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# AN OVERVIEW OF THE U.S. DEPARTMENT OF ENERGY PLANT LIFETIME IMPROVEMENT PROGRAM

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Summary

*This paper provides a brief summary of the U.S. Department of Energy's (USDOE's) cooperative effort with the nuclear industry to develop technology to manage the effects of material degradation in systems, structures and components (SSCs) that impact plant safety or can significantly improve plant performance/economics and to establish and demonstrate the license renewal process. Also included are efforts to reduce decontamination/decommission costs, and reduce the uncertainty in long-term service-life decision making.*

*During 1995, the Plant Lifetime Improvement (PLIM) Program was renamed the Commercial Operating Light Water Reactor (COLWR) Programs. The COLWR Program activities are focused on sustaining the LWR option for domestic electricity generation by supporting operation of existing LWRs as long as they are safe, efficient, and economical. The status of the key projects is discussed in this paper.*

## 1.0 BACKGROUND

In 1994 nuclear energy supplied more than 20 percent of the total electricity generated in the U.S. and displaced the equivalent of ~2.5 million barrels per day of oil. Worldwide, nuclear plants supplied 17 percent of the total electricity generated and offset the equivalent of ~8 million barrels per day of oil with the added benefits of lower fuel costs, energy security, and reduced environmental emissions. The U.S. is increasingly becoming electrified. Virtually every year, U.S. utilities must meet a demand for electricity that is greater than the previous year's demand. Electricity is expected to increase its share as a primary energy source from 36 percent today to 40 percent by 2010, and to 46 percent by 2030 [1,2].

Nuclear power can contribute to the supply of safe, reliable, economic, and environmentally acceptable electric energy for the nation as the U.S. moves into the twenty-first century. However, the availability of this source of energy is threatened as utilities face difficult decisions concerning the continued operation of their existing nuclear generating units. The concerns involve increasing requirements for electrical energy and competing policies on energy efficiency, supply security, environmental, safety, and economic regulation.

If the U.S. is to meet the rising demand for electricity, sustain and expand economic growth, and provide a cleaner and healthier environment, it cannot allow premature shutdown of more than one hundred safe, reliable, and economic operating nuclear power plants.

To avoid premature shutdown of the operating plants, the USDOE is conducting cooperative efforts with the U.S. and international nuclear industry organizations to develop technology to manage the effects of material degradation on key plant systems, structures, and components (SSCs) that impact plant safety or which can significantly improve plant performance/economics, and to establish and demonstrate the license renewal process. Also included are efforts to reduce decontamination/decommission costs and reduce the uncertainty in long-term service-life decision making.

## 2.0 USDOE COMMERCIAL OPERATING LIGHT WATER REACTOR (COLWR) PROGRAM

The COLWR Program activities are supporting continued operation of existing nuclear power plants as long as they are safe, efficient, and economical. Major COLWR Program elements discussed in this paper include:

- 2.1 Reactor pressure vessel (RPV) integrity (including vessel annealing, vessel internals, and related projects)
- 2.2 Equipment aging evaluations (including the industry reports and aging management guidelines)
- 2.3 Cable aging research (including combined thermal and radiation environments)
- 2.4 Instrumentation and controls (I&C) upgrade

Additional details for each of these elements are provided below:

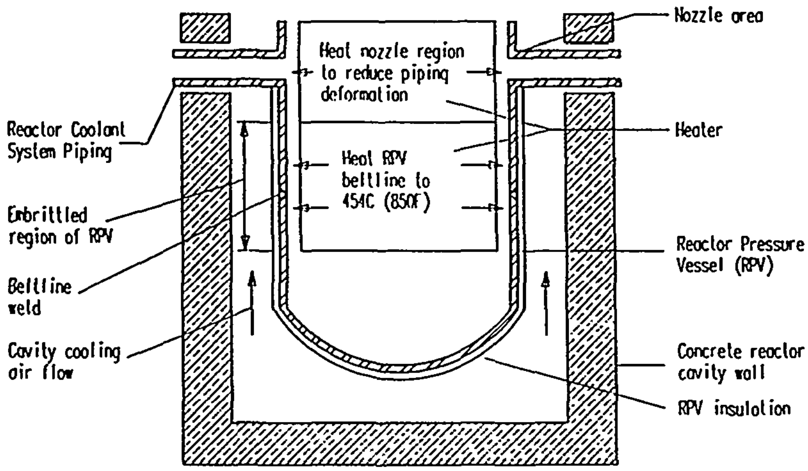
### 2.1 REACTOR PRESSURE VESSEL INTEGRITY

Maintaining reactor pressure vessel (RPV) integrity is critical to the continued safe and economic operation of commercial light water reactors. The USDOE RPV integrity programs include the RPV annealing program, RPV internals projects, and related materials research and development (R&D) projects.

