# Renewing Licenses for the Nation's Nuclear Power Plants

A REPORT BY THE APS PANEL ON PUBLIC AFFAIRS

APS physics

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Founded in 1899 to advance and diffuse the knowledge of physics, the American Physical Society is now the nation's leading organization of physicists with approximately 50,000 members in academia, national laboratories, and industry. APS has long played an active role in the federal government; its members serve in Congress and have held positions such as Science Advisor to the President of the United States, Director of the CIA, Director of the National Science Foundation and Secretary of Energy.

This report was overseen by the APS Panel on Public Affairs (POPA). POPA routinely produces reports on timely topics being debated in government so as to inform the debate with the perspectives of physicists working in the relevant issue areas.

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University of Texas at Austin

**Todd Allen**
Idaho National Laboratory

**Christina Back**
General Atomics

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**Gary Was**
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**Rosa Yang**
Electric Power Research Institute

**Steve Zinkle**
Oak Ridge National Laboratory


## APS STAFF


Francis Slakey
Jeanette Russo


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For additional information, including the participant bios and the workshop charge and agenda, please visit: *http://www.aps.org/policy/reports/popa-reports/index.cfm.*

This section summarizes the context, principal finding, and recommendations of the 2013 American Physical Society Panel on Public Affairs study on renewing licenses for operation of U.S. nuclear power plants beyond their current regulatory limit of 60 years. The conduct of the study is described in an Appendix of this report.

The United States has greater than 100 nuclear reactors with licenses that can be renewed to allow operation up to 60 years. There are no prohibitions against renewing those licenses beyond 60 years, and 20-year renewal periods are presently authorized under existing regulations. If licenses are not renewed beyond 60 years, approximately 100 gigawatts of power—roughly 20% of the nation's electricity supply today—will begin shutting down by the year 2030.

It is in the financial interests of the nuclear industry to evaluate the potential for extending the operating lifetime of nuclear reactors. Ultimately, a utility's decision to renew a license will balance an assessment of the costs of long-term operation of the nuclear plant against the costs of constructing new power generation, such as a coal or natural gas plant, or a new nuclear plant.

For several reasons, it is also in the interests of the federal and state governments to evaluate the potential for long-term operation of nuclear reactors:

- In contrast to a coal or natural gas plant, nuclear reactors do not emit any of the six air pollutants identified in the Clean Air Act: ozone, particulate matter, carbon monoxide, nitrogen oxide, sulfur dioxide, or lead.
- In contrast to a coal or natural gas plant, nuclear reactors provide a near-carbon-free source of energy, currently accounting for over 60% of the nation's near-zero-carbon energy production and displacing an estimated 600 million tons of carbon per year.[1]
- Renewing licenses preserves a low-carbon energy source at a time when there is no economical way to replace that capacity.

The decision to extend nuclear plant life is both complex and urgent. It involves interrelated technical, economic, regulatory, and policy issues. Further, replacing these units will require long-lead planning, estimated at 10 to 15 years prior to scheduled retirement of the plant. Hence, the window of opportunity is short—utilities will begin facing a decision of whether to renew licenses starting in five years.

Two closely coordinated research programs are examining the potential for long-term operation. The Department of Energy runs a federal Light Water Reactor Sustainability Program (LWRS), cost-shared with industry. And the Electric Power Research Institute (EPRI), supported by the electric power industry, runs a Long-Term Operation (LTO) Program. Current results of these programs do not indicate any technical show-stoppers that would prevent the renewal of licenses from 60 to 80 years, assuming rigorous application of maintenance, inspection and aging management programs. Component and materials aging, however, is a critical topic. The LWRS and LTO research programs are establishing a pathway of research, surveillance and response that can manage these challenges.

The LWRS and LTO programs are collecting data and developing models to predict the life span of plant components. Such results are useful in informing surveillance and response activities. There are uncertainties involved in any engineering assessment, especially over long periods of time. For example, no mathematical model can identify what bolt will corrode on which day; instead, the models predict the likelihood, with a range of uncertainty, that a portion of the bolts are likely to need replacement within an estimated period of time. The more substantial the research program is, the better the overall activity will be: uncertainty will be reduced, lead time for preventive action will be increased, predictions will be more accurate, surveillance will be better informed, and the response will be more targeted.

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1 www.nei.org/corporatesite/media/filefolder/infographic_-_Emission_Free_Sources_2011.jpg

**FINDING:** The LWRS and LTO programs have developed a beneficial pathway of research/surveillance/response that addresses the uncertainties associated with long-term nuclear plant operation.

