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AN OVERVIEW OF THE UNITED STATES DEPARTMENT OF ENERGY PLANT LIFETIME IMPROVEMENT PROGRAM

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ABSTRACT

Today, 109 nuclear power plants provide over 20 percent of the electrical energy generated in the U.S. The operating license of the first of these plants will expire in the year 2000; one third of the operating licenses will expire by 2010 and the remaining plant licenses are scheduled to expire by 2033. The National Energy Strategy assumes that 70 percent of these plants will continue to operate beyond their current license expiration to assist in ensuring an adequate, diverse, and environmentally acceptable energy supply for economic growth. In order to preserve this energy resource in the U.S. three major tasks must be successfully completed: (1) establishment of the regulations, technical standards, and procedures for the preparation and review of a license renewal application; (2) development, verification, and validation of the various technical criteria and bases for needed monitoring, refurbishment, or replacement of plant equipment; and (3) demonstration of the regulatory process.

Since 1985, the U.S. Department of Energy (DOE) has been working with the nuclear industry and the U.S. Nuclear Regulatory Commission (NRC) to establish and demonstrate the option to extend the life of nuclear power plants through the renewal of operating licenses. This paper focuses primarily on DOE's Plant Lifetime Improvement (PLIM) Program efforts to develop the technical criteria and bases for effective aging management and lifetime improvement for continued operation of nuclear power plants.

This paper describes current projects to resolve generic technical issues, including degradation of long-lived components, reactor pressure vessel (RPV) embrittlement management approaches, and analytical methodologies to characterize RPV integrity.

THE ROLE AND IMPORTANCE OF NUCLEAR PLANT LIFE EXTENSION

In February 1991, the U.S. National Energy Strategy (NES), a comprehensive blueprint for U.S. energy security [1], was released. The NES seeks to diversify U.S. energy sources in order to encourage efficiency and conservation, spur competition across energy sectors, reduce reliance on imported oil, and promote greater investment and collaborative research in advanced technologies. In particular, the NES identifies an important and continuing role for nuclear energy as part of a balanced array of energy sources for meeting U.S. energy needs, especially the growing demand for electricity.

DISCLAIMER

This strategy is important because electricity is expected to increase its share as a primary U.S. energy source from 36 percent today to 41 percent by 2010, and to 46 percent by 2030 [2]. Based on expectations for growth in gross national product and other economic indicators, the NES projects that the U.S. will need about 200,000 megawatts of additional generating capacity by 2010.

This estimate assumes aggressive and successful conservation efforts. Should such efforts fail or fall short, significant additional capacity will be required, together with additional replacement capacity for aging coal plants. The NES clearly demonstrates that nuclear power is a needed future energy source.

In 1992, nuclear power supplied 22.3 percent of U.S. electrical generation [3] and displaced about 2.5 million barrels of oil per day. Worldwide, the availability of a strong nuclear program offsets the equivalent of about 8 million barrels of oil per day with the attendant benefits of lower oil prices and energy security. Nuclear power plants provide a reliable, economic, and clean source of electricity for U.S. consumers and industry.

As the U.S. strives to meet rising electricity demand, sustain economic growth and provide a cleaner, healthier environment, we cannot afford to prematurely retire 109 operating nuclear power plants. Licenses for approximately 35 plants are currently due to expire between 2000 and 2012. Renewing the licenses of existing nuclear power plants can help meet U.S. energy needs by deferring the need to build new power plants. The NES estimates that, by 2030, approximately 66,000 megawatts of new construction can be deferred in this manner. This is equivalent to about 60 large, new plants. Moreover, the cost of safely extending the operating life of an existing plant can be much lower than the cost of a new plant [4]. If the U.S. is successful in achieving the NES goal for license renewal, energy costs can be significantly reduced. Therefore, it is prudent to protect and extend the availability of energy from the investment already made in nuclear power.

