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

April 1989

NUCLEAR REGULATION

License Renewal Questions for Nuclear Plants Need to Be Resolved

GAO/RCED-89-90

GAO

United States
General Accounting Office
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Resources, Community, and
Economic Development Division

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April 3, 1989

The Honorable Edward J. Markey
House of Representatives

Dear Mr. Markey:

On January 15, 1987, you asked us to examine the December 1986 accident at the Surry nuclear plant owned by Virginia Power and assess problems that face aging nuclear plants. On the basis of subsequent agreements with your office, we initially examined the Surry accident. On March 18, 1988, we reported to you on the accident and on a July 1987 incident at the Trojan plant in Oregon—Nuclear Regulation: Action Needed to Ensure That Utilities Monitor and Repair Pipe Damage (GAO/RCED-88-73). This report addresses problems confronting aging nuclear plants by examining the Nuclear Regulatory Commission's program to develop a license renewal policy and accompanying regulations, and the initiatives underway by the Department of Energy and the electric utility industry to extend the operating lives of these 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, Director, Energy Issues. Other major contributors are listed in appendix I.

Sincerely yours,

J. Dexter Peach
Assistant Comptroller General

Executive Summary

Purpose

A December 1986 pipe rupture at Virginia Power's Surry unit 2 nuclear power plant injured eight workers; four later died. As a result of this accident, Representative Edward J. Markey requested GAO to examine the Surry accident and assess the problems confronting aging nuclear plants. In March 1988 we reported our findings concerning the accident and a July 1987 incident at the Trojan nuclear plant in Oregon.

This report addresses problems confronting aging nuclear plants by examining the Nuclear Regulatory Commission's (NRC) program to develop a license renewal policy and accompanying regulations, and the initiatives underway by the Department of Energy (DOE) and the electric utility industry to extend the operating lives of these plants.

Background

Nuclear power has become second only to coal as the largest producer of electricity in the United States. The 110 nuclear plants currently in service are operated by 54 utilities, provide about 20 percent of the nation's electricity, and represent a capital investment of over $200 billion.

The Atomic Energy Act authorizes NRC to issue nuclear plant operating licenses for up to 40 years and provides for license extensions beyond the initial operating period. The act does not, however, stipulate the criteria for evaluating a utility request to operate a nuclear plant longer than 40 years. The oldest operating license currently in effect will expire in the year 2000. According to NRC, about one-half of the existing operating licenses will terminate by the year 2015, and most licenses will expire by about 2030.

Results in Brief

Many utilities will have to decide in the early 1990s whether to continue operating older nuclear plants or to construct new generating capacity. A clear understanding of the terms and conditions governing the license renewal process will be a key element in deciding how to meet future electricity demand. Although NRC has developed 3 possible license renewal policy options and identified 15 areas of regulatory uncertainty that need to be resolved, it has made little progress in reaching definitive regulatory conclusions. NRC expects to do so sometime in the early 1990s.

Four utilities are studying aging effects on critical systems and components at their nuclear plants. Although the studies have not identified any generic technical obstacles to preclude continued operation, NRC and

the utilities are aware of some conditions that could adversely affect the integrity of a reactor. On the basis of its research, NRC has identified 12 plants that may be affected. Alternatives, such as changing the fuel's location within the reactor, are available to forestall these conditions. Some utilities have implemented these measures and believe their plants can operate safely for at least 60 years. DOE and the industry are also working to develop and submit the first application to NRC for extended plant operations.

Principal Findings

License Renewal Policy

NRC issues operating licenses to nuclear plants for up to 40 years. The license term does not reflect how long the plants are considered useful or safe; instead, it is based on past utility financing practices. NRC can extend operating licenses beyond 40 years, but it has no criteria to evaluate a license renewal request. As a result, NRC has been working with consultants and obtaining input from industry groups to develop a license renewal policy and associated regulations. (See ch. 1.)

NRC, DOE, and the utility industry believe the central license renewal question is whether an application should be judged against the requirements in place when the operating license was initially granted or the standards that currently apply to plants. NRC developed three alternatives that could be used to address this question: (1) use the original operating license and its amendments; (2) use the licensing requirements for plants at the time a renewal request is submitted; or (3) issue a modified license that supplements, as necessary, the original license in significant safety areas.

NRC also identified 15 unresolved technical, environmental, and procedural issues. For example, NRC must determine the (1) methods it will use to verify that the design of a plant is still safe and to compensate for age-related uncertainties that are not fully understood by either NRC or the industry, (2) type of environmental analysis that should be prepared for license renewal, and (3) extent the public will be given an opportunity to participate in the renewal process. NRC expects to select an alternative and publish life extension regulations in the early 1990s. (See ch. 2.)

NRC's Research Program

NRC has been performing research to better quantify the effects of aging on nuclear plants and to develop a technical basis to evaluate license renewal requests. Experimental programs and evaluations are underway on critical components such as reactors, pipe systems, and support structures. NRC has identified some conditions that may require repair, replacement, or special treatment. However, on the basis of preliminary information, NRC has not identified any generic age-related conditions that will require nuclear plants to shut down. (See ch. 3.)

Degradation Identified at 12 Plants

Because of the effects of prolonged exposure to high levels of radiation, NRC requires each utility to monitor the condition of its reactor. In 1975 NRC established criteria to assess how well a reactor could withstand an accident. NRC revised the criteria in 1977 to more accurately reflect the effects of radiation on the different types of metal used during reactor construction. In 1988 NRC further revised the criteria to incorporate information obtained during the intervening years. The criteria are not an absolute limit on the plants, but rather alert the utilities to analyze the risk of continued plant operations. On the basis of its revisions, NRC identified 12 reactors that will reach the criteria either before or soon after their operating licenses expire. These reactors, however, are not the oldest in operation.

NRC will allow these plants to continue operating if utilities can demonstrate they are safe. Several alternatives can be used to alleviate the effects of radiation on the reactors. For example, utilities can change the fuel's location within the reactor. These measures' effectiveness, however, depends on utilities' implementing them long before the criteria are reached. (See ch. 4.)

DOE and Industry Initiatives

Because of the high cost of building new plants, utilities want to keep their existing plants in service as long as possible. To assist in deciding whether to extend the life of a plant, DOE and the industry have been conducting life extension studies at four plants. The studies have not identified any age-related degradation or technical obstacles associated with plant hardware to preclude continued operations. Although the studies identified numerous administrative and operational areas needing improvement—such as better inspection programs and upgraded recordkeeping—the utilities believe they can operate their reactors safely for at least 60 years.

Also, in September 1988, DOE and the industry selected two older plants to develop and submit the first license renewal applications to NRC. DOE and the industry believe the information developed will assist other utilities seeking to operate nuclear plants longer than 40 years. (See ch. 5.)

Some Oppose License Renewal

Several public interest groups oppose license renewal because they believe that (1) nuclear power should be phased out and replaced with other alternatives, (2) the continued operation of older nuclear plants could pose a risk to public health and safety, and (3) more information is needed regarding the effects of aging on all nuclear plant systems and components. (See ch. 6.)

Recommendations

NRC, DOE, and the industry have done substantial work to assess the feasibility of operating nuclear plants longer than 40 years. However, NRC still needs to resolve many important license renewal questions. Since many utilities will have to decide in the early 1990s whether to continue operating older nuclear plants or construct new generating capacity, NRC needs to use available information to begin making regulatory decisions. To better focus industry and government efforts, we recommend that the Chairman, NRC,

- accelerate the schedule for developing license renewal policy and accompanying regulations and stipulate the basis that will be used to evaluate renewal applications and the types of records, engineering analyses, and other historical information needed to support a request for continued operations and
- resolve the outstanding technical, environmental, and procedural uncertainties.

Agency Comments

GAO discussed the facts presented in this report with NRC, DOE, and the four utilities conducting life extension studies. They generally agreed with the facts presented but offered some clarifications that were incorporated where appropriate. As requested, GAO did not ask NRC, DOE, or the utilities to review and comment officially on this report.

Contents

Abbreviations

BWR	Boiling Water Reactor
BG&E	Baltimore Gas and Electric Company
DOE	Department of Energy
EPRI	Electric Power Research Institute
GAO	General Accounting Office
IGSCC	Intergranular Stress Corrosion Cracking
NRC	Nuclear Regulatory Commission
PTS	Pressurized Thermal Shock
PWR	Pressurized Water Reactor
RCED	Resources, Community, and Economic Development Division

Introduction

Since the mid-1950s, when the Congress enacted legislation to encourage the commercial development of nuclear power, an increasing portion of the demand for electricity has been provided by this energy source. Approximately one-third of the new generating capacity installed since 1974 to meet electricity demand has been nuclear power. Consequently, commercial nuclear power has become second only to coal as the largest source of electricity in the United States.

Under the Atomic Energy Act, the Nuclear Regulatory Commission (NRC) issues licenses to utilities to build and operate nuclear plants. As of December 1988, NRC had issued licenses to 54 utilities to operate 110 plants representing a capital investment of over $200 billion. Although nuclear power provides about 20 percent of the electricity nationwide, the degree of reliance on this energy source varies from state to state. For example, nuclear power provides more than 40 percent of the electricity for 6 states, and more than 25 percent for 18 states.

