# REPORT TO THE COMMITTEE ON GOVERNMENT OPERATIONS UNITED STATES SENATE

## BY THE COMPTROLLER GENERAL OF THE UNITED STATES

# This Country's Most Expensive Light Water Reactor Safety Test Facility

Energy Research and Development Administration
Nuclear Regulatory Commission

The Senate Committee on Government Operations asked GAO to review the Loss-of-Fluid-Test facility. This report discusses the

- --reasons for the major change in program objectives midway during the project;
- --cost growth and schedule slippages which were incurred;
- --relationship between the Energy Research and Development Administration and the Nuclear Regulatory Commission, for managing and operating the test facility; and
- --opinions of five nuclear experts on several technical questions relating to the test facility's objectives, design, and potential effects on reactor licensing.

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B-164105

The Honorable Abraham A. Ribicoff
Chairman, Committee on Government
Operations
United States Senate

Dear Mr. Chairman:

In response to a request, jointly made by you and Senator Glenn, attached is our report on the Loss-of-Fluid-Test facility. A major part of the report deals with the increased cost and schedule slippage of the facility and the opinions of five nuclear experts on the planned facility test program.

We revised the report in response to some comments of officials of the Nuclear Regulatory Commission and the Energy Research and Development Administration.

We will contact your office in the near future to arrange for the release of this report so that copies can be provided to interested Members of Congress and to other congressional committees and to agency officials.

We are also sending this report today to the Honorable John H. Glenn, Jr.

Sincerely yours,

Elmer B. Staats

Comptroller General
of the United States

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## ABBREVIATIONS

| | |
|---|---|
| AEC | Atomic Energy Commission |
| ERDA | Energy Research and Development Administration |
| GAO | General Accounting Office |
| LOFT | Loss-of-Fluid-Test facility |
| NRC | Nuclear Regulatory Commission |

COMPTROLLER GENERAL'S REPORT TO THE COMMITTEE ON GOVERNMENT OPERATIONS United States Senate

THIS COUNTRY'S MOST EXPENSIVE LIGHT WATER REACTOR SAFETY TEST FACILITY
Energy Research and Development Administration
Nuclear Regulatory Commission

## DIGEST

GAO was asked to review operations of the Loss-of-Fluid-Test facility, this country's most expensive light water reactor safety test facility which was authorized in 1963.

The test facility, located at the Energy Research and Development Administration's Idaho National Engineering Laboratory, will produce about one-sixtieth the heat output of a commercial reactor.

Originally this facility was to involve one major nuclear test--what would happen if a reactor lost its cooling water and overheated, causing its nuclear fuel to melt. (See p. 8.)

In 1967, the test facility's program was redirected to study the adequacy of analytical techniques used to evaluate emergency core cooling systems. These systems are intended to prevent the fuel from melting should a reactor lose its normal coolant.

At that time, the nuclear fuel meltdown test was dropped from consideration. The redirection was a result of increased demand for and average size of nuclear powerplants and recommendations by the Advisory Committee on Reactor Safeguards and a special Atomic Energy Commission task force established to study emergency core cooling system. (See p. 9.)

The original facility project was estimated to cost $38 million and to be completed in 1966. But as of June 30, 1975, the project had cost $162 million, with $21 million more authorized for fiscal year 1976. Nuclear tests are not scheduled to begin until the fall of 1977.

The Nuclear Regulatory Commission estimates that the total project cost will be $350 million by the time nuclear tests are completed in 1982. Costs and timeliness were generally considered less important than the technical goals of the project.

The project redirection and the many design changes to the facility while it was being built were major contributors to the cost overrun and schedule slippage. (See p. 19.)

GAO recommends that the Administrator include, as part of the semiannual report to the Congress on the status of construction projects, total projects design and construction costs including that portion funded from the operating appropriation. Officials of the Energy Research and Development Administration agreed with the recommendation in principle and are evaluating the impact it might have on their reporting requirements for construction projects. (See p. 24.)

The Energy Reorganization Act of 1975, which split the Atomic Energy Commission into the Nuclear Regulatory Commission and the Energy Research and Development Administration, gave most safety research and development responsibilities to the Nuclear Regulatory Commission.

An agreement in principle for the joint use of the test facility was signed by the two agencies in August 1975. This guaranteed the project direction to the Commission but recognized the rights of ownership and potential use of the facility by the Energy Research and Development Administration. (See p. 30.)

Emergency core cooling systems have never been tested in an actual operating reactor under accident conditions; the nuclear industry and its regulator--the Nuclear Regulatory Commission--depend on small-scale experiments and complex computer analytical techniques to determine whether these emergency systems are adequate. (See p. 3.)

Loss-of-Fluid-Test facility tests should indicate applicability of these techniques in calculating the events during a loss-of-coolant accident, but will not by themselves prove or disprove the actual effectiveness of emergency core cooling systems in a commercial reactor. (See p. 46.)

At the request of the Senate Committee on Government Operations, GAO consulted with five nuclear experts to answer several technical questions about the test facility and its planned test program. The complete text of the consultants' reports are included in the enclosure to this report. They generally believed that the current test program should be continued as now planned without any additional delays.

They did not see any benefits of using the facility to conduct meltdown experiments either because the facility is too small in scale or its design is not suited for meltdown experiments. (See p. 41.)

Four of the five experts believed, however, that the Nuclear Regulatory Commission should increase its research on nuclear core meltdowns and attendant radioactivity releases because of the many unknowns in this area and the risks and consequences of a major nuclear accident. (See p. 43.)

Three of the five experts believed that the commercial nuclear powerplant licensing process should not be changed pending the facility's test results. (See p. 48.)

# CHAPTER 1

## INTRODUCTION

As of December 1975, 56 nuclear powerplants were licensed for commercial operation and accounted for about 8 percent of our country's electrical capacity. Another 85 were under construction. Plans have been announced to construct 97 more powerplants. The Energy Research and Development Administration (ERDA) believes that nuclear power can supply more than half of the Nation's electricity by the end of the century.

Most reactors in operation, under construction, or planned are light water reactors. They use ordinary water to cool the nuclear core and generate steam to power turbine generators. ERDA believes that this Nation's short-term energy needs can be partially accomplished by building more light water reactors.

Inherent in the development and expansion of all forms of nuclear power is the protection of the public's health and safety from the hazards of nuclear materials and the consequences of a nuclear accident. In the case of light water reactors, some nuclear experts believe that the chain of events and phenomena that could be involved in a major nuclear accident are, in a theoretical sense, sufficiently understood to permit conservative designs which mitigate the effects of such an accident. On the other hand, others argue that some events and phenomena are still not clearly understood and probably not accounted for in current reactor designs.

The Atomic Energy Commission (AEC), the Nuclear Regulatory Commission (NRC), and ERDA[1] have, since the introduction of light water reactors into the economy, sponsored research to improve the theoretical and technical understanding of light water reactors. Also, AEC and NRC have studied questions surrounding the safety of these reactors. For years the single light water reactor safety project which has received the most attention and money is the Loss-of-Fluid-Test (LOFT) facility. It is hoped that once operating, this testing facility will be able to answer some questions as to whether current computer licensing analytical techniques can adequately predict the

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[1]The Energy Reorganization Act of 1974 (Public Law 93-438) abolished the Atomic Energy Commission and established the Energy Research and Development Administration and the Nuclear Regulatory Commission.

behavior of emergency core cooling systems. These systems are designed to prevent a core meltdown (the consequence of the worst possible series of reactor accidents) should the normal cooling water in the reactor be lost due to a major pipe rupture.

## THE LOSS-OF-COOLANT ACCIDENT

Although AEC's and NRC's light water reactor research and development programs have encompassed a number of areas, the loss-of-coolant accident area has always been one of the most critical. It is one of the design basis accidents and is considered to be the most severe accident when designing most of the safety systems for reactors. This accident could occur if an operating reactor lost its coolant because of a major rupture in one or more of the pipes carrying the coolant or in the pressure vessel surrounding the core.

If accidents occur, reactors are designed to quickly stop the fissioning or chain reaction by automatically inserting into the nuclear core control rods which absorb excess neutrons. Also, the massive loss of the water coolant itself, which slows the neutrons to permit fissioning, would act to halt the chain reaction. However, in the absence of continued cooling, enough residual heat would be present and generated in the fuel to eventually melt the core. If another series of unlikely events take place, this could lead to a breach of the containment building and the release of large amounts of radioactivity to the atmosphere. Although the degree of harm is disputed by various groups, it is generally believed that an uncontrolled release of radioactivity to the atmosphere could cause many deaths and much destruction of property.

The report of a recent reactor safety study, sponsored by AEC and commonly called the Rasmussen Report, concluded that the probability of a core meltdown accident in a single light water reactor is about 1 in 20,000 a year. Assuming 100 reactors are operating in the United States by 1980, the chance for 1 such accident, according to the Rasmussen Report, is 1 in 200 per year. The Rasmussen Report also concluded that with 100 operating reactors, a meltdown accident involving 1,000 or more fatalities would have a probability of 1 in 1,000,000 a year or about the same as a meteor striking the earth and causing a similar number of deaths.

Even with these low probabilities, the potential consequences of a core meltdown accident are severe enough to make its prevention of paramount importance. The Rasmussen Report estimated that the most severe accident (with a probability of one in one billion of occurring) could involve 3,300 early fatalities and about 45,000 early illnesses but that delayed health effects such as latent cancer fatalities and genetic effects would not be discernible when compared to their normal incidence rate. These estimated statistics have been questioned by groups such as the Union of Concerned Scientists. They have said that the worst statistics would be about 20,000 to 40,000 early fatalities and 100,000 early injuries.

To prevent a core from melting following a loss-of-coolant accident, commercial light water reactors are equipped with several systems designed to inject or spray cooling water on the reactor core in case of pipe breaks of various sizes. These emergency core cooling systems are also designed to be redundant so that if some components fail to operate, the core can still be cooled. However, these systems have never been tested in an actual operating reactor in an accident situation. Therefore, to predict their behavior in large commercial reactors, reliance is placed on the ability to use analytical techniques or computer codes to translate test results from small scale experiments. This is a necessary alternative to conducting full-scale tests on every component under every possible situation. Emergency core cooling systems would be of little use in the highly improbable accident involving a catastrophic rupture of the pressure vessel since the emergency water--like the primary coolant water--would be expelled from the vessel.

Because there remains a need for information on loss-of-coolant accidents, NRC is directing a large portion of its reactor safety research toward increasing detailed knowledge of postulated accidents of this type. Some of the major experiments in this research will be performed in the LOFT facility.

## LOFT FACILITY

The LOFT facility, authorized by the Congress on July 22, 1963, is a 55 megawatt (thermal)[1] light water reactor which has about one-sixtieth the heat capacity of a full-scale plant. It is located at the Idaho National Engineering Laboratory (formerly the National Reactor Testing Station) near Idaho Falls, Idaho.

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[1]A measure of heat while megawatt electric is a measure of electric power. For present generation nuclear powerplants, about three megawatt thermal are required for each megawatt electric produced.

There are two types of light water reactors--pressurized and boiling. In both types, steam is generated to power the turbine-generator equipment. In a pressurized water reactor, the water in the nuclear core is held under pressure and thus, not allowed to boil. Rather, it produces steam in a steam generator outside of the nuclear core. A boiling water reactor generates steam by directly boiling water in its nuclear core. Of the 53 commercial nuclear powerplants now operating in the United States, 33 are pressurized water reactors, and all but 1 of the remainder are boiling water reactors.

As presently designed, LOFT is a scale model of a pressurized water reactor. It consists of a mobile test assembly, containment building, and other associated buildings. The mobile test assembly includes the principal elements of a nuclear steam supply system mounted on a railroad dolly: a nuclear core with representative fuel elements, a reactor cooling system with pumps and valves, a steam generator, and an emergency core cooling system. The containment building complex includes sprays, filters, and post accident instrumentation. (See the picture of the LOFT mobile test assembly and containment building on the next page.)

The LOFT testing program will include a series of loss-of-coolant experiments initiated by deliberately opening valves in one of the reactor cooling pipes. Although LOFT is not as large as current power reactors, NRC believes that the accident phenomena will provide a test of the analytical methods used to predict the performance of larger pressurized water reactors during a loss-of-coolant accident. It will not be generally applicable to larger boiling water reactors.

In a letter dated April 7, 1975, the Senate Committee on Government Operations asked us to determine

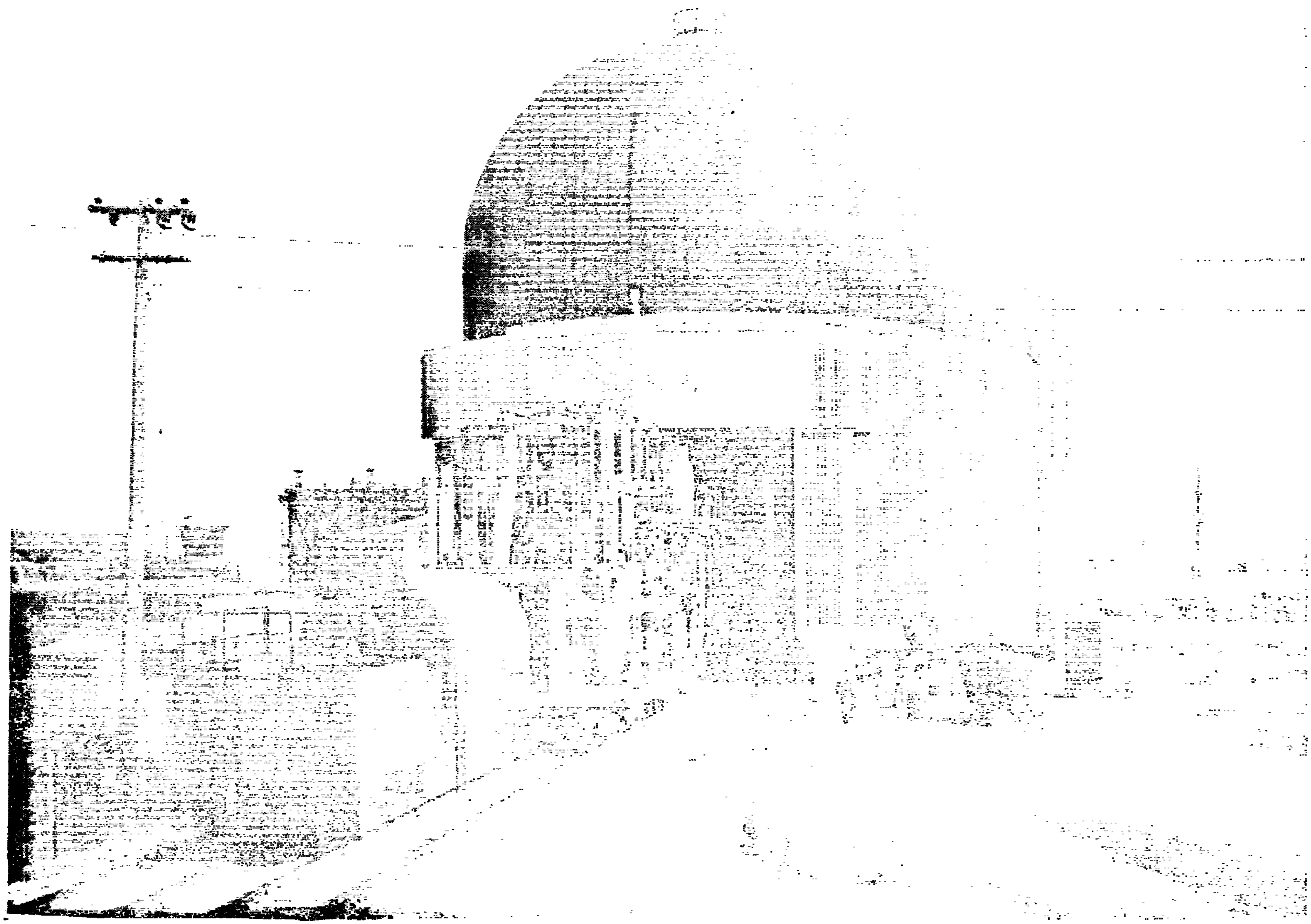
--the reasons for changing LOFT objectives and design;

--the reasons for the LOFT cost growth and schedule slippages;

--the reasons for changing LOFT management contracts;

--whether NRC can carry out independent research on the ERDA-owned LOFT facility;

--the effect on safety research and development of the 1970 deletion of the so-called "practical value" clause from the Atomic Energy Act of 1954, as amended; and



(CREDIT: NRTS)

LOFT MOBILE TEST ASSEMBLY BEING MOVED INTO THE CONTAINMENT BUILDING.

