX	73
Commonwealth Oil Refining Company	Puerto Rico	72
Exxon Company	Baton Rouge, LA	130
Monsanto Company	Chocolate Bayou, TX	57
Puerto Rico Olefins Co.	Puneulas, PR	73
Shell Oil Company	Houston, TX	110
Union Carbide	Puneulas, PR	57
	TOTAL	572

NAPHTHA - REFINERIES

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Amoco Oil Company	Wood River, IL	72
Amoco Oil Company	Whiting, IN	169
Amoco Oil Company	Sugar Creek, MO	65(e)*
Amoco Oil Company	Mandan, ND	30(e)
Amoco Oil Company	Texas City, TX	216(e)
Amoco Oil Company	Salt Lake City, UT	25(e)
Amoco Oil Company	Yorktown, VA	33(e)
Amoco Oil Company	Casper, WY	27(e)
APCO Oil Company	Arkansas City, KA	36
ARCO	Carson, CA	91
Atlantic Richfield Co.	Philadelphia, PA	51
Atlantic Richfield Co.	Houston, TX	126
Atlantic Richfield Co.	Cherry Pt. - Ferndale, WA	142
Ashland Petroleum Co.	Catlettsburg, KY	84(e)
Ashland Petroleum Co.	St. Paul Park, MN	41(e)
Ashland Petroleum Co.	N. Tonawanda, NY	40(e)
(MN-Northwestern Refining Co. - Div.)	Canton, OH	40(e)
Atlas Processing Co. (Div. Pennzoil)	Shreveport, LA	28(e)
BP Oil Company	Marcus Hook, PA	278(e)
Cenex	Laurel, MT	(48 monthly throughput)
Champlin Petroluem Corp.	Corpus Christi, TX	78(e)
Charter International Oil Company	Houston, TX	40(e)
Chevron USA, Inc.	El Segundo, CA	250(e)
Chevron USA, Inc.	Barbers Point, HI	25(e)
Chevron USA, Inc.	Pascaquola, MI	174(e)
Chevron USA, Inc.	Perth Amboy, NJ	104(e)
Chevron USA, Inc.	El Paso, TX	43(e)
Chevron USA, Inc.	Salt Lake City, UT	28(e)

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Cities Service Oil Co.	Lake Charles, LA	117
Clark Oil and Refining Corporation	Blue Island, IL	31
Clark Oil and Refining Corporation	Hartford, IL	46
Coastal States Petrochemical Co.	Corpus Christi, TX	42
Continental Oil Co.	Lake Charles, LA	59(e)
Continental Oil Co.	Billings, MT	205(e)
Continental Oil Co.	Ponca City, OK	490(e)
Cosden Oil and Chemical Company	Big Spring, TX	65
CRA, Inc.	Coffeyville, KS	135
Crown Central Petroleum Corporation	Houston, TX	62(e)
Delta Refinery Company	Memphis, TN	(44 monthly throughput)
Diamond Shamrock Corp.	Tunray, TX	35
Douglas Oil Company	Paramount, CA	40
Energy Cooperative, Inc.	East Chicago, IN	78(e)
Exxon Co., USA	Benicia, CA	38
Exxon Co., USA	Baton Rouge, LA	129
Exxon Co., USA	Billings, MT	(150 monthly throughput)
Exxon Co., USA	Linden, NJ	85
Exxon Co., USA	Baytown, TX	133
Getty Oil Company, Inc.	Delaware City, DL	94
Getty Oil Company, Inc.	El Dorado, KS	120
Good Hope Refineries, Inc.	Metairie, LA	40(e)
Gulf Oil Company	Santa Fe Springs, CA	32(e)

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Gulf Oil Company	Alliance Refinery Belle Chasse, LA	120(e)
Gulf Oil Company	Cleves, OH	25(e)
Gulf Oil Company	Toledo, OH	30(e)
Gulf Oil Company	Philadelphia, PA	125(e)
Gulf Oil Company	Port Arthur, TX	195(e)
Hawaii Independent Refinery, Inc.	Ewa Beach, HI	100
Kerr-McGee Corporation	Corpus Christi, TX	(36 monthly throughput)
Koch Refining Company	Rosemount, MN	80(e)
Lion Oil Company	El Dorado, AR	16
Lion Oil Company	Martinez, CA	306
Marathon Oil Company	Robinson, IL	(206 monthly throughput)
Marathon Oil Company	Garyville, LA	34
Marathon Oil Company	Detroit, MI	23
Marathon Oil Company	Texas City, TX	50
Mobil Oil Company	Torrance, CA	135
Mobil Oil Company	Joliet, IL	90
Mobil Oil Company	Augusta, KS	37
Mobil Oil Company	Paulsboro, NJ	90
Mobil Oil Company	Buffalo, NY	45
Mobil Oil Company	Beaumont, TX	270
Mobil Oil Company	Ferndale, WA	75
Murphy Oil Company	Meraux, LA	55(e)
Murphy Oil Company	Superior, WI	30(e)
National Cooperative Refinery Assn.	McPherson, KS	(32 monthly throughput)
Pacific Refining Co.	Hercules, CA	33(e)
Phillips Petroleum Co.	Kansas City, KS	48
Phillips Petroleum Co.	Borger, TX	51
Phillips Petroleum Co.	Sweeney, TX	108
Powerine Oil Company	Santa Fe Springs, CA	52

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Rock Island Refining Corporation	Indianapolis, IN	(57 monthly throughput)
Shell Oil Company	Martinez, CA	60(e)
Shell Oil Company	Wilmington, CA	45(e)
Shell Oil Company	Richmond, CA	200(e)
Shell Oil Company	Wood River, IL	175(e)
Shell Oil Company	Norco, LA	150(e)
Shell Oil Company	Deer Park, TX	180(e)
Shell Oil Company	Anacortes, WA	55(e)
Sinclair	Sinclair, WY	30(e)
Southwestern Refining Company, Inc.	Corpus Christi, TX	75(e)
Standard Oil Company of Ohio	Lima, OH	100(e)
Standard Oil Company of Ohio	Toledo, OH	75(e)
Sun Petroleum Products Company	Toledo, OH	(153 monthly throughput)
Sun Petroleum Products Company	Duncan, OK	47
Sun Petroleum Products Company	Marcus Hook, PA	[illegible]5
Sun Petroleum Products Company	Corpus Christi, TX	86
Tenneco	Chalmette, LA	173
Tesoro Petroleum Corp.	Kenai, OK	29
Texaco, Inc.	Wilmington, CA	55(e)
Texaco, Inc.	Lawrenceville, IL	50(e)
Texaco, Inc.	Lockport, IL	45(e)
Texaco, Inc.	Convent, LA	85(e)
Texaco, Inc.	Westville, NJ	55(e)
Texaco, Inc.	West Tulsa, OK	30(e)
Texaco, Inc.	Port Arthur, TX	250(e)
Texaco, Inc.	Port Neches, TX	30(e)
Texaco, Inc.	Anacontes, WA	50(e)
Texas City Refining, Inc.	Texas City, TX	132

COMPANY	LOCATION	CAPACITY (10^3 m^3)
Total Petroleum Inc.	Alma, MI	40
Union Oil Company of California	Los Angeles, CA	486
Union Oil Company of California	San Francisco, CA	267
Union Oil Company of California	Lemont, IL	130
Union Oil Company of California	Beaumont, TX	71
United Refining Co.	Warren, PA	25
Vickers Petroleum Corp.	Ardmore, OK	(47 monthly throughput)
	TOTAL	10,862

*(e) indicates estimated number

NAPHTHA - JET FUEL STORAGE AT LARGE COMMERCIAL AIRPORTS

None of the airports surveyed had storage or monthly throughput in excess of 23,000 m^3 of a naphtha category fuel such as JP-4 or 5 (primarily used by military aircraft). Commercial jet fuel is less volatile cut in the kerosene category. For information purposes, the following listing is given although the fuel is not actually a naphtha.

City/State	Airport	Jet Fuel Storage (10^3 m^3)	1976 Monthly Jet* Fuel Throughput (10^3 m^3)
New York/NY	JFK	12	307
Chicago/IL	O'Hare	35	260
Los Angeles/CA		22	245
San Francisco/CA		0.4	160
Dallas/Ft. Worth/TX			130
Atlanta/GA			116
Miami/FL		38	114
Honolulu/HI			109
Seattle-Tacoma/WA			88
New York/NY	LaGuardia	19	80
Boston/MA	Logan	17	78
Denver/CO			78
Anchorage/AL			58
Minneapolis-St. Paul/MN			55

City/State	Airport	Jet Fuel Storage (10^3 m^3)	1976 Monthly Jet* Fuel Throughput (10^3 m^3)
Washington/DC	National		54
Houston/TX		10	51
St. Louis/MO			50
Washington/DC	Dulles	15	45
Newark/NJ		41	45
Las Vegas/NV			44
Philadelphia/PA			42
Tampa/FL			40
Detroit/MI	Metropolitan		40
Pittsburgh/PA			38
Cleveland/OH			34
Kansas City/MO			32

*From U.S. Airline Industry Turbine Fuel Forecast 1977-81, ATAA.

APPENDIX XVI-2

DESCRIPTION OF 12 LEG FACILITIES

The information contained in this appendix was compiled from literature search, data requested from individual gas companies, and on site visits. The descriptions represent a comparative presentation of information critical to an understanding of both the key similarities and differences between LEG plant sites, storage containers, terminals, and processing capabilities. Because of the varying formats in which information was received, some of the descriptions are incomplete.

Summary sheets have been prepared for the following facilities:

LNG Marine Terminal Facilities:

Algonquin LNG, Inc., Providence, RI
Columbia LNG Corp., Cove Point, MD
Distrigas of Massachusetts, Everett, MA
Public Service Electric & Gas Co., Staten Island, NY
Southern Energy Co., Elba Island, GA

LNG Peakshaving Facilities:

Northwest Pipeline Corp., Plymouth, WA
Philadelphia Electric Co., Philadelphia, PA
Philadelphia Gas Works, Philadelphia, PA
Texas Eastern Transmission Corp., Staten Island, NY

LPG Marine Terminal Facilities:

Exxon Co., U.S.A., Everett, MA
Petrolane, Inc., San Pedro, CA
Sun Oil Company, Marcus Hook, PA

LNG MARINE TERMINAL FACILITIES
Algonquin LNG, Inc., Providence, RI

A. Type of Facility (Year of Operation): LNG Receiving Terminal and Peakshaving Plant (1973/1975). Currently operating as peakshaving and storage facility only.

B. Area Description: Facility is located on 16.5 acres along Providence River in small industrial complex adjacent to residential area. Industrial area is primarily petroleum product storage and processing. Algonquin leases the 16.5 acres from Providence Gas Co., and owns an additional 8.2 acres adjacent to it.

C. Storage Containers:

1. Number: 1
2. Type: Above-ground, double wall, cylindrical tank with suspended insulating deck and umbrella type roof
3. Builder: Chicago Bridge & Iron
4. Container Capacity:

Tank	1	Total
Liquid (MBBL)	600	600
(MCM)	95	95
Gas (MMSCF)	2040	2,040

5. Container Dimensions (Inner Shell - Ft.):

Tank	1
Diameter	184
Height	132.25
Liquid Level (maximum)	127.67

6. Overall Tank Dimensions (Ft.):

Tank	1
Diameter	190
Height	172
Pedestal Ht.	2.1

7. Construction Details:

Outer Wall: Carbon steel - 17/32" tapered to 13/32" at top

Inner Wall: 9% nickel steel (A553) - 1.036" tapered to .32" at top

Insulation: 3 ft. of perlite

Foundation: Inner Shell - concrete bearing pads and foam blocks. Tank - concrete ringwall with 12" sand pad

Penetrations (Piping):

(1) Liquid In: 30" top penetration/top fill

(2) Liquid Out: 2 - 10" bottom withdrawal

(3) Vapor Out: 24" line

Other Pertinent Features: Design pressure at top of tank 1.5 psig

8. Containment Area: Sloped wall impervious soils dike, average height 21.5', minimum distance from tank - 73'. Impoundment capacity is approximately 96 MCM.

D. Plant Capability:

1. Liquefaction: N/A

2. Regasification: 3 units at 33.3 MMCFD, total capacity - 100 MMCFD direct fluid type vaporizer.

3. Receiving: 375 MMCFD.

4. Terminal Facilities:
   Piers: 1 shoreside berth
   Truck Loading Platforms: 1 (2 trucks)
   Rail Car Platforms: N/A

Columbia LNG Corp. & Consolidated System LNG Co.
Cove Point, MD

A. Type of Facility (Year of Operation): LNG Base Load Plant (1978).

B. Area Description: 1,022 acre tract 5 miles north of Patuxent River entrance on Chesapeake Bay. Located in isolated area.

C. Storage Containers:

1. Number: 4 identical tanks
2. Type: Above-ground, double wall cylindrical tanks with suspended insulating deck and umbrella type roof.
3. Builder: Pittsburgh - Des Moines Steel Co.
4. Container Capacity:

Tank	1	2	3	4	Total
Liquid (MBBL)	375	same	same	same	1,500
(MCM)	60				240
Gas (MMSCF)	1250				5,000

5. Container Dimensions (Inner Shell - Ft.):

Tank	1	2	3	4
Diameter	162.3	*all 4 tanks identical		
Height	105			
Liquid Level (maximum)	102.4			

6. Overall Tank Dimensions (Ft.):

Tank	1	2	3	4
Diameter	168.83	*all 4 tanks identical		
Height	139			
Pedestal Ht.	7			

7. Construction Details:

Outer Wall: A131 Gr B carbon steel - 15/32" tapered to 3/8" at top

Inner Wall: 5083 aluminum - 1.859" tapered to 3/8" at top

Insulation: 30" of perlite with 9" fiberglass blanket at outer wall

Foundation: Inner shell on foam blocks with sand cushion. Tank on 12'6" ringwall on compacted sand.

Penetrations (Piping):

(1) Liquid In: 24" top penetration/top fill

(2) Liquid Out/In: 24" bottom withdrawal/fill line

(3) Vapor Out: 24" line

(4) 3 - 12" vacuum vent valves

Other Pertinent Features:

(1) Design Pressure - 2.9 psig at tank top

(2) 2 - 12" pressure relief vents set at 2.35 psi

8. Containment Area: 14 foot high reinforced earth walls with precast concrete facing panels, minimum distance from tank - 65'. Each tank separately diked with approximately 60 MCM impoundment area.

D. Plant Capability:

1. Liquefaction: N/A

2. Regasification: 1200 MMCFD. 10 - 100 MMCFD submerged, gas fired vaporizers, 2 - 100 MMCFD inter-fluid exchange type.

3. Receiving: 1.4-2.3 MCM/hr. booster pumps at each berth. Proposed quantity to be delivered by ship 650 MMCFD. Based on contracts and ship turnaround time.

4. Terminal Facilities:
   Piers: 1 - 2,500' offshore pier with 2 berths for 125,000 m^3 ships
   Truck Loading Platforms: N/A
   Rail Car Platforms: N/A

E. Other Factors:
All piping and other onshore connections from pier run through a 6,400 foot offshore tunnel. It was constructed by joining prefab sections, each section is a steel shell 16'H x 27'W x 263'L with a one foot thick concrete liner. The tunnel has one personnel access way and two for piping.

Distrigas of Massachusetts Corp. (DOMAC)
Everett, MA

A. Type of Facility (Year of Operation): LNG Receiving Terminal (1971)

B. Area Description: Located on the northern bank of the Mystic River two miles from Boston in an area of heavy population and industrial activity. Activity includes petroleum and gas processing/storage, scrap yard, electric power plant, LPG facility, etc.

C. Storage Containers:

1. Number: 2
2. Type: Above ground, double wall cylindrical tanks with suspended insulating deck umbrella type roof
3. Builder: Chicago Bridge and Iron
4. Container Capacity:

Tank	1	2	Total
Liquid (MBBL)	374	600	974
(MCM)	60	95	155
Gas (MMSCF)	1270	2040	3,310

5. Container Dimensions (Inner Shell - Ft.):

Tank	1	2
Diameter	150	184
Height	124	132.25
Liquid Level (maximum)	118.8	126.7

6. Overall Tank Dimensions (Ft.):

Tank	1	2
Diameter	156	190

Height	131.5	138.5
Pedestal Ht.	16.2	16.9

7. Construction Details:

Outer Wall: carbon steel - 15/32" tapered to 11/32" at top

Inner Wall: 9% nickel steel - .784" tapered to 5/16" at top

Insulation: 36" perlite

Foundation: Inner shell on foam glass blocks, standard ringwall tank foundation on compacted silt.

Penetrations (Piping): All top penetrations

Tank	1	2
(1) Liquid In: (top fill)	20"	24"
(2) Liquid Out:	1-18"	2-18"
	2-12"	2-12"
(3) Vapor Out:	12"	12"

Other Pertinent Features:

(1) tank operating pressure - 1.5 psig

(2) discretionary relief valve - 1.42 psig
main relief valve - 1.5 psig

8. Containment Area: Asphalt covered, stone stabilized dikes, approximately 15 feet high - a minimum of 65 feet from small tank and 105 feet from large tank. Single impounding area for two tanks - capacity approximately 141 MCM.

D. Plant Capacity:

1. Liquefaction: 11.3 GPM Partial Reliquefaction
2. Regasification: 135 MMCFD. 3-45 MMCFD submerged gas fired vaporizers.
3. Receiving: (Max) 20,000 GPM (4,500 m^3) from

ship. Normal - 12,000 GPM. Plant is designed to offload 125,000 m^3 ships. Proposed delivery 115 MMCFD based on LNG contracts.

4. Terminal Facilities:

Piers: 1 - ship size limited by 135' Mystic River Bridge overhead clearance.

Truck Loading Platforms: 2 (4 truck stations)

Rail Car Platforms: N/A

E. Other Factors:

Pipeline trestle with 24" liquid line and 12" vapor return line is approx. 1,950 feet in length from pier connection to Tank-1 and 2,400 feet to Tank-2. A significant section of the trestle is adjacent to a large, active scrap disposal area.

Public Service Electric & Gas Company (PSE&G) of New Jersey
Staten Island, NY (Rossville Plant)

A. Type of Facility (Year of Operation): LNG Receiving Terminal (constructed 1973-1975) - Application Pending DOE authorization to operate under new ownership.

B. Area Description: Located in southwest section of Staten Island on Arthur Kill Channel in low density population area. Site is adjacent to large scrap salvage yard.

C. Storage Containers:

1. Number: 2 identical tanks
2. Type: Above-ground, double wall, cylindrical concrete tank with suspended insulating deck and dome shaped roof.
3. Builder: Preload Technology, Inc.
4. Container Capacity:

Tank	1	2	Total
Liquid (MBBL)	900	same	1,800
(MCM)	143	same	286
Gas (MMSCF)	3060	same	6,120

5. Container Dimensions (Inner Shell - Ft.):

Tank	1	2
Diameter	243	same
Height	118.67	"
Liquid Level (maximum)	111.75	"

6. Overall Tank Dimensions (Ft.):

Tank	1	2
Diameter	269	same
Height	145.58	same

7. Construction Details:

Outer Wall:	9'8" concrete berm with precast concrete panel exterior wall and 1" metal clad fiberglass inner facing.
Inner Wall:	Precast concrete panel
Insulation:	40" of perlite between inner shell and fiberglass interior facing of outer wall.
Foundation:	6' standard concrete ringwall with 5" concrete slab under inner shell floor.

Roof Composition: Steel plates supported by steel radial trusses

Penetrations (Piping): All top penetrations

Tank		1	2
(1)	Liquid In:	24" bottom fill	same
		30" top fill	same
(2)	Liquid Out:	2-10" lines	same
		1-6" line	same
(3)	Vapor Out:	24" line	

Other pertinent features:

(1) Operating pressure: 2.5 psig

(2) Pressure Reliefs - normal: 2.5 psig
emergency: 2.74 psig

8. Containment Area:

Earthen berm dikes of varying heights with a series of interconnecting trenches. Primary impoundment area 223 MCM.

D. Plant Capability:

1. Liquefaction: N/A
2. Regasification: 360 MMCFD, 4 - 90 MMCFD direct fluid vaporizers

3. Receiving: Application proposed 446 MMCFD by ship. (Average daily quantity landed, based on ship turnaround times and delivery contract).

4. Terminal Facilities:

   Piers: Shoreside pier on Arthur Kill with one berth.

   Rail Car Platforms: N/A

E. Other Factors:

Plant was designed to distribute gas to New Jersey (PSE&G) and New York (Brooklyn Union).

Southern Energy Company
Elba Island, GA

A. Type of Facility (Year of Operation): LNG Base Load Plant & Receiving Terminal (1978).

B. Area Description: Plant is located in 150 acre tract on Elba Island (800 acres); relatively isolated area on the Savannah River, 5 miles east of Savannah.

C. Storage Containers:

1. Number: 3 identical tanks
2. Type: Above-ground, double wall, cylindrical tank with suspended insulating deck and umbrella roof.
3. Builder: Chicago Bridge & Iron
4. Container Capacity:

Tank	1	2	3	Total
Liquid (MBBL)	400	same	same	1,200
(MCM)	63	same	same	190
Gas (MMSCF)	1360	same	same	4,080

5. Container Dimensions (Inner Shell - Ft.):

Tank	1	2	3
Diameter	160	same	same
Height	118.5	"	"
Liquid Level (maximum)	113	"	"

6. Overall Tank Dimensions (Ft.):

Tank	1	2	3
Diameter	166	same	same
Height	166 (includes above-ground piling height)		
Pedestal Ht.	2		

7. Construction Details:

Outer Wall: carbon steel - 1/2" tapered to 3/8" at top

Inner Wall: 5083 aluminum - 2.135" tapered to 9/16" at top

Insulation: 27" perlite plus 9" resilient foam-glass blanket against inner wall.

Foundation: Tank is supported by reinforced concrete, step tapered piles with normal air space of 1.5' between pile cap and ground surface. Double bottom is insulated with a layer of sand and foam glass blocks on a concrete pad.

Penetrations (Piping):

(1) Liquid In: 24" top penetration/top fill

(2) Liquid In/Out: 24" bottom fill (same bottom 18" withdrawal penetration used)

(3) Vapor Out: 24" line

Other Pertinent Features:

(1) Operating Pressure: 0.9 psig

(2) Design Pressure: 2.0 psig

8. Containment Area:

Each storage tank is surrounded by sloped earthen dikes averaging 18' in height, minimum distance to tank - 110'. Entire area is interlaced with concrete spillways leading to LNG retention areas to control spills.

D. Plant Capability:

1. Liquefaction: N/A

2. Regasification: 540 MMCFD - 5 indirect fired, water bath combustion vaporizers at 108 MMCFD

each.

3. Receiving: Import by LNG carrier, proposed quantity approximately 50 shiploads per year, 350 MMCFD.

4. Terminal Facilities:

   Piers: Shore ide pier with one berth for 125 MCM ship.

   Truck Loading Platforms: 1 - 2 trucks

   Rail Car Platforms: N/A

E. Other Factors:

Terminal design includes equipment to raise pressure of LNG to gas pipeline pressure, vaporize the LNG and deliver approximately 325 MMCFD at 1200 psig to Southern Energy Distribution system via two 30" pipelines.

LNG PEAKSHAVING FACILITIES

Northwest Pipeline Corp.
Plymouth, WA

A. Type of Facility (Year of Operation): LNG Peakshaving Plant (1975)

B. Area Description: Plant is located on 25 acre tract, in the Columbia River Valley, 3.5 miles east of Plymouth, WA (population 100). The plant is isolated in an undeveloped area used primarily for farming and range land.

C. Storage Containers:

1. Number: 1 in use, 1 under construction (same capacity).
2. Type: Above-ground, double wall cylindrical tank
3. Builder: Pittsburgh - Des Moines Steel Co.
4. Container Capacity:

Tank	1	2	Total
Liquid (MBBL)	348	same	696
(MCM)	55	"	110
Gas (MMSCF)	1180	"	2,360

5. Container Dimensions (Inner Shell - Ft.):

Tank	1	2
Diameter	163.6	same
Height	97.4	"
Liquid Level (maximum)	92.9	"

6. Overall Tank Dimensions (Ft.):

Tank	1	2
Diameter	173.3	same
Height	133.5	same

7. Construction Details:

Outer Wall: 131 C carbon steel 1/2" tapered to 7/16" at top

Inner Wall: Tank 1 - aluminum

Tank 2 - 9% nickel steel (astm 5531) .585" tapered to .3125" at top

Insulation: 58" of perlite/fiberglass

Foundation: Standard ringwall over compacted sand/gravel

Penetrations (Piping):

(1) Liquid In: 3" bottom penetration/bottom fill

(2) Liquid Out: 12" bottom withdrawal

(3) Vapor Out: 8" line

Other Pertinent Features:

1 - 12" vacuum vent

1 - 12" pressure relief vent

8. Containment Area: Excavated to 17' below top of gravel and sand sloped dike walls. Common impoundment area displaced from tanks with spillways from tank site. Capacity 153 MCM.

D. Plant Capability:

1. Liquefaction: 13.2 MMSCFD
2. Regasification: 300 MMSCFD
3. Receiving: From Northwest natural gas transmission line during periods of low demand.
4. Terminal Facilities:

Piers: N/A

Truck Loading Platforms: 1 dock - load LNG
1 dock - unload LPG

Rail Car Platforms: N/A

E. Other Factors.

Available land and isolation allows for unique design of impoundment area. In theory primary area of spill boil-off is displaced from tanks to reduce damage in event of fire.

Philadelphia Electric Co. (PECO)
West Conshohocken Plant

A. Type of Facility (Year of Operation): LNG Peakshaving Plant (1972).

B. Area Description: Plant is located about 8.5 miles NW of downtown Philadelphia on Route 23 along the Schuylkill River. Area is surrounded by moderate industry and residential property.

C. Storage Containers:

1. Number: 1
2. Type: Above-ground, double wall cylindrical tank with integral dome shaped, double roof.
3. Builder: Chicago Bridge and Iron
4. Container Capacity:

Tank	1	Total
Liquid (MBBL)	345	345
(MCM)	55	55
Gas (MMSCF)	1173	1,173

5. Container Dimensions (Inner Shell - Ft.):

Tank	1
Diameter	150
Height	140.5
Liquid Level (maximum)	109.6

6. Overall Tank Dimensions (Ft.):

Tank	1
Diameter	160
Height	146.3
Pedestal Ht.	10.5

7. Construction Details:

Outer Wall: Carbon steel - 13/32" tapered to 9/32" at top

Inner Wall: 9% nickel steel - .748" tapered to 5/16" at top

Insulation: 5' perlite with fiberglass blanket

Foundation: 2.5' of foamglass block insulation over concrete

Penetrations (Piping):

(1) Liquid In: 3" top penetration/bottom fill

(2) Liquid Out: 12" bottom withdrawal

(3) Vapor Out: 8" line

Other Pertinent Features:

(1) Inert nitrogen gas barrier between shell and outer tank.

(2) Two manually operated internal shut-off valves for discharge lines.

8. Containment Area:

Unique high dike wall, 62' high, 12" thick pre-cast concrete panels with asbestos insulation to reduce fire damage. Wall is 28' from tank with 7' deep insulated moat. 67 MCM impoundment area.

D. Plant Capability:

1. Liquefaction: 6 MMSCFD - Nitrogen expander system.

2. Regasification: 5 water bath, immersion burner type vaporizers at 62 MMSCFD each.

3. Receiving: Pipeline natural gas at rate of 27 MMSCFD. Process 6.0 MMSCFD into LNG for storage.

4. Terminal Facilities:

Piers: N/A

Truck Loading Platforms: 1 truck loading area

Rail Car Platforms: N/A

E. Other Factors:

The storage container is normally filled during the April to November season, taking natural gas from the distribution pipeline network. On days of peak demand during the winter, LNG is vaporized and pumped back into the network.

Philadelphia Gas Works
Richmond Plant

A. Type of Facility (Year of Operation): LNG Liquefaction Plant (1969); LNG Storage and Vaporization (1974).

B. Area Description: Located in Port Richmond area on Delaware River 0.6 miles west of Frankford Creek entrance. Heavy industrial area with marine terminals, sewage treatment plant and processing/storage of petroleum products.

C. Storage Containers:

1. Number: 2 identical tanks
2. Type: Above-ground, double wall, cylindrical concrete tank with concrete dome, carbon steel outer shell and roof, and 9% nickel steel floor.
3. Builder: Walsh Construction Company (Preload Technology, Inc. - Design Engineer)
4. Container Capacity:

Tank	1	2	Total
Liquid (MBBL)	583	same	1,166
(MCM)	93	same	185
Gas (MMSCF)	1980	same	3,960

5. Container Dimensions (Inner Shell - Ft.):

Tank	1	2
Diameter	230	same
Height	81.4	"
Liquid Level (maximum)	79	"

6. Overall Tank Dimensions (Ft.):

Tank	1	2
Diameter	262	same
Height	119.17	same

7. Construction Details:

Outer Wall: 10' concrete berm between outer steel shell of tank and prestressed concrete exterior wall (11" tapered to 7" at top).

Inner Wall: 11" prestressed concrete tapered to 7" at top with carbon steel wrapper (vapor barrier) on external surface.

Insulation: 4' of perlite, pressurized with boil-off vapor.

Foundation: Reinforced concrete slab on foundation pilings.

Penetrations (Piping): All top penetrations

Tank	1	2
(1) Liquid In:	6" bottom fill	same
(2) Liquid Out:	2 - 8" lines into 10" header 1 - 2" line	3 - 8" lines into 10" header
(3) Vapor Out:	12" line	same

Other Pertinent Features:

(1) Tank operating pressure: less than 1 psig

(2) 4 Primary relief valves, one set at 0.95 psig, three set at 1.0 psig; 2 emergency relief valves set at 1.09 psig; 3 vacuum breakers set at minus .6125 inches water column for each tank

8. Containment Area: Self-contained by means of 10" thick concrete berm and its outer pre-

stressed concrete wall. Impounding basin for spill from pipe failure, capable of holding 20 minutes of flow (2575 bbl, at maximum pumping rate.

D. Plant Capability:

1. Liquefaction: 22.7 MMSCFD - mixed refrigerant cascade cycle.
2. Regasification: 500 MMSCFD - intermediate fluid plate - type heat exchangers
3. Receiving: Estimate 1,040 CM per day LNG (22.7 MMSCFD) to storage by processing natural gas from main distribution network.
4. Terminal Facilities:
   Piers: N/A
   Truck Loading Platforms: 1 (2 trucks)
   Rail Car Platforms: N/A

E. Other Factors:

PGW has an LNG satellite storage and vaporization facility at the Passyunk Plant in Southwest Philadelphia. The Passyunk plant has a storage capacity of 11.6 MCM in one double wall steel tank. LNG is transported by tank truck during the summer months from the Richmond facility to provide extra storage.

Texas Eastern Cryogenics
Staten Island, NY

A. Type of Facility (Year of Operation): LNG Peakshaving Plant (1970-72), shutdown in 1972 because of excessive boil-off. Tank is out of commission because of severe fire inside tank during internal insulation/liner repair operations. Fire resulted in death of 40 men and destruction of internal components of the tank including collapse of roof.

B. Area Description: Located on 58 acre tract adjacent to the Arthur Kill near Gulfport. Low population density area, primarily petroleum industry, processing and storage.

C. Storage Containers:

1. Number: 1
2. Type: Above-ground single wall cylindrical concrete tank with integral concrete dome (double) roof. Tank is surrounded by earthen berm.
3. Builder: Designed by Battelle Institute, Columbus Ohio
4. Container Capacity:

Tank	1	Total
Liquid (MBBL)	600	600
(MCM)	95	95
Gas (MMSCF)	2040	2,040

5. Container Dimensions (Inner Shell - Ft.):

Tank	1
Diameter	268.5
Height	62

Liquid Level (maximum)

6. Overall Tank Dimensions (Ft.):

Tank	1
Diameter	272.5
Height	100

7. Construction Details:

Single concrete wall, 24" thick, surrounded by 10' of select fill and a sloped berm (1.5 to 1) of compacted sand, covered by rocks; has below ground storage characteristics.

Insulation: Two layers of rigid 4" polyurethane foam blocks covered by thin film laminated liner of Mylar - aluminum Dacron.

Foundation: concrete footers and select sand fill.

Penetrations (Piping): N/A

(1) Liquid In:

(2) Liquid Out:

(3) Vapor Out:

Other Pertinent Features:

8. Containment Area:

None

D. Plant Capability:

1. Liquefaction: 10.7 MMCFD - Single multicomponent refrigerant, cascade cycle
2. Regasification: 195 MMCFD - 3 direct fired heat exchanges
3. Receiving: Approximately 9,134 MCFD from pipeline system to store 360 CM's of LNG.*

*Initial operation of plant involved imported LNG offloaded from ships. Two shiploads of LNG were received in 1970.

4. Terminal Facilities:

Piers: None

Truck Loading Platforms: None

Rail Car Platforms: N/A

E. Other Factors: Plant designed to liquefy and store LNG during summer months and vaporize LNG during peak periods returning approximately 199 MMCFD to pipeline distribution.

LPG MARINE TERMINAL FACILITIES

Exxon Co., U.S.A.
Everett, MA

A. Type of Facility (Year of Operation): LPG Receiving Terminal (1974).

B. Area Description: Located on Northern Bank of Mystic River, 2 miles from Boston, adjacent to Distrigas LNG Terminal, in area of heavy industrial activity.

C. Storage Containers:

1. Number: 1
2. Type: Above ground, single wall cylindrical steel tank with integral dome shaped double roof
3. Builder: Pittsburgh - Des Moines Steel Co.
4. Container Capacity:

Tank	1	Total
Liquid (MBBL)	400	400
(MCM)	64	64
Gas (MMSCF)	610	610

5. Container Dimensions (Inner Shell - Ft.):

Tank	1
Diameter	N/A (single wall tank)
Height	
Liquid Level	

6. Overall Tank Dimensions (Ft.):

Tank	1
Diameter	190
Height	85

Liquid Level
(maximum) 79.2
Pedestal Ht. 4

7. Construction Details:

Single Wall: A537 Gr B Steel, 10 rings 7'10" wide; ring thickness - 1" tapered to 0.5" at top ring

Inner Wall: N/A

Insulation: 6 layers of aluminum siding (5-34 gauge plus 1-20 gauge) separated by wood spacers on 2' centers. Total insulation barrier approximately 6".

Foundation: Standard concrete ringwall on stone with granular backfill.

Penetrations (Piping):

(1) Liquid In: 16" shell penetration/bottom fill line from pier

(2) Liquid Out: 12" bottom withdrawal

(3) Vapor Out: 16" line to compressors and flare (8" vapor return line to ship)

Other pertinent features:

(1) Design Pressure: 1 psig

(2) Operating Pressure: .5 psig

(3) Safety Relief: 1 pressure relief set at .8 psig; 3 pressure relief set at .9 psig; 1 emergency relief (24" hatch) set at 1 psig; vacuum breakers set at .8 ounces.

8. Containment Area:

Earth and concrete dikes, varying from 7' to 13' high; minimum distance from tank - 70'. Total impoundment area - 63 MCM.

D. Plant Capability:

1. Liquefaction: N/A
2. Regasification: Propane pump out rate from tank is 400 CM/hr.; liquid is reheated to +40°F for truck or pipeline delivery.
3. Receiving: Ship offloading rate - 1.6 MCM/hour Ship size restricted to 57 MCM. Estimate 300 MCM/yr by tanker.
4. Terminal Facilities:
   Piers: Shoreside pier on Mystic River, one berth.
   Truck Loading Platforms: 3 (can service 6 trucks simultaneously)
   Rail Car Platforms: None

E. Other Factors:

Plant designed for customer delivery of 2.8 MM m^3/yr. Truck deliveries must be balanced against deliveries by pipeline to Boston Gas SNG plant to equal total design capacity.

Petrolane, Inc.
San Pedro, CA

A. Type of Facility (Year of Operation): LPG Receiving Terminal (1974)

B. Area Description: Located on 20 acre tract in northern end of San Pedro in heavy industrial area, dense population. Industry primarily petroleum product processing and storage. Plant is connected to pier facility by 16" underground pipeline approximately 6,000 ft. long.

C. Storage Containers:

1. Number: 2 identical tanks
2. Type: Above-ground, double wall, cylindrical steel tanks with suspended insulating deck and umbrella roof.
3. Builder: Chicago Bridge & Iron
4. Container Capacity:

Tank	1	2	Total
Liquid (MBBL)	300	same	600
(MCM)	48	"	96
Gas (MMSCF)	460	"	920

5. Container Dimensions (Inner Shell - Ft.):

Tank	1	2
Diameter	171	same
Height	80.5	"
Liquid Level (maximum)	73.67	"

6. Overall Tank Dimensions (Ft.):

Tank	1	2
Diameter	175	same

Height 110 "

7. Construction Details:

Outer Wall: 9 rings of .25" steel plate

Inner Wall: 9 rings of A537, Grade A, steel plate - 0.993" tapered to 0.3125" at the eighth ring with a 0.993" top ring.

Insulation: 20" of perlite plus 4" resilient fiberglass blanket. Double bottom with sand and 5" foamglass blocks.

Foundation: Standard concrete ringwall on compacted sand, cut into existing slope.

Penetrations (Piping):

(1) Liquid In: 12" top penetration/top fill

(2) Liquid Out: 14" bottom withdrawal

(3) Vapor Out: 14" line

Other Pertinent features:

(1) Design Pressure 1.5 psig

8. Containment Area:

Earthen dike impoundment. Basin common to both tanks, capacity limited to contents of only one tank (48 MCM).

D. Plant Capability:

1. Liquefaction: Air-cooled heat exchanger and condenser, primarily for reliquefying tank boil-off vapor.
2. Regasification: Liquid propane is heated and transferred to 3-230 cubic meter pressure vessels for pumping to trucks or tank cars.
3. Receiving: From LPG tanker at rate of 1.6 MCM/hr. Petrolane has offloaded only one 21 MCM tanker to date (Norwegian LPGC Fernwood - November 1976)

can also receive propane by truck or tank car (rail).

4. Terminal Facilities:

Piers: Shoreside berth for one ship in the West basin of Los Angeles harbor.

Truck Loading Platforms: 4

Rail Car Platforms: 2

E. Other Factors:

Petrolane is currently storing excess summer products from local refineries, request for importation of approximately 800,000 cubic meters (about 15 ships/yr) is pending.

Sun Oil Company
Marcus Hook, PA

A. Type of Facility (Year of Operation): LPG Receiving Terminal (December 1977).

B. Area Description: Terminal and LPG Facilities are located in Sun Oil refinery at Marcus Hook on the western bank of the Delaware River, 18 miles south of Philadelphia. Area is heavily populated and includes residential section, small business (Marcus Hook) and light industry. Principal industry is Sun refinery.

C. Storage Containers:

1. Number: 2 propane caverns (also the refinery has 2 butane, and 1 propylene caverns).
2. Type: Underground, mined storage caverns
3. Builder: Fenix & Scisson, Inc., Tulsa OK
4. Container Capacity:

Cavern	#1	#2	#3	#4	#5
LPG	Butane	Propane Butane	Butane	Propylene	Propane
Storage for	Refinery	Terminal/ Refinery	Refinery	Refinery	Terminal
Liquid (MBBL)	230	395	250	75	1,150
(MCM)	37	63	40	12	183
Gas (MMSCF)	300	600	325	110	1,750

5. Storage Area: The Sun Oil caverns are horizontally excavated donut-shaped tunnels, approximately 35 feet wide by 37 feet high. The roof is supported by monolithic granite pillers, the smallest being 40 feet square. Tunnel size varies in accordance with desired capacity.

Deep well sumps are excavated in cavern floor for pumping LPG. Each cavern has two 14-inch pump casings for the LPG discharge lines and a 42-inch main casing which contains an 8-inch fill line and two 3-inch water lines to the sumps. All casings can be water sealed in the event of an emergency to prevent release of gas to the atmosphere. The first four caverns have been in service since 1960.

D. Plant Capacity

1. The terminalling throughput capacity will be 2.4 MMCM/yr. Propane will be distributed by tank truck and rail car, with a pipeline planned in 1980.
2. The shoreside pier facility should be completed by October 1977. There is one berth capable of handling an LPG carrier not over 1,000 feet LOA and 40 feet draft. Two 16-inch unloading arms can pump 2.9 MCM/hr to storage.

APPENDIX XVI-3

FEDERAL REGULATIONS

INTRODUCTION

The first section of this appendix describes the evolution of Federal regulation of LPG and LNG storage facilities. It focuses on the two agencies that have been primarily responsible for the Federal regulation of these facilities: the former Federal Power Commission (FPC)* and the Office of Pipeline Safety Operations (OPSO) in the Department of Transportation (DOT).

The second section covers the U.S. Coast Guard's authority to regulate LEG shipping and waterfront facilities.

The third section discusses the overlap in the jurisdictions of these three agencies.

The fourth section covers the Federal regulation of LEG truck and rail transportation by several DOT agencies.

1. FEDERAL CONTROLS ON LPG AND LNG

Liquid petroleum products transported by pipeline were originally regulated under the Interstate Commerce Act of 1887, as amended (49 U.S.C.1 et seq.), which generally

*The FPC was disbanded in October, 1977, when the Department of Energy (DOE) was organized under Public Law 95-91. The distribution of FPC's responsibilities within DOE had not been fully determined by June, 1978. For this reason this appendix traces the evolution of FPC's jurisdiction over LNG facilities.

provided for economic regulation and the granting of operating authority for pipeline companies engaged in interstate or foreign commerce. The Transportation of Explosives Act of 1908, as amended (18 U.S.C. 831-835), gave the Interstate Commerce Commission (ICC) specific authority to "formulate regulations for the safe transportation within the United States of explosives and other dangerous articles, including. . .flammable liquids. . ., which shall be binding on all carriers engaged in interstate or foreign commerce. . .which transport explosives or other dangerous articles by land" (18 U.S.C. 834(a)).

The Department of Transportation Act of 1966, as amended, (49 U.S.C. 1651 et seq.) transferred to the Secretary of the newly created Department of Transportation control over many safety aspects of different modes of transportation, including the specific powers of ICC to regulate the interstate or foreign transportation of dangerous articles under Title 18. (49 U.S.C. 1655(e)(4).) Certain other functions having to do with the economic regulation of interstate or foreign-connecting petroleum pipelines within the United States were left in ICC, although they have since been transferred to DOE. (42 U.S.C. 7155.)

To assist in carrying out this acquired safety responsibility as well as others, the Secretary of Transportation created the Materials Transportation Bureau (MTB), and delegated authority over the Transportation of Explosives Act to the Director. (49 C.F.R. 1.53(g).) Pursuant to a redelegation within MTB (49 C.F.R. Part 102, Appendix A), OPSO promulgated regulations, found in 49 C.F.R. Part 195, "Transportation of Liquids by Pipeline", which govern the transportation by pipeline in interstate or foreign commerce of petroleum, petroleum products, and hazardous materials, including "liquefied petroleum gases".

The Federal Power Commission

The transportation of natural gas by pipeline in interstate or foreign commerce was first regulated under the terms of the Natural Gas Act of 1938 (15 U.S.C. 717 et seq.). The Act stipulated administration and enforcement of regulation by FPC, previously established as an independent agency in 1930, by the Federal Water Power Act. By the Natural Gas Act, the Commission was granted primarily economic jurisdiction over rates and service and over the granting of general operating authority to natural gas pipeline companies. FPC specifically determined LNG to be "natural gas" within the meaning of the Natural Gas Act and thus similarly subject to its jurisdiction (49 F.P.C. 752(1972)).

FPC has exercised this authority in the process of granting Certificates of Public Convenience and Necessity, which are required by companies who "engage in the transportation or sale of natural gas—or undertake the construction or extension of any facilities therefor, or acquire or operate—" any such facilities in interstate commerce (15 U.S.C. 717f.(c)). Similar FPC authorization has been required by anyone who would engage in the importation into or the exportation from the United States of any natural gas in foreign commerce, (15 U.S.C. 717b).

The Natural Gas Act does not specifically address safety, but gives the Commission power to attach to the issuance of a certificate "such reasonable terms and conditions as the public convenience and necessity may require." With regard to foreign commerce, the Act and Executive Order No. 10485, (18 F.R. 5397), 1953, authorized the imposition of such conditions as the "public interest" may require. These "public convenience and necessity" and "public interest" standards have been interpreted as not to preclude the Commission from imposing safety standards on the transportation of natural gas. In determining "public convenience and necessity" the Commission must consider "all factors bearing on the public interest". (Atlantic Refining Co. v. P.S.C. of N.Y., 360 U.S. 378, 391, 79 S.Ct. 1246 (1959).)

The applicable parts of the Code of Federal Regulations, (18 C.F.R. Parts 153, 156, 157), do not contain specific "safety implication" requirements since FPC has no specific legislative mandate on which to promulgate such regulations. The regulations, based on Natural Gas Act authorization, do specify that applications for Certificates of Public Convenience and Necessity must include "a concise description of the proposed. . . construction," (18 C.F.R. 157.6(b)(4)), and, annexed to it, a map showing generally the location of the proposed facilities (18 C.F.R. 157.14(a)(6)).

More recently, and in addition to the Natural Gas Act authorization above, safety considerations became a part of the Commission's evaluation of applications by virtue of the National Environmental Policy Act (NEPA) of 1969, (42 U.S.C. 4321 et seq.), which requires Federal agencies to consider environmental preservation in exercising regulatory responsibilities. The requirement specifically includes the preparation of detailed environmental impact statements in actions significantly affecting the quality of the human environment. FPC, as a Federal regulatory agency, was therefore required to conduct its own environmental evaluation of proposed natural gas facilities as part of a statutory review procedure. (Calvert Cliffs Coordinating Committee v. Atomic Energy Commission, 449 F.2d 1109, D.C. Cir. 1971.) Safety is one of the factors to be considered in such an evaluation.

FPC formulated comprehensive regulations on compliance with NEPA (18 C.F.R. 2.80-2.82 and Appendix B to Part 2) and specifically addressed the area of "LNG Facilities," (18 C.F.R. Part 2, Appendix B, Guideline 9.4.1). The Commission's Order No. 485 established requirements whereby environmental aspects, including safety, of LNG facilities could be evaluated for all phases of any proposal: construction; operation, including transportation, unloading, storage, and regasification; and routine and emergency maintenance.

Office of Pipeline Safety Operations

After the passage of the Department of Transportation Act in 1966, the new Department of Transportation had safety jurisdiction over flammable and other hazardous gases moving in interstate commerce other than by pipeline, and safety jurisdiction over interstate pipeline movements of most liquid commodities including petroleum, but not natural gas. FPC was imposing conditions of compliance with industry codes on the granting of Certificates of Public Convenience and Necessity for interstate natural gas pipelines and facilities, and some of the states prescribed safety standards by legislative or state commission action for intrastate pipelines. Natural gas pipelines were the only significant mode of transportation beyond the reach of effective comprehensive safety regulations.

As a result, Congress enacted the Natural Gas Pipeline Safety Act of 1968, as amended (49 U.S.C. 1671 et seq.) to be administered by DOT. The Secretary has delegated the authority to promulgate regulations unde- this Act to the Materials Transportation Bureau (49 C.F.R. 1.53(a)), and the Bureau Director delegated this authority to the Director of OPSO (49 C.F.R. Part 102, Appendix A).

The Natural Gas Pipeline Safety Act required the Secretary to establish minimum Federal safety standards for the transportation of natural gas and for the safety of pipeline and "pipeline facilities" used in such transportation in or affecting interstate commerce. Such standards were to be applicable to the "design, installation, inspection, emergency plans and procedures, testing, construction, extension, operation, replacement and maintenance of pipeline facilities." (49 U.S.C., 1672(b).) "Pipeline facilities" were defined to include new and existing pipe ʼhts-of-way and any equipment, facility, or building used in the transportation or treatment of gas, although an important limitation was added that "rights-of-way" did not include the right to prescribe the location or routing of any pipeline or facility. (49 U.S.C., 1671(4).) Authority to determine the siting and routing of natural gas pipelines, therefore, remained with FPC, and FPC's responsibilities in certifying interstate natural gas pipelines and facilities, including safety considerations, were not diminished. Pipelines and appurtenant pipeline facilities were made subject to both FPC certification and OPSO safety regulations. Areas of shared responsibilities regarding natural gas were thus created.

This shared responsibility may be illustrated by a procedure under the Act whereby an interstate applicant may certify to FPC that it will construct and maintain its facilities in accordance with Federal and other applicable safety standards, and "such certification shall be binding and conclusive upon the Commission" for purposes of determining whether the construction and operation details of a proposed service conform to OPSO's standards, unless the applicant is otherwise reported to be in violation of the regulations (49 U.S.C. 1676). Because of this procedure the question has sometimes arisen whether FPC can impose higher safety standards than the Federal minimum which the applicant certifies to have met and which is regulated and enforced by OPSO.

The legislative history of the Natural Gas Pipeline Safety Act expressed the intent that all aspects of the movement of gas from the wellhead to the consumer, with the exception of certain gathering lines, were to be regarded as either being in, or having effect on, interstate commerce and thereby encompassed by the Secretary's authority. The Act provides for a voluntary program of State Agency Certifications or Agreements to provide safety administration and enforcement of regulations for intrastate pipelines (49 U.S.C. 1674). Under the program, agencies in 44 states, the District of Columbia, and Puerto Rico have certified that they have adopted standards equivalent to or better than the Federal minimum and that they have the capacity for effective enforcement of intrastate regulation. The states may adopt more stringent regulations for intrastate, but not for interstate, lines located within their boundaries; however, OPSO retains the overiding authority to bring Federal action against any facility which it finds to be hazardous to life or property.

The Natural Gas Pipeline Safety Act also created a "Technical Pipeline Safety Standards Committee" composed of members from government, industry, and the general public. Each member must be qualified in safety regulation or engineering, and the Act requires the Secretary to obtain their counsel before formally proposing any safety standard.

Specific LNG regulation under authority of the Natural Gas Pipeline Safety Act has developed primarily as a regulation of appurtenant production or storage facilities because the physical properties of LNG make it uneconomical to pump any distance by pipeline, such as interstate. Most of the presently proposed LNG marine terminals connect into inland gas pipeline distribution systems, which bring them under Federal regulation by OPSO as appurtenant pipeline facilities. The FPC meanwhile has had jurisdiction over marine terminals whether or not there is a connecting inland pipeline distribution system, under its Natural Gas Act authority over the import or export of natural gas, including safety aspects.

OPSO's safety standards are contained in 49 C.F.R. Parts 191 and 192: "Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards." Specific LNG standards were created by an amendment in 1972 adding Section 192.12. This adopted as the Federal LNG safety standards the National Fire Protection Association (NFPA) Standard 59A (1971 edition), as well as the other applicable requirements of Part 192. Subsequently, the 1972 edition of NFPA 59A was adopted.

In response to growing concern from many sectors, OPSO has issued an Advance Notice of Proposed Rulemaking which establishes an independent Federal code or standard applicable to all aspects of facilities involved in the transport, storage, liquefaction, vaporization, transfer, and handling of LNG in conjunction with natural gas pipeline systems. The proposed standards are written in the style of enforceable Federal regulations and in terms of performance standards which address the on-going, long-term safe operation and maintenance of LNG facilities. Industry is left free to develop and use improved technological means of meeting the required safety level, and the NFPA is not pre-empted from continuing to devise and recommend means of meeting the government standards.

OPSO's regulation of LPG and naphtha pipelines in interstate and foreign commerce is authorized under the Transportation of Explosives Act of 1908, (18 U.S.C. 831-835). The Act does not cover intrastate pipelines and facilities that merely affect interstate commerce.

The Hazardous Materials Transportation Act, enacted in 1975, excludes interstate liquid pipelines covered under the Explosives Act from its provisions. OPSO further interprets the Act to exclude jurisdiction over intrastate liquid pipelines affecting interstate commerce. No Federal agency regulates the safety of LPG storage at import terminals or at storage complexes that are not owned or operated by interstate LPG transmission companies.

2. U.S. COAST GUARD'S REGULATION OF LEG SHIPPING AND WATERFRONT FACILITIES

The U. S. Coast Guard has traditionally promulgated regulations regarding the safe transportation of LNG and LPG under the general classification of "liquefied gas ships," in which gases are liquefied by low temperatures, high pressures, or a combination of the two. LNG and LPG have to date been grouped as a common hazardous cargo.

Traditional safety considerations in the transportation of LNG/LPG by water fall into three broad categories:

- the design and construction of vessels
- the design and construction of related waterfront facilities, and
- the movement of vessels in the ports and waterways of the United States.

In addition, with the passage of the Ports and Waterways Safety Act of 1972, Title II, (46 U.S.C. 391a), the concept of vessel design and construction as a safety factor was enlarged to reflect dual objectives: (1) vessel safety, per se, and (2) vessel safety for the purpose of the protection of the marine environment.

Present day Coast Guard regulation of LNG/LPG vessels and waterfront facilities is comprehensive and reflects a broad basis of authority.

Statutory Authority

Tanker Act

One of the earliest sources of Coast Guard authority was the Tanker Act of 1936, (46 U.S.C. 391a), applicable to "all vessels. . .that shall have on board any inflammable or combustible liquid cargo in bulk." The Act authorized the Coast Guard to establish regulations with respect to "the design and construction, alteration, or repair of such vessels" to "secure effective provision against the hazards of life and property" created by them (46 U.S.C. 391a(2)1970).

The regulations promulgated, in part, under the authority of this Act are found in 46 C.F.R. Subchapter D, "Tank Vessels," Parts 30 to 40, inclusive. In 1966, Part 38 "Liquefied Flammable Gases" was specifically added to the regulations (31 F.R. 15269).

Dangerous Cargo Act

An even earlier mandate in regard to vessel safety, which the Coast Guard now administers, came from the Dangerous Cargo Act, as amended, (46 U.S.C. 170). This Act makes it unlawful to carry "explosives or other dangerous articles or substances including flammable or combustible liquids. . ." except as permitted by the regulations of the Coast Guard (46 U.S.C. 170(6)(a)). By amendment, later provisions of this Act specifically exempted the vessels carrying "inflammable or combustible liquid cargo in bulk" in their own tanks, or "tank vessels" as regulated by 46 U.S.C. 391a. above, except for one narrow provision.

The Dangerous Cargo Act applies to dangerous cargoes carried in containers and regulates labeling, container specifications, storage, and handling of such containers. In the mid-1960's the transport of bulk chemicals in large portable containers and portable tanks was becoming a problem, and with the promulgation of the "Liquefied Flammable Gases" regulations (46 C.F.R. Part 38), the Coast

Guard included regulation of the "Transportation of portable cylinders or portable tanks containing or having previously contained liquefied flammable gases in dry cargo spaces," (46 C.F.R. 38.01-2). The regulations only apply to the transportation of LNG/LPG when the containers are carried "under deck." However, containers "under deck" as well as "on deck" are regulated under the Hazardous Materials Transportation Act. As a result, if LEG is transported in containers "under deck," the vessel must meet the requirements promulgated under the authority of the Dangerous Cargo Act, as well as those under the Hazardous Materials Transportation Act.

The Hazardous Materials Transportation Act also contains specific provisions relating to investigations, records, inspections, penalties, and specific relief for the enforcement of safety regulations covered by the Act. By specific delegation of authority from the Secretary of Transportation, the Coast Guard has been empowered to exercise such functions as they apply to the transportation or shipment of hazardous materials by water (49 C.F.R. 1.46(u)). This delegation permits more centralization of enforcement responsibilities within DOT for the safe transportation of hazardous materials by water.

Magnuson Act and Executive Order 10173

Since 1950, the Coast Guard has carried out a program for port safety under regulations initially prescribed by the President in Executive Order 10173 (15 F.R. 7005) pursuant to the Magnuson Act (50 U.S.C. 191). In part, the Magnuson Act authorizes the President, upon a finding that the security of the United States is endangered, to issue rules and safeguard vessels, harbors, ports, and waterfront facilities in the United States and waters subject to the jurisdiction of the United States against destruction, loss, or injury. The President made the appropriate finding in Executive Order 10173 (1950) and prescribed regulations which, as amended, are currently codified in 33 C.F.R. Part 6.

The more relevant provisions of these regulations for LEG safety are delegations of authority to the Coast Guard:

(1) "The Captain of the Port {COTP} may supervise and control the transportation, handling, loading, discharging, stowage, or storage. . .of inflammable or combustible liquids in bulk. . .covered by the regulations. . .governing tank vessels (46 C.F.R. Parts 30 to 39 inclusive)." (33 C.F.R. 6.12-1.)

(2) "The Commandant may designate waterfront facilities {for the above}. . .and may require the owners, operators, masters, and others concerned to secure permits. . .conditioned upon the fulfillment of such requirements for the safeguarding of such waterfront facilities and vessels as the Commandant may prescribe." (33 C.F.R. 6.12-3.)

(3) "The Commandant. . .may prescribe such conditions and restrictions relating to the safety of waterfront facilities and vessels in port as he finds to be necessary under existing circumstances. Such conditions and restrictions may extend, but shall not be limited to, the inspection, operation, maintenance, guarding, and manning of, and fire

prevention measures for, such vessels and waterfront facilities." (33 C.F.R. 6.14-1.)

The Coast Guard, in implementing its delegated authority, promulgated regulations contained primarily in 33 C.F.R. Parts 124, 125, and 126. Part 124 applies to "Control over Movement of Vessels." Part 125 ("Identification Credentials for Persons Requiring Access to Waterfront Facilities or Vessels") and Part 126 ("Handling of Explosives or other Dangerous Cargoes Within or Contiguous to Waterfront Facilities") apply to waterfront facilities. These regulations, in conjunction with those in Part 6, have provided the basis for the development of local LNG/LPG contingency plans.

