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United States General Accounting Office

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Report to the Honorable Edward J. Markey, House of Representatives

ch 1988

NUCLEAR REGULATION

Action Needed to Ensure That Utilities Monitor and Repair Pipe Damage

135450

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GAO

United States
General Accounting Office
Washington, D.C. 20548

Resources, Community, and
Economic Development Division

B-223582

March 18, 1988

The Honorable Edward J. Markey
House of Representatives

Dear Mr. Markey:

On January 15, 1987, you asked us to assess the December 1986 accident at the Surry nuclear power plant owned by the Virginia Electric and Power Company and provide information on several technical problems, such as pressurized thermal shock and reactor vessel embrittlement, that face aging nuclear power plants. This report presents our findings concerning the accident at Surry as well as a July 1987 incident at the Trojan plant in Oregon. We expect to provide a detailed report later regarding the technical problems facing older nuclear plants.

Unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of this letter. At that time, we will send copies to the appropriate congressional committees; the Chairman, Nuclear Regulatory Commission; and the Director, Office of Management and Budget. We will also make copies available to others upon request.

This work was performed under the direction of Keith O. Fultz, Senior Associate Director. Other major contributors are listed in appendix I.

Sincerely yours,

J. Dexter Peach

J. Dexter Peach
Assistant Comptroller General

Executive Summary

Purpose

On December 9, 1986, a pipe rupture at Virginia Electric and Power Company's Surry Unit 2 nuclear power plant injured eight workers; f subsequently died. As a result of this accident, Representative Edwar Markey requested GAO to assess the problems confronting aging nucle plants, including the pipe degradation that led to the Surry accident.

This report addresses the Surry accident and, as agreed with Represe tative Markey's office, the July 1987 discovery of widespread pipe de rioration by the Portland General Electric Company at its Trojan plar in Oregon. It also addresses actions taken by the companies to identif and correct problems in their pipe systems and efforts initiated by th Nuclear Regulatory Commission (NRC) and the utility industry to prevent similar, future incidents. (See ch. 1.)

Background

Under the Atomic Energy Act, NRC regulates the construction and ope tion of nuclear plants and issues rules to ensure that the plants do no pose undue risks to public health and safety. As of November 1987, N had issued operating licenses to 109 plants. NRC focuses its regulatior on safety equipment and relies on each utility to ensure that nonregulated plant systems operate properly. To provide guidance to the indı try, the American Society of Mechanical Engineers has developed pip thickness standards and suggested that utilities replace pipe that doe not meet these limits. NRC has incorporated the industry standards in its regulations. However, neither NRC's regulations nor industry standards require utilities to inspect for the type of pipe degradation tha caused the Surry accident and the widespread pipe damage at Trojar (See ch. 1.)

Results in Brief

The events at Surry and Trojan raise questions about the long-term safety of pipe systems in nuclear power plants. Surry had been in ser vice for 14 years when the accident occurred, and Trojan only 11 yea Further, the damage at Trojan was more widespread than Surry's an was found in both the NRC-regulated and nonregulated portions of the plant.

In response to the Surry accident, in July 1987 NRC required utilities provide information on the extent of known pipe deterioration at eac plant. As of January 1988, NRC staff identified 34 new and mature plants with erosion/corrosion damage. NRC staff expect to gather add tional information and use it to determine whether specific regulator action is needed. In addition, a utility industry group has developed a program to help companies detect and repair pipe damage.

ncipal Findings

Surry Accident

The Surry accident surprised both NRC and the industry because it was the first time this type of accident caused fatalities at a nuclear facility. In December 1986, a valve in a main steam line closed which caused the pressure in other pipe systems to increase, and a rupture occurred. The steam released by the rupture not only damaged equipment but also resulted in eight worker injuries; four later died. Virginia Power concluded that the cause of the accident was erosion/corrosion caused by fluid passing through pipes at high temperature, pressure, and speed during the 14 years the plant had been in service.

Although the accident occurred at a pipe bend in the area of the plant that is not regulated by NRC, its effects cascaded across several regulated systems causing additional accident management problems. The steam released from the ruptured pipe activated several fire protection systems, which then adversely affected the air in the control room and the plant's security and communications systems. NRC staff told us these unexpected challenges to the plant's safety systems may be the more significant aspect of the incident.

Following the accident, Virginia Power performed extensive work at Surry Unit 2 and its three other nuclear plants to determine the extent of erosion/corrosion. As a result of these efforts, the company inspected about 1,500 components, replaced 184, and developed data that it will use to guide its erosion/corrosion program in the future. (See ch. 2.)

Trojan Incident

Seven months after the Surry accident, Portland General, during planned refueling activities, reported to NRC that it discovered widespread erosion/corrosion in both the regulated and nonregulated portions of its Trojan plant. The discovery at Trojan was the first time that a utility found extensive damage in both portions. In addition, Trojan had been in service for only 11 years, and the utility found damage in straight sections of pipe, far away from pipe curves or other unique configurations where, on the basis of industry guidance, erosion/corrosion would have been expected.

The utility initiated a comprehensive program to correct the damage found at Trojan. It inspected and replaced all important safety comp nents and damaged pipe where necessary, upgraded the plant's pipe monitoring program, and developed data to assess future erosion/co sion problems. (See ch. 2.)

NRC's Response to These Incidents

NRC sent inspection teams to both plants and began to reassess its re latory responsibilities. Although the Surry accident occurred in the r regulated portion of the plant, pipe degradation at Trojan was found the regulated and nonregulated portions. In July 1987 NRC required a nuclear utilities to provide information on the extent of known erosi corrosion damage at their plants, as well as monitoring programs tha are in place. As of January 1988, NRC staff had not completed their a ysis of these data. However, the staff's preliminary findings indicate that 34 nuclear plants have some erosion/corrosion damage—the pla have been in service from 15 months to 20 years. NRC staff expect to collect additional information from utilities and decide in the summe 1988 whether to recommend that the Commission take additional re latory action regarding erosion/corrosion. The staff does not know, however, if the Commission will address this issue or the extent of th action it may take. (See ch. 3.)

Industry Initiatives

In addition to NRC's initiatives, the industry has taken steps to encou utilities to identify and correct erosion/corrosion in nuclear plants. V ous industry groups conducted workshops to exchange information this condition. Further, the Nuclear Management and Resources Cou which serves as an interface between the nuclear portion of the indu and NRC, has recommended that companies develop an approach to i tify, inspect, and repair erosion/corrosion damage. To assist in these efforts, the industry developed a computer program that utilities car use to identify areas in pipe systems that may be most susceptible to this condition.

Although many utilities are using the computer program to detect er sion/corrosion in their plants, no industry-wide commitment exists t implement the Council's recommendations to inspect for, and repair, degraded pipe. Consequently, short of an NRC requirement, no guara exists that utilities will take the actions needed to maintain the integ of pipe systems at nuclear power plants. (See ch. 3.)

ecommendations

The December 1986 accident at Surry initiated a new era of understanding regarding erosion/corrosion at nuclear power plants. Since the accident, utilities found some erosion/corrosion in about 30 percent of the operating plants. Although NRC and the industry have taken some positive actions, no NRC requirement or industry commitment exists to ensure the integrity of pipe systems in nuclear plants. Due to the significance of the information that has been developed concerning erosion/corrosion at nuclear power plants, GAO recommends that the Chairman, NRC, require utilities to

- inspect all nuclear plants to develop data regarding the extent of erosion/corrosion in pipe systems, including straight sections of pipe;
- replace pipe that does not meet the industry's minimum allowable thickness standards; and
- periodically monitor pipe systems and use the data developed during these inspections to assess the spread of erosion/corrosion in the plants.

gency Comments

GAO discussed the facts presented in this report with NRC staff and representatives from Virginia Power, Portland General, and the Nuclear Management and Resources Council. They generally agreed with the facts presented but offered some clarifications that were incorporated where appropriate. As requested, GAO did not ask NRC, the utilities, or the industry group to formally review and comment on this report.

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Abbreviations

ASME	American Society of Mechanical Engineers
EPRI	Electric Power Research Institute
GAO	General Accounting Office
INPO	Institute of Nuclear Power Operations
NRC	Nuclear Regulatory Commission
NUMARC	Nuclear Management and Resources Council
RCED	Resources, Community, and Economic Development Division

Introduction

The Atomic Energy Act of 1954, as amended (42 U.S.C. 2011 et seq.), assigns utility companies the primary responsibility to properly buil[d] and operate commercial nuclear power plants. Because of the safety concerns that are associated with these facilities, regulations have be[en] established to ensure that public health and safety is not jeopardized [by] their operation. Until January 19, 1975, the Atomic Energy Commiss[ion] both developed and regulated commercial nuclear power. The Comm[is]sion was abolished on that date, and its regulatory responsibilities w[ere] assigned to the Nuclear Regulatory Commission (NRC).[1]

Under the Atomic Energy Act, NRC issues operating licenses to comm[er]cial nuclear plants for 40 years. NRC oversees the safe construction a[nd] operation of these facilities by developing regulatory standards, insp[ect]ing plants to ensure that utilities comply with the regulations, and is[su]ing notices of violation and levying civil penalties when companies violate the regulations. Since each utility is ultimately responsible fo[r] the safe operation of its nuclear plants, NRC requires the companies t[o] have programs and systems in place to ensure that public health and safety is protected from radiological danger.