Nuclear Plants Are Licensed to Operate for 40 Years

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

The act authorizes NRC to issue operating licenses to nuclear plants for up to 40 years. The 40-year license period does not reflect the length of time these plants can operate safely. Instead, when the act was initially drafted, the Congress arbitrarily set the expiration date on the basis of utilities' financing practices. When the act was later amended in 1954, the Congress considered a 25-year license term, but utility representatives objected to this provision. The utilities noted that they are required to provide service indefinitely and must finance generating plants on a long-term basis. Consequently, at their suggestion, the 25-year license period was extended to the 40-year amortization period commonly used to finance these facilities. The act also authorizes NRC to extend an operating license beyond 40 years. The act does not, however,

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

stipulate the criteria that NRC should use to evaluate the utility's application or define what is considered to be a timely application to extend an operating license.

According to NRC projections, the earliest nuclear plant operating license is due to expire in 2000, and by the year 2015 approximately one-half of the 110 existing operating licenses will terminate. Most operating licenses currently in effect will expire by about 2030. NRC and utility officials estimate that about 10 to 12 years is required to plan for and install alternate generating capacity.

Given this timeframe, NRC anticipates that it will begin receiving applications to renew operating licenses in the early 1990s because utilities will need to replace lost generating capacity if the operating license is not renewed. As a result, NRC is considering the type and scope of information a utility will be required to submit with its license renewal application. NRC does not expect to complete this effort until the early 1990s.

Economic Implications of License Renewal

The decision to seek a license renewal rests with each of the 54 utilities that own nuclear plants. The factors a utility must assess in reaching this decision include the (1) condition of the plant, (2) cost of new systems and components that may be required to ensure continued safe operation, (3) current and projected demand for electricity, and (4) alternatives that may be available to satisfy this demand. Because of the high cost of building new generating plants and the increasing demand for electricity, utilities want to keep their existing plants in service for as long as it is safe and economical to do so.

In January 1988 a contractor funded by the Department of Energy (DOE) published a report, U.S. National and Regional Impacts of Nuclear Plant Life Extension, that compared the costs and benefits of extending the service lives of nuclear power plants with other methods of generating electricity in the early twenty-first century. The report assessed the impact of plant life extension under a wide range of economic assumptions and conditions. Under most plausible scenarios, societal benefits result from extended nuclear plant service. On a regional basis, the greatest benefits were realized on the East Coast and in California. The report concluded that when compared with the cost of using fossil fuels to generate electricity, extended nuclear plant operation under the "most likely" conditions would provide a savings of about $200 billion (in 1985 dollars) through the year 2030.

Initiatives Underway to Assess Extended Nuclear Plant Operations

Several organizations have been formed to support and represent the electric utility industry. For example, in 1973 the Electric 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 environmental assessments, and it publishes reports in six major technical areas, including nuclear power. Its membership is composed of over 600 member utilities that provide about two-thirds of the nation's electricity. Currently, 46 of the nation's 54 utilities that own nuclear plants are members of EPRI.

DOE and EPRI are conducting a wide range of research programs to assess the technical implications of operating nuclear plants beyond the 40-year license period. Studies were initiated in 1985 to determine the feasibility of extended operations at the Monticello plant, a boiling water reactor located in Monticello, Minnesota, and Surry unit 1, a pressurized water reactor located in Surry, Virginia.[2] Two additional pressurized water reactors, Oconee unit 1 near Greenville, South Carolina, and Calvert Cliffs unit 1 near Annapolis, Maryland, were recently added to this research effort to provide a broader perspective on plant life extension. DOE and the utility industry are also working together to develop and submit the first license renewal application. In addition, NRC is conducting research on the effects of aging on critical nuclear plant systems and components, and it is developing regulations for license renewal.

Objectives, Scope, and Methodology

On January 15, 1987, Representative Edward J. Markey asked us to assess the December 1986 accident at the Surry nuclear power plant operated by Virginia Power and provide information on several technical problems that face aging nuclear power plants. On the basis of subsequent discussions with his office, we agreed to report initially on the Surry accident and its implications for the utility industry, followed by a report on the actions that NRC and the industry have taken, or plan to take, to identify and correct problems that may result from aging. We issued the first report on March 18, 1988.[3] This report addresses the remaining portion of the request regarding the effects of aging on nuclear power plants.

[2]Boiling water reactors are cooled by water that is allowed to boil as it passes through the nuclear fuel. The water is used directly to produce the steam that generates electricity. Pressurized water reactors are those cooled by water that is kept at high pressure to prevent it from boiling. The water passes through the nuclear fuel to a secondary system where steam is produced.

[3]Nuclear Regulation: Action Needed to Ensure That Utilities Monitor and Repair Pipe Damage (GAO/RCED-88-73).

To obtain the information in this report, we interviewed NRC and DOE staff and representatives from the Baltimore Gas & Electric Company, Duke Power Company, Northern States Power Company, and Virginia Power—the utilities that have been participating in life extension research programs. We also reviewed various technical reports related to the aging of nuclear plant systems and components.

At NRC we met with officials from the Office of Nuclear Regulatory Research, the Division of Reactor and Plant Systems, the Reactor and Plant Safety Issues Branch within that Division, and the Materials Engineering Branch and the Electrical and Mechanical Engineering Branch within the Division of Engineering. We discussed (1) technical information developed from NRC's research programs on aging, (2) Regulatory Guide 1.99 that is used to assess the effects of radiation on the integrity of reactors vessels, and (3) NRC's pressurized thermal shock rule issued in July 1985. We reviewed the Atomic Energy Act and met with NRC Office of the General Counsel staff to discuss the basis for the 40-year operating license. We attended briefings conducted by NRC and DOE staff and representatives from the utility industry regarding the development of regulations to renew operating licenses. We reviewed NRC's public notice in the November 6, 1986, Federal Register regarding the development of a license renewal policy and the 58 comments NRC received. We also reviewed NRC's draft entitled Regulatory Options for Nuclear Plant License Renewal (NUREG-1317, August 1988) and obtained information on the status of various NRC research initiatives.

At DOE we met with staff from the Assistant Secretary for Nuclear Energy's Civilian Reactor Development program, Division of Light Water Reactor Safety and Technology. We reviewed technical documents associated with DOE's light water reactor plant life improvement program, projections of future electricity demand, agreements between DOE and the utility industry to participate in research programs to better characterize age-related degradation and assist in preparing license renewal applications, and DOE's January 1988 contractor report, U.S. National and Regional Impacts of Nuclear Plant Life Extension.

We also visited and received briefings from officials of the four utilities that are participating in research to identify age-related degradation in major reactor systems. At the Baltimore Gas & Electric Company, we met with a principal engineer and senior engineer, who are responsible for studies at the Calvert Cliffs unit 1 plant. We discussed engineering analyses conducted on the reactor and monitoring programs that have been or will be installed to assess continued plant operation. We also met

with a principal engineer and the design engineering staff at Duke Power Company in Charlotte, North Carolina, to discuss assessments performed at its Oconee unit 1 plant. We obtained information on Duke Power's preliminary evaluations of aging effects on (1) the reactor, its internal mechanisms, and the structures that support it; (2) major pumps and valves; and (3) important pipe systems.

In addition, we visited the Monticello plant in Monticello, Minnesota, owned by the Northern States Power Company, and met with the General Manager, Headquarters Nuclear Group, and officials from the Multiple Dynamics Corporation, a contractor who is conducting assessments of the plant for the utility. We discussed the methodology used to select and evaluate critical systems and components and the results of their preliminary assessments. We also toured the plant to observe upgrades that have been made and discuss those anticipated in the future. Finally, we met with the Vice President for Nuclear Power, the Life Extension Project Manager, and other technical and engineering staff at Virginia Power in Richmond, Virginia, to determine the company's research efforts at the Surry unit 1 plant. These officials provided information on the (1) condition of the reactor, (2) surveillance program used to monitor aging effects, (3) engineering assessments conducted on various critical systems and components, and (4) measures the company may use to mitigate the effects of aging on the vessel and ensure continued safe operation of the plant.

Finally, we met with representatives from the (1) Critical Mass Energy Project, (2) Nuclear Information and Resource Service, and (3) Union of Concerned Scientists to obtain public interest groups' perspectives regarding extending nuclear plant life.

We discussed the facts presented in this report with NRC and DOE staff and representatives from Baltimore Gas & Electric, Duke Power, Northern States Power, and Virginia Power. They generally agreed with the information presented but offered some clarifications that were incorporated where appropriate. As requested, we did not ask NRC, DOE, or the utilities to review and comment officially on this report. Our work was conducted between March 1988 and November 1988 in accordance with generally accepted government auditing standards.

NRC Needs to Resolve a Number of Important License Renewal Issues

NRC staff have been developing license renewal regulations since 1986. Although many issues regarding the continued operation of nuclear plants have been identified, NRC has not made any final decisions in important areas such as the timing of the renewal process, whether public hearings will be conducted, or the basis that will be used either to extend an operating license or require additional plant modifications as a condition for extended operation.

NRC has obtained public comments on many of these issues, and its staff is working to develop a regulatory framework for license renewal. NRC staff expect to complete the license renewal regulations in the early 1990s.