The COTP has, historically, determined many jurisdictional questions raised by language stemming from Executive Order 10173. 33 C.F.R. Part 126 refers to the handling of dangerous cargoes at designated waterfront facilities of particular hazard. The regulations define "waterfront facility" as "all piers, wharves, docks, and similar structures to which vessels may be secured; areas of land, water, or land and water under <u>and in immediate proximity to them</u> (emphasis added); buildings on such structures or contiguous to them and equipment and materials on such structures or in such buildings." (33 C.F.R. 6.01-4.) The jurisdictional limitations of how far inland the Coast Guard regulations and their enforcement apply have traditionally been a matter of local determination by the COTP, illustrating the need for clarification of Coast Guard authority over port safety under the Magnuson Act and Executive Order 10173, as amended. See the discussion below of Jurisdictional Overlap.

Ports and Waterways Safety Act (PWSA)

The major source of the Coast Guard's comprehensive regulatory authority over the safe transportation of LNG/LPG by water stems from the Ports and Waterways Safety Act of 1972, as amended, Title I (33 U.S.C. 1221 et seq.), and Title II (amending 46 U.S.C. 391a). This legislation applies to the design and construction of vessels, minimum safety equipment requirements for waterfront structures, and the movement of vessels. In addition, the legislation applies to all vessels entering the navigable waters of the United States, and the goal of safety in the ports and waterways as a result of the Act is now to reflect a concern for the marine environment.

Title II of the PWSA is an amendment of the Tanker Act requiring vessels to be built to higher standards of design and construction and to be subject to higher standards in operation. It mandated that for all vessels documented under the laws of the United States or vessels entering the navigable waters of the United States there be established "minimum comprehensive standards of design, construction, alteration, repair, maintenance, and operation to prevent or mitigate the hazards to life, property, and the marine environment" (emphasis added). (46 U.S.C. 391a(1).) The rules and regulations are to apply to the ship structure and all materials; the machinery and manner used in handling and storage of cargo; the fire protection provisions; the manning requirements and qualifications of officers and crew; and the inspection of all the foregoing (46 U.S.C. 391a(3)).

One of the most far-reaching implications of Title II is that the authority to prescribe standards for the protection of the marine environment is made explicit, and the concept of vessel safety is to reflect design and construction criteria to achieve that goal. The Act mandates adoption, to the extent possible, of "standards to improve vessel maneuvering and stopping ability and otherwise reduce the possibility of collision, grounding, or other accident, to reduce cargo loss following {the above}, and to reduce damage to the marine environment by normal vessel operations such as ballasting and de-ballasting, cargo handling, and other activities." (46 U.S.C. 391a(7).) The goals reflected in this language also illustrate the growing concern that safety regulation of the transportation of such hazardous cargoes as LNG/LPG provide for the containment of a major spill or potentially catastrophic event.

The present regulations for the design, construction, inspection, manning and operation of tank vessels pertaining to vessel safety are contained in 46 C.F.R. Subchapter D, Parts 30-40, of which Part 38, "Liquefied Flammable Gases," relates specially to LNG/LPG vessels. These regulations were promulgated, in part, under the authority of the Tanker Act and Title II of the PWSA.

In 1971 the Coast Guard had requested its Chemical Transportation Industry Advisory Committee (CTIAC) to make recommendations for a thorough updating of 46 C.F.R. Part 38. In conjunction with the Intergovernmental Maritime Consultative Organization (IMCO), they completed an international "Code for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk" for new ships, which was adopted by IMCO in late 1975. The Coast Guard, which was actively involved in the development of the IMCO Code, proposed rules in October 1976 corresponding closely to the

IMCO Code. Also in October 1976, IMCO adopted the "IMCO Code for Existing Ships Carrying Liquefied Gases in Bulk." The Coast Guard published an Advance Notice of Proposed Rulemaking for construction and equipment of existing self-propelled vessels carrying bulk liquefied gases in June 1977.

Vessels are not designed to withstand a major collision or stranding without cargo release. The Coast Guard's operational controls on vessels entering, moored, or leaving U.S. ports lessen the possibility of collisions, strandings, or other incidents.

Title I of the PWSA included new legislation governing port safety "in order to prevent damage to, or the destruction or loss of any vessel, bridge, or other structure on or in the navigable waters of the United States, or any land structure or shore area <u>immediately adjacent to those waters</u>" (emphasis added). (33 U.S.C. 1221.) The PWSA goes on to provide for extensive vessel traffic services, systems, and controls over entry, movement, mooring and restricted vessel operation in hazardous circumstances or by virtue of hazardous cargo handling (33 U.S.C. 1221(1),(2),(3),(4)).

In addition, waterfront facilities are specifically covered in the limited authority to establish "procedures, measures, and standards for the handling, loading, discharge, storage, stowage, and movement. . .of explosives or other dangerous articles or substances. . .on structures subject to this chapter" and to "prescribe minimum safety equipment requirements for {such} structures. . .to assure adequate protection from fire, explosion, natural disasters, and other serious accidents or casualties." (33

U.S.C. 1221(6) and (7).) The PWSA, Title I, provides permanent statutory authority for the development of regulations regarding the safety of ports and waterways specifically including control over vessel movement and minimum safety equipment requirements for waterfront facilities.

The regulations promulgated under PWSA Title I regarding vessel movement are contained in 33 C.F.R. Parts 160, 161, 164, and 165. Part 160, "Ports and Waterways Safety-General," establishes the role of the COTP, and was recently amended to increase his authority regarding cargoes such as LEG (42 F.R. 48022). Part 161, "Vessel Traffic Management," refers only to the established system operating in the Puget Sound but illustrates an extensive traffic control system. Part 164, "Navigation Safety Regulations," establishes a comprehensive scheme prescribing rules for navigation procedures, preliminary tests, and minimum equipment for ships operation, in U.S. ports and waterways. Part 165, "Safety Zones," prescribes the procedures for establishing safety zones and general regulations for such zones. These regulations have only recently been promulgated and became effective in 1977 and 1978.

The Coast Guard is developing regulations for waterfront facilities for liquefied gases in bulk. A task group similar to the one for LNG/LPG vessel design has completed a review to expand existing port safety regulations for such waterfront facilities. As part of their task, this group specifically addressed LNG marine terminals and prepared a proposal entitled "Waterfront Facility Regulations, Liquefied Natural Gas in Bulk" to replace existing 33 C.F.R. Part 126. This proposal has been approved by CTIAC and has been presented to the Coast Guard for consideration. Additional proposals affecting all other liquefied gases, including regulations for LPG terminals, are contemplated.

Delegation of Authority

The Department of Transportation Act of 1966 (49 U.S.C. 1651 et seq.) transferred to and vested in the Secretary of Transportation ". . .all functions, powers, and duties relating to the Coast Guard, of the Secretary of the Treasury. . ." (49 U.S.C. 1655(b)(1).)

The Secretary of Transportation specifically delegated to the Commandant of the Coast Guard in 49 C.F.R. 1.46(n)(4) his authority under PWSA, which includes the historical authority vested in the Coast Guard by the Tanker Act. In addition, the Secretary specifically delegated his authority under the Hazardous Materials Transportation Act and the Dangerous Cargo Act to regulate the transportation of hazardous materials which are loaded or carried on board a vessel without benefit of containers or labels. (49 C.F.R. 1.46(t).) Authority under the Hazardous Materials Transportation Act relating to investigations, records, inspections, penalties, and specific relief was also delegated to the Coast Guard, insofar as the provisions apply to any transportation or shipment of hazardous materials by water (49 C.F.R. 1.46(u)).

Within the Coast Guard, two offices have been established which are responsible for the promulgation and enforcement of safety regulations: the Office of Merchant Marine Safety, designated "G-M," and the Office of Marine

Environment and Systems, "G-W." Regulations governing the design and construction of vessels would primarily originate out of the Office of Merchant Marine Safety, while regulations governing waterfront facilities or vessel movement would primarily originate out of the Office of Marine Environment and Systems. Such a strict division of responsibility is not an accurate description of the manner in which regulations are promulgated, however because divisions within one agency at some point participate in the development of standards that are applied and enforced by the other.

The Safety Investigation Division cooperates with the National Transportation Safety Board (NTSB) in accident investigation and records keeping. The NTSB can make recommendations to the Coast Guard but does not have the authority to enforce penalties. The Coast Guard can accept or reject the recommendations, with explanation. In addition, the Coast Guard has several advisory committees, the most important being CTIAC.

3. JURISDICTIONAL OVERLAP

The Coast Guard has authority over any waterfront operation for the importation of LNG or LPG by ship to protect the waterfront area and the environment, whether the facility connects into an inland distribution system that is interstate or intrastate. If the marine terminal connects into a pipeline system in or affecting interstate commerce, OPSO also has certain safety regulatory responsibilities, although not coterminous with those of the Coast Guard. Moreover, FPC has certain regulatory responsibilities over the facility if the marine terminal is for the importation of LNG. In most instances the primary regulatory role is different, but it is important that the agencies coordinate with one another where they share regulatory responsibility over the same facility. State, local, or municipal authorities may also have requirements over and above Federal standards as long as they are not inconsistent with them. Site selection is an area particularly requiring agency coodination.

Site Selection

Federal responsibility for the site approval of specific LNG import or export marine terminals has been exercised by the FPC, although similar authority for LPG facilities has not been assigned by law. The FPC, with regard to LNG terminals, conducts an internal assessment of siting considerations and requires certain environmental impact statement information, including safety information. During a formal hearing proceeding, evidence with respect to this information, as well as safety evidence of other interested persons, can be presented. More specifically, both OPSO and Coast Guard can present evidence with respect to each's safety regulations and each's concern regarding the particular site or sites for the specific terminal under consideration. After hearing all of the evidence, the FPC may grant a license or Certificate of Public Convenience and Necessity for the facility at a particular site.

For the FPC to most effectively consider the safety of a marine terminal facility, OPSO and the Coast Guard should have meaningful, generally applicable, safety regulations and should actively participate in the hearing process, presenting any additional safety information peculiar to the specific sites under consideration.

Compliance with these general safety regulations as well as additional safety requirements peculiar to the site may then be imposed by the FPC as conditions of its license or certificate.

Coast Guard's interest in siting to date has been one of indirect control by way of operational safety, considering such factors as the accessibility of a site and the feasibility of safe navigation in the area.

The general mandate to secure the safety of the ports and waterways, and the new mandate from the PWSA for the protection of the marine environment, "including marine and coastal ecosystems and recreational and scenic values" (46 U.S.C. 391a(1)), conceivably provide authority for the Coast Guard to consider specific siting requirements within its jurisdictional domain, including exclusion zone distances and impounding areas. An unsafe condition anywhere "immediately adjacent to the navigable waters" could pose a threat to the port and vessels nearby.

In its proposed new regulations for LNG facilities, OPSO also includes general regulations establishing siting requirements.

Such actions by both the Coast Guard and OPSO need not create jurisdictional problems between them or with the FPC's successor, as long as there is proper coodination amongst them.

Memorandum of Understanding

While OPSO and the Coast Guard each were developing proposed rules for LNG facilities, the two agencies worked to clarify their jurisdictions over waterfront facilities. After more than three years of negotiations, agreement was reached on a Memorandum of Understanding, signed on February 7, 1978 by the MTB and the Coast Guard. (See Exhibit XVI-1.) The Memorandum spells out the specific responsibilities of each agency. The two agencies agree to cooperate and assist each other in carrying out their respective regulatory responsibilities, and to consult with each other before issuing each Advance Notice of Proposed Rulemaking, Notice of Proposed Rulemaking, and final regulation affecting waterfront LNG facilities.

4. REGULATION OF LEG TRUCK/RAIL TRANSPORTATION

DOT's safety regulation of the transportation of hazardous materials is divided between the Office of Hazardous Materials Operations (OHMO) within the MTB and the agencies that regulate the various modes of transportation. OHMO prescribes regulations that are common to the different modes of transportation. The modal agencies enforce these regulations and prescribe and enforce regulations for their specific mode of transportation.

OHMO prescribes regulations under the Transportation of Explosives Act of 1908, (18 U.S.C. 831-835), and the Hazardous Materials Transportation Act (49 U.S.C. 1801 et seq.). The Explosives Act provides authority for regulation of shippers, freight forwarders, and carriers on land to secure the safety in transit of explosives and other dangerous articles, including the packaging, handling, and routing thereof. The Hazardous Materials Transportation Act extends that authority to reach any hazardous material and any manufacturer of packages or

EXHIBIT XVI-1

MEMORANDUM OF UNDERSTANDING BETWEEN THE UNITED STATES COAST GUARD AND THE MATERIALS TRANSPORTATION BUREAU FOR REGULATION OF WATERFRONT LIQUEFIED NATURAL GAS FACILITIES

I. INTRODUCTION

Within the Department of Transportation (DOT), the United States Coast Guard (USCG) and the Materials Transportation Bureau (MTB) exercise separate and overlapping safety regulatory authority affecting the siting, design, construction, maintenance, and operation of waterfront liquefied natural gas (LNG) facilities adjoining the navigable waters of the United States. The USCG derives its authority over such facilities from the Ports and Waterways Safety Act of 1972 (Pub. L. 92-340, 33 U.S.C. 1221-1227) and the Magnuson Act (50 U.S.C. 191). The regulatory authority of the MTB over these same facilities (as well as non-waterfront LNG facilities) is derived from the Natural Gas Pipeline Safety Act of 1968 (Pub. L. 90-481, 49 U.S.C. 1671 *et seq.*) and the Hazardous Materials Transportation Act (Pub. L. 93-633, 49 U.S.C. 1801 *et seq.*).

In recognition of each of the parties' respective regulatory responsibilities, the USCG and the MTB agree that a memorandum of understanding is needed to avoid duplication of regulatory efforts regarding waterfront LNG facilities and to maximize the exchange of relevant information.

II. RESPONSIBILITIES OF THE PARTIES

For the foregoing reasons, the USCG and the MTB agree to the following division of regulatory responsibilities with respect to waterfront LNG facilities and cooperation in carrying out those responsibilities:

USCG RESPONSIBILITIES

The USCG is responsible for establishing regulatory requirements for--

(1) Facility site selection as it relates to management of vessel traffic in and around a facility;

(2) Fire prevention and fire protection equipment, systems, and methods for use at a facility;

(3) Security of a facility; and

(4) All other matters pertaining to the facility between the vessel and the last manifold (or valve) immediately before the receiving tank(s).

MTB RESPONSIBILITIES

The MTB is responsible for establishing regulatory requirements for--

(1) Facility site selection except as provided by paragraph (1) of the "USCG Responsibilities" set forth in this Memorandum; and

(2) All other matters pertaining to the facility beyond (and including) the last manifold (or valve) immediately before the receiving tank(s) except as provided by paragraphs (2) and (3) of the "USCG Responsibilities" set forth in this Memorandum.

JOINT RESPONSIBILITIES

(1) The USCG and the MTB will cooperate and assist each other in carrying out their respective waterfront LNG facility regulatory enforcement activities; and

(2) The USCG and the MTB, in an effort to avoid inconsistent regulation of similar safety matters (including as between waterfront and non-waterfront LNG facilities), will consult with each other before issuing each Advance Notice of Proposed Rulemaking, Notice of Proposed Rulemaking, and final regulation affecting waterfront LNG facilities.

For the United States Coast Guard

ADM Owen W. Siler
Commandant

Date 7 FEB 1978

For the Materials Transportation Bureau

L. D. Santman
Acting Director

Date FEB 1 1978

containers used in the transportation of hazardous materials. The Act also authorizes the establishment of explicit criteria for the handling of hazardous materials including personnel requirements; detection and warning equipment; specifications regarding the use of equipment and facilities; and a system for monitoring safety assurance procedures. The Act and implementing regulations apply to transportation in or affecting interstate commerce. It explicitly provides for Federal preemption of state law if there is a conflict; however, it established a mechanism by which a state or other political subdivision can apply to avoid preemption upon a showing that its own statute or regulation affords an equal or greater level of protection and does not burden interstate commerce.

OHMO issues the regulations found in 49 C.F.R. Parts 170-179, "Hazardous Materials Regulations." Regulations have been developed to govern tank trailers used to carry LPG, but no regulations are yet applicable to LNG tank trucks. Firms proposing to transport LNG file an application for an exemption. Hazardous materials regulations governing transportation by highway are enforced by the Bureau of Motor Carrier Safety (BMCS) within the Federal Highway Administration (FHWA). Regulations governing transportation by rail are enforced by the Federal Railroad Administration (FRA).

Two separate DOT modal agencies have safety jurisdiction over LEG truck transportation: FHWA and the National Highway Traffic Safety Administration (NHTSA). Economic regulation of motor carriers, including operating authority and entry into the interstate trucking industry, is vested in ICC, which does not itself develop independent safety requirements for use in its certification procedures.

FHWA has general authority to investigate the safety compliance of any applicant seeking motor carrier operating authority from ICC, and consults with ICC on the routing of hazardous materials by truck. (Highway routing regulations are issued by OHMO but are enforced through the FHWA.) FHWA has specific authority to carry out the provisions of the Motor Carrier Act of 1935 regulating the qualifications and maximum hours of service of employees, and the safety of operation and equipment for motor carriers in interstate or foreign commerce (49 U.S.C. 304). FHWA has enforcement authority over regulations governing hazardous materials transportation by highway issued by OHMO. By successive delegation of authority from the Administrator of FHWA, BMCS issues the regulations found in 49 C.F.R. Parts 385-398, "Federal Motor Carrier Safety Regulations," and enforces those of OHMO governing hazardous materials transportation by highway. Regulations issued by BMCS apply to drivers, facilities, and the operational safety of motor vehicles used by carriers in interstate transportation.

NHTSA has authority to carry out the National Traffic and Motor Vehicle Safety Act of 1966, as amended (15 U.S.C. 1381 et seq.) requiring the development of minimum standards on design, construction, and performance of motor vehicles or equipment. The Act establishes Federal preemption over state and local motor vehicle safety standards. NHTSA issues the regulations found in 49 C.F.R. Parts 501-590, including Part 571, "Federal Motor Vehicle Safety Standards." Again, exemptions are required for manufacturers of LNG transport vehicles. Exemption applications require the testing of individual trucks by design and construction specifications determined within NHTSA.

BMCS governs operations and drivers of commercial motor carriers; thus the basic organization within DOT for the regulation of the transportation of hazardous materials by motor carrier is that OHMO prescribes regulations governing the manufacturers and shippers of hazardous material containers, including the handling and routing thereof; and NHTSA prescribes performance standards for the design and construction of trucks. We found a number of inadequacies. BMCS regulations impose no stiffer requirements upon drivers of hazardous materials than upon drivers generally. OHMO's container regulations are enforced by BMCS, but BMCS field inspectors are not trained to inspect manufacturers and containers. OHMO and NHTSA standards presently apply to LPG transport, but not to LNG.

Separate regulation of hazardous materials transportation by transportation mode, and even within a mode, without adequate coordination may result in regulatory gaps. Regulation of the transfer of hazardous materials from the storage facility to the connecting mode of transportation is fragmented and incomplete. DOT truck regulations prescribe requirements for personnel and handling procedures at trucking terminals but do not address the design of the transfer system. The new draft regulations by OPSO on LNG facilities carefully prescribe the design of transfer systems, but these only apply to pipeline connected facilities and do not apply to LPG facilities. Consequently, there are no comprehensive Federal standards for the design of transfer systems affecting truck transportation of LNG and LPG.

FRA is the DOT modal agency responsible for the safety regulation of LPG rail transportation. Economic regulation and certification for entry into the interstate railroad industry remains with ICC. New regulations, developed by FRA and prescribed by MTB, specifically address LPG railroad tank car specifications, (42 F.R. 46306, Sept. 15, 1977).

FRA has general authority to investigate the safety compliance of any applicant seeking railroad carrier operating authority from ICC, and consults with ICC on the routing of hazardous materials by railroad. Routing regulations may be issued by OHMO, but are enforced by FRA. FRA has safety regulatory authority transferred from ICC relating generally to safety appliances and equipment (45 U.S.C. 1-43), safety methods and systems (49 U.S.C. 26), and hours of service of employees (45 U.S.C. 61-66). FRA has subsequently acquired authority to carry out the Federal Railroad Safety Act of 1970, as amended (45 U.S.C. 421 et seq.), to reduce accidents, deaths, injuries, and property damage by prescribing railroad safety rules and standards to supplement existing laws. That Act declares that laws, rules, regulations, orders, and standards shall be nationally uniform to the extent practicable. Finally, FRA has enforcement authority over hazardous materials container regulations applicable to shipments by rail, as well as rail routing regulations, issued by OHMO.

FRA's own safety regulations are found generally in 49 C.F.R. Parts 211-236. These include locomotive inspection, hours of service of employees, operating rules, accident reporting, and standards for safety appliances, power brakes, track safety, and freight car safety. None of these regulations specify separate standards for LPG carriers.

The Federal Railroad Safety Authorization Act of 1976 divides the FRA on a geographical basis into not less than 8 safety offices to administer all Federal railroad safety laws. FRA has authority to issue an order prohibiting further use of any facility or piece of equipment in an unsafe condition involving a hazard of death or injury. For enforcement FRA has established a Hazardous Materials Division (HMD) which has 18 full-time inspectors and which uses on a part-time basis the 180 general railroad inspectors employed by FRA.

As with truck transportation, railroad safety regulations only extend to personnel and handling procedures at the transfer point, and not to the design of the transfer system itself between the storage facility and the connecting mode of transportation.

FEDERAL FIRE PREVENTION AND CONTROL

The National Fire Prevention and Control Administration (NFPCA) in the Department of Commerce (DOC) was established by the Federal Fire Prevention and Control Act of 1974. (15 U.S.C. 2201 et seq.) It created a National Academy for Fire Prevention and Control, to train fire service personnel, and a Fire Data Center, to select, analyze, and disseminate information. The NFPCA assists states and their political subdivisions in developing master plans by setting priorities, developing solutions to common problems, and suggesting improvements in relevant state, local, Federal, or private codes. It also is encouraging the future development of Fire Safety Effectiveness Statements for individual structures.

The 1974 Act amended the Fire Research and Safety Act of 1968 to create the Fire Research Center in DOC's Bureau of Standards, which conducts basic and applied research (15 U.S.C. 278f). It has a mandate to research hazards arising from the transportation and use of combustible gases and fluids. The results are incorporated in fire and building codes and used to develop uniform standards.

The Academy is currently developing courses on hazardous materials. The first 4,000 student [illegible] ected to graduate by 1979. The NFPCA has w [illegible] cities to develop step-by-step state and lo[illegible] plans. It has also published a manual illustra[illegible] del system approach utilizing risk analysis based on cost benefit, and is conducting research in the are[illegible]f firefighter safety equipment and smoke [illegible] he Fire Data Center has been established, with 19 states reporting at the end of 1977. While a total of 19 states is statistically adequate for national estimates, the NFPCA is seeking the participation of all states.

The Fire Research Center has not yet carried out specific research on the hazards of combustible gases and fluids. The NFPCA is allocating its present funding to the area of greatest need. Two-thirds of national losses are represented by residential fires; less than 5 percent is attributable to fires in the transportation of hazardous materials. The Administrator of the NFPCA told us, however, that the Fire Research Center is the best place to conduct LEG fire research, based on specific contract or appropriation of funds.

The NFPCA is presently construed as an information service, with no mandatory investigative or regulatory authority. The Administrator hopes to acquire investigative authority for examination of national fire problems. At present, NFPCA investigators have to be invited to the scene of an accident by state or local authorities.

APPENDIX XVI-4

STATE REGULATORY SUMMARY

INTRODUCTION

In many states, the agencies adopting specific NFPA Standards as minimum requirements for storage and handling of LEG and naphtha, frequently amend the Standard to include additional substantive and procedural amendments. In the summaries of the states' regulations where such substantive amendments apply to bulk storage of LEG and naphtha, an asterisk (*) signals that these amendments are described in the special issues analyses (Appendix XVI-5). The absence of an asterisk indicates that any amendments are not relevant to this study.

OPSC's STATE CERTIFICATION PROGRAM

Under Section 5(a) of the Natural Gas Pipeline Safety Act (49 U.S.C. Section 1674), any state agency (including a municipality) may assume Federal inspection and enforcement responsibilities for pipelines and connecting facilities located within the state that are not subject to the jurisdiction of the Federal Power Commission (FPC) under the Natural Gas Act. States and municipalities are thus authorized to assume regulatory responsibility for almost all LNG peakshaving facilities.

In order to do so, the state agency must certify annually to the Secretary of Transportation that:

1. it has regulatory jurisdiction over the safety standards and practices of such pipeline facilities and transportation of gas;

2. it has adopted each Federal safety standard applicable to such pipeline facilities and transportation of gas established under the Act as of the date of the certification;

3. it is enforcing each such standard;

4. it has the authority to require record-maintenance, reporting, and inspection substantially the same as are provided under Section 12;

5. it has the authority to require the filing for approval of plans of inspection and maintenance described in Section 11; and

6. the law of the state makes provision for the enforcement of the safety standards of such state agency by way of injunctions and monetary sanctions equivalent to those provided under Sections 9 and 10.

The state agencies are required to submit annual reports to OPSO.

Agencies in 44 states, the District of Columbia, and Puerto Rico have certified compliance with Section 5(a) to OPSO for 1978. These agencies have incorporated 49 CFR Part 192.12, which incorporates NFPA Standard 59A for LNG facilities, even though some lack an LNG site. Instead of assuming inspection and enforcement responsibilities under Section 5(a), agencies in six states are operating under a Section 5(b) agreement with DOT to assist OPSO in implementing the Federal safety standards.

Both 5(a) and 5(b) state agencies are eligible to receive up to 50 percent of the cost of personnel, equipment, and activities required to carry out their safety programs. Table XVI-1 shows the 5(a) and 5(b) state agencies. The table also shows the 14 states that act as agents for OPSO for interstate gas pipelines under Section 13(c).

Table XVI-2 shows the inspections of LNG facilities by state agencies and OPSO in 1977.

TABLE XVI-1 OPSO's STATE CERTIFICATION PROGRAM

State Agencies Under 5(a) Certification

State	Agency
Alabama	Public Service Commission
Arizona	Corporation Commission
Arkansas	Public Service Commission
California	Public Utilities Commission
Colorado	Public Utilities Commission
Connecticut	Public Utilities Control Authority
Florida	Public Service Commission
Florida	State Fire Marshal's Office, Liquefied Petroleum Gas Bureau
Georgia	Public Service Commission
Hawaii	Public Utilities Division, Department of Regulatory Agencies
Idaho	Public Utilities Commission
Illinois	Commerce Commission
Indiana	Public Service Commission
Iowa	State Commerce Commission
Kansas	State Corporation Commission
Kentucky	Public Service Commission
Maine	Public Utilities Commission
Maryland	Public Service Commission
Michigan	Public Service Commission
Minnesota	Department of Public Safety, Fire Marshal Division
Mississippi	Public Service Commission
Missouri	Public Service Commission
Montana	Public Service Commission
Nevada	Public Service Commission
New Hampshire	Public Utilities Commission
New Mexico	State Corporation Commission
New York	Public Service Commission
North Carolina	Utilities Commission
North Dakota	Public Service Commission
Ohio	Public Utilities Commission
Oklahoma	Corporation Commission
Oregon	Public Utility Commissioner
Pennsylvania	Public Utility Commission
Rhode Island	Division of Public Utilities
South Carolina	Public Service Commission
South Dakota	Department of Public Safety

State	Agency
Tennessee	Public Service Commission
Texas	Railroad Commission
Utah	Division of Public Utilities, Public Service Commission
Vermont	Public Service Board
Virginia	State Corporation Commission
Washington	Utilities and Transportation Commission
West Virginia	Public Service Commission
Wisconsin	Public Service Commission
Wyoming	Public Service Commission
District of Columbia	Public Service Commission
Puerto Rico	Public Service Commission

State Agencies Under 5(b) Agreement

State	Agency
Alaska	Public Utilities Commission
Delaware	Public Service Commission
Louisiana	Office of Conservation
Massachusetts	Department of Public Utilities
Nebraska	State Fire Marshal
New Jersey	Board of Public Utilities, Department of Energy

States Acting As Agents for OPSO for Interstate Gas Pipelines

Arkansas	Michigan	Virginia
Connecticut	Montana	Washington
Florida	Ohio	West Virginia
Iowa	Rhode Island	Wyoming
Kentucky	Utah	

TABLE XVI-2 1977 INSPECTIONS OF LNG FACILITIES BY STATE AGENCY PERSONNEL*

State	1978 Status	No. of Facilities	Facilities Inspected	Approx. No. of Inspections in CY 1977
Alabama	5a	4	4	4
Arkansas	5a	1	1	1
California	5a	2	1	1
Connecticut	5a	10	3	3
Delaware	5b	1	0	0
Georgia	5a	4	0	0
Idaho	5a	1	1	4
Illinois	5a	1	0	0
Indiana	5a	3	1	1
Iowa	5	3	3	3
Maine	5a	3	3	3
Maryland	5a	1	0	0
Massachusetts	5b	32	28	109
Minnesota	5a	4	4	6
New Hampshire	5a	3	3	4
New Jersey	5b	2	0	0
New York	5a	4	4	6
North Carolina	5a	1	1	1
Oregon	5a	2	2	12
Pennsylvania	5a	2	1	1
Rhode Island	5a	3	3	62
South Carolina	5a	2	2	3
Tennessee	5a	4	4	4
Virginia	5a	3	2	2
Washington	5a	1	1	10
Wisconsin	5a	4	2	2

*OPSO also made three inspections in 1977: the Northern Utilities satellite peakshaving facility in Lewiston, ME; the Haverhill Gas satellite peakshaving facility in Haverhill, MA; and the Columbia LNG/Consolidated System LNG import terminal at Cove Point, MD.

SOURCE: Office of Pipeline Safety Operations

SUMMARIES OF STATE REGULATIONS

In addition to the state agencies participating in the 5(a) and 5(b) programs, a variety of state agencies regulate the storage and handling of LPG and naphtha. These are described in the following summaries.

ALABAMA

Bulk storage and handling of LPG are regulated by NFPA Standard 58 as adopted by the Liquefied Petroleum Gas Commission and by regulations of the State Fire Marshal. Storage and handling of naphtha are regulated by the State Fire Marshal.

ALASKA

Alaska relies primarily upon the Department of Public Safety, Fire Protection Division, for regulating the storage, handling, and use of all flammable, combustible, and explosive substances. The Alaskan Administrative Code adopts all NFPA applicable Standards, including NFPA Standards 30, 58, 59, and 59A. In addition the Department of Labor requires informal compliance with NFPA Standard 59A for unfired pressure vessels containing liquefied natural gas. The jurisdiction of the Department of Labor specifically excludes the regulation of LPG. The Department of Environmental Conservation is presently being set up as a one-stop permit agency through which all LNG site applicants must apply for permits on construction of LNG facilities.

ARIZONA

Arizona relies chiefly upon the Fire Marshal's Office to regulate the storage and handling of LPG and naphtha. The Arizona Fire Code adopts NFPA Standards 30, 58, and 59 as general standards with amendments that are unrelated to bulk storage and handling. Although NFPA Standard 59A is not specifically adopted, incorporation by the Fire Marshal of all NFPA codes coupled with a specific chapter relating to storage and handling of cryogenic fluids would indicate that 59A would be considered as an ad hoc minimum requirement for construction of LNG sites.

ARKANSAS

The Liquefied Petroleum Gas Board in Arkansas regulates LPG by incorporating NFPA Standard 58.

The Division of Fire Prevention of Arkansas State Police confines its regulatory powers to flammable liquids. This presumably includes naphtha, but we have not been able to confirm whether or not they adopt NFPA 30. Despite enabling legislation, the Oil and Gas Commission has not adopted regulations for LPG, LNG, and naphtha storage and handling.

CALIFORNIA

California relies primarily upon the Public Utilities Commission for regulation of LEG.* The Public Utilities Commission has certified to DOT under Section 5(a) of the Natural Gas Pipeline Safety Act that it meets OPSO safety and enforcement standards. Further, under the California LNG Terminal Act of 1977, the Public Utilities Commission is designated as the exclusive permitting agency for LNG terminal site locations. The Public Utilities Code has its own administrative rules pertaining to construction of liquid hydrocarbon vessels,* and communication with representatives of the PUC indicate that they have adopted NFPA Standards 58, 59 and 59A. All storage facilities analyzed in the special issues analysis are subject to the rules of the Public Utilities Commission.

In addition, the Division of Industrial Safety has specific rules for storage and handling of LPG, but must defer, recognizing federal preemption, to the rules of the Public Utilities Commission for gas storage at utility plants. The Division of Industrial Safety has promulgated rules for construction of pressure vessels used at places of employment. Although the Fire Marshal of California has adopted NFPA Standard 59A, his jurisdiction extends only to land owned by the State of California.

San Diego County Airport authorities indicate that general NFPA Standards apply to storage of jet fuel at airports. This is informal compliance, however, and NFPA Standard 30 would apply to storage of naphtha only where local authorities have adopted NFPA Standards.

COLORADO

Colorado relies primarily on the State Inspector of Oils for rules and regulations pertaining to storage and handling of flammable liquids and LPG. The State Inspector has adopted by reference NFPA Standards 30, 58, 59 and 59A.

CONNECTICUT

Connecticut relies chiefly upon rules and regulations promulgated by the Commissioner of State Police with regard to storage and handling of flammable liquids and LPG. Those regulations basically follow NFPA Standards 30, 58, or 59, as minimum requirements. The State Police regulations do not pertain to LNG.

DELAWARE

Delaware relies chiefly on the State Fire Marshal's Office and the Fire Prevention Commission for regulations pertaining to storage and handling of LPG and naphtha. Specifically, the State Fire Marshal has adopted NFPA Standards 58 and 59A. The State Department of Transportation has not adopted specific regulations for handling or transportation of LPG, LNG, or naphtha. The Public Service Commission requires informal compliance with NFPA Standard 58, and it is under a 5(b) agreement with DOT.

FLORIDA

Florida relies primarily upon the Insurance Commission and the State Fire Marshal's Office to promulgate regulations dealing with storage and handling of LPG as well as flammable and combustible liquids. NFPA Standards 58 and 30 have been adopted as minimum requirements with substantial technical amendments.* The Oil and Gas Conservation Commission may be involved with permits for storage and transportation of LPG.

GEORGIA

Georgia relies primarily upon the Public Service Commission and the Fire Marshal's Office of the Public Safety Department for the regulation of LEG. The regulations of the Fire Marshal's Office are derived from two separate enabling acts and adopt NFPA Standards 58, 59, and 59A with amendments.* No other state agency has adopted any particular rules and regulations dealing with storage of naphtha.

HAWAII

Hawaii relies upon both the Public Utilities Commission and the State Fire Marshal's Office for regulating the storage and handling of flammable materials and LPG. The Public Utilities Commission has adopted, with unrelated amendments, NFPA Standard 59. The State Fire Marshal's Office has adopted NFPA Standard 30. In addition, the Coastal Zone Management Commission of Hawaii reviews all applications for utility facilities near the coast of Hawaii. The Coastal Zone Management Commission has promulgated no specific regulations detailing safeguards for storage and handling of LEG or naphtha.

IDAHO

The Fire Marshal Division of the Idaho Department of Labor and Industries is empowered to promulgate regulations for general fire prevention and, specifically, the handling and use of combustible liquids and LPG. The Fire Marshal Division has adopted NFPA Standards 58 and 59A. Idaho

Senate Bill 1318, effective July 1, 1977, however, enables local governments to adopt their own specific codes in lieu of those of the Fire Marshal. The City of Boise, which has an LNG facility, adopted NFPA Standards 58, 59, and 59A. Despite enabling legislation, the Department of Law Enforcement has not promulgated regulations for LEG or naphtha.

ILLINOIS

Illinois relies upon the Department of Law Enforcement which contains the Fire Protection Division, State Fire Marshal's Office, to promulgate regulations for storage and handling of LPG. That agency adopts as minimum requirements NFPA standards 58 and 59.* Communications with the Fire Marshal of Illinois indicate that they have also adopted 59A. The Department of Aeronautics has adopted NFPA Standards 30, 58, and 59 for storage of LEG and naphtha at airports.

Despite enabling legislation, the Illinois Department of Transportation and various county boards have not adopted regulations for storage and handling of combustible liquids or gases, and defer to the regulations of the Fire Protection Division.

INDIANA

Indiana relies on the State Fire Marshal's Office for all rules and regulations on storage and handling of LEG and naphtha. NFPA Standard 58 is adopted in toto while NFPA Standard 30 is adopted with substantial technical amendments for storage and handling of naphtha.* In addition, the Division of Oil and Gas requires permit approval of underground gas storage, including cavern storage of LPG; this requirement is intended to eliminate waste in such storage, and does not involve any safety regulations.

IOWA

Iowa relies primarily upon the State Fire Marshal's Office for regulations detailing storage and handling safeguards for LPG and naphtha as found in the Iowa Administrative Code. These regulations include the adoption of NFPA Standards 58 and 30.

KANSAS

Kansas relies solely upon the State Fire Marshal's Office, Fire Protection Division, for rules and regulations on storage and handling of LPG. The State Fire Marshal has adopted specific regulations for all use and storage of LPG,* except for LPG storage at utility plants, which is regulated by NFPA 59. Despite enabling legislation, the Division of Oil and Gas, within the Conservation Division of the State Corporation Commission, has issued no other regulations for storage and handling of LPG. We have found no regulations for storage of naphtha.

KENTUCKY

Kentucky relies upon both the Public Service Commission and the Fire Marshal's Division under the Commissioner of Insurance for regulation of LEG. It would appear that there is a minor overlap since both the Public Service Commission and the Commissioner of Insurance have adopted NFPA Standard 59. The Fire Marshal has also adopted NFPA 30 and 58. NFPA 59A has been adopted specifically by the Fire Marshal regulations, and the Public Service Commission has certified to DOT that it meets OPSO safety standards under Section 5(a). Neither the Airport Zoning Commission nor officials of localities containing LNG sites have adopted regulations on storage and handling of naphtha or LNG.

LOUISIANA

The Liquefied Petroleum Gas Commission regulates the storage and handling of LPG, adopting regulations that supersede those of NFPA 58.* The Oil and Gas Division of the Louisiana Conservation Commission has promulgated regulations for the prevention of fires and conservation of gas. These regulations concern tank storage of naphtha, as well as underground cavern and aboveground tank storage of LPG. There seems to be a potential for overlap between the LPG Commission and the Oil and Gas Division regarding LPG regulation.

As a result of the Natural Resources and Energy Act of 1973, the Conservation Commissioner is empowered to regulate LNG facilities as well.

MAINE

Maine Revised Statutes Annotated, Title 26, Section 141, et seq., creates a Board of Boiler Rules. The statutes state that all pressure vessels used for the transportation and storage of compressed or liquefied gases under the jurisdiction of DOT shall not be subject to the regulations of the Board of Boiler Rules, thus deferring to DOT.

The State Fire Marshal, by virtue of enabling legislation empowering him to make rules for storage and handling of petroleum products, has incorporated by reference NFPA 58. The Vehicle Equipment Safety Commission adopts only pertinent DOT regulations for all transportation of flammable liquids, otherwise enforcing traffic laws as applicable to carriers of flammable liquids.

Maine is the only state which holds natural gas companies strictly liable for injury to persons or property. (See M.R.S.A. Title 14, Section 165).

MARYLAND

Maryland relies primarily upon the Office of Fire Marshal, the Fire Protection Safety Commission and the Public Service Commission for the regulation of the storage and use of combustible or flammable liquids or gas. NFPA Standards 30, 58, 59, and 59A have been adopted. The Department of Natural Resources and the Port Administration Authorities, with similar enabling legislation, have not promulgated regulations for the storage and handling of naphtha or LEG. The Planning Commission of Calvert County, which includes the Cove Point LNG Terminal, informally requires compliance with NFPA 59A.

MASSACHUSETTS

The Energy Facilities Siting Council of Massachusetts, created in December, 1975, reviews all proposed LNG and LPG storage sites, granting approval on the two-fold basis of establishment of need and assessment of environmental impact. Litigation has confirmed the Council has authority over such issues as public safety, applicability of its decisions to energy sites already under construction, and concurrent jurisdiction with the National Environmental Protection Act. The Department of Public Utilities has adopted regulations for the transportation, handling, and storage of LEG and naphtha, adopting NFPA 30 and 59 and LNG regulations similar to NFPA 59A (1971).* The State Fire Marshal defers to the Department of Public Utilities for regulations covering the use of LEG and naphtha in public utilities, but has promulgated regulations for the transportation and handling of flammable liquids in vessels, bulk loading facilities, and tank vehicles, as well as certain LPG systems. None of these regulations adopt NFPA standards. A potential for overlap exists between the regulations of the Department of Public Utilities and the Fire Marshal for LPG storage and handling. A Massachusetts Coastal Zone Management Plan is currently being adopted, and concurrent with the powers of the Department of Public Utilities and Energy Facilities Siting Council, is intended to control the siting of LNG plants. Local fire departments and zoning boards generally defer to state authorities for regulation of LEG or naphtha storage, limiting their power to granting permits and zoning variances. Only the Massachusetts Port Authority, in the exercise of its control over Logan International Airport and Hanscom Field, has adopted NFPA standards with regard to fire prevention for the storage of jet fuels.

MICHIGAN

In Michigan, the State Fire Marshal's Office within the Department of State Police and the Public Service Commission have the primary responsibility for the regulation of LEG and naphtha.* The State Police are primarily concerned with LPG and flammable liquids while the Public Service Commission is interested in LNG and LPG. There is a potential for overlap between the Public Service Commission and State Fire Marshal in the regulation of LPG.

MINNESOTA

The State Fire Marshal has adopted regulations for storage and handling of LEG and naphtha, including adoption of NFPA Standards 58 and 30. These standards are amended with regard to procedural requirements for application and permitting. Regulations of the Minnesota Energy Agency require reporting of quantities for bulk storage of LEG and naphtha.

MISSISSIPPI

Mississippi relies upon the State Fire Marshal's Office and the Liquefied Gas Division of the Motor Vehicle

Comptroller for the regulation of the storage and handling of LPG. The regulations adopt, with procedural amendments, NFPA Standard 58.

MISSOURI

Missouri relies jointly on its Department of Revenue and Department of Agriculture for regulations pertaining to the storage and handling of LPG. Those regulations adopt NFPA Standard 58, with minor technical amendments.

MONTANA

Montana relies chiefly upon the State Fire Marshal's Office and the Department of Health and Environmental Sciences for regulations on the storage and handling of volatile liquids. The State Fire Marshal's Office has adopted NFPA Standard 30 for naphtha and NFPA Standard 58 for LPG. The Department of Public Utilities has established requirements for facility siting applications. The Department of Oil and Gas requires identification and quantitative reporting of storage of oil or gas within the State of Montana.

NEBRASKA

In Nebraska, apart from the issuance of permits and general zoning legislation, the only regulatory authority for the storage, handling, and use of LEG or naphtha is the State Fire Marshal's Office. The Fire Marshal has adopted NFPA Standards 30, 58, 59 and 59A in totality. Despite enabling legislation, neither the Tax Commissioner nor the Public Service Commissioner has adopted regulations for the storage and handling of LEG or naphtha other than in compliance with 49 CFR Part 192.12 for LNG. On a local level, the City of Omaha has adopted NFPA Standards 58, 59, and 59A.

NEVADA

Nevada relies primarily upon its Liquefied Petroleum Gas Board to regulate the storage and handling of LPG. The LPG Board has adopted NFPA Standard 58 as minimum requirements. Despite enabling legislation the Fire Marshal's Office has not promulgated regulations for the storage and handling of naphtha.

NEW HAMPSHIRE

New Hampshire relies primarily upon the State Fire Marshal and the State Board of Fire Control for regulation of flammable and combustible liquids. These agencies have adopted NFPA 58 and 59A. Despite enabling legislation, the Energy Facility Evaluation Committee has not adopted any regulation for the storage and handling of LEG or naphtha.

NEW JERSEY

New Jersey relies primarily upon the Department of Labor and Industry for the regulation of LPG. The responsibility of the State Police to regulate bulk plant storage was transferred to the Department of Labor and

Industry in 1972. Sections within both Titles 12 and 13 of the Administrative Code regulate the construction of all sizes of LPG storage tanks, as well as the operation and handling of LPG.* County Fire Marshals and Fire Marshals of cities of the first class may also regulate storage of flammables.

NEW MEXICO

The State of New Mexico relies primarily on the Fire Marshal's Office for regulations for the storage and handling of flammable liquids. NFPA standards are adopted in the enabling legislation, including NFPA 30. The Liquefied Petroleum Gas Commission is empowered to regulate all storage, handling and use of LPG in New Mexico. The Commission, in addition to requiring minimum public liability insurance, has adopted NFPA Standard 58 with amendments.*

NEW YORK

In 1976 New York enacted the Liquefied Natural and Petroleum Gas Act which gives the Department of Environmental Conservation authority over LNG and LPG facility siting and transportation, with an emphasis on safety considerations. Regulations pursuant to this Act have not yet been promulgated. Existing LNG regulations are included in Regulation 259 of the Public Service Commission. In addition, the City of New York through the New York City Fire Department has promulgated its own regulations for the storage and handling of LNG, including NFPA 59A with comprehensive technical amendments.*

Regulations pertaining to storage of LPG and naphtha are included in Public Service Commission Regulations, Part 260, entitled "Synthetic Natural Gas." All applicable NFPA standards are adopted in the headnote to 260. The Department of Motor Vehicles, the Department of Transportation, and the New York Port Authority have all adopted regulations for the transportation of dangerous articles and/or flammable liquids by tank truck or railcar. Also, the Navigation Law of New York contains a brief regulation concerning transportation of naphtha and other flammable liquids on passenger ships. All of these regulations, however, are brief, and none adopts requirements contained in NFPA standards.

NORTH CAROLINA

North Carolina relies upon the Commissioner of Insurance, the Liquefied Gas Board in the Department of Agriculture, and the Public Utilities Commission for the regulation of the transportation, handling, and storage of LPG. All three agencies have adopted NFPA Standard 58 in total. The Commissioner of Insurance and the Liquefied Gas Board have not adopted specific regulations regarding LNG or naphtha.

NORTH DAKOTA

North Dakota relies primarily on the State Fire Marshal's Office for the regulation of storage and handling of LPG and naphtha. That Office has adopted NFPA Standards 30, 58, and 59.

OHIO

In Ohio, the Fire Marshal's Office and the Department of Industrial Services regulate LPG. The language in the enabling statutes of the Fire Marshal's Office indicates that NFPA standards may be followed on an optional basis for flammable liquids. However, the Ohio Fire Code regulations are extremely brief, and the regulations of the Department of Industrial Relations just adopt NFPA Standard 58. The Oil and Gas Division has not made any specific rules and regulations for LEG and naphtha. Communications with the city and county authorities responsible for the LNG site at Green Springs, Sandusky County, Ohio, indicate that they have not adopted their own regulations and rely on state regulations.

OKLAHOMA

Oklahoma relies primarily upon the LPG Board and LPG Administrator to regulate the storage and handling of LPG. Both the enabling statutes and regulations of the LPG Board adopt NFPA Standard 58 by reference. Despite enabling legislation, the State Fire Marshal has adopted neither regulations nor any NFPA Standards for the storage and handling of naphtha or LNG.

OREGON

Oregon relies on the Fire Marshal to regulate the storage and handling of flammable liquids and LEG. The Fire Marshal has adopted NFPA Standards 58, 59, and 59A in toto. NFPA Standard 30 is adopted with slight technical amendments for the construction of small containers and for permitting.

The Department of Health may have authority to promulgate regulations for LNG sites, but has not done so. Also, the Department of Public Utilities has not promulgated specific regulations for LPG or naphtha.

The Energy Facility Siting Council has failed to obtain legislation designed to regulate LEG siting. Local and county regulatory agencies and the Energy Facility Siting Council rely primarily on general land use planning guides and zoning permits.

PENNSYLVANIA

Four agencies are empowered to regulate the use and storage of LEG and naphtha. The Public Utility Commission has certified to DOT that it meets OPSO safety standards under Section 5(a). The State Police regulate storage and handling of LPG and naphtha for all but second class counties and second class cities. Communications with representatives of those political subdivisions, however, have indicated that they in turn adopt the regulations of the State Police. While the State Police do not have specific regulations for LNG, they regulate LNG as a flammable liquid. The Department of Labor and Industry has statutory authority over the use and handling of LPG, and its regulations specifically adopt NFPA 58, with some amendments.* There is considerable opportunity for overlap between the State Police Fire Marshal and the Department of Labor and Industry on the storage and handling of LPG. The State Police regulate naphtha.

The Airport Zoning Commission is authorized to create airport hazard areas within territorial limits of airports. This authorization, however, has not resulted in the specific regulation of jet fuel storage. Therefore, at present, the storage and handling of jet fuel is solely regulated by the State Police.

PUERTO RICO

All present regulations for the storage and handling of LPG and naphtha were promulgated by the Fire Protection Service,* except for underground jet-fuel storage tanks. Despite enabling authority, the Oil Fuels Affairs Office has not promulgated regulations for storage and handling of LEG or naphtha.

RHODE ISLAND

Rhode Island regulates LEG and naphtha through the Public Utilities Commission and the State Fire Marshal in conjunction with local representatives of the State Fire Marshal. Both the Public Utilities Commission and the State Fire Marshal are enabled to regulate LEG and naphtha, and both have adopted NFPA Standards 58, 59, 59A and 30.

SOUTH CAROLINA

In South Carolina, the LPG Board and the State Fire Marshal's Office regulate the storage and handling of LPG. Both the State Fire Marshal's Office and the LPG Board adopt NFPA Standard 58 in total. In addition, the LPG Board requires minimum insurance coverage for any corporation engaged in the dealing or selling of LPG.

SOUTH DAKOTA

The Fire Marshal's Office regulates the storage and handling of LPG and naphtha in South Dakota. The State Fire Marshal has adopted in substance NFPA Standards 30, 58, 59, with minor additions.*

TENNESSEE

Tennessee relies chiefly upon the State Fire Marshal to promulgate regulations for the storage of LEG. Through the LPG Safety Act and the General Safety and Health Act, the State Fire Marshal has adopted NFPA Standards 58 and 59.

By adopting all pertinent NFPA regulations with regard to construction of new buildings and elimination of fire hazards, the Fire Marshal has also adopted NFPA Standards 30 and 59A for the new construction of naphtha and LNG facilities. The Public Service Commission has certified to DOT that it meets OPSO safety standards for LNG under Section 5(a) of the Natural Gas Pipeline Safety Act. Also, the Division of Oil and Gas has to approve any underground storage of LPG.

The City of Memphis and the County of Shelby rely on NFPA Standard 59A for LNG storage. They adopt, respectively, the Southern States Building Code for the

County and the BOCA (Builders Official Conference of America) building code for the City of Memphis.

TEXAS

Texas relies primarily upon municipal rather than state regulations for control and handling of LNG and naphtha. The Railroad Commission of Texas is the only state agency that has promulgated rules ar regulations for the storage and handling of LEG.* Since the State Fire Marshal has not promulgated regulations and defers to the Railroad Commission, the only regulations existing on the storage of naphtha are local, such as the Houston Fire Code's adoption of NFPA 30.

The LPG site located in the City of Houston is regulated by the Houston Fire Code which includes adoption of NFPA Standards 58 and 59. However, the City of Ingleside, where an LNG facility is planned, has adopted no particular LNG codes of its own. To a certain extent, there is an overlap within the City of Houston for rules and regulations dealing with the storage and handling of LPG. With the exception of LPG storage facilities at marine sites, which are clearly excluded from the rules and regulations of the Railroad Commission, it would appear that storage sites for LPG within the City of Houston are subject to both the City of Houston's Fire Code as well as the rules and regulations of the Texas Railroad Commission.

The Texas Public Safety Department has adopted the rules and regulations of DOT for the transportation of flammable liquids.

UTAH

Utah relies primarily on the Utah State Fire Prevention Board, the Fire Marshal's Office, and the Public Service Commission for regulations governing the storage and handling of flammable and combustible liquids and gases. The Fire Marshal of Utah has adopted NFPA Standards 58 and 59A.

VERMONT

The Department of Public Service in Vermont incorporates by reference NFPA Standard 58 for storage and handling of LPG. The Motor Vehicle Equipment Commission has additional safety standards for operation of a vehicle carrying flammable liquids, regarding the use of flares and reflectors at night. There are presently no regulations on bulk storage of naphtha.

VIRGINIA

Virginia relies solely upon its State Corporation Commission including the Office of State Fire Marshal to regulate the storage and handling of LEG and naphtha. The Chief Fire Marshal has adopted NFPA 58 and 59 entirely. In addition, the local Fire Marshal of Chesapeake, Virginia, an LNG site, has adopted NFPA Standard 59A. The State has also adopted the BOCA building code.

WASHINGTON

Under the Revised Code of Washington and the Washington Administrative Code, the Department of Labor and Industry has promulgated regulations for LPG, including the adoption of the National Bureau of Fire Underwriters (NBFU) Code No. 58 which is identical to NFPA Standard 58). The Department also has regulations for the transportation and storage of LPG in railcars and tank trucks. See Washington Administrative Code S.296-42-440, detailing use of specific loading procedures and equipment (e.g., check valve, vent connection and bleeder line) for railcars and trucks and trailers.

State Fire Marshals and local Fire Marshals have general powers of inspection for premises which may be hazardous fire locations, with the State Fire Marshal being subordinate where local fire codes exist. The Energy Facility Site Evaluation Council has responsibility for approving the site locations of energy facilities, specifically LNG marine terminals receiving more LNG than the equivalent of 100 million cubic feet of gas per day. In addition, the State Energy Office has authority to collect information and carry out energy-related information gathering programs for energy facilities such as LEG storage facilities.

WEST VIRGINIA

West Virginia relies primarily upon the State Fire Prevention Commission, Office of the State Fire Marshal, and the Public Service Commission for rules and regulations governing the storage and handling of LEG. NFPA standards, including 58, 59, and 59A, have been adopted generally by the State. The State Fire Marshal does not regulate the storage and handling of naphtha fuel, as communications indicate that he does not consider naphtha within his department's purview.

WISCONSIN

Wisconsin relies primarily upon the Department of Labor and Industry for regulations on the storage and handling of LPG. These are similar to those adopted by the National Fire Protection Association, but do not incorporate by reference any specific standards of the NFPA.

WYOMING

Wyoming relies primarily upon the Fire Marshal's Office and the Public Service Commission for regulation of LPG and LNG. The Fire Marshal's Office has adopted NFPA Standards 58, 59 and 59A. Wyoming Statutes Annotated 30-240, regulates storage of flammables.

The Fire Marshal's Office has not promulgated rules for the storage and handling of naphtha. The Industrial Development Information Siting Act creates the Industrial Siting Council which is empowered to review applications for any industrial facility, including any facility designed for or capable of producing 7,950 m^3 of liquid hydrocarbon product per day, or one capable of producing one hundred million cubic feet of synthetic gas per day. The Industrial Siting Council, however, has not promulgated regulations providing safeguards for storage and handling of LEG or naphtha.

APPENDIX XVI-5

SPECIAL ISSUES ANALYSES

1. The Minimum Distance Required Between the Tanks or Dike and Residential, Social, Business, and Government Facilities.

LNG* (NFPA 59A Sec. 200, 210, 211, 212; NYCFD Sec. 4.1; 6.4; NY State - PSC Sec. 259; Mass-DPU Sec. 200, 210, 211, 212, 213)

NFPA 59A states that impounding areas (an area which may be defined through the use of dikes or the topography at the site for the purpose of containing any accidental spill of LNG or flammable liquids) must be sited in accordance with the formula $d = 0.8\sqrt{A}$ where d is equal to the distance, in feet, from the property line to the nearest edge of the impounded liquid and A is equal to the surface area, in square feet, of impounded liquid. The DPU in Massachusetts also adopts this. Assuming this standard, if spilled LNG within an impoundment area is ignited, there is no wind, 50% relative humidity, and $70^{\circ}F$ temperature, the thermal radiation flux at the property line will be approximately 10,000 Btu/hr ft^2. At this heat flux level, wood may ignite without direct flame impingement and cotton fabric may ignite after about a 7-second exposure. The model and assumptions used in writing the codes are not published, but the radiation fluxes quoted are consistent with assuming that the heat release from a pool fire

*The codes are listed in the references to Chapter 16.

following the release of a full tank of LNG onto its dike is generated from a hypothetical point source at the center of the dike. If there is a strong wind, the flame will tilt, and the radiation levels in the direction of the wind will be greater. If the relative humidity is less than 50% or the temperature is more than 70°F, some objects will catch fire easier. Presumably, under the assumptions given, this NFPA 59A flux level restriction would prevent fire spread beyond the property line and persons a short distance outside the property would probably not have their clothing ignited by thermal radiation. However, persons exposed to heat flux levels close to a minimum distance property line might still sustain serious burn injuries to exposed skin. The code does not consider fire from LNG or cold natural gas that might escape the dike.

New York state employs two formulas. For an unbermed container, $d = 2.0\sqrt{A}$ where d and A are defined as in 59A. In the case of a bermed tank, $d_2 = 1.25\sqrt{A}$ where d_2 is equivalent to the distance in feet from the nearest edge of impounded liquid to process equipment, buildings, etc., and A is "equivalent to the cross-sectional area of the inside diameter" of the berm. (This definition makes no sense, but presumably the intended definition of area is the same as in NFPA 59A.) This formula corresponds to about a 2,800 Btu/hr ft^2 maximum flux at the property line. At this flux level, bare skin will blister in around 10 to 15 seconds. Within 15 seconds, a person could probably retreat from the fire without permanent injury. (Motion and clothing both offer added protection and further decrease the chance of serious injury.)

The New York City Fire Department states that the radiation flux at the property line should not exceed 1,500

Btu/hr ft^2. Large LNG containers must be surrounded by a berm at least 10 ft. thick and thermal radiation compliance requires siting in accordance with the following table or by using the formula $d_2 = 1.25\sqrt{A}$ (whichever is greater).