DOE PLANT LIFETIME IMPROVEMENT PROGRAM

Commercial U.S. nuclear generating units are licensed by the NRC for 40 years. The origin of this fixed license period was based on the capital amortization schedule for nuclear power plants and was not necessarily related to the useful life of the facility [5]. Plant refurbishment and extended life have already been demonstrated in non-nuclear generating facilities and have been shown to be economically desirable and technically feasible for nuclear generating plants [6].

To facilitate continued operation of U.S. nuclear plants beyond the current license term, the following three major tasks must be successfully completed:

- establishment of regulations, technical standards, and procedures for the preparation and review of License Renewal Applications (LRAs);

- development of technical criteria and bases for monitoring, refurbishing or replacing plant equipment; and

- demonstration of the regulatory process by a plant obtaining a renewed license.

Since 1985, the DOE Plant Lifetime Improvement (PLIM) Program has been cooperating in cost-shared efforts with the nuclear industry to address these three major tasks. This national program includes the Nuclear Management and Resources Council (NUMARC), the Electric Power Research Institute (EPRI), lead plant utilities, codes and standards-making organizations and reactor manufacturers.

An aggressive program to develop the technical bases for license renewal has also been underway. As an important first step in the DOE cooperative research program, pilot plant feasibility evaluations on Surry Unit 1, a pressurized water reactor (PWR) of Westinghouse design, and Monticello, a boiling water reactor (BWR) of General Electric design were completed in 1987 [5,7]. These pilot studies involved identification of the major degradation mechanisms and estimation of the useful remaining life for the plant system, structure, or component. The major repair, replacement, or maintenance activities that would be required for life extension were identified and cost estimates were developed. Additional tests, inspections, and research and development efforts needed to enhance the feasibility of achieving life extension in a cost-effective manner were identified.

Several technical projects are currently underway in the DOE PLIM Program to achieve life extension through license renewal. These projects, based on and consistent with the three major tasks previously stated, are organized into the following program elements:

- Materials, Inspection and Monitoring Research & Development

- Equipment Aging Evaluations

- Lead Plant Demonstration Activities

- Codes & Standards and Regulatory Process Development

- General Management and Technology Transfer

These program elements are described in detail below.

Materials, Inspection and Monitoring Research & Development

The materials research and development projects consist of a series of interrelated tasks which generally emphasize phenomena related to steel and organic materials degradation of long-lived components. The project objectives include:

- assess and document the understanding of degradation mechanisms in light water reactors (LWRs),
- determine the impact of degradation on component function,
- assess component life expectancy and develop life assessment strategies, and
- develop technology to extend/optimize service life.

The inspection and monitoring projects support the establishment of technical standards and criteria, or the use of the technical basis developed in an Industry Report (IR), described in the next section, or lead plant process. This may require, for example, diagnostic systems which provide real-time status of critical equipment or sensors which measure critical parameters required to monitor a system state or a degradation mechanism mitigation parameter.

The following projects are currently underway:

1. RPV Flaw Distribution Development Methodology - Improving the life prediction methods and strategies for RPVs is an important aspect in providing realistic characterizations of RPV integrity after long-term exposure to neutron irradiation. To facilitate the improved characterization of RPV integrity, a methodology has been developed to obtain estimates of the RPV flaw size distribution and flaw density using RPV inservice inspection (ISI) results [8,9]. The new methodology permits, for the first time, the analysis of vessel-specific ISI data for development of a vessel-specific flaw distribution. Unlike conventional histogram approaches, the new methodology can be used to develop an acceptable flaw distribution from an inspection results database containing very few flaws. Furthermore, the methodology uses a shape-flexible statistical distribution (Weibull) model of flaw size and incorporates the flaw detection reliability, flaw sizing accuracy and flaw detection threshold into the analysis. A procedure has also been developed to provide a preliminary quantitative assessment of the accuracy of the flaw distribution method in the analysis of ISI data [10]. In addition, the developed methodology can be used as justification for defining a vessel-specific "reference" flaw for calculating pressure-temperature limit curves in a deterministic evaluation of PWR reactor vessels [10].