NRC Solicits Public Comments on License Renewal

Neither the Atomic Energy Act nor NRC regulations contain guidance on extending the operating license of nuclear plants beyond 40 years. Consequently, in June 1986 NRC began to work on license renewal regulations. Its staff initiated a program plan, obtained information on age-related research underway within NRC and in the domestic and foreign utility industries, established information exchange procedures, and obtained technical assistance from a contractor.

As a first step in developing a policy, NRC published a request for public comment in the November 6, 1986, Federal Register. NRC solicited opinions on a number of major license renewal issues including the (1) length of time beyond 40 years that nuclear plants should be allowed to operate, (2) level of safety that the plants should be required to meet if their operating license is extended, and (3) extent to which NRC should consider technical issues and operating histories in the renewal decision.

NRC received 58 written comments from the industry, government agencies, public interest groups, independent consultants, and private citizens. The 43 comments received from the industry presented a consensus that (1) NRC should establish a renewal policy by the late 1980s, followed by detailed regulations in the early 1990s; (2) license renewal applications should be allowed to be submitted up to 1 year before expiration; and (3) license extension should be based on the original operating license, with any new technical issues limited to the effects of aging on the most critical safety systems and components, such as the reactor and related equipment.

In addition, NRC received 15 comments from nonutility groups, including the Department of the Interior's U.S. Geological Survey, DOE, the Wisconsin Public Service Commission, and two public interest groups. The Geological Survey stated that the renewal process should address the need to update groundwater data and uses around nuclear plants. DOE's position closely paralleled the positions taken by the utility industry. The Wisconsin Public Service Commission stated that it (1) favored the development of a renewal policy; (2) encouraged public involvement in the process; and (3) believed that although no major new investigations should be conducted for a renewal, the operating history of the plant and management performance should be fully considered. Of the two public interest groups, Ecology Alert opposed license renewal; the Ohio Citizens for Responsible Energy generally supported the concept but advocated a cautious approach on timing and technical and procedural issues. In addition, 6 of the 10 individuals who commented on license renewal opposed it. The others either favored renewal or raised specific issues without expressing an overall position.

Policy Options Developed for License Renewal

NRC staff have been working with consultants and obtaining input from industry groups to develop policy options for license renewal. On the basis of the public comments received, NRC staff determined that the central issue is the criteria, or licensing basis, that will be used to evaluate each license renewal request. NRC staff also developed the following three options that they believe reasonably capture the alternatives to formulate a licensing basis:

- use the original operating license and its amendments;
- use the licensing requirements for plants at the time a renewal request is submitted; or
- issue a modified license that supplements, as necessary, the original license in significant safety areas.

Under the first option, NRC would evaluate a plant against the engineering standards and requirements that were in place when the license was initially granted. Any amendments or license modifications would also be included in the evaluation. NRC staff believe that utilities would encounter less difficulty obtaining a renewed license under this alternative. The staff also realize that this alternative contains a potential drawback because NRC may have to rely on outdated or poorly documented licensing data. According to NRC staff, this disadvantage could

be partially offset by thoroughly updating all pertinent licensing documents and inspecting the plant to demonstrate that it conforms with the original operating license and its subsequent amendments.

The second option, according to NRC staff, may be more difficult for utilities because it could require plants to be redesigned to incorporate many new safety features, even though some may not be cost-beneficial. The staff believe that a more moderate approach would be for NRC to require a systematic evaluation of the plant's original design against current standards. Where justified, NRC would require plant modifications or allow the utility to deviate from the standards.

The third option, according to NRC staff, is the "middle-ground" option. Under it, NRC would require utilities to make changes on a plant-specific basis to ensure continued safe operation. To make these determinations, NRC would require the utility to conduct a detailed study identifying areas in the plant most likely to be adversely affected by the failure of a degraded component, system, or structure and incorporate new standards or plant modifications where needed.

However, NRC also believes that each alternative can be adapted to reflect the condition of a particular plant and the expected degradation of its systems and components during extended operation. The staff also believe that NRC's license renewal decision could be influenced by the adequacy of the utility's operating and maintenance organizations at each plant. Regardless of which alternative is chosen, NRC is primarily concerned that each plant can continue to operate safely.

Other Issues Need to Be Resolved

On the basis of the comments received on the November 6, 1986, Federal Register notice, the staff also identified 15 license renewal topics that NRC needs to resolve. The staff categorized the topics as technical, environmental, or procedural; they believe the technical and environmental topics are more developed than the procedural topics.

Technical Concerns

Neither NRC nor the industry fully understand all the effects of aging on nuclear power plants. As a result, NRC staff believe that even the best assessments of a plant's condition will involve some uncertainty. Consequently, they identified two interrelated technical concerns: the need to (1) verify the adequacy of a plant's design and (2) compensate for uncertainties related to age degradation. These concerns must be resolved when extending an operating license. NRC has identified several

potential methods for resolving these concerns, but it has not decided which one will be used.

Verify the Adequacy of Plant Design

NRC regulations require the periodic inspection of selected important safety components, such as the reactor, pipes, electrical cables, and various pumps and valves. NRC also has several programs to monitor plant operations, assess safety issues, and require modifications where necessary. Because safety standards change over time, NRC has established programs to determine the variance at plants between the time they received operating licenses and when current standards took effect. For example, in 1977 NRC began its Systematic Evaluation Program of 10 plants that received operating licenses between 1962 and 1977. NRC assessed each plant's compliance with regulatory requirements from the time the plant was licensed until 1978 and identified areas where the plants either met the intent of current criteria or needed to incorporate hardware or operational changes. This program's goal was to ensure that the licensing basis for older plants is adequate, even though it may differ from that of newer plants.

However, according to NRC staff, all older plants have not been comprehensively reviewed to determine if they meet current regulations. As revised regulations were implemented and newer plants began to operate, NRC determines whether (1) the updated requirements should be applied to all plants with operating licenses or (2) a basis exists to grant an exemption from the requirements. Consequently, NRC will have to determine whether the plant will be evaluated against current regulatory requirements or those in effect when the operating license was initially granted.

In addition, NRC believes that utilities could assess the safety-significant components in each plant to verify that the plant's design is still adequate to provide continued safe operations. The assessment could include estimates of the components' remaining useful life by considering their operating history. The assessment would also have to demonstrate that if a component fails, safety would not be compromised. NRC believes the safety significance of continued operations for critical components at each plant can be determined accurately only on a case-by-case basis.

Compensate for Aging Uncertainties

According to NRC staff, many age-related uncertainties exist because neither they nor the industry completely understand the nature and

effects of aging on the plants. In addition, the operating and maintenance practices of each utility exacerbate these uncertainties. Depending on the amount of data available and the analytical methods used to predict the effects of aging, even the best estimates of a component's condition will have some degree of uncertainty. For example, aging can be accelerated by inadequate maintenance, improper testing, or abnormal operations. Operating events could have occurred or certain tests may have been performed that were not adequately documented at all plants. If utilities do not have sufficient technical information and historical data in these areas, NRC may take a conservative position in its license renewal regulations to compensate for these uncertainties.

Environmental Issues

In order to comply with the National Environmental Policy Act of 1969, NRC will have to determine whether the agency should prepare an environmental impact statement to support its life extension rulemaking or whether it should prepare a generic environmental impact statement to address issues common to several or all nuclear plants seeking license renewal. The generic environmental impact statement would provide a framework for subsequent site-specific environmental analyses and would contain guidelines to determine when an environmental assessment would be sufficient, or when a site-specific environmental impact statement would be required.

NRC believes an important factor in the environmental issue is the extent to which impacts can be identified and characterized. In addition, NRC believes other factors must be addressed in a generic environmental impact statement including the (1) differences in the types of plants and their location, (2) availability of data, and (3) appropriateness of methods to analyze events such as a severe accident.

Procedural Questions

NRC has also identified many broad procedural questions related to license renewal that it must resolve. These questions include, but are not limited to, the (1) timing for license renewal regulations, (2) role of public hearings in the renewal process, and (3) applicability of current NRC policies and practices.

NRC staff believe they will need about 2 years to review a renewal application. Although the staff are aware that utilities need a planning horizon of 10 to 12 years before licenses expire either to refurbish existing nuclear plants or construct new ones, NRC is reluctant to grant a renewal request significantly before the initial license expires because important

operating data may be excluded from NRC's consideration. NRC staff also believe the decision regarding the license renewal term may be made on a case-by-case basis and consider specific technical concerns, such as the condition of the plant, and policy issues, such as making the renewal term of sufficient length so that utilities would not have to request additional renewals.

In addition, NRC needs to determine the extent to which the public will be given an opportunity to participate in the renewal process. Although the act does not specifically refer to license renewals, NRC staff believe that legal precedents indicate that an opportunity for public hearings is required. If hearings are held, NRC must also determine their scope. NRC currently uses formal adjudicatory procedures for hearings to issue a construction permit and an operating license. NRC is not sure, however, whether the hearings for license renewal or amendment would be subject to these procedures. If NRC determines that it is not required to use these formal procedures, the staff believe they can devise an acceptable method to provide for public participation in the process.

Finally, the relationship between backfits, or plant modifications required by NRC regulations, and license renewal policy raises a number of issues. First, NRC must decide whether the backfit rule should apply during the renewed license term. Second, NRC must address whether the renewal term should be included when calculating the cost and benefits of future backfits. Finally, where NRC previously did not consider the potential for license renewal and decided not to impose backfits due to unfavorable cost-benefit analyses, NRC now has the opportunity to reconsider its decision by including the renewal term in its previous cost-benefit analysis. NRC staff are aware that a backfit, which might not otherwise be required, could be imposed if the extended renewal term is included in the cost-benefit analysis.