NYCFD MINIMUM DISTANCE FROM IMPOUNDED LIQUID

To	Distance (ft)
Critical Occupancy (Hospitals, schools, places of assembly, bridges, tunnels, etc.)	1000
Property Line or Navigable Water	the greater of 200' or 1-1/4 tank diameters
Sewers, underground ducts, drains	50

In the event of a large unignited spill, a flammable cloud of gas may drift across the plant site boundaries. NFPA 59A (1975) first recognized this problem requiring that provision be made to "minimize the possibility" of flammable vapor from a "design spill" from reaching a property line. Design spills are based on the assumption that a major pipe break is the largest credible accident, as discussed in Issue 1, Supporting Details below. The criteria for judging whether the possibility is minimized are not given. The suggested reference for help in performing the calculation contains at least three separate methods and is not actually applicable to the design spill conditions.

The New York City Fire Department requires that a thermal radiation and vapor dispersion study be submitted, but does not give details on methodology.

California adopted SB 1081 which was signed into law on 16 September 1977 authorizing construction of an LNG import terminal in the state subject to a number of restrictions. These include a restriction on population density surrounding the terminal boundaries as of the date terminal operation is started. The criteria are less than an average of 10 persons per square mile within one mile of the site perimeter and less than an average of 60 persons per square mile within a four-mile zone. Population is defined to include permanent residents and working population not associated with the facility.

<u>LPG</u> (NFPA 58, Sec. 311; NFPA 59, Sec. 24, 330; API 2510 Sec. 4.1, R.4.1.; CAL-PUC Sec. 3f a; KAN-LPG Sec. 22-8-7; LA-LPG Sec. 2.7; MISS-MV Sec. 2.13; NJ-AC Sec. 5.8.2; PA-DLI Rule 21; TX-RRC Sec. 2.10; 3.1; WISC-AC Sec. 9.(5)

NFPA 58 states the minimum distance away that an above ground or an underground container may be installed with respect to "important buildings" or an adjoining property line, but does not consider containers larger than 120,000 gallons (455 cubic meters). "Important buildings" are not defined.

NFPA 59 details such distance information for non-refrigerated and refrigerated above-ground containers, respectively. For containers larger than a million gallons (3,785 cubic meters) capacity the distance from the container to the nearest important building not associated with the LPG plant or to an active property line is 400 feet. Lesser distances are specified for smaller quantities.

API 2510 states the minimum distance from an adjoining property to an LPG container for both refrigerated and unrefrigerated tanks. For tanks with capacity above 500,000 gallons (1,893 cubic meters), the distance is 200 feet. An exception is made when tanks are diked or have a design pressure under 15 psig. In this case, the minimum distance shall be one and one-half times its greatest dimension (diameter or height), but need not exceed 175 feet.

The states of California, Kansas, Louisiana, Mississippi, New Jersey, Pennsylvania, Texas and Wisconsin all have specific standards which detail minimum distance requirements (Appendix XVI-4). However, they do not differentiate between refrigerated and unrefrigerated tanks. With the exception of California, all of the states with LPG regulations pertaining to minimum distance requirements have charts which specify the distance as a function of container capacity. California merely states that the distance from a container to a property line should be 50 feet for an above-ground tank and 25 feet for an underground tank. However, California requires a minimum exclusion distance of 500 feet to schools or buildings with seating capacity of 100 or more.

<u>NAPHTHA</u> (NFPA 30 Sec. 2-2.1, 2-3.1; CAL-PUC 3a,f: CONN-SP Art. III Sec. 29-62-7, 8, Art IV Sec. 29-62-16; FLA-FIREM Part II Sec. 4A-16.22, 23; IND-FIREM (20-801a) E38, 40, 46; MASS-DPU Rule 27; MICH-FLAM Rule 43, 55; PA-SP Sec. 3-1, 2, 4-1; PR-FS Sec. 314-50b)

NFPA 30 states that the minimum separation distance between an above-ground container and property lines is from the diameter of tank (up to a maximum of 175 ft) up to

350 ft for tanks of about 3 million gallons (11,355 cubic meters) capacity. The shorter distance applies to floating roof tanks and the longer to tanks with fixed roof and conventional emergency relief vent valves. The floating roof can be considered a massive relief valve. For underground tanks the exclusion distance to the nearest wall of any basement or pit is one foot while the distance to a property line must be at least 3 feet.

Indiana and Pennsylvania adopt the NFPA Codes with minor changes. Connecticut includes a general statement which requires that no above-ground storage tank be built closer than 300 ft to any public building. The location of tanks with respect to property lines is stated in a chart where the separation distance is a function of tank capacity. For tanks over 50,000 gallons (190 cubic meters) the distance is set by a formula determined by tank construction and the type of extinguishing system. For example, the distance for any all-steel, gas-tight tank constructed in compliance with the vessel standards and equipped either with an approved permanently attached extinguishing system or an approved floating roof shall be the greatest dimension of the diameter or the height of the tank but need not exceed 125 ft. For underground containers, the minimum distance is 25 ft. Florida and Michigan both employ charts similar to Connecticut's above-ground tanks with the latter adding a provision similar to Connecticut's for tanks over 50,000 gallons (190 cubic meters). For underground containers, Florida adopts the NFPA standard while Michigan establishes a 3 ft minimum distance to buildings or property lines. Puerto Rico adopts the Connecticut Standard for above-ground tanks over 50,000 gallons (190 cubic meters). Puerto Rico sets no standard for underground tanks. California and

Massachusetts have set more general standards. Massachusetts states that the minimum distance to a property line must be 10 ft for a horizontal tank and one half the diameter or height (whichever is greater) for a vertical tank. California uses the standard used for LPG.

ISSUE 1, SUPPORTING DETAILS

Definition of design spill for LNG vapor dispersion accidents from NFPA 59A (1975 revision).

(a) For impounding areas serving LNG containers having bottom connections without internal valves, the "design spill" is defined as flow through an assumed opening at the bottom of the initially full container equal to the area of the largest actual liquid piping connection made to the bottom of the container. The flow is assumed to continue until the differential head acting on the opening is zero. For impounding areas serving more than one container, the "design spill" shall be applied to the container which results in the largest flow.

(b) For impounding areas serving LNG containers with "over-the-top" fill and withdrawl connections and which have no tank penetrations below the liquid level, the "design spill" is defined as the largest flow from any single line which could be pumped into the impounding area with the container withdrawl pump(s) considered to be delivering full rated capacity. The time duration of the "design spill" shall be 10 minutes provided there exists demonstrable surveillance and shutdown provisions acceptable to the authority having jurisdiction; otherwise, the time duration shall be until the initially full container has emptied.

(c) For impounding areas serving LNG containers which have all penetrations below the liquid level fitted with internal shutoff valves in accordance with 6222, the "design spill" may be computed from Formula 2 with the flow "q" lasting for a period of one hour provided there exists demonstrable surveillance and shutdown provisions acceptable to the authority having jurisdiction; otherwise, the time duration shall be until the initially full container has emptied.

Formula 2

$$q = \frac{4}{3} d^2 \sqrt{h}$$

where q = flow rate, in cubic feet per minute, of liquid

d = diameter, in inches, of largest tank penetration below the liquid level

h = height, in feet, of liquid above penetration in the container when the container is full.

(d) For impounding areas serving only vaporization, process, or LNG transfer areas, the "design spill" is defined as flow during a 10-minute period from any single accidental leakage source, or a lesser time period based upon demonstrable surveillance and shutdown provisions acceptable to the authority having jurisdiction.

ISSUE 1

EXCLUSION DISTANCE TO PROPERTY LINE

NAPHTHA - CONTAINERS WITH FLOATING ROOF

NFPA 30 and the states of Florida, Indiana, and Pennsylvania all state that the exclusion distance should be the diameter of the tank, but need not exceed 175 feet

ISSUE 1

EXCLUSION DISTANCE TO PROPERTY LINE

LNG

Container Capacity (gallons)	NFPA 59A	New York	NYCFD	Massachusetts
<125	None	Adopt NFPA 59A	Not Bermed:	None
125 - 250	10'	↓	$d = 2\sqrt{A}$ or one and a quarter tank diameters or 250' (whichever is greater)	10'
251 - 500	10'	↓	↓	10'
501 - 2,000	25'	↓	↓	25'
2,001 - 2,500	50'	↓	↓	50'
2,501 - 30,000	50'	↓	Bermed:	50'
30,001 - 70,000	75'	↓	$d = 1.25\sqrt{A}$ or one and a quarter tank diameters or 250' (whichever is greater)	75'
70,001 - 100,000	0.7 times the Container Diameter but not less than 100'	↓	↓	100'
>100,000		$d = 2.0\sqrt{A}$	↓	100'

ISSUE 1

EXCLUSION DISTANCE TO PROPERTY LINE

LPG (Above-ground)

Container Capacity (gallons)	NFPA 59*	NFPA 58	API 2510*	California	Kansas	Mississippi	New Jersey	Pennsylvania	Wisconsin
<125	Not Specified	None	None	50'	None	10'	None	None	None
125 - 500		10'	10'	50'	10'	10'	10'	10'	10'
501 - 2,000		25'	25'	50'	25'**	25'**	25'	25'**	25'**
2,001 - 30,000		50'	50'	50'	50'	50'	50'	50'	50'
30,001 - 70,000		75'	50'	50'	75'	75'	75'	50'	75'
70,001 - 90,000		100'	50'	50'	100'	Not Specified	100'	50'	100'
90,001 - 100,000		125'	50'	50'	Not Specified		150'	50'	Not Specified
100,001 - 120,000		125'	100'	50'			150'	50'	
120,001 - 125,000		Not Specified	100'	50'			150'	50'	
125,001 - 200,000	200'		100'	50'			200'	50'	
200,001 - 250,000	300'		100'	50'			300'	50'	
250,001 - 500,000	300'		150'	50'			300'	50'	
500,001 - 1,000,000	300'		200'	50'			300'	50'	
>1,000,000	400'		200'	50'			Not Specified	50'	

* Refrigerated Containers

** The above distance requirements may be reduced to not less than 10 feet for a single container of 1,200 gal water capacity or less, providing such a container is at least 25 feet from any other LP-Gas container or more than 125 gal water capacity.

ISSUE 1

EXCLUSION DISTANCE TO PROPERTY LINE

NAPHTHA - Horizontal and Vertical Containers with Relief Venting

Container Capacity (gallons)	NFPA 30	Florida	Indiana	Pennsylvania
<275	10'	10'	10'	10'
275 - 750	20'	20'	20'	20'
751 - 12,000	30'	30'	30'	30'
12,001 - 30,000	40'	40'	40'	40'
30,001 - 50,000	60'	60'	60'	60'
50,001 - 100,000	100'	100'	100'	100'
100,001 - 500,000	160'	160'	160'	160'
500,001 - 1,000,000	200'	200'	200'	200'
1,000,001 - 2,000,000	270'	270'	270'	270'
2,000,001 - 3,000,000	330'	330'	330'	330'
>3,000,000	350'	350'	350'	350'

ISSUE 1

EXCLUSION DISTANCE TO PROPERTY LINE

NAPHTHA

Container Capacity (gallons)	Connecticut	Michigan
0 - 60	10'	Not Specified
61 - 750	10'	10'
751 - 12,000	15'	15'
12,001 - 24,000	15'	15'
24,001 - 30,000	20'	20'
30,001 - 50,000	25'	25'

50,000 or more

a) if tanks have an approved permanently attached extinguishing system or an approved floating roof - minimum distance shall be the greatest dimension of diameter or height of tank, except that such distance need not exceed 120 feet.

b) if tank not equipped with either of the above - minimum distance shall be 1 1/2 times the greatest dimension, diameter or height of tanks, except that such distance need not exceed 175 feet.

California

California requires that a minimum distance of 50 feet be maintained between a naphtha container and the property line. Five hundred feet should be maintained between a naphtha container and public assembly buildings with a seating capacity in excess of one hundred persons.

2. The Minimum Distances Required Between LNG, LPG, or Naphtha Tanks and Tanks Holding Other Flammable, Explosive, Poisonous, or Toxic Materials.

LNG (NFPA 59A Sec. 200, 210, 213; NYCFD Sec. 4.1, 6.4; NYS-PSC Sec. 259.4b; MASS-DPU Sec. 200, 210, 213)

NFPA 59A establishes the minimum clear distance needed for containers with a capacity exceeding 70,000 gallons (265 cubic meters). Between any two adjacent containers, the required distance is equal to one quarter of the sum of the diameters of the two adjacent containers but not less than 25 ft. Massachusetts adopts this same standard. The New York City Fire Department states that the minimum distance between bermed containers with a capacity exceeding 2,500 gallons (9.5 cubic meters) should be the greater of 1.25 tank diameters or 250 ft.

LPG (NFPA 58, Sec. 311; NFPA 59, Sec. 24, 330; API 2510 Sec. 4.1, R4.1; CAL-PUC Sec. 3f; KAN-LPG Sec. 22-8-7; MISS-MV Sec. 2.13; NJ-AC Sec. 5.8.2, 5.8.9; PA-DLI Rule 21; SD-DPS Sec. 61:12:01:05:, 7, 8; WISC-AC Sec. 9.05)

For the above-ground containers of capacity above 30,000 gallons (114 cubic meters), NFPA 58 requires a spacing that is 1/4 the sum of the diameters of adjacent containers. Also, above-ground LPG containers must be spaced at least 20 ft distant from tanks containing liquids with flash points below 200°F. No horizontal separation is required between above-ground LPG containers and underground flammable liquid storage.

NFPA 59 requires a 50 ft separation between non-refrigerated above-ground LPG tanks and other above-ground storage of flammable liquids. Above-ground refrigerated LPG containers regardless of size are to be separated by 1/4 the sum of the diameters of adjacent tanks.

Any number of non-refrigerated underground containers can be installed parallel with ends in line. When containers are placed end to end, the separation distance should be 10 feet minimum. A 100 ft distance is required between such tanks and the above-ground storage of flammable liquids.

API 2510 establishes that non-refrigerated LPG containers may be located 2 ft from other non-refrigerated LPG containers and other pressure storage containers. A 10 ft distance must be maintained between LPG containers and containers that operate near atmospheric pressure and contain flammable liquids. The distance between refrigerated LPG containers with a capacity in excess of 50,000 gallons (190 cubic meters) should be a minimum of one-half the diameter of the smaller container. The same distance requirement should be employed when siting refrigerated LPG containers with a capacity of over 50,000 gallons (190 cubic meters) and other containers that operate near atmospheric pressure and contain flammable liquids. Ten feet is specified as the minimum distance required between refrigerated LPG storage containers and containers that contain LPG at pressure.

California, Kansas, Mississippi, New Jersey, Pennsylvania, South Dakota, and Wisconsin have all instituted regulations that deal specifically with this issue. Mississippi, Kansas, New Jersey, and Wisconsin all require that the distance between containers be equal to one-quarter the sum of the diameters of the adjacent containers. California and Kansas are the most lenient states requiring just 18 in. and 3 ft, respectively, between unspecified containers. A distance of 20 ft is required between LPG containers and tanks containing flammable liquids by the states of Mississippi, New Jersey, and Wisconsin. South Dakota details the separation between LPG containers and containers of oxygen and gaseous hydrogen. Specifications include the requirement that LPG containers having an aggregate water capacity of over 1,200 gallons shall have a 50 ft separation from oxygen containers having an aggregate capacity of more than 20,000 CF including unconnected reserves. Once again, the above states with LPG regulations do not differentiate between refrigerated and non-refrigerated containers.

<u>NAPHTHA</u> (NFPA 30 S-c. 2-2.2; CAL-PUC Sec. 3f; CONN-SP Art III Sec. 29-62-9; FLA-FIREM Part II, Sec. 4A-16.22 (3): IND-FIREM (20-801a) E39; MICH-FLAM Rule 44; PA-SP Sec. 3-3)

NFPA 30 gives the minimum distance between any two adjacent above-ground containers. The requirement for tanks up to 150 ft diameter is a spacing of 1/6 the sum of the diameters but not less than 3 ft. Larger tanks may need up to twice this spacing depending upon the design criteria of the remote impounding or diking and whether the roof is fixed or floating. Between an above-ground LPG container and an above-ground naphtha container a minimum distance of 20 ft should be maintained. No horizontal separation is required between above-ground LPG containers and underground flammable and combustible liquid tanks.

Florida, Indiana, and Pennsylvania all state that the distance between adjacent tanks should not be less than 1/6 the sum of their diameters except when the diameter of one tank is less than 1/2 the diameter of the adjacent tank. Then the distance between the two tanks shall not be less than 1/2 the diameter of the smaller tank. Connecticut and Michigan both state that the minimum distance between containers should be not less than one-half the diameter of the smaller tank (not less than 10 ft). All of the above states require a 10 foot distance between LPG containers and containers of flammable liquid. As with LPG, California is again the most lenient state requiring just 18 inches between specified containers.

ISSUE 2

INTER-TANK EXCLUSION DISTANCE

LNG

Container Capacity (gallons)	NFPA 59A	NEW YORK	NYCFD	MASSACHUSETTS
<125	None	Adopt NFPA 59A	One and a quarter tank diameters, but not less than 100 ft.	None
125-250	None			None
251-500	3'			3'
501-2000	3'			3'
2,001-2,500	5'			5'
2,501-30,000	5'		$d = 1.25 \sqrt{A}$ or one one and a quarter diameters or 250' (whichever is greater)	5'
30,001-70,000	10'			1/4 of sum of diameters of adjacent containers.
70,001-100,000	1/4 of sum of diameters of the two adjacent containers but not less than 25'			
>100,000		$d = 1.25\sqrt{A}$		

ISSUE 2

INTER-TANK EXCLUSION DISTANCE

LPG

Container Capacity (gallons)	NFPA 59*	NFPA 58	API 2510*	California	Kansas	Mississippi	New Jersey	Pennsylvania	Wisconsin
<125	Not Specified	None	3'	18"	None	None	None	None	None
125-250		None	3'	18"	3'	3'	3'	3'	3'
251-500		3'	3'	18"	3'	3'	3'	3'	3'
501-2,000		3'	3'	18"	3'	3'	3'	3'	3'
2,001-30,000		5'	3'	18"	5'	5'	5'	3'	5'
30,001-50,000			3'	18"				3'	
50,001-70,000				18"				3'	
70,001-90,000				18"				3'	
90,001-100,000				18"				3'	
100,001-120,000		1/4 of sum of diameters of adjacent containers		18"		1/4 of sum of diameters of adjacent containers	1/4 of sum of diameters of adjacent containers	3'	1/4 of sum of diameters of adjacent containers
120,001-125,000				18"	1/4 of sum of diameters of adjacent containers			3'	
125,001-200,000	1/4 of sum of diameters of adjacent containers			18"				3'	
200,001-250,000			1/2 the diameters of the smaller tank	18"				3'	
250,001-500,000				18"				3'	
500,001-1,000,000				18"				3'	
>1,000,000				18"				3'	

*Refrigerated Containers

ISSUE 2

INTER-TANK EXCLUSION DISTANCE

NAPHTHA

NFPA 30 (1976)

	Floating Roof	Fixed Roof
All tank not over 150 feet diameter.	1/6 sum of adjacent tank diameters but not less than 3 feet	1/6 sum of adjacent tank diameters but not less than 3 feet
Tanks larger than 150 feet diameter.		
A. If remote impounding is in accordance with code.	1/6 sum of adjacent tank diameters	1/4 sum of adjacent tank diameters
B. If impounding is in accordance with code.	1/4 sum of adjacent tank diameters.	1/3 sum of adjacent tank diameters.

FLORIDA - INDIANA - PENNSYLVANIA

The minimum distance between containers shall be 1/6 sum of tank diameters except when the diameter of one tank is less than 1/2 the diameter of the adjacent tank, the distance between the two tanks shall not be less than 1/2 the diameter of the smaller tank, but not less than 3 feet.

CONNECTICUT - MICHIGAN

The minimum distance between containers shall not be less than 3 feet. For tanks above fifty thousand gallons individual capacity, the distance shall be not less than one-half the diameter of smaller tank.

CALIFORNIA

The minimum distance between containers shall be not less than 18 inches.

3. Security Requirements.

LNG (NFPA 59A, Sec. 202, 95; NYCFD Sec. 4.5, 21.7; NY State PSC Sec. 259.11f; MASS-DPU Sec. 202,95).

NFPA 59A requires the installation of a protective enclosure of unspecified height such as a peripheral fence, building wall, or natural barrier enclosing major facility components such as LNG storage containers, flammable refrigerant storage tanks, on-shore loading and unloading facilities, etc. This enclosure may be continuous or there can be several independent enclosures. The enclosures shall have at least two exit gates if the area exceeds 1,250 sq ft. In regard to unattended facility operation, NFPA 59A states that "if a liquefaction plant is designed to operate unattended, it is recommended that alarm circuits be provided which will transmit an alarm to the nearest manned company facility indicating fire, abnormal pressure, temperature, gas concentration or other symptoms of trouble." The state of Massachusetts has adopted these NFPA 59A requirements as has New York state which adds the following statement: "Especially in the case of unmanned facilities, active liaison shall be established with the local fire department and utility operating personnel in regard to education in the properties of LNG and in the techniques of fighting LNG fires." The New York City Fire Department merely states: "A protective fence of incombustible material shall be erected at the property line, at least eight feet in height, having locked gates openable to only authorized persons on proper identification."

LPG (NFPA 58, Sec. 3250; NFPA 59, Sec. 255, 347; CAL-PUC Sec. 3B; FLA-FIREM Sec. 4A-1.03; GA-FIREC Sec. 120-3-16-.03; ILL-LPG Sec. 7; LA-LPG Sec. 2.17; MASS-DPU Sec. 4-255; MISS-MV Sec. 3.7; NM-LPG Sec. A.8; SD-DPS Sec. 61:12:01:09)

NFPA 58 states that areas including container appurtenances (items connected to container openings needed to make a container a gas-tight entity, e.g., safety relief devices), pumping equipment, loading and unloading facilities and container loading facilities should be protected by a six foot high industrial-type fence. As an alternative to fencing, suitable devices (which shall effectively prevent unauthorized operation of any of the container appurtenances, system valves or equipment) can be provided which can be locked in place. NFPA 59 includes the same statement for both non-refrigerated and refrigerated tanks with the added provision that breakable locks be used. Presumably this is for fire department access.

The states of California, Florida, Georgia, Illinois, Louisiana, Massachusetts, Mississippi, and South Dakota have all established regulations requiring fences, with Massachusetts and South Dakota adding a provision identical to that found in NFPA 59. New Mexico leaves the construction of a fence to the discretion of the Liquefied Petroleum Gas Commission.

NAPHTHA (CAL-PUC Sec. 3B)

The state of California has instituted a standard which states that "all holders, vessels, and above-ground piping and fittings adjacent thereto shall be properly surrounded by adequate fencing and gates that will prevent access by unauthorized persons."

4. Diking Requirements.

LNG (NFPA 59A Sec. 210, 211; NYCFD Sec. 5, 6; NYS-PSC Sec. 2[illegible]0.4a; MASS-DPU 210, 211, 212)

NFPA 59A states that for an impounding area serving a single container, the minimum volume it can hold, V, should be equal to the total volume of liquid in the container, when the container is full. The State of Massachusetts has a similar code. Both New York State and the New York City Fire Department require that the minimum capacity of the area shall be 150% of the maximum liquid capacity of the container for which the area is provided. In New York State, this percentage may be reduced to 1[illegible]% if a dike is designed of materials capable of withstanding LNG temperatures, having a vertical inner wall, located at a minimum distance from the container that conforms with the New York State standard, and if the company can demonstrate the effectiveness of the design. The New York City Fire Department further requires a 250% or greater capacity where foaming, vigorous boiling or other expansion phenomena may be encountered.

The above standards apply to unbermed containers for NFPA 59A and the States of Massachusetts and New York. The standards of the New York City Fire Department also apply to bermed containers which is the only type that they now allow. They also require a secondary dike for bermed containers.

Many impounding areas serve more than one container. NFPA 59A states that the total volume of the dike, V, should be equal to the total volume of liquid in the largest container when it is full, provided that low temperature exposure or fire exposure resulting from leakage from any one container will not cause subsequent leakage from another container. Without such a provision, the dike volume, V, should be equal to the total volume of liquid in all containers served assuming all containers are full. In a less stringent standard, because it is based on the 1971 version of NFPA 59A, the State of Massachusetts requires that the minimum volume of the diked area shall equal the amount of liquid capacity of the largest container draining into the area. Both the State of New York and the New York City Fire Department require that not more than one container shall be installed in a single dike. New York State will allow an exception to this if the container spacing is such that a LNG spill from one container will not reach other containers.

NFPA 59A and the States of Massachusetts and New York all employ standards which are intended to require spacing between the tank and dike to be sufficient to prevent liquid from a hole in the tank from jetting over the dike regardless of the amount of friction in the hole. However, the formula on which the spacing is based is not correct, as we show in Chapter 7. The New York City Fire Department requires that dike height be at least half the maximum liquid level in the tank.

An accidental LNG spill could also occur in other plant areas. NFPA 59A states that LNG vaporization, process or transfer areas should have impounding areas with a minimum volume equal to the greatest volume of LNG, flammable refrigerant or flammable liquid which could be discharged into the area during a 10-minute period from any single credible accidental leakage source. The largest accident considered "credible" is a pipe break. New York

State adopts this NFPA 59A standard. The New York City Fire Department applies the same dike capacity rule used for storage containers to LNG piping and processing equipment.

In order to contain any spilled LNG, the dike must remain structurally sound. NFPA 59A states that dikes, impounding walls and drainage channels for LNG shall be made of earth, concrete, metal and/or suitable materials. They may be independent of the container or they may be mounded integral to or constructed against the container. They must withstand the full hydrostatic head of impounded LNG, the effect of rapid cooling to the temperature of the liquid confined, any anticipated fire exposure and natural forces such as earthquake, wind and rain.

New York State adopts NFPA 59A with the following provision: berms shall only be used on containers having a concrete outer shell unless it can be demonstrated that a metallic shell can be protected against corrosion. The State of Massachusetts requires that "dike and impounding walls and drainage channels shall be liquid tight and constructed of earth, steel, concrete, or other suitable material capable of confining the liquid and of withstanding LNG temperatures and a full hydrostatic head of LNG which might be spilled. They shall also be able to confine the liquid during any expected fire exposure period."

Rain or other water in the impounding area could accelerate vaporization should LNG spill. NFPA 59A states that provision must be made to remove this water although no time requirements for water removal are given. Automatically controlled sump pumps are permitted if equipped with an automatic cutoff device which prevents their operation when exposed to LNG temperatures. Piping, valves, and fittings whose failure could permit liquid to escape from the impounding area must be suitable for continuous exposure to LNG temperatures. The State of New York adopts this standard. The State of Massachusetts requires that "provision shall be made to drain rain or other water from the diked area and said drains shall be equipped with a positive closure which shall be closed except when manually opened for draining. The valve and other parts of the drain system that may be subject to LNG temperature shall be of suitable material to withstand low temperatures (-260^{o}F). Such drains shall not permit drainage of tank content to natural water courses, public sewers or public drains. Automatically controlled sump pumps are permitted if equipped with a device or automatic cut-off switch which will prevent their operation to pump LNG from within the impounding area." The New York City Fire Department states that impounding areas shall not contain underground channels, drains, conduits, or sewers. Storm water should be pumped over the dikes by means of fixed piping and manually controlled.

If LNG were to spill into an impounded area, provision might be made to remove the spilled LNG from the dike. The New York City Fire Department has the only code which specifies preparedness for such actions. It states "Cryogenically suitable approved pumps manually controlled and piping on combustible and cryogenically suitable supports shall be used to return such spills to the tank where possible."

LPG (NFPA 59 Sec. 240h, 254, 330d, 343, 346; NFPA 58 Sec. 3114, 3115; API 2510 Sec. 4.2.2, R4.2.2; KAN-LPG Sec. 22-8-7; MASS-DPU Rule 33; MISS-MV Sec. 213 j, k; NJ-AC Sec. 5.8.10, 11; WISC-AC Sec. 9.05)

NFPA 58 states that dikes, curbs or grading should be used to prevent the accumulation or flow of liquids having flash points below 200°F under adjacent LPG containers. When tanks containing flammable or combustible liquids are within a diked area, LPG containers of any size shall be outside the diked area and at least 10 feet away from the centerline of the wall of the diked area. However, it also states that "because of the pronounced volatility of LPG in installations covered by this standard, dikes normally serve no useful purpose." This statement does not make sense although liquid accidentally released from a pressurized LPG tank would form a gas-liquid jet and only a portion might accumulate on the ground.

NFPA 59 states that non-refrigerated LPG containers shall not be located within dikes enclosing flammable liquid tanks or refrigerated LPG tanks. Dikes should be used to prevent accidentally escaping flammable liquids from flowing into LPG container areas. Similarly, refrigerated LPG containers shall not be located within dikes enclosing flammable liquids. However, refrigerated LPG containers are required to be diked, with the diked volume at least 100 percent of the capacity of the largest container enclosed. When more than one container is located in a single diked area, provision must be made to prevent liquid from any one spill from contacting other tanks if such tanks have wettable portions of their outer shells which are not suitable for -44°F temperature exposure. Further, any container foundations must be designed to withstand fire exposure. The dikes constructed should prevent the escape of liquid and withstand a full hydraulic head as well as withstanding thermal shock. Dike walls shall be no less than 5 feet i. height except where topography can provide suitable containment. Drainage procedures for the dikes are specified.

For non-refrigerated containers, API 2510 states that "because of the pronounced volatility of LPG, dikes or firewalls around LPG tanks usually are not necessary, hence their general requirement is not justified. Where site conditions permit, it is desirable for the grade to be sloped away from the container to a safe area." For refrigerated containers exceeding 10,000 bbl (1,590 cubic meters) capacity, dikes shall be provided, if necessary to prevent the spread of liquid onto other property or waterways. Capacity of the diked area, if required, shall equal the capacity of the largest tank."

The States of Kansas, Mississippi, and Wisconsin require that dikes, curbs or grading prevent the accumulation of flammable liquids under adjacent LPG containers in addition to specifying that no LPG containers can be situated within a diked flammable liquids area. The State of New Jersey employs the latter requirement in addition to stating that "when above-ground containers endanger adjacent property because of sloping ground or local conditions, each container or group of containers shall be surrounded by a dike or dikes of a capacity not less than the capacity of the container or containers in question." The State of Massachusetts requires a dike having a capacity of the tank or tanks surrounded.

NAPHTHA (NFPA 30 Sec. 2-2.2, 3; CONN-SP Art III, Sec. 29629, 12; FLA-FIREM Part II, Sec. 4A16.22 (3,7); IND-FIREM (20801a) E39, 44; MICH-FLAM Rule 44, 47; PASP Sec. 33,6; PRFS Sec. 314, 50k)

NFPA 30 establishes specifications for remote impounding (where protection of adjoining property or waterways is by means of drainage to a distant dike or topographical basin) in addition to impounding around the tanks by diking. These requirements for dike design are considerably more detailed than those for LNG or LPG and are presented in detail in the following section.

Florida, Indiana, and Pennsylvania all require either drainage (remote impounding) or impounding by diking. Florida and Indiana include detailed specifications similar to the NFPA. Pennsylvania includes a few less specifics for diking. In both Connecticut and Michigan, the Fire Marshal determines the need for diking. A few basic construction details are specified. In Puerto Rico, all tanks exceeding 50,000 gallons (190 cubic meters) should be diked with the dike capacity not less than equal in volume to that of the tanks surrounded.

The States of Connecticut, Florida, Indiana, Michigan, and Pennsylvania all require that when flammable or combustible liquid storage tanks are within a diked area, any LPG containers shall be outside of the diked area and at least 10 ft away from the center line of the wall of the diked area. More complete details on these various requirements are presented in the following section.

SPILL CONTROL REQUIREMENTS - NFPA 30 (1976)

Remote impounding systems should comply with the following standards: (a) A slope of not less than 1 percent away from the tank shall be provided for at least 50 feet toward the impounding area, (b) The impounding area shall have a capacity not less than that of the largest tank that can drain into it, (c) The route of the drainage system shall be so located that, if the liquids in the drainage system are ignited, the fire will not seriously expose tanks or adjoining property, (d) The confines of the impounding area shall be located so that when filled to capacity the liquid level will not be closer than 50 feet from any property line that is or can be built upon, or from any tank. Requirements for impounding by diking shall include the following: (a) A slope of not less than 1 percent away from the tank shall be provided for at least 50 feet or to the dike base, whichever is less, (b) The volumetric capacity of the diked area shall not be less than the greatest amount of liquid that can be released from the largest tank within the diked area, assuming a full tank. To allow for volume occupied by tanks, the capacity of the diked area enclosing more than one tank shall be calculated after deducting the volume of the tanks, other than the largest tank, below the height of the dike, (c) To permit access, the outside base of the dike at ground level shall be no closer than 10 feet to any property line that is or can be built upon, (d) Walls of the diked area shall be of earth, steel, concrete or solid masonry designed to be liquidtight and to withstand a full hydrostatic head. Specifications for earthen walls are detailed, (e) Except as provided below, the walls of the diked area shall be restricted to an average interior height of 6 feet above interior grade, (f) Dikes may be higher than an average of 6 feet above interior grade if provisions are made for normal access, necessary emergency access to tanks, valves and other equipment, and safe egress from the diked enclosure. In this case, more detailed specifications are required, (g) Each diked area containing two or more tanks shall be subdivided preferably by drainage channels or at least by intermediate curbs in order to prevent spills from endangering adjacent tanks within the diked area. Exact requirements for doing this are provided, (h) Where provision is made for draining water from diked areas, such drains shall be controlled in a manner so as to prevent flammable or combustible liquids from entering natural water courses, public sewers, or public drains, if their presence would constitute a hazard. Control of drainage shall be accessible under fire conditions from outside the dike, (i) Storage of combustible materials, empty or full drums or barrels, shall not be permitted within the diked area.

5. Requirements For Resistance to Natural Phenomena.

LNG (NFPA 59A Sec. 406, 25; NYCFD Sec. 4.2.3; MASS-DPU Sec. 405; API 620 Sec. 304 (5), 3.05.5; NBC Sec. 906,907)

NFPA 59A cites the Uniform Building Code, Volume 1, 1973 edition as a basis for design for seismic, wind, snow, and other forces. The 1975 edition of 59A also imposes a requirement for a detailed geotechnical study for all LNG sites in seismic areas (zone 2 or 3 per UBC). Although the 1972 edition which is the current Federal regulation does not include this requirement, the gas industry generally follows the more stringent 1975 version for new facilities for insurance purposes. Pre-1975 facility designs, however, do not generally follow this recommendation.

The State of Massachusetts simply states that "When applicable, seismic loads shall be considered in the design." The New York City Fire Department states "Plant sites shall be protected from the forces of nature such as flooding by rains, high tides or soil erosion by grading, draining and dikes. Grass, weeds, trees or undergrowth shall be cleared within 25 feet of any piping, container or process equipment." In regard to the design and construction of large, welded, low-pressure storage tanks, API 620 (1975) states that both wind loads and earthquake loads should be incorporated into the design so that when design loads in addition to combined seismic and wind loads act on the structure, stress values do not exceed 133% of the design stress or 80% of yield stress.

LPG (NFPA 58, Sec. 31146,g; NFPA 59 Sec. 243, 250e, 253, 332, 345; CAL-PUC Sec. 4a.10, 4c.5; KAN-LPG

Sec. 22-8-7; LA-LPG Sec. 2.18; MISS-MV Sec. 5.8.8, 7.4.3c, 7.6.1g, 7.6.3d; PA-DLI Rule 18; TX-RRC Div. II Sec. 2.5, 2.7; WISC-AC Sec. 905 (8))

NFPA 58 requires that containers be securely anchored where necessary to prevent flotation due to possible high flood waters around above-ground containers or a high water table for those underground. It also requires that combustible material be excluded from a 10 foot zone around any container.

NFPA 59 includes a similar statement regarding ignitible underbrush. It also requires that containers be "properly painted or otherwise protected from the elements." Secure anchorage or adequate pier height is required to protect against container flotation wherever high water might occur.

California, Kansas, Louisiana, Mississippi, New Jersey, Pennsylvania and Wisconsin all include similar statements requiring that the immediate area surrounding LPG containers be kept free of ignitible material such as weeds or dry grass. Texas states that loose fitting rain caps be provided on all exposed safety relief valves or discharge pipes that discharge vertically upward. Both Texas and New Jersey require that if there is a possibility of a manhole or housing becoming flooded on underground installations, discharge from relief valves and regulator vent lines should be above the possible high-water level.

If underground containers are in loose soils, firm anchoring is required to prevent floating. New Jersey requests secure anchorage in statements similar to the

NFPA.

In general, structures such as LPG tanks must be built in conformance with local building codes so wind, snow and seismic loads are defined by these criteria.

NAPHTHA (NFPA 30 Sec. 2-5, 6, 7 App. B; API 620 Sec. 3.04 (5), 3.05.5; CAL-PUC Sec. 4a.10, 4c.5; CONN-SP Art. III, Sec. 29-62-106, Art. X; FLA-FIREM Sec. 4A-16.25 (6), Chap. 4A-33; IND-FIREM (20-801a)-E61, E62, App. B; MICH-FLAM Rule 45b; PA-SP Sec. 3-431, 4-31, Art. 14)

NFPA 30 has extensive precautions which should be employed when a tank is located in an area that may be subjected to flooding. NFPA 30 also states that in areas subject to earthquakes, the tank supports and connections should be designed to resist damage as a result of such shocks. (API 620 states that both wind loads and earthquake loads should be incorporated into the design of large, welded, low-pressure storage tanks.)

The States of Connecticut, Florida, Indiana and Pennsylvania have standards for flood precautions similar to the NFPA. Michigan merely states that "The Commissioner may specify additional precautions which must be taken to protect a tank to be located in an area subject to flooding." An earthquake standard identical to that found in the NFPA codes has been established in Indiana. The California codes which apply to LPG tanks also apply to naphtha.

6. Requirements For Operating Procedures and Personnel Training.

LNG (NFPA 59A Sec. 103)

Although NFPA 59A has detailed specific operating instructions scattered throughout the code, it makes only the following vague reference to general operating procedures: "In the interest of safety, it is important that persons engaged in handling LNG understand the properties of this product and that they be thoroughly trained in safe practices for its handling." The State of New York requires operating procedures for "(1) routine operations and maintenance and (2) operations and maintenance safety procedures" while acknowledging "it is not possible to prescribe a detailed set of operating and maintenance procedures that will encompass all cases." They shall specify "equipment, piping, valves and other components to be inspected or tested, the time schedule of such inspections or tests and the program to remedy deficiencies or failures uncovered." Included shall be items such as the following: "fire protection systems, dikes, operating signal devices, relief valves inspection, structural inspection, functional inspection, pumps and compressors, valves and operators, standby electrical system inspection, communications equipment and housekeeping." An emergency response plan is also required. No reference is made to general operating procedures in other codes examined for this report. The NYCFD does, however, require that LNG facility operators obtain a Certificate of Fitness based on written and oral examinations given by the Fire Department.

LPG (NFPA 59 Sec. 150; NFPA 58 Sec. 150; CAL-PUC Sec. 49.2; LA-LPG Sec. 2.20; NM-LPG Sec. A, 6A, B)

NFPA 58 and 59 have some operating instructions for specific processes, yet have only vague statements which pertain to general operating procedures. NFPA 58 states "In the interests of safety, all persons employed in handling LP-Gases shall be trained in proper handling and operating procedures." NFPA 59 contains a similar statement. New Mexico and Louisiana require operators to be certified by the State and California states that training is necessary before an operator is delegated responsibility.

NAPHTHA (CAL-PUC Sec. 4a.2)

The State of California has instituted a standard which states "In selecting men for supervisory work at holder or vessel yards, consideration should be given to their carefulness, thoroughness, reliability, and ability to assume responsibility in time of emergency. No person shall be delegated responsibility about a holder yard until he has been thoroughly acquainted with the nature of the work through training."

7. Materials Specifications For Storage Tanks.

LNG (NFPA 59A, Sec. 41, 42, 407; NYCFD Sec. 5, 10, 11, 12, 20.2, 3; NYS-PSC Sec. 259.6b, c, 259.9; MASS-DPU Sec. 41, 42, 406; API 620 Sec. 307, 308, 313.1b, App. G, Q; ASME Code Sec. VIII, Div. I; DOT/USCG 46 CFR Part 38)

Present codes list the materials suitable for use in LNG storage tanks. For metal containers, NFPA 59A cites the American Petroleum Institute (API) Standard 620, Appendix Q for LNG containers operating at less than 15 psig while Section VIII, Division I of the American Society of Mechanical Engineers (ASME) code is cited for metal containers at more than 15 psig. For concrete containers, NFPA 59A cites various American Concrete Institute Standards. The States of Massachusetts and New York and the New York City Fire Department generally follow NFPA 59A in materials selection.

The remaining sections noted in API 620 discuss corrosion allowance. A detailed section on corrosion control is contained in the New York State Regulations.

The API Standard 620 and the ASME Codes are detailed design codes which list acceptable materials in addition to stating design requirements, fabrication methods and quality assurance specifications and techniques. The API Standard 620 requires certain results of Charpy V-notch tests in order to ensure metal toughness and weld integrity.

Tank materials must retain their strength and toughness for a long time at low temperatures to prevent structural failure. The New York City Fire Department requires that inner containers be hydropneumatically tested every five years, or in lieu thereof samples from the metal containers may be tested by the Charpy Impact Test. This is done by placing various samples of the materials used in the tank construction i.e., sheets of metal, welded samples, etc. into a basket immersed in the LNG. The samples are then withdrawn for testing at intervals of a maximum of five years.

The USCG rules require internal inspections at eight year intervals for LNG ship tanks.

The flammability of the insulation is also important. Coast Guard regulations state that the insulation on ship tanks must be self-extinguishing or incombustible. It should be vapor-proof and enclosed. The New York City Fire Department states that only incombustible insulation can be used. The other codes make no specifications.

<u>LPG</u> (NFPA 59, Sec. 21, 22, 251d, 31; NFPA 58, Sec. 210, 211; API 2510 Sec. 5, R-5; CAL-PUC Sec. 3e, n, 4d2; FLA-FIREM Sec. 4A-1.20; GA-FIREC 120-3-16-.06 Sec. 0; KAN-LPG Sec. 22-8-7; LA-LPG Sec. 2.2a; MISS-MV Sec. 2.4; PA-SP Rule 561; TX-RRC Sec. III B.7, Div. II; WISC-AC Sec. 9.03(1))

NFPA 58 cites the Regulations of the U.S. Department of Transportation (DOT), the Rules for the Construction of Unfired Pressure Vessels, Section VIII, Division 1, ASME Boiler and Pressure Vessel Code and the API-ASME Code for Unfired Pressure Vessels for Petroleum Liquids and Gases.

For non-refrigerated containers, NFPA 59 cites Section VIII of the ASME Boiler and Pressure Vessel Code. It also states that containers should be adequately protected against corrosion. For refrigerated containers with a pressure of 15 psig or more, Section VIII of the ASME Code is cited, as is API Standard 620. For pressures below 15 psig, API Standard 620 is cited.

API 2510 cites Section VIII of the ASME Code for non-refrigerated containers. For refrigerated containers, Section VIII of the ASME Code is cited as is API Standard 620.

California, Kansas, Louisiana, Mississippi, and Texas all cite Section VIII of the ASME Codes. Florida and Georgia require documentation of conformance to the ASME standards during tank construction while Wisconsin cites its own Boiler and Unfired Pressure Vessel Code. Tank corrosion is addressed in the regulations of California and Pennsylvania.

<u>NAPHTHA</u> (NFPA 30, Sec. 2 1, 2-3.3; API 620 Sec. 201, 202, App. B Sec. 307, 308, 3.13.1b, App. G; API 650 Sec. 2; CAL-PUC Sec. 3e, n; CONN-SP Art III Sec. 29-62-13, ART IV Sec. 29-62-19; FLA-FIREM Part II, Sec. 4A-16.21; IND-FIREM (20-801a)-E31, E33, E36, E48; MICH-FLAM Rule 48,58; PA-SP Sec. 3-7, 4-4, PR-FS Sec. 314-500)

NFPA 30 states general materials specifications for the design of storage tanks citing standards from Underwriters Laboratories, Inc. and the American Petroleum Institute.

The API Codes have been described in the discussions for LNG.

Indiana and Pennsylvania adopt NFPA 30 with few changes while Florida cites NFPA 30 and standards from Underwriters Laboratories and the American Petroleum Institute. In addition to citing the latter two, Connecticut has established several standards for tanks constructed of steel or concrete. Michigan adopts API and NFPA requirements in addition to establishing individual specifications for steel selection. Puerto Rico lists several brief steel specifications and has their Fire Service determine whether the ASME codes should be employed. Similar to LPG, California cites the ASME Codes (Section VIII) and discusses corrosion protection.

8. Materials Specifications For Truck Trailers and Rail Cars.

LNG (NFPA 59A Sec. 84, 861; Mass. - DPU Sec. 84, 861; NYCFD Sec. 19.1, 19.8)

NFPA 59A states that tank vehicles and tank cars under the jurisdiction of the U.S. Department of Transportation shall comply with DOT regulations. All other tank vehicles shall comply with LNG Tank Vehicles-Insulated Tank Truck for Cold Liquefied Gases, CGA-341; LPG Tank Vehicles - Storage and Handling of Liquefied Petroleum Gases, NFPA 58; Flammable Liquid Tank Vehicles-Tank Vehicles for Flammable and Combustible Liquids, NFPA No. 385. Transfer piping, pumps and compressors must be located or protected by suitable barriers to ensure safety from damage caused by rail or vehicle movements. Prior to loading LNG into the vessel of a tank vehicle, the oxygen content in the container should be determined if the tank vehicle is not in exclusive LNG service, or if the tank vehicle does not contain a positive pressure. If the oxygen content in either case exceeds 2 percent by volume, the container cannot be loaded with LNG until suitably purged.

The State of Massachusetts requires that tank vehicles and tank cars be approved for the specific service by authorities (not specified in the code) recognized by the Department of Public Utilities. The Department is also responsible for approving the design of any support, abutment or device used to protect transfer piping, pumps and compressors from damage by rail or vehicle movements. Once again a test and possible purging is required to ensure that there is a slight positive pressure and lack of oxygen in the container.

The New York City Fire Department states that flammable or combustible liquids, gases or refrigerants shall be received only by permitted trucks complying with the specifications (not documented in standard) of the Fire Department. Tank vehicles shall load or unload flammable or combustible liquids only after they have been inspected and authorized by the Fire Department and when in the charge of a person with a certificate of fitness.

About fifteen years ago the Federal Government initiated the concept of special permits or exemptions. This meant that the government (under the Office of Hazardous Material Operations - OHMO) would allow the movement of LNG in a container system that was approved under special permits. The purpose was to generate approval of a new type of transportation system. In the early 1960's, the Compressed Gas Association developed a specification known as CGA-341 (revised in 1972) which they presented to the Federal Government. They asked that it be incorporated as the governing regulation for the movement of cryogenic fluids, making it unnecessary to obtain special permits. To date, this has not been incorporated. Although HM-115 was issued as a notice of proposed rulemaking by OHMO in the early 1970's it was never issued.

CGA-341 contains some important safety elements for LNG trucks. General specifications include the requirement that the design pressure of the liquid container must not be less than 25 psig nor more than 500 psig. The liquid (pressure) container must be constructed in accordance with the ASME Code. It must be supported within the outer shell by members designed to withstand minimum static loadings of

(1) vertical downward of two (2) vertical upward of one (3) longitudinal of one (4) lateral of one-times the weight of the liquid container and attachments when filled to the design weight of lading (cold liquefied gas being transported in the liquid container) using a safety factor of not less than four based on the room temperature ultimate strength of the material used. The surface of the liquid container must be insulated with a material not subject to corrosive attack by the contents of the tank. Tank design should be such that the total heat transfer from the atmosphere at 70°F to a lading at minus 320°F does not exceed 0.20 Btu per hour per pound of water capacity. The insulation must be covered with a steel shell of not less than 3/32 inch. Aluminum was disallowed as a tank material for flammable cargoes because of its poor fire resistance. The CGA-341 requirements result in a more collision and rollover resistant truck. HM-115, as proposed, included some even more stringent provisions on hold time without venting and on design "g" loads. There are no formal Federal LNG truck container system design regulations at present.

<u>LPG</u> (NFPA 58 Sec. 6; NFPA 59 Sec. 7; KAN-LPG Sec. 22-8-16, Division III, MISS-MV Div. IV; PA-DLI Sec. VIII, TX-RRC Sec. III, Div. IV: WISC-AC Part IV)

NFPA 58 cites the U.S. Department of Transportation Regulations (MC-331). NFPA 59 has requirements which pertain only to the handling and transfer of LPG to and from tank vehicles. It requires that the area of tank truck transfer be relatively level. The tank truck loading and unloading area shall be of sufficient size to accommodate the vehicles without excessive movement or turning. Tank trucks or transports unloading into the storage containers shall be at least 10 ft. from the container and positioned so that the shut-off valves on both the truck and the container are readily accessible. While trucks are loading or unloading, the wheels shall be blocked. Kansas has instituted similar requirements.

Louisiana requires that all containers be designed, constructed and tested in accordance with the ASME Code specifications relating to vessel design. Kansas, Mississippi and Wisconsin employ the ASME Codes in their regulations to document some design specifications required. Louisiana, Mississippi, Pennsylvania, Texas, and Wisconsin all include specifications for such issues as safety equipment, tank mounting and electrical equipment.

<u>NAPHTHA</u> (Conn-SP Art. XIII, XIV: FLA-FIREM Part X; IND-FIREM (20-807) A275-A286; MASS-DPU FPR-7; MICH-FLAM Rules 5-35)

NFPA 385, adopted by the NFPA at its 1974 Annual Meeting, is a regulatory standard for tank vehicles for flammable and combustible liquids. This standard was prepared for issuance by enforcement authorities as a regulatory standard.

It establishes standards for the materials used in the design of cargo tanks used in tank vehicles. It states that all sheet and plate material should either comply with the ASME Codes or the requirements given. Consequently, steel and aluminum specifications are listed. Other design details such as thickness of sheets and heads, structural integrity and loadings are discussed. General operating procedures are also stated.

Florida and Massachusetts have adopted this code with several minor provisions. Connecticut, Indiana, and Michigan all include detailed material specifications in addition to several individual requirements.

9. Requirements For Harbor Movements and Unloading of LEG and Naphtha Tankers, and

10. Requirements For Tanker Construction.
(See also Chapter 6, Appendix VI, and Appendix XVI-3.)

The U.S. Coast Guard and other groups such as the American Bureau of Shipping have developed requirements on tanker construction and operations for a wide range of potentially hazardous cargoes including LEG and naphtha. Presently, the Coast Guard considers naphtha within its regulations for general bulk combustible liquid cargo carriers; whereas LNG and LPG are covered in a special category for liquefied flammable gases. (The Coast Guard has even more stringent rules for more dangerous flammable liquids, for certain special cargoes, and for nuclear vessels.)

LNG (DOT/USCG 46 CFR Part 30-35, 38, 42, 154; 33 CFR Part 126; 6.04, 6.14)

According to 46 CFR Part 38, the primary LNG tank to be constructed of materials meeting low temperature toughness standards and to be self-supporting. However, it states that special designs not contemplated by the standards (membrane tanks, for example) can be submitted to the Commandant for approval. A major portion of LNG ships in service today are of the membrane type. A secondary barrier must also be provided so that the barrier and contiguous hull structure retain sufficient toughness at the lowest temperature which may result from cargo leakage.

The regulations require that a ship be stable (defined as wind heel angle less than either 14° or half the freeboard) in 55 knot winds. Other stability requirements can be imposed at the discretion of the Commandant. The USCG has an announced policy of following IMCO rules for LNG ships when they are consistent with proposed rules issued in October 1976 by the USCG. These proposed rules require that the ship be designed to remain afloat assuming damage criteria which depend on the size and design configuration of the ship. These criteria include a two compartment flooding scenario. Basically, the rules are intended to make liquefied gas carriers somewhat more collision resistant than conventional tank ships. The ship is designed to survive stranding or minor side damage without cargo loss. At present, rules for a 30" distance between the outer hull and the cargo system along with practical considerations of ballasting the ships and insulating the cargo tanks, result in LNG ships being designed with double hulls and bottoms. This is a specific requirement in the proposed rules.

Vapors generated by gradual warming of the cargo can be used as ship fuel at sea, reliquefied, or be allowed to raise tank pressure. In the latter case, the insulation and tank design pressure must allow a suitable safety margin for the operating times involved. Venting is not accepted as a normal operating mode.

Extensive fire protection system requirements are detailed including dual dry chemical fire extinguishment systems, and water spray systems for deluging exposed portions of the cargo tanks and critical structures facing the tanks.

Every eight years an internal examination of cargo tanks is required and the marine inspector may also require a hydrostatic or pneumatic pressure test of the tanks at 1-1/2 times the relief valve pressure if he considers it necessary to determine the condition of the tank. Relief valves must be inspected at least every two years.

Foreign LNG carriers come under USCG scrutiny via their letter of compliance program which requires foreign LNG vessels entering U.S. ports to obtain USCG authorization. This involves an inspection to the standards required by 46 CFR Part 38. When IMCO international standards are adopted, foreign and U.S. vessels should meet the same safety requirements.

Operating restrictions on LNG carriers and contingency plan development are the responsibility of the USCG Captain of the Port (COTP) in each port receiving LNG. (33 CFR 6.04, 6.14.) The COTP can modify the rules at his discretion. Present practice in Boston includes USCG escort, establishment of a sliding safety zone around a vessel during port transit, use of tugs, restriction of transit to times of good visibility, etc.

Some requirements for personnel competence at the shore facility are contained in 33 CFR 126.

LPG (USCG 46 CFR Part 38)

Refrigerated LPG carriers are in the same category as LNG carriers so that the preceding discussions for LNG also pertain to LPG. Since LPG at atmospheric pressure has a temperature of about $-40^{O}F$, the secondary barrier requirement can be avoided if the ship's hull is constructed from a suitable low temperature steel.

For pressurized LPG carriers an additional requirement is that the cargo tanks be designed in accordance with pressure vessel standards for design pressures greater than 10 psig.

NAPHTHA (Mass. Dept. of Public Safety FPR-14; Florida - State Fire Marshal Chapt. 4A-32; USCG 46 CFR Parts 30-35)

The Massachusetts and Florida regulations generally cover operations at marine oil and refined products terminals. Fire protection for wharf areas, conditions for terminating transfer (electrical storm, fire in vicinity or other emergency conditions), and control of ignition sources in transfer area are typical of the restrictions included.

The USCG regulations pertaining to marine transport of naphtha permit carriage of the cargo in tanks integral with the hull. Critical bulkheads must be designed to withstand a one-hour fire exposure without the passing of flame or smoke. All areas containing potential ignition sources must be isolated from the cargo tanks. The requirements for vessel survivability are also based on damage criteria somewhat less stringent than for the LEG carriers.

11. Liability.

LNG Maine Revised Statutes, Title 14, Section 165; New York 1976 Laws, Chap. 892, Section 23-1717(8)

The 1976 New York Liquefied Natural and Petroleum Gas Act imposes strict liability for any personal and property damage occasioned by LNG or LPG accidents against persons engaged in the storage, handling and transportation of either fuel. In addition, Maine imposes strict liability for damages resulting from natural gas operations generally, without specifying applicability to LNG. We were unable to locate any comparable liability provisions in any other state.

The absence of a specific provision with respect to liability for accidental injury relegates the disposition of the issue to general tort law which is determined as a matter of judicial case law and can vary from state to state. An analysis of the exact status of the law for any particular state will require an examination of the applicability of negligence standards generally and the possible applicability of theories of strict liability might apply to LNG circumstances. The crucial issues in such an analysis involve the extent to which liability will exist for losses occasioned by accidents or failures which might occur despite the maintenance of due care and the degree of causation which might be required before liability will exist. Thus far, only New York has provided a statutory response to these questions.

LPG

The 1976 New York statute discussed above applies equally to both LNG and LPG. However, LPG has not been the subject of the regulatory imposition of liability standards in any other state despite its long history and frequency of use. Consequently, questions surrounding liability are subject to the same tort law considerations discussed generally above.

NAPHTHA

No state has imposed regulatory standards relative to naphtha. Again, as in the case of LNG and LPG in states other than New York, this leaves the matter to the existing tort law in each state. However, naphtha is considerably less volatile than either LNG or LPG. Thus, it is less likely to be viewed as falling in the category of extremely or inherently dangerous activities which tend to give rise to strict liability. Again this could vary from state to state.

12. Liability Insurance Requirements.

Present codes and regulations make no reference to insurance requirements.

LNG

There are no specific requirements for carrying insurance against off-site liability on the part of corporations involved in storage and handling of LNG.

LPG

Certain jurisdictions require insurance against off-site liabilities involving LPG. This is probably due to frequent LPG accidents and the consequent awareness of the general public of the volatility of that fuel.

Ten of the 50 states require proof of public liability insurance as a pre-requisite to obtaining a permit for dealing, storage, and handling of LPG. These states are:

Alabama - Regs. of Ala. LPG Board, Sec. 5.
Arkansas - State code for LPG, Sec. 53-723 (c).
Florida - LPG Rules of Insurance Commission 4A-1.17.
Georgia - Georgia Code, Sec. 73-306.
Kentucky - 806 Kentucky Admin. Regs. 50.050.
Louisiana - R.S. of L. Title 40, Sec. 1847.
Nevada - Nevada LPG Board, Rules and Regs. 13.
New Mexico - N.M.S.A., Sec. 65-7-11.
South Carolina - LPG Law 66-431.5.
Tennessee - Tenn. LPG Safety Regs. Sec. 53-3604.

The coverage required by law varies greatly from state to state. In Nevada, amounts are set on an ad hoc basis by the secretary of the LPG Board. New Mexico, Kentucky, and Florida require bodily and property liability in the varying amounts of $50,000 and $25,000 respectively. These statutes do not indicate whether these are intended to be aggregate amounts for a single accident.

South Carolina, Georgia, Tennessee, Arkansas, Alabama, and Louisiana require various types of liability coverage such as contractor property damage, etc. in varying amounts from $10,000 to $100,000 (aggregate amount for any single accident). None of the ten states require coverage in excess of $100,000.