--the opinions of five nuclear experts on whether the current plans for LOFT are in the best interests of nuclear safety.

The following chapters discuss the results of our review.

## CHAPTER 2

## LOFT PROGRAM OBJECTIVES

Although the Loss-of-Fluid-Test facility was authorized in 1963, no nuclear experiments have yet been conducted. During the past 12 years, LOFT has undergone a major change in its objective and numerous design changes. The Committee asked us to

--identify and assess the factors AEC considered in redirecting LOFT,

--provide information on the safety research recommendations of the Advisory Committee on Reactor Safeguards[1] and an AEC task force established to review emergency core cooling,

--determine why the Phillips Petroleum Company was replaced as LOFT operating contractor and whether Phillips and AEC disagreed over the design and ultimate use of LOFT, and

--determine the extent that the nuclear industry participated in designing and redesigning LOFT.

### ORIGINAL OBJECTIVE

The original LOFT objective was to measure the effects of a reactor core meltdown resulting from a simulated loss-of-coolant accident. This test, initiated by a simulated major pipe rupture, would represent the "maximum credible accident" for a light water reactor, and would possibly destroy the LOFT reactor core. AEC anticipated that information gained from the test could be used to help predict the reaction of larger reactors and serve as a basis for location, design, construction, and operation of reactors with full insurance of safety. AEC looked at LOFT as a way of possibly reducing the built-in conservatism in nuclear reactors and containment designs, thereby reducing the cost to build reactors.

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[1]A Committee established by a 1957 amendment to the Atomic Energy Act, which reviewed and advised AEC on safety studies and license applications. The functions of the Advisory Committee on Reactor Safeguards were transferred to NRC by the Energy Reorganization Act of 1974.

The original LOFT testing program was intended to measure the behavior of fission products released by the planned loss-of-coolant accident including normal containment leakage and possible breach of the containment, and to measure the behavior of the molten core. According to former Phillips and Idaho Nuclear personnel, this experiment was to be "quick and dirty." The original testing program was to be financially austere.

## CHANGE IN OBJECTIVE

In May 1967 the Director, AEC Division of Reactor Development and Technology directed a change in LOFT's objective. Instead of melting the core and measuring the resulting phenomena, LOFT was to include, on a priority basis, the testing of computer code analytical techniques used to predict the behavior of emergency core cooling systems under accident conditions. The reasons for the redirection were

- --recommendations by a 12-member task force commonly referred to as the Ergen Task Force established by AEC to study emergency core cooling systems,
- --questions being raised by the Advisory Committee on Reactor Safeguards on the effectiveness of engineered safety systems such as emergency core cooling systems in preventing a meltdown, and
- --increases in both the demand for and average size of nuclear powerplants which required more experimental data on the effectiveness of emergency core cooling systems.

### Ergen task force

In October 1966 the AEC Director of Regulation appointed a task force to report on the adequacy of power reactor emergency core cooling systems and core protection. This group was established because the AEC Regulatory staff and the Advisory Committee on Reactor Safeguards were concerned about the adequacy of emergency core cooling systems and the phenomena associated with core meltdown in light of the increasing size and complexity of nuclear powerplants.

The task force report concluded that sufficient reliance could be placed on existing emergency core cooling systems, but recommended that further evaluations of these systems be made along with small-scale meltdown experiments conducted outside a reactor. It further recommended more detailed evaluations to determine the appropriate design of particular emergency core cooling systems, and noted that improvements in certain key systems were needed to insure that they would function properly.

According to former task force members, the task force recommended more safety research and development on light water reactors so that

--successful experiments on facilities such as LOFT might permit less conservative designs of commercial reactors,

--additional confidence could be placed in the analytical techniques used to predict the loss-of-coolant accident behavior of a reactor, and

--greater insurance could be placed on the effectiveness of emergency core cooling systems in reactors which were not only increasing in size and complexity but also were being placed in areas nearer to population centers.

Two former task force members told us there were two factions in the group--experimental laboratory personnel (Argonne National Laboratory, Battelle Memorial Insitute, Phillips, and others) and industry representatives. While experimental laboratory personnel favored emergency core cooling tests, the industry representatives were worried about the possibility the report would arbitrarily recommend LOFT results be obtained before any further commerical plant operation, thus leading to the death of the commercial nuclear industry. The task force members eventually agreed that the report should emphasize the need for emergency core cooling oriented safety research.

Advisory Committee on Reactor Safeguards

In its August 16, 1966, reports on two nuclear reactors, the Advisory Committee recommended major improvements in emergency core cooling systems. On October 12, 1966, the Advisory Committee wrote the AEC Chairman emphasizing the importance of emergency core cooling as an engineered safeguard and recommended further research on core cooling processes.

The Advisory Committee told us that it believes research on both emergency core cooling systems and core meltdown is important, and that the effort on the latter should be expanded. It believes accident prevention including emergency core cooling system research is, however, the most important safety research objective with the mitigation of accident consequences (such as studies of core meltdown) being of secondary importance. NRC spent about $400,000 on meltdown research in fiscal year 1975 and is expanding that to $1 million in fiscal year 1976 and $1.4 million in 1977.

The Advisory Committee also told us that LOFT will best be used in the next several years for research on performance of existing and improved emergency core cooling systems. However, considerable study and major facility modification would be required before LOFT's usefulness for core meltdown tests could be determined. The Advisory Committee said that if such meltdown tests are conducted, they should be preceded by nuclear tests conducted outside a reactor and experiments inside a reactor on a scale smaller than LOFT.

## Demand for and size of powerplants

When LOFT was conceived in 1962, AEC and the reactor industry believed that the maximum credible accident, including core meltdown, could be contained in small commercial plants of a few hundred megawatt (electric) capacity by isolating the plant and carefully designing the containment building and pressure reduction spray systems.[1] Therefore, the early LOFT test program was designed around a single core meltdown test with careful monitoring of released fission products.

In the late 1960s, when larger plants (800 to 1,000 megawatts electric) were being designed and constructed, AEC recognized that not only would an uncooled reactor core melt, but it might also contain enough energy to melt through the reactor pressure vessel and the bottom of the concrete containment building. Consequently, emergency core cooling systems were considered essential to prevent core meltdown

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[1] Systems within the containment building which use sprays to reduce the internal pressure caused by the release of steam from the reactor during a loss-of-coolant accident.

in the event of a loss-of-coolant accident. The emergency core cooling designs which were to be incorporated in the newer and larger reactors, however, were not at that time based on extensive experimental data. Therefore, in 1967, AEC decided to change the LOFT program from a core meltdown experiment to an emergency core cooling system computer code verification program. It was also anticipated that an integral test such as LOFT would help identify any possible unexpected events not previously accounted for in reactor designs.

## REPLACEMENT OF PHILLIPS PETROLEUM COMPANY

### History of Phillips role at the site

AEC awarded Phillips its first contract for Idaho operations in 1951. Under this contract, Phillips operated the Materials Testing Reactor at the National Reactor Testing Station (which is now the Idaho National Engineering Laboratory). In September 1953, it became the prime contractor for all operations at the Idaho site. AEC extended this contract in 1957 and again in 1961.

In May 1963, AEC announced that it would try to give other qualified and interested organizations added opportunity to compete for supplying services to AEC. Under this policy, AEC did not renew the full scope of Phillips prime contract for site operations. Instead, in 1966 it awarded a new 5-year contract to Phillips covering AEC's reactor safety program, which included LOFT and two other test facilities at the Idaho site.

At the same time, AEC awarded a 5-year contract to Idaho Nuclear Corporation, a joint venture of Aerojet-General Corporation and the Allied Chemical Corporation. Under this contract, Allied Chemical Corporation operated the chemical processing plant at the site while Aerojet-General Corporation operated three test reactors and central service functions such as shops, library, utilities, transportation, and cafeterias. The AEC Chairman stated that the decision to segment the Idaho operation was in no sense a reflection on Phillips past performance.

## Dispute between AEC and Phillips

After Phillips lost part of its contractual responsibilities in Idaho, relations between Phillips and AEC began to deteriorate. Between mid-1967 and early 1969, the Director of AEC's Division of Reactor Development and Technology became increasingly dissatisfied with Phillips performance at the site. His major complaints concerning Phillips operations at Idaho Falls were its

--lack of adequate technical personnel,

--lack of direct and active participation of top management in its Idaho activities, and

--nonresponsiveness to AEC's program requirements.

While Phillips officials acknowledged that the relationship between their company and AEC grew steadily worse between 1967 and 1969, they partially blamed AEC for the problems which developed. In general, they maintained that Phillips personnel problems were not as severe as claimed, and that their top management was directly involved in the company's Idaho operations. They also said some of AEC's LOFT program requirements were unreasonable and unclear.

## Phillips exclusion from Idaho operations

From 1969 to 1971, a series of corporate and contractual activities took place which finally resulted in the total exclusion of Phillips from Idaho operations. These activities began in early 1969 when Phillips proposed a merger wherein its Idaho operations would be consolidated under the Idaho Nuclear Corporation contract. Phillips considered the merger to be a reasonable way to extricate itself from its unsatisfactory working relationship with AEC's Director of Reactor Development and Technology. Under the merger, which Idaho Nuclear Corporation and Phillips agreed to in April 1969, Aerojet-General Corporation got 52 percent of the stock in Idaho Nuclear and Phillips and Allied Chemical Corporation each received 24 percent.

On December 23, 1970, the AEC General Manager asked the President of Idaho Nuclear Corporation if his corporation wanted a contract extension. On January 14, 1971, the nine directors of Idaho Nuclear Corporation met to vote on the extension proposal. The two Phillips directors and two Allied Chemical Corporation directors voted in favor of a contract extension, but the five Aerojet-General Corporation directors abstained from voting and thereby killed the resolution. On March 25, 1971, the President of Idaho Nuclear Corporation sent a letter to AEC indicating that the corporation did not want to extend its contract.

On April 21, 1971, AEC announced that it was negotiating with Aerojet Nuclear Company, a subsidiary of Aerojet-General Corporation, for the prime contractor role at the site. In the same announcement, AEC said Allied Chemical Corporation would be given responsibility for the chemical processing plant as a subcontractor to Aerojet Nuclear Company. AEC's decision to negotiate solely with Aerojet Nuclear Company as prime site contractor was based on Aerojet-General Corporation's virtually exclusive role in site management between 1969 and 1970 as the managing partner of Idaho Nuclear Corporation.

According to AEC, Phillips corporate involvement in Idaho Nuclear Corporation's actions to improve its management effectiveness between 1969 and 1971 ranged from minimal to nonexistent. For this reason, AEC did not foresee and did not consider any future role for Phillips in site operations after June 30, 1971.

### Phillips and AEC agreement on LOFT objectives

Although Phillips and AEC had numerous conflicts over the management of LOFT, especially between mid-1967 and early 1969, AEC and Phillips officials told us that they agreed on the design and ultimate use of LOFT. Thus, neither the original nor the redirected LOFT objectives triggered Phillips' gradual departure from Idaho Falls.

## INDUSTRY PARTICIPATION ON LOFT

AEC and its contractors made a continuous effort to involve the nuclear industry in the LOFT program from its inception to the present. Industrial representatives did not object to the original LOFT meltdown experiment and provided inputs to both experiment and component designs. These inputs continued after the 1967 redirection, even though industry believed reactors were already safe and questioned the need for LOFT. AEC and the LOFT contractor responded regularly to industry's comments and suggestions and used them to formulate the LOFT design and test program.

In December 1967, AEC asked the three commercial pressurized water reactor vendors (Babcock and Wilcox, Combustion Engineering, and Westinghouse) to comment on the redirected LOFT program. The vendors supported the new emergency core cooling system objective and described aspects of the program which they believed needed more emphasis. In May 1969, Phillips asked these vendors to comment on the LOFT program document, which was the first design document for the emergency core cooling system objective. Their comments revealed some industry concerns about LOFT. Reservations were expressed about LOFT's high costs and delayed experiments as well as the effect of these delays on licensing requirements. In addition, some concern was cited about LOFT's relatively small size and its lack of typicality compared to full-scale pressurized water reactors. General Electric Corporation, the boiling water reactor manufacturer, told AEC in a July 1969 letter that the cost of LOFT was high and the timing late with respect to the benefits to safety development.

To obtain additional industry input on LOFT's design, the LOFT operating contractor awarded contracts to the three commerical pressurized water reactor firms in 1970. The firms were asked to analyze LOFT, comment on its adequacy as an experimental model of a large pressurized water reactor, and to furnish their own computer analyses of LOFT as it would behave in a loss-of-coolant experiment. The Aerojet Nuclear LOFT program manager told us these contracts were the best way to get the required vendor input on their light water reactor systems.

A December 1973 Aerojet Nuclear summary revealed vendor reservations concerning the LOFT program. Westinghouse said that because of identified differences and various assumptions that had to be used in its analyses, it was not possible to conclude that actual LOFT performance would be typical of large pressurized water reactor performance, nor that it could be used as a confirmatory test of the overall adequacy of pressurized water reactor emergency core cooling systems.

In his summary, the manager of Aerojet Nuclear's LOFT Program Division said,

> "Some of the vendors appear to be reserved in their attitude toward LOFT. They do not see LOFT as an answer to their reactor problems, but as a mechanism for creating additional problems for them."

One vendor believed LOFT would perform in a manner generally similar to, although not necessarily typical of, a large pressurized water reactor. Aerojet Nuclear's LOFT Program Division manager, however, said

"We do not believe typicality (identicalness) is required between LOFT and a LPWR [large pressurized water reactor] to have a meaningful experiment."

In May 1974, Aerojet Nuclear and AEC Headquarters personnel met with each of the pressurized water reactor vendors to discuss the LOFT Design Basis Report and asked for formal comments. The vendors made the following comments.