2. Thermal Annealing Technology Development - The recovery of RPV material properties reduced due to long-term exposure to neutron irradiation can be achieved through a thermal annealing treatment. This technique to extend RPV life has been successfully demonstrated in the former Soviet Union and by the U.S. Navy and provides a complementary approach to analytical methodologies to ensure RPV integrity. Demonstrating the technical and institutional feasibility of annealing commercial U.S. RPVs is being pursued through a cooperative effort between the nuclear industry and the DOE PLIM Program. Presently, two separate activities are under way.

a. Annealing Thermal/Stress Model Benchmarking Experiments - This activity involves experiments at Sandia National Laboratories' Radiant Heat Facility to provide heat transfer boundary condition inputs to analytical models. The experiments include extensive characterization of material response during annealing simulations performed on a section of RPV material.

b. Annealing Reembrittlement Data Base Development - Currently, limited information is available in the industry regarding the re-embrittlement behavior of RPV materials. This activity focuses on the characterization of RPV material re-embrittlement behavior as a function of irradiated fluence, annealing temperature, and time at temperature to ultimately determine optimum annealing parameters for maximum material property recovery.

3. Subsize Specimen Methodology Development - The continued operation of nuclear power plants will depend, in part, on a thorough characterization of RPV material properties during the original license period and through extended operation. This can be accomplished through materials surveillance programs. An effective surveillance program, however, will require large amounts of archive vessel materials which will be in short supply for certain older vessels. The impact of a material shortage can be lessened through the use of miniature specimens. In addition, if a licensee chooses to anneal its RPV as an embrittlement management strategy, verification of material property recovery may be required. This can be accomplished through testing of miniature specimens removed from the RPV.

   A proper correlation between miniature and full-size specimens must be demonstrated in order to realize these benefits. This project involves the development of an appropriate correlation methodology to estimate full-size Charpy V-notch impact results (upper shelf energy and ductile-to-brittle-transition temperature) from the testing of one-half and one-third size Charpy specimens. The developed methodology will be applicable in the ductile and brittle regime, typical of originally ductile RPV materials that embrittle after long-term exposure to neutron radiation. Preliminary results appear promising [11].

4. Life Prediction Methods for Cable Aging - Improvements in the life prediction of electrical cable materials is being supported through development of a "combined-environments" life prediction methodology that describes cable aging behavior in combined radiation and thermal environments [12]. This methodology has been successfully applied to predict cable degradation for several types of polymeric cable materials [12,13,14]. Further validation of this methodology is being pursued through comparison with natural aging experience.

5. On-Line Stress Corrosion Cracking (SCC) Monitor - On-line SCC monitors are used to assess the potential for stress corrosion crack propagation in RPV internals.

Present on-line SCC monitor probes have historically demonstrated poor performance for the following reasons:

- Size limitations of monitors have required difficult design considerations,
- Harsh environment, and
- Inaccurate modeling of intergranular SCC (IGSCC) phenomenon and crack growth to allow for simulation through monitor development.

The DOE PLIM Program is providing assistance to a General Electric Company (GE) effort to improve the reliability of their in-core SCC monitors. DOE PLIM Program activities include:

- development of an analytical model that probabilistically examines the influence of microstructural heterogeneity on IGSCC to assist development of a revised GE monitor design,
- development of experimental methods to characterize grain boundary sensitization levels and to benchmark the analytical model, and
- finite element modeling of revised SCC monitor designs.

GE is pursuing parallel activities to improve the reliability of their in-core SCC monitor design. Results of the DOE PLIM Program activities will being shared with GE in order to facilitate an improved SCC monitor design.