The other 40 states and Puerto Rico have only substantive regulations pertaining to the storage and handling of LPG and do not address the issue of requiring insurance coverage.

NAPHTHA

Naphtha is treated by state legislation in the same way as LNG. There is no requirement for liability insurance on the part of corporations involved in storage and handling of naphtha.

BLANK

APPENDIX XVI-6

SOME PERTINENT STATUTORY CITATIONS

Statute	Agency/Authority	Regulation
ALABAMA		
Alabama Code Title 26 §179(57)	Liquefied Petroleum Gas Commission	Rules and Regulations of LPG Commission
Alabama Code Title 48 §1-101(5), et seq.	Public Service Commission	5(a) Certificate to OPSO
Alabama Code Title 55 §30, et seq.	Fire Marshal	Regulation of Fire Marshal
Alabama Code Title 8 §309	Mineral Resource Management Committee	None
Alabama Code Title 8 §312, et seq.	Coastal Area Planning Committee	None
ALASKA		
Alaska Statutes §42.05.010, et seq.	Alaska Public Utilities Commission	5(b) Agreement with OPSO
Alaska Statutes §18.70.010, et seq.	Department of Public Safety	13 Alaska Administration Code 50.040
Alaska Statutes §30.25.010	Department of Environmental Conservation	None
Alaska Statutes §18.60.210	Department of Labor	Informal compliance with NFPA #59A

ARIZONA

Arizona Revised Statutes Annotated §23-401, et seq.	Division of Safety, Fire Marshal	Arizona Fire Code, §1.102, 15.101, et seq.
Arizona Revised Statutes Annotated §23-121, et seq.	Industrial Commission	Arizona Fire Code, §20.101 et seq.
Arizona Revised Statutes Annotated §40-201, et seq.	Public Service Commission	No Regulations
	Corporation Commission	5(a) Certificate to OPSO

ARKANSAS

Arkansas State Commission §53-111, et seq.	Oil & Gas Commission	No Regulations
Arkansas State Commission §53-711	LPG Board	LPG Board Regulations
Arkansas State Commission §82-806, et seq.	Arkansas State Police Fire Marshal	Regulations of Fire Marshal
Arkansas State Commission §73-116, et seq.	Public Service Commission	5(a) Certificate to OPSO

CALIFORNIA

California Public Utility Code §770	Public Utility Commission	94B, 5(a) Certificate to OPSO
California Vehicle Code §31300		None
California Health Safety Code §7620, 7624, 7655	Division of Industrial Safety	17 Cal Admin Code 14 (Petroleum Safety Orders)

California Public Resources Code §30,000; 30,308; 30,333		None

COLORADO

Colorado Revised Statutes Annotated §40-1-101 §40-2-101	Public Utilities	5(a) Certificate to OPSO
Colorado Revised Statutes Annotated §8-20-101, et seq.	State Inspector of Oils	Regulations of State Inspector of Oils, concerning LPG, and liquid petroleum products

CONNECTICUT

Connecticut General Statutes Annotated §29-62	Committee of State Police	State Police Committee Regulations Covering Storage, Use & Transport of Flammable Liquids
Connecticut General Statutes Annotated §29-72	Committee of State Police	State Police Committee Regulations Covering Storage, Use & Transport of Flammable Liquids
Connecticut General Statutes Annotated §16-1, et seq.	Public Utilities Control Authority	5(a) Certificate to OPSO

DELAWARE

Delaware Code Annotated 16 §6603, 6607	State Fire Marshal	Adoption of NFPA
Delaware Code Annotated 26 §101	Public Service Commission	5(b) Agreement with OPSO

Delaware Code Annotated 3 §302	Department of Public Safety	No Regulations

DISTRICT OF COLUMBIA

	Public Service Commission	5(a) Cerfificate to OPSO

FLORIDA

Florida Statute §377.22(s)	Division of Interior Resources	No Regulations
Florida Statute §366.02, et seq.	Public Service Commission	5(a) Certificate to OPSO
Florida Statute §527.06	Department of Insurance	Rules of Insurance Commission, Ch. 4A-1
Florida Statute §633.01	Fire Marshal	Rules of Insurance Commission, Ch. 4A-3.01, 4A-16; 5(a) Certificate to OPSO

GEORGIA

Georgia Code §92A-701	Safety Fire Commissioner	Rules of Safety Fire Commission #120-3-17
Georgia Code §73-302	State Fire Marshal	Rules of Safety Fire Commission #120-3-16
Georgia Code §93-708	Public Service Commission	Rules of Public Service Commission #515-9-1; 5(a) Certificate to OPSO
Georgia Code §84-60	State Building Administrative Board	No Regulations
Georgia Code §98-202	Georgia Ports Authority	No Regulations

Georgia Code §11-404	Airport Zoning Board	No Regulations
HAWAII		
Hawaii Revised Statute §269-1, et seq.	Public Utilities Div., Dept. of Regulatory Agencies	5(a) Certificate to OPSO
	Public Utilities Commission	Public Utilities Commission General Order #9, Ch. III, Part II
Hawaii Revised Statute §132-1, et seq.	State Fire Marshal	Adoption of all Applicable NFPA Standards
Hawaii Revised Statute §133-1, et seq.	Combustibles	Adoption of Pertinent NFPA Standards
Hawaii Revised Statute §205A-1, et seq.	Coastal Zone Management Act	None
IDAHO		
Idaho Code §39-2202	State Fire Marshal-LPG	Adoption of NFPA
Idaho Code §39-3501	State Fire Marshal-Fire Prevention	Adoption of NBFU
Idaho Code §39-4109	Idaho Building Code Advisory Act	Adoption of NFPA
Idaho Code §39-4116	Idaho Building Code Advisory Act	Provide Optional Adoption by Localities of State Building Code
Idaho Code §61-807	Dept. of Law Enforcement	No Regulations
Idaho Code §61-101	Public Utilities Commission	5(a) Certificate to OPSO

ILLINOIS

Illinois Revised Statutes Ch. 127 1/2 §154	Dept. of Public Safety	Informal-Adoption of NFPA #59A, and LPG Gas Regulations of Illinois
Illinois Revised Statutes Ch. 104 §119-122	Dept. of Law Enforcement	Informal Adoption of NFPA #58 and LPG Gas Regulations of Illinois
Illinois Revised Statutes Ch. 15 1/2 §48.103, et seq.	Dept. of Aeronautics	Informal Compliance with NFPA 30, 58, and 59A
Illinois Revised Statutes Ch. 127 §1253	Dept. of Transportation	No Regulations
Illinois Revised Statutes Ch. 109 §109	Illinois Commerce Commission	5(a) Certificate to OPSO
Illinois Revised Statutes Ch. 91 §604	Illinois Environmental Protection Agency	I.E.P.A. Rule #205
Illinois Revised Statutes Ch. 39 §422	County	No Regulations

INDIANA

Indiana Code §22-11-5-1 et seq.	State Fire Marshal	State Fire Prevention Commission Regulation §20-801a
Indiana Code §13-4-7-1, et seq.	Department of Natural Resources Oil & Gas Division	None
Indiana Code §8-1-1-1, et seq.	Public Service Commission	5(a) Certificate to OPSO

IOWA

Iowa Code §100.1 et. seq.	State Fire Marshal	Iowa Administrative Code 680-5.250(101)
Iowa Code §101.1 et seq.	Liquefied Petroleum Gases	I.A.C. 680-5.300(101)
	State Commerce Commission	5(a) Certificate to OPSO

KANSAS

Kansas Statutes Annotated §31-132, et seq.	Fire Protection (State Fire Marshal)	LPG Regulations
Kansas Statutes Annotated §66-101, et seq.	State Corporation Commission	5(a) Certificate to OPSO
Kansas Statutes Annotated §55-1101, et seq.	LPG	None
Kansas Statutes Annotated §55-501, et seq.	Transportation and Sale of Oils & Liquid Fuel	None

KENTUCKY

Kentucky Revised Statute §278.040	Public Service Commission	Kentucky Administration Regulations 807K.A.R. 2:025; 5(a) Certificate to OPSO
Kentucky Revised Statute §227.210-.300	Commissioner of Insurance, Fire Marshal	806K.A.R. 50:010
Kentucky Revised Statute §234.130-.180	Commissioner of Insurance, Fire Marshal	806K.A.R.50:060.070
Kentucky Revised Statute §183.861	Airport Zoning Commission	No Regulations

Kentucky Revised Statute §85.220	Municipality	No Regulations
Kentucky Revised Statute §96.595	Municipality	No Regulations

LOUISIANA

Louisiana Revised Statutes §30:1, 30:3	Louisiana Conservation Commission, Oil and Gas Division	Rules of Oil & Gas Division, Section VII,C, Also State Order 29-M
Louisiana Revised Statutes §40:1841, - 1855	Liquefied Petroleum Gas Commission	Rules and Regulations of LPG Commission
	Office of Conservation	5(b) Agreement with CPSO

MAINE

Maine Revised Statutes Annotated Title 35, §15	Department of Transportation - Carriers	None
Title 35, §2537, et seq.	Public Utilities Commission	5(a) Certificate to OPSO
Maine Revised Statutes Annotated Title 25, §2441	Commissioner of Public Safety	Adoption of NFPA #58
Maine Revised Statutes Annotated Title 26, §141, et seq.	Boilers & Pressure Vessels	Adoption of DOT Requirements
Maine Revised Statutes Annotated Title 29, §1512, et seq.	Vehicle Equipment Safety Commission	Adoption of DOT Standards
Maine Revised Statutes Annotated Title 14, §165	Strict Liability	None

MARYLAND

Maryland Annotated Codes, Art. 38A§3, 7, 8	State Fire Marshal, State Fire Protection Commission	Rules & Regulations of the State Fire Prevention Commission, Maryland Fire Prevention Code, Rule # 12.03.01.08 12.03.01.16 12.03.01.21
Maryland Annotated Codes, art. 32§2	Municipality	No Regulations
Maryland Annotated Codes, art. 66C§676	Dept. of Natural Resources	No Regulations
Maryland Annotated Codes, art. 62B§5	Maryland Port Administration	No Regulations
	Public Service Commission	5(a) Certificate to OPSO

MASSACHUSETTS

Massachusetts General Law, Ch. 164 69I	Energy Facilities Siting Council	Procedural Regulations
Massachusetts General Law, 164,66 et seq., 105A	Department of Public Utilities	Massachusetts Gas Distribution Code DPU11725f; 5(b) Agreement with OPSO
Massachusetts General Law, Ch. 148 9 et seq.	Department of Public Safety, Fire Marshal*	
Massachusetts General Law, Ch. 85 2B, 15	Department of Public Works	No Regulations

MICHIGAN

Michigan Compiled Laws Annotated §29.3A	Dept. of State Police	Storage, Handling & Use of Inflammable Liquid and LPG

*Board of Fire Prevention Regulations, FPR 5,7,8,13,14, and 17.

Michigan Compiled Laws Annotated §29.5A	Dept. of State Police	Transportation of Flammable Liquids and Compressed Gases
Michigan Compiled Laws Annotated §29.3A	Dept. of State Police	Storage, Handling & Use of Inflammable Liquids, Michigan Administrative Code, R28.6
Michigan Compiled Laws Annotated §29.3A	Dept. of State Police	Michigan L.P.G. - R28.3801, R28.401, R28.561
Michigan Compiled Laws Annotated §29.5A	Dept. of State Police	Traffic Regulations for Vehicles Transporting Flammable Liquids - State Police Correspondence File: 04.1[illegible].19[illegible]
Michigan Compiled Laws Annotated §483.151	Public Service Commission	Michigan Gas Safety Code, R460.14052; 5(a) Certificate to OPSO
Michigan Compiled Laws Annotated §259.51	Aeronautics Commission	No Regulations
Michigan Compiled Laws Annotated §125.1503	State Construction Code Commission	No Regulations

MINNESOTA

Minnesota Statutes Annotated §299F.19	State Fire Marshal	5(a) Certificate to OPSO; Storage and Handling of LPG, Fire Marshal Regulations 11-14
Minnesota Statutes Annotated §299F.19	State Fire Marshal	Flammable and Combustible Liquids, Fire Marshal Regulations 20-23

Minnesota Statutes Annotated §116H.01	Minnesota Energy Agency	Minnesota Energy Agency Regulations 300-500
Minnesota Statutes Annotated §116G.04	Minnesota Environmental Quality Board	Minnesota Environmental Quality Board Regulations 21-57
Minnesota Statutes Annotated §116H.01	Minnesota Energy Agency	Minnesota Energy Agency Regulations Pertaining to Air Pollution Control #13

MISSISSIPPI

Mississippi Code Annotated 45-11-1 et seq.	Fire Marshal	Regulations of Mississippi Fire Marshal
Mississippi Code 75-57-1	Liquefied Gas Division of Motor Vehicle Comptroller	LPG Regulations
Miss[illegible] Code 77-[illegible] seq.	Public Service Commission	5(a) Certificate to OPSO

MISSOURI

Missouri Revised Statutes §323.010, et seq.	Department of Revenue Officer in Charge of Motor Vehicle Fuels	Rules and Regulations for LPG of Department of Agriculture
Missouri Revised Statutes §320.010,et seq.	Fire Protection, Fire Marshal	None
	Public Service Commission	5(a) Certificate to OPSO

MONTANA

Montana Revised Codes Annotated §70-101, et seq.	Public Service Commission	5(a) Certificate to OPSO

Montana Revised Codes Annotated §70-801, et seq.	Department of Natural Resources and Conservation	None
Montana Revised Codes Annotated §82-1201, et seq.	State Fire Marshal	Adoption of NFPA Standards 30 & 58
Montana Revised Codes Annotated §82A-601, et seq.	Department of Health and Environmental Sciences	Regulation of Department of Environmental Sciences
Montana Revised Codes Annotated §60-124, et seq.	Oil & Gas Conservation Commission	None

NEBRASKA

Nebraska Revised Statute §81-502	State Fire Marshal	Adoption of NFPA Standards; 5(b) Agreement with OPSO
Nebraska Revised Statute §66-501	Tax Commission	No Regulations
Nebraska Revised Statute §75-501	Public Service Commission	No Regulations

NEVADA

Nevada Revised Statutes §590.465, et seq.	LPG Board	Rules & Regulations of LPG Board
Nevada Revised Statutes §477.030	Fire Marshal	None
Nevada Revised Statutes §703, et seq. §704.210, .215	Public Service Commission	5(a) Certificate to OPSO

NEW HAMPSHIRE

New Hampshire Revised Statute Annotated, Section 153: 1, et seq.	State Board of Fire Control	Adoption of NFPA #58 59A
New Hampshire Revised Statute Annotated Section 162-F: 1, et seq. Section 162-F: 1, et seq.	Bulk Power Supply Facility Site Evaluation Committee	No Regulations
New Hampshire Revised Statute Annotated, Section 362: 1, et seq.	Public Utilities Commission	5(a) Certificate to OPSO

NEW JERSEY

New Jersey Revised Statutes 21:1B-2,1B-9	Commission of Labor and Industry	LPG Regulations New Jersey Administrative Code 12:200
New Jersey Revised Statutes 21:1B-2, 1B-9	State Police	LPG Regulations New Jersey Administrative Code 13:52
New Jersey Revised Statutes 58:10-351	Department of Conservation and Economic Development	No Regulations
New Jersey Revised Statutes 40A:14-1	County Fire Marshal	No Regulations
New Jersey Revised Statutes 40:174-120	Municipal Fire Marshal	No Regulations
	Board of Public Utilities Dept. of Energy	5(b) Agreement with OPSO

NEW MEXICO

New Mexico Statutes Annotated §4-16-1, et seq.	State Fire Marshal	General Compliance with NFPA
New Mexico Statutes Annotated §65-7-1, et seq.	LPG Commission	Rules and Regulations of LPG Commission
New Mexico Statutes Annotated §68-5, 7, et seq.	Public Utilities Commission	No Regulations
	State Corporation Commission	5(a) Certificate to OPSO

NEW YORK

Vehicle & Traffic Law §378.21	Commission of Vehicle and Traffic	Regulation #67
Transportation Law §14F, §378, §379	Commission of Transportation	Regulation #822
Public Service Law §66	Public Service Commission	Regulations #3(C)-259, #3(C)-260; 5(a) Certificate to OPSO
1976 Laws, Chap. 892 Liquefied Natural and Petroleum Gas Act	Department of Energy Conservation	Not yet published
Navigation Law §37		No Regulation
Environmental Conservation Law §3-0101		No Regulation

NORTH CAROLINA

North Carolina General Statute §69-1, et seq.	Fire Protection	Informal Compliance with NFPA 54 & 58

North Carolina General Statute §119-48, et seq.	LPG - Board of Agriculture	Adoption of NFPA Standards
North Carolina General Statute §62-211	Utilities Commission	Informal Compliance with NFPA Standards; 5(a) Certificate to OPSO

NORTH DAKOTA

North Dakota Cent. Code §18-01-33	State Fire Marshal	North Dakota Fire Law 1809.01
North Dakota Cent. Code §18-09-02	State Fire Marshal (LPG)	North Dakota Law #1809.01
North Dakota Cent. Code §49-01-01, et seq.	Public Service Commission	5(a) Certificate to OPSO

OHIO

Ohio Revised Code §3737.01, .17, .18	State Fire Marshal	Ohio Fire Code Rule 1301: 7-7-08
Ohio Revised Code §1509.01, .01, .03	Division of Oil & Gas	No Regulations
Ohio Revised Code §4101.08	Department of Industrial Relations	Ohio Pressure Piping Rules BB-201
Ohio Revised Code 4161.01	Office of Mines and Minerals	No Regulations
Ohio Revised Code §4905.04	Public Utility Commission	5(a) Certificate to OPSO

OKLAHOMA

Oklahoma Statutes Title 52 §420.1	LPG Administrator	Rules & Regulations Oklahoma LPG Board
Oklahoma Statutes Title 79 §329.1	Fire Marshal	None

Oklahoma Statutes Title 17 §151	Corporation Commission	5(a) Certificate to OPSO
OREGON		
Oregon Revised Statutes §480.420	State Fire Marshal	LPG, Oregon Admin. Order 837-30-005
Oregon Revised Statutes §476.030	State Fire Marshal	Flammable & Combustible Liquids, Oregon Admin. Order 837-20-005
Oregon Revised Statutes §476.030	State Fire Marshal	Liquefied Natural Gas, Oregon Admin. Order 827-80-005
Oregon Revised Statutes §476,030	State Fire Marshal	Fire & Lift Safety Act, Oregon Admin. Order 837-40-005
Oregon Revised Statutes §757.039	Public Utility Commissioner	5(a) Certificate to OPSO
Oregon Revised Statutes §191.120	Oregon Coastal Conservation and Development Commission	No Regulations
Oregon Revised Statutes §469.310	Energy Facility Siting Council	No Regulations
PENNSYLVANIA		
Pennsylvania Statutes Title 35,§1181	State Police	"Storage, Handling and Use of Flammable and Combustible Liquids"
Pennsylvania Statutes Title 35 §1321	Dept. of Labor & Industry	"Storage & Handling of LPG"
Pennsylvania Statutes Title 66§461	Public Utility Commission	5(a) Certificate to OPSO

Pennsylvania Statutes Title 2 §1559	Airport Zoning Board	No Regulations
Pennsylvania Statutes Title 75 §2401	Hazardous Substances Transportation Board	No Regulations
Pennsylvania Statutes Title 55 §442	Commission on the Navigation of the Delaware River	No Regulations

<u>PUERTO RICO</u>

Puerto Rico Laws Annotated Title 25, §311	Puerto Rico Fire Protection Div.	Administrative Code of Puerto Rico Title 25, §31-3, et seq.
Puerto Rico Laws Annotated Title 239 §1051	Oil Fuel Affairs Office	No Regulations
Puerto Rico Laws Annotated Title 27 §1101	Public Service Commission	5(a) Certificate to OPSO

<u>RHODE ISLAND</u>

Rhode Island General Laws Annotated §45-2-17	Division of Public Utilities	5(a) Certificate to OPSO
	Public Utilities Commission	Adoption of NFPA #59A
Rhode Island General Laws Annotated §23-28.22-1, et seq.	Fire Marshal	Adoption of NFPA #30
Rhode Island General Laws Annotated §23-28.33-1, et seq.	Fire Marshal	Adoption of NFPA #59A
Rhode Island General Laws Annotated §23-28.20-1, et seq.	Fire Marshal	Adoption of NFPA #58, 59

Rhode Island General Laws Annotated §23-27.2-1, et seq.	State Building Codes Standard Committee	Adoption of BOCA
SOUTH CAROLINA		
South Carolina Code Annotated §37-56, et seq.	State Fire Marshal	Rules and Regulations of Insurance Commission
South Carolina Code Annotated §66-431, et seq.	LPG Board	Rules and Regulations of LPG Board
South Carolina Code Annotated §58-101, et seq.	Public Service Commission	5(a) Certificate to OPSO
SOUTH DAKOTA		
South Dakota Code §34-29-3, et seq.	Fire Marshal	Rules and Regulations of South Dakota Fire Marshal
South Dakota Code §34-39-1, et seq.	Fire Marshal	Rules and Regulations of South Dakota Fire Marshal
South Dakota Code §49-1-1, et seq.	Public Service Commission	No Regulations
	Department of Public Safety	5(a) Certificate to OPSO
TENNESSEE		
Tennessee Code Annotated §60-104	Oil & Gas Board	Regulation of Oil & Gas Board #1040-4-8-.01
Tennessee Code Annotated §65-414, 422, 1515	Public Utility Commission	Regulations of P.U.C. #1220-2-1-.20
Tennessee Code Annotated §53-3607	Fire Marshal	Liquefied Petroleum Safety Act of Tenn.

Tennessee Code Annotated §53-2536	Fire Marshal	Fire Code #0780-2-3-.01
Tennesse Code Annotated §46-601, 6-657	Municipal Corporation	No Regulations
TEXAS		
Texas Insurance Code art. 1.09	Fire Marshal	No Regulations
Texas Revised Civil Statute, art. 6049C, 6053	Railroad Commission	5(a) Certificate to OPSO, Rules & Regulations of Texas Railroad Commission, Oil and Gas, Section III, 'LPG'
Texas Revised Civil Statute, art. 1606C	County Fire Marshal	No Regulations
Texas Revised Civil Statute, art. 1015, 1068, 1175	Municipal Corporations	Fire Code of Houston
Texas Revised Civil Statute, art. 67010	Texas Dept. of Petroleum Safety	D.O.T. Regulations
UTAH		
Utah Code Annotated §63-29-1, et seq.	Utah State Fire Prevention Board, Fire Marshal	Regulation of State Fire Marshal
Utah Code Annotated §52-1-1	Division of Public Utilities	5(a) Certificate to OPSO
	Public Service Commission	
VERMONT		
Vermont Statutes Annotated, Title 30, Section 1, et seq.	Department of Public Service	Incorporation of NFPA #58 and 59A
	Public Service Board	5(a) Certificate to OPSO

United States of America, Title 23, Section 1, et seq.	Motor Vehicle Equipment	None

VIRGINIA

Virginia Code Annotated §27-72	Fire Marshal	Virginia Statewide Uniform Building Code Fire Protection & Safety Practices
Virginia Code Annotated §27-87	Fire Marshal	LPG Regulations of Fire Marshal
Virginia Code Annotated §27-30	Local Fire Marshal	Regulations of Local Fire Marshal
Virginia Code Annotated §56-338.20-22	Public Service Commission	No Regulations
	State Corporation Commission	5(a) Certificate to OPSO

WASHINGTON

Washington Revised Code §43.22.050	Department of Labor & Industry Division of Industrial Safety & Health	Washington Administration Code, §296-41 §296-42-440
Washington Revised Code §48.48.010-.130	State Fire Marshal	No Regulations
Washington Revised Code §80.50.020	Energy Site Evaluation Council	No Regulations
Washington Revised Code §80.09.010	Public Utility Commission	Washington Administration Code, 480-73-010
	Utilities and Transportation Commission	5(a) Certificate to OPSO

Washington Revised Code §43.21F.010	Energy Office	No Regulations
Washington Revised Code §78.52.010	Mines, Minerals & Petroleum	No Regulations
Washington Revised Code §70.	Hazardous Substances	No Regulations

WEST VIRGINIA

West Virginia Code Annotated §29-3-1, et seq.	State Fire Prevention Commission	Regulations Not Available
West Virginia Code Annotated §24-2-2	Public Service Commission	5(a) Certificate to OPSO

WISCONSIN

Wisconsin Statutes §101.16	Department of Labor Industry	LPG Regulations of Department of Labor and Industry
Wisconsin Statutes §196.01, et seq.	Public Service Commission	5(a) Certificate to OPSO

WYOMING

Wyoming Statutes Annotated §35-436.1	Department of Fire Prevention and Electrical Safety	Adoption of NFPA Standards 58, 59, and 59A
Wyoming Statutes Annotated §30-240, et seq.	Storage of Inflammable Materials	None
Wyoming Statutes Annotated §37-1, et seq.	Public Service Commission	5(a) Certificate to OPSO
Wyoming Statutes Annotated §35-502.75, et seq.	Industrial Development Information Siting Act	None

APPENDIX XVIII

CONTENTS | PAGE

BLANK

APPENDIX XVIII-1 APPLICATIONS TO THE FEDERAL POWER COMMISSION FOR LNG TERMINAL FACILITIES

Applicant	Site Location	FPC Docket No.	Filing Date	Proposed Quantity of LNG MM Cubic Meters/Yr. (landed)	FPC Action Date of Authorization
Phillips Petroleum Co. and Marathon Oil Co. (Baseload Liquefaction)	Kenai, Alaska	CI66-1226	3/8/67	2.4	4/19/67
Southern Energy Co.	Elba Island, Georgia	CP71-264 CP71-151 CP71-267	5/4/71	6.0	6/28/72 10/5/72
Columbia LNG Corp. and Consolidated System LNG Company	Cove Point, Maryland	CP71-289 CP71-68 CP71-153 CP71-290	6/4/71	11.2	6/28/72 10/5/72[1] 4/10/75
Algonquin LNG, Inc.	Providence, Rhode Island	CP73-139 CP73-47	11/22/72	3.0	Pending
Distrigas of New York Corporation[2]	Staten Island, New York	CP74-122 CP70-196 CP73-132 CP73-47	11/2/73	6.4	Pending
Distrigas of Massachusetts Corp.	Everett, Massachusetts	CP74-137 CP70-196 CP73-132 CP76-9	11/15/73	2.0	Pending ALJ+ 6/28/77
Trunkline LNG Company	Lake Charles, Louisiana	CP74-138 CP74-139	11/15/73	8.4	4/29/77 6/30/77[3]
Pacific Alaska LNG Co. (Baseload Liquefaction)	Cook Inlet, Alaska	CP75-140	11/11/74	6.9	Pending
Western LNG Terminal Co.[4]	Point Conception, California	CP75-83-1 CP75-96	3/3/75	15.5	Pending
Western LNG Terminal Company	Los Angeles, California	CP75-83-2	3/3/75	-	Pending
Western LNG Terminal Company	Oxnard, California	CP75-83-3	3/31/75	-	Pending
Tenneco LNG Inc.	West Deptford, New Jersey	CP76-16	7/15/76	8.6	Pending
El Paso LNG Terminal Co.	Port O'Conner, Texas	CP77-269	3/1/77	16.0	Pending ALJ+ 10/25/77
Natural Gas Pipeline LNG Inc.	Ingleside, Texas	CP77-448	6/20/77	6.9	Pending

+Administrative Law Judge's initial decision issued, pending final decision by the Commission.

1. Amended application pending.

2. In 1975 Public Service Electric and Gas Company (New Jersey) bought 100 percent of the stock of the Distrigas of New York Corporation from Cabot Corporation. The corporate name was subsequently changed to the Energy Terminal Services Corporation. The terminal facility application to the FPC has not been affected by the cancellation of the Eascogas LNG, Inc. gas purchase contract with Algeria on May 31, 1977. PSE&G now plans to import 60% of the original 620 MMcfd Eascogas contract. The LNG would only come to the Staten Island Terminal.

3. Trunkline LNG Company accepted the modified FPC certificate in July 29, 1977 letter to the FPC.

4. In November 1977, Western LNG Terminal Associates amended its applications, shifting the receiving terminal sites from Los Angeles and Oxnard to Point Conception.

BLANK

APPENDIX XVIII-2

LIST OF SAFETY EVIDENCE PRESENTED TO THE FEDERAL POWER COMMISSION

At GAO's request, the Federal Power Commission provided the following list of exhibits or testimony related to the siting and safety of LNG importation projects for which applications have been filed. The projects are listed alphabetically; the descriptive details provided in the citations vary. The list concludes with citations of safety and siting exhibits or testimony related to three peak-shaving facilities for which applications have been filed.

Columbia LNG Corporation, et al.
Docket No. CP71-68, et al.

Three companies—Columbia, Consolidated, and Southern—proposed to import LNG in amounts up to 28 million cubic meters of LNG into two terminals at Cove Point, Maryland, and Savannah, Georgia. Although facilities were approved and constructed, actual shipments are awaiting completion of Algerian facilities.

Exhibit Number	Description	Date
3	Algerian Facilities to be constructed by Sonatrach	3/23/71
4	Liquefaction Plant at Arzew, Algeria	3/23/71
12	Map of Pipelines and Principal Cities in Algeria	3/23/71
30	Flow Diagram, Design Capacity	3/23/71
31	Flow Diagram, Maximum Capacity	3/23/71
32	Flow Diagram Data	3/23/71
33	Description of Facilities at Cove Point, MD	3/23/71
35	Location of Facilities at Cove Point, MD	3/23/71
36	Factors Evaluated in joint use of Right-of-Way	3/23/77
64	Proposed Plot Plan, LNG storage and regasification facilities in Savannah	4/8/71
65	Applicant Environmental Report	4/8/71

Exhibit Number	Description	Date
66	Fabrication testing and Code Applications	4/8/71
67	Flow Diagram of LNG Facility	4/8/71
73	Location of Related Southern Facilities	4/8/71
84	Flow Diagram of Related Southern Facilities	4/8/71
85	Flow Diagram Data	4/8/71
215	Detailed Environmental Impact Statement prepared by Columbia Gas, published January 3, 1972	1/11/72
	Testimony of Edward D. Callahoun, V.P. of Columbia Gas, sponsor of exhibit 215	1/11/72
216	Department of the Interior, Bureau of Outdoor Recreation Land and Water Conservation Fund Agreement, June 25, 1971	1/13/72
217	Letters: From (1) Department of Transportation to Max Levy; (2) Max Levy to U.S. Coast Guard	1/14/72
218	Letter of December 17, 1971, to David Kearnes, FPC, from Maryland Department of Natural Resources	1/17/72
219	Detailed Environmental Impact Statement	1/17/72
	Testimony of Frank O. Heintz, Maryland House of Delegates concerning State of Maryland land use laws as pertaining to Cove Point terminal	1/20/72
221	Request for change in Wetlands Boundary, from Department of Chesapeake Bay Affairs	1/21/77

Distrigas Corporation

Docket Nos. CP70-196 and CP73-135

Distrigas proposed to import over a 20 year period approximately 610,000 cubic meters per year of LNG from Algeria at its Everett, Massachusetts terminal and at a terminal on Staten Island, New York. By Commission Opinion No. 613 issued on March 9, 1972 (47FPC752) Distrigas proposal was approved; however, the Everett terminal facilities were not fully declared within the Commission's jurisdiction until the issuance of an order on June 14, 1977. The Staten Island terminal has never been certificated but is involved in a pending proceeding—EASCOGAS incorporated, et al. Docket Nos., CP73-47 et al. The environmental and safety questions with the terminal are presently before the Commission.

Exhibit No. or Transcript Citation	Description of Exhibit or Testimony
2	Location Map of LNG Marine Import Terminal at Everett, Massachusetts
3	Schematic Illustration of Facilities at Everett
4	Layout of Facilities
5	Cross-section of Tank Design
6	Contracts with Chicago Bridge and Iron Company and with Perini Corporation
7	Location of Facilities to be Constructed on Staten Island
8	Layout of Staten Island Facilities
9	General Layout of LNG Barge to be Constructed
10	Ship Arrival Schedule for 3 years

Exhibit No. or Transcript Citation	Description of Exhibit or Testimony
11	Inventory Profiles for Everett and Staten Island Terminals
12	Projected Construction Cost of Everett installation, Staten Island installation, and LNG Barge
13	Summary of Projected Operating and Maintenance Expenses for First 3 years of Operations. (For Everett and New York)
24	Relevant State and Local Construction Codes and Permits
25	Sonatrach/Alocean contract dated September 10, 1970.
26	Gazocean/Alocean Contract Covering Transportation of the LNG to be sold to Distrigas
27	Summary Description of plan for Financing Proposed Facilities
28	English translation of LNG Sales Agreement between Distrigas Corp. and Alocean dated December 3, 1969
29	English Translation of LNG Sales Agreement between Distrigas Corporation and Alocean dated September 10, 1970
Tr. Volume R-5	Testimony of Staff Witness, John Leiss on Geology
Tr. Volume R-5	Testimony of Dudley Chelton from National Bureau of Standards
Tr. Volume R-4	Statements taken at local hearing in Boston, Massachusetts
Tr. Volume 8	Testimony of J.A. MacKay on LNG contract and construction codes and permits
Tr. Volume 10	Testimony of D.W. Oakley on LNG Policy
Tr. Volume 11	Testimony of Norton Sloan on LNG terminal financing

Exhibit No. or Transcript Citation	Description of Exhibit or Testimony
Tr. Volumes 11 and 12	Testimony of Jacek Makowski on LNG contracts
Reference E-1	Final Environmental Impact Statement
Reference E-2	NBS Cryogenic Division Report on the Everett LNG terminal engineering design
Tr. Volume R-5	Testimony of staff witness Robert Arvedlund on Safety
Tr. Volume R-5	Testimony of Staff witnesses John E. Estep and Fortunato R. Barceluna on environmental impact statement.
June 28, 1977	Initial Decision of Administrative Law Judge on Safety Issues
Tr. Volume 46 of CP73-47 *et al.*	Testimony of Captain Cassidy of Boston Harbor

Distrigas Corporation

Docket Nos. CP76-9 et al.

Distrigas proposed to import over an 18 month period increased quantities of LNG from Algeria into its Everett Massachusetts terminal. Because of difficulties in Algeria, it appears that no deliveries will ever be made under the program.

Exhibit	Description
Item D	Final Environmental Impact Statement
Item A	Environmental Report Filed September 16, 1975, Part of CP76-9 application
Item B	LNG sales contract, part of CP76-280 application

Distrigas of Massachusetts Corporation

Docket Nos. CP77-216, *et al.*

Distrigas of Massachusetts Corporation and Distrigas Corporation propose to increase their imported quantities of LNG from Algeria to approximately 1.8 million cubic meters annually for 20 years, in addition to modifying its Everett terminal facilities. This is currently under Staff review.

Exhibit or Transcript	Description
G to CP77-216 app.	Flow Diagrams
E to CP77-218 app.	LNG Contract
Z to CP77-218 app.	Environmental Report
Response to deficiency questions filed May 27, 1977	Additional Facility Information
Joint Hearing Transcript 1	Testimony of Abdelmadjid Kazi Tani on Algerian LNG Facilities
Joint Hearing Transcript 2	Testimony of Tayeb Mazouni on Algerian LNG Policy

Eascogas LNG Inc.
Docket No. CP73-47

Eascogas proposed to import into the United States from Algeria an aggregate of 190 million cubic meters of liquefied natural gas over a twenty year period to terminals constructed at Staten Island, New York, and Providence, Rhode Island. Hearings were held beginning in September of 1973; however, no final decision has ever been made on this case since the Applicants have continually revised, modified, or refined their proposal. The basic LNG contract with Algeria has been mutually rescinded but negotiations may resume towards the goal of formulating a new contract with a lesser volume of LNG to be purchased.

Exhibit No. or Transcript Citation	Description
Tr. Volume 1-A/161-193; Tr. Volume 1; Tr. Volume 2/795-848	Testimony of James Randel, Jr., on LNG Contract and Policy
Tr. Volume 1-A/229-254; Tr. Volume 3	Testimony of Bertrand L. DeFrondevelle on LNG shipping Services
Tr. Volume 1-A/229-254; Tr. Volume 4	Testimony of David Hellstrom on environmental impact of Staten Island Project
Tr. Volume 1-A/260-278; Tr. Volume 4, 8	Testimony of Rolf Glasfeld on shipping design and safety
Tr. Volume 1-A/279-300; Tr. Volume 5, 6	Testimony of Captain Sorie L. Knox on LNG shipping safety procedures
Tr. Volume 1-A/301-314; Tr. Volume 7, 8, 9, 10	Testimony of Donald S. Allen on risks of LNG cargo release

Exhibit No. or Transcript Citation	Description
Tr. Volume 1-A/ 315-325; Tr. Volume 9	Testimony of Jesse M. Calhoun of AFL-CIO on LNG shipping
Tr. Volume 1-A/ 325-529	Testimony of Eugene L. McCahe of AFL-CIO on LNG shipping and construction
Tr. Volume 1-A/ 393-406; Tr. Volume 6, 85	Testimony of James Watson on Algerian LNG Supply
Tr. Volume 1-A/ 407-414	Testimony of Sid Ghozali on Algerian LNG policy
Tr. Volume 1-A/ 432-444; Tr. Volume 20	Testimony of John B. Thorn on LNG Policy relative to Providence, Rhode Island site
Tr. Volume 1-B/ 474-507; Tr. Volume 14, 17	Testimony of William Coates on Providence R.I. site selection
Tr. Volume 1-B/ 508-514; Tr. Volume 15, 16	Testimony of Stanley Dale on LNG risks at Providence
Tr. Volume 1-B/ 515-533; Tr. Volume 14, 15	Testimony of David Hellstrom on Providence environmental impact
Tr. Volume 1-B/ 590-609; Tr. Volume 16	Testimony of Galen E. Jones on environmental impact on Providence site
Exhibit No. 9	Coast Guard Regulations Governing ship operations
Exhibit No. 10	Summary of LNG transportation on water
Exhibit No. 11	The Collision Resistance of the General Dynamic 125,000 M^3 Ship
Exhibit No. 12	Probabilities of Collision and Damage Affecting the General Dynamics 125,000 M^3 Ship
Exhibit No. 13	Acceptability of Risks

Exhibit No. or Transcript Citation	Description
Exhibit No. 14	Thermal Radiation Hazards from Burning Pool of LNG
Exhibit No. 34	Artist's Rendering Showing the Plant Site
Exhibit No. 35	General Plan of Providence Facility
Exhibit No. 36	Preliminary Engineering Decision for Providence Terminal
Exhibit No. 37	Proposal 2 Tank Plan Fire Protection System
Exhibit No. 38	Pertinent Codes and Standards
Item by Ref. G	Report of Algonquin Company concerning NEPA
Tr. Volume 20/ 2620-2632; Tr. Volume 21/2716-2729	Testimony of R. A. Yowell of Maritime Administration on CDS program
Tr. Volume 20/ 2633-2648; Tr. Volume 21/2730-2792	Testimony of Richard Norman of Maritime Administration on loan Guarantee program
Tr. Volume 20/ 2649-2656; Tr. Volume 21/2793-2798	Testimony of Morman Hammer of Maritime Administration on LNG ship engineering and costs
Exhibit No. 65	Percentage of Competition of Vessels C of 9-30-73
Exhibit No. 66	Letters to Coast Guard and Replies
Item by Ref. CC	Letter of Commitment MARAD
Tr. Volume 23/ 2825-2962	Testimony of William Donahue of Staten Island City Planning Dept. on LNG site environments
Exhibit No. 67	Staten Island Pictures
Exhibit No. 68	Population Estimates

Exhibit No. or Transcript Citation	Description
Exhibit No. 69	Map, Borough of Richmond, NY City
Tr. Volume 241 2977-3096; 25/ 3122-3266	Testimony of James A. Fay on LNG hazards
Tr. Volume 27/ 3410-3451	Rebuttal testimony of D. S. Allen To James Fay
Tr. Volume 26 Tr. Volume 28 Tr. 3461-3474	Testimony of E. Saltz population estimates of Staten Island area
Tr. Volume 30/ 3541-3543; Tr. Volume 41	Testimony of Theodore Needles of FPC staff on risk analysis
Tr. Volume 30/ 3544-3546; Tr. Volume 33;34	Testimony of Carl N. Shusten, Jr. on alternatives for FPC staff
Tr. Volume 30/ 3547-3550; Tr. Volume 36	Testimony of Lawrence Boesch for FPC Staff on LNG vapor clouds
Tr. Volume 30/ 3550-3551; Tr. Volume 37, 38	Testimony of Theodore Horner for FPC Staff on probability risk assessment of LNG hazards
Tr. Volume 30/ 3552-3555; Tr. Volume 35, 36, 39, 40	Testimony of Lillian Stone of FPC Staff on LNG Safety and risk assessment
Tr. Volume 30/ 3556-3560; Tr. Volume 31, 32, 36	Testimony of R.K. Arvedlund of FPC Staff on environmental impacts and safety
Tr. Volume 30/ 3561-3562; Tr. Volume 33	Testimony of George R. Kelly of FPC Staff on LNG plume dispersion
Tr. Volume 30/ 3564-3566 3581-3637	Testimony of Douglas Kleinsmith of FPC Staff on Water Quality

Exhibit No. or Transcript Citation	Description
Tr. Volume 30/ 3568-3570; Tr. Volume 35	Testimony of Robert Jimeson of FPC Staff on Alternatives
Tr. Volume 30/ 3571-3574; 3627-3690; Tr. Vol. 31	Testimony of Jonathan D. Isaacs on population for FPC Staff
Exhibit No. 501	Environmental Impact Statement - Staten Island
Exhibit No. 500	Cryogenic Safety Report Staten Island
Tr. Vol. 42, 43	Testimony of Captain Linde and Commander Kline of Coast Guard on vessel LNG design and requirements
Tr. Volume 44	Testimony of Captain Moser of Coast Guard on LNG port Safety Laws
Tr. Volume 44,45	Testimony of William McConnaughey of Coast Guard on LNG hazards
Tr. Volume 45	Testimony of Captain Oliver of Coast Guard on N.Y. Port Plans
Tr. Volume 46	Testimony of Captain Oliver of Coast Guard on Safety
Tr. Volume 46	Testimony of Captain Cassidy of Coast Guard on Boston Point plans
Tr. Volume 48,49	Testimony of D. Kleinsmith of FPC Staff on Aquatic impact of Providence terminal
Tr. Volume 48,50	Testimony of Jonathan Isaacs of FPC Staff on climate, land ore, and socio-economic impact
Tr. Volume 48,49	Testimony of R. Arverlund of FPC Staff on environmental impact of Providence terminal
Tr. Volume 48,50	Testimony of Carl Shuster of FPC Staff on Alternatives to Providence terminal

Exhibit No. or Transcript Citation	Description
Tr. Volume 48	Testimony of Geone Kelly for FPC Staff on LNG plume dispersion for Providence terminal
Tr. Volume 48	Testimony of Lawrence Boesch for FPC Staff on LNG spills
Tr. Volume 48,51	Testimony of Theodore Horner for FPC Staff on LNG probability risk assessment for Providence terminal
Tr. Volume 48,50, 51	Testimony of Theodore Needles of FPC Staff on Safety and risk analysis of Providence terminal
Exhibit No. 73	Cryogenic Safety Review Providence RI
Exhibit No. 74	Final Environmental Impact Statement - Providence
Tr. Volume 52,51	Testimony of Robert Jimeson on alternative energy sources to Providence proposal
Tr. Volume 52	Testimony of William Coates on engineering of Providence LNG terminal
Tr. Volume 52	Testimony of Robert Sweeney for Rhode Island Co=sumer's Council on adverse impact of a Providence terminal
Exhibit No. 76	LNG terminal and marine facility schematic
Tr. Volume 53,55	Testimony of Thomas Ruch for New York City Fire Department
Tr. Volume 53,55	Testimony of Augustus Beekman for New York City Fire Department
Tr. Volume 53,54	Testimony of James Love for New York City Fire Department
Tr. Volume 53,54 55	Testimony of Milton Fishkin for New York City Fire Department
Tr. Volume 53,57	Testimony of Paul Buzse for New York City Incorporated Economic Development Council for the LNG project

Exhibit No. or Transcript Citation	Description
Tr. Volume 53,65	Testimony of Gerald O'Driscott on shipping
Tr. Volume 53,66	Testimony of Eugene R. Hanson on marine impact for New York City Dept. of Water Resources
Tr. Volume 53,66	Testimony of Anthony Galande for New York City on LNG barge operations
Tr. Volume 53,57	Testimony of Harold Nudelman of New York City on fog
Tr. Volume 53,67	Testimony of Douglas Powell for Public Advocate of New Jersey on LNG risks
Tr. Volume 53, 65	Testimony of Joseph Jugan for NJ Public Advocate on NJ Fire Fighting Facilities
Tr. Volume 53,60	Testimony of Dr. Donovan for NJ Public Advocate on Safety
Tr. Volume 53,59 60	Testimony of Peter Hunt on siting analysis
Tr. Volume 53,66	Testimony of Richard Lapinski for Town of Woodbridge, NJ, on NJ environs and risks
Tr. Volume 53,60	Testimony of Norman Hamlin on LNG ship collision risks
Tr. Volume 53,67	Testimony of Jon Schoenhorn on U.S. Coast Guard materials
Tr. Volume 53,63 64	Testimony of Dr. William Fairley on LNG risk assessment methodology
Tr. Volume 53,61	Testimony of William Baxan on LNG risk assessment methodology
Tr. Volume 53,62	Testimony of Dr. Borjess on environmental impact statement analysis
Tr. Volume 53,64	Testimony of James Fay on LNG spills and risks

Exhibit No. or Transcript Citation	Description
Tr. Volume 53	Testimony of Helen Niedham on environmental impact requirements
Exhibit 503	Distrigas Facility Criteria 1
Exhibit 505	Pre-Fire Plan
Exhibit 507	Pre-Fire Plan for LNG Barge Shipment
Exhibit 508	Update of Coast Guard contingency plan
Exhibit 509,510	Charts of N.Y. Harbor
Exhibits 511-515	Climatological Data
Exhibit 516	Environmental Guide for 7 ports
Exhibit 517	Industrial Development Middlesex County
Exhibit 519	EPA's Comment to FEIS
Exhibit 520	Raritan Bay Hazard Zone Map
Exhibit 530	Probable Outflow from LNG vessel
Exhibit 524,525	List of Studies
Tr. Volume 54,59	Testimony of Victor Rossi for City of New York on vessel operations
Exhibit 542	LNG impact siting risk and impact study
Exhibit 543	Preliminary tanker collision and grounding analysis
Item by Ref. I-R	Unconfined Vapor Cloud Explosions
Exhibit 545	Comparison of Equations relating to pool size and spill size
Tr. Volumes 68, 68A, 69	Testimony at local hearing in Providence, Rhode Island by interested parties
Tr. Volumes 70,71	Testimony at local hearing in Staten Island, New York by 40 interested parties and statements by 16 interested parties

Exhibit No. or Transcript Citation	Description
Tr. Volume 72	Testimony of William Jaques on insurance provisions for Providence terminal
Tr. Volume 73	Testimony of Peter Athens in rebuttal to Norman Hamlin and William Farley on tanker accidents
Tr. Volume 73,74	Testimony of Elizabeth Drake in rebuttal to Dr. Fay on LNG spills
Tr. Volume 74	Testimony of Peter Athens on LNG vessels
Tr. Volume 75	Testimony of Arthur Brown in rebuttal to Dr. Fay on LNG safety
Exhibit No. 1000	Distribution curve
Exhibit No. 1001	Article by Kurt Wendell
Exhibit No. 1003	LNG risk assessment items
Tr. Volume 76	Testimony of Douglas Kleinsmith on Staten Island population for FPC Staff
Tr. Volume 76	Testimony of Theodore Needles on Revised risk analysis for FPC Staff
Tr. Volume 76,77	Testimony of R. Arverlund on LNG risk analysis
Tr. Volume 78,79	Testimony of Howard Emmins on LNG vapor clouds and fireballs
Tr. Volume 78	Testimony of Dr. Pan on thermal radiation from vapor clouds
Tr. Volume 79	Testimony of Phani Raj on Thermal Radiation
Tr. Volume 79	Testimony of Robert Kingston on LNG vessel safety and insurance
Item by Ref. N-B	Letters from Corps of Engineers
Item by Ref. N-C	Procedures for movement of LNG/LPG, Captain of Port of New York

Exhibit No. or Transcript Citation	Description
Tr. Volume 81,82	Testimony of Richard Morel about Staten Island Terminal
Tr. Volume 83	Testimony of Campbell Anderson on ship insurance cargo and liability
Tr. Volume 85	Testimony of Abdel Madjid on Sonatrach LNG facilities
Tr. Volume 87	Testimony of Eugene Logan on Staten Island revised project
Exhibit No. 1002	Supplement to FEIS on Staten Island
Exhibit No. 1005	Visible Flame Heights
Exhibit No. 1006	On the Burning of a large flammable vapor cloud
Exhibit No. 1007	Number of LNG vessels in operation
Exhibit No. 1008	History of LNG Transportation
Item by Ref. N-A	Booz-Allen report for Maritime Administration
Item by Ref. N-B	Letters and replies involving Corps of Engineers
Item by Ref. N-E	Report of Japanese Collision

El Paso Alaska Company
Docket No. CP75-96 et al.

El Paso Alaska proposes to liquify Prudhoe Bay gas in Alaska near Point Gravina on Prince William Sound and ship such gas to Point Conception, California, where it would be revaporized. Hearings were held, a Judge's decision was rendered and The Commission has sent its recommendation to the President pursuant to Public Law 94-586, October 22, 1976. Unless otherwise indicated the testimony and exhibits below should be considered as the Applicants.

Exhibit No., Transcript Citation or Date Filed	Description
Exhibit EP-1	Shipping Contract
Exhibit EP-55	LNG Letter Agreement
Exhibit EP-61	Overall Construction Schedule
Exhibit EP-64	Flow Diagram
Exhibit EP-65	Facility Costs
Exhibit EP-66	Overall Material Balance
Exhibit EP-67	Alternative LNG Process Designs
Exhibit EP-68	Description of Marine Facilities
Exhibit EP-70	Design Criteria
Exhibit EP-71	Terminal Steel Quantities
Exhibit EP-72	Description of Gravina Site
Exhibit EP-73	LNG Carrier Fleet Facilities
Exhibit EP-74	LNG Safety Report
Exhibit EP-75	Safety Analysis

Exhibit No., Transcript Citation or Date Filed	Description
Exhibit EP-76	LNG Report
Exhibit EP-77	Letter Agreement on LNG Contract
Exhibit EP-78	Economics of LNG Shipping
Exhibit EP-123,124	Flow Diagrams
Exhibit EP-125,126	LNG Technical Documents
Exhibit EP-143	LNG site slides
Exhibit EP-154	Capital and operating costs
Exhibit EP-156	Estimated steel quantities for terminal
Exhibit EP-157,158, 159, 160, 162	LNG Fleet costs
Exhibit EP-176,177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, & 189	LNG Plant Costs, Scheduling and Manpower Requirements
Exhibit EP-196 thru 230	Alternative terminal design and costs
Exhibit EP-254	Financing and how lenders view the risks of the project
Exhibit AP-13	The alternatives "A Summary of Three Proposals to Move Prudhoe Bay Gas"
Item by Ref. EP-C	Net National economic benefits and risk analysis by DOI
Exhibit ST-22	Draft Environmental Impact Statement DEIS, Volume II on Liquification Facilities
Exhibit ST-23	DEIS on revaporization facilities
Exhibit ST-19	Final Environmental Impact Statement FEIS, Volume II on liquefaction facilities

Exhibit No., Transcript Citation or Date Filed	Description
Exhibit ST-18	FEIS Conclusions
Exhibit ST-36	Slide presentation of terminal sites
Exhibit AA-25	Earthquake Criteria Data
Exhibit AA-74 thru 82	LNG Transportation Cost Analysis
Tr. Volumes 13,14 15	Testimony of Howard Boyd on LNG Policy
Tr. Volumes 44,45 93, 170	Testimony of G.H. Tseklenis on LNG terminal engineering
Tr. Volumes 45,46 93	Testimony of Alfred Sacken on LNG liquefaction engineering
Tr. Volume 47	Testimony of Horstman G. Freytag on LNG Safety
Tr. Volumes 51,52 53, 54, 94, & 95	Testimony of Ivan W. Schmitt on LNG Marine Transportation
Tr. Volumes 54,57	Testimony of Joseph Porricelli on LNG carrier safety
Tr. Volumes 57,60 61	Testimony of Robert McCollom on environmental impact and LNG site selection
Tr. Volumes 49,50	Testimony of James E. Harris on LNG site selection
Tr. Volumes 89,90 91	Testimony on how lenders perceive LNG risks by L. Katzenback and S. Lewand
Tr. Volume 94	Testimony of Robert Gibson on design criteria of marine terminal
Tr. Volume 94	Testimony of William Jarda on marine terminal costs
Tr. Volume 90	Testimony of Benjamin S. Hadad on shipping costs
Tr. Volume 164	Testimony of Arthur Darrow III on seismic conditions at LNG site

Exhibit No., Transcript Citation or Date Filed	Description
Tr. Volumes 142,144	Testimony of Theodore Needels from FPC staff on LNG safety
Tr. Volumes 143, 144, 145, & 146	Testimony of Robert Anverlund, Richard Shinn, Joseph Pizzo, John Leiss, John French, and Robert King on LNG siting and risks, all on behalf of FPC staff
Tr. Volume 216	Testimony of Donald G. Colley, Earle Klohn and David Young on Environmental Impact from LNG project from Alcan Pipeline Company
Tr. Volumes 68, 152 & 153	Testimony of K.C. McKinney, M.E. Fullin and J.W. Olsen on LNG revaporization facilities
Tr. Volume 69	Testimony of N. Yaghoubian on LNG revaporization facility impacts
Tr. Volume 153	Testimony of J.T. Kopecek on safety analysis
Tr. Volume 156	Testimony of Benjamin Martino and Maurice Leon on behalf of Arctic Gas Pipeline Company on LNG costs
Tr. Volume 162	Testimony of Robert Anderson on behalf of Arctic Gas on LNG costs
Tr. Volume 157	Testimony of Nathan M. Newmark on LNG Seismic conditions on behalf of Arctic Gas
Exhibit WL-5	Location of Revaporization facilities
Exhibit WL-6	Design capacity of revaporization facilities
Exhibit WL-9	Major components of terminal facilities
Exhibit WL-11	Safety systems
Exhibit WL-14	Detailed Environmental Analysis for LNG facilities
Exhibit WL-17	Downwind Vapor travel

Exhibit No., Transcript Citation or Date Filed	Description
Exhibit WL-18	Thermal radiation
Exhibit WL-25	Environmental testimony of N.F. Yaghoubian
Exhibit WL-26	Supplemental Environmental Report
Exhibit WL-29	Location of facilities
Exhibit WL-38	Overall plot plan
Exhibit WL-49	Multiple Terminal Study
Exhibit WL-50	Facilities and costs supporting multiple terminal study
Exhibit WL-51	LNG risk assessment, Oxnard, CA
Exhibit WL-52	LNG risk assessment, L.A. Harbor, California
Exhibit WL-53	LNG risk assessment, Point Conception, California
9/13/76	Staff Initial Alaskan Liquefaction Terminal Brief
10/4/76	Staff Reply Alaskan Liquefaction Terminal Brief
9/8/76	Staff California Regasification Terminal Brief
2/1/77	Presiding Judge's initial decision
5/2/77	Commission decision
Exhibit ST-37	Oceanographic Institute of Washington Report - Cook Inlet Siting
Exhibit ST-38	Coast Guard Correspondence regarding Cook Inlet
Exhibit EP-231	Alaska Transportation Systems - DOI Report pp 83-88, 134-35, 170-172

El Paso Eastern Company, et al.
Docket Nos. CP77-330 et al.

El Paso Eastern Company has filed an application to import 45,000 cubic meters of LNG per day to a terminal to be located in the vicinity of Port O'Connor, Texas, on Matagorda Bay. Application for authorization to construct the terminal was filed by El Paso LNG Terminal Company in Docket No. CP77-269.

Exhibit or Transcript	Description
Tr. 144-153	Prepared direct testimony of Mr. Schmitt on shipping and site selection criteria
Tr. 206-210	Further prepared direct testimony of Mr. Schmitt on safety
Tr. 579-582	Further prepared direct testimony of Mr. Schmitt on changes in the design of the marine terminal
Exhibit 5	Algeria II project LNG carrier fleet
Exhibit 6	Joint safety report of El Paso applicants
Ref. E, Ex. Z-1	Engineering and Cost Data - Marine Terminal
Ref. E, Ex. Z-2	Engineering and Cost Data - Onshore Facilities
Exhibit 17	Alternative marine terminal Schmitt design
Tr. 154-167	Prepared direct testimony of Mr. Cole concerning design and construction of the marine terminal
Tr. 583-587	Further prepared direct testimony of Mr. Cole concerning alternative design of the marine terminal

Exhibit or Transcript	Description
Tr. 174-181	Prepared direct testimony of Mr. Lister concerning engineering and design of the onshore facilities and site selection
Tr. 592-597	Further prepared direct testimony of Mr. Lister on changes in onshore facilities
Tr. 182-88	Prepared direct testimony of Mr. Drucker concerning process design of onshore facilities
Tr. 588-591	Furthermore prepared direct testimony of Mr. Drucker on changes in the onshore terminal facilities
Exhibit 20-30	Exhibits related to changes in the onshore terminal facilities.
Tr. 211-234	Prepared direct testimony of Mr. Wesson, Mr. Porricelli, and Mr. Nair concerning safety
Ref. G (three volumes)	Joint Environmental Report
Tr. 308-390, Tr. 605-626	Prepared direct testimony and further prepared direct testimony of Mr. Craig, Mr. Batra, Mr. Conwell, Mr. Mangarella, Mr. Robilliard, and Mr. Smith
Exhibit 37	Seawater Intake and Discharge Studies Supplement I: Alternative Configurations
Tr. 1175-80	Further prepared direct testimony of Mr. Hadad concerning shipping agreement with Sonatrach
Exhibit 40	Transportation agreement for an LNG tanker between Sonatrach and El Paso Atlantic Company

Pacific Alaska LNG Company

Docket No. CP75-140, *et al.*

Pacific Alaska LNG Company (PacAlaska) proposes to buy natural gas in Cook Inlet from the gas production area of South Alaska, gather the gas, liquefy and store the LNG in cryogenic tanks at the Nikiski terminal facility, and at that facility load the LNG for transport by LNG tanker to the Los Angeles harbor LNG terminal facility where the gas will be unloaded, regasified and sold into the California natural gas market. Southern California Gas Company (SoCal) and Pacific Gas and Electric Company (PG&E) will be the purchaser of the regasified LNG. The LNG terminal in Los Angeles harbor is proposed to be constructed and operated by Western LNG Terminal Associates (Western). This proposal is the subject of Western's certificate application in Docket No. CP75-83-2.