#### 2.1.1 RPV Annealing Program

Reactor pressure vessel embrittlement caused by neutron irradiation may become a significant issue for some pressurized water reactor (PWR) plants. Given the significance of RPV safety and existing U.S. Nuclear Regulatory Commission (USNRC) requirements, this issue has the potential to impact continued operation of a significant number of the operating plants in the United States. Based on the current USNRC requirements for assessing RPV embrittlement, approximately 20 of 109 operating plants <u>may</u> exceed the USNRC's pressurized thermal shock (PTS) screening criteria during a 20 year license renewal term.

RPV material properties affected by long-term irradiation can be recovered through a thermal annealing treatment (see Figure 1). Thirteen Russian-designed RPVs and several U.S. Navy RPVs have been annealed. However, owing to differences between Russian/Naval and U.S. plant designs and regulatory requirements, uncertainty exists regarding applicability of these anneals to U.S. plants. Even though preliminary studies indicate that annealing U.S. RPVs is viable [3,4], utilities have stated that an annealing demonstration of a U.S. RPV is a prerequisite to gain confidence that annealing is an economically viable option that can adequately address technical and institutional issues [5,6].




Schematic of PWR Reactor Pressure Vessel Annealing

Figure 1

The USDOE, with technical support from Sandia National Laboratories, has initiated a three phase program to establish a viable annealing option for U.S. plants. The phases are described below.

Phase 1 Appropriate experimental data will be gathered and/or generated with a focus on:

a. Overall system and component thermal response: Determine the behavior of the RPV, reactor coolant system (RCS) piping, concrete reactor cavity, RPV support structures, other components during an anneal, and verify RPV dimensional stability during and after the annealing process.

b. Material property recovery: Measure material condition before and after an anneal. Determine the rate of radiation-induced reembrittlement and recovery from anneal.

Phase 2 Experimental data will be evaluated and used to support the development of regulatory requirements, Codes and standards, and for reviewing/understanding those requirements.

Phase 3a. First commercial anneal by a plant operator, including appropriate USNRC review and approval, and restart of the unit.

Phase 3b. Support development of requirements to optimize postanneal operability of RPVs (e.g., RPV inspections, operational changes).

The current USDOE focus is on Phase 1a. This phase has been titled an "Annealing Demonstration Project (ADP)," and is described below. An overview of the other phases and their relationship to an ADP is provided below:

1. Other active projects are addressing material property recovery issues (Phase 1b). One of the key requirements associated with both Phases 1a and 1b is the need to produce technical results suitable for input into Phase 2 efforts.

2. The USNRC has prepared a draft of the annealing Rule and Regulatory Guide (Phase 2), which discusses the time-temperature profile, kind of equipment to be used, and guidance regarding requalification of the RPV. An ADP must produce results that can be used as a basis for USDOE/industry review and comment on the proposed USNRC Rule and Regulatory Guide. Similar to the Rule and Regulatory Guide, industry consensus Codes and standards (ASME, ANSI) are being or will be developed (Phase 2).

3. The effort described in Phase 3a, a "commercial" anneal followed by appropriate USNRC review and approval to restart, is dependent on previous phases and therefore is not well defined at this time. Post-annealing operability issues (Phase 3b) will be better defined following Phases 2 and 3a.

*OVERVIEW OF ANNEALING DEMONSTRATION PROJECT (Phase 1a)*

The proposed ADP is structured to take advantage of previous experience and ongoing projects. The project is of a cooperative, cost-shared nature with the participation of many important stakeholders (e.g., utilities and major utility-supported R&D organizations). The goals of the ADP are:

1. Provide and benchmark with experimental data a thermal/stress model to predict the response of key elements.
2. Verify the dimensional stability of critical internal and external RPV dimensions before and after the ADP and verify the overall dimensional stability of the RPV. RPV internals must fit properly after the anneal. RCS piping must not suffer adverse effects.
3. Provide a full reporting of all results and data to provide technical basis for USDOE input for the development of draft annealing Rule, Regulatory Guide, and Codes and Standards.
4. Gain insights on worker radiation exposure related to insulation and placement of annealing equipment (e.g., furnaces and instrumentation and control systems).