NRC staff presented their proposed license renewal options to the Commission on July 12, 1988, along with a recommendation that the Commission publish the options to obtain public comments. In the August 29, 1988, Federal Register, NRC solicited public comments on the proposed options. NRC staff are analyzing the comments received and expect to provide the Commission with a proposed license renewal rule about June 1989.

NRC's Milestones for License Renewal

Subsequent to an NRC reorganization on April 12, 1987, responsibility for the license renewal program was transferred to the Division of Reactor and Plant Systems within the Office of Nuclear Regulatory Research. After revising their plans several times, NRC staff proposed a schedule to publish license renewal regulations for public comment in September 1989, the final regulations in 1992, and complete all regulatory guidance documents by 1995.

On November 13, 1987, DOE's Principal Deputy Assistant Secretary for Nuclear Energy wrote the Chairman, NRC, and expressed concern with NRC's policy development time frames. According to the Deputy Assistant Secretary, from its efforts with the utility industry since 1985 to develop life extension technology, DOE believes that no insurmountable technical issues exist that would affect continued operation of nuclear plants beyond 40 years. Because of utilities' planning requirements for replacement generation, the Deputy Assistant Secretary urged NRC to adopt a more aggressive schedule that would (1) complete its policy statement by the end of 1988, (2) formalize its regulations by the end of 1990, and (3) have regulatory guidance documents in place by 1993. The Deputy Assistant Secretary also noted that this proposed schedule was consistent with NRC's receiving the first application for license renewal, possibly sometime in 1991.

In addition, various NRC units have expressed concern with the policy development schedule. In a January 1988 memorandum, the Director of NRC's Program Management, Policy Development and Analysis Staff, Office of Nuclear Reactor Regulation, stated that he believes the schedule should be accelerated to prepare both a proposed policy statement and license renewal rule by the end of 1988. In response to the memorandum, the Director, Division of Reactor and Plant Systems, Office of Nuclear Regulatory Research, concluded that the staff could save time if NRC did not issue a proposed policy but instead published a proposed rule. According to the Director, this change would not reduce the opportunity for public input and may better focus public comments on more essential license renewal matters. As a result of this change, NRC staff expect to issue their proposed rule for public comment in September 1989, the final rule by 1991, and complete the regulatory guidance documents in the early 1990s. Although they prefer that NRC first develop and publish a policy on license renewal, DOE officials and utility representatives we interviewed believe the revised time frames should be compatible with current industry initiatives regarding plant life extension.

NRC's Age-Related Research Program

In addition to developing a regulatory framework for license renewal, NRC has been conducting technical research on age-related degradation at nuclear plants. Experimental programs and evaluations are being conducted on critical components, such as reactor vessels, pipe systems, valves and electrical cables, and support structures. The objective of these efforts is to develop a technical basis to permit evaluations of continued safe operations. Utilities can also use the data to assess the effects of aging at their plants.

NRC's Research Program Is Focused on Critical Systems and Components

NRC defines aging as the cumulative degradation of a structure, system, or component that occurs, if unchecked, over time. NRC staff also believe that all reactor structures, materials, systems, and components are affected to various degrees by aging. Factors that contribute to the aging process include (1) normal wear and vibration; (2) improper installation, use, or maintenance; and (3) conditions under which the systems and components have operated. If the effects of aging are allowed to proceed unchecked, the continued safe operation of a nuclear plant can be impaired. Therefore, NRC is concerned that aging could lead to equipment failures, accidents, or other abnormal plant conditions that might jeopardize safety.

NRC's program is designed to better assess the effects of aging on nuclear plants during either their initial 40-year license period or extended operating term. The program's objectives are to (1) measure and validate degradation prediction methods, (2) learn from operating experience and expert opinion, (3) identify age-related failures and potential safety problems, and (4) develop recommendations for surveillance and maintenance procedures to alleviate aging concerns. As part of this program, NRC is also monitoring and assessing industry initiatives to ensure safe plant operations beyond 40 years. NRC's research program is devoted to assessing aging effects on (1) reactor vessels; (2) pipe systems; (3) steam generators; and (4) important components, systems, and structures. NRC is also conducting research work on methods to examine and characterize important plant systems and components. It believes these research efforts will help resolve technical safety issues and define policies and regulatory positions pertaining to extended nuclear plant operations.

Research on Reactor Vessels

Reactors at nuclear plants are large, steel, cylindrical vessels that can weigh almost 1,000 tons and vary from 45 to 70 feet in height. The walls of these vessels range from 7 to 11 inches thick. In comparison to boiling

water reactors (BWRs), pressurized water reactors (PWRs) generally have thicker walls and shorter overall dimensions.

The structural integrity of a reactor vessel is critically important to the safe operation of a nuclear plant. Concern about reactors dates back to the late 1960s when the Atomic Energy Commission took steps to ensure that vessel failure did not occur. If the vessel were to fail, the uncontrolled release of radiation could be catastrophic. The objective of NRC's reactor vessel research program, therefore, is to develop methods and analyses to predict the types of conditions that will cause a reactor to fail and to provide NRC with a technical basis to allow continued plant operations.

NRC's experimental programs include determining the (1) changes that occur in metal as it is subjected to prolonged radiation, (2) extent that cracks or flaws affect the integrity of the reactor, and (3) methods that could be used to treat the reactor after prolonged radiation exposure to restore its integrity. Much of NRC's work involves testing and comparing metal samples that have been subjected to various levels of radiation with samples that have not been exposed. NRC uses this information to revise regulatory standards and monitor the condition of reactor vessels.

NRC's reactor vessel research program is an ongoing process that combines data from reactors currently in service and new information from experiments, tests, and various analyses. According to the Chief of NRC's Materials Engineering Branch, Office of Research, some conditions may require repair, replacement, or special treatment. However, on the basis of the information developed to date, NRC has not identified any generic life-limiting conditions that would preclude the continued safe operation of reactor vessels beyond 40 years.

Research on Pipe Systems

A typical nuclear power plant contains between 10 to 50 miles of pipe that must be designed to withstand various operating environments ranging from a potential earthquake to normal expansion and contraction caused by temperature changes. In assessing the condition of the pipe and its ability to function longer than 40 years, NRC and the utilities must consider the combined effects of temperature changes, operating environment, and fatigue to which the pipe has been subjected. NRC's pipe research program focuses on developing information regarding (1) pipe system design, (2) repair techniques for damaged pipe, and (3)

flaws and other conditions that may cause pipes to rupture. The objectives of this research are to provide a basis for making regulatory decisions, conducting inspections, and assessing the feasibility and effectiveness of safety improvements.

A plant's pipe system is designed to expand and contract during normal operation and accommodate some potential movement during earthquakes. If some movement is not allowed, the resulting stress placed on the pipe may cause it to leak or break. NRC has determined that its design requirements may unnecessarily restrict the movement of some pipe systems and may need revision. NRC is conducting research to demonstrate and justify the need for a change. NRC expects to complete most of its pipe system research by fiscal year 1991.

In addition, cracks in nuclear plant pipe systems were first reported in 1965. Since that time, various leaks and cracks have occurred as a result of fatigue, corrosion, and other factors. Over 400 pipe-cracking incidents have been reported throughout the world. The most significant pipe cracking problems have been observed in BWRs as a result of a condition known as intergranular stress corrosion cracking (IGSCC). IGSCC usually occurs in the area where sections of stainless steel pipe are welded together. Some utilities have had to replace major portions of their BWR pipe systems as a result of this condition.

The following elements must exist in combination for IGSCC to occur: (1) material that is susceptible to this condition, (2) significant stress, and (3) an operating environment that promotes the development of this condition. NRC has concluded that improvements in all these elements should be pursued to mitigate the effects of IGSCC and reduce the probability of it occurring. Although NRC has conducted some research in this area, most of the research has been conducted by the industry.

During the past 8 years, NRC has focused on independently assessing near- and long-term repairs, conducting experiments, and providing technical support for regulatory issues related to IGSCC. On the basis of this work, NRC has raised questions concerning the adequacy of fatigue analyses for pipe systems. NRC believes that additional information is needed on the (1) effects of fatigue in pipe systems, (2) environment to which the pipe has been subjected while in service, and (3) relationship of these conditions to extended nuclear plant operation.

NRC previously postulated that if a pipe were to fail, it would do so violently without warning. It currently believes, however, that pipes will

leak before they break, thereby warning the utility that the pipe has lost its integrity before total failure occurs. NRC's revised judgments are based on experimental data and improved analyses of the conditions that could cause pipes to fail.

NRC has several programs underway to support the "leak before break" theory. For example, it has evaluated pipes of various material and diameter to determine if a cracked pipe can withstand normal and accident conditions. NRC believes this work will lead to improved methods for predicting the types of conditions that will cause pipes to lose their integrity and fail. Eventually, this research will help to better define the engineering and design margins necessary to ensure continued safe operation of pipe systems in nuclear plants.

Research on Steam Generators

Steam generators produce steam in PWRs. They are about 60 feet tall and are some of the largest equipment in a nuclear plant. Large pipes connect the steam generators to the reactor. The number of steam generators at plants varies from two to four.