However, with the window of opportunity so short—a mere five years before plants begin facing renewal decisions—additional pathways can be pursued that would make license renewal for a nuclear plant more feasible, thereby limiting the construction of alternative power generation, such as a coal or gas plant. Therefore, the Committee recommends:

- **Recommendation #1: An Enhanced Energy Strategy Pathway**

  For as long as licenses can be safely renewed, U.S. energy strategies should make renewal a feasible choice. For example: for energy security and climate change reasons the federal government or individual states could enact policies that support lowest-carbon sources; or, financial institutions could weight environmental impact in valuating utilities.

- **Recommendation #2: An Enhanced Research Pathway**

  A more substantial fundamental research effort, with a long-term commitment, would better inform the assessments that will drive a decision whether to seek continued operation beyond the current license period. With additional resources, the current program at DOE would grow both deeper and broader serving to buy down risk, and reduce uncertainties.

Whatever pathways are pursued, the renewal of licenses is not an end in itself. The current fleet of nuclear reactors cannot be renewed indefinitely. However, while renewal is not a long-term solution, it does provide valuable time to establish a balanced and durable energy future for the nation. That time must be used to develop a clean energy future that should include, in part, the re-establishment of U.S. leadership in nuclear energy technology as urged by the American Physical Society,[2] so that the U.S. remains at the forefront of nuclear energy practice and understanding. The Committee therefore recommends:

- **Recommendation #3: An Enhanced Leadership Pathway**

  The U.S. government should have a concentrated program to support the development, manufacturing and licensing of new nuclear reactors that can be built, operated, and eventually decommissioned in a manner that is safe, environmentally sound, and cost-effective.

## CONCLUSION

Safe and economical long-term operation of the nation's nuclear plants accomplishes several things: it keeps an essential, clean and secure energy asset available and sustains the operational infrastructure needed to re-establish the nation's leadership position in nuclear power. This report identifies three distinct actionable pathways to achieve these critical national goals.

2 APS, Statement on Nuclear Energy, 1993, http://www.aps.org/policy/statements/93_7.cfm

## CURRENT STATUS OF REACTORS

As of the start of 2013, the United States had greater than 100 nuclear reactors with licenses that allow operation up to 60 years. As of June 2013, 73 units have been granted the renewal to 60 years, one of which was subsequently closed. Fifteen units are under review, 9 units are intending to renew and 7 are shutting down or are not intending to renew. The dates of the initial licenses spans several decades:

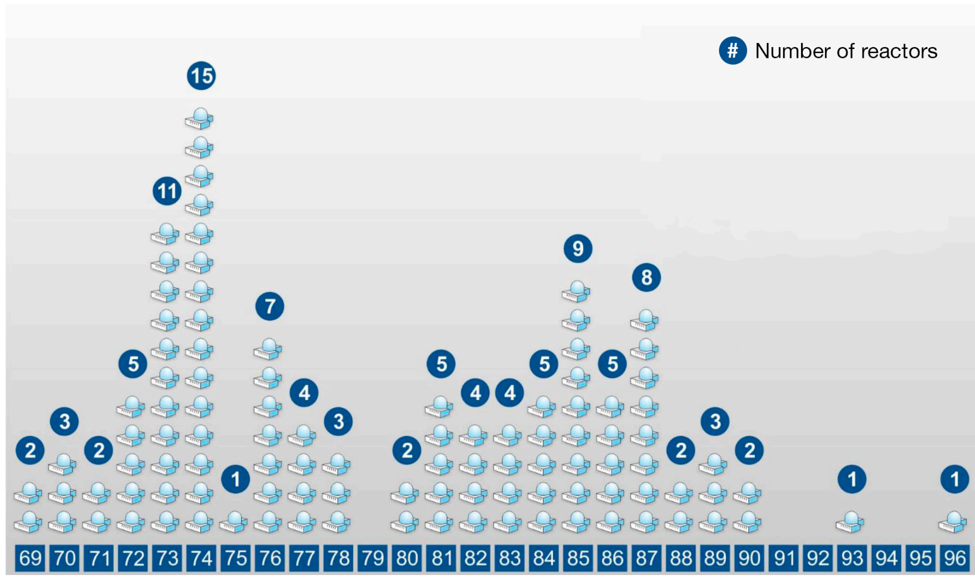


**Figure 1.**
Year U.S. NRC License was Granted.[3]

There are no statutory prohibitions against renewing those licenses beyond 60 years, and up to 20-year renewal periods are presently authorized under existing regulations. However, the Nuclear Regulatory Commission (NRC) is considering if new rules may be required for license renewal beyond the current term of 60 years. If all U.S. nuclear reactors were retired at the end of a licensed 60-year lifetime, and no new reactors were built to compensate, then approximately 100 gigawatts of the nation's nuclear-based electricity supply would begin shutting down by the year 2030 and would need to be replaced by other generating sources.