Combustion Engineering

Combustion Engineering was concerned about analyses to be performed, the method for comparing pretest analyses to test results, and the acceptance criteria to be used. They were also concerned with specific technical areas where they expect more severe problems in LOFT than would occur in a large pressurized water reactor. One Combustion Engineering representative described areas where he believed LOFT is and is not useful for resolving large pressurized water reactor licensing problems. He even suggested extensive core damage--10 percent meltdown--be allowed on LOFT in a late test to prove the core could still be cooled.

Babcock and Wilcox

Babcock and Wilcox stressed a general concern for more accurate and appropriately located measurements on LOFT, especially temperature measurements. The company felt initial temperatures have a large effect on the ability of current nuclear accident computer codes to predict accident responses. Babcock and Wilcox also believed LOFT should be used for loss-of-coolant induced fuel failure tests instead of the Power Burst Facility. The Power Burst Facility, like LOFT, is a test reactor used for safety research at the Idaho site.

Westinghouse

Westinghouse reiterated its belief that it is not possible to conclude that actual LOFT performance will be typical of large pressurized water reactor performance. Westinghouse did not believe LOFT could be used as a confirmatory test of the overall adequacy of pressurized water reactor emergency core cooling systems. According to Westinghouse, typicality statements on LOFT should be qualified carefully until nonnuclear LOFT verification tests are completed. In addition, Westinghouse cited several technical concerns. In particular, Westinghouse questioned such areas as the scale and analytical modeling of a core component, typicality of the fuel, lack of instrumentation testing, and positioning of the steam generator.

## CHAPTER 3

## LOFT COST GROWTH AND SCHEDULE SLIPPAGES

The Loss-of-Fluid-Test facility was originally authorized and funded as part of AEC's safety test engineering program. Of the $19.4 million in plant and capital equipment funds which the Congress authorized for this program, $17.6 million was for LOFT construction, and $1.8 million was for construction of a related project, the Nuclear Test Facility. This facility was later canceled and funds for it were transferred to the LOFT project. An additional $19.1 million for operations cost and $1.3 million for related capital equipment were also estimated as part of the initial project costs. NRC now estimates that the total cost to construct the project and perform the tests will be about $350 million.

Originally, LOFT facility construction was expected to be completed in March 1966. After a major program redirection, numerous design changes, and dozens of schedule slips, LOFT construction was not completed until December 1975, a total slippage of almost 10 years.

The Committee asked us to identify reasons for cost increases and schedule slippages and to determine if AEC and LOFT contractors made reasonable efforts to complete the facility promptly. The Committee also asked us to identify the major design changes and their cost impact.

### LOFT COST GROWTH

As of June 30, 1975, the total project cost had increased from $38 million to about $162 million.

| Cost element | 1964 total estimate | Actual cost as of June 30, 1975 | Increase |
|---|---|---|---|
| | | (millions) | |
| Construction | $17.6 | $ 36.5 | $ 18.9 |
| Operations | 19.1 | 118.3 | 99.2 |
| Related capital equipment | 1.3 | 7.1 | 5.8 |
| Total | $38.0 | $161.9 | $123.9 |

ERDA does not expect the final construction and related capital equipment costs to vary much from June 30, 1975, totals after minor audit adjustments have been made. However, an additional $21.7 million in operating funds is authorized for the project in fiscal year 1976 and another $30.5 million is included in the ERDA and NRC fiscal year 1977 budgets. NRC officials told us that by the time the current series of planned tests are completed in 1982, the total project cost will be about $350 million.

Besides the inflation that would normally occur over the life of such a project as LOFT, the cost increases as of June 30, 1975, can generally be attributed to

--the 1967 redirection of the LOFT project,

--the lack of firm preliminary designs before and during construction,

--the lack of adequate project cost estimates,

--the upgrading of engineering and quality assurance standards by AEC, and

--the use of improperly scoped fixed price construction subcontracts.

LOFT redirection

Probably the biggest reason for the cost increase was the project redirection in 1967. At that time about $8 million of construction funds and $14 million of operating funds had been spent. The new emergency core cooling system objective, however, caused a major redesign of LOFT's mobile test assembly and related components. The existing assembly support frame and some components had to be scrapped and rebuilt to meet the new program requirement. In addition, the redirection resulted in other major design changes to give greater insurance that the project would give the technical results necessary to meet its objectives.

Most of these additional costs were financed with operating funds rather than with construction funds. AEC decided very early in the project that since the assembly was mobile, experimental in design, and would be partially destroyed during testing, its fabrication should be financed with operating funds. The Joint Committee on Atomic Energy was aware that these costs would be funded with operational funds and, as early as 1967, regarded the described costs as appropriate for inclusion in AEC's operating expenses authorization. Therefore, only the containment and support buildings were financed with construction money. Most of the remainder of the project was paid for with operating funds.

As of June 30, 1975, about $70 million of the $118 million operations cost was spent on the assembly fabrication. The other operations funds were spent for research and development, fuel fabrication, and costs of preparing to operate LOFT, such as supplies and salaries. (See app. I.)

ERDA officials attributed all of the $5.8 million cost increases in related capital equipment to the project's redirection. This is equipment not related to construction but required for the facility. It is reusable once the experiment is completed.

Lack of firm preliminary designs

The original construction estimate of $17.6 million included a 25 percent contingency factor because it was prepared with incomplete project criteria and without a preliminary design. This contingency factor proved to be insufficient since the cost estimate increased steadily until it had reached $24 million by the time the project was redirected in May 1967. (See app. II.)

In 1969, AEC, in order to meet the redirected program objectives, requested and received additional project construction authorization from the Congress bringing total authorization to $35 million. This has not changed substantially since that time. The final construction cost is $36.6 million.

After the LOFT project was redirected in May 1967, AEC decided that the architectural-engineering firm which originally designed the LOFT project would continue with the design of the containment buildings but the responsibility for redesigning the mobile test assembly was given to the LOFT operating contractor.

The project fabrication was stopped during 1969 and 1970 to procure long lead items and to permit the operating contractor to redesign the mobile test assembly and related components. While a new base design was established during this period, we found that it was not firm and that numerous design changes, many of them major, were still a common occurrence after this period. (See app. III.) While many of these changes were considered necessary to accomplish the technical goals of the project, they often resulted in additional redesigns and costs.

Lack of project cost estimates

After the LOFT project was redirected, neither AEC nor its operating contractor estimated the total cost to complete the assembly or its components. Instead, this portion of the project was estimated and funded on a per year basis. ERDA Idaho Operations Office officials explained that since this part of the project was financed with operating funds it was not a requirement to estimate total costs to obtain annual appropriations from the Congress. These officials also told us that after 1969, the LOFT contractor worked on a level of effort basis. When a design change was required, in most cases the redesign was made and the work was initiated without an estimate of its cost impact on the project. Therefore, we believe that AEC officials lacked the necessary cost information to make decisions on whether to proceed with the design changes or seek a less costly alternative. ERDA officials indicated that LOFT is not typical of their normal construction project and this situation should not occur in any future projects. They attributed most of the problems to the contractor's inability to adequately schedule and project the cost impact of design changes.

Upgraded engineering and
quality assurance standards

The Director, Division of Reactor Development and Technology, imposed requirements on the contractor in 1966 and 1967 to upgrade its engineering practices, and to improve the quality assurance of LOFT's components. To accomplish this, he directed the contractor to prepare and use system design descriptions and quality assurance standards. Both NRC and ERDA officials considered these necessary for the adequate technical performance and understanding of LOFT and thought that they should have been a part of the original LOFT program. If they had, these officials do not believe that they would have significantly affected the project's overall costs.

System design descriptions were working technical reference documents. These had not been prepared by the operating contractor in the past, so the contractor was required not only to prepare them in all future designs but also for systems already designed or built.

Figures were not available on the actual cost impact of the system design description requirements, but an AEC estimate made in March 1969 indicated that the additional work would add approximately $2 million to construction and operation costs.

Aeroject Nuclear officials indicated that a change in procedures to more formal standards greatly affected both the construction and operating aspects of the program. The standards imposed more stringent procurement requirements on nuclear plant vendors and placed design constraints on LOFT operating contractor officials.

One Aerojet Nuclear official said that improved quality assurance standards increased costs substantially on some items. He cited an example where the standards had increased the costs of the upper fuel module by $130,000. A supplier had submitted a bid of $581,000 before the imposition of the standards and subsequently raised his bid to $711,000 to incorporate changes required by the standards.

Incomplete scope of fabrication and construction contracts

In the fall of 1972, several small AEC fixed-price subcontracts for painting, excavating, pipe insulation, and other small jobs on the LOFT facility were successfully completed. Because of this success Aerojet Nuclear Company tried to finish the remaining LOFT fabrication work in 1972 through 1973 by awarding three major fixed-price subcontracts to two subcontractors for piping and mechanical work, instrumentation, and electrical work. However, Aerojet Nuclear Company underestimated the difficulty and complexity of the work covered by these subcontracts and did not completely define the scope. As a result, hundreds of change orders took place during the subcontracts and instead of costing $3.3 million as estimated, the three subcontracts cost about $7.1 million.

## COST IMPACT OF MAJOR DESIGN CHANGES

ERDA officials did not have a list of changes or criteria by which to define a major change. Therefore, at our request, ERDA and contractor officials identified the changes they considered major based on their overall impact on either the project cost or schedule. (See app. III.) Because the cost systems were not set up to designate any changes, we were unable to identify the complete cost of any major design changes. However, we were able to measure some impact of several changes which are shown below.

| Construction costs | Identifiable cost increases |
| --- | --- |
| Changes to LOFT containment vessel: | |
| Door | $1,079,000 |
| Core inspection | 264,000 |
| **Operations costs** | |
| Changes to LOFT experimental equipment (caused by 1967 redirection): | |
| Core length change | 667,000 |
| Reactor vessel | 1,700,000 |
| Emergency core cooling system | 1,508,000 |
| Suppression tank | 658,000 |

## CONCLUSION

The 1967 program redirection caused an almost complete redesign and rebuilding of the mobile test assembly. Because the original and the redesigned mobile test assemblies were fabricated with operations funds, AEC, NRC, and ERDA did not prepare formal estimates of total LOFT assembly costs. In addition, we found no evidence in the authorization and appropriation hearings that these agencies ever informed the Congress of the total operating funds spent on LOFT. In our opinion, the absence of total cost projections hindered AEC and ERDA from effectively controlling the assembly's total costs.

In a January 1975 staff study, we noted a similar situation with ERDA's Fast Flux Test Facility--a key testing facility for fuels and materials used in the liquid metal fast breeder reactor. Facility construction was originally authorized at $87.5 million in July 1967 but is now estimated at $540 million. In addition, operating and other capital equipment costs, which were not estimated at the time of the authorization, are estimated at $614 million, bringing the total estimated costs to $1.154 billion. We recommended, and AEC concurred, that the Congress, when authorizing complex research and development projects, may wish to require that supporting cost and schedule estimates be (1) complete as to the inclusion of all major associated project costs and (2) based upon relatively firm designs. We also recommended that milestone estimates and anticipated cost increases should be submitted to the Congress promptly to prevent incurring substantial project costs before sufficient data is available for informed decisions.

ERDA has since changed its procedures to require that all major costs, including operating, be estimated and submitted to the Congress during the initial authorization and appropriation process. It has also obtained increased funding for preliminary design efforts to insure that the submissions to the Congress are reasonably firm. ERDA officials told us, however, that because of the nature of complex research projects, there is no insurance that initial project estimates, even if considered firm at the time, will not experience cost overruns. They said that major changes in the project design and concept are sometimes unavoidable because of new information.

ERDA prepares a semiannual report to the Congress which updates the completion dates and costs of all construction projects. Although this report identifies increases in estimated construction costs, it does not identify similar increases in operating costs. In some cases, such as LOFT and the Fast Flux Test Facility, portions of the design and fabrication are funded from the operating appropriation and are an important part of the total project costs and the area where costs have grown the most. This information would better enable the Congress to review ERDA's construction projects and would provide a better basis for its consideration of future authorizations and appropriations.

## RECOMMENDATION TO THE ADMINISTRATOR, ERDA

We recommend that the Administrator of ERDA include, as part of his semiannual report to the Congress on the status of construction projects, total project design and construction costs including that portion of the project funded from the operating appropriation. ERDA officials agree with the recommendation in principle and are evaluating the impact it might have on their reporting requirements for construction projects.

## LOFT SCHEDULE PROBLEMS

Originally the LOFT facility was to be completed by March 1966. This schedule slipped several times and by April 1967 the estimated completion date for facility construction was December 1969.

When AEC redirected LOFT in May 1967 the schedule slipped 5 months to May 1970. Between mid-1967 and late 1974, the estimated completion date of facility construction was continually revised and the schedule slipped over 5 years. (See app. IV.)

AEC, ERDA, Phillips, and Idaho Nuclear personnel generally agreed that timeliness was not given the highest priority in the LOFT program. It usually ranked somewhere below the technical goals of the program.

On December 1, 1975, LOFT facility construction was essentially complete. LOFT nonnuclear experiments with a simulated nuclear core will begin in February 1976. The nuclear experiments are presently scheduled to begin in the fall of 1977.

The reasons for individual minor LOFT schedule slips were numerous and varied, ranging from construction workers' strikes to unusually bad weather during critical construction periods. But the most important identifiable reasons for major slips, each of which delayed the project by a year or more, were incomplete design, major design changes, and the incomplete scope of three LOFT fabrication and construction subcontracts.

## Incomplete design

LOFT construction was to begin by December 1963; however, this was delayed about 9 months because the architect-engineer had difficulty completing the preliminary design due to changes dictated by Phillips and AEC. During 1965, the architect-engineer was still reworking the original design causing several more months of slippage.

## Major design changes

The major design changes (described in app. III) which occurred before and after the redirection, had a very decided impact on the LOFT facility construction completion schedule. For example, before the redirection, design problems of the containment building foundation caused a schedule slip of about 18 months, and the evolution of the containment door design delayed the completion of the building by about 1 year.

Although records were not available to determine the schedule impact of all the major design changes after the redirection, we were able to identify the schedule slips caused by two of them--increased structural requirements and the addition of a suppression tank.

The redirected LOFT program includes a series of loss-of-coolant accidents which would have increased the thermal shock effects on various LOFT components. Consequently, in late 1968 the entire support frame had to be scrapped and rebuilt to meet the new specifications. According to LOFT operating contractor reports, this problem extended the LOFT facility construction completion date by 14 months.

An Aerojet Nuclear subcontractor made repairs on LOFT's suppression tank at the site for over 14 months because, according to an ERDA Idaho Operations Office official, the original fabricator was guilty of shoddy workmanship and the tank was damaged while in transit to Idaho. This repair work and subsequent modifications of the tank's structural support contributed to a 1-year slip.

Incomplete scope of fabrication and construction subcontracts

Aerojet Nuclear Company attempted to finish some remaining LOFT fabrication work by awarding three fixed-price subcontracts. However, hundreds of change orders took place during the subcontracts because Aerojet Nuclear Company failed to properly define the scope of the work. This was compounded by late delivery of some materials and work schedule conflicts.