Some nuclear power plants are reaching the point where utilities wil[l] have to decide whether to seek approval to operate their plants bey[ond] the 40-year license period or develop alternative methods to produce electricity. As of November 1987, NRC had issued operating licenses [for] 109 plants. Of these plants, 11 began operating between 1961 and 19[..] During the subsequent 5 years, utilities placed 39 additional plants i[n] service. NRC and the electric utility industry are currently reviewing [the] effects of aging on the continued safe operation of pipe systems and other critical safety components in nuclear plants.

NRC Regulates Nuclear Plant Safety Systems

The Atomic Energy Act authorizes NRC to prescribe regulations it de[ems] necessary to protect public health and minimize danger to life or pro[p]erty. NRC issues rules, regulations, and general design criteria contai[ned] in Title 10, Chapter 1, Code of Federal Regulations (collectively refe[rred] to as regulations). Although these documents are formal, legal requi[re]ments, they are primarily general statements that do not specify the details or methods utilities must use to achieve compliance. Consequently, NRC's regulations establish only general safety standards. U[tili]ties are free to select their own methods to comply with these

[1]Energy Reorganization Act of 1974, Title II, 42 U.S.C. 5841-5851.

requirements but must demonstrate to NRC that the alternatives selected ensure safe plant operations.

Commercial nuclear plants are divided into primary and secondary sections. Most of NRC's regulatory effort is directed toward safety systems in the primary portion of the plant where steam is produced. Included in this section is the nuclear reactor, the containment building that houses the reactor, and the systems, components, and safety features inside the containment building that support the reactor's operation. NRC requires utilities to install safety systems in this portion to prevent and/or mitigate an accident and protect public health and safety from the escape of radiation if an accident occurs.

The steam produced in the primary portion is transferred through pipes to the remainder of the plant, known as the secondary portion. This section contains the turbine and generator that produce electricity, as well as the various systems and components needed to process and supply water to equipment located in both the primary and secondary portions of the facility.

NRC classifies equipment in nuclear plants according to its safety function. Systems and components designated as "safety-related" ensure the integrity of the reactor vessel, its coolant, and the pressure boundary associated with its operation. Safety-related equipment is needed to (1) shut down the reactor and maintain it in a safe condition or (2) prevent or mitigate an accident that could result in the escape of radiation. Although equipment may be classified as safety-related, it can be located outside the primary portion of a plant.

In contrast to safety-related equipment, systems and components classified by NRC as "non-safety-related" do not have a direct safety protection function. Although the failure of non-safety-related equipment can lead to an accident, safety-related equipment exists to mitigate the accident's effects. NRC relies on utilities to ensure that systems designated as non-safety-related function properly.

To provide guidance to the utility industry, the American Society of Mechanical Engineers (ASME) has developed standards to guide the operation of large industrial installations, including nuclear plants. ASME has developed pipe thickness standards and suggested that utilities replace pipe that does not meet these limits. NRC has incorporated pertinent sections of ASME's boiler and pressure vessel standards into its regulations governing safety-related equipment. NRC has not developed regulations for non-safety-related equipment. Instead, NRC requires utilities to ope ate in accordance with the ASME standards and allows companies to select the specific methods and procedures to meet these standards.

Neither NRC's regulations nor industry standards require utilities to inspect pipe systems for the type of wear or deterioration that can result from continuous operation. Instead, they require utilities to inspect safety-related welds that are used to join pipes together to det cracks or other defects that may adversely affect the integrity of the pipe. NRC's regulations and industry standards also require utilities to inspect the areas immediately surrounding the welds, known as heat affected zones, to ensure that pipe integrity is not degraded by the he produced by the welding process.

Industry Groups Assist Utilities

Several organizations, funded by utility companies, have been formed support and represent the electric utility industry. In 1973 the Electri Power Research Institute (EPRI) was established to expand electric energy research and development. EPRI conducts its research in areas such as advanced technology systems, energy analysis, and environm tal assessments and publishes reports in six major technical areas, including nuclear power. Its membership is composed of over 600 mer ber utilities that provide about two-thirds of the nation's electricity. Currently, 46 of the nation's 54 utilities owning nuclear plants are me bers of EPRI.

After the 1979 accident at Three Mile Island, the industry created the Institute of Nuclear Power Operations (INPO) to help improve the oper tion of nuclear plants. INPO analyzes events that occur in the construc tion, testing, and operation of nuclear plants worldwide to identify possible problems that could result in an accident. To accomplish this INPO operates a network that allows utilities to report information on operating incidents at their plants. INPO then analyzes the data, prepa reports on the most important events, and distributes the informatior all its member companies. INPO also conducts evaluations approximate every 15 to 18 months of member plants. All of the nation's nuclear u ities are INPO members.

In addition to EPRI and INPO, early in 1984 the electric utility industry formed the Nuclear Utility Management and Resources Committee (n the Nuclear Management and Resources Council (NUMARC)) to serve a an interface between the nuclear portion of the industry and NRC.

NUMARC develops and presents the industry position before NRC on matters of generic regulatory importance. According to NUMARC officials, if 80 percent of the member companies agree to conduct an activity or adopt a policy, it then becomes an industry policy to be adhered to by all member utility companies. Senior level personnel from its 54 member utility companies are asked to serve NUMARC in various capacities.

bnormal Events at ıe Surry and Trojan .ants

The Surry power station, located on the James River approximately 12 miles from Newport News, Virginia, is owned and operated by the Virginia Electric and Power Company. The site contains two nuclear plants, Units 1 and 2, which were placed into commercial operation in December 1972 and May 1973, respectively.

On December 9, 1986, Unit 2 experienced an operating incident that resulted in the rupture of a pipe containing heated, pressurized water. The pipe, located in the secondary portion of the plant and classified as non-safety-related, released heated water that immediately flashed to steam. The steam caused equipment malfunctions and injured eight workers; four later died from their injuries.

The incident surprised NRC and the utility industry. Although previous incidents of this nature had occurred at coal and nuclear plants, the accident at Surry was the first time fatalities occurred at a nuclear plant. Virginia Power concluded that the accident was caused by erosion/corrosion. Erosion/corrosion results from a combination of operating conditions, such as the (1) temperature, (2) speed of fluids passing through pipe, (3) configuration or geometry of the piping, and (4) chemical composition of the pipe and water. It occurs primarily in carbon steel components and pipe that are subjected to the fast, turbulent flow of heated water or steam with high moisture content. When these conditions exist, pipe thinning, or the gradual removal of the interior wall of the pipe, occurs. After the accident, Virginia Power disseminated information through news conferences, briefings, and tours of the plant. The company also briefed NRC staff and conducted six workshops throughout the country.

NRC and industry concerns regarding the integrity of pipe systems were increased when, during the 1987 refueling outage, workers discovered extensive erosion/corrosion in components and pipes that supply cooling water to the equipment that produces steam at the Trojan nuclear plant owned by the Portland General Electric Company. The plant, located 32 miles from Portland, Oregon, began operating in May 1976. NRC classifies some of the damaged pipe as safety-related. Although no pipe rupture occurred at Trojan, the extent of erosion/corrosion was more widespread than at Surry and was located in both the safety-related and n safety-related portions of the plant.

Objectives, Scope, and Methodology

On January 15, 1987, Representative Edward Markey asked us to ass the accident at Surry and technical problems, such as pressurized the mal shock and reactor vessel embrittlement, confronting aging nuclea plants. On the basis of subsequent discussions with his office, this rep addresses the incidents at Surry and Trojan, the actions taken by the respective utilities to correct the problems, and the efforts taken by N and the utility industry to prevent similar accidents from occurring in the future. We expect to provide a detailed report later regarding the technical problems facing older nuclear plants, and the actions NRC an the industry have taken, or plan to take, to identify and correct opera tional problems that may result from aging. The report will also discu NRC and industry initiatives to extend the operating licenses of nuclea plants beyond 40 years.

