Joint DOE-EPRI Strategic Research and Development Plan
to
Optimize U.S. Nuclear Power Plants

HIGHLIGHTS

JUNE 14, 2001

Executive Summary

The Nuclear Energy Plant Optimization (NEPO) Program, jointly funded by the Department of Energy (DOE) and industry, was established in Fiscal Year (FY) 2000 in response to the recommendation of the President's Committee of Advisors on Science and Technology (PCAST) "that DOE work with its laboratories and the utility industry to develop the specifics of an R&D program to address the problems that may prevent continued operation of current [nuclear power] plants". This *Joint DOE-EPRI Strategic Research and Development Plan to Optimize U.S. Nuclear Power Plants* is the foundation and planning document for the NEPO Program and contains a market-based assessment of R&D to improve the operation of the present U.S. nuclear plants.

The latest update to the Joint R&D Plan was prepared in October 2000, and is available on the NEPO website maintained by DOE (http://nepo.ne.doe.gov/). This "Highlights" document provides a summary of the plan and an update on the ongoing NEPO activities. A summary of the FY2000 funded projects and results to date are provided in Attachment A.

Continued operation of existing nuclear power plants is an essential part of the evolving U.S. energy strategy. Continuing the operation of existing nuclear plants through their original license term and a renewed license term of 20 additional years will help reduce the number of new baseload nuclear and fossil power plants that need to be built, and avoid substantial carbon emissions. R&D can contribute to achieving this goal for all U.S. plants in a cost-effective manner.

Industry has made major strides in achieving high levels of safety and performance at U.S. nuclear power plants. Further progress will require more investment in new technologies that can further improve the performance and reduce the costs of nuclear generation, by addressing aging management and the long term reliability of systems and components, and by up-grading to modern digital instrumentation and control and other generation optimization opportunities. Implementation of the Joint R&D Plan is key to continued improved performance.

The R&D performed by the nuclear industry – exceeding $90 million each year - is critical to the maintenance of safe and economic operation of U.S. nuclear power plants. However, the nuclear industry has been forced to invest the bulk of its R&D spending on near-term activities that are needed to enhance day-to-day operational performance and to respond to emerging regulatory issues.

Robust nuclear energy R&D carried out jointly by industry and the federal government will benefit the U.S. energy portfolio and expanding economy by:

- Maintaining a prudent, balanced range of options for national energy security

- Helping ensure continued high availability of nuclear-generated electricity to meet the Nation's growing demand for electricity

- Focusing R&D on the bottom line, i.e., reducing costs, improving performance and extending plant operating life, while maintaining a strong focus on safety

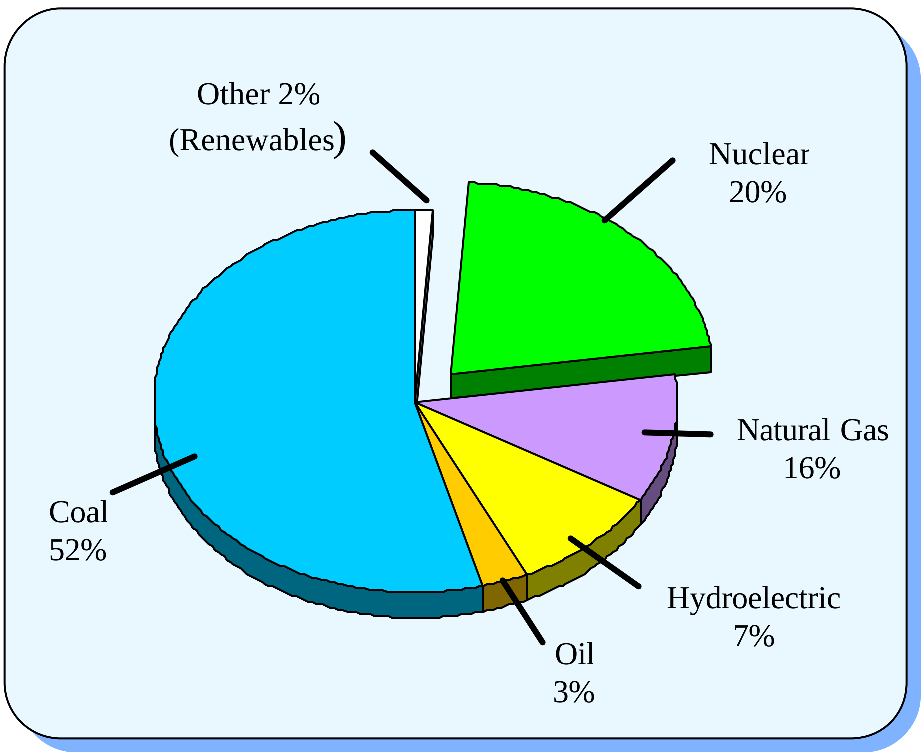
- Providing a major contribution to reduction of air pollution and greenhouse gas emissions

- Contributing to U.S. economic strength, balance of trade, and high-tech domestic jobs

- Maintaining global leadership in a critical technology area that requires U.S. influence (e.g., safety and non-proliferation policy) to promote vital national interests and to fulfill the obligations under the Non-Proliferation Treaty for support of peaceful-use technologies

- Capitalizing on past investment in operating nuclear plants and infrastructure through safe and cost-effective license renewal.