Originally, the work under the three subcontracts was to be completed in about 5 months but as a result of the problem cited above, one of the subcontractors needed 18 months to complete the work and the other required 13 months. These subcontracts delayed other LOFT fabrication and construction work and were the primary cause of an 18-month slip in the overall LOFT construction schedule.

Other reasons for schedule slips

According to past and present ERDA Idaho Operations Office and contractor officials the following reasons also contributed to the overall 9-year slip in LOFT facility construction completion, although the extent of the contribution was not known.

--AEC upgraded engineering requirements, specifically system design descriptions and Division of Reactor Development and Technology standards.

--Management direction problems developed between AEC and the operating contractor because AEC Headquarters controlled key design decisions and program documents and the funding for LOFT.

--Unrealistic and overoptimistic scheduling throughout the project by the LOFT operating contractor, including target dates that did not allow sufficient time to meet unforeseen technical problems and other contingency items.

--Periodic contractor manpower shortages which occurred in the key areas of design, procurement, material control, quality assurance, and test support.

Attempts to expedite LOFT construction

AEC and the LOFT contractor made many efforts to expedite LOFT construction, but they were generally unsuccessful. For example, during the late 1960s AEC used directed-end-dates in an effort to keep LOFT contractors on schedule. A directed-end-date was the AEC decreed day on which LOFT facility construction was to be completed. Former Phillips and Idaho Nuclear Corporation Program Evaluation and Review Technique 1/ specialists considered these dates unrealistic because they were the dates when AEC wanted a facility construction completed rather than when a analysis would project the facility to be completed. To prepare schedules which met directed-end-dates, the contractors' analysts had to either compress the normal construction period or, as was more typical, indicate negative slack--the amount of time actual construction was

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[1] Programing Evaluation and Review Technique focuses attention to the timing of critical construction events and their impact on other events and the overall schedules.

behind schedule. Because the directed-end-dates were unrealistic, negative slack increased as problems developed. Periodically, AEC would slip a directed-end-date to cut down the amount of negative slack. For example, in July 1967, with 66 weeks of negative slack accumulated, AEC changed the directed-end-date of April 3, 1969, to April 3, 1970, and cut the negative slack to 14 weeks.

According to former Phillips and Idaho Nuclear Program Evaluation and Review Technique specialists, directed-end-dates discouraged rather than encouraged most contractor employees because each of these dates tended to start them out behind schedule.

ERDA officials disagreed that the directed-end-dates were unrealistic. They said that the operating contractors had always agreed to the directed-end-dates that were established and that in some instances these dates were based on the contractors' estimates. They said that most of the problem was the contractor's inability to properly estimate and schedule completion dates.

In another attempt to complete facility construction, Aerojet Nuclear awarded the three fixed-price subcontracts for final LOFT fabrication and construction in 1972, but due to an incomplete scope, this attempt backfired.

## CONCLUSION

Anytime a project is over 9 years behind schedule, questions can be raised as to whether the responsible agency made reasonable efforts to expedite its completion. Certainly this applies to LOFT. AEC officials made many decisions which delayed LOFT's completion but which they felt were necessary to achieve the technical goals of the project. They also made efforts to keep the project on schedule or to expedite its construction. While these efforts were generally unsuccessful, it must be recognized that LOFT is a complex one-of-a-kind research and development project which could help answer questions about the safety of commercial nuclear powerplants. AEC officials, therefore, thought it extremely important to insure that the LOFT project was of technically high quality. Under these circumstances, it would be difficult for us to conclude that efforts to expedite construction were not reasonable. We do believe, however, that greater emphasis could have been placed on achieving a balance between the project's technical goals and the timeliness of its test results.

# CHAPTER 4

## NRC AND ERDA MANAGEMENT OF NUCLEAR SAFETY RESEARCH AND DEVELOPMENT

The Energy Reorganization Act of 1974 separated AEC's licensing and related regulatory functions from its research and development functions. The Act gave NRC the responsibility for such research as was necessary for the effective performance of NRC's licensing and regulatory functions. The research aspect of NRC's licensing and regulatory functions was characterized by the conference report as "confirmatory assessment." According to the report, confirmatory assessment relates to research involving "* * * the safe operation and the protection of commercial reactors, other facilities, and material subject to regulations, licensing, and inspection by the Commission [NRC]." To enable NRC to carry out its confirmatory assessment responsibilities, the report emphasized that NRC would have "* * * an independent capability for developing and analyzing technical information related to reactor safety, safeguards and environmental protection in support of the licensing and regulatory process." Thus, NRC's confirmatory assessment responsibilities were intended to be distinct from ERDA's responsibilities for conducting nuclear research and development to meet short-term and long-range energy needs.

However, it was not intended that NRC build its own laboratories and research facilities. Instead, section 205 of the Act calls upon the ERDA Administrator and the head of every other Federal agency to

--furnish to NRC, on a reimbursable basis, through their own facilities, by contract, or other arrangement, research services requested by NRC;

--cooperate in establishing priorities for the furnishing of research services;

--consult and cooperate with NRC on research and development matters of mutual interest; and

--provide NRC with information and physical access to ERDA facilities to assist NRC in acquiring the expertise necessary to perform its licensing and regulatory functions.

The Committee asked us to look into the NRC/ERDA relationship in carrying out the construction and ownership of LOFT.

## NRC/ERDA RELATIONSHIP

A problem confronting NRC and ERDA when they originated was the working arrangement for operating NRC programs on ERDA facilities. The Energy Reorganization Act called for ERDA to cooperate with NRC, furnishing necessary research service to it on a reimbursable basis, thus enabling the Commission to carry out its "confirmatory assessment" responsibilities. While NRC is responsible for establishing its own "independent" safety research program, the facilities on which this NRC work is presently done were transferred to ERDA by the Energy Reorganization Act of 1974 and, in addition, ERDA administers the contracts for the operation of these facilities.

On August 8, 1975, the NRC Chairman and the ERDA Administrator signed a memorandum of understanding establishing a formal working relationship for the LOFT program. The memorandum was to be a model for detailed interagency agreements, not only for LOFT but also for other safety-related facilities which remained to be negotiated by NRC and ERDA. It contains the following provisions.

--NRC and the ERDA contractor will formulate the program, outlining the scope, schedule, and funding. NRC insures that ERDA is kept informed on the status of program formulation.

--NRC will provide the proposed program scope, schedule, and funding level to ERDA.

--ERDA will determine whether the resources are adequate to carry out the program within the program's defined scope and schedule and that the experiments are acceptable from a safety point of view.

--ERDA will insure that it has adequate resources to carry out its program responsibilities.

--ERDA will authorize its contractor to carry out the experimental and analytical program within the agreed upon scope, funding, and schedule under the program direction of NRC.

Generally, the memorandum of understanding gives NRC the responsibility for program direction of LOFT, while ERDA is given overall responsibility for the management of contractor operations at the site. In the event a planned experiment is expected to result in a major disabling of the LOFT facility, the memorandum calls for approval of the experiment by both the NRC Chairman and the ERDA Administrator.

The memorandum also makes ERDA responsible for managing and directing the completion of LOFT to the point of readiness for the first nuclear loss-of-coolant experiments. NRC will provide program guidance to ERDA in this respect and will certify that the facility meets its requirements. Further the memorandum states that ERDA will provide "* * * within congressional and budgetary restraints, any funds necessary, in addition to those for which NRC has budgeted for LOFT construction in fiscal year 1976, to complete LOFT on schedule * * *." It is expected that NRC will reimburse ERDA for reactor safety research programs carried out by NRC in the LOFT facility.

If an NRC change in LOFT objectives increases the scope, cost, or schedule of the project, the memorandum provides that ERDA will determine whether resources are available to carry out the program and if the program change would be acceptable from a safety point of view. NRC and ERDA officials said that if an NRC change requires a major modification to the facility, ERDA, as the owner, will be responsible for obtaining funds from the Congress. NRC will obtain appropriations for all lesser modifications.

Finally, while the memorandum states that LOFT will be dedicated to the NRC program at this time, it also indicates that there may develop opportunities for its use in ERDA's reactor safety program to which NRC and ERDA may jointly agree. If NRC agrees, ERDA will budget for such of its own work as may be carried out in LOFT.

ERDA's proposed light water reactor technology program

To determine what ERDA might do to improve performance of current and future generation light water reactors and to make these reactors more attractive for future utility investors, the ERDA Administrator established a task force in March 1975 to identify potential cooperative research programs with other Government agencies and private industry. The task force report resulted in a proposed ERDA light water reactor technology program initiated in fiscal year 1976 at $3 million with expected expansion to $10 million in fiscal year 1977.

The major part of this technology program will be to identify plant operating problems, to alleviate the problems through the development of standards and improved plant components, to improve the light water reactor technology base so that the power output or rating of the plants can be increased, and to reduce the high cost and extended design and construction periods of the light water reactors. The program could also involve some future light water reactor safety design research.

According to ERDA officials, any safety research they perform would not be intended to overlap NRC's responsibility of confirming existing safety systems and technology. Instead the emphasis would be placed on designing new or advanced safety systems (such as advanced emergency core cooling systems) and conducting research to more precisely define safety margins. ERDA believes that it could potentially use LOFT for research on simplified emergency core cooling systems or for other light water reactor research opportunities.

ERDA officials explained that such safety research is not included in their plans. The agency had originally requested $40 million in fiscal year 1977 for the technology program but after the normal budget reviews by the Office of Management and Budget and the White House, the amount was reduced to $10 million. This forced the deletion of plans for light water reactor safety research during 1977. ERDA officials said, however, that if funding is increased in future years, consideration will once again be given to performing some type of safety research. At this time however, ERDA has not received clear indication from the Office of Management and Budget as to what the level of funding for this program will be in future years. Questions have been raised by the Office of Management and Budget as to whether the Government should be supporting the nuclear industry in this manner.

## STATUS OF DETAILED AGREEMENT ON LOFT

A detailed interagency agreement which was to follow the memorandum of understanding on LOFT, had not been approved as of April 1, 1976. Normally the ERDA Idaho Operations Office, through its contractor, would perform the tests to NRC's specification. In this situation, however, NRC believes that it must direct the project to insure that its goals are met. It is therefore establishing a field office in Idaho for this purpose. NRC does not yet know how many people will be assigned to this office. NRC gave us the following reason for this action.

> "NRC believes that intervention of an ERDA management layer between NRC and NRC programs could compromise the independence that these programs must have from ERDA objectives and priorities. It would reduce the responsiveness of these programs to specific NRC requirements, as they change in response to the findings of the research programs. Therefore, NRC has sought a compromise that preserves for ERDA its basic management prerogatives and that keeps NRC directly in control of the technical content of the program."

While ERDA has recognized that LOFT is an NRC confirmatory assessment project, it has been reluctant to turn over the complete control of the project to NRC. Since the LOFT facility was transferred to ERDA by the Energy Reorganization Act of 1974, ERDA believes that it must maintain sufficient control to (1) insure the safety of the LOFT test program, (2) meet its responsibilities as the contracting authority for the project, and (3) insure that the money it budgeted for is properly controlled.

The two agencies told us that they are now in general agreement as to how the project will be run. A cooperative type management will be established; ERDA will be kept fully informed on NRC-contractor actions but will have approval authority only over those actions which change the overall scope or schedule, or affects the safety of the project. However, the agencies have discarded the idea of one interagency agreement. Instead they will rely on the broad language and principles in the memorandum of understanding to develop position papers or subagreements on various issues to define or guide the management and operation of LOFT. This was in part brought about by the disagreements between the agencies and in part by the complexity of one single agreement covering or defining every issue. The agencies believed that the issues could be agreed to more easily if they were dealt with separately.

In a March 10, 1976, report to the Senate Committee on Government Operations, however, we found that NRC and ERDA

--have not formally agreed to detailed operating procedures on the conduct of LOFT and

--have not agreed to procedures resolving disputes on the LOFT program.

We also noted that until these agreements are reached, delays in the LOFT program could be experienced. We recommended that NRC and ERDA agree to these procedures so that LOFT can be effectively managed and operated.

Ownership of research facilities

The conference report on the Energy Reorganization Act of 1974 said that NRC should have the ability to independently develop and analyze the technical information related to reactor safety in support of the licensing and regulatory process. However, the conferees said that they did not intend for NRC to build its own research facilities or duplicate ERDA's responsibilities.

Although NRC has not taken a formal position on its authority to own safety research facilities, NRC officials told us that the Energy Reorganization Act of 1974 does not necessarily preclude NRC from owning safety research facilities, should they be needed to meet the licensing and regulatory responsibilities of NRC.

ERDA officials told us, however, that the legislative history of the Reorganization Act very clearly indicates that safety-related research should provide for the use of ERDA-owned and operated facilities on a reimbursable basis. Thus, according to ERDA, the Congress believed that the safety research that NRC might need could be accomplished through using ERDA facilities and that this intent is evidenced by, among other things, the transfer of all of AEC's pertinent safety research facilities to ERDA rather than to NRC.

However, aside from these differing views, it is clear that the Congress wanted NRC and ERDA to cooperate on safety research projects so that NRC would conduct its required confirmatory assessment research without having to duplicate the construction, contractual, and other administrative capabilities already possessed by ERDA. There has not been enough experience gained subsequent to the passage of the Energy Reorganization Act of 1974 to clearly indicate whether a transfer of safety research facilities to NRC would be warranted. We plan to continue monitoring the relationship between ERDA and NRC on this matter.

## CHAPTER 5

## EFFECT OF THE PRACTICAL VALUE CLAUSE ON SAFETY RESEARCH AND DEVELOPMENT

In 1954, the Congress authorized the AEC to conduct research leading to the demonstration of the "practical value" of nuclear facilities for commercial or industrial purposes. Under section 102 of the Atomic Energy Act of 1954, as amended, the AEC was authorized to determine that a particular type of nuclear facility was sufficiently developed to be of practical value for industrial or commercial purposes. The Commission could then issue a commercial license to a facility determined to be of practical value. A finding of practical value with respect to a particular type of nuclear facility would have prevented AEC from further supporting research demonstrating the practical value of that facility.

However, legislation enacted in 1970 abolished the concept of practical value and eliminated the requirement that the AEC make a finding of practical value prior to the issuance of a commercial license. The Committee asked us to determine how the practical value clause affected AEC's support of light water reactor safety research in general and of the LOFT project in particular, both before and after the clause was deleted.

The short answer to this question is that the clause itself did not affect safety research and development because the promotion of safety was always a permissible research area, irrespective of a Commission finding of practical value. The remaining part of this chapter develops this point and describes the practical value issue and its affect on overall research.

### BACKGROUND

With certain minor exceptions, all nuclear facilities must be licensed either as research and development facilities or commercial facilities. Before 1970, a commercial license could not be issued until AEC ruled that the type of nuclear facility in question had practical value. In the absence of a practical value finding, nuclear powerplants were licensed as research and development facilities even though they might have been determined to be highly satisfactory from an engineering standpoint and were delivering electrical power to commercial systems.