To obtain the information in this report, we interviewed NRC staff and representatives from Virginia Power and NUMARC. At Virginia Power, met with company officials at their headquarters in Richmond, Virgin and operating staff at the Surry nuclear plant. We discussed the chan in design and operating procedures that have been instituted since th accident, as well as measures that have been taken to detect erosion/ corrosion in the future. In addition, we toured the plant to observe th modifications that have been made since the accident. We reviewed v ous technical reports and the final study prepared by Virginia Power entitled Surry Unit 2 Reactor Trip and Feedwater Pipe Failure Report dated March 27, 1987, as well as its consultants February 1987 repor entitled Metallurgical Evaluation of Virginia Power Surry Unit 2 "A" Main Feed Pump Suction Line Failure.

At NRC we met with officials from the Office of Nuclear Reactor Regu tion and the Division of Engineering and Systems Technology within that office, the Division of Engineering within the Office of Nuclear R ulatory Research, and the Reactor Operations Analysis Branch withir the Office of Analysis and Evaluation of Operational Data. We review the Atomic Energy Act and NRC's (1) inspection report compiled after the Surry accident, (2) information notices and July 1987 bulletin iss to the industry, (3) technical reports on erosion/corrosion, and (4) po guidance initiated in response to the Surry accident and the condition observed at Trojan. We attended briefings conducted by NRC staff and company officials who presented information developed on the erosion/corrosion conditions observed at the Surry and Trojan plants. Although we did not visit the Trojan plant, we obtained reports submitted by Portland General to NRC regarding the damaged pipe, interviewed NRC staff who inspected the plant, and reviewed NRC's analysis of the damage. We also met with NRC staff to discuss the actions that have been taken in response to the Surry and Trojan incidents, reviewed their preliminary analyses of data submitted by utilities regarding erosion/corrosion, and obtained information on future actions that NRC may take to mitigate the effects of this condition.

In addition, we met with representatives from NUMARC responsible for developing programs to detect and monitor erosion/corrosion in pipe systems. We also reviewed the technical bases used for these efforts and obtained information on other initiatives to improve industry erosion/corrosion inspection programs.

We discussed the facts presented in this report with NRC staff and representatives from Virginia Power, Portland General, and NUMARC. They generally agreed with the information presented but offered some clarifications that were incorporated where appropriate. As requested, we did not ask NRC, the utilities, or NUMARC to review and comment officially on this report. Our work was conducted between April 1987 and January 1988 in accordance with generally accepted government auditing standards.

Severe Erosion/Corrosion Damage Encounterec at the Surry and Trojan Nuclear Plants

During the past year, Virginia Power and Portland General have foun widespread erosion/corrosion damage in their nuclear plants—Surry and Trojan, respectively. These incidents raise questions about the lo term safety of pipe systems at nuclear plants. The accident at Surry occurred after Unit 2 had been in service for 14 years; the damage at Trojan occurred after only 11 years of service. At Surry, the pipe rup ture resulted in extensive damage to equipment, four worker fatalitie and the unexpected malfunction of important plant systems. Althoug no pipe rupture occurred, in July 1987 Portland General reported the discovery of pipe damage in its Trojan plant that was more widesprea than was found at Surry. Some of the damage was in the regulated po tion of the plant. Following these incidents, both utilities conducted detailed examinations of their pipe systems, replaced a significant po tion of components and pipe, and initiated inspection programs to mo tor erosion/corrosion in the future.

The Pipe Rupture at Surry

On January 13, 1984, a valve in one of the three main steam lines at Surry Unit 2 unexpectedly closed. The valve closure caused the press in other pipe systems, known as feedwater lines, to increase approxi- mately 45 percent, but the pipes remained in tact. Almost 3 years late while operating at full power during the afternoon of December 9, 19 Unit 2 experienced another unexpected valve closure in a main steam line. This time the pressure in the feedwater system increased approx mately 20 percent. Although the pressure was not as great as in 1984 feedwater pipe ruptured in the secondary portion of the plant. Conse- quently, during the period of time between these incidents, erosion/cc rosion occurred in the feedwater system to the point of failure.

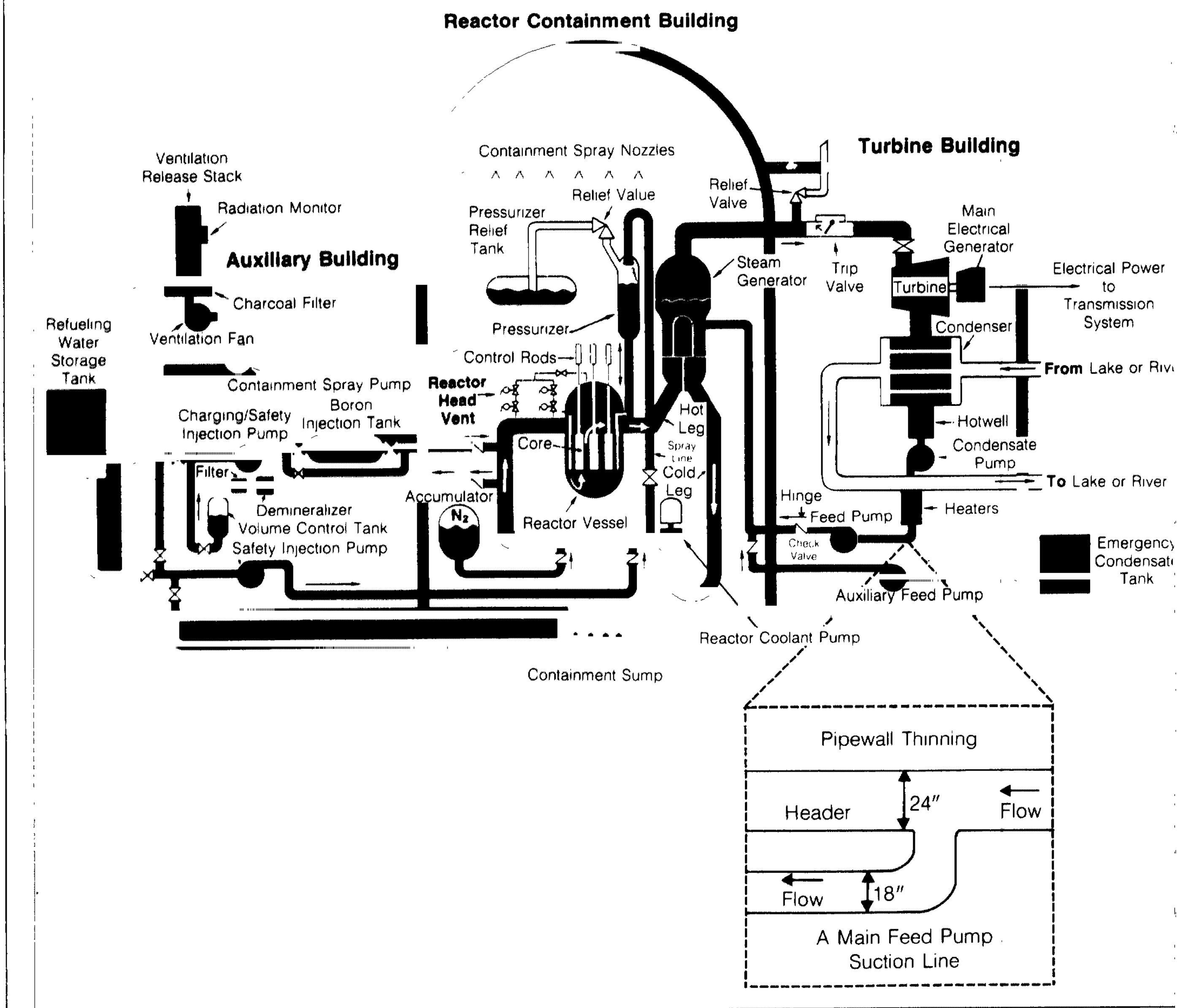
Prior to the accident, the portion of the feedwater line that failed was operating normally at 374 degrees fahrenheit and 367 pounds of pres sure. When the steam valve closed, several actions occurred quickly. Alarms indicating improper steam flow sounded in the control room, t automatic safety protection systems shut down the reactor, and stear pressure in the steam lines increased rapidly. Approximately 35 seco after the valve closed, the plant staff heard a small steam release; thi sound was followed about 7 seconds later by a very loud noise. The noise was a pipe rupture in the feedwater system that recirculates wa back to the equipment that produces steam. When the failure occurre a section of pipe measuring approximately 2 feet by 3 feet blew out a landed on other equipment about 15 feet away. The force of the ruptu moved the remaining pipe section approximately 6.5 feet.