Exhibit or Transcript	Description	Date
Exhibit 1 Tr. Volume 5/192-343	Prepared Direct Testimony of K.C. McKinney, Vice President and General Manager of PacAlaska and Western LNG	6/22/76
Exhibit 2	Additional Prepared Direct Testimony	6/22/76
Exhibit 3	(KCM-1) Liquefied Natural Gas Shipping Agreement Between Pacific Alaska LNG Company and Pacific Lighting Marine Co.	6/22/76
Exhibit 4	(KCM-2) Definitive Agreement for Terminal Service Between Western LNG Terminal Company and Pacific Alaska LNG Company	6/22/76
Exhibit 32 Tr. Volume 9-10/858-1015	Prepared Direct Testimony of M. E. Fuller, LNG Task Force Manager for Pacific Alaska	6/29/76

Exhibit or Transcript	Description	Date
Exhibit 33	Additional Prepared Direct Testimony	6/29/76
Exhibit 34 Tr. Volume 6-28, 29-76	(MEF-1) Location of Facilities Alaska	6/29/76
Exhibit 35 Tr. Volume 12/ 1251-1256	(MEF-2) Design Capacity - Alaska Facilities	6/29/76
Exhibit 36	(MEF-3) Capital Costs Alaska	6/29/76
Exhibit 37	(MEF-4) Location of Facilities Los Angeles Harbor	6/29/77
Exhibit 38	(MEF-5) Design Capacity - Los Angeles Harbor Facilities	6/29/76
Exhibit 39	(MEF-6) Capital Costs - Pipeline Los Angeles Harbor	6/29/76
Exhibit 40	(MEF-7) Simplified Block Flow Diagram	6/29/76
Exhibit 41	(MEF-8) Capital Cost Alaska Pipeline	6/29/76
Exhibit 42	(MEF-9) Capital Cost Estimate Los Angeles Harbor	
Exhibit 43 Tr. Volume 10, 11 & 12/1018-1168	Prepared Direct Testimony of J.W. Olson, Project Manager Fluor Engineers & Construction, Inc.	7/1/76
Exhibit 44 Tr. Volume 6-29, 30 & 31-76	Additional Prepared Direct Testimony	7/1/76
Exhibit 45	(JWO-1) Major Components of Liquefaction Facilities - Alaska	7/1/76
Exhibit 46	(JWO-2) LNG Storage Tank Drawing - Alaska	7/1/76

Exhibit or Transcript	Description	Date
Exhibit 47	(JWO-3) Codes, Regulations, and Standards - Alaska	7/1/76
Exhibit 48	(JWO-4) Capital and Operating Cost Estimates - Alaska	7/1/76
Exhibit 49	(JWO-5) Project Schedule - Alaska	7/1/76
Exhibit 50	(JWO-6) Major Components of Terminal Facilities - L.A.	7/1/76
Exhibit 51	(JWO-7) LNG Storage Tank Drawing - L.A.	7/1/76
Exhibit 52	(JWO-8) Codes, Regulations and Standards - L.A.	7/1/76
Exhibit 53	(JWO-9) Capital and Operating Cost Estimates - L.A.	7/1/76
Exhibit 54	(JWO-10) Project Schedule - L.A.	7/1/76
Exhibit 55	(JWO-11) Major Components of The Liquefaction Facilities Alaska	7/1/76
Exhibit 56	(JWO-12) Capital and Operating Cost Estimates - Alaska	7/1/76
Exhibit 57	(JWO-13) Major Components of Terminal Facilities, Los Angeles	7/1/76
Exhibit 58	(JWO-14) Capital and Operating Cost Estimates - Los Angeles	7/1/76
Exhibit 59 Tr. Volume 12, 13/1260-1353	Prepared Direct Testimony of F.F. Drucker, Principal Process Engineer, Fluor Engineers and Construction, Inc.	7/2/76
Exhibit 60 Tr. Volume 7-1, 2-76	Additional Prepared Direct Testimony	7/2/76
Exhibit 61	(EFD-1) Block Flow Diagram - Natural Gas Feed System	7/2/76

Exhibit or Transcript	Description	Date
Exhibit 62	(EFD-2) Block Flow Diagram - Natural Gas Feed System	
Exhibit 63 Tr. Volume 31, 14/1354-1483	Prepared Direct Testimony of L.E. Bell, Manager of Cryogenics for PacAlaska and Western LNG	7/12/76
Exhibit 64 Tr. Volume 7-2, 12-76	(LEB-1) Cargo Transfer System	7/12/76
Exhibit 65 Tr. Volume 14 & 15/1487-1655	Prepared Direct Testimony of J.R. Welker, University Engineers, Consultants to PacAlaska and Western	7/13/76
Exhibit 66 Tr. Volume 7-12, 13-76	Additional Prepared Direct Testimony	7/13/76
Exhibit 67	(JRW-1) Major Components of Fire Safety Systems for Nikiski, Alaska Liquefaction Plant	7/13/76
Exhibit 68	(JRW-2) Major Components of Fire Safety Systems for the Los Angeles Receiving Terminal	7/13/76
Exhibit 69	(JRW-3) Major Components of Fire Safety Systems for Nikiski, Alaska Liquefaction Plant	7/13/76
Exhibit 70 Tr. Volume 15, 16/1656-1985	Prepared Direct Testimony of W.G. Neal, Jr. of Keystone Shipping Company	7/14/76
Exhibit 71 Tr. Volume 7-13, 14-76	(WGN-1) Description of the 130,000 M^3 LNG Vessel Contracted for at Sun Shipbuilding and Dry Dock Company by Pacific Lighting Marine Company	7/14/76
Exhibit 72	(WGN-2) Regulations for the Transport and Discharge of LNG and LPG in Los Angeles and Long Beach Harbors	7/14/76

Exhibit or Transcript	Description	Date
Exhibit 73	(WGN-3) Projected LNG Carrier Operating Cost for Payroll, Supplies, Maintenance, and Miscellaneous Items based on 1973 cost	7/14/76
Exhibit 74 Tr. Volume 16, 17 & 18/1986-2371 7-14, 15 & 16-76	Prepared Direct Testimony of J.A. Aspland, Marine Transportation Analyst for PacAlaska & Western LNG	7/16/76
Exhibit 75	(JAA-1) Operations Guide Nikiski Marine Terminal Complex	7/16/76
Exhibit 76	(JAA-2) Los Angeles - Long Beach Port Safety Council	7/16/76
Exhibit 77	(JAA-3) Western LNG Terminal Company Ship/Shore Operations Procedures	7/16/76
Exhibit 78 Tr. Volume 19/2377-2483	Prepared Direct Testimony of R.O. Parker, LNG design consultant to PacAlaska and Western LNG	8/2/76
Exhibit 79	Additional Prepared Direct Testimony	8/2/76
Exhibit 80	(ROP-1) Downwind Vapor travel	8/2/76
Exhibit 81	(ROP-2) Thermal Radiation	8/2/76
Exhibit 82	(ROP-3) Downwind Vapor Travel Nikiski Liquefaction Plant	8/2/76
Exhibit 83	(ROP-4) Thermal Radiation Nikiski Liquefaction Plant	8/2/76
Exhibit 84 Tr. Volume 19, 20/2486-2558	Prepared Direct Testimony of J.T. Koepcek of Science Applications, Inc.	8/3/76
Exhibit 85 Tr. Volume 19, 20/2486-2558 8-2 and 3-76	(JTK-1) LNG Facility Risk Assessment Study for Nikiski, Alaska Report No. SAI-75-613-LJ	8/3/76

Exhibit 86	Prepared Direct Testimony of W.G. England of Science Applications, Inc.	8/3/76
Exhibit 87 Tr. Volume 20, 21, 22/2560-2812 8-3, 4 & 5-76	Prepared Direct Testimony of R.L. McCollum, Jr. of Dames and Moore	8/5/76
Exhibit 88	(NFY-1) Detailed Environmental Analysis Concerning a Proposed Liquefied Natural Gas Project for Pacific Alaska LNG Company	8/3/76
Exhibit 89	(NFY-2) Supplemental Detailed Environmental Analysis Concerning a Proposed Liquefied Natural Gas Project for Pacific Alaska LNG Company (Beaver Creek Pipeline Supplement)	8/5/76
Exhibit 143	Map - Dredging Plan Nikiski, LNG Terminal	8/5/76
Exhibit 90 Tr. Volume 22,23 2813-2987	Revised Prepared Direct Testimony of N.F. Yaghoubian of Dames and Moore	8/6/76
Exhibit 91	(NFY-3) Detailed Environmental Analysis Concerning Proposed Liquefied Natural Gas Facilities and Associated Gas Transmission Pipelines Volume I LNG Facilities Los Angeles Harbor, California	
Exhibit 92	(NFY-4) Supplement to Exhibit Z-IV and Z-VII Detailed Environmental Analysis Concerning Proposed Liquefied Natural Gas Facilities and Associated Gas Transmission Pipelines Los Angeles Harbor, California	8/6/76
Exhibit 144	Letter Report from Linvall and Richter	

Pacific Indonesia Company, et al.
Docket Nos. CP74-160, et al.

Pacific Indonesia LNG Company proposes to import, in 20 years, 180 million cubic meters of LNG. Pacific Indonesia proposes in Docket No. CP74-207 to sell the daily output at the terminal tailgate to Southern California Gas Company and Pacific Gas and Electric Company in equal quantities. Western LNG Terminal Associates proposes in Docket No. CP75-83-3 to construct a receiving terminal at Oxnard, California.

Exhibit No. and Date Accepted Into Evidence	Description	Cross-Examination Date of Hearing
Exhibit 9 1/8/76	Prepared direct testimony of W.G. Neal, Jr., Manager of Special Projects, Keystone Shipping Co., describing the regulations and design features which affect the safe operation of LNG vessels at unloading terminals.	8/883-943 1/8/76
Exhibit 10 1/9/76	Prepared direct testimony of M.E. Fuller, Manager of Facilities Engineering for Western LNG Terminal Company describing his exhibits.	8/945-951 1/4/76 9/955-1025 1/26/76
Exhibit 11 1/9/76	(MEF-1) Location of Facilities - Oxnard.	1/9/76
Exhibit 12 1/9/76	(MEF-2) Design Capacity - Oxnard Facilities.	1/9/76
Exhibit 13 1/9/76	(MEF-3) Capital Costs - Oxnard to La Vista Pipeline.	1/9/76

Exhibit No. and Date Accepted Into Evidence	Description	Cross-Examination Date of Hearing
Exhibit 14 1/28/76	Prepared direct testimony of J.W. Olsen, Project Manager Fluor Engineers and Construction Inc., describing his exhibits.	8/1627-1634 1/9/76 9/1646-1160 1/26/70 10/1163-1216 1267-1291 1/27/76 11/1297-1344 1/28/76
Exhibit 15 1/28/76	(JWO-1) Major Components of Terminal Facilities - Oxnard.	1/9/76 - 1/28/76
Exhibit 16 1/28/76	(JWO-2) LNG Storage Tank Drawing - Oxnard.	1/9/76 - 1/28/76
Exhibit 17 1/28/76	(JWO-3) Codes, Regulations Standards - Oxnard.	1/9/76 1/28/76
Exhibit 18 1/28/76	(JWO-4) Capital and Operating Cost Estimates - Oxnard.	1/9/76 1/28/76
Exhibit 19 1/28/76	(JWO-5) Project Schedule - Oxnard.	1/9/76 1/28/76
Exhibit 20 1/27/76	Prepared direct testimony of J. Peraino, President and Chief Engineer, Raymond Technical Facilities, Inc., describing his exhibits.	10/1218- 1267 1/27/76
Exhibit 21 1/27/76	(JP-1) Marine Facilities - Oxnard.	1/27/76
Exhibit 22 1/27/76	(JP-2) Berthing Area Drawing - Oxnard.	1/27/76
Exhibit 23 1/27/76	(JP-3) Capital Cost Estimates Marine Facility and Trestle.	1/27/76
Exhibit 24 1/27/76	(JP-4) Project Schedule - Oxnard Marine Facilities.	1/27/76

Exhibit No. and Date Accepted Into Evidence	Description	Cross-Examination Date of Hearing
Exhibit 25 2/2/76	Prepared direct testimony of N.F. Yaghoubian, Partner, Dames and Moore, describing his exhibits.	13/1590-1615 1/30/76 14/1617-1742
Exhibit 26 2/2/76	(NFY-1) Detailed Environmental Analysis Concerning Proposed LNG Facilities and Associated Gas Transmission Pipelines, Vol. II, LNG Facilities - Oxnard.	1/30/76 2/2/76
Exhibit 27 2/2/76	(MFY-2) Supplement to Exhibits Z-1 and Z-VIII Detailed Environmental Analysis Concerning Proposed LNG facilities and Associated Gas Transmission Pipelines, Oxnard.	1/30/76 2/2/76
Exhibit 28 2/3/76	The prepared direct testimony of L.M. Campbell, Senior Project Manager, Woodward-Clyde Consultants describing his exhibit.	14/1744-1754 2/2/76 15/1758-1801
Exhibit 29 2/3/76	(LMC-1) Detailed Environmental Analysis Concerning Proposed LNG Facilities and Associated Gas Transmission Pipeline Vol. V, Gas Transmission Pipeline, Oxnard.	2/2/76 2/3/76
Exhibit 30 1/29/76	The prepared direct testimony of J.R. Welker, University Engineers, explaining his exhibit.	12/1354-1471 1/29/76
Exhibit 31 1/29/76	(JWR-1) Major Components of Five Safety Systems for the Oxnard Receiving Terminal.	1/29/76
Exhibit 32 1/30/76	The Prepared direct testimony of Dr. R.O. Parker describing his exhibits.	13/1477-1588 1/30/76

Exhibit No. and Date Accepted Into Evidence	Description	Cross Examination Date of Hearing
Exhibit 33 1/30/76	(ROP-1) Downwind Vapor Travel.	1/30/76
Exhibit 34 1/30/76	(ROP-2) Thermal Radiation.	1/30/76
Exhibit 54 1/9/76	Prepared Direct Testimony of M.E. Fuller, Manager of Facilities Engineering for Western LNG Terminal Company, describing his exhibit.	8/945-951 1/9/76 9/955-1025
Exhibit 55 1/9/76	(MEF-4) Capital Costs Oxnard to La Vista Pipeline.	1/9/76
Exhibit 56 1/28/76	Prepared direct testimony of J.W. Olsen, Project Manager, Fluor Engineers and Constructors Inc., describing his exhibits.	1/26/76 1/28/76
Exhibit 57 1/28/76	(JWO-6) Capital and Operating Cost Estimates - Oxnard.	1/26/76 1/28/76
Exhibit 57-A 1/28/76	Oxnard LNG Terminal, 550 MM SCFD Base + 450 MM SCFD Peaking, September 1975 Control Estimate, Capital Cost (1979 Completion).	1/26/76 1/28/76
Exhibit 94	Material from Prior Data Responses (6 parts) (1) Report of Foundation Investigation Proposed LNG Terminal - Oxnard, (2) Soil-Structure Interaction Study for Oxnard Facility LNG Tanks, 4/75, (3) Project Description, (4) LNG Storage Tank Drawings, (5) Fire and Leak Detection Safety Alarm and Shutdown System, and (6) Specification SP-45 3334-00-7, Earthquake Engineering.	

Exhibit No. and Date Accepted Into Evidence	Description	Cross Examination Date of Hearing
Exhibit 95 1/27/76	Exhibit of J. Peraino (JP-5) Oxnard LNG Terminal, Marine Facility and Trestle Capital Cost Estimate (1979 completion) as per September 1975 Costs.	1/27/76
Exhibit 115 3/8/76	Prepared direct testimony of Capt. J.A. Aspland, Marine Transportation analyst for Pacific Indonesia, describing his exhibits.	23/2840-2931 3/8/76
Exhibit 116 3/8/76	(JAA-1) L.A. - Long Beach Port Safety Council Regulations.	3/8/76
Exhibit 117 3/8/76	(JAA-2) Western LNG Terminal Company, Ship/Shore Operations Procedures.	3/8/76
Exhibit 118 3/27/76	Prepared direct testimony of J.W. Olsen, Project Manager, Fluor Engineers and Contractors, Inc., describing the LNG storage tanks.	
Exhibit 119 3/29/76	Prepared direct testimony of T.A. Benvegnu, Supervisor of Design Engineers, Chicago Bridge and Iron Company discussing the LNG storage tanks.	
Exhibit 126 3/31/76	Department of Transportation Coast Guard, Liquefied Natural Gas Views & Practices, Policy and Safety, CG-478.	
Exhibit 132 2/23/77	Prepared direct testimony of R.L. Solomon, Chief, Policy and Program Evaluation, Energy Resources, Conservation and Development Commission of the State of California describing his exhibits.	33/3935-4035 2/22/77 34/3036-4051 2/23/77

Exhibit No. and Date Accepted Into Evidence	Description	Cross-Examination Date of Hearing
Exhibit 133 2/23/77	(RLS-1) The California Coastal Act.	2/22-23/77
Exhibit 134 2/23/77	(RLS-2) ERCDC Biennial Report - Fossil Fuel Issues, Part I: Liquefied Natural Gas.	2/22-23/77
Exhibit 135 2/23/77	(RLS-3) Resource Planning Associates: LNG Decision in California.	2/22-23/77
Exhibit 136 2/23/77	(RLS-4) ERCDC Resolution No. 76-1117-13.	2/22-23/77
Exhibit 137 2/23/77	(RLS-5) County of Santa Barbara Letter Dated August 10, 1976.	2/22-23/77
Exhibit 138 2/23/77	(RLS-6) Governor's Office of Planning and Research Letter Dated November 24, 1976.	2/22-23/77
Exhibit 139 2/23/77	(RLS-7) Governor's Office of Planning and Research Letter dated December 15, 1976.	2/22-23/77
Exhibit 140 2/23/77	(RLS-8) Governor's Office of Planning and Research Letter dated December 16, 1976.	2/22-23/77
Exhibit 141 2/23/77	(RLS-9) ERCDC Letter of November 26, 1976.	2/22-23/77
Exhibit 142 2/23/77	(RLS-10) United States Dept. of Commerce, NOAA Letter dated December 2, 1976.	2/22-23/77
Exhibit 143 2/23/77	(RLS-11) Statement of Chairman Richard Maullin before the Energy Resources Council.	2/22-23/77
Exhibit 144 2/23/77	(RLS-12) Statement of Senior Counsel Frederick E. John before the Energy Resources Council.	2/22-23/77

Exhibit No. and Date Accepted Into Evidence	Description	Cross-Examination Date of Hearing
Exhibit 145 2/23/77	(RLS-13) Statement of Chairman Richard Maullin before the Energy Resources Council, Phase II.	2/22-23/77
Exhibit 146 2/3/77	(RLS-14) Report of State Seismic Safety Commission.	2/22-23/77
Exhibit 147 2/23/77	(RLS-15) Letter to Richard Maullin of the ERCDC from the Office of Planning and Research.	2/22-23/77
Exhibit 148 2/23/77	(RLS-16) Senate Bill 2008.	2/22-23/77
Exhibit 152 2/24/77	FPC Staff Final Environmental Impact Statement.	
Exhibit 153 2/24/77	Prepared direct testimony of R.R. Hoffman, Sanitory Engineer, of FPC Staff, discussing FEIS.	
Exhibit 154 2/24/77	Prepared direct testimony of J.S. Leiss, Geologist of FPC Staff, discussing FEIS.	35/4132-4158
Exhibit 155 2/24/77	Prepared direct testimony of C.M. Zerby, Environmental Engineer of FPC Staff, discussing FEIS.	
Exhibit 156 2/24/77	Prepared direct testimony of A.L. Barnett, Hydrologist of FPC Staff, discussing FEIS.	
Exhibit 157 2/24/77	Prepared direct testimony of L.R. Crook, Jr., Historian, of FPC Staff, discussing FEIS.	
Exhibit 158 2/24/77	Prepared direct testimony of W.A. Douglas, Environmental Specialist, of FPC Staff, discussing FEIS.	

Exhibit No. and Date Accepted Into Evidence	Description	Cross-Examination Date of Hearing
Exhibit 159 2/24/77	Prepared direct testimony of F.A. Barcelona, Wildlife Biologist of the FPC Staff, discussing FEIS.	
Exhibit 160 2/24/77	Prepared direct testimony of R.K. Arvedlund, Chemical Engineer of FPC Staff, discussing FEIS.	
Exhibit 161 2/24/77	Prepared direct testimony of Dr. C.N. Shuster, Jr., Ecological Systems Analyst of FPC Staff, discussing FEIS.	
Exhibit 162 2/24/77	Prepared direct testimony of R.L. Kane, Physical Scientist of FPC Staff, discussing FEIS.	
Exhibit 163 2/24/77	Cryogenic Safety Review, Prepared by the National Bureau of Standards, Cryogenics Division, Authors: Dudley B. Chelton, mechanical engineer specializing in cryogenic refrigeration and liquefaction techniques; Alan J. Schmidt, mechanical engineer, specializing in investigation of cryogenic fluid phenomena involving the pressurization, stratification, cooling, heating, and flow of such fluids.	
Exhibit 195	Summary Report, Seismic Design Consideration, Proposed LNG Facility, Oxnard. Dames & Moore. Job No. 0011-167-02.	
Tr. Volume 24/ 908-913 5/26/76	Prepared Direct Testimony of K.C. McKinney, Vice President and General Manager of Pac Indonesia and Western Terminal discussing the reliability of terminal operation and Exhibit No. JH1.	31/24,915- 24,042 5/26/76 32/25,273- 5,280 5/27/76

Exhibit No. and Date Accepted Into Evidence	Description	Cross-Examination Date of Hearing
Ref. JH-1 5/26/76	(JH-1) Multiple Terminal Study.	
Tr. Volume 25/ 043-049 5/26/76	Prepared direct testimony of M.E. Fuller, Manager of Facilities Engineering for Western Terminal describing exhibit No. JH2.	31/25,049 25,079 5/26/76 32/25,081- 25,153 5/27/76
Ref. JH-2 5/26/76	(JH-2) Facilities and Cost Supporting Multiple Terminal Safety.	5/26/76
Tr. Volume 25/ 156-160 5/27/76	Prepared direct testimony of J.T. Kopecek, Manager of the Science Application Institute Safety Studies discussing exhibit JH-3.	32/25,166- 25,271 5/27/76
Tr. Volume 25/ 162-165 5/27/76	Prepared direct testimony of W.G. England, Assistant Manager of the Energy and Environmental Services Division of SAI, discussing exhibit JH-3.	32/25,166- 25,271 5/27/76
Ref. JH-3 5/27/76	(JH-3) LNG Risk Assessment Study for Oxnard, California Report No. SAI-75-615-LJ, December 22, 1975, by Science Applications, Inc.	5/27/76
Item A 1/27/76	Response to 9 questions in 5/11/75 letter from FPC requesting detailed engineering safety and environmental data.	
Item B 1/27/76	Response to 117 questions in 8/11/75 letter from FPC requesting detailed engineering, safety and environmental data.	
Item C 1/27/76	Western Terminal Control Estimate and Scope Definition.	

Exhibit No. and Date Accepted Into Evidence	Description	Cross-Examination Date of Hearing
Item D 1/27/76	Spill Design Data, Detector Shutdown Sequence, Narrative Specification.	
Item E 1/29/76	Foundation Investigations, Design Criteria for Underground LNG Transfer System, Summary of Proposed Five Protection and Alarm Systems, Response of Safety Systems Process Safety Shutdown Systems.	

Tenneco LNG Inc.
Docket No. CP76-16

Tenneco LNG, Inc. proposes to use an LNG terminal site near West Deptford, New Jersey, to revaporize foreign LNG which it might buy from the Soviet Union or Nigeria. It has not received a commitment from these nations to buy LNG.

Exhibit No. Transcript Citation or Date Files	Description
Exhibit F to CP76-16 App.	Location of Facilities
Exhibit G-GI to CP76-16 App.	Flow Diagrams for Project
Exhibit G-II to CP76-16 App.	Engineering Data
Exhibit K to CP76-16 App.	LNG Project Costs
Exhibits 2-1, 2-2, and 2-3 to CP76-16 App.	Environmental Report and Safety Analysis
2/18/76	Environmental and Safety Prepared testimony of Victor V. Staffa of Tennessee Gas Pipeline Company, Gerald Strobel of Ecology and Environment, Inc., Frank Silvestro of Ecology and Environment, Inc., and Hugh Lusk, independent consultant.
2/18/76	Environment and Safety Exhibits accompanying testimony (7 Exhibits).
3/25/76	Deficiency letter response from Tenneco on LNG Safety and Environment. Volumes I, II, III, and IV.

Exhibit No. Transcript Citation or Date Files	Description
12/76	Staff Draft Environment Impact State A.
	Comments were filed in response to Draft EIS from Pennsylvania Fish Commission; New Jersey Dept. of Public Advocate; Wilmington Metro Area Planning Coordination Committee; EPA - Region II (NY); Delaware Dept. of Natural Resources and Environment Control; Maryland Dept. of State Planning; Dept. of HEW, Delaware River Basin Council; U.S. Coast Guard; DOI; Dept. of Commerce; NRC; New Jersey DOT; Tenneco LNG, Inc.; County of Delaware, Pennsylvania Advisory Council on Historic Preservation; Amenipuct; ERDA.

Tennessee Atlantic Pipeline Company

Docket No. CP77-100 *et al.*

Tennessee Atlantic Pipeline Company proposes to bring Algerian LNG to the coast of Canada near St. John, New Brunswick, for revaporization and subsequent transportation through Canada into the United States across the states of Maine, New Hampshire, Massachusetts, New York, and Pennsylvania by the construction of a new pipeline. This is presently in hearing with an anticipated Commission decision due December 1977, about one year from the date when the application was filed.

Exhibit No. Transcript Citation or Date Filed	Description
Exhibit 1	Testimony of Roger N. Stark of Tenneco LNG, Inc. on Siting Policy
Exhibit 1	Testimony of George W. White of Tennessee Gas Pipeline Company on LNG shipping
Exhibit 1	Testimony of Chester L. Long of Newport News Shipbuilding and Dry Dock Company on LNG shipping
Exhibit 1	Testimony of Sherman H. Clark of Sherman Clark Associates on LNG supply security
Exhibit 1	Testimony of Anthony V. Leness of White, Weld and Company Incorporated, James M. Smith, Jr., of Morgan Stanley and Company Incorporated, and E. Wayne Hopkins of Tennessee Gas Transmission Company, all involving financing of LNG projects and the lenders perception of the risks involved
Tr. Volume 1 pp. 61-69	Testimony of Ewell H. Muze III of Tennessee Gas Transmission Company on LNG shipping arrangements

Exhibit No. Transcript Citation or Date Filed	Description
Tr. Volume 1 pp. 102-111	Testimony of James A. McDonald of Canadian Pacific Limited on LNG siting in Canada
Tr. Volume 1 pp. 113-119	Testimony of David G. Toole of Canadian Pacific Limited terminal on LNG costs
Tr. Volume 1 pp. 120-125	Testimony of Mortimer S. Bistrisky of Canadian Pacific Limited on Canadian LNG regulation requirements
Tr. Volume 1 pp. 107-138	Testimony of Stephen H. Grote of Brown and Rost, Inc. on LNG terminal facilities and safety
Tr. Volume 1 pp. 139-147	Testimony of Frank B. Silvestro of Ecology and Environment, Inc. on LNG hazards and risks
Tr. Volume 1 pp. 148-153	Testimony of Dr. Eugene Kuckun on LNG terminal environmental impacts
Tr. Volume 1 pp. 154-179	Testimony of Arthur Nesbitt of Nesbitt, Thomson and Company, Ltd. and Ronald M. Freeman of Salomon Brothers on LNG Financing and a lenders perception of LNG risks
Tr. Volume 1 pp. 180-185	Testimony of John C. McMillian of the Royal Bank of Canada on Canadian lenders perception of LNG risks
Tr. Volume 1 pp. 190-199	Responses from Secretary of Defense and State on proposed Tenneco LNG project
Exhibit 2	Map of LNG import project
Exhibit 3	LNG contract
Exhibit 5	LNG terminal contract
Exhibit 24	LNG Schematic Volume Balance
Exhibit 25	Ocean Route Chart

Exhibit No. Transcript Citation or Date Filed	Description
Exhibit 26	Simplified Schematic of LNG Shipping Model
Exhibit 27	Shipping Memorandum
Exhibit 28	Draft Shipping Contract
Exhibit 29	Shipping Costs
Exhibit 30, 31, and 32	Shipping Contracts
Exhibit 33, 34, 35, 36, 37	LNG Shipping Equipment and Safety Apparatus
Exhibit 51, 52, 53	LNG Shipping Costs
Exhibit 66	Map of LNG Terminal Site
Exhibit 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82	LNG Terminal Cost and Maintenance Costs
Exhibit 83	LNG Engineering Study
Exhibit 84	LNG Safety Analysis
Exhibit 85	Environmental Import Study
Joint Hearing Transcript Docket No. CP77-216 _et al._ Volume 1, p. 8-27	Testimony of Kazi Tani of Sonatrach on Alterian LNG terminal construction, operation, and safety
Joint Hearing Transcript Vol. 1, p. 78-84	Testimony of Tayeg Mazouni on LNG siting
7/11/77	Staff Draft Environmental Impact Statement

Exhibit No. Transcript Citation or Date Filed	Description
8/1/77	Northeast United States Coast LNG Site Analysis Phase I
Exhibit G to App. in Docket No. CP77-100	Project Flow Diagrams

Trunkline LNG Company, et al.
Docket Nos. CP74-138, et al.

Trunkline LNG Company proposed to import from Algeria 140 million cubic meters of LNG in a 20-year period. To receive the LNG Trunkline LNG proposes in Docket No. CP74-138 to construct at Lake Charles Louisiana a receipt, storage and regasification terminal. Trunkline Gas Company in Docket No. CP74-140 proposes to transport and sell in interstate commerce the regasified LNG.

Exhibit No. Transcript Citation or Date Filed	Description	Cross-Examination Date of Hearing
Tr. Volume 3/ 313-329 2/28/74	Prepared direct testimony of A.D. Roy, Vice President of Woodward-Envicon, discussing his exhibits.	3/330-361 2/28/74
Exhibit 22 2/28/74	Environmental Impact and Safety Report for Trunkline LNG Company.	2/28/74
Exhibit 23 2/28/74	Environmental Impact and Safety Report for Trunkline Gas Co.	2/28/74
Tr. Volume 3/ 368-386 2/28/74	Prepared direct testimony of R.A. Bergman, Project Manager of Kellogg Company discussing his exhibits.	3/388-435 2/28/74
Exhibit 24 1/28/74	(RAB-1) Design Capacity reflecting Operations with proposed facilities.	2/28/74
Exhibit 25 1/28/74	(RAB-2) Plot Plan.	2/28/74
Exhibit 26 1/28/74	(RAB-3) LNG Terminal Storage Tank.	2/28/74
Exhibit 27 2/28/74	(RAB-4) Simplified Flow Diagram.	2/28/74

Exhibit No. Transcript Citation or Date Filed	Description	Cross-Examination Date of Hearing
Exhibit 28 2/28/74	(RAB-5) Required Permits.	2/28/74
Exhibit 29 2/28/74	(RAB-6) Cost of Facilities.	2/28/74
Exhibit 30 2/28/74	(RAB-7) Construction Schedule.	2/28/74
Exhibit 31 2/28/74	(RAB-8) Fire Protection System.	2/28/74
Tr. Volume 3/ 442-458 2/28/74	Prepared direct testimony of L.C. Sullivan, Assistant Chief Engineer of Trunkline discussing his exhibits.	3/452-474 2/28/74
Exhibit 32 2/28/74	(LSC-1) Location of Facilities.	2/28/74
Exhibit 33 2/28/74	(LSC-2) Flow Diagram.	2/28/74
Exhibit 34 2/28/74	(LSC-3) Flow Diagram Data.	2/28/74
Exhibit 35 2/28/74	(LSC-4) Cost of Facilities.	2/28/74
Tr. Volume 3/ 479-485 2/28/74	Prepared direct testimony of A.W. McAnneny, Vice President a=d Chief Engineer of Trunkline discussing his exhibit.	3/487-511 2/28/74
Exhibit 36 2/28/74	(AWM-1) Location of Facilities.	2/28/74
Tr. Volume 11/ 1298-1301 10/18/76	Prepared direct testimony of L.C. Sullivan, Assistant Chief Engineer of Trunkline discussing his exhibit.	11/1303-1327 10/18/76
Exhibit 56 10/18/76	(LCS-5) Cost of Facilities.	10/18/76

Exhibit No. Transcript Citation or Date Filed	Description	Cross-Examination Date of Hearing
Tr. Volume 12/ 1562-1567 10/19/76	Prepared direct testimony of R.A. Bergman, Project Manager Kellogg Co., discussing his exhibits.	12/1565-1586 10/19/76
Exhibit 67 10/19/76	(RAB-19) Cost of Facilities.	10/19/76
Exhibit 68 10/19/76	(RAB-10) Construction Schedule.	10/19/76
Tr. Volume 17/ 2137-2139 11/16/76	Prepared direct testimony of F.L. Fleming Environmental Biologist of the FPC Staff, discussing the FEIS.	17/2140-2156 11/16/76
Tr. Volume 17/ 2152-2156 11/16/76	Prepared direct testimony of R.R. Hoffman, Sanitary Engineer of the FPC Staff discussing the FEIS.	17/2159-2205 11/16/76
Exhibit 84 11/16/76	Final Environmental Impact Statement of FPC Staff.	11/16/76
Exhibit 85 11/16/76	Cryogenic Safety Review prepared by the National Bureau of Standards Cryogenics Division. Authors: Dudley B. Chelton, mechanical engineer specializing in cryogenic refrigeration and liquefaction techniques; Alan T. Schmidt, mechanical engineer, specializing in investigation of cryogenic fluid phenomena involving the pressurization stratification, cooling, heating, and flow of such fluids.	11/16/76
Exhibit 86 11/16/76	Department of Transportation Coast Guard, Liquefied Natural Gas, Views and Practices, Policy and Safety. (CG-478)	11/16/76

Safety or siting exhibits and testimony in connection with three peak-shaving facility applications are listed below:

Northern Natural Gas Company, et al.
Docket No. CP76-52, et al.

This is an LNG peaking project in Hancock County, Iowa, designed to permit storage of gas during the summer to be used during the winter for high-priority loads.

Item C. by Ref.	Environmental Report Submitted by Northern Natural Gas, Peoples Division.
Exhibit 1	Engineering Exhibit.
Exhibit 17	National Bureau of Standards Report on LNG design.

Northern Natural Gas Company
Docket No. CP74-264

This is an LNG peaking project in Hancock County, Iowa, designed to permit storage of gas during the summer to be used during the winter for high-priority loads.

Exhibit 3	Engineering Exhibit

Chattanooga Gas Company
Docket No. CP73-329

This is an LNG peaking project near Chattanooga, Tennessee designed to permit storage of gas during the summer to be used during the winter for high-priority loads.

Exhibit 1	Testimony of T.R. Bell and Attachments.
Exhibit 1	Testimony of Kenneth Royse and his exhibits.

APPENDIX XIX

JAPANESE ENERGY USE

This appendix consists of the following tables:

JAPANESE ENERGY USE

Table XIX-1 LNG Receiving Terminals in Japan

RECEIVING TERMINAL	EXPORT TERMINAL	IMPORT COMPANY	IMPORT QUANTITY CONTRACTED (10^3 m^3/y)	YEAR OF OPERATION	STORAGE TANKS (AS OF 1979) NO. OF TANKS	TOTAL CAPACITY (10^3 m^3)	TYPE
Negishi	Kanai (Alaska)	Tokyo Electric Power Co. Tokyo Gas Co.	1,550 520	1969	4	160	above ground
	Lumut (Brunei)	Tokyo Electric Power Co. Tokyo Gas Co.	970 730	1973	2 4	70 260	above ground in-ground
Sodegaura	Lumut (Brunei)	Tokyo Electric Power Co. Tokyo Gas Co.	6,460 1,550	1973	8 5	420 300	above ground in-ground
	Das Island (Abu Dhabi)	Tokyo Electric Power Co.	4,430	1977	1 8	60 480	above ground in-ground
Samboku No. 1	Lumut (Brunei)	Osaka Gas Co.	1,360	1972	3 1	135 45	above ground in-ground
No. 2	Arun (Indonesia) Badak (Indonesia)	Osaka Gas Co. Kansai Electric Power Co.	2,800 1,500	1977	8	600	above ground
Tobata	Arun (Indonesia) Badak (Indonesia)	Kyushu Electric Power Co. Nippon Steel Corp.	3,230 1,290	1977	6	360	above ground
Chita	Arun (Indonesia) Badak (Indonesia)	Chubu Electric Power Co.	3,660	1977	4	300	above ground
Himeji	Arun (Indonesia) Bakuk (Indonesia)	Kansai Electric Power Co.	3,650	1979	4	280	above ground
	Undecided	Osaka Gas Co.	4,300	U N D E C I D E D			

Table XIX-2 LPG Supply and Demand in Japan ($10^3 m^3$).

YEAR	1970	1973	1974	1975	19[illegible]
SUPPLY	12,491	17,925	18,472	19,089	30,691
Indigenous refinery production	7,225	8,530	8,017	8,408	9,924
Import	5,267	9,395	10,445	10,681	20,767
DEMAND (% total)	11,982	17,662	18,144	18,922	30,510
Residential and commercial	5,988 (50.0)	8,392 (47.5)	8,786 (48.4)	9,248 (48.9)	13,070 (42.8)
Industrial Fuel	2,116 (17.6)	3,652 (20.7)	3,874 (21.4)	4,263 (22.5)	9,817 (32.2)
Town gas	320 (2.7)	729 (4.1)	907 (5.0)	1,020 (5.4)	1,765 (5.8)
Motor cars	2,660 (21.7)	2,718 (15.4)	2,632 (14.5)	2,765 (14.6)	3,183 (10.4)
Feedstock of chemicals	958 (8.0)	2,171 (12.3)	1,943 (10.7)	1,625 (8.6)	2,683 (8.8)

BLANK

Table XIX-3 Future Energy Supply and Demand program in Japan's Gas Industry

FEEDSTOCK	1973 CONSUMPTION	1973 ENERGY (10^9 kcal)	1973 PERCENT OF TOTAL	1980 CONSUMPTION	1980 ENERGY (10^9 kcal)	1980 PERCENT OF TOTAL	1985 * CONSUMPTION	1985 * ENERGY (10^9 kcal)	1985 * PERCENT OF TOTAL
LNG (10^3 m^3)	2,100	12,000	18%	10,800	67,000	45%	32,300	195,000	65%
Naphtha (10^3 m^3)	2,660	19,000	28	5,000	38,000	25	7,000	49,000	17
Crude oil (10^3 m^3)	460	3,000	4	700	5,000	3	1,400	10,000	3
LPG (10^3 m^3)	780	5,000	7	1,800	12,000	8	2,700	18,000	6
Domestic natural gas and others (10^9 m^3)	1.8	18,000	26	1.8	18,000	12	1.8	18,000	6
Coal (10^3 metric tons)	6,600	11,000	17	6,600	10,000	7	6,000	10,000	3
Total gas energy demand		68,000	100		150,000	100		300,000	100

* These values indicate the most desirable level from the global view of energy conservation and environmental preservation.

Table XIX-4 Japan's Long-Range Energy Supply-Demand Program

JAPANESE FISCAL YEAR ENDING MARCH

	1973	1980	1985	AVERAGE ANNUAL GROWTH (%)
Energy demand without conservation (10^{12} kcal)	3,830*	5,660	7,840	6.2
Conservation rate		6.4%	9.4%	
Energy Demand with conservation (10^{12} kcal)	3,830*	5,300	7,100	5.3

Primary energy		1973 Production	1973 Energy Equivalent (10^{12} kcal)	1973 % of Total	1980 Production	1980 Energy Equivalent (10^{12} kcal)	1980 % of Total	1985 Production	1985 Energy Equivalent (10^{12} kcal)	1985 % of Total	AVERAGE ANNUAL GROWTH (%)
Domestic Energy	Hydro ordinary	21,200 Mw	180	4.6	23,500 Mw	220	4.2	28,300 Mw	260	3.7	3.4
	pumping-up	1,400 Mw			6,800 Mw			14,100 Mw			
	Geothermal	30 Mw	0.6	0.0	300 Mw	6	0.1	2,100 Mw	36	0.5	39.7
	Oil and natural gas	3,700 kcm	35	0.9	6,400 kcm	60	1.2	14,000 kcm	133	1.8	10.8
	Coal	21,680 kt	150	3.8	20,000 kt	134	2.5	20,000 kt	133	1.9	0.8
	Total (A)		370	9.5		440	8.1		570	8.0	3.7
Nuclear power (B)		2,300 Mw	20	0.6	16,600 Mw	230	4.4	49,000 Mw	680	9.6	32.3
(A) + (B)			390	10.1		670	12.5		1,250	17.6	10.2
Imported energy	LNG	5,100 kcm	32	0.8	44,300 kcm	270	5.2	90,400 kcm	560	7.9	27.1
	Coal	58,000 kt	450	11.7	92,000 kt	710	13.4	102,400 kt	800	11.2	4.8
	Oil	318,000 kcm	2,960	77.4	393,000 kcm	3,650	68.9	485,000 kcm	4,490	63.3	3.5
	Total (C)		3,440	89.9		4,630	87.5		5,850	82.4	4.5
(A) + (B) + (C)			3,830	100.0		5,300	100.0		7,100	100.0	5.3
Crude oil equivalent of (A) + (B) + (C)		410 Mcm			560 Mcm			760 Mcm			5.3

Notes:

* Actual consumption

Mw = 10^6 watts
kcm = 10^3 cubic meters
kt = 10^3 metric tons
kcal = 10^3 calories
Mcm = 10^6 cubic meters

7:79

BY THE COMPTROLLER GENERAL

Report To The Congress

OF THE UNITED STATES

Liquefied Energy Gases Safety: Federal Agency Comments

VOLUME 3 OF THREE VOLUMES

UNITED STATES GENERAL ACCOUNTING OFFICE

EMD-78-28

PREFACE

This is Volume 3 of a three-volume report. Volume 1 contains the Executive Summary and the report chapters with conclusions and recommendations. Volume 2 contains the appendixes that support and supplement the findings presented in Volume 1.

In keeping with our policy, the draft of this report was provided for comment to all Federal agencies having responsibility for the matters discussed. This volume contains the formal, written comments from:

--Department of Commerce

--Department of Energy

--Department of State

--Department of Transportation

--Interstate Commerce Commission

--National Transportation Safety Board

Due to the breadth and potential impact of the report, over 50 private companies were also provided with copies of the report chapters in which they were discussed. We received written comments from 34 companies. These are available for review at the U.S. General Accounting Office, 441 G Street, N.W., Washington, D.C.

We agreed with many of the comments and have made appropriate revisions in the final report. We also disagreed with many of the specific comments, which we evaluated at the end of the relevant chapters in Volume 1. In addition, chapter 21 of Volume 1 provides an overview of the most important concerns discussed in the report.

Contents

UNITED STATES DEPARTMENT OF COMMERCE
The Assistant Secretary for Policy
Washington, D.C. 20230

February 14, 1978

Mr. Henry Eschwege, Director
Community and Economic Development
Division
United States General Accounting Office
441 G Street, N.W.
Washington, D.C. 20548

Dear Mr. Eschwege:

Attached are preliminary comments on the General Accounting Office's draft report prepared for the Congress on LNG, LPG and Naptha Safety. While the comments on the report are critical of many of the findings and the structure of the report, the Department of Commerce would be pleased to discuss these comments with the GAO staff and is willing to help in any way to support your efforts in the analysis of this important issue. With additional time to evaluate the rather voluminous report, the Department's comments could have been final and more substantive.

Several agencies of the Department of Commerce commented on various chapters of the report. The Maritime Administration (MarAd), being actively involved in the construction and operation of liquefied natural gas ships, was directed to develop and coordinate the Department of Commerce's response. In addition to MarAd's comments, a review of the draft document was undertaken by the Office of Ocean, Resource and Scientific Policy Coordination (OORSPC), the National Fire Prevention and Control Administration (NFPCA), and the National Oceanic and Atmospheric Administration (NOAA). Where the comments of these organizations have been incorporated in this reply, their abbreviations are noted in parenthesis following the comment.

In our view, this GAO draft report is misleading and should be comprehensively reworked. Although it contains much useful material, it does not present the kind of balanced, objective analysis upon which rational policy can be based. It is in essence a highly imaginative and alarmist compendium of potential disasters, rather than a dispassionate review of their actual probability of occurrence. It ignores in large part the procedures and technology that have been developed as safeguards against the kinds of incidents it describes. It should be reworked if only to place in proper perspective the valuable material that it does contain.

The magnitude of the GAO's comprehensive document, delving into most all aspects of transportation, storage and distribution of liquefied energy gases (LEG) will invite significant comments, debate and challenge from other government agencies and private industry. We assume the

APPENDIX I

opinions of these informed sources will be permitted equal status with this report in order to avoid any acceptance of the erroneous impressions created by the draft document.

The Department's response is divided into two prime categories, (I) Overall Comments and (II) Chapter Comments. A conclusion section (III) completes the response.

Sincerely,

James W. Curlin
Deputy Assistant Secretary for Policy

Enclosure

I. OVERALL COMMENTS

Character of Report

1. The GAO draft report raises some very important questions relative to handling and storage of liquefied energy gases and with some editing and tightening will serve as a very useful reference and source guide for discussion of the safety issues which it raises. (OORSPC)

2. The report, at the same time, suffers from its very compendium-type character especially in its attempt to cover all forms of energy gases, as many safety issues as possible, and in its lack of systematic analytical treatment of each of the issues raised. Many questions are raised that are not answered. An extensive number of recommendations are made without pros and cons being weighed. As a survey of issues, the report is excellent; as a program for action based on reasoned and dispassionate analysis, it is somewhat less useful. (OORSPC)

3. The GAO study lumps together LNG, LPG and naphtha for purposes of this analysis. The validity of such an approach is recognized for the broad study that GAO has executed. However, the properties of each component of LEG may be significantly different and may warrant different research projects, regulations and standards. "Federal, State and Local Regulations" of Chapter 21 recognizes the distinctions in discussing regulations applicable to storage facilities. (NFPCA)

As a result the report often confuses the reader by attempting to deal with LPGs and naphtha, as well as LNG. In some issue areas and chapters the discussion is entirely with reference to LNG (e.g. Chapter 13). Often the reader is not sure until late in the discussion that reference is being made to only one particular LEG. It may have been better if the report had dealt with LNG alone. This is what most people who have not read the report, but who have heard of it assume to be the subject. LNG terminal siting and terminal operations are major public interest questions at the present. Hence, the value of a single focus. (OORSPC)

4. The organization of the report and its reliance on a "topical" structure is also a drawback to readability and a disappointment to those expecting to find a coherent and systematic treatment of LNG or LPG safety issues. A systems breakdown to include liquid gas delivery, transfer (unloading), storage, distribution, along with a discussion of the hazards and risks associated with each system component, a discussion of the empirical and experimental data available on each, and an estimate of ultimate risks would have been more helpful. It is recognized that the survey character of the study makes this more traditional study approach less appropriate, but why choose an order of presentation that starts off with the 1944 Cleveland disaster? One can only assume it is for psychological impact. (OORSPC)

5. While the report on the whole is well written and does a very good job of living up to its promise to keep the technical discussion in terms a layman can understand, it still needs considerable tightening and a single editorial hand. At present it seems fragmented, because of its length and the number of chapters and appendices involved. There is also a good deal of repetition in the device used to restate key facts and data presented earlier in a chapter as "findings" at the end of the chapter. The uncertain use of the "headings" system chosen (in some cases 3rd order heads seem to supersede 2nd order heads) makes for confusing reading at times. (OORSPC)

Tone of the Report

1. On an overall basis the tone of the report gives the reader several erroneous impressions. First, that liquefied gases are the most dangerous of all bulk commodities being transported in bulk today. Second, each accidental spill or discharge will result in a catastrophe. Third, present design, construction and operating regulations are inadequate and are not providing a level of safety judged by the GAO staff as being adequate to the public.

2. It is a well recognized fact that in complex systems such as hazardous material transport and storage, the exposure to the risk of an accident and the possibility

of some form of sabotage exists. However, the potential dangers must always be weighed against the desired benefits attainable through the use of these products. We should never let ourselves reach the point where potential dangers prevent us from functioning in a logical and rational manner, or delude ourselves into thinking that because of the real or unreal potential dangers we would be better off without the use of these energy resources. If the alarmist nature of this draft report is believed by Congress and the American people to be a correct portrayal of the dangers in handling LNG, we are in real danger that the above attitudes will become prevelant. For the good of the country this report must be carefully examined from an unbiased view in order that fear will not sweep us away, to the detriment of our energy needs.

Since the GAO draft report is alarmist to the extreme, it is entirely possible that those valid conclusions and recommendations in the report will be overlooked if the overall credibility of the report, as a whole, is questioned. It is our belief that this is a distinct possibility.

3. It is illogical to believe that government officials from the many agencies that are involved in regulating liquefied energy gases would permit participating companies to engage in unsafe operating procedures that would prove ultimately inadequate and unsafe to the public. However, this impression is given by the draft report.

4. A noted serious shortcoming of the draft report is the lack of statistical information on marine, trucking or rail performance regarding the transportation, storage and distribution of LEG. The historical experience obtained to date, if presented, would serve to document the safety record which has been attained in recent years with respect to handling dangerous commodities. Vast amounts of hazardous materials have been moved safely for years, yet the draft report neglects to submit this data for the consideration of Congress. Such information would tend to negate the false impression that the contingent government agencies are not fully concerned with the safe handling of liquefied energy gases.

5. The tone of the report is an over-reaction to the hazards of LEG with an overbearing emphasis placed upon catastrophic scenarios. These scenarios rely primarily

APPENDIX I

on hypothetical situation and ignore the vast amount of actual experience in transporting or storing dangerous cargoes. The catastrophic scenarios are, in turn, used to derive findings that safety standards, regulations, practices, etc., are deficient and incapable of providing adequate safety measures.

6. The failure to note any positive developments or improvements in LNG and LPG safety over the years, e.g., cryogenic technology, metallurgy, storage techniques, tanker construction, warning and navigation systems, is a serious omission. No mention is made of the very impressive safety record of LNG industries here and abroad since LNG has been transported internationally in quantity and since some 75 peak shaving plants here in the U.S. have been in operation. The failure to say anything on the positive side contributes to the impression that the report suffers from a "worst case" syndrome; or worse, that it is biased; or worse yet that it engages in "scaremongering." The problem is that this impression, false though it may be, diverts attention from the many very important (and valid) points made, e.g., the need for increased regulatory attention to LNG and LPG safety issues and the need for a more focused and early-results oriented research effort in this field. (OOPSPC)

Sabotage

1. The detailed descriptive nature of the chapter on sabotage is unnecessary, potentially dangerous and should be omitted in its entirety from the final report in its present form. We strongly urge the GAO to carefully consider the type of information presented and its method of presentation before including this chapter in the final text. It is entirely possible, in our opinion, that the extensive sabotage details on weapons, ammunition, methods of sabotage, etc., coupled with television exposure of a sensational variety, could lead to the very sort of situation the report hopes to prevent. Irrational groups and persons who have absolutely no conception of LEG will seize upon the possibility that hijacking an LNG truck, for instance, could serve as a means of attaining an objective, in a manner similar to the rash of plane hijackings which publicity had a role in expanding.

2. The report is literally inundated with the concept of sabotage to the point where all other safety aspects are relegated a back seat. We most seriously suggest that a clear look be given at the role of sabotage in the report, and while it may be included as a general discussion, its dominant position should be reduced.

3. The section on sabotage presents a very provocative discussion. Findings that a determined group of terrorists could penetrate an LEG facility are not surprising. In fact, based upon our experience, the same finding would hold true for marine, truck or rail terminals handling chlorine, phosphorus, vinyl chloride, anhydrous ammonia, and other products requiring maximum protective or significant preventive measures from a safety standpoint. The reason these terminals could oe penetrated is relatively fundamental, namely, a "peacetime" environment is deemed to exist throughout the U.S.

4. It would appear that the GAO would desire to install a wartime security system in order to achieve an acceptable level of safety. Among the numerous recommendations put forth in the report is that the Secretary of Transportation "systematically determine the critical vulnerabilities to

APPENDIX I

sabotage of ships carrying hazardous materials in U.S. ports and require appropriate preventive and mitigating measures." Does this imply that military ships be used to escort LNG vessels in coastal areas, or that commercial carriers should be outfitted with degaussing systems to achieve an acceptable strategy to avoiding sabotage? While it is important to strive to improve safe operating conditions, it would be inappropriate, during peacetime, to establish a system of martial law capable of thwarting all potential attacks during the transportation, storage and distribution of these commodities.

5. Assuming that weapons are available, and sabotage is attempted at a facility, if shots are fired and storage tanks punctured, this still does not necessarily mean that a massive rupture or more important an explosion would take place. To support this point, actual experience can be examined.

In November 1974, a ship collision took place at the entrance of Tokyo Bay involving the PACIFIC ARES and the LPG tanker YOYU MARU NO. 10. The YUYO MARU reportedly was loaded with 20,202 tons of propane, 6,442 tons of butane and 30,831 tons of naphtha. Although some 30 lives were lost, primarily because of the failure of the PACIFIC ARES crew to abandon ship immediately, the YUYO MARU continued to burn for some three weeks. Ultimately, the decision was made to sink the ship. Because of the compartmentation and safety features built into the ship, it took four destroyers, four frigates, four antisubmarine frigates and finally a submarine to sink the vessel. Reportedly, they fired 857 shells, 12 rockets, depth charges and four torpedoes. Since the GAO study team visited Japan it is somewhat surprising that the difficult task of sinking a large, approximately 50,000 cubic meter LPG vessel was not included in the report. Here, the initial fire and probably the loss of 29 lives from the PACIFIC ARES, was due to the naphtha and not LPG. The report tends to concentrate on theoretical situations, rather than mentioning actual occurrences.

The points to be learned from this occurrence was that: (1) there were no explosions with the arsenal of weapons used, and (2) the compartmentation and safety features of LPG vessels are greater than GAO realized. A major theme running throughout the report is that liquefied energy gases present catastrophic explosion possibilities through sabotage. The YUYO MARU showed it is very difficult to cause an explosion. Surely a terrorist group would not be allowed the time and effort the Japanese spent to sink the vessel.

Since LNG vessels are viewed by the report as significantly less vulnerable than LPG vessels, the possibility of the effective use of sabotage on LNG vessels resulting in an catastrophic occurrence is even less remote.

Liability and Compensation

1. The conclusions and recommendations with respect to statements requiring that the companies involved in supplying LNG and LPG be liable to the full extent of the assets of their parent corporations would be totally unacceptable to any corporate board of directors. If the liability conditions suggested by the GAO were to be imposed on the industry, the effect would surely be the total withdrawal and disinvolvement of private enterprise with LEG projects or any project that has unlimited risk. No private corporation could assume that type of exposure in any one element of its overall business activities. Such a requirement would have the same effect on the industry as the Cleveland disaster in 1944, which as the report indicates virtually halted the use of LNG for 20-years.

2. It is very important to offer a reasonable level of compensation for accidents to injured parties, especially private citizens who suffer losses as an extension of a major mishap. It would seem reasonable that beyond some acceptable level of private financial responsibility that the Federal Government would have to assume the role of ensuring that individuals and businesses are compensated for offsite damages. It would also be impractical to suggest that the facility operators be released from total financial responsibility, but there should be a ceiling established which places a limit on the corporate exposure; a figure that would permit activities to proceed without adding a prohibitive insurance expense. The cost of maintaining a specified level of liability insurance is a charge that the consumer will have to ultimately bear.

3. The extensive treatment given to questions of liability and compensation detract from the main thrust of the report -- safety issues, risk analysis and the adequacy of current regulatory arrangements in this area. Liability matters could well be the subject of a separate report. It is almost disingenuous to justify their inclusion in this report on the basis that without extensive liability potential, LNG companies may not be adequately motivated to pursue all possible safety measures. (OORSPC)

GAO's Conclusions

1. It is stated in the introduction to the report that the Federal Government has not acquired sufficient knowledge or competence regarding LEG, and therefore, because of this lack of information the Government has been unable to act prudently in protecting the public's health and safety. Based upon the experience of this Department and its relations with other government organizations in shipping and shipbuilding matters the GAO's statement is improper. The Maritime Administration's activities require our constant association with the Coast Guard, both in Washington and in field assignments. It has been our experience that the Coast Guard follows very conservative procedures to ensure safety in the construction and operation of American flag LNG ships. If some uncertainty exists, the authorized practices and margins of safety will usually prove to be in excess of what is required to provide adequate protection of life at sea and the resources in our nation's harbors.