The integrity of steam generators is very important to the safe operation of a PWR. Heated, radioactive water is pumped from the reactor to the steam generator where it is circulated through approximately 3,300 tubes that are surrounded by nonradioactive water. The heat from the radioactive water is transferred through the tubes to the nonradioactive water to produce steam. If a failure were to occur in the tubes that circulate radioactive water and transfer heat, a pathway could be created that could allow radiation to escape from the steam generator into the containment building.

The tubes in some steam generators have experienced age-related degradation after just 7 or 8 years of operation. Tube damage usually occurs in the form of corrosion, pitting, cracking, or thinning of the tube wall. Most of this degradation is due to the harsh conditions and chemicals in the water that circulates through the steam generator. If a tube is found to leak or be defective, the utility can plug it, thereby allowing the steam generator to operate.

The objective of NRC's steam generator research program is to assess the effectiveness of its inspection requirements for these components and determine the amount of degradation that must occur before a tube needs to be plugged. For example, when one of the steam generators from Virginia Power's Surry unit 2 was retired from service, NRC sent it

to DOE's Pacific Northwest Laboratory in Richland, Washington, for further study and analysis. Evaluations were conducted to identify better methods to perform inspections, detect flaws, and determine the conditions that cause tubes to fail. More than 550 metal specimens were removed from the steam generator for evaluation and analysis.

Although NRC concluded this portion of its research effort in fiscal year 1987, it has not yet compiled a final report on its findings. According to the Chief, Materials Engineering Branch, the most significant factors affecting the life of steam generators appear to be the chemistry of the water used in these components and the maintenance procedures used by utilities. In addition, preliminary research results indicate that some steam generators may require replacement as a condition for continued operation; others may not.

Research on Other Components, Systems, and Structures

In 1985 NRC developed the Nuclear Plant Aging Research program, a three-phase effort to assess aging effects on other components, systems, and structures that affect the safe operation of nuclear plants. The objectives of phase I are to identify and characterize (1) failures in plants that may be attributable to aging and (2) aging effects and trends that may lead to the detection of failures in those three areas. During phase II, engineering studies will be performed based on measurements and examinations of components subjected to extended service in nuclear plants, and NRC will identify improved methods to inspect, monitor, and determine the amount of remaining useful life for these items. In phase III, NRC plans to resolve any remaining issues that have been identified earlier in the program. NRC had spent about $11 million on research for components, systems, and structures as of the end of fiscal year 1988 and anticipates spending about $40 million more to complete the program in 1994 or 1995.

NRC currently has 20 ongoing projects to study the effects of aging on individual components, systems, and structures. Electrically operated valves, electric motors, emergency generators, and systems that contain these components are included in the projects. NRC has also identified other components and plant systems that it intends to study in the future. NRC does not plan to perform in-depth engineering evaluations for all significant systems and components in nuclear plants. Instead, NRC will study a few representative items to demonstrate how the industry can assess the effects of aging on its plants. According to NRC staff, each utility is responsible for characterizing and evaluating important

components and systems at its nuclear plants and ensuring their continued safety.

Research on Nondestructive Examination Methods

Utilities use either destructive or nondestructive methods to assess the integrity of components in nuclear plants. In a destructive examination, a representative sample of an item is destroyed to determine how its characteristics have been altered by the environment to which it has been exposed. The information derived can be used to assess the condition of components that are still in service. In contrast, items that are subjected to nondestructive examinations are not damaged or destroyed and can be returned to service after they have been evaluated.

Various nondestructive techniques such as x-rays and ultrasonic tests are used to assess the integrity of components in nuclear plants. Ultrasonic tests are performed by placing an instrument directly on the component and pulsing a sound wave through it. The sound wave is reflected back and is used to characterize any flaws that are detected. These types of examinations are required while components are being manufactured, before they are placed in operation, and periodically while they are in service. The nondestructive examinations are to ensure that flaws are detected, unacceptable components are repaired or replaced, and possible generic defects are identified.

NRC believes that only research on nondestructive techniques has a direct impact on improving safety. Since fiscal year 1978, NRC has sponsored research to improve the reliability of these techniques and provide more accurate detection and characterization of flaws in nuclear plant components. NRC is currently working with the industry to develop better methods of monitoring the initiation and growth of cracks in components. As part of this program, the Surry steam generator is being used to test various nondestructive techniques. NRC expects work on this program to continue through 1993; the results will be used as a basis for developing regulatory guidance as needed for the extended operation of nuclear plants.

NRC and Utilities Monitor Pressurized Thermal Shock

The integrity of reactors has always been of primary concern at nuclear plants. To ensure continued safety, each utility has a surveillance program to monitor the condition of the reactors. On the basis of NRC's assessment of the results of these programs and research efforts, NRC has identified some age-related degradation that could affect the continued operation of 12 nuclear plants. However, NRC and utility officials believe that mitigative measures can be taken to alleviate these conditions and enable continued plant operations.

Concerns About Vessel Integrity Are Not New

Scientists recognized as early as 1942 that prolonged exposure to high levels of radiation could cause the metal in reactors to become more brittle and susceptible to failure. The industry also recognized that when assessing the effects of radiation on reactor vessels, each one has to be treated individually because of its unique exposure to radiation. In order to monitor and evaluate the changes in reactors and predict potential damage, NRC requires each reactor to contain specimens of metal identical to that used in the plates and welds when the vessel was constructed. The purpose of this requirement is to expose the metal specimens to radiation at a faster rate than that experienced by the vessel. NRC requires utilities to periodically remove the specimens, test and evaluate them, and report the results to NRC. By monitoring the changes in the characteristics of the specimens over time, NRC and utilities are able to assess the (1) extent to which the characteristics of the metal in each reactor have been altered as a result of prolonged radiation exposure and (2) ability of the vessel to withstand a potential accident.

In 1975 NRC issued Regulatory Guide 1.99, which, for the first time, provided a comprehensive methodology to predict the effects of radiation on the integrity of reactor vessels. In April 1977, NRC issued Regulatory Guide 1.99, Revision 1 to more accurately reflect the effects of radiation on the different types of metal used to construct reactors. This revision was based on data obtained from test programs and metal specimens removed from operating reactors.

The 1979 accident at Three Mile Island focused NRC's and the industry's attention on the potential for reactors to fail because of pressurized thermal shock (PTS). According to NRC, PTS is a condition that can occur in PWRs as the result of severe overcooling of the reactor concurrent with or followed by a pressure increase in the vessel. NRC believes the likelihood of a PWR failing because of PTS increases as the metal in the reactor becomes embrittled from prolonged radiation exposure. According to NRC, PTS is not a concern for BWRs because of the (1) large amount

of water contained in the vessel that reduces the amount of radiation reaching the wall of the reactor; (2) improbability of high pressure and low temperature occurring simultaneously in the vessel; and (3) reduced amount of stress, in comparison with a PWR vessel, that might cause a crack or flaw to grow.

The ability of a PWR vessel to withstand a PTS event depends on the metallurgy of the vessel plates and the welds that join them together. NRC believes that certain welds are most sensitive to radiation damage and have the greatest propensity for containing flaws. NRC also believes that if the toughness of the vessel has been sufficiently reduced as a result of radiation exposure, a PTS event could cause a small flaw that might exist in the welds or plates of the reactor to grow through the reactor wall and release the water contained in the vessel.

On July 23, 1985, NRC issued its PTS rule. The rule (1) establishes criteria to define the limit of embrittlement beyond which a vessel cannot be operated without further analysis, (2) requires utilities to analyze the effects of PTS on their reactors and develop a program to avoid exceeding the screening criteria, and (3) requires utilities to perform detailed safety evaluations to support continued operation if their reactors exceed the screening criteria. If a reactor exceeds the screening criteria, the PTS rule provides for continued operations only after NRC reviews and approves the utility's safety evaluation.

NRC Has Developed New Regulatory Guidance to Assess Reactor Integrity

NRC issued Regulatory Guide 1.99, Revision 2 in May 1988. On July 12, 1988, NRC sent the revision to all utilities with reactors in operation and under construction. NRC required that within 180 days the utilities submit technical analyses of the revision's effects on their reactors and a proposed schedule of actions needed to meet the new criteria.

NRC's objectives of Revision 2 are to

- update the criteria used to assess reactor vessel integrity by incorporating improved knowledge developed from tests of the metal specimens removed from operating reactors during the 11 years since the previous revision was published,
- more accurately account for the embrittlement effects of radiation on the various types of metals that were used in the welds and plates when the reactors were built,
- provide the basis for revising the operating procedures used to start up and cool down reactors,

- better characterize the growth of an assumed crack through the reactor wall and provide a basis for analyzing flaws that may be detected during inspections, and
- restore reactor safety margins to their intended levels.

According to NRC staff and utility representatives, the industry agrees with the methodology NRC used to develop Regulatory Guide 1.99, Revision 2, and many companies have already incorporated this guidance into their operating procedures. In addition, NRC staff stated that within 18 months, they plan to update the PTS rule to be consistent with Revision 2. On the basis of the information developed by testing metal specimens removed from operating reactors, NRC has determined that 12 reactors will reach the screening criteria established in the PTS rule either before or soon after their operating licenses expire. Table 4.1 shows the plants that NRC has identified, the year they are predicted to reach the screening criteria, and the year their operating licenses are scheduled to expire.