Figure 1. Fuel Shares of U.S. Electric Generation in 2000



Source: Energy Information Administration

Purpose of the Joint DOE-EPRI R&D Plan

The *Joint DOE-EPRI Strategic Research and Development Plan to Optimize U.S. Nuclear Power Plants* is a market-based assessment of energy supply R&D needs for current plants. It is the strategic planning document for industry and government collaboration on nuclear energy R&D needs, and has become the foundation and planning document for the jointly funded Nuclear Energy Plant Optimization (NEPO) Program. The Joint R&D Plan is updated annually to support nuclear utility executives and other key stakeholders in a decision process that identifies and prioritizes nuclear R&D projects, and recommends to DOE and EPRI the highest value tasks for inclusion in their respective budgets for the next year's NEPO Program. The Joint R&D Plan is a two-volume report. Volume 1 addresses the overall plan, goals and needs assessment, and current R&D status of the NEPO program. Volume 2 identifies the R&D tasks being proposed for funding for the coming year.

The NEPO Program develops key technologies to help ensure that our nation's existing nuclear power plants can continue to deliver reliable and affordable energy supplies up to and beyond their initial 40-year license period. NEPO works to resolve open issues related to plant aging, and applies new technologies to improve plant reliability, availability, and productivity. This research addresses the long-term effects of component aging; improved nuclear plant capacity factors; optimization through efficiency and productivity improvements; and increased power output while maintaining high levels of safety. NEPO is carried out cooperatively by DOE and the nuclear industry with joint management and cost sharing.

Nuclear Energy in the United States

103 large, commercial nuclear power reactors provide one fifth of the electricity for the United States. Since 1977, nuclear electric generation in the U.S. has nearly tripled.[1] Many states depend on nuclear energy for a substantial portion of their electricity. Of all U.S. electric generating technologies, only coal produces more electricity than nuclear energy.

Nuclear energy plants operating in the U.S.:

- Set a new reliability record of 89.6 percent capacity factor for 2000, contrasted to less than 60% in the early 1980s.

- Provide power at the lowest overall production cost of any electricity source in the U.S. In 1999, the total production costs (sum of operations, maintenance, and fuel costs) for U.S. nuclear power plants averaged 1.83 cents per kilowatt-hour (kWh), considerably less than the 3.04 cents/kWh averaged in 1989. Nuclear energy's 1.83 cents/kWh production costs were better than coal at 2.07 cents/kWh, natural gas at 3.52 cents/kWh, and oil at 3.18 cents/kWh.[2]

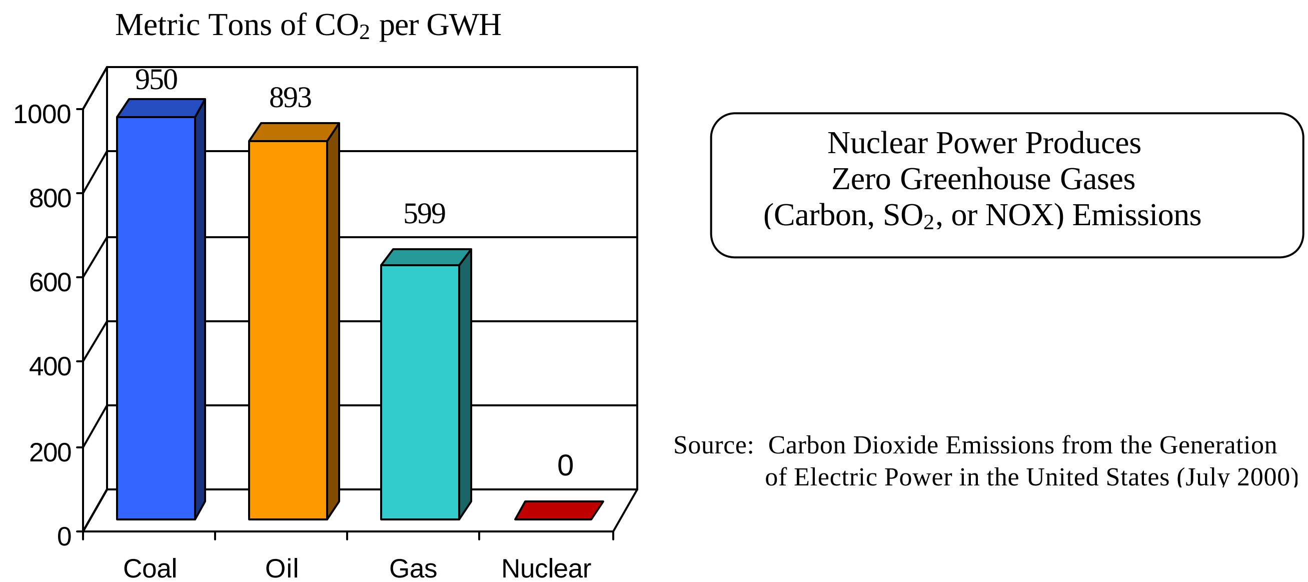
- Have proven themselves to be safe, reliable, and cost-effective sources of baseload electricity. All the key indicators of U.S. nuclear energy plant safety and reliability have

1 Information Digest, 2000 Edition, USNRC
2 UDI for actual data, converted to 1999 dollars by Nuclear Energy Institute

improved markedly over the past decade—fewer unplanned shutdowns, fewer safety system actuations, fewer forced outages, and higher reliability. U.S. nuclear plant performance, as measured by these and other indicators, is among the highest in the world.[3]

- Produce 69.2% of all U.S. emission-free electricity, while hydroelectric power produces 29.1%, geothermal produces 1.3%, wind produces 0.34%, and photovoltaic (solar) produces less than 0.1%.[4] Between 1973 and 1999, U.S. nuclear energy plants cumulatively avoided more than 60 million tons of sulfur dioxide, 30 million tons of nitrogen oxide, and 2.62 billion metric tons of carbon emissions. 90 percent of the carbon dioxide emissions avoided by U.S. utilities during this period was attributable to nuclear energy.