2. The report's conclusions are slanted with a continual obsession for using hypothetical situations. Many "ifs," "probably," "might" and "could lead to" statements are considered in order to develop catastrophic scenarios the research staff wishes to entertain. For example, the dikes surrounding LEG facilities are critized as being capable of containing only one half of the fluid "if" a tank should tip over, or "if" its walls should rupture. No statistics are provided or available to verify the accuracy of this statement.

3. In the transport system it is argued that "if" an LNG ship is struck by a sufficiently large vessel going fast enough, a very large spill could result. It is questioned whether or not the GAO has made studies to determine how large the ship would have to be, and how fast it would have to be moving at the time of the collision to cause the alleged very large spill. What constitutes a very large spill? No figures are presented.

4. With respect to transportation on land, the report indicates that because truck trailers carrying LNG have a higher center of gravity than other tank trucks, they are susceptible to rolling over and resulting in explosions. It would have perhaps proved interesting if GAO would have fully documented the number of instances when explosions have occurred. The report in Appendix IX - I - "Some LNG Truck Accidents," provides meaningful data on experiences to date, which seems to contradict GAO's conclusion in this area. In the twelve accidents documented, including six rollovers of the trailer and one with a roll down an eighty foot embankment, no fires or explosions resulted. No catastrophe. In fact, the record seems to indicate that present construction of trailers is rather good and seems sufficient for the service.

5. Truckers are critized some for not taking precautions to prevent hijackings, yet no information with respect to how many hijackings, if any, have occurred is furnished by the GAO.

6. Trucking accidents, such as supposing that the vehicle rams through a guard rail and splits open on city streets, are mentioned. The disaster occurring from this is described as one in which the sewers, tunnels, subways, etc., would be filled with gas vaporizing and mixing with air in flammable proportions. No actual occurrences are referenced. It is our opinion that before reaching these conclusions, the GAO should have statistics available to support the ideas and losses suggested.

APPENDIX I

7. These types of fabricated conclusions, along with inappropriate analogies, such as, comparing World War II bombing raids with potential LEG accidents, indicate clearly that the draft report lacks a logical and documented foundation on which to build its conclusions.

LNG Shipping

1. It is particularly pleasing to find that the report acknowledges that LNG ships are the least vulnerable segment of all the systems involved in LNG transportation and storage. In view of the almost continuous flow of negative statements and lack of a presentation of the benefits accruing from LNG, it is especially meaningful to receive some token of praise from the GAO researchers and their independent consultants.

2. LNG transportation is still in its infancy. Containment design, methods of joining dissimilar metals, special cryogenic steels, electrical control circuitry and equipment improvements are constantly being developed as this segment of the shipbuilding market matures. The Maritime Administration is proud of the role it has played in providing financial and technical assistance enabling American shipbuilders to participate in the development of the import market for LNG. Three American shipbuilders have built or are constructing sixteen 125,000 cubic meter class ships and a fourth shipyard holds a contract to construct two other vessels.

3. It should be emphasized that before a shipyard embarks on a production schedule, detailed plans and specifications, welding procedures and essentially all elements which affect the ships' structural strength and safety are reviewed by or must be in compliance with the regulations of government agencies including the U.S. Coast Guard, the Federal Communications Commission, the U.S. Department of Health, Education, and Welfare and the Treasury Department's Bureau of Customs. Requirements of the American

Bureau of Shipping must also be adhered to. Inspection and enforcement of quality control is maintained throughout the construction period by the Federal Government, the classification body and the owner's representatives.

4. American flag vessels are built in accordance with numerous marine construction codes prepared and tested by professional engineering organizations in addition to the Coast Guard regulations. The Maritime Administration has every reason to believe that our ships are built to the highest standards in the world and that these proven methods applied to LNG ship construction will meet the scrutiny of any unbiased organization studying the marine mode of transportation. It is recognized that the multitude of regulations which American shipbuilders must comply with does add significantly to the construction costs. However, our country is provided with a fleet of efficient and safe vessels directly under the control of U.S. corporations. These American flag vessels will be required to be maintained in full compliance with the operating regulations of the Coast Guard and all other pertinent port authorities throughout their economic lifetime.

5. The delegation of surveillance and regulating authority and the coordination of these responsibilities is producing a sound mode of transportation which the GAO apparently recognizes. There is no reason to believe that similar responsible criteria are not or cannot be applied to shoreside facilities to ensure the highest level of safety and protection in the entire process of storing and distributing energy from liquefied energy gases to American industries and to the homes of our citizens.

GAO's Recommendations

1. The draft report gives no indication what the additional costs will be for LNG, facilities, transport modes, or federal and state government operations if recommendations made by the GAO are implemented.

2. The GAO recommends that the Secretary of Energy and the Chairman, Federal Energy Regulatory Commission (FERC) "reconsider their possible authority to assert jurisdiction over LNG companies." It is our understanding that FERC is no longer responsible for LNG import projects. The Energy Regulatory Administration, in the Department of Energy, has the responsibility.

We strongly oppose giving any agency of the Department of Energy jurisdiction over LNG tanker owners or operators. The Department of Energy has no maritime expertise. Both Coast Guard and the Maritime Administration do, and therefore, these agencies should continue to have jurisdiction in matters related to the waterborne transport of liquefied energy gases.

3. The creation of an overall energy safety regulatory agency may have some merit. However, there does not appear to be evidence that support has been rallied or even if the case for such an agency has been made.

Detailed comments pertaining to specific chapters of the report are provided in the following section.

II. CHAPTER COMMENTS

Chapter 2 - LEG Primer

1. This chapter provides a brief overview of the characteristics and history of liquefied energy gases with the emphasis being placed on LPG and LNG. The chapter would be substantially reinfc[illegible]ed if statistics were given on commodity movement of not or[illegible] LNG, LPG and n[illegible]htha, but also gasoline and other hazardous commodities; such as, chlorine and phosphorus. The latter would serve to place in better perspective the daily mover[illegible]nts of hazardous materials, as opposed to LEG.

2. Information on the exports and imports of major hazardous chemicals for 1976 compiled by the Bureau of Census shows that slightly more than 1,000,000 tons of Class 1 and 2 chemicals (products which require maximum and significant preventive measures, respectively) were imported to or exported from the United States. Actual movement within the U.S. for 1976 was greater than this amount since the statistics do not show [illegible]ducts produced and consumed within the country. Neverthe-[illegible] the movement of chemicals compares with the import/export [illegible]75,000 tons of gasoline, 970,000 tons of propane and [illegible]000 tons of naphtha. Propane would be considered a [illegible] 2 hazard, whereas, gasoline and naphtha are Class 3 [illegible]uire a degree of containment) hazards.

While the GAO draft expresses concern about LNG and LPG, there is as great and possibly greater movement of equally hazardous materials being transported on a normal and routine basis. The significant point is that large quantities of hazardous materials are moved dail[illegible] [illegible] and out of the country on a relatively safe basis; hence, [illegible]so-called dangers of LNG and LPG must be placed in [illegible]spective with the movement of these other products.

3. The report indicates there are approximately 16,300 LPG rail tank cars and 25,000 LPG transport trucks. Statistics on the number of gasoline tru ks, chemical trucks, barges and railcars needs to be presented again to place the movement of LEG in perspective.

4. Thus far, there have been over 2,700 voyages completed by LNG tankers with a perfect safety record. The report should also present statistical information on the number

of actual shipments completed by LNG trucks. Statistics documenting actual LNG service performance have not been assembled and would be most revealing.

5. In discussing Japan's dependence on imported LNG and Europe's importation projects since 1964, some mention of the safety record would be appropriate. In Japan and Europe receiving terminals, revaporization plants and storage facilities are generally located in populated or industrially developed areas. For example, Yokohoma, Japan, a city with a population of about 2.6 million, has received approximately 275 shiploads of LNG from Kenai, Alaska, since 1969 with a perfect safety record.

Chapter 3 - Cleveland, 1944

1. Why start out the report with this Chapter? Why not incorporate the Cleveland disaster in Chapter 11 - "Large Urban Fires"? The point will still be made that a major uncontrolled spill can bring catastrophic consequenses. (OORSPC)

2. The narrative of the 1944 collapse of a LNG storage tank and the resultant fire and destruction is most illustrative. However, this industrial accident, which took place 34 years ago, must be placed in the proper perspective. Technology of construction safety and cryogenics have made enormous advances over the past 34 years as one would expect in a manner similar to other technologies; such as, medical care, aircraft and space flight.

3. The fact that the GAO had to go back 34 years to find a major LEG storage facility accident points out the recent safety record of LEG facilities resulting from the enormous advances in cryogenic technology, LEG construction, safety and reliability.

4. Although alluded to in the narrative, the draft report fails to stress the seriousness of the oversights that contributed to the industrial accident in the first place. These oversights could not happen with today's technology.

strict construction safety codes and sophisticated and redundant monitoring equipment. For example, any facility would be immediately shut down if frost developed on the outer tank walls, and the defect corrected.

Chapter 5 - Vulnerability of LEG Facilities to Sabotage

1. This chapter, by the way it is written, has as its obvious result, the unnecessary arousel of fear and worry about the transportation and storage of liquefied energy gases. If sabotage is a rational design consideration, the facility design and safety of other dangerous material manufacturing and storage sites must be compared to the LEG sites as a means of assessing the danger. For example, how does the plant design and security compare with petroleum refineries, chemical plants, natural gas pipelines and storage tanks and chlorine barge systems? If such a total comparison is not made, one can only conclude that the authors want to arouse the fears of the readers that these are the only type facilities that are so dangerous that the subject need be considered.

2. As noted in the overall comments, we strongly urge that this chapter either be omitted in its entirety from the final report or that it be rigorously rewritten. If rewritten, it should include only a general discussion of the vulnerability of LEG systems, plants and storage facilities to sabotage, without including the specifics on weapons and explosives, their damage capabilities and methods of attack.

3. The rigorous coverage of weapons, explosives and their damage capabilities to LEG transportation systems and storage facilities is something that we would expect to find in military or revolutionary publications and has no place in a GAO study of LEG safety. This type of information could provide the stimulus for radical groups to blackmail or attack existing or planned LEG facilities.

4. Assuming that weapons are available, shots fired and storage tanks punctured, there is no evidence in the report which clearly confirms that a massive rupture or explosion would take place.

APPENDIX I

5. We recognize that improvements can be made in security, however, even where elaborate security measures are in force, such as airports where passengers are screened or searched, airplane hijackings by single individuals or small groups still continue to take place.

Chapter 8 - Ship Design, Personnel and Operation

A. Ship Design

1. The GAO discussion on LNG tank ruptures due to overpressure leaves the impression that a tank filled with LNG would split open with the slightest increase in pressure. This is not so. The settings of relief valves, as is the pressure in the tanks, is quite low. Calculations indicate that LNG tanks will not require venting from boil-off when in port. Even where the safety valves were locked closed, a tank would not rupture anywhere from a few days to a couple of weeks depending on the type of containment system. The maximum time limit for not venting in port for each type of containment system has been established by the Coast Guard. As noted in the report, a 125,000 cubic meter LNG vessel can be unloaded in less than fifteen hours.

2. An important factor in assuring the safety and reliability of LNG tankers and equipment is the application of an equipment test and trial under actual LNG operating conditions. The Society of Naval Architects and Marine Engineers has recently published T&R Bulletin No. 5-2, "Gas Trials Guide for LNG Vessels," which provides definitive information on test procedures to prove the safe and adequate operation of all systems and their component parts involved with or pertaining to the shipboard storage and transfer of LNG. U.S. flag LNG vessels are using this guide.

B. Personnel

1. The draft report stresses the need for formal training of all shipboard personnel having LEG responsibilities and in this we concur. Eight criteria for training are given. While the majority of the criteria are acceptable and reasonable, we find that the references to "simulator" and

"simulated environment" to be vague with regard to meaning. Simulators can be extremely costly, both to create and to operate. Further, simulators, by their nature as we know them at present, operate in real time with direct man-machine interface resulting in low training capacity. That is, a simulator can generally be manned only by the number of persons actually used in the operation and the simulation takes as long as the real time incident. We can agree that simulators should be considered in devising effective training systems, but their high cost and low throughput capacity must be measured against the margin of incremental training effectiveness. Simulators are currently a glamor item in training. There is a need for extremely careful evaluation prior to committing substantial funds. It is too easy to recommend use of simulators without adequate study of cost effectiveness.

2. The training criteria generally are in conformance with the current Inter-Governmental Maritime Consultative Organization (IMCO) draft, "Resolution on Training and Qualifications of Masters, Officers and Crews of Ships Carrying Liquefied Gases in Bulk," except in the area of simulators. Consideration is being given by the U.S. delegation to IMCO that this resolution be converted to mandatory form and become a requirement as part of a convention. This training procedure will then be the basis for regulations on training of LNG and LPG ship crews.

C. <u>Ship Operations</u>

1. The thrust of the GAO report on directives is that hard and fast safety rules need to be established and that these rules must be applied rigidly in all instances. We disagree. We believe that a more flexible approach with the Coast Guard's Captain of the Port having the final decision based on regulations, guidelines, experience and the events at hand is proper and has proven effective in the past.

2. The report infers that the Captain of the Port would be swayed from the safe course of action by the consideration of financial interests of the owner of a vessel. We do not know of any instance wherein the safety of a ship has been compromised because of the owner's desire to meet a schedule. The report states that a Coast Guard officer working with

vessel movements in the Boston Harbor indicated that the Coast Guard considers the cost to shipowners when deciding whether to hold up a ship's entry. There are many items not of major safety significance that may hold up a ship's entry. It would be useful to have the report state what the instance was where the ship's safety was compromised by considerations of cost to the owners.

3. The report discusses an instance wherein one LEG ship had entered the harbor and had reached a point where it had been predetermined that even with a loss of visibility a ship should proceed to its berth. This is a judgment matter in which the dangers of attempting to have the ship turn back to sea may be greater than the dangers encountered in proceeding to berth. This is an example of why a knowledgeable Captain of the Port should be able to make a decision, rather than rely upon rigid regulations.

4. The extent of control of air traffic alluded to in the report is excessive. The fact that one aircraft crashed in making a landing should not lead to the conclusion that it can be expected that additional crashes will happen farther from the airport in the ship's channel.

5. The analysis of the airport situation regarding location of LEG facilities does not sufficiently indicate whether the Boston example was just that, an example, or the result of a more comprehensive analysis of LEG siting problems. This should be clarified and if the Logan Airport case is only an example, perhaps more potential conflicts in the other LEG proposed sites should be presented. (NOAA)

6. We are concerned with the recommendation that the Coast Guard should: "require that the deck officer in charge of cargo operations aboard an LEG ship have no other duties in handling the vessel." A non-watchstanding Chief Mate is specified as cargo officer on all currently certificated U.S. flag LNG vessels. This should, in our opinion, satisfy this recommendation even though the Chief Mate may have other functions, as part of his responsibility, occurring at times when cargo operations are underway. In our view the narrow wording of the recommendation is not justified since it can be interpreted to mean no other duties whatsoever regardless

of whether cargo operations are being undertaken. It should be understood that the cargo officer, who is part of the ship's crew, can have other duties which do not interfere with his primary responsibility.

Chapter 11 - Large Urban Fires

1. This chapter sets forth general findings on the nature of fires caused by LEG incidents. We agree with the fundamental concept that such fires may have many ignition points far from the urban facility or location of the spill. Although we support the basic findings of the chapter, we do not believe that its analysis extends far enough. For example, the chapter should consider the present ability of most emergency services to plan and to respond to such incidents. Studies should be initiated for both the present situation and alternative approaches in the event of LEG fires. One recommendation of the studies may be that the industry or government should be required to make resources and training available to all energy services which could be reasonably affected by the storage, transportation or use of LEG. (NFPCA)

Chapter 12 - Liability and Compensation

1. The draft report notes that insurance clubs limit the amount of protection and indemnity coverage available for a U.S. flag ship to the value of the hull while imposing no limit for foreign-flag vessels. We believe a technical error has been made inasmuch as the limit is $200 million for U.S. flag ships without regard to the value of the hull.

2. It is suggested by the draft report that this limit on U.S. coverage reflects the U.S. statutory limitation on the liability of shipowners and charters. However, many of the prominent maritime nations have statutory limitations on the liability of shipowners and charters. Moreover, two international limitation of liability conventions are currently in force and a third was adopted in 1976, although it is not yet in force.

3. The report fails to discuss the generally recognized fact that U.S. courts, in many cases, will not enforce the U.S. limitation of liability. On the other hand, it is generally accepted in this area of the law that foreign courts do, in most cases, enforce limitation statutes.

4. The draft report suggests that the disparity between shipowner's statutory liability and available hull insurance may encourage shipowners to keep ships in service that are of questionable safety. The Department of Commerce has no information to indicate such a conclusion. Further, since existing LNG vessels are relatively new and modern, the relevance of this suggestion is not clear.

Chapter 14 - Detonation and Flame Propagation Research

1. This chapter summarizes the research on vapor clouds and flame propogation. We believe that the summary is thorough and may be of value even to members of the public who are not experts in the field. (NFPCA)

2. The critique of ERDA's LEG research activities are particularly relevant and the GAO suggestions are valid. GAO could improve upon the report by carrying this analysis one step further. The specific suggestion we would like to make regarding the type of research ERDA should do (in conjunction with those studies recommended by GAO) is that ERDA begin a research program designed not only to describe and predict detonation and flame propagation, but also to determine what remedial measures can best be used to fight such conflagrations. That is, research not only how flame spill is likely to behave, but also research what to do about it. (NOAA)

3. We agree there is a need for intensified and expedited research and testing. It is not clear, however, why the ERDA program cannot be modified to accomplish this. (OORSPC)

4. We do not agree with the lack of need for data collection based on large experimental LNG spills. This may be the only good way to test the models now being used or proposed (i.e., dispersion models.) (OORSPC)

5. Chapters 13 and 14 (and Chapters 7 and 8) contain much detailed scientific information. Perhaps the report could be more effective if these data were placed in their entirety in an appendix. The major points extracted and placed in these chapters would benefit decisionmakers who may not read through the complex scientific study results to get to the analytical results. (NOAA)

Chapter 18 - Japan LNG Use

1. The analysis of Japanese LEG operations is excellent. We note, however, that only findings and conclusions were made. We suggest that the Japanese experience be further analyzed and recommendations be made based upon this. The coverage of Japanese experience is incomplete without recommendations that would enhance the treatment of LEG activities in the United States. (NOAA)

Chapter 21 - Overall Conclusions

1. In general, many of the conclusions reached in the GAO draft report are not substantiated by the text of the report. Conclusions not substantiated by fact or scientific reasoning should be eliminated.

2. We strongly believe that both the benefits and hazards associated with LEG should be discussed in detail. However, one without the other does not facilitate the making of proper or beneficial decisions. In its entirety, the GAO draft report discusses, within the framework of catastrophe scenarios, the apparent dangers associated with LEG. Nowhere in the report is there discussed the long safety record of LEG or the benefits that will occur through the continued safe import, transportation, storage and distribution of LEG. This is a major shortcoming of the report.

3. The report states "... because many large LEG tanks with small safety margins will be impacted by winds, floods, or earthquakes greater than those they are required to withstand, it is likely that some of them will fail; probably by turning over on their side, immediately spilling all of their contents."

This appears to be an overstatement of the hazard. Are full tanks as likely to overturn as empty tanks? In order that this statement be substantiated, it is recommended that examples be used whereby similar existing storage tanks, such as petroleum, chemical, crude oil, etc., have failed under these conditions, spilling all of their contents.

4. The methodology used by GAO to calculate overflows from dikes should be fully described. It is important to verify this methodology experimentally, before asserting exactly what will be the magnitude of an overflow. The likelihood of massive failure or collapse should also be estimated.

The report fails to discuss or scrutinize the construction and capacity of currently planned dikes for new LEG storage facilities. These dikes will be capable of containing a volume greater than 100 percent of the capacity of the storage tanks they will surround.

5. The conclusions on LNG ship transport fail to take into consideration the actual safety record of LNG vessel transportation worldwide. There have been over 2,700 LNG voyages completed with a perfect safety record. LNG vessels have the most modern, sophisticated navigation and collision avoidance equipment available today. Responsible authorities worldwide have developed safety rules intended to insure that the LNG vessels are not involved in collisions.

6. The draft report states that "no specific plans or equipment exist to cope with a major LEG spill, or to partially offload and thus lighten an LEG ship that has gone hard aground in inland water." The Marine Board, under joint sponsorship of the Maritime Administration, the Department of the Navy and U.S. Coast Guard is currently investigating this subject.

7. The GAO staff appears to disregard the validity of existing small scale experimental test results. On the other hand, they state DOE's plans for large expenditures to create facilities for very large experimental spills is not an appropriate way to spend LNG safety research funds. This inconsistency should be corrected. Either large scale tests must be performed, or small scale tests must be accepted as being valid.

8. In describing Japanese LNG storage areas, the report infers that vertical reinforced concrete dikes are superior to sloped earthen dikes frequently used in the United States. However, in another section of the report it was implied that sloped dikes offer superior resistance to sabotage. Such inconsistencies should be resolved.

9. The report states that the Japanese believe that inground tanks are intrinsically safer than above ground systems. What evidence of this exists? Have any inground tanks been subject to flooding or earthquakes? The conclusion that LEG safety facilities should be inground may be premature.

Chapter 22 - Recommendations

1. The GAO draft report recommends that the Secretary of Transportation enforce numerous security measures to protect LEG facilities against intrusion. It is suggested that the final GAO recommendations for the LNG/LPG industry be expanded to apply to the entire U.S. chemical/petroleum industry. It makes little sense to propose very strict requirements for one segment of the U.S. industry and ignore the 1,000,000 ton (plus) of equally hazardous materials going in and our of the United States, plus the large amounts moving domestically.

2. The GAO recommends that the Commandant of the U.S. Coast Guard "require calculations on collision resistance for all vessels carrying hazardous cargoes." This requirement appears premature at this time. Presently, there are no requirements or criteria for determining what resistance is needed. In addition, the assumptions concerning the structural configuration, speed, angle of incidence, and a number of other factors make such calculations largely on academic exercise. We would, however, support the need for other work in the area of collision resistance.

3. The GAO recommends that the Commandant of the U.S. Coast Guard "require precision position fixing equipment, bridge control of main engine, and collision avoidance systems as a means of improving the maneuverability of gas carriers, many of which already have this kind of equipment." We fully

agree. MarAd has been leading in this area for a number of years. All LNG vessels built under MarAd's aid programs have or will have, when constructed, this equipment on board.

4. The GAO recommends improved training for LEG personnel. The report notes that human error is the major contributing factor in 85 percent of all marine casualities and operating problems. This would also hold true for truck, rail and terminal casualities regardless of industry. More rules are not the sole path to safety as the majority of accidents that take place have already violated existing rules. Therefore, the GAO recommendations for improved training can be endorsed.

5. The report recommends that the Commandant of the Coast Guard "require pressure-activated switches on LNG ships entering U.S. waters that automatically shut off relevant equipment in case there is too high a differential pressure between the cargo tanks and the atmosphere or between the cargo holds and the atmosphere." We recommend that this safety device also be included on LPG ships.

6. The GAO recommends that Congress amend the 1851 Charter Act limiting the liability of shipowners and bareboat charters of ships by substantially raising the statutory limit for vessels carrying hazardous materials. The United States participated in the 1976 international conference which adopted the new Convention of Maritime Limitation of Liability. The United States, in that conference, supported new monetary limits which would in many cases result in very substantial increases over the limits that would result from application of the 1851 statute.

Presumably, there would be no objection to substantial limitation increases in line with the availability of commercial insurance at a cost which would not be unacceptable from a business point of view. Any proposed legislation should be consistent with U.S. efforts in international law to develop a uniform approach to liability for hazardous materials. In this regard, the IMCO Legal Committee has given some preliminary consideration to the question of how to treat hazardous materials relative to the concept of limitation of liability. Overall, as far as the recommendations for legislative proposals are concerned, they would, of course, all require executive branch review and decision prior to this Department taking any position on them.

7. The GAO recommends that Congress pass legislation that would "allow injured parties in a hazardous material accident to sue individually or as a class, for all damages beyond those covered by insurance and the Fund, all of the companies in the corporate chain." The Department of Commerce strongly opposes this GAO recommendation as noted in the overall comments.

III. CONCLUSION

1. Based upon the nature of this Department's comments it should be evident that we have serious reservations on the report. These reservations have necessitated the length and detail of our response.

2. Liquefied natural gas and liquefied petroleum gas are hazardous commodities that require safe handling and storage. In fact, the high energy content and clean burning properties of these fuels are the exact reasons for the growing demand by U.S. consumers for such energy sources to support industrial growth and employment for workers, heating and lighting for homes and families, and all the other uses that collectively keep this nation moving forward.

3. The overwhelming incontrovertible evidence is that the United States needs to continue to develop its capacity to import LEG in order to supply our nation's gaseous energy requirements in the future decades. Without the projects and the facilities which are currently in use and being developed to meet the demand for our nation's energy needs time will quickly start to work against the establishment of properly planning for the required facilities, located in isolated areas where the impact of an accident or act of sabotage would have minimal effect on lives and offsite property. The long range planning, regulatory action, and financial commitments to import LNG to the U.S. presently requires many years of effort. These undertakings should not be curtailed because of generalized and erroneous claims of potentially massive losses allegedly attributed to unsafe transportation and storage systems and the performance of federal agencies.

4. Finally, we believe that the overall safety record of the U.S. LNG/LPG industries has been good. Certainly the number of annual fatalities is well below the 50,000 deaths cited by the GAO draft report for automobiles. While

improvements in safety may be needed in certain areas, the GAO report does not document that public safety has been compromised. In fact, the LNG safety record has been virtually perfect and thus we must conclude that the tone of the GAO report is highly misleading.

Department of Energy
Washington, D.C. 20545

MAR 8 1978

Mr. Morte Canfield, Jr., Director
Energy and Minerals Division
U. S. General Accounting Office
Washington, D. C. 20548

Dear Mr. Canfield:

We appreciate the opportunity to review and comment on your draft report entitled "Liquified Energy Gases Safety." We have reviewed the draft with members of your staff and we understand that some changes and clarifications are being made.

We generally agree with the technical content of the suggested research tasks and note that most portions are well written and finely edited. However, we believe that the time and cost estimates developed by GAO are optimistic. Also, we assume that the suggested program is not meant to be inclusive of all research and development necessary as it did not cover work such as further analyses of existing models, development of a suitable facility, conducting many small scale tests (5-100^{3}m) prior to larger scale spill tests, detailed plans including complete procurement actions and the analyses of present release prevention and control mechanisms, and the investigation of possible additional mechanisms or procedures.

Also, we believe that our present liquid energy gases safety plans as contained in our report "An Approach to LNG Safety and Environmental Control Research" contains work elements which, if completed, would answer most existing LNG safety questions.

The report also states that the Department of Energy (DOE) should undertake an effort to establish safety standards for LNG facilities. Our offices of Natural Gas Regulations, Oil and Gas Policy, and Policy and Program Evaluation are currently undertaking a joint effort in the area of safety and siting of LNG import facilities. These offices are developing a Programmatic Environmental Impact Statement for imported LNG which will address many of the same issues raised in the report. It is expected that this effort will be completed this year as an element of the overall development of our LNG import policy.

We note that GAO recommends that the Congress create a new agency to handle all energy health and safety regulations and that the agency could be completely independent of the DOE or included in DOE with strong statutory provisions to ensure its isolation. We do not believe

APPENDIX II

that the report substantiates or supports the need for such a recommendation and, in our opinion, it is inappropriate in view of the recent establishment of the DOE.

Enclosed are more specific comments on various chapters of the report. The comments pertaining to the content of Chapter 15, "Federal Power Commission," have been grouped into six general categories and page numbers cited for ease in identification. The comments on Chapter 15 were prepared by staff and have not been reviewed or approved by the Federal Energy Regulatory Commission and the comments should not be construed as representative of the Commission.

Sincerely,

Fred L. Hiser

Fred L. Hiser, Director
Division of GAO Liaison

Enclosure:
As stated

COMMENTS ON GAO DRAFT REPORT

"LIQUIFIED ENERGY GASES SAFETY"

CHAPTER 1

Page 1, para. 1: "Naptha . . . much less dangerous material (than) LNG and LPG."

It is foreseeable that each of these commodities will be most hazardous under a given set of circumstances. The GAO should stipulate and document the information which permits them to reach this conclusion.

CHAPTER 2

Page 3, para. 1: "Both LPG and LNG clouds can explode in confined spaces."

A reference giving data to support this conclusion should be provided to the readers. Is any particular geometry or configuration assumed?

Page 9, para. 1: "The liquid vapor ignited . . . "

A more correct statement would be "Vapor from the spilled liquid ignited . . ."

CHAPTER 5

General: We believe that this chapter had too much technical weapons information that has little to do with the security issue. It would be sufficient to state that minimum security standards should be established at LNG sites.

Page 16, para 1: ". . . was enough air to dilute the rich vapor to the flash point."

The statement is not technically correct; we suggest that "flash point" be replaced with "flammable range."

CHAPTER 7

Page 24, NOTE:

It is not clear why the spill volume percent from the Philadelphia tank was exluded from computing the average percent spill. This should be documented with a reference available in the public domain.

General: Concerning LNG flow over containment dikes, remedies to this problem, including suggested design changes, should be spelled out.

CHAPTER 8

Page 11, para. 3: "A minor spill can escalate to a major spill through failure to take prompt corrective action."

This point has been recognized and properly identified in the DOE assessment. Negotiations to initiate a project on this subject are presently underway. Significant results are expected by December 1978.

Page 41, para. 3:
Same response as above

CHAPTER 11

General: No documentation or data is introduced to support claims concerning the effects of spills creating large urban fires.

CHAPTER 13

General: This section critizes current theoretical assumptions but proposed alternatives are not substantiated or described at all.

Page 1a, para. 2: ". . ., we make detailed suggestions in this and the following chapter for a program that would cost much less, take less time, and get more useful results."
The research tasks in Chapters 13 and 14 are certainly appropriate. However, the program identified is incomplete and, therefore, to some extent, misleading and perhaps even misrespresentative of the nature and extent of the problems to be solved. DOE engineering analyses suggest that the GAO time and cost estimates (given without any documentation) are very optimistic.

Page 8, last para: ". . . large scale experimentation is not scheduled until FY 1982."

Page 9, para. 2: "It is unlikely that timely useful information will come from this program."
In reviewing the Technical Plan section of the draft DOE report, "An Approach to LNG Safety and Environmental Control Research," the GAO apparently failed to realize that safety information will become available on a continuous basis throughout the program. If funded in its entirety, the program foresees many experiments in the range 5-100 m^3 before planned large scale experimentation. If fully funded, many of these tests will be completed within 2-3 years.

Page 9, para. 1: ". . . the questions may be moot since most facilities will have already been approved."
The safety of the existing peak shaving plants, satellite facilities, export and import terminals (approximate total of 100) should be considered. Construction of future additional storage facilities must

be anticipated, especially if gas is discovered off the east coast (to be transmitted ashore as gas, then liquefied and stored for use during periods of pead demand). This is an operational option which, at this time, cannot be discounted.

Page 10, para. 1: ". . . accurate spill models could be completed by early 1979."

At the ERDA (now DOE) sponsored LNG Workshop in December 1976, some 40 persons expert and interested in LNG formed a consensus that additional models are not deeded at this time. The crucial problem is the determination of scaling laws. Experiments of several orders of magnitude will be necessary to validate (or disprove) existing models. A consensus supporting a maximum spill experiment of 1000 m^3 was agreed upon. Recommendations which emanated from the Workshop were circulated to all attendees to obtain their further review and comment. Most attendees responded promptly. It should be noted, however, that the GAO respresentative at the meeting did not provide comments. Considering the number of intermediate sized experiments necessary to develop appropriate scaling laws, a completion time of 1979 is considered unreasonable.

Page 14, para. 5: "We believe that . . . results for distance flammability . . . to be five to ten times too low."

The technical basis for this conclusion should be given.

Page 15, para. 1: "Testing of models and suitable improvements to them can be made by small scale experiments along with larger size tests of scaling. Results should be obtainable in one to two years."

Existing models can be analyzed and improvements hypothesized (12-18 months). Some small scale tests can be conducted to begin the process of verifying the models. However, large scale experiments are mandatory. Large scale experiments cannot be conducted within the GAO suggested two year time frame without sacrificing the implied safety and sophistication needed of a series of experiments of this magnitude if such experiments are to be meaningful.

Page 18, last para. and page 19: ". . . OPSO and the Coast Guard have studied . . . studies be done by the agencies involved in regulating the areas."

A suggestion of this nature means a continuation of the fragmented Federal R&D effort relating to LNG, LPG, etc. It also supports the notion that regulatory agencies should perform research (on a cost sharing basis with industry). Such an arrangement raises questions as to conflicts of interest and objectivity of the resultant research and development.

Page 20, para. 1: "The present plan to channel the bulk of LNG safety research through ERDA . . ."
We are not aware of any such plan.

Page 13, para. 3: "Large expenditures to create facilities for very large experimental spills are not a sensible way to spend LNG safety research funds."
This statement is in conflict with other GAO statements that large experiments (400 m^3) should be accomplished. At the present time, the only experimental facility designed to spill commodities such as LNG exists at the Naval Weapons Center, China Lake; its capacity is 5.7 m^3. To conduct any larger experiment, whether it be 35, 100, 400, or 1000 m^3, will require the preparation of a new facility.

CHAPTER 14

Page 2, para. 1: ". . . fact that no accidental detonations are known . . ."
It is suggested that this be changed to read ". . . fact that no confirmed accidental detonations are known . . ." The positiveness of the original statement misleads the reader.

Pages 3-5: Statement of the Problem
This section is nicely written and reflects much thought on behalf of the author. The problem areas are objectively outlined.

Page 13, para. 2: ". . . the data are not extensive enough to provide good estimates of vapor cloud concentration contours."
This statement points out the inadequacy of present research instrument capabilities. Present vapor sensors are not able to discriminate among the various species present in an LNG vapor cloud nor are the response times adequate to determine concentration contours. A joint DOE/USCG NASA/AGA(GRI) task is presently analyzing instrument designs to collect the needed data. Significant progress will be available by December 1978. The importance as well as the time and cost of this effort was not addressed.

Page 15, para. 2: "For a considerable larger spill, the flame . . . may . . . create its own strong inward wind . . ."
It was for reasons such as this that the attendees at the ERDA (now DOE) sponsored Workshop generally concluded that experiments of up to 1000 m^3 were needed.

Page 16, para. 3: "Experiments have demonstrated that . . . unconfined mixtures of air with the LNG and LPG . . . will detonate . . ."
This is true for LPG. The statement relating to LNG is not true--the results to date remain inconclusive.

Page 21: Differential Boiloff of LNG--Task 1 "Tests should be . . . range of 1 to 35 m^3 . . . relatively rapidly and inexpensively." Preliminary data indicate that differential boiloff does occur. There are indications that the differential boiloff is influenced by the white material observed to form on the water during some of the China Lake tests; a study of this material is contemplated. Simply to obtain accurate boiloff data on the 5.7 m^3 scale requires an estimated $40K and 3 months depending upon the availability of the test facility. Tests at the GAO suggested size of 35 m^3 require a new facility or expansion of the present Naval Weapons Center facility at China Lake. It is estimated that facility expansion can be accomplished in 9 months at cost of $400-500K, with incremental costs of approximately $50K per experiment. There will be additional costs if any land spills are desired. It should be noted that the present facility at China Lake is located in an area whose terrain is unacceptable for experimental spills of more than 60-80 m^3.

Another alternative is to spill 35 m^3 directly from an LNG tank truck. Adequate protection (perhaps in the form of a long spill line) for the truck and driver would have to be provided. This approach would certainly be cheaper, but it has some definite disadvantages: it would be a slow spill which would not duplicate an accidental fast spill, the spill rate would not be controllable, and the long spill line could cause fractionation of the LNG components. This alternative seems to have little to recommend it.

TASK 1--DOE Estimates

Prepare facility	$400-500K	9 months
Ten boiloff experiments	$500K	2 months
Analyze test results	$100K	2 months
TOTAL DOE ESTIMATE	$1,100K	13 months
TOTAL GAO ESTIMATE	$ 300K	8 months

(If land spills are required, more time and money will be required, according to DOE estimates.)

Page 21: Detonation Initiation Sources--Task 2 "Survey, . . . and describe all current and foreseeable future sources of rapid energy release . . . 5 km from LEG terminals and major storage areas . . . screening experiments . . . capable of detonating methane . . . for use in cloud detonation experiments." There are presently approximately 100 LNG facilities (export terminal, import terminals, peak shaving plants, storage tanks, satellite facilities) in the U. S. Assuming that there are an equal number of LPG, and naptha, facilities, an estimated 300 facilities, covering approximately 22,500 square km, must be surveyed. The GAO estimate of 6 months and $100K is reasonable for only the survey. Compilation and physical description of the energy sources requires additional cost and time.

Small scale screening experiments can be conducted at an estimated $12K each. Experiments with lightening require an extensive new facility. Experiments requiring confinement can only be done on a large scale. (Because of time limitations imposed in preparing these comments, we have been precluded from determining cost and time estimates for these latter experiments.)

TASK 2--DOE Estimates

Survey	$100K	6 months
Small experiments	$120K	2 months
Analyze data	$ 20K	2 months
Prepare report	$ 5K	1 month
TOTAL DOE ESTIMATE	$245K	11 months
TOTAL GAO ESTIMATE	$100K	6 months

Page 22: Wind Tunnel Vapor Plume Tests -Task 3

Cost and time estimates for this task appear reasonable provided that simulation gases are available for each component to be simulated, that sensors are available to accurately detect each simulant gas, and that the wind tunnel is available for use when needed.

TASK 3--DOE ESTIMATE	$200K	8 months minimum
GAO ESTIMATE	$200K	8 months

Page 23: Detonation Initiation and Propagation Experiments--Task 4

"Perform experiments . . . methane/ethane, . . . air with methane . . . and propane . . . including multiple stage processes . . . stoichimetric and off-stoichimetric . . . inhomogeneous fuel/air mixtures . . . direct-initiation . . . (and) ignited with a weak source . . . effects of turbulence, dust and partial confinement should be included."

We agree generally with the technical content of this task. Based upon the variables listed, approximately 240 experiments (no duplications counted) must be conducted. If two experiments are conducted each week, approximately two years would be needed for this work. This assumes that the existing U. S. Navy test pad is dedicated to this task throughout the duration. The GAO estimate of $750K for 100 experiments does not include time or funds for analyzing the data or reporting the results.

TASK 4--DOE Estimates

240 experiments @ $10K	$2,400K	24 months
Analyze data, 240 @ $2K	$ 480K	2 months
Prepare report	$ 10K	1 month
TOTAL DOE ESTIMATE	$2,890K	27 months
TOTAL GAO ESTIMATE	$ 750K	8-12 months

Page 24: Large Vapor Count Field Experiments--Task 5 "Conduct . . . experiments . . . 400 m^3 LNG and about 150 m^3 of propane . . . on water and soil, and attempt to detonate . . . with . . . initiators . . . perhaps 10 to 20 initiators would be activated simultaneously in each test cloud . . . repeat tests would be performed to provide an adequate statistical base . . . results . . . provide high-confidence answers . . . a program of six tests would cost about $2.5 million . . . planning is accomplished during the first year. . . program could be completed in the second year."

We are in general agreement with the technical content of this task. Results from the ERDA Workshop provided a consensus that a maximum spill(s) of 1000 m^3 would be required to establish appropriate scaling factors. This included a number of spills of lesser sizes (not mentioned by GAO) and increasing to 1000 m^3. GAO has neglected to include the time and cost for preparing a facility at which to conduct these experiments. An architectural and engineering study performed for DOE has provided an estimated cost of $16-18 million and 2 years to prepare a test facility to spill intermediate as well as 1000 m^3 spills at variable spill rates on land and on water. The cost and time for preparing such a facility might be reduced by going to a one-purpose site designed for a series of demonstrations.

Operating expenses for the facility, exclusive of technical personnel and consumable test material, are estimated to be $100K/month. A test facility to spill only the GAO recommended volume (400 m^3) would not be 400/1000-th of $16-18 million, but rather in the neighborhood of $10-12 million.

If detonations (10 or 20 HE initiators) are to be integral portion of the field program, the facility must be "hardened" to withstand the overpressures. An estimate of costs to do this is not available.

GAO states that six experiments of this type would provide an adequate statistical base. To establish such a base, 60 experiments (without any failures) are needed for a reliability of 0.95 at the 95% confidence level. In addition, these six experiments cannot be accomplished, analyzed, and reported in one year if results of one experiment are to be completely analyzed before doing the next experiment as GAO has suggested.

We feel that the entire program will involve approximately 100 experiments of varying size. These experiments will consume an estimated 20,000 m^3 of LNG at approximately $100/$m^3$.

TASK 5--DOE Estimates (for spill program including 1000 m^3 spills)

Prepare facility, including design	\$18,000K	24 months
Operating costs (\$100K/month)	\$ 1,200K	(12 months)
100 experiments @ \$50K average	\$ 5,000K	12 months minimum
20,000 m^3 LNG @ \$100/m^3	\$ 2,000K	time may be a factor regarding supply of LNG
Analyze data @ \$10K	\$ 1,000K	6 months
Prepare report	\$ 10K	2 months
TOTAL DOE ESTIMATE (1000 m^3)	\$27,210K	44 months
TOTAL GAO ESTIMATE (6 x 400 m^3)	\$ 2,500K	24 months

(DOE estimate of a program to make 6 spills of 400 m^3 each, based on extrapolation from data needed to prepare a facility and conduct a program of 100 m^3 spills, is \$13,870K and 34 months.)

Page 26: Two Phase Cloud Detonation--Task 6 "Perform experiments . . . spray of LNG or LPG . . . more or less easily detonated . . ." We concur with the technical content of this research task. Spray-droplet experiments will be difficult to perform because the heat in the plastic bag causes rapid vaporization of the droplets. A rapid dispensing/dispersing system to perform the experiments would probably be so violent that it would likely rupture the plastic bag.

Explosive dispersion and detonation could be attempted. This must be accomplished by trail and error (i.e., each step of the two-step function must be developed by trial and error) just as the military weapon was developed. It would require many more than 10 tests.

TASK 6--DOE Estimate

Two phase experiments	\$900K	12 months
TOTAL DOE ESTIMATE	\$900K	12 months
TOTAL GAO ESTIMATE	\$900K	9 months

CHAPTER 15

Pages 2 & 3: (Consideration of environmental and safety matters) The draft report indicates, in several places, that economic considerations have overshadowed safety issues in FPC proceedings. The relative emphasis given to various issues depends, in part, on the project. In all cases, both environmental, including safety, and economic factors have, in the past, been given independent and major weight in FPC proceedings. In this regard all staff LNG environmental impact statements (EIS), which determine that a project is or is not acceptable from an environmental viewpoint, contain separate conclusions on safety and the biological environmental and only then are these two balanced to determine whether a project is environmentally acceptable or unacceptable. These EIS's have been subject to scrutiny both during the EIS comment review process and during hearings. Staff anticipates that environmental factors, including safety, will continue to be given top priority. Expected actions, as expressed here and elsewhere, are dependent on the resolution of the jurisdictional issues referred to on page 8.

Page 4: (FPC procedures)

Pre-filing conferences have been held infrequently. At these conferences information which will be required with the application in order to aid staff's analysis is discussed. No approvals are given. No staff processing of a proposal begins before an application is filed. The pre-filing conference insures the filing of a more complete application, minimizes piecemeal staff review of often interconnected issues, and avoids regulatory elays.

In this regard, the draft report suggests that the staff discusses matters freely with a potential applicant before an application is filed but insulates itself from all discussion with anyone after the application is filed. After an application is filed, staff can contract anyone who is not a party and obtain data and discuss issues raised by the case. Moreover, upon notice to all parties, staff can discuss the case in a technical conference or make data requests in order to obtain information. Requests and responses are public documents. All parties receive copies. The staff can and does request and receive all necessary information, in a manner which avoids prejudice and impropriety.

Staff does not believe that the publication of notices is appropriate when an LNG site is discussed for the first time with staff (page 22). Notice would be premature because an application for a certificate might never be filed. Perhaps a more effective alternative which would insure the more complete consideration of issues, which is one purpose of notice, would be to establish a minimum time period between the filing of an LNG application and the beginning of formal hearings.

Local hearings have been provided in a number of instances and official site inspections for proposed LNG terminal sites have been scheduled (also page 22). For example, local hearings were held concerning the Everett, Massachusetts project (Docket Nos. CP73-135, et. al.), the Staten Island project (Docket Nos. CP73-47, et. al.), and the Raccoon Island project (Docket Nos. CP73-258, et. al.). The Commission will continue to order local hearings where appropriate. In this regard, it should be noted that the FPC seldom denied petitions to intervene by local interests since active intervenors can aid the development of an adequate record.

Pages 4 & 5: (Staffing)

The draft report suggests that staffing is inadequate. It is not clear at the present time what authority the FERC will have over LNG terminals given the provisions of the Department of Energy Organization Act. Assuming that the FERC will continue to have some authority in this area, staffing, as in the past, has been adequate to assess LNG terminal applications. Within FERC, the Office of Pipeline and Producer Regulation (OPPR), the Office of the Chief Accountant, the Office of the General Counsel, and the Office of Regulatory Analysis all have input into processing an application for an LNG terminal. In the Environmental Evaluation Branch of OPPR, about 20 professional staff members participate in environmental and technical aspects of LNG cases, including safety and design considerations. In addition, the staff efforts of OPPR have been aided through contracts with the National Bureau of Standards for cryogenic safety and seismic design reviews; private contractors to study siting, safety, engineering, and economic feasibility; and information and data the staff obtains from other agencies such as the U. S. Coast Guard. The Staff's ability to undertake a complete and detailed engineering, economic, and environmental, including safety, study of two alternative sites in the TAPCO project (Docket Nos. CP77-100, et. al.) is indicative of the quality and adequacy of staff efforts concerning LNG terminals.

Pages 5 & 6: (Risk Analysis)

The draft report states that the first risk model developed by the staff is, with minor modifications, still in use. While we agree that the first model can be said to serve as a base, the staff has substantially refined its risk analysis. These revisions have had substantial effects on safety conclusions as noted below.

Staff continues to update and refine its risk analysis. The staff is currently computerizing the risk mode. This will allow a detailed sensitivity analysis, utilizing various vapor cloud, fire radiation, and flame propagation models, in the ultimate determination of risk. Staff is also developing a three-dimensional vapor travel model similar to the Science Application, Inc. (SAI) model. In that GAO's comments on the SAI model are being reviewed. Staff anticipates that this review will continue in the future.

With respect to more specific comments in the draft report, staff has considered the longer clouds which the draft report would predict by changing evaporation rate, spill size, plume densities, etc. This analysis has been undertaken despite the fact that the probability of ignition of the cloud approaches unity at a finite distance downstream. The primary question generated by changing the assumptions is: What effects do these longer plumes have on the conclusions to be derived from the risk analysis? Recent EIS's for the TAPCO and El Paso II projects ask and answer this question. Risks are determined and compared for both the staff's plume model and for cloud distances up to 16 miles, which is four miles beyond that suggested in the draft report.

Staff has testified that the "maximum credible shipping accident" for an LNG vessel is the rupture of one cargo tank. On numerous occasions the Coast Guard has also testified that the rupture of one cargo tank is the major credible accident for the LNG vessel. Staten Island LNG project (Docket Nos. CP73-47, et. al.). While staff presently believes that the rupture of one cargo tank remains the maximum credible shipping accident, it will continue to assess the probability of shipping accidents. It should be noted that GAO was asked by an Administrative Law Judge (ALJ) to submit testimony on this and other issues but declined to do so. The draft report criticizes ALJ's for not calling for further evidence.

Potential accidents at the terminal itself are considered in staff's safety analysis. Land based spills into diked areas have been considered for every LNG import project. The methodology is presented in the Calcasieu LNG project FEIS (Docket Nos. CP74-138, et. al.). Another evaluation in this area was presented in the Staten Island LNG project FEIS (Docket Nos. CP73-47, et. al.). Staff's general conclusion is that spills from equipment and/or storage tank spills into diked areas pose little or no significant hazard offsite, particularly with the mitigating measures which have been implemented or proposed at all sites analyzed to date or which have been accomplished through staff's independent recommendations. Staff fully expects that review of potential accidents at the terminal will continue in the future.

The draft report suggests that the risk model does not consider the total number of fatalities which could be caused by a shipping accident in a specific crowded harbor area and the effect of the density of people and structure on the risk per person per year. We believe that this is incorrect. Reference should be made to the following EIS's which discuss this matter:

- Final Environmental Impact Statement for the TAPCO project, September 1977 (Docket Nos. CP77-100, et. al.).

- Final Environmental Impact Statement for the El Paso II Matagorda Bay project, September 1977 (Docket Nos. CP77-330, et. al.).

- Final Environmental Impact Statement for the Everett, Massachusetts, project, September 1976 (Docket Nos. CP73-135, et. al.).

- Draft Environmental Impact Statement for the West Deptford, New Jersey, project, December 1976 (Docket No. CP76-16).

Pages 7, 8, 10 & 16: (Safety analysis of specific sites)
With respect to safety analyses at specific sites, the draft report notes that the EIS on the Pacific Indonesia LNG Company project (Docket Nos. CP-74-160, et. al.) at Oxnard, California did not consider that the site is adjacent to the city's sewer plant where chlorine is stored or that LNG could flow into the system after an accident (page 10). The staff was aware of the location of the Oxnard sewage plant about ,000 feet to the northwest of the proposed LNG facility area. The staff was also aware that only sanitary wastes from the LNG terminal would be pumped to the treatment plant through a closed pipeline system. No open sewers are involved. Further, the staff was aware that the LNG storage tanks would be enclosed by individual high-walled concrete dikes and that the perimeter service road around the LNG plant would provide a secondary means of diking. The staff recommended diking around the LNG unloading transfer lines. For these reasons, spills into the sewer system were not considered credible.

The draft report discusses the change in staff's position concerning the construction of an LNG terminal in the Delaware Valley (Docket Nos. CP73-258, et. al.). During the course of refining the risk model, staff initiated a review of prior impact statements using the refined model and, of its own accord, made a decision to supplement its impact statement for the LNG terminal in the Delaware Valley. This example demonstrates that the effects of refinements in the risk model have not been minor. Furthermore, subsequent to staff's supplemental impact statement, which concluded that the site was environmentally unacceptable because of safety, the application for the terminal was withdrawn. As noted above, staff anticipates additional refinements in the risk model when warranted.

The National Bureau of Standards (NBS) and staff have made follow-up visits to LNG facilities during construction and after operations have begun (page 7). Visits have been made to Staten Island, Providence, Cove Point, and Elba Island facilities during construction and to the Everett facilities during both construction and operation. Follow-up visits have been made to many of the jurisdictional peak-shaving facilities. The FPC has required semiannual operational reports concerning abnormal operating experiences or behavior of LNG terminals. Specific abnormalities are noted. Final design plans for LNG terminals are required to be submitted to the FPC before commencement of construction.

The draft report asserts that the FPC has allowed LNG facilities to operate in large cities without adequately assessing the threat to the public from such facilities. Only one LNG import terminal has been allowed to operate in or near a large city--Everett, Massachusetts. As noted below, the Everett, Massachusetts project has a unique history among LNG terminal projects. In an event, the FEIS for that project provides a detailed analysis of the risks to the public.

The FEIS for the Everett, Massachusetts project also contains recommendations on safety which were adopted as conditions by the ALJ in his Initial Decision. These recommendations required that contingency plans and procedures in the event of a major accident be outlined and submitted for review. Operational procedures for the storage facilities were outlined to alleviate rollover problems. Adequate dike heights, ditching, and land sloping were required to contain LNG in the event of an LNG transfer line failure. The filing of semiannual operational reports was provided for.

Page 11: (Sufficiency of environmental impact statements)
The draft report asserts that no comprehensive site selection effort has been made. Review of all staff EIS's on LNG terminals, in particular, recent ones such as the TAPCO project, or the El Paso II Matagorda Bay project, shows that comprehensive site studies have been performed by the staff. Potential sites along virtually the entire Gulf Coast and existing terminals along the East Coast were examined in the El Paso II Matagorda Bay project. Alternative sites along the East Coast between Maine and New York City were e amined in the TAPCO project. After a complete environmental and economic analysis of two sites by staff, an alternative site was recommended by staff. This policy of detailed considerations of alternatives has been followed by the staff for a number of years. Staff is presently reevaluating its analysis of alternative sites along the West Coast. Staff expects that the analysis of alternative sites will continue and be updated as needed in the future.

The draft report states that no alternative sites were considered in the EIS for the Everett, Massachusetts facility. That project is unique and is not representative of staff's consideration of alternatives. The facility was originally found to be nonjurisdictional by the FPC. Therefore, the facility was operational before the EIS was drafted. Based on an analysis by staff, the facility was determined to be environmentally safe and acceptable. As noted above, visits to this facility have been made during both construction and operation; and detailed safety conditions have been recommended by staff and adopted by the ALJ.

Staff has advocated combined LNG terminal projects in a number of proceedings and has investigated the possibility that gas exchange programs would minimize the number of urban LNG terminals (also page 16). Three terminals have been proposed on the East Coast in urban areas. Since Everett, Massachusetts was the first urban terminal to be built, no exchange program with other LNG terminals was possible. The Providence, Rhode Island terminal is no longer a viable application; and the Staten Island, New York terminal is still in hearing and still under staff investigation.

Staff recognizes the potential benefits of combining terminals as long as safety is not compromised. However, potential obstacles in terms of space availability, gas supply and exchange agreements, institutional problems, and legal problems will need to be resolved before gas exchange programs and combined terminals becomes feasible.

The draft report states that neither environmental impact statements nor safety analyses have been prepared for all jurisdictional peak-shaving facilities (page 3). An environmental assessment and safety review is made of all jurisdictional facilities, including, in particular, LNG peak-shaving facilities, prior to a decision on the need for an environmental impact statement. If, based on that review, it is concluded that approval of a given proposal will not be a "major Federal action significantly affecting the quality of human environment" within the meaning of the National Environmental Policy Act of 1969, then an environmental impact statement is not required. Environmental factors are fully considered in accordance with statutory provisions.

CHAPTER 16

Page 1:

LPG does not represent one-fourth of the Nation's energy. At best, LPG could account for only three percent.

Page 1, para. 4:

The statement reading "...the costs of moving LPG are higher than those for coal, oil or pipeline gas" provides no documentation of how these costs are measured. There is a great deal of dispute, for example, of what it costs to move one Mcf of gas through a pipeline fairly depreciated versus what it would cost an equivalent unit of energy of LPG by pipeline, truck, etc., to an ultimate consumer.

Page 2, para. 2:

Documentation should be provided to show how 1980 non-urban terminals could handle all import requirements for LPG. Are such items as shipping and unloading requirements, ships' turnaround time, site availability, etc., sufficient to handle such volumes?

Page 3, para. 4:
The statement reading "There are many empty natural gas transmission lines" is incorrect. Pipelines may be operating at low load factors but they are certainly not empty.

Page 8, para. 1:
Injecting LPG into a gas pipeline has technical limitations and this should be indicated in the statement.

CHAPTER 17

Page 2:
Table 17-1 should fully document how the conclusion that LNG supplies projected for 1990 could be handled in non-urban sites. The volumes are so substantial that absent of a discussion of ship requirements, berth facilities, etc., the statements per se are inconclusive.

DEPARTMENT OF STATE

February 16, 1978

Mr. J. K. Fasick
Director
International Division
U.S. General Accounting Office
Washington, D.C.

Dear Mr. Fasick:

I am replying to your letter of January 27, 1978, which forwarded copies of Chapter 8 of the draft GAO report: "Liquefied Gases Safety." Regarding the suggestion made therein that ". . . the Secretary of State give strong support to the Coast Guard's efforts to bring about the adoption of new IMCO training standards for ship personnel, " the Department, in conjunction with the Coast Guard, has been instrumental in moving forward (to June-July 1978) the joint ILO/IMCO International Conference on Training and Certification of Seafarers, which will consider such measures.

This accelerated schedule reflects the great importance accorded ship's personnel training and certification in the U.S. initiatives on tanker safety and pollution prevention (TSPP) outlined in President Carter's March 17, 1977 message to Congress. More rapid entry into force of the IMCO International Convention on Training and Certification of Seafarers should bring about significant marine safety and environmental benefits far beyond the transport of hydrocarbons alone.

Thus the combined efforts of the Coast Guard and the Department to accelerate international action on improved tanker crew standards and certification procedures would seem to have already substantially satisfied the cited recommendation in the draft GAO report. The Department will, of course, continue to strongly support and assist the Coast Guard in this endeavor wherever possible.

Sincerely,

Daniel L. Williamson, Jr.
Deputy Assistant Secretary
for Budget and Finance

OFFICE OF THE SECRETARY OF TRANSPORTATION
WASHINGTON, D.C. 20590

ASSISTANT SECRETARY
FOR ADMINISTRATION

March 27, 1978

Mr. Henry Eschwege
Director
Community and Economic
Development Division
General Accounting Office
Washington, D.C. 20548

Dear Mr. Eschwege:

We have reviewed the draft report on Liquefied Energy Gases Safety (LEG). The lack of a digest or summary in a report of this length and complexity has been particularly disconcerting. Because of the large scope and extent of the report, the task of DOT properly reviewing and commenting on the recommendations proved to be a time-consuming task. Since the report delves deeply into the responsibilities and activities of several DOT operating elements, we are attaching their detailed comments which we expect will be included verbatim in your final report.

We have found many of the details insufficient to support the findings, conclusions and recommendations. In some instances, the report seems to lack a grasp of the complex technical matters addressed.

We believe the perceived threats of sabotage or risks to the public in the transportation of LEG, and more importantly, the extensive solutions recommended in the report are overstated. In this regard, the report tends to overlook the many more readily available hazardous materials targets for sabotage such as gasoline and poisons. Moreover, we believe it is most unwise to include the details of how sabotage could be undertaken, in a report which will be made public and could be unfortunately suggestive.