If, however, AEC had made a practical value finding for a particular type of facility and initiated commercial licensing proceedings, several statutory consequences would result. First, an applicant for a commercial license would be subject to a prelicensing antitrust review. This review would not be required for a research and development license. Second, a commercial license would not receive capital grants to conduct research activities leading to the demonstration of their already established practical value.

This last consequence lost most of its significance even before the practical value clause was deleted in 1970. In 1957 and again in 1963, legislation was enacted which reduced AEC's spending authority for nonreimbursable support of research and development. With certain minor exceptions, the undertaking of research and development activities at commercial nuclear facilities without full reimbursement, the waiver of nuclear fuel use charges, or any other form of financial assistance to the nuclear industry, were forbidden without prior and specific congressional authorization. Therefore, the rendering of research and development assistance to any nuclear plant or type of facility could not be undertaken without congressional approval.

AEC had declined twice, once in 1964 and again in 1966, to make a finding of practical value for light water reactors because of the relative short operating experience of these reactors on those dates. This prevented the issuance of a commercial license even though existing reactors were generating and delivering electricity to commercial systems. More importantly, however, the research and development licenses which AEC was issuing did not require an antitrust review before the license was granted. The Joint Committee on Atomic Energy held hearings in 1969 to 1970 on the practical value clause and the antitrust issue. The uncertain definition of practical value, the Commission's failure to make a practical value finding with respect to any nuclear facility, and the avoidance of prelicensing antitrust reviews, led the Congress to abolish the concept of practical value.

## RELATIONSHIP OF PRACTICAL VALUE TO RESEARCH AND DEVELOPMENT

Assuming the successful completion of the annual authorization and appropriation process, the Atomic Energy Act of 1954, as amended, authorized AEC to support six areas of research and development. Only one of these areas, subsection (4), related to practical value. Subsection (4) permitted AEC to conduct research activities leading to "* * *the generation of usable energy, and the demonstration of the practical value of utilization or production facilities for industrial or commercial purposes."

Subsection (4) was amended in 1970 to permit AEC to conduct research leading to the "* * * demonstration of advances in the commercial or industrial application of atomic energy," without regard to practical value. Even before this change, however, AEC had authority from the other statutory research areas to conduct most of the research it desired, including the promotion of safety, even if a facility at which safety research was to be conducted had been determined to be of practical value.

Although AEC never made a finding of practical value, if they had, the finding would not have precluded the Commission from supporting the promotion of safety research and development at practical value facilities. However, ERDA and NRC officials said that pressure was applied by the Congress, the Office of Management and Budget, and the nonnuclear utilities to get AEC out of the reactor business and let the nuclear industry stand on its own.

In response to this pressure, AEC phased out its support of the commercial light water reactor development research program in 1967. In addition, AEC completed a special analytical study in reactor safety in 1969 which investigated ways of minimizing Federal expenditures for light water reactor safety research and maximizing industrial participation. While the study reaffirmed AEC's need to continue supporting a vigorous safety research and development program for light water reactors, three approaches were suggested to get more industrial involvement and funding.

The first concerned persuasion and the establishment of requirements on industry, primarily through the licensing process. The second approach would have taxed industry for the "independent" portion of work being conducted in Government facilities in direct support of the regulatory groups. The third would require a clear definition of responsibilities between Government and industry, with industry conducting all research except that

--performed on Government and military reactors and

--required to meet AEC regulatory's need for an independent check on the industry effort.

AEC concluded the first approach should be followed since it recognized the practical difficulties of organizing the industry, insured the timely availability of research information, allowed for the possibility of reduced Government costs, and provided a suitable transition to orderly implementation of the third approach for the long term.

To carry out the program, AEC initiated a cooperative funding program with industry in 1970 which was to be about 75 percent safety related and which was to cover the transition phase from AEC support to full industrial support of nuclear research. Under this program, AEC actively encouraged industry to participate and help fund research and development projects. Combustion Engineering, Westinghouse, and General Electric entered into three such projects in which AEC provided up to 75 percent of the operating funds while industry supplied the test facilities.

In June 1973, reactor safety research was transferred from the Division of Reactor Development Technology to a newly created Division of Reactor Safety Research. The new Division Director, in an attempt to prevent any possible appearance of conflict of interest and to maintain an independent research posture, changed the cooperative policy with industry. While recognizing the desirability of the cooperatively funded projects, this type of arrangement was not actively solicited. Instead, the new Division developed a policy of cooperation and coordination with industry which included sharing information and reviewing and analyzing each other's safety programs. The three ongoing contracts with the reactor vendors were continued--one is now complete, one is still active, and the other is being extended--but new cooperatively funded safety projects were not initiated.

In June 1975 after the Division of Reactor Safety Research had been transferred to NRC by the Energy Reorganization Act of 1974, NRC established guidelines for cooperative research arrangements with industry. NRC said that it would review each arrangement case by case based on the following criteria.

--The information to be obtained is necessary to the NRC mission.

--Alternative means of acquiring the necessary information are not reasonably available.

--A legal or substantial appearance of conflict of interest does not exist and all applicable laws and procedures are honored.

--Government funds are not being used as a substitute or replacement for private funds.

--Appropriate arrangements can be established to protect NRC's interests.

While ERDA officials told us that they also adhere to the above principles, they have taken a different approach in developing their light water reactor technology program. They intend to solicit and use industry funding and facilities to the full extent possible.

## CHAPTER 6

## SUMMARY OF CONSULTANTS' COMMENTS ON THE LOFT TECHNICAL PROGRAM OBJECTIVES AND DESIGN

The Committee asked us to consult with five nuclear experts on selected technical questions relating to the Loss-of-Fluid-Test facility objectives, design, and potential effects on reactor licensing pending the outcome of LOFT test results. The five experts we selected were acceptable to NRC, ERDA, the Office of Technology Assessment, and the Committee. All the parties involved agreed that the selected experts would provide a full spectrum of opinion on the Committee's questions. This chapter summarizes the experts' views. The complete texts of their answers are included as an enclosure to this report.

The five experts are:

--Dr. Joseph M. Hendrie, Chairman, Department of Applied Science, Brookhaven National Laboratory;

--Mr. Romano Salvatori, Manager, U.S. Projects Department, Pressurized Water Reactor Division, Westinghouse Electric Corporation;

--Mr. Carl J. Hocevar, Engineer, Union of Concerned Scientists;

--Dr. Fred C. Finlayson, Engineer, the Aerospace Corporation; and

--Dr. Nunzio J. Palladino, Dean, College of Engineering, Pennsylvania State University.

The backgrounds and experience of the experts are presented in appendix V.

### LOFT CORE MELTDOWN

The original LOFT program was intended to investigate the sequence of events in a core meltdown accident to insure that containment buildings for reactors being built in the early 1960s could retain (or adequately mitigate the loss and dispersion of) fission products resulting from such an accident. In 1967 the objective was changed to an evaluation of emergency core cooling systems designed to prevent core meltdowns. The Committee asked us if, in the best interests of nuclear safety, LOFT should be used for meltdown experiments as originally planned. It also asked if LOFT should be used on a timely basis to study the means of retaining molten cores and measuring the consequences of steam explosions[1] and radioactive releases resulting from a meltdown.

All five experts believe that LOFT should not be used at this time for nuclear core meltdown experiments. They think that LOFT would be best used by conducting--without additional delays--the planned series of tests for which it was designed. This does not mean, however, that the experts think core meltdown research is unimportant--quite the contrary. Messrs. Hendrie, Hocevar, Palladino, and Finlayson said that NRC[2] should expand the effort to understand the phenomena involved in a core meltdown and the resultant release of fission products. Mr. Salvatori believes that the overall risk of a meltdown accident to the public and the environment is quite small and that such efforts are not of primary importance.

The experts give many technical reasons why meltdown experiments should not be conducted on the LOFT facility. These included several design features peculiar to LOFT which could result in test data not typical of larger commercial reactors. One or more of the experts noted that the

--LOFT core is too small when compared to the size of the surrounding pressure vessel. This could prevent a substantial melting of the core (Messrs. Hendrie, Hocevar, and Finlayson);

--mobile test assembly, because of its mobility and physical separation from the containment floor, could cause the meltdown process to depart from that in a typical large pressurized water reactor (Messrs. Palladino and Finlayson);

--concrete foundation, because it is different from that found beneath a large reactor, would poorly simulate the interaction of a molten core with the concrete (Dr. Finlayson); and

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[1]An explosion caused by the sudden interaction of molten uranium fuel with water.

[2]ERDA officials told us that meltdown research could be determined to be an ERDA responsibility.

--less-than-full size LOFT core (which is 5-1/2 feet long compared to 12 feet in a commercial reactor), and related inherent scaling compromises raise many questions about the typicality of a meltdown experiment in LOFT (Messrs. Palladino, Hocevar, and Finlayson).

Messrs. Finlayson and Hocevar noted that the problems might be partially overcome if analytical techniques were available which could adequately predict the behavior of a reactor during a meltdown accident. The results from small-scale LOFT tests could then be used to evaluate our ability to understand the accident phenomena in a large reactor. However, they said that such analytical methods are not sufficiently developed to justify performing small scale meltdown tests at this time.

Messrs. Salvatori and Hendrie noted that a meltdown experiment would contaminate the facility with radioactive debris and make it unusable for the many years of planned tests and for potential tests of other accidents that are more likely to occur than a sudden loss of reactor coolant. Dr. Hendrie, along with Dr. Palladino, also said that since data from only one run, at best, would be available, there would always be questions about whether those data were truly representative. As Dr. Hendrie summarized in his report:

"The question of using the LOFT facility for meltdown experiments thus involves balancing many years of loss-of-coolant and system transient experiments, for which the facility is well-suited and unique and from which valuable data are virtually guaranteed, against a single meltdown from which the data will be suspect* * *"

The second part of the Committee's question concerns the use of LOFT to study the means of retaining molten cores (core catcher)[1] and measuring the consequences of steam explosions and radioactive releases resulting from a meltdown. These are tests which might logically be part of an overall core meltdown experiment, so the experts generally gave the

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[1]A core catcher is a device located below or inside a reactor vessel which, in the event of a core meltdown, is intended to spread out the core debris. This would prevent material from reforming into a mass capable of a chain reaction and prevent core residue from melting through the bottom of the reactor.

same reasons for not conducting these tests on LOFT as those presented above. Other reasons were also developed, however. Messrs. Palladino, Salvatori, and Hendrie felt that such tests could be better dealt with and understood if they were studied individually in controlled separate effects tests[1] rather than in integral test facilities such as LOFT. Dr. Finlayson added that it would be very difficult to conduct an experiment which would permit all of these objectives to be satisfied simultaneously.

Need for meltdown experiments

All the experts except Mr. Salvatori indicated that a better understanding of the core meltdown phenomena was needed. While Mr. Salvatori believes that there are quite a few areas of uncertainty involved in a core meltdown, he said it is possible to put reasonable upper bounds on these uncertainties. He said that when the upper bound (or worst) consequences of a core meltdown are weighed against its likelihood of occurring, the overall risk to the public and environment is quite small. Therefore, he concluded that:

> "* * *a detailed investigation of the various phenomena associated with core meltdown is not a primary importance."

He recommended that before significant amounts of money are allocated to studying core meltdown in detail, other areas both in and out of the energy field should be considered and priorities assigned.

The other four experts had opposing viewpoints. Messrs. Finlayson, Hendrie, and Hocevar indicated that the Rasmussen Report has shown that the possibility of a core meltdown accident is greater than previously estimated and for that reason experimental and analytical studies of the meltdown phenomena are needed.

Mr. Hocevar noted that a partial core meltdown occurred in 1966 at the Fermi plant near Detroit. Dr. Palladino also recommended additional meltdown research even though he noted that the probabilities of a meltdown accident are very small. He said that

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Tests where only one separate phenomena is studied with the interrelated influence of other effects deliberately excluded.

"* * *it is essential to conduct meltdown experiments of a phenomenological nature to understand the characteristics of the events involved and to provide a sounder technological basis for judgement in predicting the consequences of a large core meltdown under a wide variety of postulated circumstances."

Dr. Finlayson went into some detail in his report to question the meltdown consequence predictions of the Rasmussen report. He explained that sufficient information on fission product release and dispersal in the atmosphere is not available and therefore the worst results of a single meltdown accident predicted by Rasmussen--3,300 deaths--may actually be much higher. He believes that this potential for such high fatality accidents, even though it may be extremely low in probability--coupled with the mystique of death from radioactivity--is the dominant source of problems with public acceptance of nuclear power. In spite of his questions on the magnitude and probability of Rasmussen's predictions, Finlayson acknowledges that risks to the public from such accidents are very low. Consequently, like Mr. Salvatori, Dr. Finlayson believes that meltdown should be studied in the proper perspective of a well developed, prioritized, and balanced overall reactor safety research program--where research emphasis would be more upon accident prevention than determination of postaccident results.

The major point to be considered about nuclear consequences and the point taken by four of the five experts is that there is a lack of information about meltdown phenomena and the manner in which fission products are released and dispersed. This makes the consequences of a core meltdown very uncertain. A recent report prepared for NRC by the Sandia Laboratory entitled "Core Meltdown Experimental Review," which was highlighted by Mr. Hocevar in his report, concludes that several critical events in the meltdown and fission product release sequences are poorly understood.

These four experts recommended additional core meltdown research but they did not agree as to the type of research necessary. Mr. Hocevar said that past NRC small-scale meltdown experiments are inadequate because current computer code analytical techniques are not capable of projecting data from these experiments to large reactors. He recommended that experimental data be obtained over a wide range of parameters including those from larger facilities more characteristic of current reactor systems.

Dr. Finlayson also noted the difficulty in projecting results from small-scale experiments (tests using from 30 grams to 2 kilograms of nuclear fuel) to large masses of molten fuel (about 90,000 kilograms). He recommended that meltdown analytical models be developed by a well organized program of separate effects tests and theoretical analysis followed by a system level test, perhaps at a scale similar to LOFT. He also recommended that NRC start planning for a series of tests in the LOFT facility to investigate those accidents identified by the Rasmussen Report as having a greater probability of leading to a core meltdown than a large scale pipe rupture, along with investigations of their associated mechanisms for meltdown prevention. Like the current LOFT program, these tests would not be expected to be carried to meltdown.

Dr. Palladino recommended separate effects experiments performed by appropriate specialists in properly designed facilities. He said that such experiments, as opposed to system level tests such as LOFT can be controlled to yield results over a wide range of conditions for use in determining the worst consequences of a variety of possible nuclear plant accidents.

Dr. Hendrie, noting that experiments on meltdown phenomena have been largely neglected until recently, also said that such aspects of core meltdown are better studied in separate effects experiments than in system level tests. Any recommendation for integral tests, according to him, could wait until after results from separate effects tests are received and evaluated.

## VALUE OF LOFT TEST RESULTS

LOFT, which is approximately a one-sixtieth scaled version of a large commercial pressurized water reactor, is the largest and best integral test facility available for conducting loss-of-coolant type experiments. The relatively small scale of this facility, however, has necessitated many scaling compromises[1] for LOFT to simulate the major behavioral aspects of a large commercial reactor and has

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[1]Some components in LOFT and their resultant reaction to loss-of-coolant accident will not be typical of larger reactors because they are not scaled in the right proportion. This was necessary so that the overall LOFT system response would resemble that of a larger reactor.

raised a question about the applicability of LOFT test results to large commercial reactors. The Committee asked that we present this question, along with a question on the need for a larger LOFT-type test facility, to the five experts.