Figure 2. Greenhouse Gases Emissions by Fuel Sources.



Source: Carbon Dioxide Emissions from the Generation of Electric Power in the United States (July 2000)

R&D has played an important role in this progress and will become even more important to addressing new issues and opportunities in maintaining these assets.

Challenges and Opportunities for Nuclear Energy in the United States

Nuclear energy in the United States faces important challenges in sustaining and improving its high level of performance. Deregulation and competition require continual improvements in economic performance, while maintaining high levels of safety. Regulatory reform at the NRC presents both opportunities and uncertainties. Nuclear waste management issues must be addressed. Unanticipated materials degradation, such as small cracks in piping welds, need to be better anticipated and detected, and require advanced repair and mitigation technology solutions.

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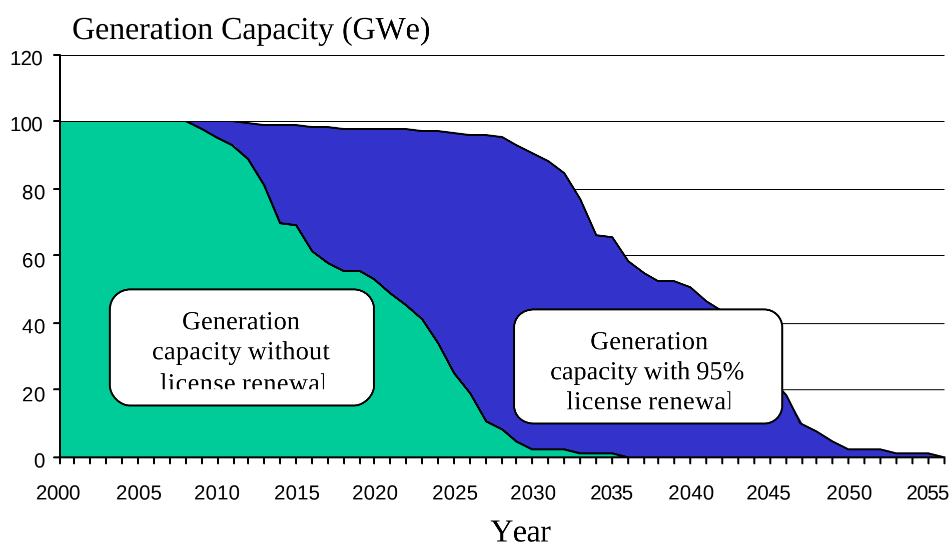
3 WANO Performance Indicators, from Nuclear Energy Institute web site
4 Energy Information Agency

The U.S. is facing a growing energy supply crisis that will remain for an extended period. Despite the challenges, nuclear energy will play a critical role in providing a major share of electricity to Americans. It will do this in three ways:

- Plant license renewal, which increases the licensed operating limit of current nuclear power plants by 20 years. It now appears that virtually all 103 U.S. nuclear plants will apply for a 20-year license renewal to help meet energy demands. License renewal is seen by industry as an attractive option to effectively recover more value from current nuclear plant assets. Technologies developed under the NEPO Program will help maintain high plant reliability and ensure 60 year operating lives for most or all of our currently operating plants.

Figure 3. U.S. Nuclear Generation Capacity with and without License Renewal.



- Increasing nuclear generation from currently operating plants, through strategies that result in further productivity increases, reductions in refueling outage duration, longer fuel cycles, and power uprates. These strategies rely extensively on new technologies, as well as human performance improvements, and have resulted in an almost 40% increase in nuclear generation over the last decade – the equivalent of building over 20 new large nuclear plants. Further enhancement of generating capacities is possible, with major help from NEPO.

- Building new nuclear plants, an important goal for DOE and EPRI programs, but outside the scope of the NEPO program.

Nuclear Energy Supply Research and Development: Pathway to High Performance

Nuclear energy supply depends on sustained research and development (R&D) to maintain and improve its economic and environmental contributions to society. R&D helps forge technology-based solutions for continued improvement in plant performance as well as solutions to safety, regulatory and equipment reliability issues for current plants. Through R&D, new technology available from related power sector and other high-tech enterprises can be adapted to nuclear energy plants to maintain a modern, competitive technology base.

Nuclear energy supply R&D is important to U.S. national interests. Nuclear energy R&D provides the basis for a technology solution to growing environmental concerns over air pollution and greenhouse gas emissions. It contributes to U.S. economic strength and a more favorable balance of trade, and reduces U.S. dependence on foreign fuel supplies. Finally, a strong nuclear energy R&D program gives the U.S. greater technical leverage and credibility to positively influence the nuclear programs of other countries. Success in these R&D programs will sustain U.S. leadership in nuclear technologies to safely extend the life of currently operating plants around the world – enhancing our nation's security and economic interests.

Nuclear energy has a limited federal R&D program supporting future development when compared with other energy options. Fossil energy (coal, oil, natural gas), renewable energy, energy efficiency and conservation programs, and fusion energy have had large sustained R&D programs during the last decade. Over the same period, federal funding for nuclear energy was significantly reduced and is a small fraction of the funding for other energy supply R&D categories. On average, these four alternatives to nuclear energy have each received about 15 times more federal funding than nuclear energy over the last five years.