We oppose the recommendation in the report for inclusion of the safety aspects of transporting energy fuels in a new Energy Health and Safety Regulatory Agency to be established in the Department of Energy (DOE). These safety functions are now carried out in the Department of Transportation (DOT) as part of an overall safety program devoted to the transportation of hazardous materials in general, including transportation by marine vessel. The risks posed by energy fuels are, in many cases, not dissimilar from other hazardous materials regulated by DOT which move in volume in interstate and foreign commerce. To separate and transfer the fuel aspects of the hazardous material program, when there are many benefits of a consolidated hazardous materials program in terms of regulatory and enforcement actions and R&D, would be inimical to an efficient, comprehensive and well coordinated national safety program.

The report understates the effectiveness of both Federal and State regulations, such as current Coast Guard regulations and the current regulatory process on LNG plant facilities by the Materials Transportation Bureau which addresses most of the concerns in the report.

Given the large volume of LEG being moved, we do not feel that the report adequately discusses the costs of implementing its recommendations in relation to possible benefits.

As the report is controversial and its recommendations would be extremely costly, it is essential that time and effort be spent to produce an accurate and comprehensive document. It is recommended, therefore, that the report be redrafted to reflect the comments of the various Federal agencies and be recirculated for final comments prior to its release.

Sincerely,

for Robert L. [signature]
Edward W. Scott, Jr.

Enclosures

UNITED STATES GOVERNMENT

Memorandum

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD

G-MP-1
5741

DATE: 10 MAR 1978

SUBJECT: Coast Guard Comments on GAO Draft Report, "Liquefield Energy Gases Safety"

FROM: Commandant, U.S. Coast Guard

TO: Assistant Secretary for Policy and International Affairs

1. Enclosure (1) contains specific comments on the GAO Draft Report, "Liquefied Energy Gases Safety." The following general comments concern the report:

a. The report lacks overall organization and coordination making it extremely difficult to study and comprehend the information that the authors are attempting to convey.

b. The report lacks objectivity by entirely stressing the negative. First, it fails to mention at all the extensive carriage of LPG in barges on our inland waters or the export of LNG by ships from Alaska. Both have a long history of safe transportation and have formed the foundation for the design, construction and operation of the LNG/LPG ships under question in the GAO report. Secondly, there are only a few positive statements made about the current Government regulations and industry standards and practices regarding LEG safety. The accomplishments on the part of both Government and industry appear to have been totally ignored.

c. The report mentions naphtha quite often. The introduction claims this is done for comparison purposes, but the only comparison is in the potential harm from sabotage. We wonder why naphtha was used since gasoline is more abundant, is more familiar to the layman, and is more available to the saboteur.

d. The report addresses complex technical matters covering several disciplines. It is regrettable, but understandable, that the authors lacked the expertise to fully understand and therefore accurately report all the information derived in preparing their report. For example, the authors mistakenly report that Type A tanks on LEG ships are built to the same standards as bulkheads in oil tankers. Further documentation appears in enclosure (1).

2. Since the report is likely to be controversial, recommends the expenditure of billions of tax dollars, and questions the effectiveness of several Government agencies, it is worth the time and effort

SUBJ: Coast Guard Comments on GAO Draft Report "Liquefied Energy Gases Safety"

to produce an accurate and comprehensive document. It is recommended that the report be redrafted to reflect the comments of various Federal agencies. This redraft should be circulated for final comments prior to its release.

W. H. STEWART
Captain, U.S. Coast Guard
Acting Chief of Staff

Encl: (1) Detailed Comments on GAO Draft Report

Detailed Comments on GAO Draft Report

a. Chapter 1: There is no statement as to why naphtha is much less dangerous than LNG or LPG. There is no indication as to how a comparison can be made. There is no supporting statement as to why LNG and LPG are to be considered "highly dangerous."

b. Chapter 2:

(1) Table 2-2 does not show the physical properties of naphtha (which vary widely depending on which type of naphtha is meant), the fuel the report supposedly uses for comparison. The table, under flash point, lists methane as a flammable gas, whereas the other entries list the flash point. The flash point of methane is -306°F. The heading "ignition temperature" should be "auto-ignition temperature."

(2) Page 5 - there is a new 100,000 m³ LPG ship. Also, many LNG ships can and do carry LPG.

(3) Page 6 - LPG, as shipped in the marine mode at least, is not pure propane. Commercial propane contains up to 7% ethane and has a boiling point closer to -55°F. There are

two isomers of butane, one with a boiling point of 31°F, the other 11°F.

The first paragraph on page 6 suggests that a vessel's draft governs the size of LNG/LPG ships. While this is a consideration, the economic factors are more important. The cubic capacity of a ship is determined by at least three major factors - length, breadth, and depth. If draft is limited, the others may be varied to increase capacity.

The second paragraph mentions two LNG exporters, Algeria and Brunei. The United States (Alaska) is currently a net exporter of LNG. It is unfortunate that this should be overlooked, not only in this chapter, but in the entire report. The report tends to lead one to think that only importing LNG is potentially dangerous. Between October 1969 and March 1977 there have been 249 shipments of domestic LNG from Kenai, Alaska without incident.

In the third paragraph it should be noted that not all LNG tanks are double-walled. The last line should read ". . . supported by insulation lining the <u>inner</u> hull."

(4) Page 7 - There are no systems to warm the "storage" tanks on an LNG ship. There are vaporizers that could be

used to inject warm gas into an empty tank prior to gas-freeing. While it may appear obvious that one would not warm LNG tanks while liquid is in them, certain statements in Chapter 8 (see comments below) indicate that this is not obvious to the author of the report. In addition, there are currently no "systems" in use for cooling the tanks either. The liquid is maintained at its boiling point by drawing off vapors, but this should not be confused with a refrigeration or reliquefaction system.

The description of the emergency shutdown system in the second paragraph is misleading. There is an emergency shutdown system on a gas ship with a maximum allowable relief valve setting (MARVS) of 10 psig or higher. It is activated automatically whenever the power system fails or, in the event of fire, it is activated by the melting of fusible plugs. It can also be operated manually. In addition, there is an automatic overfill shutdown to prevent tanks from overflowing. Shore facilities may also have emergency shutdown systems but they are usually manually activated.

(5) Page 8 - The first paragraph indicates that dikes in the U.S. are capable of containing 100% of the volume of the largest tank. In Chapter 18 (page 5) and other places, the

report implies that there are no dikes around LNG tanks in the U.S. See also the comments on Chapter 3.

The third paragraph again ignores the exportation of LNG from Alaska.

(6) Page 9 - It is noted that this same accident is repeatedly mentioned throughout the report. To balance the picture, the modern record of LNG transportation and storage should be included here. For instance, Japan has extensive LNG shipment and, since no major accidents are reported, it is assumed that their operation has proven safe. Also, there have been over 2700 shipments of LNG worldwide since 1964, and not one major accident has occurred. If one must repeatedly refer to an accident occurring over 30 years ago, which involved outdated technology, it seems only fair to point out the lack of accidents using modern technology. See also the comments on Chapter 3.

c. Chapter 3:

(1) The inclusion of an account of the 1944 Cleveland LNG incident in this report without stressing the fact that the apparent causes of this mishap do not exist at today's LNG facilities is misleading. The 3.5% nickel alloy steel used

in 1944 is no longer used for such applications. It should be borne in mind that commercial cryogenics was a very new field at that time and that technology in this field has now advanced to a state of high reliability.

(2) In the past ten years more than 150 large tanks have been erected for LNG service and not one of these tanks has failed in cryogenic service.

(3) The statement under "Provisions for Spills--Pits and Dikes" that current LNG storage site dikes are designed to contain only relatively slow leaks is misleading in that design criteria have changed since 1944. See page 24 of Chapter 19 of the report for a more accurate description of current dike requirements.

d. Chapter 5:

(1) This chapter refers several times to single-hull LPG ships and compares them to conventional tankers. While it is true that LPG ships are not required to have an inner hull, the implication that they are similar to conventional tankers is erroneous. LPG ships may use the outer hull as the secondary barrier, but cargo is <u>not</u> carried against the outer hull as in conventional tankers. Thus, there are at

least two "walls" and intervening insulation separating the cargo from the sea. The majority of LPG ships use independent, self-supporting tanks within the ship. They are much more resistant to damage than the report indicates.

(2) Two incidents involving explosions in sewer systems are mentioned; one involved naphtha and the other "either industrial wastes or gasoline leaking into a sewer or a combination of these." It was stated, with regard to gasoline, that "a total leakage of about 1/2 cubic meter would have provided an explosive mixture sufficient to cause the disaster." The recommended security measures would not preclude terrorists from initiating similar sewer explosions.

(3) The security measures proposed for LEG facilities, if imposed continually, are a classic example of an "overkill" approach to protect one possible terrorist target while leaving other equally desirable targets unguarded. Furthermore, the recommended security measures would not deter the effective use of the mortar and rocket weapons which the report states are in the hands of potential saboteurs. Neither would these precautions at LEG facilities in any way affect the availability to saboteurs of gasoline or their access to drains for introducing many

times the required 1/2 cubic meter into every sewer system in this country.

(4) It can be shown that a potential threat against LEG facilities exists and that the results of sabotage could affect large numbers of persons; however, it should be recognized that there are numerous other facilities handling vast quantities of other materials which pose an equal or greater threat to communities.

(5) The Federal Bureau of Investigation indicates that there is no known threat at this time to any LNG facilities by terrorist organizations. The probability of a threat against a vessel is believed to be influenced more by the vessel's nationality than by the cargo carried. Should intelligence information reveal a suspected terrorist threat to a specific facility or vessel, appropriate additional security measures would be taken.

e. Chapter 6: The Coast Guard does not sponsor research aimed at quantitative determination of critical crack length for spherical and cylindrical ships cargo tanks used to transfer LNG and LPG. However, the Coast Guard requires the designer to determine these lengths. Then, through extensive non-destructive testing and inspection during the tank construction, flaws are limited to a very small size. If a flaw were to grow, it would grow to a small through-crack and allow detection of the leaked gas long before the crack ever approached critical crack length. Laboratory testing for the aluminum spherical tanks has shown that it would require several ship-lives of loading to grow a fatigue crack to a length approaching critical crack length. Technology in this area has advanced considerably beyond what was available in 1944.

f. Chapter 8: Many of this Chapter's recommendations were made based either on misconceptions or on isolated examples. Although more effort was expended in reviewing this chapter than any other, time did not permit more than the correction of the errors rather than a thorough explanation of the Coast Guard's program for safety of liquefied gas ships. Since many of the findings and recommendations are based on inaccurate or misunderstood statments, they should be reconsidered. The following specific comments apply:

(1) Page 3, paragraphs 2 and 3 - Move "secondary barriers" from the category "reactive safety features" to "preventive safety features" to establish their importance and function. Providing a secondary barrier is tantamount to having another tank outside the primary barrier; it is

intended primarily to contain any leaks which might develop in the primary barrier rather than to combat the effects of an accident. That fact is not brought out in the report and the fact that a secondary barrier is required is often left unmentioned. This change would be consistent with the inclusion of "secondary barrier" in the discussion of "preventive characteristics" on pages 4 and 5.

(2) Page 5, 1st paragraph - Polyvinyl chloride and polyurethane foam insulations may also be load bearing.

(3) Page 5, 2nd paragraph - Add at the end of the first sentence "Current designs far exceed the 15-day requirement."

(4) Page 6 - The description of LPG tank design in the second paragraph is erroneous. The IMCO Gas Code has no "A1 type" tank, and LPG tank design and stress analysis has nothing to do with "tank bulkheads in oil tankers." The reference to "deep tank standards" in Proposed 46 CFR 154.439 identifies a calculation standard for Type A tanks, since their structural arrangement lends itself to this most conservative shipboard stiffened plate analysis. The fact that the additional loads required to be analyzed are not addressed here should be corrected. In fact, LNG and LPG

ships alike must meet the same standards set forth in the IMCO Gas Code. The major differences would result from warmer service temperatures and higher specific gravities for LPG cargoes. There is no foundation for drawing a drastic distinction between LNG and LPG tank design standards. Additionally, typical tank materials are 2.5% nickel and carbon manganese steel, not 2.5% nickel steel. There are no "single wall" LPG ships. The outer hull may act as the secondary barrier, but cargo is not carried against the outer hull (as in most oil tankers) as the last sentence implies.

(5) Page 7, paragraph 4 - It is not clear what would be achieved with similar studies on other designs. The minimum distances between outer hull and tank boundaries are, by regulation, the same for all types. The difference lies in some variation in probability that a tank boundary will be involved with certain penetrations into the LEG vessel. More information is being sought through research on collisions for ships in general and the knowledge gained will be useful for application to LEG vessels.

(6) Page 8, last paragraph - The reference to proposed Coast Guard rules may imply that the design parameters referred to were not previously considered. This is not

true; the Coast Guard's Letter of Compliance (LOC) program has included these for many years.

(7) Page 10, last sentence of paragraph continued from page 8 - Delete the sentence, "However, data on buckling of membrane designs are not required." Membranes by definition cannot withstand compressive loads. The design must preclude compressive loads. Maximum allowable pressure differentials for membranes are calculated and pressure control (both pressure relief and vacuum protection) of both sides is required.

(8) Page 10, last paragraph - The cargo tank pressure is normally maintained by the equipment described in the report, namely the gas compressor control system (LNG) and the cargo reliquefaction equipment (LPG). To prevent damage due to external overpressure, certain redundant systems are provided as follows:

(a) Rupture discs and safety valves are provided for the inert gas generator supply header to prevent overpressurization of the inter-barrier and hold spaces,

(b) Safety valves or rupture discs are provided for the hold and inter-barrier spaces, and

APPENDIX IV

(c) Either vacuum relief valves are fitted on the cargo tanks or independent pressure switches are provided to give an alarm and subsequently stop all equipment taking suction on the cargo tank before reaching the maximum external pressure differential.

Additionally, numerous alarm systems are required on the LNG vessel to provide early warning of conditions that might develop into a dangerous situation.

(9) Page 11, paragraph 1 and 2 - The second paragraph appears to exaggerate the vulnerability of LNG tanks to sabotage by isolation. The manner in which this could be accomplished is oversimplified, the amount of vapor generated is overestimated, and the importance of calculating tank bursting pressures is overstated. The "blocking" of a safety relief valve or the "blind-flanging of vapor outlets" by a saboteur are neither simple nor rapi to effect. The typical size of a vent line is 16 inches in diameter, adding significantly to the time required to dismantle connections and remove obstructive sections of piping. However, should all this be accomplished for each tank, the cited value of 12,000 cubic meters of liquid per hour is much larger than any reasonable estimate. A contractual boiloff rate of 0.25% of the total cargo per da

is typical and a value of 0.10% per day is normally achieved (125 to 312 cubic meters of liquid per day for a 125,000 cubic meter vessel). The point of the 12,000 cubic meter value is not clearly explained, although it appears that the potential pressure buildup rate within an isolated LNG tank was intended. The actual values offer more of a margin of safety.

The Coast Guard does not directly require bursting pressure calculations for LNG tanks or pressure vessels. The design of an LNG tank (or pressure vessel) inherently limits the maximum allowable stress experienced by the tank to a specified percentage of the ultimate strength of the tank material, leading to a safety factor of at least four on tank bursting pressure. Requiring the submission of a calculation for the actual bursting pressure would be superfluous.

(10) Page 11 - In this discussion, a cargo fire around an LNG ship is described while the findings mention a fire on the LNG ship. Only the tank dome extends above the deck and the safety valve calculations consider the fire situation.

(11) Page 14 - Change the last sentence to read - "They asked that the proposed regulations be amended so as not to

exceed the Code." Their complaint was that the U.S. regulations were more stringent than the Code, not that they did not "comply."

(12) Page 15 -

(a) The manning scales for these vessels provide for a three watch system which, under normal circumstances, is sufficient in limiting the crew's working hours. In addition, on these vessels, the Chief Mate is designated as a non-watchstander, which further reduces the workload on all the licensed deck officers. The designation of the First Assistant Engineer as a non-watchstander and the granting of the authority for the cargo to be transferred under his direct supervision is another plus in the reduction of the workload.

(b) U.S. LNG ships presently certificated are required to be manned by a Master and four mates, and a Chief Engineer and four assistant engineers. The Chief Mate is designated the cargo officer and is a non-watchstander. The First Assistant Engineer is designated the cargo system engineer and is a non-watchstander. The transfer of cargo is required to be under the direct supervision of the cargo officer and/or system engineer.

In addition, the Master, Chief Engineer, Chief Mate, and First Assistant Engineer are required to be holders of a Coast Guard-Certified letter attesting to their competency in the carriage and transfer of liquefied gases. This competency is obtained by intensive training at a company or maritime union sponsored school.

The designation of the Chief Mate as a non-watchstander relieves this officer of his bridge watchstanding duties permitting him to concentrate all his efforts towards the loading, the monitoring of cargo while underway, and discharging. The same applies to the First Assistant Engineer which allows him to oversee the cargo systems.

(13) Page 19, last paragraph - The criteria is now being met by the shipping companies in the training of vessels' crews prior to their joining the ship. It is realized that not all of these criteria are met by the proposed Tankerman Regulations, but work is underway within IMCO to adopt a convention on standards of training and watchkeeping. The proposed training for liquefied gas ship crews is very comprehensive.

(14) Page 21, last paragraph - Although CTIAC initially drafted proposed LNG facility regulations, the Coast Guard

has made significant revisions to the initial CTIAC draft. CTIAC's next task is not limited to LPG facilities; rather, it will include all waterfront bulk liquefied gas facilities.

(15) Page 22, 3rd paragraph - The Coast Guard does not have the authority to enforce U.S. training regulations on foreign vessels entering U.S. ports. Foreign vessels can be boarded and examined to determine that they are manned in accordance with the regulations of the flag country and to ensure that there are sufficient licensed officers aboard for the safe operation of the vessel.

(16) Page 23, 2nd paragraph - The proposed regulations referred to were not intended to include all of the IMCO recommendations for liquefied gas carrier personnel, as these recommendations have not yet been completed. Upon the completion of the International Convention on Training and Certification of Seafarers in June of 1978, the regulations will be expanded as necessary.

(17) Page 27, 2nd paragraph - While it is true that Boston is the only active LNG import terminal, Kenai, Alaska has been exporting LNG since 1969.

(18) Page 27, 3rd paragraph - Since Coast Guard regulations and operating procedures are all directed at preventing the release of liquefied gases, it is unclear how the properties of LPG in the vapor phase (i.e., after release) should influence those procedures.

(19) Page 27, 4th paragraph - The report incorrectly indicates that the Coast Guard is concerned only about "the peril (LNG) tanks pose to ships and docks but not to surrounding communities." When Coast Guard personnel carry out waterfront facility inspections for safety purposes, their activities result in a safer facility, port, and port community. In addition, the Coast Guard and MTB/OPSO have agreed upon an MOU, which has been signed by the Commandant of the Coast Guard and the Director of MTB.

(20) Page 28 - The brief discussion of the Letter of Compliance (LOC) program does not do it justice. Extensive, detailed review of the design, construction, and equipment of ships carrying bulk dangerous cargoes is conducted. In most cases, many changes are required before the ship meets Coast Guard standards. After the Coast Guard has satisfied itself that the ship has been built or modified to its standards, the ship is inspected to verify that it is in accordance with the plans and that all safety systems are

operating properly. The inspection has no time limit and may last longer than 4 1/2 hours. The LOC is issued for a period of two years, but may be revoked sooner if the ship fails to maintain the standards under which it was approved. The LOC has long been recognized as the highest standard in the world for ships of this type. In fact, some foreign countries have required ships visitng their ports to have a Coast Guard LOC. The LOC program provided the impetus for the development of the IMCO Codes for chemical tankers and gas ships.

(21) Pages 28 and 29 -

(a) The report overstates the extent to which vessel traffic management decisions should be made in Washington rather than at the local level. On-the-spot decision-making by COTP's with knowledge of the facts is strongly encouraged by the Coast Guard. The alternative approach of attempting to address all conceivable situations in advance through Federal regulations leads to over-regulation and arbitrary criteria.

(b) Although the COTP Authority Update Regulation became effective on October 25, 1977, it was published on September 22, 1977. Emphasis is placed on inconsistences in policies among COTP's. The example cited is apparently based on the practices of not issuing both a Local Notice to Mariners and a Security Broadcast regarding restrictions placed on navigation during a LEG ship passage. This is not an inconsistency. If there is time, both a Local Notice to Mariners and a Security Broadcast are issued. If time is of the essence, a Security Broadcast along with Coast Guard patrol craft can handle the job.

(c) The report emphasizes the fact that CG-476 addresses only LNG and not LPG. The reason for this is the inordinate public, Congressional, and news media interest in LNG. The Coast Guard found it beneficial to publish this information to satisfy repeated inquiries. The Coast Guard is aware of the hazards of LPG and many other liquefied gases, but because there has not been the same overwhelming cry for information, it has not been deemed necessary to publish a pamphlet for each liquefied gas carried in bulk marine shipments.

(22) Pages 30-32 - The Coast Guard does require its officers and warrant officers to satisfactorily complete the Marine Safety Basic Indoctrination Course upon being assigned to any Marine Safety Unit. During this 12-week course, the basics of LEG properties, hazards, technology,

and cargo operations are covered by 29 hours of direct instruction and 27 hours of indirect training. To supplement this basic training, the 6-day Liquefied Gas Carrier Course covers the same areas in more detail as well as techniques of inspection and state-of-the-art instruction. The 3-week hazardous chemical course for officers and petty officers devotes 34 hours to direct instruction and 23 hours of indirect training on chemical and gas hazards, properties, technology, and cargo operations. The 5-week Marine Safety Petty Officers Course and its forerunners, while not mandatory, have processed between 90 and 95 percent of all petty officers presently assigned to marine safety duties. This course dedicates a considerable amount of time concentrating on the basics of LEG hazards, properties, and cargo operations. The subsequent training available to officers is also available to petty officers.

(23) Page 34, last paragraph, reason 1 - As stated in comments relative to Coast Guard personnel training, there is, at present, suitable mandatory basic training of marine safety personnel, supplemented by advanced training for key personnel. This instruction, training, and experience combine to provide a COTP with sufficient expertise to make rational decisions concerning vessel and facility safety.

(24) Page 35, paragraph 1, reason 2 - GAO concern with the Coast Guard and its COTP's considering the economic impact of their regulatory activities overlooks the PWSA requirement to consider "economic impact and effects" together with several other factors. Certainly the Coast Guard must consider the economic consequences of its actions - to do otherwise would be irresponsible. This does not mean, however, that a ship that is considered unsafe would be allowed to enter port just because of the economic consequences. In fact, on many occassions, ships have been denied entry or delayed until repairs are effected.

(25) Page 35, reason 3 - The Coast Guard is unaware of "confusion in the world shipping industry as to the U.S. Coast Guard's safety standards for admitting LNG ships." In the few locations in which LNG ships have entered or shortly will enter the U.S., the COTP's have conferred in detail with all involved parties so that everyone understands what requirements each COTP is imposing.

(26) Page 35, 2nd paragraph - The example of the LPG carrier FARADAY does illustrate the kind of decisions the COTP must make. The report's analysis of it illustrates the lack of understanding of the author. The FARADAY had made a previous trip to the U.S. when this problem was discovered.

Analysis of the hold space atmosphere by a gas chemist showed that the gas causing the alarm was, in fact, CO_2. The readings were monitored to determine if there was any increase; there was not. Since an infrared analyzer is basically a "molecule counter," any LPG vapor that had leaked into the hold space would add to the reading caused by the CO_2. The COTP in Boston had been in contact with Coast Guard Headquarters' technical staff and was aware of the situation. The decision of the COTP was correct and did not involve any unusual risk. The last sentence of the paragraph is a gross overstatement leaving the impression that a minor leak could result in catastrophic failure.

(27) Page 35, last paragraph - The fact that two relief valve seals on the LUCIAN were broken is not a serious problem. The Coast Guard boarding team could easily determine the pressure in the tanks and be assured that the pressure was not excessive. The valves on that ship have multiple settings and the seals could easily have been broken when changing the settings. It is not known how one could "tamper" with the valves to make them inoperable without more visual indication than broken sealing wires. There are high pressure alarms on the ship to indicate excessive tank pressure. There is no "relevant equipment" to be shut down in the event of high pressure on the LUCIAN.

The only equipment affecting tank pressure on the LUCIAN serves to lower tank pressure; therefore why shut it down?

(28) Page 37, 1st paragraph - Perhaps the fact that LUCIAN is a much smaller vessel (29,000 m^3 compared to the 50,000 m^3 DESCARTES) was considered when allowing two tugs vice three.

(29) Page 41, 2nd paragraph - The Coast Guard does not concur in the need to pre-position equipment to partially off-load an LEG ship that has gone aground in inland waters. In situations where a grounded LEG vessel could be refloated by off-loading cargo, there are other, practical methods that could be employed.

(30) Pages 41-42 - COTP's <u>do</u> <u>not</u> require special vessel traffic control <u>systems</u>. Vessel traffic services are established by the Commandant through Federal regulations. COTP's issue orders and directives affecting vessel traffic pursuant to PWSA delegations in 33 CFR Part 160. There are several functioning traffic services, (not "systems"), and not just in the Houston Ship Channel. Others are in San Francisco, Puget Sound, Prince William Sound, and New Orleans.

(31) - Findings, pages 43-48 -

(a) The first finding is incorrect. See (4) above.

(b) Findings 3 and 4 are basically correct, but may be misleading. See (5) above.

(c) Finding 5 is correct, but there is an obvious reason why buckling calculations are not required. (See (7) above.)

(d) Finding 6 is oversimplified and indicates a basic misunderstanding of liquefied gas ship design. There are many ways that a gas ship could be sabotaged - just as there are many ways that any ship could be sabotaged. The method indicated is probably one of the most unlikely. It is very difficult to tamper with relief valves to the extent necessary to cause catastrophic destruction of the ship. Pressure alarms are available to alert the crew that something is wrong. Pressure control systems on gas ships are installed to reduce pressure, not increase it.

(e) Finding 7. It is unlikely that insulation, except for that on the tank dome, would be exposed to fire except where the hold was already breached.

(f) Finding 13. As noted in (13) above, the proposed tankerman regulations may be changed upon adoption of the IMCO convention.

(g) Finding 16 recognizes the difficulty in setting one set of standards for all varieties of gas ships, ports, etc., yet the report criticizes the Coast Guard for not doing it. This is one of the reasons for vesting control authority in the COTP.

(h) Finding 18 is correct. Nor has the Coast Guard issued a document similar to CG-478 for any other of the 150 or so hazardous cargoes shipped in bulk. CG-478 was issued to save the Coast Guard time and resources in responding to the many similar inquiries about LNG. If the public interest had been aroused by LPG instead of LNG, then it is likely that the Coast Guard would have issued a pamphlet about LPG. Some of the guidelines included in this publication will be incorporated into regulations but most could not, in practice be inflexibly imposed as regulation due to the unique configuration, traffic patterns, hydrographic conditions, etc., of the individual ports.

(i) Finding 19 - See (18) above.

(j) Finding 20 - The Coast Guard has not established security zones around LLG facilities, and, evidence warranting such action as a matter of routine has not been discovered.

(k) Finding 21 - They key word is "mandatory." The Coast Guard does have adequate formal training programs for officers and enlisted personnel. Some courses are attended by all personnel. Others are available to key personnel.

(l) Finding 22 is misleading in that it indicates that all that is required of a foreign LNG ship entering a U.S. port is a "2-1/2 hour inspection." The inspection referred to is a routine safety boarding conducted at the discretion of the COTP. The vessel is also required to have a Letter of Compliance which is much more involved than a 2-1/2 hour inspection. See (20) above. Also, it should be noted that all foreign tankships are given a navigation safety examination at least once a year.

(m) Finding 23 is erroneous and misleading. See (22) through (28) above.

(n) Finding 24 is correct, but the Coast Guard does not see the need for such equipment. Off-loading LEG is not the only method of lightening a ship.

(o) Finding 26 - the Coast Guard District Inspection Staff does, in fact, conduct such inspections and evaluations.

(32) Recommendations, pages 48-53:

(a) Recommendation 1 - The Coast Guard is conducting research on collision resistance of ships, but it is not limited to gas ships.

(b) Recommendation 2 - Analytic determination of tank stresses is, and has been for many years, required. The analysis does not include tank bursting and membrane buckling for the reasons given in (7) and (9) above.

(c) Recommendation 3 - The stress analysis of LPG tanks provides a margin of safety at least as great as that for LNG tanks.

(d) Recommendation 4 - The ways a tank might be ruptured by pressure, except for sabotage, have already been considered and preventive measures taken. As explained above in several places, requiring pressure switches to shut off relevant equipment would reduce rather than enhance safety.

(e) Recommendation 5 - The Coast Guard, in cooperation with IMCO, is developing requirements of this type for all tankers.

(f) Recommendation 6 - Cargo containment systems are required to be able to withstand fire exposure without failure. Cargo vapors, however, will be vented by relief valves. Insulation is normally protected by steel sheathing or the vessel's hull. The scenario the recommendation envisions apparently is one where fire is surrounding the ship, the inner and outer hulls have been breached, and the tank insulation is exposed. To design to such criteria is not practical.

(g) Recommendations 7-14 - See (12) through (15) above. A Coast Guard officer serves as chairman of the Sub-Committee on Standards of Training and Watchkeeping of IMCO. Through this organization the Coast Guard is promoting the development of international training standards for officers and crews on all liquefied gas ships. The IMCO Sub-

APPENDIX IV

Committee on Standards of Training and Watchkeeping will address the subject of manning in its future work program.

(h) Recommendations 18 and 20 - The Coast Guard is revising CG-478 and will include a chapter on LPG. The recommendations concerning making CG-478 a directive are addressed in paragraph 31(h).

(i) Recommendations 19 and 21 through 30 have been addressed previously in paragraphs (31) or (32) above.

g. Chapter 9: This chapter should be combined with chapters 10 and 20 into a single chapter. This would eliminate redundancy and ensure a consistent approach to trucks and train tank cars. The calculations involving the filling of subway and sewer systems with a flammable concentration of LNG vapors are only theoretical and could not occur to the extent cited in real life. It would have been interesting to include the theoretical effects of a naphtha spill also as a comparison. A real accident of this type is mentioned briefly in Chapter 11. Since gasoline, naphtha and other fuels are much more plentiful than LNG/LPG, and since there have probably been a proportional number of accidents, it is interesting that no mention is made of accidents involving these materials. Sabotage of gasoline or naphtha trucks is not seen as any more difficult than sabotage of LNG trucks. Have there been instances of gasoline or naphtha truck sabotage?

h. Chapter 10:

(1) Page 7 - The generalization is made that inspection of tank cars at 10-year intervals and safety valves every 5 years is inadequate. Does data exist to support this conclusion? Coast Guard standards require internal inspection every eight years and relief valves every four. It would seem that the less hostile environment of railroad cars would allow slightly longer periods. The report also notes that rusted LPG tanks were observed. Pictures are included in the report and a recommendation is made to prohibit use of rusted cars. In the absence of any determination as to whether a corrosion allowance was included in the design of the cars in question, and in view of the admission that "we did not determine the depth of the rust", it is irresponsible to draw conclusions about the possible hazardous condition of the cars.

(2) Page 11 - Does the New York City Fire Department object to the transportation of other hazardous materials

APPENDIX IV

through New York City? Or, are they also guilty of singling out LNG/LPG and ignoring other hazardous materials?

(3) Page 13 - The recommendation for large placards saying "flammable gas" that can be read at considerable distances seems inconsistent with the authors' concern about sabotage.

i. Chapter 11: This chapter and its appendices are excellent examples of the alarmist tone of the report. Certainly, a major release of LNG or LPG (or most other liquid or gaseous fuels) in a city is potentially catastrophic. Again the authors have only identified the same major accident involving Cleveland in the infancy of LNG storage. Comparing an LNG release to the bombing of Tokyo and Hamburg in World War II is misleading. As the Appendix (but not the report) notes, those bombing raids were carefully planned to create maximum destruction. Also, the population density and housing construction of Tokyo largely contributed to the destruction. One can correctly say that if the same TNT equivalent of LNG as each bomb dropped on Tokyo were similarly distributed throughout a city, were detonated as effectively and as quickly, and the city had the same population density, housing construction, and all other conditions as existed in Tokyo in 1945, then an LNG spill is like the bombing of Tokyo. It is felt that the possibility of an LNG/LPG spill in a city is recognized as a potentially catastrophic event without the use of scare tactics.

j. Chapter 12:

(1) This chapter of the proposed GAO study is characterized by numerous legal errors and overstatements, most of which do not affect the Coast Guard or the final recommendations of the study. Typical of these errors are the recitation of the Carriage of Goods by Sea Act provisions (Page 28 (46 U.S.C. 1304)) as bearing on the vessel's liablity to injured offset parties in a catastrophic incident and overstatement of the principles relating to navigational errors (Page 28).

(2) This chapter has been written on the assumption that an LNG incident will cause injuries of the same magnitude as a serious nuclear disaster, to which existing legal systems will be unable to adequately respond. If that assumption is correct, then the GAO recommendations should be amended to reflect the following considerations:

(a) Diversity of Laws. The report indicates correctly that a claimant may be faced with different state and Federal laws which could complicate recovery or inhibit claims by parties unable to afford the expenses of prolonged litigation. However, the report fails to discuss the most logical approach to this problem. Due to the potential serious impediments to recovery by victims, a comprehensive Federal preemptive statute is needed to eliminate the variegated state schemes. This approach would be favored by industry because it would provide a degree of certainty in determining potential liability and eliminate conflicting and burdensome state provisions.

(b) Single System. Under a single comprehensive Federal framework, legal issues can be statutorily resolved to eliminate uncertainty stemming from differing statutory and common law principles. In this way, the issues concerning statutory strict liability, damages, defenses, parties, and recourse among parties, which troubled the writer of chapter 12, can be settled.

(c) Legislative Approach. If the assumed need for a new system of compensation is valid, then it should have a sound legal basis. The risks involved in utilizing the tenuous provisions of Section 7 of the Natural Gas Act clearly should not be accepted when legislation is going to be needed for certain aspects of the program anyway. It is quite obvious, for example, that liability limitations established by 46 U.S.C. 183 can only be statutorily changed. One approach to this would, rather than changing 46 U.S.C. 183, merely involve a phrase in a comprehensive act stating that 46 U.S.C. 183 does not apply. (See e.g. 33 U.S.C. 1321(f)(1), "...notwithstanding any other provision of law, (the owner or operator of an oil spilling vessel shall) be liable to the U.S. government for...") Since legislation is going to be needed, it should cover all aspects of the problem.

(d) Extent of Liability. While the chapter only discusses facts concerning LNG, the findings and recommendations extend to liability and compensation for all hazardous materials incidents. Thus, there will have to be some clarification of the materials to be covered by this plan. In addition, it must be noted that the chapter finds the $560 million liability regime for nuclear accidents to be inadequate for hazardous materials accidents and advocates unlimited liability. Clearly, this will require close Congressional scrutiny and a balancing of potential victims' needs against the national interest in assisting industry and energy sources. It is doubtful that an unlimited liability system is feasible. However, a large Federally administered fund, such as has been proposed for oil pollution by S. 1187, a comprehensive liability and compensation bill, should receive serious consideration.

(e) International Considerations. The chapter deals at some length with problems that might be encountered in dealing with foreign vessels and foreign parties. However, no mention or thought has been given to international agreements and negotiations as a possible solution. Therefore, it is pointed out that IMCO has been holding discussions on liability for hazardous materials. These discussions include LNG as a hazardous material and the discussions have specifically addressed incident prevention and compensation.

(3) A number of statements concerning liability are inaccurate or overly broad. However, it is likely that there is a need for a new liability and compensation system. Such a system should be established by a comprehensive Federal statute addressing preemption, liability, liability limits, creation of a compensation fund, and other necessary legal issues.

Chapter 13:

(1) Pages 4, 5 - The authors should use the measured speed of the flame, 6-12 mph, and delete such qualitative expressions as "quickly." It could be argued that a flame speed of 6-12 mph is rather slow for a burning vapor cloud. The flame speed of nitromethane, for example, is on the order of 3 miles per second.

(2) Page 5 - The Coast Guard has conducted LPG tests using hemispherical balloons, pool burns, and cloud burns (reports to be issued).

(3) Page 6 - In all LNG research there has never been any evidence for assuming that a very large pool fire could form a fireball.

(4) Page 6 - Some of the Phase II China Lake work is applicable to the underground conduit issue. Methane-air propane-air, and ethylene oxide-air (not an LEG) were ignited in short shock tubes and the deflagration and detonation properties were measured.

(5) Page 7 - Site considerations such as restricting LEG facilities to areas with a low population density should be

augmented by provisions keeping that density low for the life of the facility. Fifty years, the life span for LEG facilities used in this report, is a long time for an area's population density to remain constant.

(6) Page 9 - Based on the Coast Guard's extensive experience with LEG research, the time estimate for performing vapor dispersion research is totally inadequate. The Department of Energy's schedule for their program is realistic.

(7) Page 10 - Even if the GAO-proposed plan were completed in 1979, many decisions would have already been made on the next generation of LNG terminals.

(8) Page 11 - The flammable vapor cloud dispersion distance is a function of spill size. The Science Applications, Inc. (SAI) estimate is for a spill of 37,500 m^3 while the others are for 25,000 m^3.

(9) Pages 11-15 - The rejection of the SAI model is not supported by the evidence; too many statements are given without any proper supporting data or reasoning. While the Coast Guard feels there is insufficient evidence to support the SAI model, neither is there sufficient evidence to

APPENDIX IV

reject it. For this reason our consultant, Prof. Jerry Havens, is continuing to work in this area.

(10) Page 13 - In the SAI model, the momentum diffusivity is modeled as a function of the vertical temperature gradient which is not necessarily a linear function of height; thus, the GAO statement that momentum diffusivity is a linear function of height is not necessarily correct.

(11) Page 14 - The SAI computer model of vapor dispersion cannot be tested sufficiently by small-scale tests. SAI might validly say that the findings from small-scale tests are not applicable to large-scale spills because the gravity spread/air entrainment phenomena only operate on a large scale. SAI's model, as well as several other models, have been validated by data from small spills where gravity spread and air entrainment occur.

(12) Page 17 - Although a single event could cause more than one LNG tank to fail, the example given (Cleveland, 1944) is not appropriate. Certainly the failure of the inner wall of the cylindrical tank would directly lead to the failure of the outer wall (not really a tank as it was made of mild steel), given the porous nature of the insulation. The fact that only one of the remaining three

tanks failed due to fire suggests something about the fire resistance of these relatively primitive tanks.

(13) Page 19 - Large-scale LNG importation could increase through the early part of the 21st century as domestic reserves of natural gas are depleted and LNG from the Persian Gulf (now too expensive for the U.S. market) and other areas becomes economically competitive.

(14) Page 20 - While the Coast Guard has not evaluated LNG safety issues to "the last decimal place," if that is possible, enough is known to permit a reasonable, conservative evaluation. This evaluation provides guidelines for Coast Guard regulations.

(15) Page 21 - By rating hazardous materials in order of increasing need for research, LNG research would be placed at a lower priority than the authors suggest.

1. Chapter 14:

(1) General Comments

(a) The emphasis of R&D work should be shifted from LNG to LPG and other hazardous materials. Considering the limited resources available and the considerable work already done on LNG, it seems reasonable to now spend more time and money on other hazardous materials.

(b) Any additional LNG R&D effort should first be directed toward the development of a rapid response detector for methane, ethane, and propane since measurement of cloud concentration variations as a function of time are extremely difficult to obtain with currently available equipment. Such an instrument would require one to two years to develop. Also, a suitable test chamber is needed.

(c) The time and cost estimates presented by GAO are extremely optimistic based on Coast Guard experience.

(d) The report only addresses further work on detonation and flame propagation. Other problems which might be addressed are: rollover, underwater release, release inside a ship's hull, pool spread rate, the flameless explosion phenomena, and tank car and tank truck BLEVE's (Boiling Liquid, Expanding Vapor Explosion).

(2) Page 3 - Fractionation is visually apparent in a pool fire.

(3) Page 4 - Another question to consider is whether detonation in a confined space such as a building could initiate a detonation in an unconfined cloud?

(4) Page 9, 1st paragraph - The 90% methane/10% propane mixture failed to detonate with a 2kg initiator, not a 1kg initiator. An 85% methane/15% propane mixture did detonate with a 3kg initiator.

(5) Page 18 - Prof. R. C. Reid of MIT has shown experimentally that fractionation exists. Since the boiling points of methane, ethane, and propane are so different, fractionation would be expected in a pool or land burn.

(6) Page 19 - The recommendation to the Secretary of Energy should include (1)(a) and (1)(b) above.

(7) Page 20 - Spills on open water are extremely hard to instrument without rapid response detectors. The time and cost estimates for the experimental program are very optimistic.

(8) Page 21 - Detonation initiation sources are to be surveyed for the Coast Guard by the Naval Weapons Center.

(9) Page 22 - Comments (1)(a) and (1)(b) apply to the wind tunnel vapor plume tests. Note that the Coast Guard is developing a rapid response detector for total hydrocarbon vapor concentration. Completion is scheduled for the first quarter 1979.

(10) Page 23 - Concerning detonation initiation and propagation:

(a) Detonation to deflagration transitions should also be studied.

(b) The possibility of confined and unconfined propane detonations triggering unconfined methane detonations should be studied.

(c) The Coast Guard has found that the maximum flame speed for hydrocarbons occurs at concentrations of 110% of stoichiometric. Initial tests should be at 110%.

(d) Comment 1.(1)(a) applies to this issue.

(11) Page 24 - Run-up distances to methane detonation should be measured for both confined and unconfined

mixtures. The cost and time estimates are unrealistically low.

(12) Pages 24-26 - Concerning the large vapor cloud field tests, it is worth noting that the largest instrumented spill on water has been $10m^3$; spilling $400m^3$ would require more than two years to carry out. Practically, how would one activate 10-20 initiators simultaneously? Thermal radiation and fireball tests with propane would be useful, also.

m. Chapter 15.

(1) Page 6: While the Federal Power Commission's various models for LNG vapor cloud dispersion may owe something to "Coast Guard analysis," the Coast Guard does not endorse these models.

(2) Pages 8-9: The current edition of the LNG/LPG Contingency Plan for the Port of Boston does not make use of vapor cloud propagation and thermal radiation models.

n. Chapter 18:

APPENDIX IV

(1) General - Despite the high level of Japanese transportation and storage of LNG/LPG, no mention is made of their safety record except for minor accidents with no damage. The Japanese have more than 150 LPG ships which are mostly in domestic service. Since there is no mention of serious accidents, one must assume their safety record is excellent. Furthermore, since naphtha was supposedly used as a comparison, it is interesting to note that a collision in Tokyo Bay involving a LPG ship which was also carrying naphtha was not mentioned. The LPG tanks were not breached and did not fail during the fire. The naphtha, however, contributed heavily to the ultimate destruction of both vessels involved.

(2) Page 5 - As noted earlier, the statement about diking of LNG tanks in the U.S. is inconsistent with information in Chapter 2. The second paragraph states that an LNG plant at Sembokur has more elaborate firefighting equipment than a "typical" U.S. installation. Is the size, age, and configuration of the Japanese plant equivalent to the "typical" U.S. installation?

(3) Page 8 - The last paragraph about Japanese philosophy is out of place in a technical paper and weakens the credibility of the foregoing presentation.

o. Chapter 19:

(1) Page 8:

(a) The current regulations for ships carrying LEG and some types of naphtha are in 46 CFR Parts 30 to 40, not 35. Part 38 deals specifically with liquefied flammable gases.

(b) Portable containers of liquefied flammable gases are not regulated by 46 CFR 146. 46 CFR 146 was combined with 49 CFR 170-179. 49 CFR 170-179 is administered by the MTB.

(c) The regulations in 46 CFR 151 cover unmanned barges only. They do <u>not</u> include barges carrying the substances involved in this report.

(d) The regulations in 46 CFR 154 definitely <u>do</u> cover LPG. One must, however, look under "B" for butane and "P" for propane, rather than "L".

(e) The statement that 49 CFR 171-173 does not include LNG is erroneous. LNG is listed under "methane" or "hydrocarbon gases, liquefied."

(f) Coal tar naphtha is regulated under 46 CFR 153 as a bulk liquid chemical.

(g) New regulations have been drafted for liquefied gases shipped in bulk. The Notice of Proposed Rulemaking was published in October 1976. The final rule is currently being circulated within the Coast Guard for final clearance.

(2) Page 13 - Design and construction of ships carrying LEG and naphtha are developed at Coast Guard Headquarters. Currently, the Coast Guard has final regulations governing the design, construction, and, to some extent, operation of ships carrying liquefied gases in bulk, circulating for clearance. These are based on the Inter-Governmental Maritime Consultative Organization's Code for liquefied gas ships published in October 1975. Since only the local Captain of the Port (COTP) knows and is responsible for the local conditions of the ports under his jurisdiction, he is in the best position to develop operational controls for vessels carrying LEG and all other cargoes in his port.

(3) Page 24 - This part correctly describes the requirements for diking. The authors of Chapters 2 and 3 apparently did not read Chapter 19.

(4) Page 28 - The finding that "It is <u>virtually</u> <u>certain</u> that design events will be exceeded a <u>large</u> <u>number</u> of times. . . . ", does not appear to be consistent with the statistical analysis on page 26. How does one get from a 78% chance that one of three phenomena will occur at one of 100 facilities in 50 years to "virtually certain" (i.e. 100% chance) that design events will be exceeded a "large number" of times? In view of the fact that there are more than 50 LNG facilities and 100 large LEG facilities (does the 100 LEG figure include the 50 LNG facilities, or did the author mean 100 large LPG facilities?), why not present the record? How many have experienced events exceeding their design? It is doubted that real life is bearing out either the statistical analysis on page 26 or the extrapolated finding on page 28.

(5) Page 30 - Again trucks and rail cars are mentioned. This same, or similar, information is included in three other chapters. This repetition makes the report unnecessarily long and difficult to review and follow.

(6) Page 31 - The statement that design and operating requirements are at the discretion of the Commandant or the COTP is misleading and overstates the case. Some design details must be specially approved by the Commandant. This

does not mean, however, that they are subject to whim as may be implied. Some operating requirements are at the discretion of the COTP since they are dependent on local conditions. COTP's do not issue design requirements.

Again, the implication is made that LPG ships are similar to conventional tankers and are somehow less protected than LNG ships. See the comments in d.(1) above. The last sentence of finding 3 should be deleted.

p. Chapter 20: As noted in this chapter and in chapter 9, there are very few inspectors for hazardous materials tank cars and trucks. Considering the number of Coast Guard inspectors per ship carrying hazardous materials, it is strange that chapter 8 calls for more Coast Guard personnel, but chapter 20 does not do likewise for the other modes. Similarly, more training of Coast Guard inspectors is called for, yet no recommendation is made for FHWA or FRA. If there is a reason for this, other than that there were different authors of the chapters, it should be given. The accident record of the modes tends to indicate that more effort needs to be exerted in highway and rail enforcement rather than in the marine mode.

q. Chapter 21 and 22: Since these chapters are a compilation of the conclusions and recommendations reached in previous chapters, a repetition of the response to each recommendation and conclusion here would not be worthwhile.

r. Appendix VIII -1

(1) The number of each type fire fighting equipment suggests that the appendix is describing a typical 125,000 m^3 LNG ship.

(2) The Emergency Shut Down System applies only to ships with tanks with relief valve settings greater than 10 psig. It is not automatically activated by alarm conditions. The valves close in 30 seconds or less, not "in 30 seconds to prevent shock," which implies they must not close faster.

(3) There is another system to prevent overfilling of the tanks. It consists of automatic valves that are activated by a level switch.

(4) The hold spaces around pressure vessel tanks and spherical tanks like the ones being built by General Dynamics do not have to be inerted all the time. The holds

around the spherical tanks can be inerted rapidly if a gas leak is detected.

(5) The gas detection system does not take continuous suction on all spaces. The requirement is that each sampling point be sampled within a 30 minute period. Some detectors operate continuously, but they are of the catalytic combustion type and do not take suction.

s. Appendix VIII -2 - It is questioned why this chapter was developed at all. There are a number of excellent papers readily available that cover the subject in detail. They were written by recognized experts in the field and could have been appended to the report without rewriting, thus avoiding the introduction of error. There are several minor errors in the appendix which the Coast Guard did not take time to correct. There are two, however, that need to be corrected:

(1) Page 7 - A partial secondary barrier is required in these vessels. The text leads one to believe that a secondary barrier is not required, but the builder installed one anyway.

(2) Page 10 - To pressure off-load a spherical tank, one does not close the relief valves. The relief valves on these tanks have multiple settings. The highest setting (about 30 psig) is used for pressure off-loading.

t. Appendix XIII - Table XIII-1:

(1) For the Vapor Cloud Explosion Study, Phase I, a better summary is as follows: "Developed a theoretical model on non-ideal explosions and calculated the dispersion of a large LNG spill. Large hemisphere tests of flame propagation through unconfined vapor clouds of propane were run, and an experimental plan for the future was prepared."

(2) Prof. Jerry Havens' study of vapor cloud dispersion should be included. He is continuing this work by studying computer models of vapor dispersion for the Coast Guard. The following should be added to this Table:

(a) "Predictability of LNG Vapor Dispersion From Catastrophic Spills Onto Water: An Assessment" (CG-M-09-77)

(b) April 1977

(c) Applied

(d) $50,000

(e) In-House

(f) Analysis of six models of LNG vapor dispersion concluded that the Science Applications, Inc. (SAI) model had the potential of being superior to the others and thus warranted more detailed analysis.

(3) The third entry on page 2, the Operations Research, Inc., project, is available from the NTIS in three volumes, AD-A026108, AD-A026109, and AD-A026110.

u. Appendix XV-1 - In this Appendix the exportation of LNG from Alaska is not included. This has been involved in at least two cases before the Federal Power Commission, South Alaskan gas to California, and North Slope gas to California.

v. Appendix XV-2 - Page 1. The LNG exportation terminals in Alaska should be included in this discussion. Page 16. The item identified as "Tr. Volume 16" should be attributed to Phani Raj, not Phani Nas.

w. Appendix XIX-1 - Page 5. Missing from this list is the Boston Gas Terminal at Dorchester, MA. It has been reported that no imports are currently planned, but ships have delivered LNG in the past. The barge MASSACHUSETTS has loaded LNG at Dorchester and delivered LNG to New York City and Providence, RI. Also, the damaged Texas Eastern Cryogenics facility at Staten Island, NY, received a shipload of LNG.

x. Appendix XIX-2 - Page 1. The Texas Eastern Transmission Corp. Staten Island, NY, facility, referred to as Texas Eastern Cryogenics in Appendix 19-1, did receive a shipload of LNG. Page 11. Since the Public Service Electric Gas Company of New Jersey facility is incomplete and has never operated, the "Year of Operation": "1973-1975" is inappropriate.

y. Appendix XIX -3:

(1) Page 16, 3rd and 4th sentences - The information about the CTIAC is misleading. First, the CTIAC does not "draft" regulations. It offers advice and recommendations to the Coast Guard. The work started in 1972 has been completed. Shortly after the Coast Guard asked CTIAC to offer recommendations in revising the gas ship regulations,

APPENDIX IV

IMCO began work on the Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk. The CTIAC and Coast Guard worked very closely in developing the U.S. input to the IMCO work. Since the Code was viewed as forming the basis for new regulations for gas ships, further work on revising the regulations became pointless. The IMCO Code was completed and adopted in 1975. Since then the Coast Guard has issued a Notice of Proposed Rulemaking implementing the provisions of the Code. Final regulations will be issued shortly. Therefore, the CTIAC has completed its task and to imply that nothing has resulted from their work is simply wrong.

(2) Page 18 - The CTIAC has approved the work of the group on LNG marine terminals and presented its report to the Coast Guard. Subsequent work will be on all other liquefied gases, not just LPG.

(3) Page 19 - The Office of Merchant Marine Safety and the Office of Marine Environment and Systems (G-M and G-W) are not "agencies." They do not operate independently and there is no "strict division of responsibility." The Cargo and Hazardous Materials Division does not develop all regulations governing design and construction of vessels. In fact, several divisions within the Coast Guard perform

that function and it is untrue to say that any one division does it "particularly."

(4) Other corrections are as follows:

(a) 46 U.S.C. 391a contains Title II, not Title I, of the Ports and Waterways Safety Act of 1972. Tank vessel regulations are in Subchapter D of Title 46, not Title 49, CFR.

(b) Coast Guard waterfront facility regulations in 33 CFR Part 126 have been reissued under the authority of the Ports and Waterways Safety Act of 1972 in lieu of the Magnuson Act.

(c) An additional purpose of the PWSA is "to protect the navigable waters and the resources therein from environmental harm resulting from vessel or structure damage, destruction, or loss." See 33 CFR 1221.

(d) The Secretary of Transportation's delegation of PWSA authority to the Commandant of the Coast Guard is in 49 CFR 1.46(n)(4), not 1.46(4).

(e) The Coast Guard <u>does</u> have authority "over an LNG/LPG storage facility that is simply located at the water's edge when the facility does not import LNG/LPG by ship." A Coast Guard waterfront facilities Advance Notice of Proposed Rulemaking will be published covering these terminals under the authority of the PWSA ("any land structure or shore area immediately adjacent to those waters" 33 U.S.C. 1221).

(f) The GAO draft fails to explain the extensive delegation to COTP's contained in 33 CFR Part 160. See 42 Federal Register 48022 (September 22, 1977). It also does not reflect the publication of 33 CFR Part 165, Procedures for Establishing Safety Zones (42 FR 63368 (December 15, 1977)).

(g) The suggestion that legislation is desirable to clarify USCG/OPSO LNG facility jurisdiction is inappropriate since a Memorandum of Understanding has been signed by the Commandant of the Coast Guard and the Director of the Materials Transportation Bureau.

z. Appendix XIX-5, Special Issue No. 10.- Considering that there is an entire chapter devoted to the Coast Guard and its requirements for LEG ships, it is a little surprising to find another section of the report dealing with the same subject.

(1) It is misleading to imply that the Coast Guard has "even more stringent rules for more dangerous liquids" than for LNG/LPG. The Coast Guard has different rules for different cargoes depending on the nature of the cargo.

(2) Part 38 regulations do not apply to ammonia. Ammonia is regulated by 46 CFR Part 98 for ships and 46 CFR 151 for barges. The new regulations for liquefied gas ships will include ammonia and will supersede Part 98.

(3) Part 38 will shortly be superseded for liquefied gas ships. Due to the existence of the IMCO Gas Code and proposed Coast Guard implementing regulations (46 CFR Part 154), it is not worth discussing the specifics of Part 38.

(4) The proposed damage stability requirements depend on the size of the vessel and the cargo it carries, not on its configuration.

(5) The "suitable safety margin" required for tank pressure build-up is 21 days. At present, no ship used

APPENDIX IV

pressure build-up as a means of cargo vapor control. Also no LNG ship in existence uses reliquefaction.

(6) The Letter of Compliance program is not limited to LNG. See 46 CFR 154 for a list of the cargoes included in the program.

(7) There are no damage stability requirements for ships carrying most forms of naphtha. Coal tar naphtha must be carried in a chemical tanker that has stability standards similar to those for gas ships. See 46 CFR 153.

APPENDIX IV

UNITED STATES GOVERNMENT
Memorandum

DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS DIRECTORATE

DATE: MAR 20 1978

In reply refer to:

SUBJECT: GAO Draft Report - "Liquefied Energy Gases Safety"

FROM: Acting Director, Materials Transportation Bureau, DMT-1

TO: Chief, Safety Division, P-24

Attached are the Materials Transportation Bureau's (MTB) comments on the subject report.

MTB requests adequate time for R. L. Beauregard (DCC-1) to review the Department's final response prior to its being forwarded to GAO. Being appreciative of GAO's M[illegible] deadline, MTB is submitting these comments earlier than requested (Wednesday, March 22) to facilitate such a review.

L. D. Santman

Attachment

TO THE SECRETARY OF TRANSPORTATION AND THE SECRETARY OF ENERGY

We recommend that the Secretary of Transportation and the Secretary of Energy:

1 - Require that LNG and LPG tanks in populated areas be built and operated under the same standards as nuclear plants.

Response:

LNG plant characteristics, nature of hazards, criteria for safeguards, and measures available to mitigate hazard are not similar to those of nuclear facilities. For example, when control rods are fully inserted or fuel rods pulled, fission becomes subcritical. In this condition when cooled, a reactor could withstand any conceivable seismic action and safety provided by criteria, such as an "operating basis earthquake" and a "safe shut down earthquake." Since an LNG tank cannot be quickly emptied, this type of criteria is not valid when applied to LNG facilities.

Also, compared to the distance which a radioactive cloud may travel, even the long distances predicted by modeling for an LNG cloud are small. On the other hand, hazards of radioactive exposure are largely time dependent. Therefore, warning and escape from hazard by evacuation or seeking shelter would likely offer protection. Time may not be relevant in the case of a large LNG cloud, since the full extent of the hazard exists with the presence of the cloud and its contact with an ignition source.

For these, and many other reasons, such as variability in size and type of LNG plants, this recommendation is not in the best interests of safety.

GENERAL OVERALL RECOMMENDATIONS

TO THE SECRETARY OF ENERGY, THE SECRETARY OF TRANSPORTATION AND THE CHAIRMAN OF THE FEDERAL ENERGY REGULATORY COMMISSION

We recommend that the Secretary of Energy, the Secretary of Transportation, and the Federal Energy Regulatory Commission take whatever steps are necessary to insure that:

1 - No new, large LEG storage facilities are built in urban areas--and no present ones are expanded.