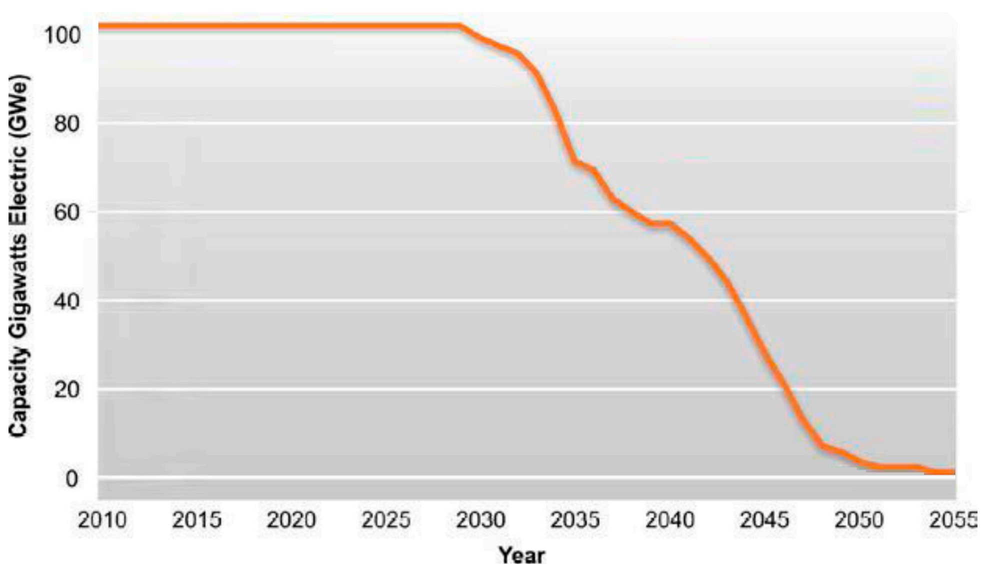


**Figure 2.**
Loss of gigawatts over time if current reactors operate for 60 years, but no longer.[4]

3 Source: http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html#future

4 Source: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1350/v23/sr1350v23-sec-2.pdf

## THE DECISION TO RENEW A LICENSE

The decision on whether or not to continue operating a nuclear plant is complex, involving interrelated technical, safety, economic, regulatory, and public policy issues. (See Sidebars)

### Benefits to Renewal

There are no current regulatory prohibitions against renewing the licenses from 60 years to 80 years and there would be several advantages to doing so:

- License renewal, where appropriate, would extend the nation's most affordable low-emission (low carbon and other atmospheric pollutants) source of electricity.
- The existing nuclear fleet provides reliable, affordable baseload power. The United States' electricity demand is expected to rise by more than 30% by 2030[5]. The industry must maintain the availability of substantial baseload power. Continued operation of existing nuclear plants preserves a significant near-zero carbon emissions generation source of baseload power.
- In most cases, nuclear plant owners have paid off the debt associated with capital investments in existing plants. Continued operation of these plants is inexpensive relative to new low-carbon energy sources. This enables owners and their customers to avoid capital outlays required for new low-carbon generation.

### Risks to Renewal

While there are clear advantages to renewing licenses, there are also substantial technical questions in the areas of safety and reliability that in turn can add uncertainty to the economics. Research can address those challenges to better inform decisions about long-term operations. Replacing certain reactor components, for example, might be easier to justify if confidence is high that the remainder of the plant will operate reliably for another 30, rather than 10, years. To assess the risks of renewal, plant owners and operators require comprehensive, objective technical information including:

- Better understanding of physical degradation mechanisms is necessary to guide the choice to sustain, repair, replace, or even change to new materials.
- New technologies must meet a high standard for safety before being used in nuclear plants. Rigorous tests and analyses are required before any new technologies are adopted. As a result, the nuclear industry has traditionally been slow to take full advantage of modern technology. Through the successful development and demonstration of diagnostic, prognostic, and other "smart" technologies, existing nuclear plant owners could reduce component failure, optimize performance, improve asset planning, and avoid long repair outages.
- The allocation of capital to plant refurbishment, uprate, or modernization hinges on the expected remaining operating period of the plant. Such decisions demand detailed knowledge of technical issues. Nuclear plant owners will have more confidence in the prudence of potential billion-dollar investments if supported by robust models based on sound technical data.