Overall Funding Requirements

Funding for NEPO was $5 million in both FY00 and FY01. In both FY00 and FY01, EPRI provided well in excess of the matching cost share required by Congress. Each year, DOE and EPRI staff identified about $18 - $20 million in total annual funding requirements, from which about $11-13 million in total annual work was approved (DOE funding at $5 million and EPRI funding at $6-8 million). Many of these projects have multi-year funding requirements, so at any point in time, the total cost of the approved NEPO projects typically requires $30-$50 million to complete over 2 to 5 years. The President's Committee of Advisors on Science and Technology (PCAST) had recommended a level of $10 million/year for this program.

The Process: Goal-Based, Impartial, and Effective

Each year, a Coordinating Committee for this Joint R&D Plan identifies and prioritizes nuclear energy R&D needs from a marketplace perspective. The Coordinating Committee is comprised of twelve utility executives, plus representatives of the Nuclear Energy Institute (NEI), the Institute of Nuclear Power Operations (INPO), the NRC, and the national laboratory and university communities. Based on a detailed review of the large number of priority research projects in the Joint R&D Plan, the Coordinating Committee recommends to DOE and EPRI's Nuclear Power Council (NPC) those tasks that should be conducted in the next fiscal year under the NEPO Program. The NPC is a larger group comprised of executives from all U.S. and international nuclear member utilities that reviews these recommendations and approves the funding for cost-shared activities. The Operating Plant Subcommittee of DOE's Nuclear Energy Research Advisory Committee also reviews these recommendations and provides comments to DOE management. The final project selections are made jointly by DOE and EPRI management and typically closely follow the Committee's recommendations. Contractors are then selected for these approved projects by DOE and EPRI using documented objective criteria, which emphasize competition.

Goals of the Joint R&D Plan

The following strategic goals guide this Plan. They serve both the Federal Government's responsibility for energy security and environmental quality, and industry's responsibility for sustained safe and economic performance of its current fleet of nuclear energy plants.

Goal 1: Ensure current nuclear plants can continue to deliver adequate and affordable energy supplies up to and beyond their initial 40-year license term by providing a strong technical basis for long-term operation, by resolving open issues related to aging mechanisms, and by applying new technologies to improve the cost-effectiveness and predictability of the life-cycle management process.

Goal 2: Ensure current nuclear plants can continue to deliver adequate and affordable energy supplies by continuing to develop and apply the best technology to enhance nuclear plant reliability, availability, and productivity, while maintaining an adequate level of protection of the health and safety of the public.

Scope of the Joint R&D Plan

The Joint R&D Plan includes both short-term, low-risk nuclear R&D that industry alone is pursuing to meet its own responsibilities, as well as short-term and medium-term R&D to be conducted on a cooperatively funded partnership basis to meet the joint responsibilities of industry and government. The Plan does not currently include long-term nuclear energy R&D, and does not include nuclear R&D that is not the responsibility of DOE's Office of Nuclear Energy, Science and Technology (e.g., spent fuel repository R&D).

The Joint R&D Plan is focused on technical issues in two broad areas: Aging Management and Generation Optimization.

Technical Issues: Aging Management

Current nuclear plants were designed and are operating with technology developed over twenty-five or more years ago. As these nuclear plants continue to age, components and structures age or become obsolete, introducing inefficiencies or added costs. Component and structural material degradation occurs in nuclear plants as a result of long-term operation and exposure of materials to harsh environmental conditions. Material degradation occurs in harsh conditions that include radiation and elevated temperature and pressure environments in the reactor pressure vessel, reactor internals, steam generator tubes, system piping, structures, and electrical cables. These components incur degradation over time in the form of corrosion, heat and stress related fatigue and cracking, and reductions in fracture toughness due to neutron irradiation and thermal embrittlement. These material degradation mechanisms have been anticipated but are becoming evident due to the age of operating nuclear plants. Research will provide a better understanding of each degradation mechanism, enabling development of the most cost-effective aging management strategies, which will provide improved capabilities to more effectively prevent, detect, mitigate, or repair the degradation.

Technical Issues: Generation Optimization

Optimizing the long-term economic performance of current plants requires development of technologies that will increase capacity factors, lower operating costs, and increase power output where excessive design or regulatory margins exist. Key R&D areas include:

Instrumentation and Controls (I&C): R&D to address the technological, institutional, and regulatory issues which impact the feasibility and cost effectiveness of replacing deteriorating, obsolete, and inefficient analog I&C systems with digital systems, particularly for safety significant systems.

Advanced Sensor Technologies: R&D required to improve the accuracy, reliability, and comprehensiveness with which key process variables are measured and other plant information is obtained.

Advanced Monitoring, Diagnostics, and Control Systems: R&D to develop systems that will provide effective on-line and off-line support to plant operations, maintenance, and engineering staffs to optimize plant operation and maintenance functions.

Advanced Nuclear Fuel: R&D to improve reliability and resolution of recent licensing issues related to high burnup fuel performance, and to achieve even higher burnup fuel cycles, using higher enrichment fuels, in order to extend the time between refueling outages.

Risk Technologies: R&D to develop more accurate and comprehensive probabilistic risk assessments (PRAs), to improve knowledge of low power and shutdown risk, and to improve and expand the uses of PRA for decision-making (e.g., developing a risk-informed approach to determine the effects of implementing digital technology, or to establish objective performance indicators).