*STATUS OF THE ANNEALING DEMONSTRATION PROJECT*

Two ADP contracts were awarded in May 1995. The projects will be performed in parallel and each will take two years to complete. The two project teams are:

1. The MPR team composed of MPR Associates, Inc., MOHT-OTJIG RM ("MOHT"), the Russian Annealing Consortium, and B&W Nuclear Technologies.
2. The ASME Research team composed of the American Society of Mechanical Engineers Center for Research and Technology Development, Westinghouse Electric Corp., Cooperheat, Inc., and other subcontractors.

The MPR team will perform their ADP at Midland, a B&W skirt-supported 2-loop design. The ASME team will perform their ADP at Marble Hill, a 4-loop, nozzle supported Westinghouse design. The Midland site was more than 90 percent complete when construction was halted, while the Marble Hill site was about 65 percent complete. The MPR team will use a MOHT-designed electric resistance furnace to heat the RPV, while the ASME team has chosen to use a new method called "indirect gas-fired heating," pioneered by Cooperheat.

The USDOE has entered into a memorandum of understanding (MOU) with the USNRC for information exchange and cooperation on the RPV annealing program. Consumers Power Co. (CPCo) has indicated to the USNRC that they will submit an application to anneal the Palisades RPV during 1998. USDOE is cooperating and coordinating its activities with CPCo.

### 2.1.2 RPV Internals

Stress corrosion cracking (SCC) has been identified as a major technical issue for RPV internal components. The program is pursuing resolution of RPV internals technical issues through cooperation with various nuclear industry elements. Current efforts are focused on the resolution of issues associated with the characterization and prediction of the behavior of materials exposed to SCC environment. The following projects are underway:

*STRESS CORROSION CRACKING MODEL DEVELOPMENT*

The objective of this effort is to develop a probabilistic computer model to accurately describe intergranular SCC (grain boundary sensitization and stress distribution). This model will be used by industry to resolve issues of long-term internals degradation through (1) better estimation of remaining component life, and (2) quantification of SCC crack growth rate for internals to predict future maintenance activities (applicable to BWRs and PWRs). Specimen testing to benchmark the developed model is in progress. This effort is being coordinated with the boiling water reactor vessel internals project (BWRVIP) and the Electric Power Research Institute (EPRI).

*BWR CORE SHROUD CHARACTERIZATION*

The objective of this effort is to characterize residual stress distribution and sensitization of BWR core shroud materials by testing of samples removed from actual BWR core shrouds. Field measurements of fabrication residual stresses were performed on an unirradiated core shroud located at Grand Gulf. Measurements were taken directly on the weld fusion line, in the heat affected zone (HAZ), and adjacent to the HAZ for all circumferential welds on the core shroud (a total of five welds). Residual stresses were characterized for the inner- and outer-diameter surfaces at two locations around the circumference of the core shroud. Additional samples will be removed from the core shroud and forwarded to Sandia for degree of sensitization measurements (susceptibility to SCC) and to Oak Ridge National Laboratory (ORNL) for neutron diffraction studies to determine through-thickness residual stress. This effort is being coordinated with the BWRVIP and EPRI. A summary of the information will be provided to the BWRVIP for inclusion in a crack growth topical report being prepared by the BWRVIP.

*NOBLE METAL CHEMICAL ADDITION PROJECT*

The objective of this effort is to demonstrate an advanced mitigation technique developed by General Electric to resolve SCC issues associated with BWR internal components by adding a noble metals (e.g., Platinum/Rhodium) in solution form to enhance the effectiveness of hydrogen water chemistry and reduce worker exposure. This is a cooperative effort with the BWR Utilities and EPRI.

### 2.1.3 Related Materials R&D Projects

Several other efforts are underway to resolve technical issues associated with RPV integrity including nondestructive examination method to characterize embrittlement, subsize specimen development, and flaw size/distribution codification project, to characterize mechanical properties. These efforts are summarized below.