Ultimately, the decision to renew or not will be based on the economics of doing so in a safe manner. Approximately half of current U.S. reactors were first licensed prior to the 1979 Three Mile Island accident, before the digital communications era. Many of these reactors required retrofits to incorporate the lessons learned from that accident. As components are replaced at the end of their useful life, maintenance costs may increase due to replacement parts not being available. Plant modifications may be required to replace obsolete systems or components. In addition, the new appearance of seismic activity at sites previously thought to be inactive, as happened in Virginia in 2011, may demand remedial steps that could be prohibitively expensive.

5 Energy Information Administration, http://www.eia.gov/forecasts/ieo/electricity.cfm

**Bloomberg**

### Largest U.S. Nuclear Plant Wins 20-Year License Extension

By Simon Lomax and Peter J. Brennan
Apr 21, 2011

U.S. regulators granted a 20-year license extension to the Palo Verde nuclear station in Arizona, the nation's largest atomic power plant.

The three-reactor plant, owned by Pinnacle West Capital Corp. (PNW), is about 50 miles (80 kilometers) west of Phoenix. A careful review found "no safety concerns" to prevent the plant from operating until 2047, the U.S. Nuclear Regulatory Commission said today in a statement.

**THE WALL STREET JOURNAL.**

BUSINESS | February 5, 2013

### Duke Energy to Close Florida Nuclear Plant

Rebecca Smith

Duke Energy Corp. said Tuesday it will retire its idled Crystal River nuclear plant in Florida, resolving a problem that figured prominently in a boardroom feud at the giant utility.

The company said it is likely to ask state regulators for permission to replace Crystal River with a comparably sized gas-fired power plant. It recently built a similarly sized gas plant, with about 900 megawatts of capacity, in North Carolina for a cost of about $900 million, far less than the $1.3 billion to $3.4 billion it would cost to repair Crystal River.

In short, meeting the technical challenges described in the following sections is a necessary, but not sufficient, requirement if the useful life of currently operating U.S. reactors is to be extended. It will also be necessary to show great vigilance in monitoring the consequences of aging and renovation on the safety with which these valuable power sources can be operated.

While a research program can provide an estimate of the risks and costs associated with long-term operation, a utility will balance these considerations against uncertainties and the costs of constructing new power generation. Consequently, the policy environment established by Congress or the Administration—on issues such as climate change, air pollutants, or nuclear waste management—can significantly impact the attractiveness of nuclear power and a utility's decision on whether to renew a license.

## OVERVIEW OF TECHNICAL CHALLENGES

Component degradation trends associated with long-term operation of nuclear power plants have been closely monitored for decades. As degradation has been observed, the industry has put responses into place.

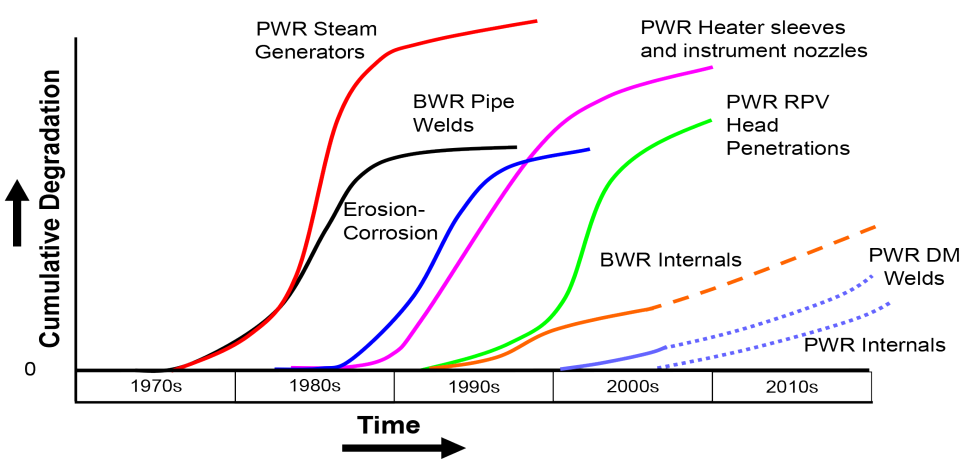


**Figure 3.**
Degradation over time of Boiling Water Reactor (BWR) and Pressurized Water Reacter (PWR) components.

In general, the technical tools needed to support long-term operation of nuclear plants are well established:

- *Measurements of degradation*: High-quality data on component and subsystem degradation provides key information.
- *Mechanisms of degradation*: Basic research to understand the underlying mechanisms of selected degradation modes leads to better prediction and mitigation.
- *Modeling and simulation*: Improved modeling and simulation efforts have great potential to reduce the experimental burden for long-term operation studies.
- *Mitigation*: Development of improved materials and operational strategies to provide for continued safe and economical operation of the plant.
- *Monitoring*: Non-destructive monitoring is utilized to anticipate potential failures before they appear in destructive inspections.