All five stressed that LOFT is not, and is not intended to be, a demonstration of the ability of an emergency core cooling system to prevent a core meltdown accident. Instead, the main purpose is to provide additional information on the ability to use computer analysis techniques to predict the behavior of emergency cooling systems under a major accident condition. The experts generally agreed that LOFT results would permit the improvement of computer codes and might identify physical reactions not previously accounted for during a loss-of-coolant accident, but they disagreed as to the significance of this type of test results.

Dr. Palladino and Dr. Hendrie emphasized that LOFT is only part of the overall safety program and that its test results should not be taken of themselves to prove or disprove the effectiveness of emergency core cooling systems. They said that computer codes are developed by combining various computer models of reactor subsystems which have been calibrated or derived from separate effects experiments. These models are mathematical equations which, with the use of a computer, are used to predict the component or subsystem reaction to various conditions. They are a necessary alternative to conducting full-scale tests on every component under every possible situation. This combination of models involves making important assumptions about the way various phenomena interact. According to Dr. Palladino, the adequacy of the overall codes depends on both the accuracy of the separate effects models and the adequacy of the assumptions made when combining the models. These experts feel that LOFT experiments should provide a check on the way the existing computer codes combine the various models and help identify reactions heretofore overlooked. They indicated that a larger LOFT-type test facility would be nice to have, but considering the complexity and cost of such a facility and the relatively low return in safety that would be obtained, it is not justified at this time.

Dr. Finlayson and Mr. Hocevar agreed in principal with (1) the role of separate effects tests, (2) the consequent empirical basis for current analytical models, and (3) that LOFT system test results will benefit the overall light water reactor safety program and could help increase confidence in the ability to predict emergency core cooling system responses. However, they disagreed with the conclusion that a larger test probably would not be cost effective. They drew a distinction between the computer code improvements and their verification, and indicated that sufficient data will not be obtained from the LOFT experiments to verify the ability of emergency core cooling analysis methods to simulate the real event. Mr. Hocevar said that the instrumentation on LOFT is probably the most outstanding weakness of the program and indicated that several critical experimental measurements cannot be made. He attributed this to the complexity of the LOFT system and the physical phenomena involved, however, rather than to incompetence.

Dr. Finlayson noted that the many scaling compromises in the LOFT system, which were required for the practical design of LOFT, absolutely prevent its complete simulation of full-scale commercial reactor system performance in a loss-of-coolant accident. Consequently, computer code maturation (adjustment of the codes to match the test results) to LOFT scale is the most that can be expected of the test program, rather than code verification for commercial applications.

Both Dr. Finlayson and Mr. Hocevar stressed that the loss-of-coolant accident/emergency core cooling system codes are based on many empirical correlations rather than on basic principles of physics and said that uncertainties exist as to the ability of the codes to adequately predict the behavior of a reactor system in emergency situations. Their solution is to develop more sophisticated computer codes based on the fundamental laws of physics and therefore less on empirical correlations, and/or build a larger scale test facility to eliminate or reduce the scaling compromises.

Dr. Finlayson believes that large-scale system testing, supplemental to LOFT, is cost effective and will ultimately be recognized as needed to achieve public confidence in reactor safety.

Mr. Salvatori contends that because of the numerous separate effects and system effects tests already performed and the philosophy used in the design of nuclear powerplants--upper bound and range of assumptions--there are no unanswered relevant safety questions in the area of emergency core cooling system performance. He stressed that it is no longer necessary to exactly understand the nature and the physical phenomena but rather to confirm that the worst conditions or range of assumptions are reasonably understood and accounted for in a conservative reactor design. He suggested that LOFT be continued, however, because it is aimed at improving the understanding of phenomena associated with a sudden rupture of a reactor coolant pipe particularly in some localized areas such as pumps, fuel rods, and steam generators.

Mr. Salvatori was against a larger scale LOFT test facility because of low probability of the accident it would investigate, its potential large cost, its lack of potential for improving public safety beyond what is already known, and because the data would be too late to be of use.

## EFFECTS OF LOFT TEST RESULTS ON REACTOR LICENSING

The Committee requested that we ask the five experts if they thought reactor licensing should be modified in any way pending the results of LOFT experiments or experiments on a larger LOFT-type test facility. Messrs. Salvatori, Hendrie, and Palladino replied that licensing should not be modified. Dr. Finlayson did not believe that major restrictions on licensing are required, but recommended changes in the Emergency Code Cooling System Acceptance Criteria. Mr. Hocevar thought that licensing should be slowed or halted until needed safety information is obtained.

Mr. Salvatori said that LOFT is not the major light water reactor safety project since it will not provide any safety breakthroughs nor raise any serious doubts about current reactor designs. He said that other research and development projects, some of them in support of LOFT, have already provided the basic knowledge needed in developing conservative models for the safety design of commercial reactors.

Dr. Hendrie, who also stressed that LOFT is not the definitive safety test, and Dr. Palladino noted that there is more to reactor licensing than accident analysis. They said that the current commercial licensing basis puts heavy emphasis on careful and high quality design, construction, installation check out, startup and operation of the plant. This, coupled with redundant safety systems, the low chance of a major pipe rupture, and a high probability of successful emergency core cooling system success, are their major reasons for not changing the licensing process pending the results from only one test facility. Dr. Palladino emphasized that it is this effort to prevent accidents that contributes most to nuclear safety and makes a loss-of-coolant accident a low probability event.

Dr. Finlayson said that LOFT results will not be definitive enough to result in relaxation of the critical conservations in emergency core cooling system design. Though much useful and important information was recognized to be forthcoming in LOFT, he feels that resolution will not be obtained for the critical areas of uncertainty in emergency core cooling system performance (steam binding restricted core reflooding rates, fuel rod swelling and rupture induced core blockage, consequent three dimensional fluid diversion, and fluid flow restrictions in the core). Thus, while agreeing that no major changes were imperative in commercial licensing procedures, he suggested a change to the NRC-Emergency Core Cooling System Acceptance Criteria[1] to increase the minimum rate the core is to be reflooded with emergency core cooling water following a loss-of-coolant accident.

Mr. Hocevar held an opposing viewpoint on this question. He said that the present licensing processes should be slowed drastically and possibly halted until the current questions regarding reactor safety are satisfactorily answered. He believes that the commercial licensing programs have developed too fast since much of the data from LOFT and other important reactor safety experiments will not be available for at least several years. Therefore, he concludes that large numbers of reactors are being built and planned without the benefit of required safety research information.

Mr. Hocevar does not believe that LOFT will provide any major safety breakthroughs by itself, however. He noted that there are many uncertainties in current commercial licensing computer codes, and data from LOFT experiments will not be sufficient to improve these uncertainties.

Mr. Hocevar's main argument for modifying the present licensing procedure is that the computer codes which are being used have not been adequately justified and verified by experimental data. He cites recent tests which could not be accurately predicted by the most accurate codes available and said that these tests imply that the special

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[1] Performance standards developed by NRC which are used to evaluate the design of emergency core cooling systems in the licensing process.

licensing computer programs are not highly conservative as claimed by NRC. According to Mr. Hocevar, even though these extremely important tests were performed in May 1975, NRC has still not performed an analysis of the data using the licensing programs.

LOFT APPLICABILITY TO A BOILING WATER REACTOR

LOFT is a small pressurized water reactor which has been scaled so that test results will simulate the anticipated effects of a loss-of-coolant accident on a large pressurized water reactor. Because there is not a similar test facility for a boiling water reactor, we asked the experts whether LOFT results will be applicable to boiling water reactors or whether a similar LOFT experiment for boiling water reactors is needed.

Messrs. Hendrie and Salvatori thought a large-scale boiling water reactor test was not needed and Messrs. Finlayson and Hocevar thought it was. The remaining consultant, Dr. Palladino, said that a boiling water reactor is sufficiently different from a pressurized reactor to require additional study.

Dr. Hendrie, while noting that there are differences between the emergency core cooling systems of boiling and pressurized water reactors, believes that some LOFT results will be useful in the boiling water reactor computer code development. He said that some of the phenomena during a loss-of-coolant accident are similar for both the boiling and pressurized water reactors and any dissimilarities which exist can be adequately investigated in other already planned test facilities. Therefore, because the performance of the emergency core cooling system is easier to predict in a boiling water reactor, because the costs of a new mobile test assembly would be significant, and because many years of current LOFT testing must be done before a boiling water reactor could be tested, Dr. Hendrie concluded that a new test with a boiling water reactor system would not be worthwhile.

Mr. Salvatori, who believes that we could do without the current LOFT test program, said that based on his knowledge of the large amount of separate effects and system effects testing which has been conducted on the pressurized water reactor and the evenhanded policy applied by AEC/NRC, he "would be surprised to hear that a LOFT experiment using a boiling water reactor test assembly is needed."

Dr. Finlayson and Mr. Hocevar both gave greater emphasis to the dissimilarities between the two reactor systems and said that greater stress should be placed on understanding the responses unique to a boiling water reactor system. Dr. Finlayson said that boiling water reactors have their own set of analysis problems and that a very limited portion of LOFT data will be general enough to be useful for verification of boiling water reactor analysis methods. He noted that NRC, General Electric Corporation, and the Electrical Power Research Institute are jointly conducting small scale tests on an electrically heated boiling water reactor system about one-thirtieth the size of LOFT. He said that these tests represent a useful first step but that it appears that a larger scale test--at least as large as LOFT (and probably larger)--will be required before confidence will be achieved in the adequacy of boiling water reactor-emergency core cooling system analysis methods and predicted results.

Mr. Hocevar noted that there has not been an extensive independent Government assessment of a loss-of-coolant accident and emergency core cooling system phenomena which would occur in a boiling water reactor. Therefore, he concluded that if confidence is to be placed in their computer codes a boiling water reactor test facility is needed. The size would depend on the sophistication of the computer codes, but in any event it should be large enough for a full length core (12 feet).

Dr. Palladino said that much information obtained from LOFT will be applicable to boiling water reactors but it is not clear whether this information will be sufficient to confirm computer codes. He noted that there were some similarities but also some dissimilarities that will not be checked by LOFT. He suggested that studies should be made to determine the extent to which features peculiar to boiling water reactors could be tested in a later phase of the LOFT program. He recognized that an extensive modification of LOFT would be required and the results would be several years away, but he thought that it would still be worthwhile.

## TEST OF LOFT CONTAINMENT VESSEL

When LOFT testing begins and a valve is opened to release the coolant water and simulate a loss-of-coolant accident, the water will be blown into a specially designed tank rather than into the containment vessel. Because of this, there are no planned tests of the containment vessel's ability to control the increased pressure and fission product activity that would normally be released during such an accident. We asked the experts if such a test of the containment vessel would be appropriate for LOFT.

All five of the experts said that LOFT should not be used for containment tests. There were many technical reasons given which related mostly to the uniqueness of the LOFT facility. Some of the predominant reasons given are summarized below.

--The volume of steam released by the LOFT reactor system during an accident would be too low to provide a representative test of the containment building's ability to withstand high pressure.

--The fission product control and removal tests would require substantial melting of the nuclear core to insure a high level of fission product activity. Such a test would contaminate the facility and make it useless for further testing without substantial decontamination. It would also increase the cost of decommissioning the plant.

--The current suppression system will control the radioactive releases that may occur when the coolant is blown out of the reactor system. This will help prevent contamination of the facility so that the personnel can quickly have access to the test facilities and continue with the planned series of tests.

--LOFT is not designed for containment type tests and many features are not representative of current commercial reactors. For instance, the containment building is all steel while large pressurized water reactor containments are steel-lined reinforced concrete. This would produce different heat transfer characteristics.

Dr. Palladino and Mr. Salvatori indicated that current and past programs when coupled with existing analytical techniques, adequately safisfy the data requirement in the area of containment tests other than on LOFT. In contrast, Mr. Hocevar said that past and current separate effects tests are too small and when combined with unsophisticated analytical techniques do not provide data useful in evaluating containment structures and systems.

Dr. Finlayson believes that fission product control and removal is probably the area of reactor meltdown analysis for which conservative bounding analyses are now most reliably available. Consequently, although some further studies of containment decontamination may be needed, especially for fission product aerosols other than iodine, they should be conducted as part of a well-balanced program of reactor safety research, with relatively low priority compared to meltdown prevention research programs.

## CHAPTER 7

## SCOPE OF REVIEW

We reviewed certain aspects of the light water reactor safety program, putting special emphasis on the Loss-of-Fluid-Test facility and obtained the information used in this report by reviewing planning documents, reports, correspondence, and other records, and by interviewing officials at

--ERDA Headquarters, Germantown, Maryland;

--NRC Headquarters, Bethesda, Maryland;

--ERDA Idaho Operations Office, Idaho Falls, Idaho;

--Kaiser Engineers, Oakland, California;

--Phillips Petroleum Company, Bartlesville, Oklahoma; and

--Aerojet Nuclear Company, Idaho Falls, Idaho.

We obtained additional information from past AEC, Phillips, and Idaho Nuclear employees located in Washington, D.C.; Bethesda, Maryland; and Idaho Falls, Idaho.

We made no attempt to make technical assessments, but employed five experts who addressed the technical questions of the Senate Committee on Government Operations.

## CATEGORIZATION OF LOFT OPERATIONS COSTS FOR FISCAL YEAR 1963 THROUGH FISCAL YEAR 1975

| Fiscal year | Research and development | Fuel fabrication | Operations | Reactor experiment fabrication | Test irradiations | Totals |
|---|---|---|---|---|---|---|
| 1963 | $ 508,458 | $ - | $ - | $ - | $ - | $ 508,458 |
| 1964 | 926,515 | - | - | 327,750 | - | 1,254,265 |
| 1965 | 1,835,146 | - | - | 735,582 | - | 2,570,728 |
| 1966 | 2,529,950 | - | - | 928,882 | - | 3,458,832 |
| 1967 | 4,638,566 | 677 | - | 1,624,999 | 89 | 6,264,331 |
| 1968 | 6,340,115 | 46,579 | - | 1,374,454 | 164 | 7,761,312 |
| 1969 | 6,067,007 | - | - | 1,793,466 | - | 7,860,473 |
| 1970 | 4,859,879 | - | - | 1,162,552 | 5,978 | 6,028,409 |
| 1971 | 3,268,982 | - | 59,352 | 4,713,759 | 329 | 8,042,422 |
| 1972 | 1,752,693 | 545,492 | 168,855 | 11,253,151 | 25,000 | 13,745,191 |
| 1973 | 1,331,732 | 2,087,908 | 362,449 | 16,873,361 | 62,121 | 20,717,571 |
| 1974 | 1,725,974 | 1,213,004 | 807,199 | 17,038,028 | - | 20,784,205 |
| 1975 | 3,287,461 | 1,719,695 | 2,898,257 | 11,446,743 | - | 19,352,158 |
| Total | $39,072,478 | $5,613,355 | $4,296,112 | $69,272,727 | $93,681 | $118,348,353 |

## Definitions of operating cost categories

Research and development--costs for analytical, experimental, and developmental work which precedes the fabrication of reactor experiments.