Equipment Aging Evaluations

Projects required to develop generic technical standards, criteria, and scope for license renewal include the following equipment aging evaluations:

1. Industry Reports - The Nuclear Management and Resources Council (NUMARC) License Renewal IRs generically perform detailed technical evaluations of ten groupings of critical systems, structures and components originally identified, in part, through the pilot plant program. Initial drafts of the IRs were submitted to the NRC during 1991 and 1992. NRC/industry meetings have been held to discuss/resolve comments and pursue formal NRC approval for each IR. As generic documents, IRs were used as the basis for industry-wide negotiation with the NRC rather than relying on ad-hoc, plant-specific negotiation. The IRs and NRC review process are expected to lead to more predictable license renewal criteria and regulations. In addition, consensus industry standards and criteria for license renewal can be developed based on the technical evaluations. The ten reports are:

    a. BWR Primary Containment
    b. BWR Reactor Coolant Pressure Boundary
    c. BWR Reactor Pressure Vessel
    d. BWR Reactor Pressure Vessel Internals
    e. PWR Containment
    f. PWR Reactor Coolant System

g. PWR Reactor Pressure Vessel
h. PWR Reactor Pressure Vessel Internals
i. Class I Structures
j. Low Voltage, Environmentally Qualified Cables

2. Aging Management Guidelines (AMGs) - AMGs provide guidance on performing detailed evaluations of aging mechanisms and aging management strategies applicable to critical equipment groups beyond those addressed in the Industry Reports. AMGs for the following groups of components are under development:

- Batteries (Safety-Related DC Power)
- Battery Chargers, Inverters, Uninterruptible Power Supplies
- Heat Exchangers
- Motor Control Centers
- Pumps
- Switchgear
- Transformers

The Electrical Switchgear AMG was published and distributed in July 1993. The remaining AMGs will be published and distributed in late 1993.

Lead Plant Demonstration Activities

Having demonstrated the technical feasibility and economic desirability of extending plant service life through license renewal with the pilot plant studies, two lead plants were chosen to demonstrate the license renewal process by preparing and submitting LRAs. Yankee Atomic Electric Company's (YAEC) Yankee Rowe plant was chosen as the PWR lead plant and Northern States Power's (NSP) Monticello plant was chosen as the BWR lead plant. The work performed provides the plant-specific technical bases and the operations, maintenance, and inspection programs information necessary to support the LRA. The demonstration activity also provides for the development of the LRA format in cooperation with the NRC. In addition the demonstration activity provides the applicants with the required supporting documentation and supports the defense of the LRA submittal and response to NRC questions or concerns which arise during NRC LRA review.

In February 1992, YAEC announced the permanent shutdown of the Yankee Rowe plant. The primary factors in this decision included:

- recessionary economics during present-license operation (i.e., abundant low cost power was available starting in late 1991 that was not available in 1988 at the start of the Yankee Rowe License Renewal project), and

- uncertain regulatory requirements related to reactor pressure vessel integrity issues.

A project summary report is in preparation to document the license renewal activities performed at Yankee Rowe prior to plant shutdown. This report will be publicly available in September 1993.

In November 1992, NSP decided to complete the Monticello LRA but indefinitely defer the decision to submit it to the NRC. NSP cited four reasons for "holding" the submittal, which was scheduled for December 15, 1992:

- uncertainty regarding high level waste disposal,
- license renewal regulatory uncertainty,
- high Operation & Maintenance (O&M) costs, and
- . escalating low level waste disposal costs.

NSP's decision to "hold" the LRA submittal did not impact the effort to complete the technical and licensing work required to quickly restart the project when significant progress to resolve the issues noted above can be measured. The Monticello Environmental Report was essentially completed in January 1993. The LRA and Technical Support Documents were essentially completed in March 1993.

NSP will be evaluating the LRA against recently proposed rule changes to Title 10 of the Code of Federal Regulations, Part 54 (10 CFR Part 54), "Requirements for Renewal of Operating Licenses for Nuclear Power Plants," and will be maintaining the LRA to reflect plant configuration changes and improved aging management strategies. Inspection, maintenance and surveillance procedure changes and design, replacement, and other activities required to implement the commitments in the LRA are being investigated.

NSP, DOE and EPRI sponsored a License Renewal Workshop in July 1993 to discuss key insights from the Monticello Lead Plant demonstration project. Additional information regarding the status and accomplishments of the Monticello license renewal project is presented elsewhere [15].