In February of 2008, the Department of Energy teamed with the Nuclear Regulatory Commission to hold a workshop to identify potential materials degradation issues that are unique to extending operation to 80 years. A report from this workshop identified and prioritized numerous research needs.[6] In addition, there have been many more interactions with NRC, the Electric Power Research Institute (EPRI), and the nuclear industry, further refining knowledge of the problems associated with long-term operation. The challenges to long-term operation of nuclear plants fell into five main categories:

- Primary system metals, welds and piping
- Concrete and containment structures
- Electrical cables
- Reactor pressure vessel
- Buried piping

6 NRC/DOE Workshop on Nuclear Plant Life Extension R&D, February, 2008: http://www.mendeley.com/research/life-beyond-60-workshop-summary-report/

Two coordinated research programs are underway to address these challenges and lay the groundwork for license renewal. A federal Light Water Reactor Sustainability (LWRS) Program, cost-shared with industry, has been established within the Department of Energy and a Long-Term Operation (LTO) Program is being carried out by EPRI, supported by the electric power industry. The federal program has the following stated policy goal:

> *Extending the operating lifetimes of current plants beyond 60 years and, where practical, making further improvements in their productivity is essential to realizing the administration's goals of reducing greenhouse gas emissions to 80% below 1990 levels by the year 2050.*[7]

These programs have not uncovered any technical show-stoppers that would prevent the renewal of licenses from 60 to 80 years. However, more research is needed to characterize aging mechanisms of materials and validate aging models. Many technologies, including nuclear power plants, follow a "bathtub" curve that characterizes the rate of defects likely to occur over time. The curve has three distinct parts: 1) initial "birth defects," which gradually decrease over the early period of the system's life; 2) a quiescent, relatively trouble-free period as the system matures; and 3) an "aging" wear-out period marked by a rise in defects, requiring parts to be repaired or replaced more frequently. When a system is in the aging phase the maintenance required to keep it operational becomes more substantial.

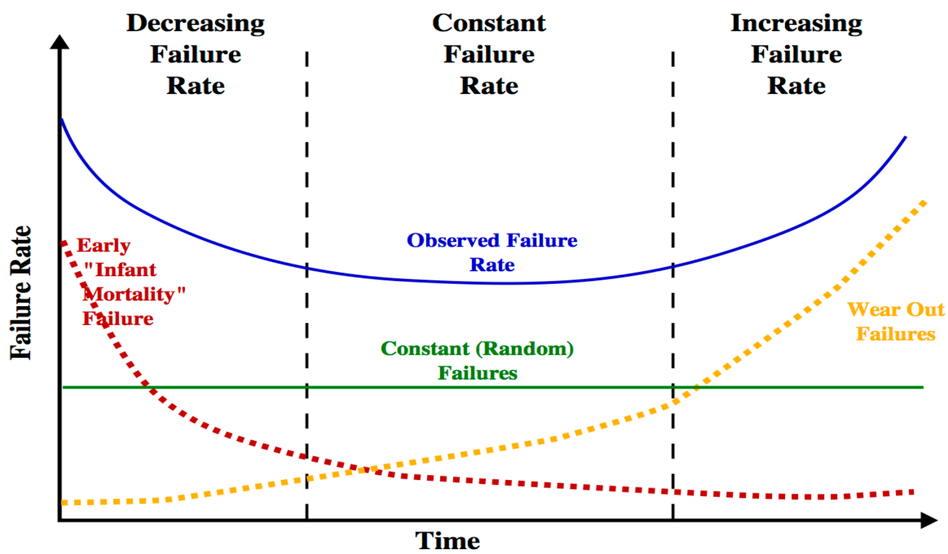


**Figure 4.**
Generic "bathtub" curve.

To effectively respond to the likelihood of more frequent component replacements, the LWRS and LTO research programs are establishing a broad program of research, surveillance, and response to failures.

There is an urgent need to develop and advance the LTO and LWRS programs. A utility's decision on whether to pursue a license renewal or instead replace a unit requires long-term planning, estimated at 10 to 15 years prior to scheduled retirement of the plant.[8] Hence, the window of opportunity is short, with only about five years until some utilities will have to decide whether or not to pursue license renewal.