Relationship to NRC Research

This Joint R&D Plan element complements other industry and government R&D activities, and is being conducted in close coordination with other organizations such as NRC. Industry-sponsored work is primarily focused on solutions to technical and regulatory issues, and on cost-savings opportunities. The ongoing confirmatory research by NRC focuses on issues related to safety. NRC must be assured that assessments of degraded components by the industry are sufficiently conservative to provide adequate safety margins.

NRC serves on the Coordinating Committee for the Joint R&D Plan, and participates in the annual process of proposing work for joint NEPO funding. Since some NEPO tasks address regulatory issues, DOE and EPRI cooperate with NRC on this work and any relevant R&D being conducted by NRC. Opportunities for cooperation with NRC (e.g., information-sharing, joint data collection) are identified and pursued where practical.

ATTACHMENT A: STATUS SUMMARY OF ALL FY2000 NEPO PROJECTS

3-1 Steam Generator (SG) Non-Destructive Examination (NDE) Test Mockup Facility

Task: Develop a library of well characterized, laboratory generated axial, circumferential, inner diameter and outer diameter cracks for use in assessing advanced NDE methods being developed by DOE and EPRI.

Results to date:

- Planned inspections on the SG mockup include the +Pt array probe from Zetec and pancake array probes from Mitsubishi Heavy Industries.
- Efforts are underway to obtain probes to evaluate the new SG inspection technology.
- A meeting took place at Argonne National Laboratory (ANL) in December 2000, to review project progress and provide input on work needed to support the ongoing Nuclear Regulatory Commission (NRC) SG round robin project.

3-2 Steam Generator Advanced Eddy-Current Inspection System for Automatic Detection and Characterization of Defects in Steam Generator Tubes

Task: Develop an advanced eddy-current inspection technique and data analysis methodology for more reliable detection and accurate sizing of defects in steam generator tubes.

Results to date:

- Bobbin and Motor-Driven Rotating Pancake Coil data has been acquired from a test section containing three axial cracks of varying depths. Data has been acquired with and without interfering artifacts, such as tube supports and deposits.
- An effort was initiated on the development of automated data analysis algorithms to perform the function of anomaly detection and classification.
- Work on developing software to automatically analyze eddy current data from array probes has begun.

3-3 Overcoming Solubility Limitations to Zinc Addition in Pressurized Water Reactors (PWRs)

Task: Develop the solution thermodynamics of the Zn/ZnO system at high temperature in order to allow PWRs to safely inject as close as possible to the maximum Zinc concentration without ZnO precipitation on the core. Zinc addition to a PWR primary system reduces crack initiation frequency in Inconel Alloy 600, but excessive Zinc can have adverse effects on nuclear fuel.

Results to date: Task complete. Optimum Zinc addition level established; implemented in demonstration at Farley-2.

Zinc injection into the reactor coolant of pressurized water reactors is expected to prolong the life of key components in these plants. Zinc does this, for example, by inhibiting the rate of crack growth caused by primary water stress corrosion to tubes in steam generators. Cracking in Alloy 600 tubes is a worldwide phenomenon and is common as steam generators age. Laboratory studies initiated in the 1980's revealed real promise in the addition of zinc.

Several utilities have begun zinc addition with the expectation of prolonging the service life of their steam generators. However, the steady-state zinc injection amount and duration of the injection over an operating cycle have been restricted below optimum levels. The reason for this restriction has been the lack of solubility information on zinc oxide at fuel surface temperatures. Should zinc solubilities be exceeded at the fuel surface, fuel integrity concerns would arise.

The focus of this NEPO project is to utilize the unique laboratory capabilities of Oak Ridge National Laboratory to answer the thermodynamic questions of a zinc/zinc oxide system at high temperature. Should the results of this work support higher and longer injection amounts, then utility cost savings and material reliability may be significant increased. Additionally, due to budget constraints, this project could not be supported financially by the industry in the time frame desired. The collaboration between EPRI and DOE has facilitated the delivery of this work. The project results, with final report, are scheduled for completion in November 2001.

3-7 Develop Empirical Data to Characterize Aging Degradation of Polymers Used in Electrical Cable

Tasks: Compare natural aging to model predictions based on accelerated aging; obtain naturally-aged samples; develop and confirm aging models; investigate bonded jacket cable failure mechanisms; evaluate coaxial connector backshell moisture intrusion and moisture dams.

Results to date: Although still in the early stages of research, it is already evident that several of our approaches should have a large impact on cable aging problems.

- Early results show that two new condition monitoring (CM) techniques based on modulus profiling and nuclear magnetic resonance measurements may be among the best CM techniques available for determining cable condition in existing nuclear power plants.
- First proof-of-principle experiments using our newly conceived wear-out approach show that it offers unique capabilities for predicting the remaining lifetimes of nuclear power plant cable materials.
- Bonded jacket insulation failure mechanism evaluation is proceeding well. Test specimens have been received from utilities and prepared. Test plan has been developed. Aging ovens were started 3/9/00.
- Coaxial moisture intrusion study is also proceeding well. Cable and connector components have been assembled. The Plan is nearing finalization and testing to start shortly.

3-8 Develop Condition Monitoring (CM) Techniques for Electric Cable

Tasks: Develop a basis with material-specific correlation between non-destructive examination (NDE) data and destructive examination for localized (sample) inspections; develop electrical

NDE techniques capable of detecting incipient defects along an entire cable run; develop NDE techniques suitable for implementation at nuclear power plants; develop distributed fiber optic temperature/radiation sensing methodology.