At the time of the accident, eight contractor employees, some on scaffolds, were working in an area adjacent to the pipe that failed. When the workers heard the initial steam release, they jumped off the scaffolds and ran to escape. They were about 20 feet away when the pipe ruptured. As the pipe failed, the water, now under about 550 pounds of pressure, was released, immediately flashed to steam, and engulfed the secondary portion of the turbine building. The workers suffered a wide range of injuries. Two received treatment for minor first degree burns and were released. Six workers, however, had critical burns that required more extensive care. Medical evacuation helicopters and ambulances transported the workers to area hospitals. Four workers subsequently died from their injuries.

The pipe that failed was 18 inches in diameter and was welded to a 24-inch diameter pipe. The failure occurred approximately 1 foot from this joint, in an area where the pipe had been bent in a 90 degree angle to form an elbow. According to Virginia Power officials, the wall of the 18-inch diameter pipe should have been one-half inch thick. Upon examination, some areas were found to have eroded to the thickness of a credit card.

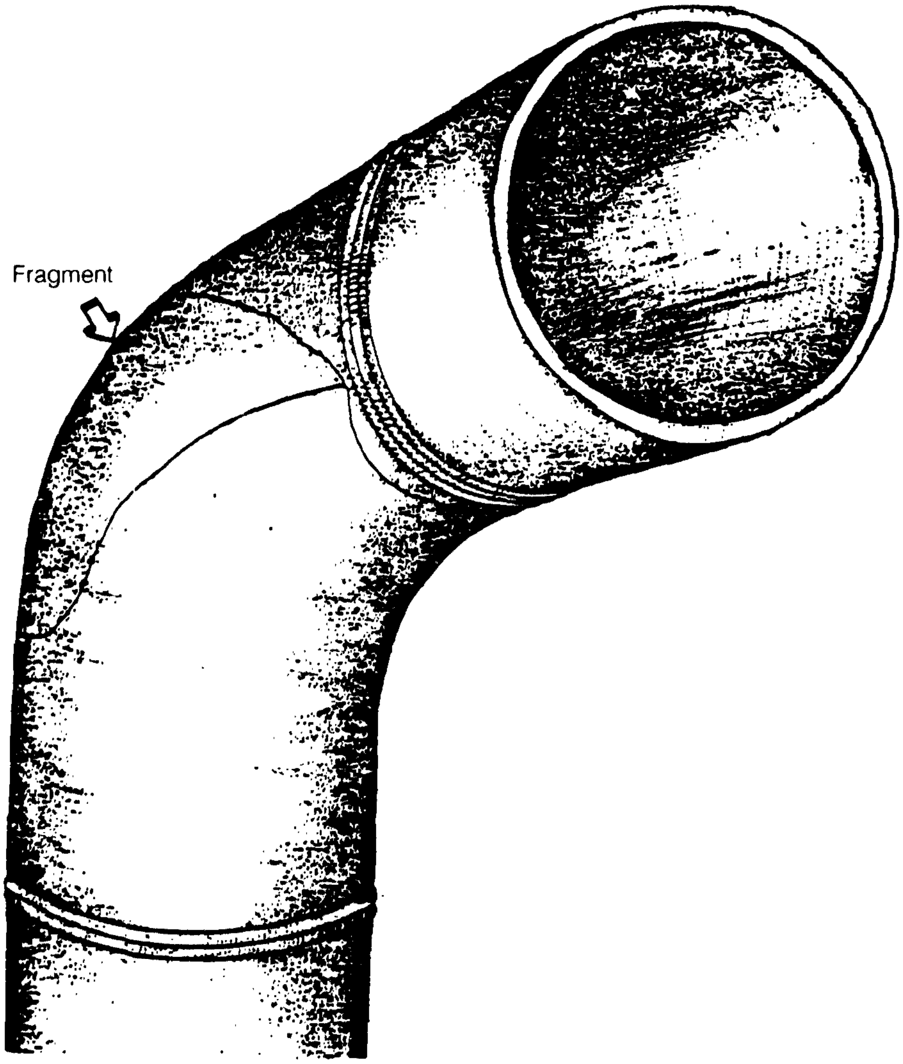
Figures 2.1, 2.2, and 2.3 provide a general approximation of the Surry nuclear plant and the pipe that failed. Figure 2.1 shows the location of the ruptured pipe in relation to the rest of the plant. Figure 2.2 illustrates the pipe before it failed, and figure 2.3 shows the pipe after it failed.

Figure 2.1: The Piping System That Failed at Surry in Relation to the Rest of the Plant



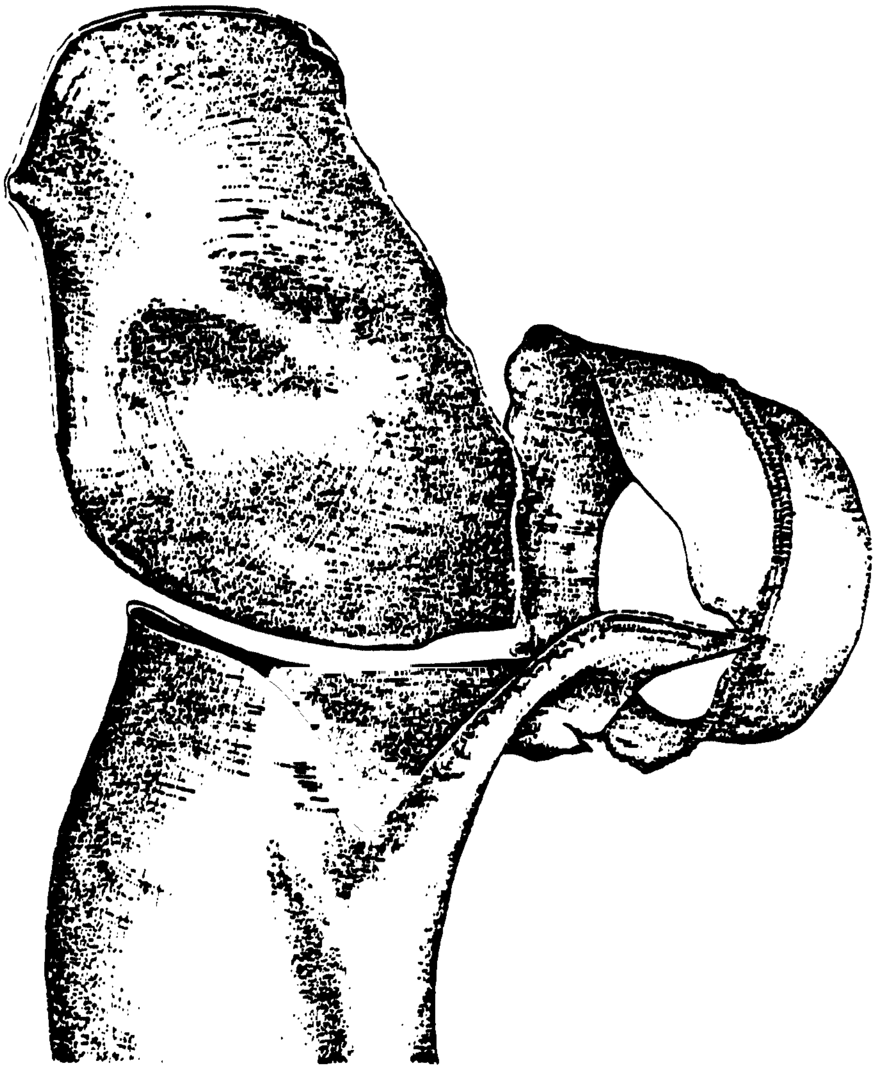
Source: Virginia Power.

ure 2.2: Drawing of the Pipe Before Rupture Indicating the Area of Failure



Source: Virginia Power.

Figure 2.3: Diagram of the Failed Pipe Illustrating the 2 Foot by 3 Foot Section That Ripped Away



Source: Virginia Power.

Other Systems Activated by the Pipe Failure

Virginia Power and NRC officials told us the plant's operators respond properly to the accident. Several unanticipated events, however, com cated the accident response and made the incident more difficult to m age. The massive steam discharge unexpectedly activated several fire protection systems, which then adversely affected the air in the contr room and the plant's security and communications systems.

ıtrol Room Air

Within minutes of the pipe rupture, portions of the automatic fire protection system activated, opening 62 sprinklers to cool the atmosphere in the area of the rupture. The water from the sprinklers seeped into electrical panels, shorted out several electrical circuits that control other fire suppression equipment, and activated some systems containing carbon dioxide. The carbon dioxide combined with other fire retardants and seeped into the control room.

At the time of the failure, eight reactor operators were on duty in the control room. A shift technical advisor was also on duty in the technical support center adjacent to the main control room. Some reactor operators experienced physical discomfort such as shortness of breath, dizziness, and nausea. When they recognized that fire suppressant gas was present, the operators turned on the control room's emergency air supply fans. According to Virginia Power's report, even under these conditions, the actions of the operators were not adversely affected. Nevertheless, the company plans to modify the fire protection systems to prevent future unexpected activation.