## THE EPRI PROGRAM

EPRI conducts research and development in the public's interest on the production, transmission, distribution, and utilization of electric power, including research intended to improve the safety, reliability, and economy of nuclear power plants (NPPs). Most of the Institute's funding is provided by its membership and the electric utility industry. EPRI provides technical solutions needed to address long-term operational challenges, and to address important societal issues related to climate change and energy security.

7 Light Water Reactor Sustainability Program, Department of Energy, January 2012: http://www.ne.doe.gov/pdf Files/INL-EXT-11-23452%20LWRS%20Program%20Plan%2001-31-12.pdf

8 http://energy.gov/sites/prod/files/2013/05/f0/LWRS-LTO_Joint_R%26D_Plan_Rev_2.pdf

Recognizing the many technical challenges confronting nuclear plant operation over 60 or 80 years, and perhaps longer, EPRI launched the Long-Term Operation Program. LTO is defined to mean high-performance nuclear plant operation for 60 years, 80 years, or beyond. High performance is measured by safety, reliability, availability, and cost of operations. The EPRI program has three overarching program areas: Aging, Enabling Technologies, and Modernization. Within those areas are several ongoing projects that are summarized below, all of which are intended to address both the safety and economic risks associated with license renewal.

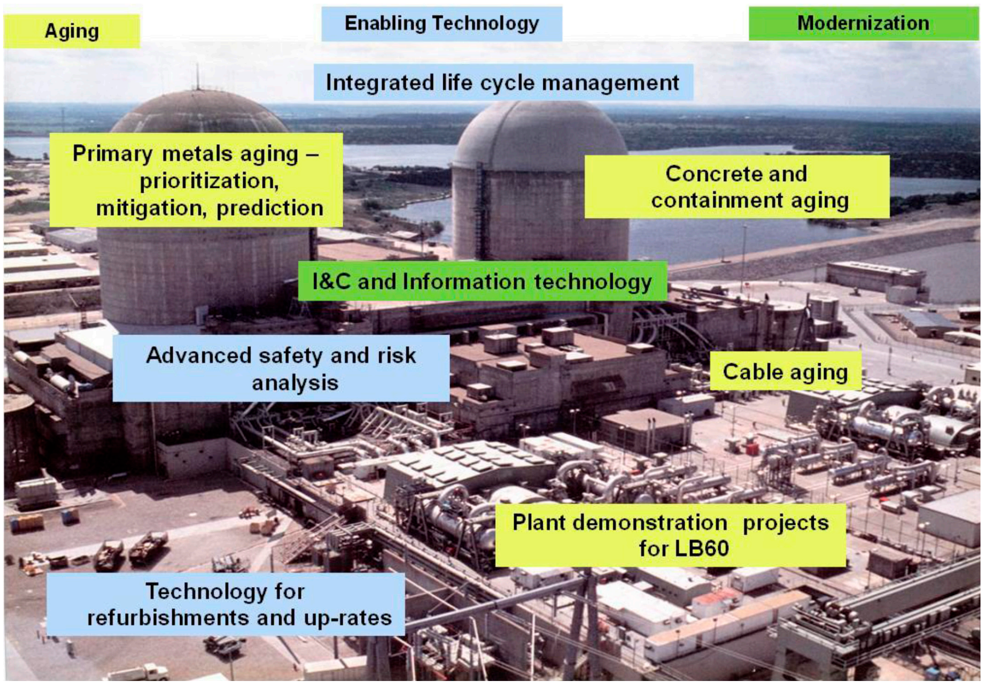


**Figure 5.**
EPRI Long-Term Operation Program projects.

### Primary System Metals

Degradation of metals in the primary systems of nuclear power plants is a key focus of aging management activities at operating nuclear plants. Failures or unexpected degradations significantly affect safety, plant availability, and cost of operation; and the likelihood of their occurrence will increase with long-term operation. Better understanding of crack initiation and propagation processes, improved predictive models, and effective countermeasures against embrittlement and stress corrosion cracking are all necessary.

### Concrete Structures

To date, the performance of post-tensioned and reinforced concrete structures in nuclear power plants has been good. However, several recent issues in existing nuclear power plants suggest that these structures are beginning to show their age, including the development of small cracks in a shield building, as well as alkali-aggregate reactions and cracking in a control building electrical tunnel. There are a variety of kinetic processes that can lead to the degradation of concrete structures, and these may be accelerated by operating environments specific to nuclear plants (e.g., spent fuel pool leakage). The goal of research in this area is to develop a deeper understanding of degradation phenomena and their causes in operating plants.

### Cable Aging Management

This LTO project area is intended to manage aging cables through enhanced inspection and pre-emptive replacements. The LTO Program develops and executes projects to improve the understanding of cable aging mechanisms, provide better information on cost and likelihood of extensive cable replacement, and provide validation of testing methods and prediction tools to determine remaining useful life.