Response:

The President's National Energy Plan calls for strict siting criteria to foreclose construction of other LNG facilities in densely populated areas. On January 4, 1978, the DOE held public hearings on this and other LNG issues to aid in the development of criteria and recommendations. The siting criteria contained in OPSO's ANPRM would not specifically rule out new facilities in urban areas. Rather,protection would be provided by appropriate exclusion zones to limit the population around a facility. Where land is not available for a zone to protect against the hazards resulting from accidental spills, a facility could not be built.

2 - Any new, large LEG storage facilities not built in remote areas should be inground, with the highest level of fluid below ground level.

Response:

Under OPSO's ANPRM, if storage tanks are designed for belowground construction, the required exclusion zone dimensions can be reduced. This trade off results in the same level of public safety but permits construction where land costs are high or land is not readily available. It does not appear appropriate to mandate a particular method of construction where more economical ones can be used to yield comparable safety.

RECOMMENDATIONS IN THE CHAPTERS

CHAPTER 5 VULNERABILITY OF LEG FACILITIES TO SABOTAGE

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation:

1 - Enforce the requirement, stated in 33 CFR Part 126.15(a), that guards provided by the owner or operator of an LEG facility be in such numbers and of such qualifications as to assure adequate surveillance and to prevent unlawful entrance.

Response:

If it is intended that possible group activity by saboteurs and terriorists with explosives and military weaponry, addressed by Chapter 5, is to be neutralized through strict enforcement of 33 CFR 126.15(a), it would be necessary to be specific as to the number and qualifications of guards necessary for each facility on a case by case basis much as it is now done for security at the far less numerous major airports around the nation. Even what could be considered a large security force for a particular facility could be overwhelmed, or security could be breached from remote locations based on the conditions described in Chapter 5. Accordingly, it appears that regulations and their associated cost, consistent with the intent of Chapter 5 conditions, would not produce a commensurate safety benefit.

We believe that Subpart L of DOT's Advance Notice of Proposed Rulemaking on LNG facility safety, with possible modifications, can provide a more workable framework for the establishment of appropriate security measures.

In particular we recommend that the Secretary make and enforce regulations requiring:

1 - That every truck and train car is carefully checked for weapons and explosives before it enters the facility.

Response:

Even if a "careful check" is not meant to require a search of the interior of the tank, a search of the outside and undercarriage of a truck or rail car would not be effective in light of the potential for concealment and resulting lost time and costliness. For trucks, driver control and identification coupled with transportation procedures would be a more realistic and suitable security measure.

1) - That every driver and passenger in a vehicle is positively identified before they enter the facility. Picture badges should be issued to all frequent visitors.

Response:

Picture identification is desirable, particularly if issued on compeltion of suitable training. The I.D. should indicate the function of the bearer, and be rigorously controlled by the issuing party for currency of function, clearance level, photographic representation, and recovery at termination of employment.

Alternate measures for control of unauthorized entry at unattended facilities will be necessary.

2) - Surveillance of site boundaries and key components on a 24-hour basis.

Response:

We essentially agree. Comparable provisions are included in DOT's proposed regulations. However, alternate requirements for unattended facilities are needed.

3)- That devices be installed which can immediately detect unauthorized entry. These should include completely lighted fences, intrusion alarm systems which can detect if the fence is damaged or crossed, and low light televeision cameras which can see any area of the boundary.

Response:

We essentially agree. DOT's proposed regulations would require similar intrusion devices for facilities with 250,000 bbl storage or more. Again, however, flexibility must be provided for small unattended plants and designs which are intrinsically less hazardous.

4) - Battery powered redundant communications through which security personnel at any point on the facility can communicate to each other and to local law enforcement officials.

Response:

We generally agree if liaison with law enforcement officials is indirect. DOT's proposed regulations include this provision, but alternate measures may be more appropriate for small, remote, or unattended facilities due to the level of hazard or communications problems caused by topographical shielding.

5) - Employee screening and training procedures. The training should include threat awareness, recognition of hazardous devices, special safety precautions, and preventive actions that can be taken.

Response:

A comparable provision is in Section 193.1123 of DOT's proposed regulations. Additional requirements specifically addressing these factors would be reasonable and could be included.

6) - A written security plan which details appropriate procedures for all of the above and is routinely promulgated to all employees.

Response:

Written procedures would have to be prepared and followed under Section 193.1123 of DOT's proposed regulations, and would address the above factors if included as specific requirements.

2 - Require that loaded LEG trucks and railroad cars not be left unattended outside the plant area.

Response:

This proposal appears reasonable and economically acceptable for loaded trucks in transit, since there is little justification for the truck to be unattended while enroute.

For railroad cars, however, the proposal appears unjustified since mobility is limited and attendance when moving is not practical.

3 - Determine what security procedures are necessary to prevent LEG trucks from being sabotaged or hijacked and used for destruction. Particular attention should be paid to unavoidable movements of LEG through densely populated areas.

Response:

The development of effective preventive action to limit the sabotaging or the hijacking of an LEG truck or railroad car and to prevent the use of either for purposes of destruction is a highly desirable objective which we all share. The particular measures for accomplishing this necessarily depend on a thorough evaluation of the various methods of sabotage, hijacking, and destructive use that are possible. A comprehensive examination to enumerate all such possibilities would appear to be the appropriate first step to be development of alternate means of preventing or reducing the likelihood of sabotage, hijacking, or destruction. This information should then be evaluated on a cost benefit basis to determine the probability of failure of the system, the resultant loss as a result of the system failure, and the cost of the system.

Meanwhile, there are some clearly cost beneficial steps that can be taken to reduce the risks, such as prohibiting unattended vehicles in transit, use of driver-initiated engine breakdowns controls, manual reset wheel locks, locked valves, the installation of tire pressure release devices, gas tank water injectors, "on only" visual audible alarms, and automatic emergency signal transmitters.

Our recommendations, in this instance, are made because terrorist activities are forecast to increase over the next decade, and while trucks may be particularly susceptible to ad hoc terrorism, many of the hazards may be ameliorated by simple, relatively inexpensive deterent measures.

4 - Identify all the specific design vulnerabilities to sabotage at each facility and determine the amount of hardening of key components that is needed to reduce facility vulnerability to sabotage and to control forceful entry.

Response:

The DOT's proposed LNG regulation, §193.1123, would require that possible damage effects to critical components be described in advance and addressed by written procedures. Instructions regarding a breach of security and other emergencies would have to be included. Accordingly, identification of facility vulnerabilities and responsive courses of action, which could include "hardening" of key components would be a prerequisite. Although not specifically designated, consideration of sabotage is implicit under this section.

GAO recommendations focus extensively on sabotage. More explicit reference to potential damage from sabotage could be reasonably included in DOT regulations. However, it should be recognized that the conceptual limits of sabotage are unbounded and therefore cannot be predetermined precisely. Consequently, the ultimate source of protection from the effects of sabotage is necessarily the fundamental safety feature of a facility, such as impounding and exclusion zones.

5 - Require that emergency generators be located away from hazardous areas, with a fuel supply that is well protected from fire and explosions.

Response

This is generally covered by Section 193.123(b) of DOT's proposed regulations, which can be made more specific for component separation. The recommendation is reasonable and will be included in the NPRM.

6 - Require that automatic check valves be placed along pipelines which run from piers to storage tanks.

Response:

The benefit from multiple check valves is questionable. NFPA 59A, Sec. 812, has requirements for checks located close to a backflow source, but back flow control is more effectively addressed by the performance language of proposed Section 193.607, although some modification is needed. More effective provisions to minimmize spill volumes are set forth in proposed Section 193.605.

7 - Prohibit the transmission of LEG through pipelines whose integrity is threatened by nearby offsite industrial activity.

Response:

We essentially agree. DOT's proposed regulations would require that the effects of present and predictable adjacent activities be determined (§193.105), and prohibit a facility being located where failure of a critical component could be expected as a result (§193.121). Although not similarly addressed under present liquid standards, this aspect will be considered in rulemaking currently in progress for LPG.

8 - Examine the total handling and storage system at each facility to see if an external pipeline breach in conjunction with the misuse or disabling of appropriate system components could cause a major spill outside the containment area. DOT should require whatever modifications are needed to make this impossible.

Response:

Although we essentially agree with the recommendation as applied to new facilities, in the absence of any showing of an imminent hazard, we believe the intended retrofitting of existing facilities is unjustified, and short of shutting down a large number of facilities, implementation is not possible. Such action could have a dire impact on public welfare with associated greater risk than continued operation of the facility. Jurisdiction over LNG facilities derives from the Natural Gas Pipeline Safety Act of 1968 (49 USC et. seq.) which limits general regulatory authority over design, construction, and testing to new facilities.

However, a case by case evaluation of existing facilities invoking selective modifications on a site specific basis to minimize the most significant hazards would appear to be reasonable.

9 - Examine all facilities near LEG storage sites to see the consequences of simultaneous failures at several sites from a single cause and whether failures at one facility could cause failures at others.

Response:

As expressed, this recommendation would not serve a useful purpose, since the consequences of a single failure at one facility may far outweigh the consequences of simultaneous failures at another facility. Moreover, if it is assumed that the e mination is to be followed by preventive modification, the adverse impact on public welfare could be excessive where facilities may be shut down resulting in the closing of industries, unheated dwellings, loss of cooking fuel and numerous similar events. In light of the safety record of existing facilities, retrofit to specific standards is unjustified. However, limited site specific modifications as suggested in item 8 may be reasonable.

10- Determine whether LEG or LEG vapor accumulating under a tank elevated on piles could cause an explosion that could rupture the tank bottom.

Response:

This is an overly simplistic and extremely costly proposal. It is defective from both a technical and organizational viewpoint. If included in R&D, as appropriate, R&D costs would be greatly increased without commensurate benefit. Analysis of the results of proposed detonation R&D can provide desired information. Moreover, safety is more effectively and efficiently served by prohibiting such designs of new facilities, as provided in OPSO's proposed Section 193.535. Although not similarly addressed by existing standards for LPG tanks, this aspect will be considered in rulemaking currently in progress.

(11-14) - USCG response.

APPENDIX IV

CHAPTER 8 SHIP DESIGN, PEPSONNEL, AND OPERATIONS

CREW TRAINING

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation through the Office of Pipeline Safety Operations:

1 - Require and enforce for LEG terminal personnel the same eight training requirements we have recommended for LEG ship personnel, possibly including the licensing of supervisory personnel.

Response:

Two of the draft regulations in OPSO's Advance Notice of Proposed Rulemaking on LNG facilities deal with the training of plant personnel (§§193.1115 and 193.1311). However, they do not cover the "hands-on" and "simulation" type of training called for by criteria 4, 7, and 8 (pgs. 8-19). Since MTB believes that training is an area in which the present regulations, NFPA 59A, may be deficient, these additional criteria will be considered in the development of a Notice of Proposed Rulemaking on LNG facilities.

2 - Consult with the U.S. Coast Guard about the means both agencies could employ to familiarize terminal and ship personnel with each other's LEG operations.

Response:

The largest risk involving both ship and terminal personnel arises during transfer operations. The OPSO Advance Notice sets out in Subparts G and L proposes requirements for safely transferring LNG between a vessel and the terminal, including both design features and operating procedures. Compliance with many of the procedural requirements by terminal operators would necessitate prior consultation with ship personnel. Specifically, draft §193.1117(e) requires that marine transfer may not begin until the officer in charge of the vessel and the person in charge of the shore terminal have met and approved transfer procedure. This matter will be further considered in the development of our LNG rulemaking, particularly in light of the MOU between the MTB and the Coast Guard regarding waterfront LNG facilities.

CHAPTER 9 TRUCK SHIPMENTS

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation:

1 - Prohibit trucking of LEG through densely populated areas and any areas that have features which are very vulnerable to a major LEG spill (e.g., sewer systems, tunnel openings, subways) unless delivery is otherwise impossible. DOT should also give particular attention to routes with highway configurations which make tank rupture accidents likely (e.g., elevated roadways, overpasses, high-speed traffic, roadside abutments).

Response:

Highway routing is a matter which in the past has been extensively regulated by local jurisdictions who are thoroughly familiar with their individual local conditions. However, the Department of Transportation is currently examining a New York City health ordinance which prohibits the transportation of most radioactive materials. In order to determine what the proper relationship is between that particular form of highway use restriction and the Hazardous Materials Transportation Act, conclusions reached in that examination may warrant a substantial reevaluation of the relationship between State highway use restrictions generally and requirements under the Hazardous Materials Transportation Act.

There is no routing requirement which could be drafted that would completely eliminate the possibility of tank rupture. The Department's motor carrier safety regulations already instruct highway carriers of hazardous materials, which include LEG, not to traverse densely populated areas unless there is no other practicable alternative ("practicable" does not include operating conveniences).

The use of propane and butane, delivered by truck, as a peak shaving tool by industries and commercial enterprises who are on interruptible natural gas supplies, would of necessity require some truck shipment into densely populated areas. In addition, propane and butane are used routinely as processing materials for, aerosol packaging, paint drying, paper fabric mill process drying, and other commercial activities too numerous to list. These specialized uses of LEG also would necessitate continued truck delivery into some densely populated areas.

2 - Require that the relatively vulnerable front end of LEG trailers be protected with heavier steel and cushioning material or shock absorbing equipment.

Response:

In this recommendation, only the front head is to be protected -- most probably because of the one accident cited in the background material. Other data shows results of rear-end collisions which can occur in multiple vehicle accidents after an LEG trailer has been turned onto its side. In this scenario, all areas of the tank are subject to puncture by bridge abutments, guard rail posts, fire plugs, curbing, and following vehicles. To require the increased cargo tank integrity necessary to protect against such an accident is likely to result in a decreased willingness to transport compressed gases due to unfavorable economics. Other alternatives such as cushioning of the entire tank to economically achieve the desired level of protection should be evaluated.

3 - Require that the cabinet housing the control valves of LEG trucks and the valves themselves be kept locked.

Response:

Measures of this type, although reasonable, may serve to deter the impromptu terrorist only. The solution to the problem addressed by this recommendation may well be found in another of GAO's recommendations that LNG trucks must be continuously attended while in transit.

4 - Forbid LNG trucks to carry hoses. The hoses should remain attached to the storage facilities.

Response:

Although cryogenic hoses for LNG are appreciably more expensive than hoses used for the transfer of LPG and other volatile liquids, the cost to implement this recommendation should be comparatively minor for large facilities. For small, remote facilities, this arrangement might be not only financially burdensome, but since the facility could be unattended, protection from vandalism might be actually reduced where hoses are carried on trucks.

5 - Require LEG hoses to have positive coupling devices which would override a required check valve in the exit line. The check valve would prevent the outflow of the liquid into anything other than the special coupling hoses.

Response:

The issue of truck vandalism may be carried to extremes. If a truck in transit has locked discharge valves, continuous attendance and communication contact, deterence of vandalism should be adequate. However, neither these factors nor this additional proposal would deter the dedicated terrorist. Also, since some trucks may be prohibited from carrying hoses, and where hoses are carried, they, together with the proposed devices, would permit discharge from the truck in a manner the prohibition is intended to prevent, we believe this proposal is without merit.

6 - Develop emergency procedures, teams, and equipment to deal with LEG trailer rollovers and spills. Equipment should include empty trailers and portable pumps suitable for transferring LEG from a ruptured vessel. Different equipment will be needed for LNG and LPG.

Response:

The development of emergency procedures is an excellent idea. The use of specialized teams and equipment, however, is questionable. When a spill occurs, reaction and clean up must be immediate to prevent ignition of the vapors. The transfer of LNG to another cargo tank can only be accomplished if the receiving tank has been cooled down --a process that takes time. To maintain such a piece of equipment, for such purpose only, within ready access to any accident, at any location nationwide, is not a practical or viable solution. Certainly, plans can be made to utilize other equipment that is in service as was tried in the one example cited by the authors of this proposal without adding further economic burdens on the system. This practice has been followed in many LP-gas incidents.

7 - Require LEG truck drivers to receive more extensive instruction on the properties of LEG, proper handling of LEG trucks, and proper transfer procedures.

Response: (OPSO)

As indicated by our response to Chapter 5, item 2, suitable training should be required.

8 - Require LPG trailers to be insulated to prevent explosions.

<u>Response</u>:

Rail cars are already required to be insulated. A major determinant for this requirement is that rail cars are shipped in groups of cars and can therefore affect each other in an accident. A requirement of this nature for LPG trailers should be reviewed to determine the increase in transportation costs due to loss of capacity and the additional cost increases in new equipment. It is suggested that insulation at best may only delay - not prevent explosions.

9 - Require all LPG trailers to have a large, correct, secure, easily changeable sign on each side indicating whether or not LPG is odorized.

<u>Response</u>:

An "easily changeable" sign, which, due to human error, might incorrectly indicate that the LPG is odorized could be a very real safety hazard. Also, it should be noted that any LPG vapor cloud is not visible and the presence of visible ice or water particles, which can result only if the escaping vapor chills the atmosphere to its dew point, does not necessarily define the location of hazardous vapor.

Therefore, we believe that this proposal is not in the interest of safety. Odorization control from suppliers should be handled by the bill of lading,

APPENDIX IV

and all signs should state that the cargo may not be odorized, accompanied by a warning to stay well clear, upwind, and not in line with the cylinder centerline if leakage is a likely possibility. Damage and fire control should be part of the "suitable" training for drivers and other responsible persons.

APPENDIX IV

CHAPTER 10 TRAIN SHIPMENTS

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation:

1 - Require a large increase in the size of the placards saying "Flammable Gas" so that they can be more easily read from a considerable distance in the jumble and possible fire of a train wreck.

Response:

The color of the present placard indicates flammability and the symbol as well as the words denote the presence of gas. Because of the unique shape and current size of the placard, it is recognizable from a distance sufficient, in most cases, to provide safety to the viewer.

2 - Require that all LPG cars be prominently labeled "Insulated" or "Non-Insulated" until insulation is required on all of them at the beginning of 1982. This information will be of great help to firemen confronted with a train wreck involving LPG cars and may save many lives.

Response:

This would be valuable if the firemen are fully advised as to the relative value of insulation. A false sense of security may develop. It must be pointed out that the insulation may only delay the ultimate catastrophic failure of the car.

3 - Take immediate action toward requiring stronger, tougher steel in tank cars, or additional puncture protection for the sides of tank cars.

Respc 1e:

Although technically feasible as it relates to puncture protection and lower transition temperature sensitivity steels (tougher steels), it is not known whether such requirements would produce a favorable cost-benefit ratio. There is no need for stronger steels since the tensile strength of steels currently in use is adequate considering wall thickness and design pressure of the tanks.

4&5- Take immediate action to inspect hazardous materials tank cars and remove from service those that are obviously not being maintained properly.

Require inspection every two years of all safety related features of LEG tank trucks and railcars.

Response:

Regular maintenance and inspection of tank cars and cargo tanks carrying hazardous materials are very necessary to maintain safety in transportation. Appearance of rust as noted in this report and a 10-year period of time between retests is not necessarily evidence of unsafe or inadequate maintenance and inspection. None of the incidents cited or the ones discussed provided any evidence that the current regulatory requirements are inadequate or have been causal factors in any accident situation. Rather, the incident reports received to date support the adequacy of the current inspection and testing regulatory requirements.

6 - Prohibit the travel of LPG railroad cars to or through densely populated areas unless it is impossible to deliver it without going through densely populated areas.

Response:

Comments made earlier under Chapter 9 for tank trucks apply equally to this recommendation for tank rs. The term "densely populated area" is used repeatedly in this report, but it is never defined. The Department of Energy LNG Task Force, on which DOT is participating, is presently addressing that very issue.

7 - Require that the Bills of Lading on any train containing hazardous materials have detailed instructions on fire-fighting and other emergency measures which should be taken in the event of a wreck. If the train is to go through any densely populated areas, the instructions should explicitly address the dangers peculiar to such areas.

Response:

Even if each train contained only one hazardous materials car, the practicality of this recommendation may be hampered by the varying reaction capabilities of fire departments (this is especially critical in rural communities in the event of large disasters). In addition, all communities are not alike in their exposure to hazardous materials. A train leaving a large chemical center will have many hazardous materials in many forms. It would literally take hours to read all the "detailed instructions" on such a train. Any instructions so detailed as to address the dangers peculiar to all and each danger area found in proximity to a railroad right-of-way for each hazardous material carried on a particular train would become useless because of time to access the information, digest the information, and then respond to the information.

There are many sources of such information presently available to emergency personnel. OHMO has developed training aides in cooperation with the National Fire Protection Association. The Manufacturing Chemists Association maintains a 24-hour emergency response center known as Chemtrec. In addition, many large chemical producers such as DuPont and Union Carbide Corporation maintain 24-hour emergency response centers. Considering these aspects, instructions on Bills of Lading referencing an information source would be a reasonable and more effective alternative to the recommended approach.

CHAPTER 13 SAFETY RESEARCH AND DISPERSION MODELS

TO THE SECRETARY OF ENERGY AND THE SECRETARY OF TRANSPORTATION

We recommend to the Secretary of Energy and the Secretary of Transportation that:

1 - The primary goals of Federal research on hazardous materials be to: (1) clarify the hazards, risks, and consequences of their use, so that appropriate regulations can protect the public; (2) aid in assuring that the plans and practices of operating facilities are adequate to satisfy the regulations; and (3) investigate techniques to reduce the risk of their storage and transportation.

Response:

We generally agree as indicated in OPSO's 7/29/77 letter to DOE, which suggested many modifications in a DOE research proposal. OPSO emphasized the need for: (1) large scale testing to obtain timely "hazard information;" (2) development of simplified formulae and procedures suitable for regulatory application; and (3) greater emphasis on means to control or mitigate hazards.

2 - An immediate, significant research program be focused on the interaction of hazardous substances with manmade structures such as buildings, subways, sewers, and ships.

Response:

We agree, but this is merely one in a number of subsidiary items in the investigation of explosion initiation and propagation which is needed.

3 - An immediate program be started to investigate the possibility of preventing or mitigating the effects of sabotage on the storage and transportation of hazardous materials in populated areas.

Response:

Although a number of security provisions recommended by GAO, previously had been incorporated in draft LNG regulations, and agreement with other reasonable recommendations is indicated by our response herein, we believe the draft report overemphasizes sabotage as a principal safety issue. Many of the design requirements included in the draft LNG regulations will serve to mitigate effects of sabotage. Moreover, as partly discussed under Chapter 5, item 1, the extent and nature of an act of sabotage is unbounded and therefore indeterminate. The simple solution would be to require that all critical components be located belowground, but we view this course as logically unsupportable. Accordingly, some investigation may be justified, but with reduced emphasis.

TO THE SECRETARY OF ENERGY

We recommend that the Secretary of Energy replace immediately the department's present LEG safety research plans with a less costly two-year effort focused on the sort of studies of detonation, fire characteristics, flame propagation, vapor dispersion, crack propagation, and interaction with manmade structures that we have outlined in this and other chapters.

Response:

We have thoroughly reviewed the DOE Assessment Plan. Although this plan is intended to be flexible, permitting odification as information is gained, we believe that it should be changed now, generally in accordance with our earlier suggestions. The Plan proposes evaluation of models, laboratory tests, and gradual scaling of field experimentation, incorporating all parameter variations including precipitation. Final large scale experimentation and model verification is scheduled for completion in 5 years. Due to the indefiniteness and weather dependency of this project, we believe completion incorporating all variables will take even longer.

Even with a 5 year completion date, much needed safety information will not be available in time for application to proposed facilities. Therefore, priorities should be reordered to first develop information using only variations in parameters needed for facility safety. Models dealing with all parametric variations to be used for response decisions associated with water spills should be relegated to a subsequent phase. We do not believe, however, that the very extensive necessary research can be completed in two years at less cost.

TO THE CONGRESS

We recommend that the Congress provide to the organizations directly responsible for LEG safety (OPSO, FERC, ERA, NHTSA, OHMO, Coast Guard, etc.) adequate budgets and personnel to make informed technical judgments and do research on safety procedures and equipment to be used under their jurisdiction.

Response:

Although we agree that adequate resources are fundamental to successful research, LEG research to date has been fragmented and often duplicative because of the interrelated needs of the responsible agencies. Maximum efficiency and prevention of overlap can be accomplished only by a comprehensive, well coordinated program that is responsive to the needs of the responsible agencies. The program must be structured in strict accordance with the areas of investigation and required results presented in order of priority by each agency.

APPENDIX IV

CHAPTER 14 DETONATION AND FLAME PROPAGATION RESEARCH

TO T. SECRETARY OF ENERGY

The following comments relate to recommendations made to the Secretary of Energy regarding LNG detonation research and the several suggested experiments:

LNG Detonation Research

We agree that DOE's research efforts should answer critical questions as quickly as possible. However, we believe the investigation should not be restricted to detonation, but must address all explosion phenomena to determine all levels of hazard. Also, we believe the time and cost scales are unrealistic in light of problem complexities, uncertainties, and permutations.

Differential Boiloff of LNG Constituents

For time and cost efficiency, using appropriate instrumentation, this effort should be included as a subsidiary element of large scale cloud dispersion/explosion/pool burning experiments. We believe the indicated scale selection is arbitrary, and should be supported or be subject to more extensive determinations.

Detonation Initiation Source

We agree with the intent, if potentially damaging pressure waves from all explosion phenomena is included. This issue is addressed in draft §193.109 of OPSO's LNG draft regulations.

Wind Tunnel Vapor Plume Tests

This effort should be deferred or eliminated in favor of the earliest possible large scale testing, (as indicated by OPSO's letter to DOE of July 29, 1977) since residence time may be a significant factor.

Detonation Initiation and Propagation Experiments Using Plastic Bags

We agree, particularly with respect to confinement configurations for preliminary determination of boundry limits if all damaging pressure waves are included. Large scale tests then may possibly be restricted to "bracketing" tests.

Large Vapor Cloud Field Experiements

As OPSO stated in its letter to DOE of July 29, 1977, integrated large scale cloud tests should be given highest priority. We, therefore, agree in essence with this proposition. However, many problems are unresolved, particularly in instrumentation. In our view, the cost and time effort are unrealistically low in light of the permutations involved.

Two Phase Cloud Detonation

We believe that on a laboratory scale this test lacks technical justification since all current evidence and logic indicate that cloud size is a primary determinant. This testing should be conducted as part of large scale vapor cloud testing for viable information to be acquired.

CHAPTER 15 FEDERAL POWER COMMISSION

TO THE CONGRESS

We recommend that Congress create an Energy Health and Safety Regulatory Agency (EHSRA) to handle all energy health and safety regulation. As described in our earlier report, the EHSRA should include the Nuclear Regulatory Commission; the Mining Enforcement Safety Administration in the Department of the Interior; the safety aspects of transporting fuel on land, now under the Department of Transportation, the safety aspects of importing energy, now handled in the Department of Energy, and all safety responsibilities carried out in the past by the Federal Power Commission. The Environmental Protection Agency should retain the responsibility for setting air and water quality standards, including those impacting energy development and use, and waste disposal.

The new agency could be completely independent of the Department of Energy (DOE), or be included in DOE with strong statutory provisions to ensure its isolation.

Response:

We oppose inclusion of the safety aspects of transporting energy fuels in a new Energy Health and Safety Regulatory Agency to be established in the DOE. This function is now carried out in the Department as part of an overall safety program devoted to the transportation of hazardous materials in general, including transportation by marine vessel. To separate and transfer the fuel aspects of this program, when there are many related benefits in terms of regulatory and enforcement actions and R&D is inimical to an efficient, comprehensive and well coordinated national safety program. Also, we believe the Department's safety functions are central to its mission and more closely related to its other modal responsibilities than to the duties of DOE.

The following recommendations are intended only if an Energy Health and Safety Commission is not formed, or until it is formed. The suggestions should be carried out by EHSC if it comes into existence.

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation:

1 - Require companies handling hazardous materials to file routine operation summaries annually and to report any unusual occurrences within 48 hours to the Office of Pipeline Safety Operations in a manner analogous to the reports required by NRC. Reportable occurrences should include any venting or leakage of hazardous material; any overpressuring of tanks; any transportation breakdown; any vital machinery breakdown; and any attempt by unauthorized persons to enter company premises. These reports should be available to the public in Washington, D.C., and at an appropriate office near the site of the unusual occurrence.

Response:

Operators are now required to submit under 49 CFR Part 191, incident reports on pipeline facility leaks of LNG. Annual operating summaries (except for leaks) and reports of unusual operating occurrences (such as machinery breakdown) are not required. Because of the serious risks associated with handling and storing LNG, these additional reports may be necessary to identify potential safety problems before leaks occur. It would appear more effective to notify local authorities in the event of unauthorized entry on facility property.

APPENDIX IV

2 - Form a central analysis group which would have the staff and resources to discover patterns in the data reported from companies handling hazardous materials. It makes no sense to require companies to go through the expense and trouble to submit annual operation reports and unusual occurrence reports if they are not going to be analyzed in sufficient depth so that serious future malfunctions can be prevented. The Office of Hazardous Materials Operations' Accident Analysis Branch does not operate in this fashion. (See Chapter 20.)

Response:

MTB is forming a central analysis group for the purposes stated in this recommendation for OPSO and OHMO operations. The staff would of necessity be highly trained accidents analysts and qualified engineers familiar with the current standards to determine corrective actions.

CHAPTER 19 FEDERAL, STATE, AND LOCAL REGULATIONS

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation direct:

1 - OPSO to issue standards for detailed operating procedures and for operator qualification and training. It should periodically review operating plants to see that they are meeting those standards.

Response:

Suggested requirements for operating procedures and the qualification and training of personnel are in OPSO's ANPRM or LNG facilities. Additional detail may be appropriate and will be considered, but precise detail is precluded by the wide variation in facility types and sizes.

2 - OHMO to promulgate standards for LNG vehicle design.

Response:

These standards are being developed currently.

CHAPTER 20 FEDERAL REGULATION OF LEG TRUCK AND RAIL CARS

TO THE SECRETARY OF TRANSPORTATION

We recommend that the Secretary of Transportation:

1 - Issue through OHMO specific regulations prohibiting LEG trucking in densely populated areas, and on streets having underground conduits unless there is no other way to accomplish deliveries.

Response:

The response to Recommendation 1, Chapter 9, is applicable to this recommendation.

2 - Develop standards for hazardous material trailer manufacturers which would complement the standards for shippers and enforce both with the same inspection and compliance apparatus.

Response:

These standards have existed for many years in the case of LP-gases and other hazardous materials in 49 CFR Part 178. Cargo tank specifications for manufacturers of LNG equipment are being developed currently by OHMO.

The various modal administrations in the Department such as FRA and FHWA also have enforcement capabilities and inspection and compliance functions in place. The MTB is reorganizing to enhance its operations in the compliance and enforcement areas.

3 - Impose harsh penalties on companies that fail to report hazardous material releases.

Response:

The current laws under which the Department regulates LNG safety provide the authority to impose such penalties. MTB is reorganizing to enlarge and increase the effectiveness of their enforcement and compliance activities in all areas under the MTB control, including incident reporting.

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

WASHINGTON, D.C. 20591

DATE: February 8, 1978

IN REPLY REFER TO:

SUBJECT: GAO Draft Report Entitled "Liquefied Energy Gases Safety"

FROM: Director of Accounting and Audit, AAA-1

TO: Director of Environment and Safety, P-20

As requested by TAD-1 in his January 31 letter, here are our comments on the subject report for your consideration in preparing the Department's response to the General Accounting Office (GAO).

We agree that there is a potential for widespread disaster in the event of an accident involving an aircraft landing on Runway 4R at Boston and a Liquefied Energy Gases (LEG) ship in transit through the shipping channel.

The air traffic control tower at Logan International Airport has a program for detection of ships in Boston Harbor. The system makes use of radar, closed circuit television, and verbal communications to detect, track, and identify ships with tall masts. Such vessels can be an obstruction to aircraft making instrument approaches to Runway 4R. We will expand our tall mast detection program and clear aircraft landing on Runway 4R at Logan Airport so that the aircraft will not fly directly over large LEG vessels operating within the boundaries of the instrument landing system protected airspace trapezoid. The Captain-of-the-Port, U. S. Coast Guard, has assured us the U. S. Coast Guard will provide sufficient advance warning of the LEG vessels with cargo. Implementation of the service will require at least two months for completion of procedural arrangements and controller training.

We are confident that establishment of this additional service will meet the GAO safety recommendations and reduce to the minimum any chance of incident between aircraft and surface vessels.

We appreciate the opportunity to provide our comments on this report.

for E. M. KEELING

Form FHWA 121 (Rev. 5-73)

UNITED STATES GOVERNMENT

DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

Memorandum

SUBJECT: ACTION: Request for Proposed Reply to GAO Draft Report dated January 20, 1978, (Assistant Secretary Scott's memorandum of January 31, 1978, copy attached)

DATE: MAR 2 1 1978

In reply refer to: HPR-1

FROM : Deputy Administrator

TO : Mr. Chester C. Davenport
P-1 Assistant Secretary for Policy and International Affairs

This is in response to the subject memorandum requesting FHWA comments on the GAO draft report, "Liquefied Energy Gases Safety."

For the record, our response was delayed because of a departmental request to GAO for an extension of time for completion of DOT comments which we understand was denied by GAO.

Accordingly, the attached comments are offered for your consideration for inclusion in the departmental response. Our specific comments are limited to Chapters 9, 19, and 20, since they are directly related to FHWA's area of responsibility. We also have several comments on the report as a whole.

We appreciate the opportunity to comment on this draft report.

Karl S. Bowers

Attachment

APPENDIX IV

FEDERAL HIGHWAY ADMINISTRATION (FHWA)

COMMENTS ON

GENERAL ACCOUNTING OFFICE (GAO)

DRAFT REPORT ON

"LIQUEFIED ENERGY GASES (LEG) SAFETY"

GENERAL COMMENTS

1. We believe the report understates the effectiveness of both Federal and State regulatory schemes.

2. We believe the extreme solutions to perceived threats of sabotage or risks to the public are overstated. If terrorists wanted to select a target for sabotage, there are many more readily available candidates, including tank trucks that carry gasoline, poisons, and other hazardous materials. Given the volume of movements of hazardous materials and the degree of exposure, the case has not been made for the costly and complex solutions proposed.

3. We disagree with the proposal to shift Department of Transportation (DOT) transportation safety functions to the Department of Energy, since the basis for forming the DOT was to consolidate transportation functions.

4. We believe the report does not adequately discuss the costs of its recommendations in relation to possible benefits.

5. We believe the report generalizes about accident risks based on single or very few reported accidents, which can be very misleading.

SPECIFIC COMMENTS

I. Chapter 9 - Truck Shipments

1. Page 7 - In referring to Vulnerability to Sabotage, a statement is made that "A remote controlled shutoff valve is also built into this line, but is normally left in the open position." (Emphasis added) The Department's Regulations governing cargo tanks require a "self closing internal valve with remote controls" (49 CFR 178.337-11), and that the valves be closed during transportation (49 CFR 177.840(g)). While our inspections have found some cargo tanks being operated with these valves open, it has been the exception rather than the rule.

2. Page 18 - It is recommended by GAO that the Secretary of Transportation "prohibit trucking of LEG through densely populated areas . . . with particular attention to routes with highway configuration which make tank rupture accidents likely." The Federal Motor Carrier Safety Regulations (FMCSR), in Section 397.9, specifically require that all vehicles transporting hazardous materials follow routes which do not go through or near heavily populated areas, places where crowds are assembled, tunnels, etc., unless there is no practical alternative. The subject of elevated expressways is not addressed in the FMCSR as the FHWA feels this is best left to the discretion of the individual municipalities. The FMCSR do require that carriers follow laws and ordinances established by municipalities in which a vehicle is operated, such as truck routes.

3. Page 19 - The GAO recommends that Liquefied Petroleum Gas trailer tanks be insulated to help prevent explosions. Research by the Federal Railroad Administration has proven that insulation on a tank has two benefits: (1) the length of time a tank can be exposed to fire before exploding is greatly increased; and (2) an insulated tank explodes with less severity. Insulating a cargo tank adds several hundred pounds of weight to the vehicle. Since motor carriers are faced with highway weight restrictions, the amount of LEG that can be carried by a highway vehicle will be reduced by the added weight of the insulation. This will mean more trips by the highway vehicle, thus more exposure to accident potential.

Industry sources have estimated a cost of about $2,000 to insulate a cargo tank. It would be difficult to justify this cost against the good safety record of these vehicles.

II. Chapter 19 - Federal, State, and Local Regulations

1. Page 1 - The GAO states that "Federal regulations are similar to those of the States and municipalities because of their common reliance on National Fire Protection Association (NFPA) Codes." While there may be some reliance on the NFPA Code by the States and municipalities for storage requirements, transportation requirements are common among the Federal and local jurisdictions because of reliance on Federal (DOT) regulations. To date some 33 States have adopted the Federal Hazardous Materials Regulations in whole or in part. The DOT specifications for cargo tanks often have a greater safety factor than do industry or NFPA standards.

III. Chapter 20 - Federal Regulations of LEG Trucks and Rail Cars

1. Page 2 - The first paragraph, below reference to Materials Transportation Bureau, should read: "The Administrator of the FHWA has delegated his authority to the Director of the Bureau of Motor Carrier Safety (BMCS) . . . ."

2. In the last paragraph on that page, reference is made to the number of BMCS inspectors. The current number of inspectors is 128. On this page and page 3, reference is made to the FHWA Assistant Regional Directors. Their correct title is Director, Regional Motor Carrier Safety Office.

3. Page 7 - The reference to the FHWA's driver qualifications has several errors. In the first paragraph, it is stated that ". . . the FH(W)A's physical requirements do not apply to intermittent or temporary drivers." The second paragraph states that "All drivers must take a road test or have a State license for the category of vehicle to be driven." The only drivers excused from the physical requirements are those used in a commercial

zone or a city and then only if they do not transport hazardous materials. The intermittent or temporary drivers need not have the written test, road test, or background test, but must meet the physical requirements.

Form FSA F 8 (10-73)

UNITED STATES GOVERNMENT

Memorandum

DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION

DATE: 2

SUBJECT: Response to GAO Draft Report "Liquefied Energy Gases Safety"

In reply refer to: RAD-44

FROM: Federal Railroad Administrator, ROA-1

TO: Assistant Secretary for Policy and International Affairs, P-1

We have reviewed the subject report and prepared the attached detailed response pursuant to your memorandum of January 31, 1978.

JOHN M. SULLIVAN

Attachment

Form DOT F 1320.1 (1-67)

UNITED STATES GOVERNMENT

Memorandum

DEPARTMENT OF TRANSPORTATION
OFFICE OF THE SECRETARY

DATE: January 31, 1978

In reply refer to: TAD-222

SUBJECT: ACTION: Request for Proposed Reply to GAO Draft Report Dated January 20, 1978

FROM: Edward W. Scott, Jr.
Assistant Secretary for Administration

TO: Commandant, United States Coast Guard
Federal Aviation Administrator
Federal Highway Administrator
Federal Railroad Administrator
National Highway Traffic Safety Administrator
Acting Director, Research and Special Programs Directorate

We are requesting that you and your staff prepare comments on the General Accounting Office (GAO) draft report, "Liquefied Energy Gases Safety." We have asked the Assistant Secretary for Policy and International Affairs to prepare and coordinate a Departmental reply. In order for your comments to be considered in the reply they must reach the Office of the Assistant Secretary for Policy and International Affairs by February 13, 1978. In order to facilitate meeting the due date your GAO liaison officer has been provided with an advance copy of the report.

If you or your staff have questions concerning this request, please call John Dawkins on extension 60580.

Attachment

FEDERAL RAILROAD ADMINISTRATION REPLY TO GAO DRAFT REPORT ENTITLED

LIQUEFIED ENERGY GASES SAFETY

Overall, we have been overwhelmed by the size of the report. The lack of a digest or summary in a report this large has been particularly disconcerting. On the other hand, although the report is voluminous, we found the chapters relating to rail matters to lack the details necessary to support many of the findings, conclusions and recommendations.

Chapter 10 Train Shipments

Findings

We disagree with the finding that Boiling Liquid-Expanding Vapor Explosions (BLEVE) are caused by the steel of the uninsulated single-wall tanks weakening from intense heat to the point where it can no longer hold the normal tank pressure. We believe in addition to the steel weakening, the build-up of pressure contributes to the BLEVE. Moreover, tests sponsored by FRA indicate that the required safety valve is not adequate to maintain safe pressure levels for uninsulated tanks which have overturned.

We also disagree that present static pressure tests are not adequate to ensure that the cars are safe in extreme conditions.

We consider that the finding that rusted tank cars are currently being used is very superficial. GAO noted 2 tank cars out of about 20,000 had some rust but the depth of the rust was not determined. The rust observed could conceivably been surface rust only and, if so, did not result in any degradation of the tank shell's structural integrity. For GAO to conclude from this that "improperly maintained tank cars holding hazardous materials under high pressure are a sizable and unnecessary danger to the public" is unwarranted. In none of the many National Transportation Safety Board and FRA railroad accident investigations involving Liquefied Energy Gases (LEG) cars, has improperly maintained tank shells been identified as causing or aggravating the accident. It is improper maintenance of wheels, bearings, axles, etc., that is more likely to cause or aggravate a hazardous material railroad accident.

With regard to sabotage, while it is certainly true that a group of LEG rail tank cars "can be derailed at a predetermined time and place" by saboteurs or extortionists, similar opportunities are available to such individuals, such as stationary LEG storage installations, hotels, office buildings, etc. It should be noted that the vast majority of derailments involving LEG rail cars do not result in release of LEG and only a small number cause deaths, injuries or extensive property damage.

APPENDIX IV

Recommendations

We disagree with the recommendation to increase the size of the placards. We believe there is no practical size placard that can be read safely in an accident. Train billing and other information is used to alert emergency service personnel. The placards and product stencils assist carriers in performing proper handling and assist in providing information about leakages.

We disagree with the recommendation requiring all Liquefied Petroleum Gases (LPG) cars be prominently labeled "Insulated" or "Non-Insulated" since firefighters would receive no useful information.

We disagree that tougher, stronger steel should be required in tank cars. We believe existing steels are the most practical for this service. Although extremely expensive steels could improve puncture resistance, there have been few punctures that would not have been prevented by head shields.

We also disagree with the recommendations requiring immediate action to inspect hazardous materials tank cars and remove those not being maintained properly and requiring inspection every two years of all safety related features of LEG tank trucks and railcars. Such action in both cases is being done right now.

We disagree with the recommendation prohibiting travel of LPG cars through or to densely populated areas unless it is impossible to do otherwise.

We disagree with the recommendation requiring that Bills of Lading on trains containing hazardous materials have detailed instructions on firefighting and other emergency measures in the event of a wreck. We do not believe there need be special information for handling accidents in densely populated areas. We believe the existing systems are adequate.

Concerning the third recommendation, both Calspan and Railway Progress Institute/Association of American Railroads (RPI/AAR) have explored the cost-effectiveness of requiring either thicker steel walls or tougher steel and concluded that neither concept was cost-beneficial. RPI/AAR also considered the cost-effectiveness of a shell-shield and found that this latter concept had a very unfavorable cost-benefit ratio. It should be noted that the recommendation could only be applied to new cars and, therefore, it would be at least 40 years before this recommendation could be fully implemented.

APPENDIX IV

Discussions within the chapter

PAGE 1, Paragraph 1, Line 1

We believe railroads handle about 8 to 10 percent of the long distance LPG instead of 4 percent.

Paragraph 3, Line 1

We believe all LPG railroad traffic is part of interstate commerce and not subject to local regulation.

PAGE 2, Paragraph 1, Line 1

Suggest the following rewording "The AAR's research department and the tank car committee of the Railway Progress Institute cooperate ...."

Paragraph 2

Suggest the following number changes:

Line 1 - 10,248 instead of 10,450

Line 2 - 158 deaths instead of 108
1,282 injuries instead of 980
1.54 deaths instead of 1.03

Line 3 - 12 injuries per hundred accidents instead of 9.38

Line 4 - 2,360 accidents due to human error instead of 2,476

Line 5

"...4,260 accidents resulted from defects in railroad structure, track and roadbed, 2,174 from defective equipment, and 1,454 from miscellaneous defects."

Paragraph 3, Line 4

20,000 evacuations instead of 10,750

PAGE 4, Paragraph 2, Line 2

850-1,000 psi instead of 500-1,250

Paragraph 2, Line 7

Suggest the following rewording: "All cars carrying LPG are required to be labeled with 10 1/2 square foot diamond oriented placards saying 'Flammable Gas' and with lettering on both tank sides identifying the flammable gas."

Paragraph 4, Line 7

We disagree that there is imminent danger when ignition is immediate and believe such a condition still possesses a high hazard.

PAGE 5, Paragraph 1, Line 6

Suggest the following rewording: "...a 45,000 pound steel section..." instead of "the 45,000."

Paragraph 2, Line 8

Suggest "at ambient temperatures" instead of "near 220°C."

PAGE 7, Paragraph 4, Line 3

Virtually no support for this statement.

Line 5

We do not believe it can be described as "rust." The cause is oxidation of white paint and the result is not diminutive of tank shell thickness.

PAGE 9, Paragraph 2, Line 4

Railroads charge shippers on a per ton basis.

Line 6

Title 49 instead of 4a

PAGE 11

In an FRA sponsored study, Calspan has investigated the cost-effectiveness of imposing additional restrictions on the placement of LPG cars in a train. Calspan concluded that these restrictions were not indicated.

In the last sentence, GAO indicated that they did not agree with FRA that HM-144 was sufficient. This sentence should be clarified. HM-144 was based on an extensive research and development program which has been documented in numerous reports, public briefings, and notices in the Federal Register. It would be desirable if GAO included a summary of the analysis that they have performed that leads them to conclude that HM-144 is not sufficient.

PAGES 15 and 16

In the Notice of Proposed Rulemaking for HM-144, 25 technical reports were referenced. In the references section of the draft GAO report only one of these reports is cited and that particular report is the least relevant of the 25. Many of the 24 reports GAO did not cite specifically address points raised by GAO.

Chapter 19 Federal, State, and Local Regulations

Special Issues Analysis

8. Materials Specifications for Truck Trailers and Railcars

The report states that there are no requirements for periodic inspection of rail tank cars or tracks for corrosion. However, the cars are inspected externally every trip and internally every 5 years. Tracks are also inspected periodically.

General - In listing the various regulations concerning LEG safety, the report omits FRA regulations concerning the construction of railroad employee sleeping quarters in the immediate vicinity of switching or humping operations. FRA has promulgated interim rules that require railroads proposing to build employee sleeping quarters within a one-half mile radius from a facility where a switching or humping operation occurs to provide FRA with estimates of the volume of LEG shipment through the facility.

Interstate Commerce Commission

Washington, D.C. 20423

OFFICE OF THE CHAIRMAN

MAR 7 1978

Henry Eschwege
Director
United States General
Accounting Office
Washington, D. C. 20548

Dear Mr. Eschwege:

In your letter of January 20, 1978, you request comments on a GAO draft report on Liquefied Energy Gases (LEG) safety.

I am pleased to forward to you the attached comments of the Commission.

If I can be of further assistance, please contact me.

Sincerely yours,

A. Daniel O'Neal
Chairman

Attachments

(Commissioner Clapp was absent and did not participate)

COMMENTS OF A. DANIEL O'NEAL
CHAIRMAN, INTERSTATE COMMERCE COMMISSION
ON GAO DRAFT REPORT
LIQUEFIED ENERGY GASES SAFETY

Thank you for the opportunity to comment on this vital safety matter. We were asked to address proposals in Chapters 9, 10, 12, and 19. Summarized in Chapter 22 are the specific recommendations relating to this Commission. They are:

- -not allow LEG to be carried under a certificate for petroleum products. It should require a special certificate for LNG and a separate special certificate for LPG. This will limit responsibility to fewer carriers with more experience.
- -not allow trucking companies which are licensed to carry LNG to lease these rights to other companies which have not demonstrated their competence to the ICC.

Apart from these recommendations, several other comments warrant discussion.

Motor carriers with authority to transport petroleum products are authorized to transport LEG, as stated in Chapter 9 of the draft report; and LNG can be transported under liquid chemicals authority.

The recommendation that special certificates should be required for the transportation of LEG arises out of the drafters' conclusion that dangers in transporting LEG are far greater than those in trucking petroleum products. Apparently overlooked is the fact that chemicals and petroleum products are regularly transported by very specialized carriers, using special equipment and trained personnel subject to specific safety regulations. The equipment has to be precisely matched to the commodity being transported, and special handling is required in the loading, unloading, and line haul and in cleaning the equipment. The very specialization of these carriers' operations is a significant factor, for it brings to the carriers in the ordinary course of their business many dangerous commodities, and requires of them a special competence.

Prohibiting ICC licensed carriers from transporting LEG under broad generic descriptions would not produce the effect sought by the GAO. The reason is that a very substantial part of interstate truck transportation in this country is in private or exempt operations. In April 1977, the Commission released a study entitled "Empty/Loaded Truck Miles on Interstate Highways During 1976." The study included a survey of trucks passing certain points, and that survey as depicted in Table VIII of the report provides an insight into the importance of non-regulated carriers in the liquid petroleum products industry. Of those surveyed there were 139 petroleum products trucks operated under Commission authority, 15 were exempt from our regulation, and 154 were private carriers. It thus appears that, even if the ICC were to take some restrictive action as to the "petroleum" haulers, well over half the trucks carrying petroleum products would be unaffected. A copy of the April 1977 report is attached.

There is a serious legal obstacle to reducing the scope of a motor carrier's ICC authority. Such a reduction would be tantamount to a partial revocation of authority subject to Section 212 of the Interstate Commerce Act, and that section requires notice and a hearing. If we attempted an industry-wide revocation, we would need a body of evidence to justify the revocation. At the hearing many carriers would undoubtedly seek to show that they transported LEG safely for years.

Nowhere in the GAO draft report has a nexus been established between the danger sought to be avoided and the transportation of LEG by the purportedly less experienced carriers of petroleum products. Mere hypothesis will not do in this situation.

The GAO also should not overlook the fact that shippers have become dependent upon the services of these carriers, and would be disadvantaged if they were not able to find replacement carriers immediately. In the alternative, they would be forced to appear as supporting witnesses in other application proceedings, probably for the same carriers that have served them previously. In the end this would result in more paperwork for everybody, to arrive at the status quo insofar as carriers, vehicles and operators are concerncd.

There are proper avenues at present for the Department of Transportation to recommend revocation of a certificate or permit on the basis that a carrier has violated applicable safety regulations. DOT can appear as a complainant in a proceeding before the Commission and request revocation. While Chapter 20 of the report relates that this has been recommended in the past, without revocation having been achieved, the report does not intimate what issues or evidence was involved in these cases, nor does it identify the cases. We have ordered carriers to suspend operations for a time because of a safety complaint, as in Federal Highway Administration v. Safeway Trails, Inc., 113 M.C.C. 815 (1971). And in Ewen Brothers, Inc., Common Carrier Application, 108 M.C.C. 878 (1969), a motor carrier applicant was found not fit to

APPENDIX V

receive a certificate under safety related circumstances.[1] Finally, our fitness flagging procedures, 49 C.F.R. 1067.1 et seq., provide a mechanism for the Department of Transportation to intervene in application proceedings on the issue of an applicant's fitness to conduct proposed operations. See 49 C.F.R. 1067.5. The Department of Transportation and the Commission have established a liaison on these issues, and cooperation between the two agencies has continued. DOT has appeared as an intervenor in proceedings before the Commission, and we have encouraged such intervention on matters of safety.

Chapter 9 recommends that the Commission not allow trucking companies licensed to carry LNG to "lease these rights" to other companies which have not demonstrated their competence before the Commission. This reflects misconception. Under the lease and interchange rules operating rights are not leased. The carrier with the franchise in a particular territory leases the equipment of the connecting carrier. The lease of rights, on the other hand, occurs normally as a preliminary to a conveyance of the rights. (See 49 C.F.R. 1132.5), but that is not the context in which the term is used in the draft report.

---

[1] Where a motor carrier's request for operating authority indicates a proposed regular movement of a dangerous commodity, the Commission imposes a five-year limitation, or less, on the authority so that safety fitness can be evaluated on a recurring basis. This normally occurs in applications for operating rights authority where there is a specific request for authorization to transport dangerous explosives, radioactive materials, LPG, LNG, and other compressed gases such as liquid hydrogen, oxygen or nitrogen.

There are several short-term situations where an entity other than the originating carrier provides the equipment and driver for all or part of the transportation. One carrier may perform a joint movement with another carrier (interlining), where each holds a portion of the relevant territorial authority. A carrier with the specified rights may lease equipment from another carrier, and use the lessor carrier's driver; but it is the duty of the lessee carrier to ensure that the driver is familiar with the Motor Carrier Safety Regulations of the Federal Highway Administration. See 49 CFR 1057.5(e). Owner-operators may perform short-term services for one carrier, and eventually offer services to another carrier.

These practices are widely employed in the trucking industry. They arose out of the need to provide flexible operations, to meet urgent demands for equipment, and to eliminate deadhead mileage. Leasing a truck with driver usually entails the acquisition of a person with experience and training in handling the equipment and the lading.

As to the demand for service within the transportation industry, it is variable in terms of quantity and location; and to forbid the lease and interchange practices would seriously disrupt the industry. This is especially true of the tank-truck operations, where equipment is highly specialized and inherently inflexible as to use. This inflexibility is commonly recognized, and is reflected by the relatively high empty mileage of tank-trucks. See pages 6 through 8 of Empty/Loaded, supra.

It would be economically unsound to forbid flexible use of tank-truck equipment in the transportation of LEG. The result would be higher transportation costs of this form of energy, which would translate into higher energy costs. And there would be no benefits in terms of safety. Our suggestion is that a focus be put on safety regulation at the driver-equipment level. Such a focus would be the direct and most effective way to achieve the goals espoused by the GAO in the draft report. It would not matter what trucking company authority was actually being used to perform the move; the important preventive focus would be on the daily operations level.

MISCELLANEOUS COMMENTARY

Chapter 9 of the draft report comments that certificates issued by the Commission are in the form of irregular route, or broad geographic authority. In other words, the Commission would not normally specify a route over which LEG was to be transported. The report correctly observes that 49 CFR 397.9 governs the actual prohibition of dangerous routings and is not within our jurisdiction. However, the draft continues by stating that "The ICC merely seeks to assure itself that would-be entrants have sufficient financial resources to meet normal operating costs." Entrance into the interstate motor carrier industry, and expansion of one's authority, requires a finding by the Commission that the public requires the service. In addition, each carrier must prove that it is fit, willing and able to comply with the Commission's regulations. Safety fitness is an issue in these proceedings, as noted above, and the Department of Transportation can intervene in a case if it believes that a carrier should not be granted authority because it lacks competence to handle dangerous articles safely or has a poor safety record.

The draft report also states that the Commission imposes "one significant limitation" on companies transporting LPG, in that they are not allowed to ship it by trucking subsidiaries. Apparently what is being addressed here is the transportation operations for compensation or direct benefit by one corporate entity for an affiliated company. This issue was discussed in Intercorporate Parent-Subsidiary Transportation, 123 M.C.C. 768 (1975), and it involves all commodities. We fail to see what direct bearing this has on the safety-related issues under discussion, and believe the reference should be discarded.

At page 2 of chapter 9, specified trucking companies with LNG certificates are said to believe the ICC should not allow LNG to be transported under a "petroleum products" certificate. The GAO agrees, saying the dangers involved in LNG trucking require such a conclusion. This wording implies that the comments of the trucking companies were based on safety factors. In all probability those carriers were taking this stand on economic grounds knowing their share of the business could increase if fewer carriers were authorized to participate. On this point the GAO report should be clarified.

CONCLUSIONS AND SUMMARY

The Department of Transportation has primary responsibility for railroad and motor carrier safety. That is acknowledged in the draft report. 49 U.S.C. 1655 outlines the transfer of the safety functions from the I.C.C. to DOT. Those functions cover explosives and other dangerous articles as well as protection of employees and travelers, hours of service, safety and operation of transportation equipment, and appliances and equipment on railroad engines and cars. The responsibility

APPENDIX V

of the Commission goes primarily to economic control, stability and efficiency in the transportation industry.

The Commission practices sought to be changed do not involve economic regulation. We do not believe those practices have a direct effect on safe transportation of the commodities under discussion nor that the proposed changes would contribute significantly to the draft report's objective. There is an effective mechanism through which ICC and DOT can collaborate in improving carrier safety and by intensified effort it can be made more effective. Whenever safety fitness is in issue, DOT can participate in proceedings before the Commission and even initiate action here. Greater emphasis on that program should be encouraged.

Fitness, including safety fitness is a threshold issue in motor carrier licensing and adequacy of service cases. The Commission has encouraged DOT participation in those cases and is openly receptive to complaints and evidence on the issue.

We do not believe wholesale revocation of operating authority is warranted absent evidence that such an act would accomplish positive safety goals. Plainly such is not indicated here and we believe the revocation would be disruptive to carriers, shippers and the public they serve.

Again, thank you for the opportunity to comment upon these proposals.

National Transportation Safety Board

Washington, D.C. 20594

March 29, 1978

Mr. David Rosenbaum
United States General Accounting Office
Washington, D. C. 20548

Dear Mr. Rosenbaum:

We have not yet had an opportunity to read in detail your report "Liquefied Gas Energy." We intend to do that in the near future after which a mutually beneficial meeting could be arranged.

As I mentioned in our phone conversation, I did get to read the conclusions and recommendations. I found no reason to disagree with your findings, many of which are similar to those made by the National Transportation Safety Board. As I said, I am less able to comment on the recommendations at this time. My hesitation is based on the fact that I have not yet been able to evaluate their practicability and priority.

Your recommendations regarding personnel and training I found both important and doable. If carried out they could have a significant effect on safety rather quickly and at minimal cost. I might add that to achieve the full impact of a personnel/training program it must have the support of professionals who understand the need for and the means of systematically defining the critical trainable tasks.

In the interest in getting this to you it has not run past the Board. Thank you for the opportunity to review your draft. I will be in touch.

Sincerely,

C. P. Seitz, Ph. D.
Chief, Analysis Division
Bureau of Plans and Programs

☆U.S. GOVERNMENT PRINTING OFFICE: 1978-724-294/1179-31

(00199)