ɘ Security System

The Surry facility, like all other nuclear plants, is equipped with a security system to control access to certain critical areas. The utility issues security cards, similar to a credit card, to authorized personnel. When entering a controlled area, personnel must insert the security card into a reader that is linked to a computer. The computer then determines whether to allow access into the area. If access is granted, the computer unlocks the door.

When the feedwater pipe failed, it released water and steam that saturated a security card reader located approximately 50 feet from the point of rupture. The card reader shorted out and disabled the plant's security system for about 20 minutes. Because the system would not open the doors, in accordance with its policy governing an unusual event, the company posted security guards at the control room, and the doors were kept open to allow easy access and improve ventilation. The guards admitted employees on the basis of personal recognition; they did not allow nonessential workers in the control room.

During the event, one member of the operating staff was delayed in the stairway outside the control room because the card reader had failed. Because of the conditions in the plant, the staff member had no safe way to exit other than through the control room. The control room staff admitted the employee after hearing him pound on the door. Virginia

Power officials plan to install override switches to permit the opening electronically locked doors in emergency situations.

Communications Systems

Virginia Power uses an intercom system and radios to communicate throughout the plant. The utility has also installed radio repeaters to amplify the signals and provide clearer communication. The radio repeaters are located in an area that contains the fire suppression equipment.

Water from the ruptured pipe seeped into various electrical systems i this area and activated the carbon dioxide fire suppression system. T entire volume of carbon dioxide was discharged and covered the radi repeaters with a thick layer of ice. As a result of the ice, plant commu cations were limited, and the staff had to use hand radio sets. Becaus of the limited broadcast power of the hand sets, some communication clarity was lost between staff in various locations throughout the pla Although intercom communications were available, Virginia Power's report on the accident stated that the response to the incident may ha been complicated by the need to repeat radio transmissions or relocat to establish effective communication.

Cause of the Accident Determined to Be Erosion/ Corrosion

Following the accident, Virginia Power formed a group of company of cials to determine the cause of the accident and recommend correctiv actions. The group concluded that the failure resulted from extreme thinning of the pipe caused by erosion/corrosion that occurred during the 14 years the plant had been in service.

Nuclear plants use both single- and two-phase pipe systems. Single-phase systems contain only one medium, such as a liquid or moisture-free steam. Two-phase pipe systems contain a mixture of liquid and steam. Utilities had previously observed erosion/corrosion in two-pha systems. However, NRC and Virginia Power officials told us that Surry was the first time erosion/corrosion had been recognized as a problem a single-phase pipe system. The officials also stated that on the basis the deterioration observed after the accident, the pipe in Unit 2 would have ruptured eventually during normal operation from the effects of continued erosion/corrosion.

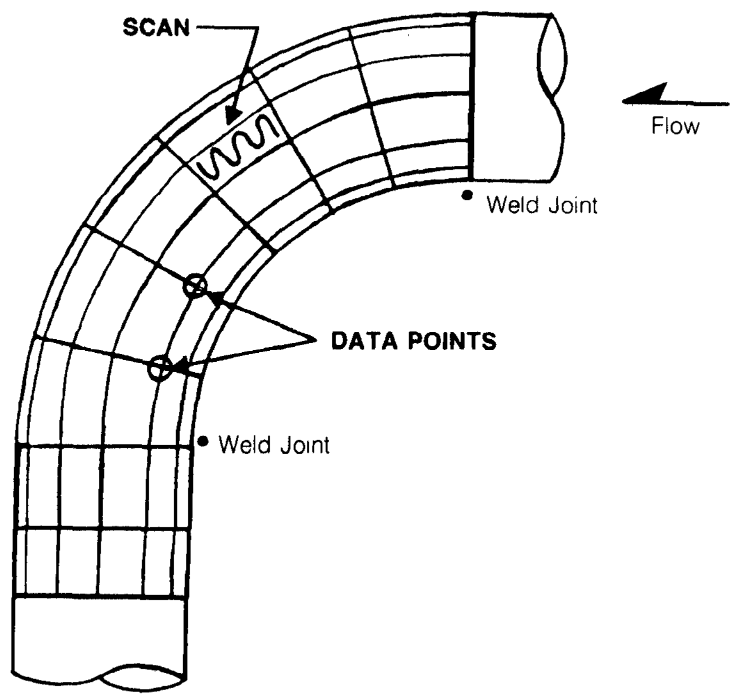
ction Taken by irginia Power to etect and Correct rosion/Corrosion

On December 10, 1986, Virginia Power officials decided to take Surry Unit 1, which is identical to Unit 2, out of service to inspect for damaged pipe. They based this decision on the preliminary findings at Unit 2 that indicated the possibility of significant pipe thinning. Inspections performed on Unit 1 disclosed similar, but not as severe, pipe thinning. After thinning was discovered at Surry Unit 1, Virginia Power inspected its North Anna Unit 1. The company observed some limited pipe thinning but took no immediate action because the thinning was within allowable industry standards. Virginia Power decided to revise its inspection program before inspecting North Anna Unit 2.

trasonic Tests Used to spect Piping Systems

Utilities cannot detect erosion/corrosion by visual observation because it progresses outward from the interior of a pipe. According to NRC staff, utilities can use two methods to determine the thickness of pipe: ultrasonic tests or radiography. Ultrasonic tests are performed by placing an instrument directly on the pipe and pulsing a sound wave through it. The sound wave is reflected back and converted into a thickness measurement. Radiography uses X-rays to measure pipe. The thermal insulation surrounding pipes must be removed before ultrasonic tests can be performed but can be left in place for radiography. Figure 2.4 illustrates a typical grid pattern that is used to perform ultrasonic tests.

Figure 2.4: Typical Ultrasonic Test Grid Pattern



Source: NUMARC.

After the accident, Virginia Power used ultrasonic tests to determine t pipe thickness at its Surry and North Anna plants. The company selected inspection areas on the basis of fluid velocity and pipe config ation, paying particular attention to those portions of the systems wit turbulence-inducing configurations, such as elbows. According to Virginia Power officials, they took approximately 50,000 individual ultrasonic readings, some approximately 1 inch apart, on 529 components in Unit 1. Company officials also told us that on the basis of knowledge obtained from the Unit 1 inspection results, they were able reduce their inspection to 335 components in Unit 2 while maintaining the same level of confidence in their results.

Using the ultrasonic test results, Virginia Power determined pipe thicl ness and developed criteria based on industry standards to select the pipe and components that should either be replaced immediately, scheduled for future replacement, or monitored during their remaining operating life. If the company determined that the rate of metal loss due to erosion/corrosion, subtracted from the original pipe thickness, would not allow the pipe to safely remain in operation until the next scheduled plant outage, the pipe was replaced. According to Virginia Power officials, they used conservative engineering judgment to guide these decisions and replaced a significant amount of pipe that was still usable.

Table 2.1 presents the number of components (valves, elbows, and straight pipe) that, as a result of the accident, Virginia Power inspected, replaced immediately, or scheduled for replacement in the future.

le 2.1: Results of Virginia Power's lear Plant Inspection Program

	Surry		North Anna	
	Unit 1	Unit 2	Unit 1	Unit 2
Components inspected	529	335	225	400
Components replaced	47	61	27	49
Components designated for future replacement	11	14	16	46

During the inspection process, workers recorded the ultrasonic test results on the pipe to document the procedure and provide a benchmark for measurements that will be made in the future to determine the extent that erosion/corrosion has progressed in the plant. Approximately 6 months after each nuclear unit is returned to service, Virginia Power plans to reinspect the plant at a minimum of six locations. According to Virginia Power's report on the Surry accident, the inspection data and other information will be used to guide future inspections.

nited Modifications ıde to Plant Design and ımponents

Virginia Power made only a few design modifications to the pipe systems at Surry. At both units, the pipe configuration in the area that failed was changed from a 90 degree angle to a less severe 45 degree angle. According to company officials, if large-scale changes had been made, the plants would have been out of service for 6 months to 1 year while they completed the required engineering analyses, design changes, and other modifications.

These officials also told us that extensive modifications were not made to the routing of the pipe at Surry because the plants have been designed to accommodate a certain piping configuration, and many large pieces of equipment already had fixed locations in the plants. Virginia

Power concluded that a major redesign to reduce the sharpness of the pipe bends and curves throughout the plants could adversely affect t[illegible] operation of other plant systems. Company officials added that at the time the Surry plants were constructed, their design was typical of th practices used throughout the rest of the nuclear industry. They indicated that the North Anna plants do not have the same sharp pipe be[illegible] as the Surry plants because they incorporate newer designs.