Results to date: Excellent progress is being made on these cable condition-monitoring tasks:

- Cable aging assessment training aids are being developed – cables have been received from utilities. The plan has been approved and aging of cable specimens will begin shortly.

- Ten research groups have agreed to provide data. Assembling and review of data is under way to create a cable condition monitoring database.

Understanding and monitoring the degradation of cables is important to optimizing nuclear power plant performance. NEPO Project 3-7 aims at developing better predictions of cable material lifetimes, whereas NEPO Project 3-8 is evaluating small sample (essentially non-destructive) methods for determining the condition of field-aged cables. The goal is to preclude the need for premature replacement of cable systems and to assure that cable is replaced before it becomes a problem. In this highlight, details on the small sample aging research are presented.

The small sample testing tasks include a careful and systematic investigation of the correlation of elongation results with data taken from several promising and innovative condition monitoring techniques, each offering the potential for making measurements on very small samples (< 1 mg). The initial measurements are being done on nuclear power plant cable jacket and insulation materials that are undergoing or have already undergone aging and mechanical property measurements in previous Sandia cable aging programs. For situations where a particular CM approach appears to be promising, further studies are being conducted to optimize the CM approach, understand its connection to mechanical properties and determine how any observed correlation depends on environmental stress level (e.g., on the temperature or radiation dose rate). These latter studies are critically important since the accelerated stress levels where the correlation is derived will be much higher than the stress levels appropriate under the ambient aging conditions of interest to the eventual application of CM techniques.

One promising technique, modulus profiling, involves the use of an apparatus capable of mapping modulus (related to hardness) values with 50-micrometer (2-mil) resolution. There is a remarkable predictive correlation between surface modulus and elongation which is independent of aging temperature, strongly suggesting that a similar correlation will hold under ambient nuclear power plant aging conditions. Similar results hold for five additional hypalon jackets from four different manufacturers with every material reaching similar modulus values (~50 MPa) when tensile elongation drops below ~50% absolute. This suggests generic behavior that may be extremely useful for determining the condition of any existing hypalon-jacketed material. Another exciting new CM technique involves nuclear magnetic resonance (NMR) relaxation time (T_2) measurements taken on samples swollen in a suitable solvent at elevated temperature, easily done on many commercial NMR machines. Early results indicate that this method may be particularly useful for Cross-Linked Polyethylene materials, important insulation types that have proven difficult for other CM techniques.

3-13 Mechanical Behavior of Irradiated Structural Stainless Steels.

Tasks: Determine the mechanical behavior of irradiated structural stainless steels under conditions of interest to Light Water Reactors (LWR); develop tools to predict component life assess the results of NDE examinations and guide the timing of corrective actions; determine the effect of irradiation history on the irradiation assisted stress corrosion behavior of multiple alloys of austenitic stainless steel and multiple heats of selected materials in Pressurized Water Reactor (PWR) water.

Results to date: Hot cell testing of bolts extracted from Farley Unit 1, Ginna, and Point Beach Unit 2 has been performed. The testing revealed that no cracking was observed in the strain hardened 316 stainless steel bolts from Farley. For the annealed 347 stainless steel bolts from Point Beach, cracking was found in the head to shank fillet. Out of the 728 Point Beach bolts inspected only 55 showed Ultrasonic Testing (UT) indications and of the 639 Ginna bolts inspected only 59 showed indications. Out of the 114 indications, approximately 14 were substantiated failures. There was no observed degradation in the performance of these bolts. The tensile testing showed reduction of yield stress due to irradiation but the bolt material remained ductile. More studies are being conducted to quantify the bolt operating environment and parameters such as fluence level, temperature, material properties, etc.

3-30 PWR Materials – Swelling

Tasks: Characterize irradiation-induced void swelling and stress relaxation related to degradation that could occur in operating reactors, and calibrate and extend the liquid metal reactor-based swelling model for PWR applications.

Results to date: A state-of-the-art review of void swelling and irradiation enhanced stress relaxation was performed. The review revealed that infinitesimal but measurable void swelling was observed in baffle bolts removed from operating PWRs. However, present data are sketchy to quantify long-term void swelling in the PWR environment. The data on irradiation enhanced creep and stress relaxation occurring under PWR operating conditions are limited. Some limited transient creep (primary creep) has been observed in experiments performed inside of PWR fuel rods. Little steady state creep data are available at PWR operating conditions. In situ measurement of void swelling is being developed. Tests are being conducted in the laboratory to benchmark the application of electropotential and ultrasonic methods to void swelling measurement based on resistivity and ultrasonic signal changes.

3-24 Fatigue

Tasks: Provide cost-effective methods of evaluating the cyclic life of nuclear components, including the effects of reactor coolant environment, based on the safety margins of the American Society of Mechanical Engineer (ASME) code, and provide utilities with appropriate tools to manage fatigue effects.

Results to date: Most initial deliverables of this project have been completed; testing is underway:

- Issued a Interim Thermal Fatigue Management Guideline to assist utility operators in taking a pro-active approach in preventing unplanned leakage from piping attached to reactor coolant systems.
- Developed a Interim model for a thermal fatigue screening tool.
- Issued draft Guidelines for Addressing Fatigue Environmental Effects in a License Renewal Application. This document provides guidance for consideration of reactor coolant environmental effects and to minimize the amount of plant-specific work necessary to comply with NRC requirements for addressing this issue in a license renewal application.