*NONDESTRUCTIVE EXAMINATION METHODS TO CHARACTERIZE EMBRITTLEMENT*

The objective of this project is to use existing ultrasonic in service inspection technology to nondestructively measure (insitu) mechanical properties of RPV materials. This technique could be used to verify material property recovery during and following a thermal annealing treatment and obviate the need for material removal. Feasibility has been demonstrated. Irradiated materials are being pursued to perform ultrasonic measurements before and after annealing.

*SUBSIZE SPECIMEN DEVELOPMENT*

Continued operation (following thermal annealing or license renewal) will require additional material surveillance to monitor RPV integrity. The lack of available archive material and the potential need to remove material from the RPV for analysis can be minimized or eliminated by successful development of appropriate subsize mechanical testing specimens and the correlation of subsize specimen testing results with full-size specimen behavior. This project is pursuing the development of the optimum subsize Charpy V-notch specimen and a correlation methodology for upper shelf energy and ductile-brittle transition temperature. A correlation methodology has been developed for subsize Charpy samples [7]. The optimum sample design has been characterized through dynamic finite element analyses. Project documentation is in progress. The USDOE's LWR Technology Center at Sandia is also coordinating the American Society of Testing and Materials cross-comparison exercise on the benchmarking of testing techniques for subsize specimen. A number of countries are participating in this cross-comparison exercise.

*FLAW DISTRIBUTION*

Improving the life prediction methods and strategies for RPVs is an important aspect in providing realistic characterizations of RPV integrity. 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 in service 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 a database of inspection results containing very few flaws. Furthermore, the methodology uses a shape-flexible statistical distribution (Weibull) model of flaw size and incorporates 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 integrity [10]. The current effort is aimed at codifying results from the flaw distribution project which developed a methodology to prepare a vessel-specific flaw distribution from in-service inspection results.

## 2.2 EQUIPMENT AGING EVALUATIONS

The projects needed to develop generic technical standards, criteria, and scope for license renewal include the following:

### 2.2.1 Industry Reports (IRs)

License renewal IRs contain generic technical evaluations of ten groupings of critical systems, structures and components that are considered important to license renewal. These IRs have been submitted to the USNRC. There are ten IRs, eight covering Containment, Reactor Coolant Pressure Boundary, RPV, RPV Internals (separate report for BWRs and PWRs), and one for Class I Structures, and one for Low-Voltage, Environmentally-Qualified Cables.

The IRs concentrate on "long-lived" passive SSCs that are important to operation beyond 40 years. Of the 1100 questions raised by the USNRC, 84 unresolved questions require further technical resolution.

The 84 unresolved questions are associated with fatigue (environmental effects, updated fatigue analysis, transient definitions, enveloping actual transients), environmental qualification, focused inspection, inspection adequacy, thermal aging of cast austenitic stainless steel (CASS) components, and irradiation embrittlement.

The USNRC plans to incorporate the technical agreements into the License Renewal Regulatory Guide and Standard Review Plan.

### 2.2.2 Aging Management Guidelines (AMGs)

AMGs contain detailed evaluations of aging mechanisms and aging management strategies applicable to critical equipment groups beyond those addressed in the IRs. AMGs are based on industry information (e.g., the Institute for Nuclear Power Operation's Nuclear Plant Reliability Data System, INPO NPRDS) and utility practices, and provide enhanced approaches for managing age-related degradation. The intended users are plant system engineers and maintenance personnel.

The USDOE coordinates this effort with industry through EPRI and host utilities. AMGs for batteries (safety-related DC power), battery chargers, inverters, uninterruptible power supplies, heat exchangers, motor control centers, pumps, switchgear, and transformers have been published.

Two draft AMGs (electrical cables & terminations and tanks & pools) are expected to be published by October 1995. Two more AMGs (containment penetrations and non-reactor pressure boundary piping and tubing) have just been started.

There are numerous detailed results in each AMG; however, overall, AMGs show that:

a. Existing knowledge is sufficient to identify and describe applicable aging mechanisms; no new aging mechanisms were discovered.

b. Comparisons of aging mechanism evaluations in AMGs and USNRC's nuclear plant aging research (NPAR) program reports are generally in agreement.

c. Qualitatively, NPRDS and licensee event report (LER) data show similar results, but not quantitatively. However, existing data from NPRDS or LER databases are not sufficiently complete or accurate to be able to accurately predict mean time between failures.

d. In most cases, existing programs are effective in managing aging, but in a few cases, program enhancements are desirable.