Table 4.1: Nuclear Plants Predicted to Reach NRC's Screening Criteria

Plant	State	Predicted to reach screening criteria	License expires
Fort Calhoun	Nebraska	1993	2008
Calvert Cliffs 1	Maryland	1997	2014
Palisades	Michigan	1989–92	2007
Kewaunee	Wisconsin	2004	2013
Zion 1	Illinois	2005	2008
Point Beach 2	Wisconsin	2008	2013
Three Mile Island 1	Pennsylvania	2007	2008
Diablo Canyon 1	California	2008	2008
Indian Point 3	New York	2010	2009
Point Beach 1	Wisconsin	2011	2010
Surry 1	Virginia	2013	2012
Oconee 2	South Carolina	2014	2013

NRC's screening criteria are not intended to impose an absolute limit on the operating life of a reactor but rather to serve as a "trigger point" that alerts utilities to the need to conduct detailed studies of the risks that may be involved if the reactor continues to operate beyond the

screening criteria. NRC requires each utility to update its safety assessments to reflect significant changes that are made to the reactor, such as the location of fuel within the reactor or the results of periodic inspection programs. The objective of these requirements is for each utility to develop a baseline of information regarding the continuing effects of radiation on the reactor and determine the corrective actions that may be required to ensure continued safe operation.

If a utility determines that its reactor is approaching the PTS screening criteria, it must notify NRC 3 years in advance of the date the reactor is predicted to exceed the limits. The utility must also determine the equipment, systems, or operating modifications that are needed to prevent reactor failure if an accident occurred. Consequently, a reactor may exceed the screening criteria, but if a utility can demonstrate that the reactor can continue to operate safely, NRC's regulations state that it can remain in service.

NRC's regulations also outline several types of corrective actions, such as the location of the fuel within the reactor or improved monitoring programs that utilities may use to delay the effects of PTS. These measures can be used either to stay within the screening criteria or ensure continued safe operation if the screening criteria are exceeded. Some of these measures' effectiveness, however, depend on their implementation well before the screening criteria are reached. If utilities choose to use these alternatives, they will have to perform plant-specific analyses to determine the impact on safety of implementing the alternatives, explain to NRC the steps being taken, and document how they will improve reactor integrity. To successfully use these measures, utilities need to have an aggressive program of inspecting and characterizing their reactors.

Changing the Configuration of the Fuel in the Reactor

Utilities use a specific pattern to place nuclear fuel in reactors to maximize the amount of heat produced. During the nuclear reaction that produces heat, some neutrons will strike the wall of the reactor vessel. If a large number of neutrons strike the vessel over a long period of time, it will become embrittled. A utility can reduce the amount of neutrons that strike the vessel wall by modifying the pattern and composition of the fuel, which reduces the rate of embrittlement and protects against vessel failure.

According to NRC, most nuclear plants can avoid reaching the screening criteria if this option is implemented in a timely manner. To be most

effective, however, utilities must institute these measures well before their reactors approach the screening criteria.

Plant Modifications

According to NRC, a wide range of hardware modifications may be useful to reduce the potential of a PTS event occurring at nuclear plants. For example, instruments could be installed to monitor the temperature and pressure of critical systems, and changes could be made to systems that respond automatically to accident conditions. NRC also believes that utilities should consider increasing the temperature of the water that would be used to cool the reactor during an accident. This modification would protect against cooling the reactor too fast, thereby reducing the amount of stress placed on the vessel. However, utilities must consider the effect of these modifications on other plant systems and operating conditions.

Annealing the Vessel

The metal in reactor vessels loses its toughness as it becomes embrittled. Some portion of this toughness can be recovered if the metal is annealed, or subjected to high temperature for a period of time. The increased temperature relieves the embrittlement accumulated during operation and makes the vessel more resistant to failure.

Although the Westinghouse Corporation has conducted several programs to explore the feasibility of annealing a reactor to reduce embrittlement, this procedure has not been used in the United States to restore the integrity of commercial plants currently in operation. According to NRC staff and utility representatives, this procedure may be viewed as a "last ditch" effort to restore vessel integrity. As discussed above, other measures and operating procedures are available to ensure the vessel does not become so embrittled that it requires annealing.

Improving Operating Procedures, Training, and Inspection Programs

NRC believes that the actions of utility staff who operate reactors play a key role in the initiation and mitigation of PTS events. As a result, NRC has recommended that utilities develop and upgrade reactor operator training programs to ensure that operators' actions are always in accordance with approved operating procedures and guidelines. The training programs should provide operators with the opportunity to control and protect reactor systems during abnormal operating conditions. Guidance should also be provided to operators on measures to use if the pressure and temperature of reactors vary outside acceptable limits. NRC believes that utilities should conduct these training programs

using a "team" approach that emphasizes the importance of the operating crews working together in a coordinated manner if a PTS event occurs.

NRC also believes utilities should use the best available state-of-the-art techniques to inspect reactors for flaws or cracks. Existing inspection programs should be reevaluated to ensure that they adequately address all the unique features of each reactor. NRC also believes utilities should consider increasing the extent of their reactor vessel inspections.

DOE and Industry Initiatives to Support License Renewal

The electric utility industry has been exploring the option of extending nuclear plant operations since 1979. In 1985 DOE, EPRI, Virginia Power, and Northern States Power entered into agreements to study the feasibility of extended operation for a BWR and a PWR; phase I of these studies were completed in 1987. The utilities have not identified any age-related degradation or technical obstacles to preclude continued operation beyond 40 years. In fact, on the basis of the feasibility studies, Northern States Power determined its reactor could operate safely for 70 years, while Virginia Power believes its reactor could operate safely for at least 60 years.

Despite these conclusions, both utilities identified several areas of plant operation that require additional analyses. In addition, DOE and the industry selected two other nuclear plants to participate in age-related research to supplement the information developed by Northern States Power and Virginia Power. The data obtained from these efforts will provide a broader perspective on nuclear plant aging. To assist utilities seeking to operate their nuclear plants longer than 40 years, DOE and the industry have also embarked upon a 5-year program to develop and submit the first application to NRC for extended plant operations.

DOE and the Industry Are Studying Nuclear Plant Aging

Beginning in 1979, EPRI initiated studies to assess the feasibility of extending the operating lives of nuclear plants. On September 29, 1981, DOE and EPRI entered into an agreement to advance the safety, efficiency, and reliability of electrical energy systems. On April 23, 1986, DOE and EPRI entered into an agreement to identify research efforts that would serve as the basis for extending nuclear plant's operating lives. DOE believed the agreement would contribute to maintaining the nuclear option to meet the nation's future energy needs. EPRI agreed to transfer the research results to member utilities to assist in deciding whether to seek license renewals for their plants.

Early in 1985, DOE, EPRI, Northern States Power, and Virginia Power initiated pilot studies to (1) identify and evaluate plant components and systems that may have a major influence on life extension decisions; (2) identify potential obstacles to life extension; (3) develop a life extension approach that could be used by other utilities; and (4) recommend to DOE, EPRI, and the rest of the industry the research and development activities required to support life extension. These studies were to be based on detailed assessments performed at the Monticello plant, a BWR owned by Northern States Power, and Surry unit 1, a PWR owned by Virginia Power.

Phase I of the pilot plant studies has been completed. The results of the work at Monticello were published in May 1987 and the Surry report was published in July 1987. Although this portion of the project has been completed, work is continuing at both plants to expand upon the information that was developed and better characterize the effects of age-related degradation. The following summarizes the study approach used and the principal findings observed at each plant.

The Monticello Pilot Plant Study

The Monticello nuclear plant is located about 30 miles from Minneapolis, Minnesota. Plant construction began in 1967, and commercial operation began on June 30, 1971. The General Electric Company designed the Monticello reactor, which provides about 10 percent of the company's total generating capacity. Its operating license is scheduled to expire in the year 2010. Six U.S. nuclear plants also use the design of Monticello's steam supply system, and 24 plants have similar containment systems. Northern States Power made two major modifications since Monticello began operating. Between 1977 and 1982, the company modified the systems and components that would contain heat and radioactivity during an accident. In 1984 the pipe system that circulates cooling water through the reactor was replaced because it showed evidence of cracking.

In 1985 Northern States Power initiated a two-part study at Monticello. Phase I resulted in the identification and prioritization of 120 major plant components. Phase II is underway and will examine additional components, review maintenance programs, and develop a component life prediction and surveillance manual for the plant. During phase I, Northern States Power identified and categorized the structures and components in the plant that could have the most influence on a decision to extend the life of the plant. According to company officials, a team comprised of company staff, utility consultants, and the reactor designer reviewed approximately 5,000 items in the plant and developed screening guidelines to select the systems and components that would be most affected by continued operation.

Using the guidelines, the team identified 120 components and systems and selected 27 of the most important for in-depth examination and analysis. The components included (1) the reactor vessel and its cooling system, (2) selected mechanisms contained in the vessel, (3) major concrete structures, (4) the control center, and (5) the emergency diesel generator that provides back-up electrical power. Northern States Power also reviewed applicable standards and regulations, plant operating and

maintenance histories, and incidents that have occurred since the plant has been in service. The company compiled reports describing each of the critical components, and where appropriate, made recommendations in areas such as improved operating and maintenance procedures or additional research and development activities. Northern States Power assessed the remaining 93 components in less detail to identify major repair or maintenance activities that could affect the decision to operate the plant longer than 40 years.