Additional license renewal demonstration activities are also underway in the U.S. nuclear industry. The Baltimore Gas & Electric's (BG&E) Calvert Cliffs' Life Cycle Management program has been very active for a number of years. In 1993 BG&E plans to begin submitting topical reports as they work towards a License Renewal Application in 1997. In 1992, the Babcock & Wilcox Owners' Group (B&WOG) initiated a significant effort to prepare a generic License Renewal Application for the seven operating B&W units; Arkansas Nuclear One Unit 1, Crystal River, Davis Besse, Oconee Units 1, 2 and 3, and Three Mile Island Unit 1. In early 1993, the Westinghouse Owners' Group (WOG) initiated a license renewal effort for all Westinghouse plants similar to the B&WOG program. In addition, the BWR Owner's Group (BWROG) and the Combustion Engineering Owner's Group (CEOG) are in the process of developing license renewal program plans.

Codes & Standards and Regulatory Process Development

The following items are important factors in a U.S. utility's decision to pursue license renewal and obtain a renewed operating license:

- economic viability,
- Codes & Standards for aging concerns, and
- safety regulatory processes compliance.

These projects support the development and establishment of safety regulatory processes, including interaction with the NRC. Economic viability is another key element. Codes & Standards, while important to the success of license renewal and continued plant operation, are secondary to safety regulatory and economic considerations. These individual elements are described below.

1. Economic Viability - A decision to pursue nuclear plant life extension is based on economic evaluations that are an integral part of a utilities' electrical supply strategy. A complex mix of national, regional and local utility constraints must be considered in these evaluations. For national planning purposes, national and regional economic conditions must be analyzed to identify federal economic regulatory positions that will enhance the life extension option. The DOE PLIM Program has previously assessed the costs and benefits of nuclear power plant life extension [4]. Efforts are underway to update this previous effort and address financial and license renewal cost estimate changes.

2. Codes & Standards - Detailed technical evaluations of critical equipment may result in recommendations for codes and standards (C&S) modifications. Codes and Standards requirements are often incorporated into rules and regulations developed by the NRC. Thus, close cooperation with and participation in C&S activities is important. This will ensure that C&S decisions affecting license renewal are based on available technical research by nuclear utilities, EPRI, DOE and other organizations.

   The DOE PLIM Program also continues to actively support participation in numerous C&S groups including:

   - American Society of Mechanical Engineers (ASME) Section XI
   - American Society for Testing and Materials (ASTM)
   - Institute of Electrical and Electronics Engineers (IEEE)

   In addition, the DOE PLIM Program actively supports participation in several international organizations including the International Atomic Energy Agency and the Organisation for Economic Co-Operation and Development Nuclear Energy Agency.

3. Regulatory Process Compliance - The needs in this area are defined by the NRC's rulemaking activities and implementing documents (e.g., the license renewal Regulatory Guide, Standard Review Plan, instructions and procedures). Activities include reviewing NRC documents; preparing DOE position papers on important NRC policies, regulations and procedures that will establish the license renewal process; officially responding to NRC comment requests; and ensuring effective communication with all NRC management levels on key regulatory issues.

General Management and Technology Transfer

This program element provides support for technology transfer, coordination of the PLIM Program, and additional efforts to monitor the activities of both utility and Owners' Group License Renewal activities related to, but not funded by, the PLIM Program. Overall technical management support is provided by the DOE LWR Technology Center @ Sandia National Laboratories. Industry, utility workshop/seminar, and international cooperative program support is provided.

CONCLUSIONS

The DOE PLIM Program, through the various program elements described above, is pursuing its objective to establish U.S. technical requirements and procedures for license renewal and demonstrate the license renewal process. By working cooperatively with industry, DOE is contributing to the technology and information needed to establish the technical basis for safe operation during the license renewal term. In addition, the DOE PLIM Program is pursuing efforts to stimulate license renewal activities at a large number of utilities, preserve the license renewal option, and support demonstration efforts to verify and validate the regulatory process.

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