In addition, Virginia Power officials stated that they replaced pipes a[illegible] components with the same type carbon steel as the pipe that rupture[illegible]. Because the areas most susceptible to erosion/corrosion had already been identified, the officials believed that using different metal more resistent to erosion/corrosion could shift degradation to other areas i[illegible] the system, thereby diminishing the value of the ultrasonic measurements they had taken.

Additional Pipe Thinning Detected Inside the Containment Building

As a result of the inspection program initiated after the accident, Virginia Power identified two locations inside the containment building a[illegible] Surry Unit 2 where erosion/corrosion had occurred. The company detected these areas when it decided to use the previously described inspection program in portions of the plants that had not been examined.

In fashioning the expanded inspection program, company officials reviewed the various pipe systems inside the Unit 1 containment buil[illegible]ing and selected a system that, on the basis of its configuration, might[illegible] susceptible to erosion/corrosion. The company performed ultrasonic examinations of this system but did not find any pipe deterioration. I[illegible] then made a similar review of a pipe system inside the Unit 2 containment building and detected some limited pipe thinning. As a result of these findings, the company performed more ultrasonic tests on a diff[illegible]ent piping system inside Unit 1, but again, found no deterioration. Th[illegible] company then performed a second examination on another piping system inside Unit 2, and detected some limited thinning.

On the basis of these findings, Virginia Power decided to repair the tw[illegible] areas showing erosion/corrosion inside Unit 2 by building up the affected locations with additional weld material. According to compa[illegible] officials, they performed the repairs in accordance with industry stan[illegible]dards. The company has not yet determined the origin of the thinning [illegible] these two locations. However, company officials told us that they installed new equipment in this area of the plant in 1979, and the replacement parts could have been manufactured with thinner metal. Company officials pointed out that the weld repairs demonstrate their efforts to correct pipe thinning abnormalities at Surry.

xtensive Erosion/ orrosion Discovered : the Trojan Nuclear lant

As a result of a pipe rupture experienced in the secondary portion of the Trojan plant in 1982, Portland General began monitoring for erosion/corrosion in two-phase pipe systems. Following another pipe rupture in 1985, the utility expanded its monitoring program. On July 10, 1987, Portland General reported to NRC that workers discovered extensive erosion/corrosion in numerous locations throughout its Trojan plant. The company noted that "under current industry guidance, many of these locations may not have been identified as being likely sites where this phenomenon would occur." Portland General found erosion/corrosion in pipes inside the containment building, as well as in secondary pipe systems outside containment. The utility also reviewed the 1985 pipe rupture and determined that like Surry, the failure was caused by erosion/corrosion in a single-phase, non-safety-related feedwater line.

During a planned refueling outage, the company noted a design discrepancy in equipment that supports pipes inside the containment building. As part of the corrective action, workers cut a feedwater pipe to replace fittings and found erosion/corrosion damage in this straight length of pipe, approximately 16 feet from locations in the system where erosion/corrosion would have been expected. Prior to this, the company had detected this condition only in curves downstream from fittings or in other unique pipe configurations. According to NRC, a pipe failure in this location can adversely affect the plant's safety systems and cause complex challenges to operating staff and other systems, such as electrical distribution, fire protection, and security.

Upon observing the damage, Portland General again expanded its pipe inspection program. The company used ultrasonic tests to inspect safety-related and non-safety-related feedwater pipe and welds at 1 foot intervals. A grid pattern was used to maintain a space of 4 inches between each ultrasonic test location. If the ultrasonic tests indicated pipe thinning, the company performed additional tests using shorter spacing intervals or smaller grid patterns to define the damage more precisely. As a result of these tests, Portland General identified approximately 30 locations in the main feedwater pipe system where (1) the thickness of the pipe was less than allowed by industry standards or (2) the pipe was predicted to erode to the minimum allowable thickness before the next refueling outage. Ten areas identified were in the NRC-regulated portion of the plant inside the containment building; the rest were in the plant's nonregulated pipe system.

Once Portland General determined the extent of erosion/corrosion dam-age, it began a program to replace pipe. According to documents submi-ted to NRC, the utility developed conservative criteria on the basis of operating experience to guide its pipe replacement decisions. The com-pany obtained pipe thickness data from the ultrasonic tests and devel-oped a formula to estimate the rate of erosion/corrosion that had been experienced since the plant began operating. The formula assumed tha the rate of erosion/corrosion was constant for each year of plant opera-tion. Using the formula, the company derived a minimum allowable pi thickness and then doubled the predicted rate of erosion/corrosion to determine if an adequate margin of safety existed until the next outag scheduled for April 1988. If, after these calculations, the pipe did not meet minimum allowable industry standards, the company replaced it.

Using this criteria, Portland General replaced 19 elbow-shaped section and 2 straight runs of pipe in the safety-related portion of the feedwat line. In the non-safety-related portion of the feedwater system, the con-pany replaced 35 items including elbows and straight pipe sections. Table 2.2 summarizes the results of Trojan's program to inspect and replace pipe.

Table 2.2: Results of Portland General's Nuclear Plant Inspection Program

	Safety-related	Non-safe relat
Inspected		
Fittings	38	203
Piping	366 feet[a]	1,158 f
Welds	All	78
Replaced		
Fittings	21	35
Piping	204 feet[a]	171 f
Weld repairs	7	

[a]According to Portland General officials, they replaced over 50 percent of the pipe because it was mc convenient to replace a larger amount than just the portions affected by erosion/corrosion.

On the basis of the experience gained from the inspections and the rec-ommendations of a private consultant hired to evaluate the incident, Portland General modified its program to monitor for erosion/corrosio at Trojan. According to company documents, it will evaluate the 1987 inspection results and use them to guide the 1988 scheduled outage inspection. The utility believes that, as a result of these efforts, the 1988 pipe inspection will benefit from the following enhancements:

- More definitive guidance will be provided on the selection of pipe and the sample size.
- Ultrasonic testing techniques will be standardized to allow year-to-year comparison of the data.
- More definitive guidance will be provided to evaluate the inspection data, including computerized evaluation of the rate of erosion/corrosion.

In addition to these refinements, Portland General plans to establish a data base to trend erosion/corrosion information. It also plans to generate computer drawings to identify the extent of erosion/corrosion occurring on each inspected fitting, pipe section, and weld.

NRC and Industry Response to the Surry and Trojan Incidents

Until the accident at Surry, NRC did not focus attention on erosion/cor sion in the non-safety-related portion of nuclear plants. Since the acci dent, NRC has disseminated information to utilities on possible mitigat measures. NRC also required utilities to report on erosion/corrosion m itoring programs and the damage found in their plants. On the basis o NRC's preliminary analysis, 34 plants have some erosion/corrosion da age. The plants have been in service from 15 months to 20 years. NRC staff plans to collect additional information and determine during the summer of 1988 whether additional requirements should be placed o the industry.

In addition to NRC's efforts, various industry groups have taken steps ensure that utilities detect pipe deterioration at nuclear plants. The industry formed an erosion/corrosion working group that conducted a series of workshops to provide information on this condition and deve oped a computer program to help utilities identify areas in their pipe systems that may be susceptible to erosion/corrosion. Although the c puter program did not initially identify straight sections of pipe as pr mary candidates for inspection, subsequent to Trojan it was revised t include them. Industry representatives told us that they will continue revise the computer program to reflect updated inspection results received from utilities.

NRC's Response to the Surry Accident

NRC assigns a resident inspector to each nuclear plant to monitor day- day operations. Approximately 2 minutes after the Surry pipe ruptur the senior resident inspector went to the control room to assess the si ation. He then reported his findings to NRC Region II officials in Atlan Georgia, and headquarters, set up an accident response center, and established an open telephone line between the plant and the NRC ope tions center. Later in the afternoon, NRC regional management decided send an inspection team to the site.

The team arrived at Surry that evening, met with plant management obtain updated information on the status of the facility, and toured th scene of the accident. The next morning NRC staff met with Virginia Power officials who agreed to (1) quarantine the damaged equipment for NRC's inspection and (2) obtain concurrence from NRC before begin ning any restoration work. Also during that morning, NRC assigned an engineer from the Office of Nuclear Reactor Regulation to the inspect team. During the week of December 12, 1986, the team conducted inspections to ascertain the circumstances surrounding the accident.

On December 16, 1986, NRC issued an information notice to all nuclear utilities; supplements to this notice were issued on February 13, 1987, and March 18, 1987. The notices described the conditions at Surry, requested recipients to review the information to determine its applicability to their facilities, and recommended that utilities take actions to prevent a similar occurrence at their plants. The notices also stated that NRC did not require utilities to take specific action or submit a written response.