In May 1987 EPRI published the results of the Monticello evaluation in a report entitled BWR Pilot Plant Life Extension Study at the Monticello Plant: Phase I. The report concluded that no technical obstacles were identified that would preclude operating the plant for 70 years. In fact, the company concluded that the ratio of benefits to costs was about 4 to 1 in favor of extended plant operation. However, the report identified over 200 potential follow-on activities, ranging from major generic research and development programs to plant-specific changes. The report also made 10 recommendations for extended operation, such as the following:

- Records to support life extension must be accumulated now. Many needed records are currently not kept or kept only for a limited period of time.
- Reliable baseline data must be recorded as soon as possible to better predict and assess plant degradation.
- A long-term program should be developed to ensure that spare parts will be available.
- Improvements are needed to monitor and diagnose the effects of aging on components. Research should also be conducted to develop better (1) inspection techniques, (2) component repair and replacement programs, and (3) assessment techniques for concrete structures.
- Because degradation for some components could be accelerated by extended plant outages, utilities should develop programs to protect equipment better when outages are longer than normal.

According to Northern States Power officials, the ongoing phase II studies will build on the information obtained during phase I. For example, they expect to conduct additional analyses of the 93 components initially identified as low priority. Efforts are also being directed toward improving plant maintenance and inspection programs and evaluating equipment used for refueling, electrical components, control room components, and protective coatings used in the containment building. Information gained from this effort will be provided to other utilities that

operate BWRs. According to Northern States Power officials, they expect to complete phase II by the end of 1989.

The Surry Unit 1 Pilot Plant Study

The Surry power station, located approximately 12 miles from Newport News, Virginia, is owned and operated by Virginia Power. The site contains two nuclear plants, units 1 and 2, which were placed into commercial operation in December 1972 and May 1973, respectively. Both reactors were designed by the Westinghouse Corporation. The operating license for Surry unit 1 is scheduled to expire in the year 2012, and Surry unit 2 in 2013. The Surry plants, combined with Virginia Power's two other nuclear units, provide approximately 30 percent of the company's generating capacity.

Like the Monticello effort, Virginia Power divided its feasibility studies into two phases. Phase I began in January 1985 and was completed in December 1986. During this portion of the study, Virginia Power assessed the technical feasibility and economic implications of continued plant operations and developed a management strategy to follow if the company decides to pursue this option. The primary objective of phase I was to identify components whose failure might preclude continued operation.

Virginia Power formed a life extension project team comprised of utility staff, the reactor designer, construction contractor, and consultants. The team developed a list of 23 potentially critical systems and components that individually or collectively could impact plant life extension. The systems and components included the (1) reactor and the equipment it contains, (2) major pipe systems that supply cooling water to the reactor and the structures that support it, (3) electrical cables in the containment building, (4) steam generators, and (5) containment building that houses the reactor.

The team performed technical evaluations on each system or component to determine its potential impact on the life extension option. Measures were also identified that could be implemented to enhance the possibility of extended operations. Virginia Power obtained information for these evaluations from applicable regulations and standards, inspection and repair records, and operating histories of events that have occurred while unit 1 has been in service. The company compiled reports on each component's operating history, degradation experienced while in service, and projected design life.

In July 1987 EPRI published the results of this work in a report entitled PWR Pilot Plant Life Extension Study at Surry Unit 1: Phase I. According to Virginia Power officials, phase I did not reveal any technical reasons or economic factors that would preclude the operation of Surry unit 1 for at least 60 years. The study did, however, identify several components and areas of plant operation in need of additional analysis. For example, the study recommended that Virginia Power develop a systematic program to prolong the life of critical components and document their conditions to ensure they continue to meet acceptable safety levels. The study also recommended that Virginia Power revise its maintenance program to ensure equipment will operate longer and more reliably. The study included about 270 recommendations to support continued operation at Surry unit 1. Most of the recommendations were generic in nature and focused on the need to upgrade (1) research and development; (2) engineering and analysis; (3) operation and maintenance; (4) monitoring, testing, and inspection; and (5) recordkeeping.

Virginia Power initiated phase II in January 1987 to evaluate and prioritize the data obtained during phase I and further develop the technical basis and management strategy that will be needed to support a request for continued operation of unit 1. Virginia Power is now performing analyses to further characterize the effects of age-related degradation on several important systems and components. For example, concrete samples have been taken from the containment building and several other structures. The samples will be studied to determine whether the integrity of the concrete has been affected by continued exposure to water and other operating conditions. Long-term studies are also being conducted on the operating environment inside the containment building. Samples of electrical cables have been installed to determine how the insulation on the cables is affected by continued exposure to heat and radiation. The results from these and other programs will be used by Virginia Power to develop an overall management strategy to implement actions that will prolong the service life of its nuclear plants.

Other Utilities Are Conducting Similar Studies

Although nuclear plants use the same generic process to generate heat and produce electricity, each plant contains systems and features that are unique to that plant. Consequently, the effects of aging may affect each plant differently. As a result, the industry has begun a program to determine whether the Monticello and Surry findings are applicable to other reactors. These studies are being conducted in conjunction with EPRI at Oconee unit 1, owned by Duke Power, and Calvert Cliffs unit 1, owned by the Baltimore Gas and Electric Company (BG&E).

Oconee Unit 1

Duke Power operates seven nuclear plants that provide approximately 50 percent of the utility's generating capacity. Unit 1 began operating in July 1973 and is one of three PWRs located at the Oconee nuclear station, approximately 30 miles from Greenville, South Carolina. The Babcock & Wilcox Company designed the reactor, which is typical of other PWR vessels the company built that are in operation. The operating license for Oconee unit 1 is scheduled to expire in the year 2013.

In 1987 Duke Power and Babcock & Wilcox began an evaluation of the unit 1 reactor system. EPRI sponsored one-half of the project because information concerning vessel integrity could be beneficial to other utilities operating similar reactors. The study focused on the reactor, its internal mechanisms, the structures that support the vessel, major pumps and valves, and the pipe systems associated with its operation. Included in the assessment was an evaluation of the effects of several aging mechanisms such as radiation exposure, corrosion, and sustained, elevated operating temperatures. Duke Power limited its evaluation to the technical feasibility of extended operations.

Although portions of the evaluation are still in process, Duke Power officials said they have not identified any issues to preclude the continued operation of Oconee unit 1. They also stated that the results of the study are consistent with the conclusions drawn from the Surry study. Duke Power officials also stated that a specific reactor component will need to be replaced, but the vessel was designed to accommodate the needed replacement. Duke Power also believes that the Oconee unit 1 reactor can be safely operated for 60 years. The company plans to continue activities that will prolong the operation of its nuclear units. For example, at all seven of its nuclear plants, Duke Power has modified the configuration of the fuel to reduce radiation exposure and embrittlement of the vessel.

On the basis of the information developed during its study, Duke Power believes that the industry should consider several recommendations to better plan for continued plant operations including the following:

- Enhance existing techniques for examining the interior of the reactor vessel to minimize downtime during refueling outages.
- Develop remote welding repair capability for certain reactor vessel components.
- Continue investigations on the effects of embrittlement on reactor vessels.

Calvert Cliffs Unit 1

BG&E operates two nuclear plants at Calvert Cliffs, located on the Chesapeake Bay approximately 40 miles from Annapolis, Maryland. The Combustion Engineering Company designed the reactors; they provide approximately 55 percent of BG&E's generating capacity. Unit 1 began commercial operation in May 1975; unit 2 began operating in April 1977. The operating license for unit 1 is scheduled to expire in the year 2014. BG&E officials told us the units cost about $778 million to construct, yet they have saved about $4.4 billion in fuel costs to BG&E customers. Consequently, BG&E believes that continued operation of these plants is crucial to operating its electrical generating system economically.

BG&E began its evaluation at Calvert Cliffs unit 1 in April 1987 with partial funding from EPRI. The objective of this effort was to determine the applicability of the findings from Surry unit 1 to a PWR design constructed by a different company. BG&E contracted with Combustion Engineering to perform this comparative evaluation. The results of this work will be provided to all utilities operating Combustion Engineering reactors.

BG&E also performed a detailed evaluation of the reactor vessel to develop a program for its continued operation. The company used a wide range of information to evaluate the condition of the reactor, including (1) enhanced, state-of-the-art ultrasonic technology; (2) historical data of the welding process used to construct the vessel; and (3) the results of the reactor vessel surveillance program. On the basis of this evaluation, BG&E concluded that extended operation for unit 1 is feasible if certain specific tasks are conducted. Additional engineering analyses and continued monitoring will be required to further assess the effects of radiation on the vessel, and certain minor components will probably have to be replaced before the operating license expires. According to BG&E officials, the reactor was designed and constructed to provide for this, and they do not consider the replacements to be a critical issue in deciding whether to continue reactor operations.

BG&E officials also explained that before the unit 1 evaluation, the company was aware of one weld area in the reactor that may exceed NRC's embrittlement screening criteria in 1998. During the 1990 refueling cycle they will reconfigure the fuel in the reactor and believe it can operate safely for at least 60 years. According to these officials, this measure will be implemented well before the reactor reaches the screening criteria. BG&E officials also told us that in accordance with NRC regulations, the company will notify NRC 3 years in advance of meeting the screening

criteria. The notification will include BG&E's plan to accommodate the effects of vessel embrittlement on continued operations.