### On-line Monitoring and Advanced Instrumentation and Controls

This LTO project area addresses the specific issues that may help achieve higher levels of performance and efficiency as plants age. Specific projects are planned to define and develop technology for on-line monitoring of critical equipment, as well as effective implementation of advanced instrument and control technology to address reliability, availability, and life-cycle management of equipment in light of obsolescence and aging. The research will also provide implementation guidelines, technology enhancements, and pilot applications for this technology.

### Advanced Safety and Risk Analysis Tools

During extended operating periods, nuclear power plants (NPPs) will need to undergo design and operational changes, and operators will need to manage aging degradation while preventing significant safety-related events and demonstrating improved nuclear safety. This LTO project area addresses specific issues that may be helpful in achieving these objectives. As new technologies and capabilities become available, they will present opportunities to enhance plant operational, safety, and economic performance. Such enhancements could include operating for longer periods of time between service interruptions and plant shutdowns.

### Demonstration Projects

This project reviews and evaluates actions undertaken by two nuclear plants currently operating under licenses renewed to 60 years. The plant actions will be assessed for both their validation of already implemented aging management programs and their applicability to license renewal beyond 60 years. As appropriate, enhanced component assessment techniques and processes may be applied to provide data useful to estimating life performance for structures, systems, and components (SSCs). Recommendations and guidelines will be developed from the evaluations at the demonstration plants. Specific areas of research include the reactor vessels and their internal components, the reactor containment systems, and other major components as mutually agreed upon by the participants.

### Integrated Life Cycle Management (ILCM)

This project area is intended to develop methods that nuclear operators can use to determine the likelihood of failure of selected large capital assets. This methodology will provide consistent information for plant operators to use in optimizing their long-range plant and/or fleet strategic, technical, and business decision models. Guidance will be developed to describe the method and basis for determining large capital assets that should be considered during extended operations, when and why they are anticipated to fail, and the amount of capital funding that will be required to refurbish or replace the failed asset. Software optimization tools will be developed to enable plant operators to perform simulation and sensitivity analysis of the input variables. Such analyses will allow operators to optimize replacement and refurbishment of capital assets and anticipate related capital funding requirements.

### Technical Bases Gap Assessment for Aging Management Programs

The Aging Management Program (AMP) Assessment project is intended to identify additional mechanisms, locations, conditions, and methods for consideration as a part of LTO. The technical bases consist of the data and associated implementation tools (e.g. guidelines, analytical models, evaluation bases, etc.) that assess the current condition of the subject SSCs to allow safe operation through a defined period. Under this project, a typical set of AMPs are to be reviewed for their applicability to a period of extended operation (60 to 80 years). The review will ask four key questions:

- Are there changes in the aging mechanisms, their rates, or their extent that may occur after 60 years of operation?
- Are such changes being addressed by current or planned R&D efforts?
- Are technical tools required to effectively address new or changed aging management requirements?
- Are there opportunities to improve AMPs to facilitate effective implementation?

The overall goal is to identify gaps in the industry technical bases for using aging management programs to ensure safe, reliable long-term operation. Once identified, such gaps will be used to refine industry R&D efforts and reduce the uncertainties for utility decision-making concerning LTO for a specific plant.

## THE DOE PROGRAM

The DOE Light Water Reactor Sustainability (LWRS) Program focuses on aging phenomena and issues that require long-term research and/or unique DOE laboratory expertise and facilities. The program's results are applicable to most reactors currently operating. DOE and its national labs possess large theoretical, computational and experimental capabilities that are unique and do not—and economically cannot—exist at the individual company level.

The DOE LWRS program has the following goals: (1) develop the fundamental scientific basis to understand, predict, and measure changes in materials and systems, structures, and components as they age in environments associated with continued long-term operations of existing reactors; (2) apply this fundamental knowledge to develop and demonstrate methods and technologies that support safe and economical long-term operation of existing reactors; and (3) research new technologies to enhance plant performance, economics, and safety. To achieve these objectives, the LWRS program has three major areas of focus:

- Materials Aging and Degradation
- Advanced Instrumentation, Information and Control Systems Technologies
- Risk Informed Safety Margin Characterization

### Materials Aging and Degradation

A common link between all of the diverse materials used in a nuclear power plant is the incomplete knowledge regarding fundamental property degradation mechanisms. For example, cracking in baffle bolts due to irradiation-assisted stress-corrosion-cracking has been observed in some reactors during prolonged operation. The probability of cracking does not simply correlate with any single environmental variable, such as neutron dose or grain boundary chromium concentration, but instead appears to be the result of synergistic influences of stress, temperature, and irradiation dose. Improved understanding of degradation mechanisms is being pursued via tightly coupled modeling and simulation in concert with high-fidelity post-irradiation measurements of reactor materials and components.