The NRC inspection team sent a summary of significant facts about the accident to Region II on December 17, 1986. The team conducted subsequent plant inspections during the weeks of December 22 and 29, 1986, and January 12, 1987. In addition to the team inspections, NRC assigned personnel knowledgeable of security, fire protection, water chemistry, and valve design to review specific concerns in these areas.

On February 10, 1987, NRC issued the team's inspection report. The report contained a detailed outline of the sequence of events leading up to and following the Surry accident and discussed important aspects of the incident, such as problems encountered with the security system, the unexpected activation of the fire protection system, and control room habitability. NRC stated that it had concerns about worker safety and control room habitability as a result of the unanticipated events that occurred during the accident.

In addition to the inspection report, NRC issued a notice of violation to Virginia Power for "failure to provide detailed instructions in maintenance procedures for corrective maintenance of safety-related equipment." The violation, however, did not cite Virginia Power for the pipe rupture at Surry. NRC required Virginia Power to provide within 30 days (1) an admission or denial of the violation, (2) the reason for the violation, (3) the corrective steps taken and the results achieved, (4) the corrective actions planned to avoid additional violations, and (5) the date when full compliance would be achieved.

On March 11, 1987, Virginia Power responded to the notice of violation and agreed with NRC that the conditions observed at Surry after the rupture resulted from various procedural deficiencies. The company acknowledged that it did not have adequate instructions for the proper disassembly, inspection, and reassembly of certain equipment that had not operated as planned during the accident. The utility also outlined a corrective action program to ensure that equipment is properly inspected and tested to verify its operability and committed to review approximately 2,000 safety-related procedures on a biannual basis. ginia Power stated that it corrected the deficiencies identified in the notice of violation and expected to complete other long-term correcti actions by September 1, 1987. Virginia Power officials told us that th completed these actions by that date.

NRC's Response to the Conditions Observed at Trojan

On July 22 and 23, 1987, an NRC task force visited Trojan to (1) gath information on pipe thinning, (2) review the utility's pipe monitoring program, (3) evaluate the results of the pipe failure analysis conduct by the utility's consultant, and (4) select pipe samples for independe analysis. On the basis of its inspection of the damaged pipe and othe information obtained during the visit, the task force concluded that t utility provided reasonable assurance that the feedwater systems at Trojan could be operated safely until the next planned outage in Apr 1988. The task force also determined that the corrective action taker the utility will reduce the possibility of further erosion/corrosion. W it becomes available, the task force plans to review the pipe failure a ysis conducted by the company's consultant and other data to detern the long-term operability of Trojan's feedwater systems.

Because the pipe damage observed at Trojan was the first time that utility found thinning in the safety-related portion of a nuclear plant NRC issued an information notice on August 4, 1987, to alert the indu of this potentially generic problem. The notice contained data on oth types of failures that had occurred and requested utilities to review consider the information for applicability at their facilities, as well a consider taking action to preclude similar problems. NRC also stated t utilities were not required to take specific action or provide a writter response.

The notice described the operating parameters that had been used at Trojan, the damage that the company observed, and the corrective actions taken. It also stated that on the basis of plant operating expe ence and the projected extent of erosion/corrosion, the affected pipe would have eroded below allowable limits before the next major sche uled outage. The notice stated that the utility plans to replace the pi before returning the plant to service.

An additional point made by the notice was that the damage at Troja occurred in straight sections of pipe far away from locations previou identified as being subject to erosion/corrosion. Consequently, the no stated that the industry's inspection criteria would not have identified the straight pipe sections as candidates for inspection.

:C Requests ditional Erosion/ rrosion Information om Nuclear Utilities

On the basis of an informal staff survey of 91 nuclear plants conducted during the first week of February 1987, NRC concluded that a significant amount of secondary plant pipe thinning exists in two-phase systems. Furthermore, NRC staff found that utilities do not adequately monitor for pipe thinning or ensure that appropriate corrective action is taken when they find it. Therefore, NRC staff proposed that senior management issue a bulletin to utilities to verify the survey data and obtain additional information on pipe inspection programs at nuclear plants.

On March 16, 1987, NRC's Office of Inspection and Enforcement contacted NRC's regional offices to update the information obtained from the informal staff survey. NRC concluded that industry attention to this issue was substantial but varied markedly among utilities. According to an April 1987 summary of the survey effort, many questions still remained regarding the quality and quantity of utility efforts to inspect pipe systems.

As a result of this finding, on July 9, 1987, NRC issued a bulletin requiring utilities to provide information within 60 days on their programs to monitor the thickness of pipes in all safety-related and non-safety-related systems in their plants. To support this regulatory action, NRC cited the analyses and studies of the Surry accident, which concluded that the pipe failure was caused by erosion/corrosion. NRC also acknowledged that Virginia Power, consistent with general industry practice, did not have an inspection program to examine the thickness of feedwater pipe systems at Surry.

The bulletin indicated that failure of these systems can lead to undesirable challenges of plant systems that are needed to safely shutdown a reactor and mitigate an accident. NRC requested utilities to provide data on the

- standards that governed the design and fabrication of the pipe;
- scope, extent, and criteria of programs to select and examine pipes to ensure that the thickness is not below allowable limits;
- factors, such as pipe material and configuration, water temperature, and flow rates, that the utility considered in establishing criteria to identify locations that should be monitored;

- results of all inspections that have been performed to identify pipe t ning, whether thinning was discovered, and any other inspections w pipe thinning was observed even though pipe thinning was not the o nal purpose of the inspection; and
- plans for revising existing pipe monitoring procedures or developing new or additional inspection programs.

As of January 21, 1988, NRC staff had identified 34 plants with some erosion/corrosion damage. The plants had been in service from 15 months to 20 years. Seventeen plants reported damage in a single-ph system similar to the one that ruptured at Surry; 11 others reported damage in straight sections of pipe similar to Trojan. According to th NRC staff, their analysis is too preliminary to determine the extent of erosion/corrosion at all nuclear plants. Nevertheless, the staff expec report this information to the Commission by the end of February 19 and continue to gather information on erosion/corrosion. During the summer of 1988, the staff expect to determine whether they should ommend that the Commission take additional regulatory action. The staff does not know, however, if the Commission will address this iss or the extent of the action it may take.

Table 3.1 shows the plants that had reported erosion/corrosion dama as of January 21, 1988, the date of initial operation for each plant, a the areas where erosion/corrosion has been detected.

e 3.1: Nuclear Plants Reporting Evidence of Erosion/Corrosion

			Location Where Erosion/Corrosion Was Detected				
t	State	Date of Initial Reactor Operation	Single-Phase	Elbows	Straight Pipe	Fittings	Other
Onofre Unit 1	California	June 1967					X
dam Neck	Connecticut	July 1967	X				X
er Creek	New Jersey	May 1969	X	X			
den Unit 2	Illinois	January 1970	X	X			
Robinson Unit 2	South Carolina	September 1970					X
im Unit 1	Massachusetts	June 1972	X	X			
y Unit 1	Virginia	July 1972	X			X	
ey Point Unit 3	Florida	October 1972				X	
y Unit 2	Virginia	March 1973	X			X	
Calhoun	Nebraska	August 1973	X	X	X		
St. Vrain	Colorado	January 1974			X		
ne Arnold	Iowa	March 1974		X	X		X
nsas Unit 1	Arkansas	August 1974	X	X			X
cho Seco	California	September 1974			X		
ert Cliffs Unit 1	Maryland	October 1974		X	X		X
tone Unit 2	Connecticut	October 1975	X	X			X
an	Oregon	December 1975	X	X	X		X
ert Cliffs Unit 2	Maryland	November 1976		X	X		X
m Unit 1	New Jersey	December 1976	X				X
Cook Unit 2	Massachusetts	March 1978		X			
h Anna Unit 1	Virginia	April 1978	X	X	X		
nsas Unit 2	Arkansas	December 1978					X
h Anna Unit 2	Virginia	June 1980		X	X		
uoyah Unit 1	Tennessee	July 1980	X	X	X		
m Unit 2	New Jersey	August 1980	X				X
uoyah Unit 2	Tennessee	November 1981	X	X			
Onofre Unit 2	California	July 1982	X				X
Onofre Unit 3	California	August 1983	X				X
lo Canyon Unit 1	California	April 1984		X	X		
away	Missouri	October 1984	X	X			
lo Canyon Unit 2	California	August 1985		X			X
r Bend Unit 1	Louisanna	October 1985					X
y	Ohio	June 1986			X		
aron Harris	North Carolina	October 1986					X
l			**18**	**18**	**12**	**3**	**17**

Actions Taken by Industry Groups to Address Erosion/ Corrosion

As discussed in chapter 1, utilities have formed several industry grou to conduct research, improve nuclear plant operations, and represent the industry at regulatory proceedings. In response to the Surry accident, in March 1987 NUMARC formed a working group to address erosi corrosion. The Vice President for Nuclear Operations at Virginia Pow chairs the working group. The goals of the working group are to (1) coordinate with EPRI to develop an understanding of the technical elements of erosion/corrosion; (2) identify factors in plant design, inspec tion, and maintenance requirements that may need modification; and determine whether an industry-wide program to monitor erosion/corr sion is technically justified.