Fuel fabrication--costs for product or production drawings, fabrication and preparation of control elements, reactor fuel, and fuel elements.

Operations--costs for salaries and wages of the operating staff, power, supplies, maintenance, and repairs, and costs of preparing to operate.

Reactor experiment fabrication--costs incurred in the fabrication of a reactor experiment after the ideas of conceptual design are crystallized. Includes design and engineering, procurement, fabrication, erection and installation of materials and equipment.

Test irradiations--costs for reactor space, capsule facility tubes, baskets, and spacers.

LOFT CONSTRUCTION COST ESTIMATE REVISIONS

| Date | | Total estimated cost (millions) |
|---|---|---|
| July | 1963 | $17.6 |
| November | 1964 | 17.8 |
| December | 1964 | 18.4 |
| January | 1965 | 18.5 |
| February | 1965 | 18.1 |
| April | 1965 | 18.3 |
| May | 1965 | 19.4 |
| September | 1966 | 21.9 |
| November | 1966 | 22.5 |
| February | 1967 | 24.5 |
| March | 1967 | 25.5 |
| April | 1967 | 23.7 |
| May | 1967 | 24.0 |
| September | 1967 | 24.3 |
| October | 1967 | 24.4 |
| November | 1967 | 25.0 |
| March | 1968 | 25.5 |
| April | 1968 | 30.5 |
| July | 1968 | 30.8 |
| August | 1968 | 31.6 |
| September | 1968 | 34.0 |
| November | 1968 | 35.0 |
| October | 1973 | 37.1 |
| November | 1973 | 37.2 |
| December | 1973 | 36.6 |

## MAJOR DESIGN CHANGES

### Containment bottom head--1965 to 1966

AEC originally intended to build a conventional containment vessel with a hemispherical bottom head. However, when AEC learned that the site geology included a lava bed, which would make excavation more difficult and costly, it decided to redesign the bottom head, flattening it somewhat to avoid the additional excavation. After this decision was made, however, stress problems were discovered which caused major design problems.

### Containment door design--1965 to 1967

We were told the original design called for a door to be welded to the containment vessel after the mobile test assembly, which included the LOFT reactor, had been pushed inside. According to a former Phillips employee, as early as 1965 AEC and Phillips decided that for safety considerations they would examine operable door designs. AEC believed personnel working to open a welded door after the experiment would be unnecessarily exposed to high levels of radiation. The operable door would allow the mobile test assembly to be taken out of the containment vessel in a shorter period of time and would allow safer access to the experiment.

A number of operable door designs were originally considered. Design work was begun on a latch door, but was abandoned in 1967 in favor of a design providing a tighter seal and more reliability in withstanding certain stress conditions. This design involved using pneumatic sealing tubes around the door.

### Emergency core cooling systems--1968 to 1969

With the redirection, AEC added a new emergency core cooling system, representative of those associated with commercial pressurized water reactors. This included all the hardware associated with emergency core cooling systems such as accumulator systems, high- and low-pressure injection systems, and associated components.

### Core and reactor vessel--1968 to 1969

At the time of the redirection in 1967, the LOFT core and reactor vessel which was to be used for a meltdown experiment bore little resemblance to commercial pressurized water reactors. AEC had the core and reactor vessel completely redesigned to meet typicality requirements. This involved changing fuel pins and other core internals, lengthening the core from 3 feet to 5-1/2 feet, and redesigning the reactor vessel. These changes were made to insure that the physics of the LOFT core and the reactor vessel configuration would resemble those of a commercial reactor.

New instrumentation--1968 to 1972, 1975

The redirected LOFT needed new instrumentation to make its results more applicable to emergency core cooling system performance in large pressurized water reactors. This instrumentation, much more complex than in the original LOFT experiment, included temperature, pressure, density, flow distribution, and velocity measurements in the core, reactor vessel, primary coolant system, and emergency core cooling system.

The recent changes in instrumentation, which started during 1975, have involved better flow measurement capability in the core and primary coolant system.

Core inspection--1972

The plan for the original LOFT meltdown test called for transporting the mobile test assembly by a shielded railroad locomotive to another building for core inspection after completion of the test. However, after the redirection, AEC determined that it was not practical to transport the mobile test assembly to the inspection area after each emergency core cooling system test. Therefore, they designed a system for inspecting the core for fuel or core damage while the mobile test assembly was still in the containment. This design called for a shielded vessel filled with borated water to be lowered over the reactor vessel by means of a crane. One fuel element at a time would be raised into this "swimming pool" for inspection. A special cask which holds one fuel element was also designed. A fuel element could then be transferred to the inspection area within a cask loaded on a flatbed truck. This would allow the mobile test assembly to remain in the containment for continuing tests.

After this in-containment inspection was decided upon, project officials realized the 15-ton crane designed for the containment was too small. Consequently, the crane, bridge, and trolley were replaced with a 50-ton version.

Fuel handling--1972

The original LOFT program included just one core, while presently there are enough fuel assemblies for more than two full nuclear cores. This permits replacement of fuel assemblies damaged or removed for inspection. Onsite fuel fabrication by Aerojet Nuclear required the construction of a fuel handling building complete with a crane for handling the fuel assemblies.

Suppression tank--1971 to 1972, 1973 to 1974

AEC's desire to run a series of loss-of-coolant tests without containment cleanups after each test eventually resulted in the design and fabrication of a special tank inside the containment to handle the escaping steam from the simulated break. The initial design of this tank was completed in July 1972, with additional redesign work done in 1973 to 1974. This later design work incorporated a spray injection system which will spray water on the steam that rushes into the tank during a simulated loss-of-coolant accident. This permits simulation of various containment pressures.

Structural analysis--1968 to 1974

The test requirements of emergency core cooling systems under the redirected LOFT program resulted in major design changes to various components to insure the handling of thermal shock effects of repeated loss-of-coolant accidents. These changes were required in the reactor vessel and vessel head, the support frame, the piping, and all major components the primary coolant water touches. In addition, the suppression tank foundations and pump and generator foundations had to be strengthened to account for the anticipated forces.

Primary coolant pump coast down--1971

Large pressurized water reactor primary coolant pumps have flywheels attached which provide additional inertia after the pumps are shut down. Cooling water is pumped to the core of a large commercial reactor after the pumps are shut down. This is called a coast down. The LOFT pumps do not have the attached flywheels and consequently slow down more rapidly after the pumps are shut down. Consequently, AEC developed a powered coast down for LOFT using a flywheel-generator-pump system to slow the pump shutoff sequence, thus simulating the normal coast down of pumps in commercial plants.

Core coolant temperature rise--1968 to 1969

The temperature of the coolant water in a commercial pressurized water reactor increases about 65° as it travels through the core. However, because the LOFT core is only 5-1/2 feet long compared to 12 feet for the commercial reactor cores, the coolant temperature rises only about half as much in the LOFT core at similar flow velocities. Therefore, AEC determined that the rate of flow had to be slowed so the temperature rise of the coolant would better simulate that of a commercial reactor. AEC had to design a speed control system adding this to the primary pumps so that the coolant flow could be slowed.

Purification and makeup systems--1971 to 1972

AEC headquarters determined that the LOFT purification and makeup systems should simulate those of small Navy, high-pressurized water reactors because it felt these systems would be more reliable and compact. This affected the design, since AEC and Aerojet Nuclear had been working on a low pressure system. The purification system filters the water in the primary coolant loop, removing other chemical impurities, thus minimizing corrosion. The makeup system controls the effect of the primary coolant on the core and adds coolant to restore amounts lost from small leaks in the primary coolant system. An ERDA Idaho Operations official told us this change was not related to the emergency core cooling system objectives for LOFT.

We were told this change did not directly affect the emergency core cooling system experiments on LOFT, but was directed by AEC headquarters.

The LOFT emergency core cooling system design originally included a diesel as an electrical power backup system. AEC headquarters decided to switch to batteries because they believed the diesel would be unreliable. Since the diesel might not start when needed for a test it would have to be running in order to be used when needed. The batteries were eventually placed in the hangar building adjacent to the containment. Diesels were added as a long term backup. Currently, the LOFT facility has two sets of batteries and two backup diesels.

## CHANGES TO ESTIMATED COMPLETION DATE OF LOFT FACILITY CONSTRUCTION

| Date of estimate | | Contractor estimated completion date for facility construction | |
|---|---|---|---|
| September | 1962 | March | 1966 |
| January | 1965 | December | 1967 |
| December | 1965 | May | 1968 |
| June | 1966 | September | 1968 |
| January | 1967 | March | 1970 |
| April | 1967 | December | 1969 |
| June | 1967 | May | 1970 |
| January | 1968 | June | 1970 |
| February | 1968 | August | 1970 |
| March | 1968 | February | 1971 |
| April | 1968 | March | 1971 |
| July | 1968 | July | 1971 |
| September | 1968 | August | 1971 |
| December | 1968 | October | 1972 |
| January | 1969 | December | 1972 |
| February | 1969 | November | 1972 |
| March | 1969 | October | 1972 |
| April | 1969 | August | 1972 |
| May | 1969 | November | 1972 |
| June | 1969 | December | 1972 |
| September 2, | 1969 | April | 1973 |
| September 18, | 1969 | November | 1973 |
| October | 1969 | March | 1974 |
| December | 1969 | January | 1973 |
| January | 1970 | June | 1972 |
| October | 1971 | December | 1972 |
| November | 1971 | November | 1972 |
| January | 1972 | December | 1972 |
| September | 1972 | February | 1973 |
| December | 1972 | April | 1973 |
| February | 1973 | June | 1973 |
| April | 1973 | August 15, | 1973 |
| May | 1973 | August 31, | 1973 |
| July | 1973 | September | 1973 |
| September | 1973 | December | 1973 |
| October | 1973 | April | 1974 |
| December | 1973 | June | 1974 |
| March | 1974 | August | 1974 |
| September | 1974 | December | 1974 |
| December | 1974 | June | 1975 |

APPENDIX V

BIOGRAPHICAL INFORMATION

CARL J. HOCEVAR - Union of Concerned Scientists, 1208 Massachusetts Avenue, Cambridge, Massachusetts 02138

Birthplace and Date: - Sheboygan, Wisconsin - January 11, 1940

Present Home Address: 51 Eldred Street, Lexington, Ma. 02173

Education:

B.S. - Mechanical Engineering, University of Wisconsin, 1962
M.S. - Mechanical Engineering, University of Washington, 1965
Graduate work toward Ph.D. in Mechanical Engineering, University of Washington, 1964-67

Professional Membership:

ASME - Associate Member

Honors:

Phi Eta Sigma
Sophomore Honors
BSME Cum Laude

Experience:

October, 1974 to Present: Union of Concerned Scientists, Cambridge, Massachusetts. Evaluation of nuclear reactor safety. Solar energy and general energy studies.

May, 1967 through September, 1974: Aerojet Nuclear Company, Idaho Falls, Idaho. Developed analytical models to simulate the thermal and hydraulic response of light-water nuclear reactors during a postulated loss-of-coolant accident. Developed the THETA1-B hot channel analysis computer code and worked on advanced computer prediction techniques.

Carl J. Hocevar - Page 2

October, 1964 through March, 1967: Mechanical Engineering Department, University of Washington, Seattle, Washington. Graduate study and Teaching Assistantship.

June, 1962 through October, 1964: Boeing Company, Seattle, Washington. Analyzed thermal protection systems for space vehicles.

Technical Interests:

Nuclear Reactor Safety - Loss-of-Coolant and Emergency Core Cooling thermodynamic and fluid dynamic analysis and boiling heat transfer

General energy supply and demand studies

Solar energy

Non-technical Interests:

Environmental - Was very active in State and regional environmental groups while in Idaho. Involved in wilderness, forest land practices, general land use, mining, dams and river use, and noise pollution issues. Held directorship, elected office, and committee chairman positions in several environmental organizations.

Publications:

Nuclear Reactor Licensing - A Critique of the Computer Safety Prediction Methods, Union of Concerned Scientists, Cambridge, Mass. (September 1975).

"Nuclear Power Safety: An Engineering Overview", Professional Engineering (May 1975).

THETA1-B, A Computer Code for Nuclear Reactor Core Thermal Analysis, (Co-author), IN-1445 (February 1971).

LOFT Core Length Study, IN-1391 (August 1970).

## BIOGRAPHICAL INFORMATION

JOSEPH MALLAM HENDRIE

Home Address: 4 Eastgate Drive
Sayville, N. Y. 11782

Business Address: Department of Applied Science
Brookhaven National Laboratory
Upton, N. Y. 11973

Occupation: Nuclear Engineer

Born: Janesville, Wisc.; March 18, 1925

Education: Case Institute of Technology 1946-50; B. S. 1950; physics major, Columbia University 1950-55; Ph.D. 1957; physics major

Employment:

Research Assistant, Columbia University 1950-55

Brookhaven National Laboratory
- Assistant Physicist, Reactor Physics Division 1955-57
- Associate Physicist 1957, Physicist 1960, Physicist with Tenure 1960, Senior Physicist 1971
- Project Engineer and Chairman of the Steering Committee, High Flux Beam Reactor Project 1958-65
- Acting Head, Experimental Reactor Physics Division 1965-66
- Project Manager, Pulsed Fast Reactor Project 1967-70
- Associate Head, Engineering Division, Department of Applied Science 1967-71
- Head, Engineering Division, Department of Applied Science 1971-72
- Deputy Director for Technical Review, Directorate of Licensing, US Atomic Energy Commission 1972-74
- Chairman, Department of Applied Science, Brookhaven National Laboratory

Other Professional Activities:

- Consultant, Columbia University Radiation Safety Committee 1964-72
- Advisor, US Delegation, Third United Nations International Conference on the Peaceful Uses of Atomic Energy 1964

JOSEPH MALLAM HENDRIE - Page 2

Member, Editorial Advisory Board, "Nuclear Technology" 1967-
Member, Advisory Committee on Reactor Safeguards, USAEC, 1966-72; Vice Chairman 1969; Chairman 1970
Lecturer on nuclear power plant safety and licensing in special sessions at Massachusetts Institute of Technology 1970- ; Georgia Institute of Technology 1974- ; Northwestern University 1974-
US Representative, International Atomic Energy Agency's Senior
Advisory Group on Reactor Safety Codes and Guides 1974-
Consultant, US Nuclear Regulatory Commission 1974-75

| | |
|---|---|
| Fields of Professional Interest: | Nuclear power plant design and safety analysis; design and utilization of research reactors and experimental facilities; electrical power transmission; high-strength concrete structures and vessels; stress analysis; reactor physics research; molecular physics |
| Membership in Professional Societies: | American Nuclear Society; elected Fellow in 1968<br>American Physical Society<br>American Society of Mechanical Engineers<br>American Concrete Institute<br>Institute of Electrical and Electronics Engineers<br>New York Society of Professional Engineers<br>Maryland Society of Professional Engineers<br>National Society of Professional Engineers |
| Licenses: | Registered Professional Engineer; New York, PE 045136 |
| Patents: | "High Flux Beam Reactor", No. 3,143,478, 1964; with J. Chernick, K. Downes, J. Hastings, and H. Kouts |
| Honorary Societies: | Sigma Xi<br>Tau Beta Pi |