## 2.3 CABLE AGING RESEARCH (including combined thermal and radiation environments)

Electrical cable qualification beyond 40 years is required for license renewal. The combined environments methodology describes cable aging behavior in combined radiation and thermal environments [11]. This methodology has been successfully used to predict the degradation of several types of polymeric cable material [11,12,13] and needs to be extended to as many other materials as possible. Conservative cable life predictions based on Arrhenius methodology will be validated for many thermally sensitive materials. The objectives of the ongoing projects are to further test the applicability of the "combined environments" accelerated aging methodology to predict the condition of naturally aged, commonly used cable materials; to check the sufficiency and conservatism of the Arrhenius methodology for predicting cable lifetime in thermal-dominated environments; and to develop nondestructive examination techniques that can help confirm a cable system's ability to perform its electrical function under accident conditions.

A new facility and facility upgrades are under development at Sandia National Laboratories which will significantly expand the experimental capability to resolve these issues. Key projects are described below.

### 2.3.1 Naturally Aged Cable Studies

Naturally aged cables, with up to 32 years of aging between 1960 and 1992 will be used to benchmark the "combined environments" methodology in a manner that minimizes the time extrapolation (i.e., the time extrapolation is a critical variable) and addresses the regulatory agency concerns regarding accelerated aging. Sandia is testing cables that were subject to significant thermal and/or radiation aging in the as-received condition (natural aging). In addition, matching cables from low-temperature, low-radiation areas will be subjected to accelerated (laboratory) aging. A formal report documenting this study is expected to be published by August 1996.

### 2.3.2 Laboratory Aged Cable Studies

Efforts to develop "combined environments" methodology and to provide the scientific and engineering bases for material behavior continue. Recently, Sandia demonstrated the initial feasibility of performing low temperature activation energy measurements, at temperatures as low as room temperature (which minimizes the temperature extrapolation concern). In addition, Sandia documented the initial concept of polymer annealing behavior in semi-crystalline materials (ethylene-propylene rubber (EPR), cross-linked polyethylene (XLPE), which must be understood in more detail. Laboratory-aged cable studies will continue over the next two to three years; results will be published as sufficient data is collected.

### 2.3.3 Development of a Nondestructive Examination Technique

Sandia is preparing a facility that can be used to develop and proof test electrical nondestructive examination techniques that are sufficiently robust to provide reasonable assurance that a cable system will perform its design function under accident conditions. The facility will be available for Phase I testing in October 1995.

Sandia initiated studies to develop a proposed "large pulse" approach to nondestructive examination. This concept is an extension of USDOE/Sandia pulse technology. A 50,000 to 100,000 volt pulse, with nanosecond rise time, current limited, and short duration, will be investigated (i.e., the parameters will be an order of magnitude beyond current systems yet be nondestructive).

## 2.4 INSTRUMENTATION AND CONTROLS (I&C) UPGRADE

The increasing obsolescence of instrumentation and controls (I&C) presents issues that confront nuclear power plant operators. The driving issues are the inability to maintain obsolete I&C

equipment, inadequate performance of certain I&C equipment, need to decrease generation costs, the lack of standardization, and regulatory uncertainty for upgrading from analog to digital systems.

The I&C upgrade project will develop and demonstrate instrumentation and control solutions common to multiple users for application in domestic and international nuclear power facilities using available and future cost-effective technology. Through cost-sharing arrangements with utilities, vendors, and other industry stakeholders, three industry-led projects with identified industry champions--instrument surveillance and calibration verification (ISCV), application specific integrated circuit (ASIC), and programmable logic controllers (PLCs)--have been initiated.

## 3.0 CONCLUSIONS

The U.S. nuclear power plants are operated safely and economically today. However, these plants are vulnerable to premature shutdown if technology and information are not available in a timely manner. Before state-of-the-art equipment or new technology can be used, its applicability, reliability and licensibility must be demonstrated. The COLWR Program is focused on providing technology and information to help avoid premature shutdown of operating nuclear power plants and preserving the license renewal option within the constraints of a changing economic, political, and budget environment. The USDOE is cooperating with industry to resolve the critical issues that impact continued operation.

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