3-27 Assessment of Aging Effects

Tasks: Obtain materials and components that have been in service in operating reactors to be used for comparison with laboratory aged materials to validate models for aging effects and non-destructive examination methods.

Results to date:

- The Big Rock Point Condition Assessment Project is complete.
- A survey of utilities and materials aging experts has been developed and distributed to industry to identify key components requiring samples for potential aging testing/model validation.
- A feasibility review was initiated with Southern California Edison for obtaining core shroud samples from San Onofre Unit 1 for analysis.

5-10 Qualification of Smart Transmitters for Nuclear Safety Applications

Task: Qualify selected smart transmitters, performing the qualification testing and evaluation activities that can be done on a generic basis. This will save utilities and equipment suppliers from individually repeating the tasks for each application, and enhance regulatory acceptance.

Results to date: The project is essentially complete. Documentation of the tests and evaluations that were performed is complete; a qualified Rosemount 3051C smart transmitter is available as a 1E device from Rosemount for utility use. The new transmitter will provide a more accurate, more stable, and more capable replacement for the analog pressure transmitters that are widely used in safety-related applications.

Pressure transmitters are extremely important to control and safe operation of nuclear plants. They are used to sense pressure, flow, and level in safety and non-safety applications. The current electronic devices have served the industry well but are based on designs from the 1970's. These devices are becoming obsolete and manufacturers will not produce them indefinitely. Modern designs with digital electronics are available; however, previous to this project, they were not proven for use in nuclear power plant applications. A key concern is validation and verification of the software used in the devices. Additionally, the qualification must confirm electromagnetic compatibility, and seismic ruggedness. These modern designs have much higher accuracy, repeatability, and stability of calibration, which will allow significant savings to nuclear plant operators by allowing less frequent calibrations. Currently, nuclear plant personnel spend tens of thousands of hours each year in calibrating equipment. With the new technology, the need to calibrate the devices can be determined electronically and calibrations may be performed only when they are needed, reducing surveillance, testing and maintenance costs as well as personnel exposure to ionizing radiation. Accordingly, developing a process for verifying the adequacy of smart transmitters for use in nuclear applications is highly desirable.

The Smart Transmitter Qualification task developed a generic qualification methodology and qualified a Rosemount 3051C smart transmitter. This qualification will allow replacement of old 1150 series analog pressure transmitters, which are based on an early 1970's design, that are widely used in safety related applications. Current requirements for analog transmitter calibration range from 3 months to 2 years. The manufacturer indicates that the new sensors should be calibrated every 10 years, a reduction in calibration frequency of a factor of five or more. Also some calibrations currently require four people for monitoring, and also require access to the sensor. The new sensors can use remote checks of their electronics from the control room, saving time, manpower, and radiation exposure. The non-electronic parts are so stable that intervals between checks can be extended greatly. The evaluations in the pilot project concluded that the Rosemount 3051C is acceptable for mild environment nuclear safety-related and non-safety-related plant applications. The transmitter will be offered by Rosemount Nuclear Instruments for procurement under their 10CFR50 Appendix B quality assurance program.

Improved accuracy can let plants operate closer to licensed limits while maintaining required safety margins. The more accurate, more stable sensors allow a plant operate closer to trip setpoints because of the reduced uncertainty in the measurements. Diagnostic capabilities of the new equipment allows virtually instantaneous detection of problems, with correspondingly higher availability. It also allows a more focused approach to maintenance.

The new components are typically more reliable than their predecessors, and with digital technology, it is common to use fault-tolerant architectures that continue to function normally, even as problem notifications and repairs are being made.

The smart transmitter qualification task is based on generic qualification activities previously developed by EPRI as described in EPRI TR-106439, *Guideline on Evaluation and Acceptance of Commercial Grade Digital Equipment for Nuclear Safety Applications*, and EPRI TR-107339, *Evaluating Commercial Digital Equipment for High Integrity Applications*.

5-12 Revision of Guideline on Licensing Digital Upgrades Based on New 10CFR50.59

Task: Develop an industry consensus approach for implementing digital upgrades to safety systems under the new 10 CFR50.59 regulation and gain NRC approval of the approach. This task is to revise and update EPRI TR-102348, "Guideline on Licensing Digital Upgrades," which was developed to stabilize the regulatory environment in 1993.

Results to date: Electric Power Research Institute (EPRI) and Nuclear Energy Institute (NEI) have established a joint utility Task Force to execute this task. A working draft has been prepared and is under review by the NEI Task Force. Meetings are scheduled with NRC to obtain input. A complete draft will be sent to all utilities for review in May 2001.

5-17 Scoping Study, Optimum Fuel Burnup

Task: Identify and lay the basis of optimum fuel burnup and optimum cycle length for the nuclear power plants (Boiling Water Reactor (BWR) and Pressurized Water Reactor (PWR)) to achieve maximum environmental, safety and economic benefits. Specifically, identify the optimum burnup from the current licensed limit of 62 GWD/T to the optimum level supported by the 5% enrichment limit, and identify the optimum burnup level and cycle length without the 5% enrichment limit.

Results to date: Utility team identified to carry out assessment, and agreement reached on the parameters to be used for the study and dates for reaching key milestones. Study underway with important conclusions to date, which will be factored into utility strategic planning.