On April 7, 1987, the working group briefed NRC staff on their activiti and 1 week later, conducted a workshop to discuss erosion/corrosion problems encountered by utilities. These efforts caused the working group to realize that many nuclear utilities had initiated various insp tion programs after the Surry accident. It also became clear, however that a need existed for the industry to take further action and establi initiatives to prevent additional pipe failures. The working group ider fied the following areas where the industry needed additional guidan

- a process to select locations in pipe systems that should be inspected,
- inspection methods and techniques,
- possible near-term options to remedy erosion/corrosion, and
- the nature and extent of future inspections.

Computer Model Developed

As part of its ongoing research program, EPRI developed a computer p gram to help utilities identify locations in pipe systems that may be su ceptible to erosion/corrosion and calculate the rate of erosion/corrosi According to EPRI, the computer program will

- identify 10 locations in the system most susceptible to erosion/ corrosion,
- rank all components in the pipe system in order of susceptibility to er sion/corrosion, and
- use inspection data to develop a plant-specific model to predict the tir it will take to reach the minimum allowable pipe thickness.

On May 28, 1987, the working group met with NRC staff to demonstrat the computer program and provide an update on its activities. According to NRC staff and NUMARC representatives, the working group was doing a thorough job to develop an erosion/corrosion inspection program. In a June 1987 letter, NRC's Assistant Director for Engineering, Office of Nuclear Reactor Regulation, informed the working group that NRC staff had reviewed the proposed erosion/corrosion inspection program and was supportive of the group's efforts. Although the letter raised two questions regarding the sampling process and the techniques used to detect damage, it stated that NUMARC's program generally is an acceptable way for a utility to assess the integrity of its pipe systems. The letter also pointed out that the program must allow utilities to use engineering judgment in selecting additional pipe locations to be inspected.

After meeting with NRC, the working group requested utilities to provide information to INPO on the dates of past inspections, the techniques used, and the number of components found to be below acceptable thickness standards. INPO will maintain this information and provide reports to NUMARC. In addition, on June 30, 1987, EPRI and NUMARC conducted a workshop in Washington, D.C., to present the computer program to the industry. NRC staff attended the workshop, and according to NUMARC representatives, a copy of the program may be provided to NRC.

Representatives from NUMARC told us that significant utility resources will be required to use the computer program. Companies will have to develop an extensive amount of historical data on operational parameters, such as water flow rates, pipe configuration and thickness, and water chemistry before they can identify locations susceptible to erosion/corrosion. NUMARC has received the results of some initial inspections, but representatives told us that the data are too preliminary to indicate industry-wide trends. They did point out, however, that the computer program has been tested using data from Surry, and it identified the area where the pipe failed as a location that should have been inspected. NUMARC representatives also told us that, following the discovery of pipe damage at Trojan, they revised the computer program to address straight sections of pipe. They also said that they will update the program as additional inspection data are received from utilities.

As a result of these efforts, the NUMARC working group has recommended that the industry use the following three-tier approach to identify and correct erosion/corrosion damage:

- Use the EPRI computer model or other equivalent evaluation methods to help analyze pipe systems, perform inspections, and develop a baseline for measuring the rate of future erosion/corrosion progress. The initial inspection sample should include the 10 most susceptible erosion/co sion locations, as well as 5 random locations selected on the basis of their unique operating conditions or situations.

- Determine the extent of pipe thinning and repair or replace compon as necessary. If erosion/corrosion is observed, calculations should b made to ensure that the pipe will meet industry thickness standards a period of time at least 10 percent longer than the current operatin cycle or the interim until the next refueling outage. If components d meet these standards, the utility should inspect adjacent component and similar systems. Engineering judgment should be used to guide t decision. The inspection results will be provided to INPO for use in its programmatic reviews and plant evaluations.
- Perform follow-up inspections and take longer term corrective actio

Although NUMARC has urged each utility to adopt these recommenda tions, NUMARC's Board of Directors has not yet approved the progran therefore, no formal industry-wide commitment exists to follow the recommendations. NUMARC representatives told us that 46 of the 54 nuclear utility companies have been authorized to use the computer gram, and others have expressed an interest in using it, including fo eign nuclear utilities and domestic utilities operating fossil plants.

onclusions and Recommendations

Erosion/corrosion in single-phase pipe is an emerging issue that was not anticipated by either NRC or the nuclear utility industry. Prior to the accident at Surry, neither NRC nor the industry believed nuclear plants were susceptible to deterioration caused by this condition. However, the accident at Surry showed that utilities should monitor for erosion/corrosion damage in single-phase pipe systems. In January 1984 Surry experienced an operating problem similar to the one that resulted in the December 1986 pipe rupture. The pipe did not fail in 1984. In the interim, however, erosion/corrosion progressed to the point where the pipe ruptured, causing four worker fatalities. Since neither NRC regulations nor industry standards require monitoring for erosion/corrosion in single-phase pipe, this condition continued until a catastrophe occurred.

Another important lesson learned from the Surry accident is the effect that a pipe failure can have on the safety protection systems at nuclear plants. The accident occurred in an area of the plant that is not regulated by NRC, but its effects cascaded across several regulated systems causing additional accident management problems. NRC staff told us this may be the more significant aspect of the Surry accident.

Seven months after the accident, damage in pipe systems that was more widespread than Surry was found at Trojan in both the regulated and nonregulated portions of the plant. The discovery at Trojan was the first time that a utility found extensive erosion/corrosion in the regulated portion of a nuclear plant. Further, the utility found degradation in straight sections of pipe that were not previously considered to be susceptible to this condition. Consequently, failure of this pipe could have led to another serious accident.

Virginia Power and Portland General have taken actions to correct the erosion/corrosion found at their plants. Both utilities replaced unacceptable pipe and some that was not in need of immediate replacement. They also plan to replace some additional damaged pipe in the future. In addition, NUMARC has recommended a three-tier approach for utilities to identify and correct erosion/corrosion damage, but the industry has not adopted these recommendations. Therefore, no industry-wide commitment exists to ensure that all utilities take actions to assess the integrity of pipe systems; and short of an NRC requirement, no guarantee exists that utilities will do so.

In addition, because of the significance of the Surry accident, NRC began to focus on erosion/corrosion at other nuclear plants. NRC provided the industry information on the event and required all utilities to report the extent of known erosion/corrosion damage at their plants. As of Janu ary 21, 1988, NRC staff had identified 34 plants—about 30 percent of those with operating licenses—with some erosion/corrosion damage. Some plants had damage in single-phase and straight pipe similar to Surry and Trojan, respectively.

Conclusions

The December 1986 accident at Surry initiated a new era of understa ing regarding erosion/corrosion at nuclear power plants and demonstrated that unchecked erosion/corrosion can lead to a fatal accident the interim, NRC staff have identified a significant number of plants v some erosion/corrosion damage. The staff expect to gather additiona information before deciding in the summer of 1988 whether to recom mend that the Commission take additional regulatory action. The sta does not know, however, if the Commission will address this issue or extent of the action it may take. We believe, however, that NRC needs mechanism to ensure that utilities periodically assess the integrity of pipe systems in their plants to reduce the risk of future injury to plar personnel or damage to equipment caused by erosion/corrosion.

Recommendations

Due to the significance of the information that has been developed co cerning erosion/corrosion at nuclear power plants, we recommend th the Chairman, NRC, require utilities to

- inspect all nuclear plants to develop data regarding the extent that er sion/corrosion exists in pipe systems, including straight sections of pi
- replace pipe that does not meet the industry's minimum allowable thi ness standards; and
- periodically monitor pipe systems and use the data developed during these inspections to monitor the spread of erosion/corrosion in the plants.

Major Contributors to This Report

Resources, Community, and Economic Development Division, Washington, D.C.

Keith O. Fultz, Senior Associate Director (202) 275-1441
Mary Ann Kruslicky, Group Director
William D. McDowell, Jr., Evaluator-in-Charge
Karen R. Bartlett, Secretary

Norfolk Regional Office

Wilbur D. Campbell, Regional Manager
Robert L. Coleman, Evaluator

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