APPENDIX V

JOSEPH MALLAM HENDRIE - Page 3

| | |
|---|---|
| Honors: | US Atomic Energy Commission's Ernest O. Lawrence Memorial Award, 1970 |
| Clubs: | Sigma Alpha Epsilon |
| Listings: | Who's Who in America; American Men and Women of Science; Engineers of Distinction: Who's Who in Atoms; Leaders in American Science; World Who's Who in Science |

## BIOGRAPHICAL INFORMATION

NUNZIO J. PALLADINO - Dean of the College of Engineering and Professor of Nuclear Engineering, The Pennsylvania State University, University Park, Pa. 16802

Birthplace and Date: Allentown, Pennsylvania - November 10, 1916

Present Home Address: 333 West Park Avenue, State College, Pa. 16801

Education:

B.S. in Mechanical Engineering, Lehigh University, 1938
M.S. in Mechanical Engineering, Lehigh University, 1939
University of Tennessee, Graduate Program in Nuclear Engineering
University of Pittsburgh Business & Management Program, 1955, Certificate D. Eng. (Hon.), Lehigh University, 1964

Professional Memberships:

ASEE - Member
ASME - Member
ANS - Fellow; Vice President 1969-70 and President 1970-71
Member - Cosmos Club, Washington, D.C.
Professional Engineering License - Commonwealth of Pennsylvania No. 8916
Past Member - Council of Associated Midwest Universities, Argonne National Laboratory
Member - Board of Directors, Argonne Universities Association
Member - National Academy of Engineering; Chairman, Annual Meeting May 1969
National Committees:
- Past Member, ASME Reactor Engineering Committee (Past Chairman)
- Past Member, ASME Nucleonics Heat Transfer Committee
- Past Member, Committee on Objective Criteria on Nuclear Engineering Education - ASEE and ANS
- Past Member, ASEE Com. on Relations with U.S. Atomic Energy Commission

Biographical Information - Nunzio J. Palladino - Page 2

Past Member, International Heat Transfer Committee
Past Member, Board of Engineers' Joint Council
Past Member, U.S. Atomic Energy Commission Advisory Committee on Reactor Safeguards (Past Chairman)
Past Member, Pa. Advisory Com. on Atomic Energy Development and Radiation Control; Chairman
Member, Engineering Education & Accreditation Committee, ECPD
Member, Governor's Science Advisory Committee in Pennsylvania, Chairman, Energy Management Subcommittee
Member, Governor's Energy Council (Pennsylvania)

Honorary Societies and Awards:

Sigma Xi Honor Society
Tau Beta Pi Honor Society
Sigma Tau
Pi Mu Epsilon Society
Gotshall Scholar
Westinghouse Order of Merit for Technical Direction of Reactor Design of Atomic Submarine NAUTILUS & Shippingport Nuclear Power Plant (1956)
Prime Movers Award of ASME for being co-author of paper regarding the Shippingport Nuclear Power Plant (1958)

Experience:

Nov. 1, 1966 to Present: Dean, College of Engineering, The Pa. State Univ.
July 16, 1959 to Oct. 31, 1966: Professor and Head, Nuclear Engineering Department, The Pa. State Univ.
May 1, 1950 to July 15, 1959: Westinghouse Electric Corp., Pittsburgh, Pa.
Manager PWR Reactor Design Subdivision. Was in responsible charge of work on the design of Submarine Prototype Reactor, Mark I, on NAUTILUS Reactor and on Shippingport Reactor. Initiated burnout studies at Westinghouse.

Biographical Information - Nunzio J. Palladino - Page 3

Oct. 1948 to April 30, 1950: Argonne National Laboratory, Lemont, Ill.
Staff Assistant to the Division Manager. (On loan from Westinghouse)
June 15, 1946 to Sept. 30, 1948: Oak Ridge National Laboratory, Oak Ridge, Tennessee.
Senior Engineer. (On loan from Westinghouse)
May 1942 to December 1945: U.S. Army - Company Commander and First Army Staff Officer.
Highest Rank - Captain
July 1, 1939 to May 1942 and December 1945 to June 15, 1946: Westinghouse Elec. Corp., Phila., Pa. Steam Turbine Design Engineer.

Research Interests:

Reactor Engineering - Integration of Mechanical, Thermal and Nuclear Design
Reactor Fuels Management - Economics of Power Reactor Design
Heat Transfer and Fluid Flow - Boiling and Burnout
Reactor Transient Problems - Reactor Safety and Reactor Protection Accident Analysis

University Activities:

Member, External Affairs Committee of University Senate
Member, University Tenure Appeals Board
Member, College of Engineering Executive Committee
Member, University Senate
Member, Open Expression Committee of University Senate
Member, Council of Academic Deans
Past Member, Continuing Education Committee of University Senate
Past Member, Educational Policy Committee of University Senate
Past Member, University Senate Reorganizing Committee
Past Member, University Development Committee
Past Member, University Isotope Committee
Past Member, Penn State Reactor Safeguards Committee

Biographical Information - Nunzio J. Palladino - Page 4

Publications:

Engineering is a Creative Art, The Penn State Engineer, November 1975.

Current Status of Nuclear Engineering Education, NUCLEAR TECHNOLOGY, September 1975.

Chapter on "Mechanical Design of Components for Reactor Systems" The Technology of Nuclear Reactor Safety, Vol 2, The MIT Press, 1973.

Technicians, Technologists & Engineers for Nuclear Power. (Co-author) Proceedings of Geneva Conference, 1971.

Nuclear Engineering, The Brittannica Review of Developments in Engineering Education. Newman A. Hall, Editor, Vol. I, pp. 207-249, June 1970.

Engineering Education in a Multicampus University (Co-author), ASEE Journal, December 1969. (Delivered at Engineering Conference, Paris, France, December 1968.)

New Opportunities for Service, The Spectrum, May 1967.

The Social Sciences & Humanities in Engineering, The Spectrum, October 1967.

Chapter on "Atomic Energy" (Co-author), Mark's Handbook, McGraw-Hill Co., Inc., 1967.

Table of Bessel Functions to Argument 85 Bessel Functions (Co-author), Engineering Research Bulletin B-85, The Pennsylvania State University, University Park, Pennsylvania, September 1962.

Intrinsic Reactor Safety Through Design (Co-author), IAEA Symposium on Reactor Safety and Hazards Evaluation Techniques, May 1962.

Engineering Development of the PWR Core and Vessel, Transactions of the ANS, June 1959.

The Engineering Design of Power Reactors (Co-author), Nucleonics, June 1960.

Chapter 4 - Reactor, Shippingport Pressurized Water Reactor (Co-author), Addison-Wesley Press, September 1958.

Mechanical and Thermal Problems of Water Cooled Nuclear Power Reactors (Co-author), ASME (57-NESC-119), March 1957.

Description of the Pressurized Water Reactor Power Plant at Shippingport, Pa. - Part C Core Design (Co-author), Proceedings of the Int. Conf. in Geneva, August 1955.

The Thermal Design of Nuclear Power Reactors, Trans. ASME, July 1955.

Atomic Energy Possibilities in Industry, Tool Engineer, July 1950.

A number of Classified Reports for the AEC (1946-1959).

# BIOGRAPHICAL INFORMATION

ROMANO SALVATORI - Manager of U. S. Projects Department, Nuclear Energy Systems, Westinghouse Electric Corporation, P. O. Box 355, Pittsburgh, Pa., 15230

Birthplace and Date: Foggia, Italy - March 17, 1938

Present Home Address: 201 South Lexington Ave., Pittsburgh, Pa., 15208

Education: "Dottore in Ingegneria Elettrotecnica", University of Rome (Italy) 1962 Post-graduate courses in Reliability and Nuclear Engineering at Penn State University and Carnegie-Mellon University

Professional Memberships:

ANS - Member; Chairman, WG-1 of ANS 20 in 1971
IEEE - Member; Member SC-5 (Reliability Analysis Guide) in 1970
AIF - Member; Member of Steering Committee on Reactor Safety in 1973
ANSI - AIF Representative on Nuclear Technical Advisory Board Sierra Club - Member

Experience:

Jan. 1975 to Present: Mgr., U. S. Projects Dept., Westinghouse Electric Corp.
Nov. 1974 to Jan. 1975: Mgr., Nuclear Safety Dept., and Acting Director of Public Acceptance. Westinghouse Electric Corp.
Aug. 1973 to Nov. 1974: Mgr., Nuclear Safety Dept., Westinghouse Electric Corp.
Sept. 1972 to Aug. 1973: Mgr., Safety & Licensing, Nuclear Safety Dept., Westinghouse Electric Corp.
Nov. 1970 to Sept. 1972: Mgr., Safety & Licensing, Engineering Dept., Westinghouse Electric Corp.
March 1969 to Nov. 1970: Mgr., Reliability, Engineering Dept., Westinghouse Electric Corp.
Feb. 1968 to Feb. 1969: Sr. Engineer/Leader, Safeguards Development, Engineering Dept., Westinghouse Electric Corp.
June 1965 to Feb. 1968: Engineer, Safeguards Analysis and Licensing, Engineering Dept., Westinghouse Electric Corp.

Biographical Information - Romano Salvatori - Page 2

June 1962 to May 1965: Nuclear Safety Engineer, Italian AEC, Rome, Italy

Special Qualifications or Experience:

Professional License in Engineering in Italy
Instructor of Nuclear Safety Course at University of Pittsburgh (1974, 1975, 1976)
Lecturer at the Nuclear Safety Course at Massachusetts Institute of Technology (1974, 1975)
Consultant to the General Accounting Office, Resources and Economic Development Division, Washington, D.C.
Panelist on the Atomic Industrial Forum Info-75, "The Technical Man As A Communicator"
Panelist at 1975 ASME Meeting, "Energy Independence"

APPENDIX V

Biographical Information - Romano Salvatori - Page 3

ARTICLES, BOOKS OR PAPERS

| | Year | Jnl./Publ./Society | Title |
|---|---|---|---|
| | 1967 | IAEA Mtg., Japan | Ultimate Strength Criteria to Ensure No Loss of Piping and Vessels under Earthquake Loading (co-author) |
| Fall | 1969 | Carnegie-Mellon | Safety Criteria for Light Water Reactors |
| Winter | 1970 | Lecture at Alabama Power Co. Nuclear Training Program | Safety of Pressurized Water Reactors |
| Sept. | 1970 | ANS Power Division Conference | Experimental Bending Tests on Pressurized Piping Under Static and Simulated Accident Conditions |
| Nov. | 1970 | IEEE Nuclear Science Symposium | Systematic Approach to Safety Design and Evaluation |
| Feb. | 1972 | IEEE Tutorial Course | Pressurized Water Reactor Plant Safety |
| Feb. | 1972 | AEIC Conference | The Licensing Scene Today |
| Jan. | 1972 | Illinois Pollution Control Board | Statement on the Zion Emergency Core Cooling System |
| | 1973 | ASME | Probability As A Design Parameter for Plant Design Against Missiles |
| Nov. | 1973 | AIF Workshop | Licensing Problems of Classification |
| Fall | 1973 | Nuclear Digest | Nuclear Power Plants and The Environment in the United States |
| Oct. | 1973 | Fifth Foratom Congress | The Environmental Impact of Nuclear Power Plants in The United States |
| | 1974 | Public Utilities | Changing Face of Licensing |
| June | 1974 | ANS Panel | A Standard of Missile Protection |
| Dec. | 1974 | AIF Workshop | A Vendor Perspective on Implementation of Standardization Options |
| Oct. | 1974 | State of Michigan | Testimony on Nuclear Power Plant Safety before Nuclear Power Pollution Subcommittee of Committee on Marine Affairs of Michigan House of Representatives |
| June | 1974 | Rensselaer Polytechnic Institute | The Environmental Impact of Nuclear Power Plants in The United States |
| May | 1974 | U. S. Congress | Testimony on Risks Associated with Nuclear Power |
| April | 1975 | European Nuclear Conference | Time To Settle Down |
| May | 1975 | Wisconsin State | Testimony - "Nuclear Power - An Energy Source for Today and the Future" |
| Feb. | 1975 | AEIC Conference | Licensing Progress |
| Summer | 1975 | Women's Magazine Editors | The Nuclear Energy Issues |
| Sept. | 1975 | Indiana Nuclear Energy Conference | Pressurized Water Reactor Technology |
| June | 1975 | National Aerospace and Electronics Conference | How To Avoid Another Energy Crisis |
| Feb. | 1975 | AIF | The Technical Man As A Communicator |

## BIOGRAPHICAL INFORMATION

### Fred C. Finlayson, Staff Engineer, Energy Programs Group Energy and Resources Division

### SPECIAL QUALIFICATIONS

As staff Engineer, Energy Programs Group, Dr. Finlayson has been responsible for a variety of projects dealing with nuclear power energy supply and demand, and advanced power conversion concepts. He has completed an independent review of the effectiveness of the emergency core cooling systems (ECCS) for nuclear power plants and has recently served as a member of the American Physical Society's select committee on Light-Water Reactor Safety. He has also directed and conducted recent research in the general aspects of the safety of nuclear power generation including a study of hazards associated with transportation of spent nuclear fuel in the western regions of the United States. Dr. Finlayson has also been actively conducting research in the broader areas of energy supply and demand, having conducted recent investigations of the conceptual design and evaluation of hybrid solar/geothermal power systems, as well as a variety of studies in energy consumption and the effectiveness of specific concervation measures.

### EDUCATION

B.S., Mechanical Engineering, Brigham Young University, 1958
Ph.D., Mechanical Engineering, Northwestern University, 1964

### EXPERIENCE

### The Aerospace Corporation (1972 to present)

Dr. Finlayson is currently responsible for planning and conducting programs in energy systems analysis and hazards analysis of elements of the nuclear fuel cycle. In a previous assignment, he was temporarily attached to the Environmental Quality Laboratory of the California Institute of Technology where he was responsible for evaluation of problems in nuclear power plant safety.

Physics International Company (1968 to 1972)

Dr. Finlayson was Manager of the Systems Development and Assessment Department where he directed and conducted research related to strategic and tactical weapon systems survivability/vulnerability and numerical analyses of the propagation of strong shocks in geologic media and structural materials as well as structure-medium interactions.

The Aerospace Corporation (1964 to 1968)

Dr. Finlayson was Manager of the Ground Systems Survivability Section of the Nuclear Effects Department where he directed and conducted investigations of ground based system survivability to all relevant effects of nuclear weapons.

The General American Transportation Corporation (1960 to 1964)

As a Research Engineer in the MRD Division, Dr. Finlayson conducted research on the interactions of strong shocks in air and earth materials with above-ground and buried structures.

PROFESSIONAL ACTIVITIES

Dr. Finlayson is that author of a number of papers and reports on the dynamics of strong shocks in solids and fluids and their interactions with structures, as well as the safety of nuclear power reactors, energy consumption and conservation. He is currently a member of the American Geophysical Union and the American Nuclear Society.