5-19 Impact of Nickel Oxide Solubility on AOA

Task: Resolve problems with recently observed anomalous core flux depressions due to increased primary coolant corrosion product deposition (primarily Nickel Oxide) onto the fuel as design thermal duties have been increased, creating a phenomenon called axial offset anomaly (AOA) which can require a power reduction to maintain regulatory shutdown margin. This project will develop the database on Nickel solubility from NiO up to clad temperatures.

Results to date: Project is complete. Data have been obtained and reported to utilities. These data are essential to understanding and managing corrosion product transport and deposition in the potential AOA core. Ultimately, solubility screening tools should be coupled to core design thermal hydraulic and neutronic codes to produce high duty cores with reduced AOA risk.

In attempts by the commercial nuclear industry to operate their pressurized water reactors (PWR) more efficiently, higher energy cores have been designed and implemented as a means of remaining cost-competitive. Accompanying these high-energy cores have been changes in composition and mass of corrosion products depositing on the fuel in these reactors. Negative consequences have resulted from these deposits:

1. The deposits have been implicated in the failure of fuel rods in two plants. The failed rods necessitated replacing them with new ones leading to economic penalty for the utilities. Another consequence of replacing the fuel is that additional spent fuel rods will now require burial sometime in the future.
2. The deposits have been implicated to be a key component to the observance of axial offset anomaly (AOA) at over a dozen PWRs. Approaching reactor axial offset limits

can cause operators to de-rate a PWR, while exceeding the limits can cause a shutdown. The most severe case to date with AOA resulted in a 1200 megawatt plant to reduce power to 70% for approximately 6 months spanning an entire summer. Not only does this place the utility in an adverse economic position, but is also a reliability issue and places energy supplies at risk. In the case of this plant, 360 megawatts of lost generation resulted.

3. When these deposits are released during shutdowns (e.g. refueling & maintenance outages), elevated radiation fields have been experienced at these plants. The elevated radiation fields have meant increased occupational exposure for nuclear plant workers. A main characteristic of these core deposits is the fact they are rich in nickel. Aside from nickel being a corrosion product constituent, it also becomes activated in the core and contributes significantly to radiation fields at these units.

A large percentage of the materials in a PWR reactor coolant system are comprised of nickel, yet there is little known of the high temperature (~660°F) thermodynamics of the metal. Because nuclear fuel surfaces operate at such high temperatures, this knowledge would permit chemists to estimate the stability and solubility of the mixed phases of nickel at high temperature and offer strategies to prevent nickel deposition on the fuel.

As the focus of this NEPO Project, scientists at Oak Ridge National Laboratory are utilizing their unique laboratory capabilities to measure nickel oxide solubilities as a function of temperature over a wide range of chemical environments. The solubility results will establish an accurate set of thermodynamic equations that will help describe the nickel species that exist under high energy core conditions. With this knowledge, utilities are placed in better position to mitigate the accumulation of corrosion products (nickel) on the fuel, and thus help prevent the negative issues arising from the design of high-energy cores. The Oak Ridge work, with final report, is scheduled for completion December 2001.

5-21 Human Performance Indicators and Corrective Action Plans

Task: Develop guidance on the selection and use of leading indicators to support early identification of human performance problems in maintenance, repair, and operations; extend the range of utility of the analytical indicator approach and software capabilities to related issues (e.g., employee concerns); Develop a more comprehensive database of corrective actions taken in response to human errors at other organizations and industries.

Results to date: "Guidelines for Trial Use of Leading Indicators of Human Performance" published in September 2000. Field validation in progress. "Proactive Assessment of Organizational and Workplace Factors" (PAOWF) is in use at two nuclear power plants.

This project was completed in FY2000. The key products developed from this project (at a cost to DOE of $125,000) allow nuclear plant leaders to measure the main drivers of human performance. These measurements provide insight about the likely trend in overall human performance at a station. Nuclear plant leaders can use these insights to intervene and correct declining performance before major undesirable outcomes occur. Applying these tools improves the reliability of nuclear electric generation stations and avoids costly shutdowns.

Two key products are in use as a result of this project: Proactive Assessment of Organizational and Workplace Factors (PAOWF) and Leading Indicators of Organizational Health. The two products provide diverse approaches to obtaining the necessary insight. The “bottom-up” approach is used in PAOWF, to allow direct measurement and trending of selected conditions in the workplace that affect human performance. The “top-down” approach of the Leading Indicators of Organizational Health measures organizational-wide influences on performance.

PAOWF is in use at two utilities and is being installed at several more. It consists of a computerized tool to easily obtain data directly from workers about conditions in the workplace that are helping hindering effective performance. Supervisors and managers are using this tool to identify and respond to worsening conditions before unacceptable outcomes occur. A side benefit of the tool is improved alignment among workers and leaders about what conditions need to be changed to improve people’s performance. The industry has responded to the availability of PAOWF by applying the tool in innovative ways. For example, one station uses PAOWF as a cultural survey tool, and also as a tool to improve safety observation programs.

Leading Indicators of Organizational Health are in use at two utilities and are under consideration at several more. The product consists of a process for developing site-specific leading indicators. These leading indicators are measures in seven theme areas that relate to the organization’s capacity for improvement. Station leaders are using this process to focus attention and resources. As a result, improvements in a wide variety of processes and conditions can be implemented. The industry has responded to the availability of the Leading Indicators of Organizational Health by applying the process in innovative ways. For example, one station uses the process as a means of aligning senior management on the issues affecting future performance. Another station is applying the concept of leading indicators to department-level issues as well as station-level issues.