According to BG&E officials, they are gathering additional data to support continued operation for Calvert Cliffs unit 1. A plan for developing a program was presented to BG&E management in the fall of 1988. The plan identified short- and long-term planning needs, including (1) cost analyses, (2) factors affecting the life extension decision, and (3) research and development requirements.

DOE and EPRI Plan to Support the Industry's First License Renewal Request

According to officials in DOE's Division of Light Water Reactor Safety and Technology, the continued operation of nuclear plants currently in service is an important element in ensuring adequate supplies of electricity in the future. DOE has, therefore, been working with EPRI to demonstrate that nuclear plants can be operated safely beyond their 40-year license period. The objective of this effort is to develop and submit the first application to NRC for extended operation of one BWR and one PWR. DOE believes that it should be active in this effort because (1) NRC has not yet developed a license renewal process; (2) the demand for electricity is constantly growing; (3) many years are required to construct new generating capacity, yet no utilities are building new large replacement plants; (4) the nuclear plants that are in service are valuable investments that should be utilized to the fullest extent possible; and (5) extending the life of a plant can be accomplished for a fraction of the cost to build replacement capacity.

In June 1988 EPRI and DOE issued proposals for utilities to participate in a 5-year program to develop and submit license renewal applications to NRC. According to DOE officials, the objectives of this effort are to demonstrate the technical, environmental, and institutional requirements for renewing operating licenses. Six utilities showed an interest, but according to DOE officials only Northern States Power, Virginia Power, and Yankee Atomic Electric submitted formal responses. Yankee Atomic operates the Yankee Rowe nuclear plant located near Pittsfield, Massachusetts. Yankee Rowe, a PWR that began commercial service in 1961, is the oldest nuclear plant currently operating and is the first operating license that will expire. After evaluating each submittal, on September 26, 1988, DOE and EPRI selected the Monticello and Yankee Rowe plants to participate in the program. According to DOE officials, the work that will be performed at these plants should result in an acceptable, validated method for license renewal. Once the license

renewal process is developed and tested, DOE officials believe it will assist other utilities seeking to operate their plants longer than 40 years.

Some Organizations Do Not Support License Renewal

Several public interest groups oppose license renewal, primarily because they are concerned about whether the continued operation of older reactors can be accomplished without undue risk to public health and safety. In addition, these organizations believe that NRC should address long-standing safety concerns associated with older plants, instead of structuring its license renewal policy to provide an economic incentive for utilities to operate their nuclear plants longer than 40 years.

The Critical Mass Energy Project

The Critical Mass Energy Project does not support any of NRC's license renewal policy options because it opposes the (1) use of nuclear power to generate electricity and (2) continued operation of nuclear plants beyond their 40-year license term. According to Critical Mass representatives, as nuclear plants advance in age, they become increasingly costly to operate and maintain, and their safety and reliability decline. In addition, they do not believe that utilities have shown they can effectively manage nuclear plants during the initial 40 years. Consequently, Critical Mass believes that nuclear power should be phased out and replaced with other alternatives, such as better use of conservation and natural gas.

The Nuclear Information and Resource Service

The Nuclear Information and Resource Service representatives commended NRC's early action in addressing license renewal issues but noted that its efforts were influenced by the industry. According to Nuclear Information and Resource Service representatives, NRC is devoting resources to promoting license renewal when it should be solving basic safety issues, such as PTS and pipe failures at nuclear plants. They also stated that by allowing nuclear plants to continue operating in the absence of solutions to these problems, NRC has reduced the level of safety at these facilities.

However, if NRC allows nuclear plants to operate longer than 40 years, the Nuclear Information and Resource Service believes NRC should require utilities to meet the licensing requirements in place for plants at the time NRC receives the renewal application. In addition, because every part of a plant is susceptible to age degradation, the Nuclear Information and Resource Service believes that NRC should review and inspect the condition of all systems and components at nuclear plants, not just those that are subject to NRC regulation, and NRC should hold public hearings before renewing a nuclear plant license.

The Union of Concerned Scientists

The Union of Concerned Scientists believes it is still unclear whether older nuclear plants can be operated without undue risk to public health and safety. Consequently, the Union of Concerned Scientists believes NRC should base its license renewal policy on a clear understanding of what is necessary to protect public health and safety, without regard to what it may cost to implement these measures. In addition, the Union of Concerned Scientists believes that NRC should conduct the license renewal process in the same manner as an initial operating license and require utilities to demonstrate that, unless the plant should be exempt from some particular requirement, it meets current regulatory standards. For each plant requesting a renewed operating license, the Union of Concerned Scientists believes NRC should conduct a thorough inspection of the critical safety systems and components and review the adequacy of important programs, such as maintenance and inspections. Finally, the Union of Concerned Scientists believes that NRC should use adjudicatory hearings to allow the public to participate in the license renewal process.

Conclusions and Recommendations

Conclusions

Continued operation of nuclear power plants is an issue of national importance. Without the generating capacity provided by the plants now in operation, the adequacy of future electricity supplies may be in question. Because of the varied concentration of nuclear plants across the country, those areas depending most heavily on nuclear power stand to be most affected. This issue will become increasingly important as older plants move closer toward the conclusion of their current operating licenses.

Many utilities will have to decide in the early 1990s whether it is more economical to renew an operating license for nuclear plants that have been in service for decades or construct new generating capacity. A clear understanding of the terms and conditions governing the license renewal process will be a key element in each utility's decision when planning to meet future electricity demands. Because of the lengthy planning horizons required to construct new generating capacity, DOE and the industry believe NRC should have a reliable, predictable license renewal program in place long before the current operating licenses begin to expire.

A substantial amount of work to assess the feasibility of operating nuclear plants beyond their license period has been performed by NRC, DOE, and the industry. Although several different analytical approaches have been used, these efforts have focused on similar systems and components and produced similar findings. Included in these efforts are studies at four different plants to assess the effects of aging on critical systems and components. On the basis of preliminary evaluations, no commonly related or generic technical obstacles have been identified that would cause nuclear plants to be shut down. The utilities have determined, however, that much more needs to be done to support continued operation in areas such as (1) recordkeeping; (2) testing; (3) inspection and surveillance; (4) maintenance, repair, and replacement; and (5) research and development.

Another important factor that could affect continued operation for some nuclear plants is embrittlement of the reactor vessel. On the basis of NRC's regulations, some plants will meet the screening criteria shortly before or soon after their operating license expires. Neither NRC nor industry officials believe, however, that the screening criteria impose an absolute limit on the service life of a reactor. They agree that utilities have a wide range of measures available either to forestall meeting the screening criteria or continue operating after they have been exceeded.

If utilities want to continue operating beyond the screening criteria, they must first submit their mitigative measures to NRC for approval.

During the past 8 years, NRC's age-related research program has concentrated on components such as reactor vessels and steam generators, pipe systems, electrical equipment, and support structures. Specimens from equipment used in operating plants have been analyzed and evaluated. NRC has also conducted experiments to develop better methods for examining components, detecting flaws, and performing repairs. Some of NRC's research work has been completed, and some is scheduled to continue into the 1994-95 time frame.

NRC has not been working as long, however, to develop license renewal regulations. NRC staff began work in this area in 1986 and have identified three regulatory options available for license renewal. The staff believe the criteria NRC will use to evaluate each request for license renewal is the central regulatory issue that could significantly influence each utility's decision regarding continued nuclear plant operations. Much of the research and analyses that utilities are doing or plan to do could depend on the option NRC selects. Utilities' efforts to prepare for the license renewal process could be better focused if NRC quickly identifies the option it will use to evaluate each application.

In addition, NRC has identified many technical, environmental, and procedural issues that need to be resolved. Any of these issues could have a major impact on the license renewal process. For example, NRC has not determined the method it will use to verify that an older plant can continue to operate safely in light of technical advances and the operating conditions the plant has experienced during the years it has been in service. Some of these issues, such as the extent of public hearings and the amount of environmental information that will be required, were in question when the plants were initially licensed. Although these types of issues have been identified, NRC has made little progress in reaching definitive regulatory conclusions.

The efforts expended to date by DOE and the industry have been on their own initiative with little or no regulatory guidance from NRC. We do not believe that this approach is in the best interest of ensuring adequate electricity supplies in the future. We also believe this approach becomes increasingly less desirable as the time to decide on extending plant life draws closer for each utility. Given the important role electricity plays in the economic growth and progress of this country, we do not believe life extension issues should be allowed to evolve in a regulatory vacuum.

Recommendations

NRC, DOE, and the industry have done substantial work to assess the feasibility of operating nuclear plants longer than 40 years. However, NRC still needs to resolve many important license renewal questions. Since many utilities will have to decide in the early 1990s whether to continue operating older nuclear plants or construct new generating capacity, NRC needs to use available information to begin making regulatory decisions. To better focus industry and government efforts, we recommend that the Chairman, NRC,

- accelerate the schedule for developing license renewal regulations and stipulate the basis that will be used to evaluate renewal applications and the types of records, engineering analyses, and other historical information needed to support a request for continued operations, and
- resolve the outstanding technical, environmental, and procedural uncertainties.

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