This improved knowledge is needed to develop robust predictions of allowable material lifetimes before replacement is necessary. Premature replacement of sound components (or detailed in-reactor nondestructive inspection of all components) would be prohibitively expensive and time consuming. Conversely, unplanned material failures would result in costly stochastic down time of reactors for maintenance and repair, and could represent a safety concern.

The diverse materials degradation phenomena in nuclear reactors represent several facets of the broader scientific topic of materials in extreme environments. Neutron-induced radiation damage represents a classic example of multi-scale, multi-physics phenomena, where events initiated with nanometer-scale displacement cascades that are created in short ($10^{-15-10-11}$ s) timescales subsequently interact with the surrounding microstructure ($10^{-8}$-$10^{-4}$ m) and evolve over timescales up to multiple decades (>$10^{9}$ s) to produce pronounced structural changes that influence the properties of large scale (~0.01-10 m) components. For example:

- For electrical cables, basic information is lacking regarding the roles of prolonged exposure to moisture, radiation, temperature, mechanical stress, and electrical fields on the properties of the polymeric insulation. The general influence of the complex residual stress states associated with structural material joining operations on stress corrosion cracking (including radiation-induced stress relaxation and flow localization phenomena) is not well understood.

- For the reactor pressure vessel steel, current models predict a late-term formation of solute clusters that may cause significant hardening and embrittlement for operational lifetimes well beyond 40 years; experimental validations of the model predictions are needed to develop accurate estimates of the allowable reactor lifetimes.

Long-term operations of our LWR fleet require the ability to confidently predict the performance, safety, and reliability of these reactors 20 to 40 years into the future. Certification of extended operations will be a balance between the confidence in our ability to predict safe performance of existing systems and the economic viability of replacing systems or components. The power companies perform extensive cost and risk mitigation analyses, and the significant uncertainties in component or system performance predictions can cause a plant to resort to perhaps prematurely replacing a component or system to minimize risk.

Often fundamental R&D can reduce these uncertainties and hence the risk and cost of extending long-term operations for a power plant. Advanced understanding of the mechanisms of materials degradation and aging allows performance prediction models to be more science-based. Early models based on empirical data can offer a large degree of confidence in performance prediction of current operations, but science-based models are needed for prediction of performance outside of the empirical database.

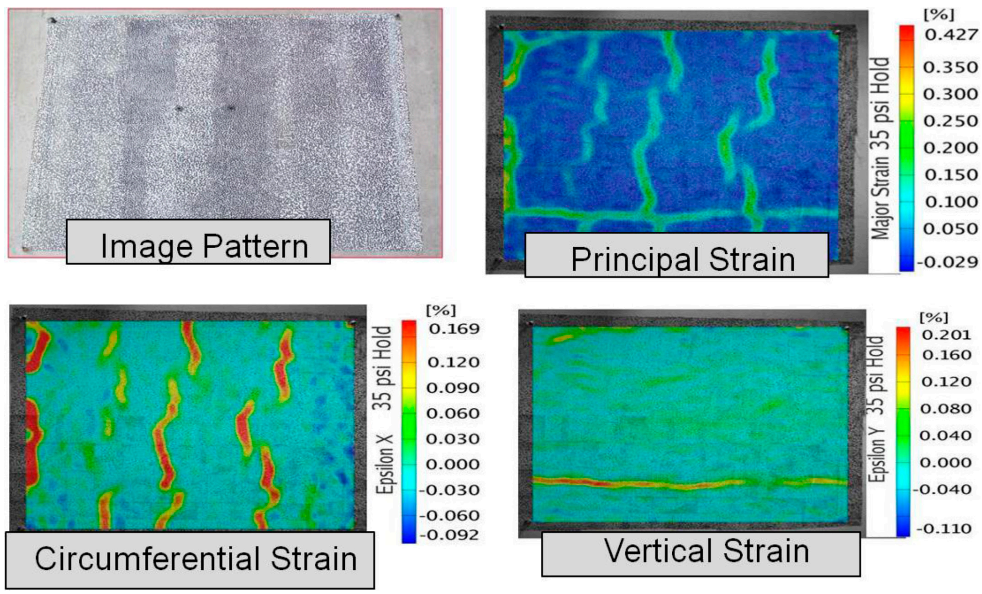


**Figure 6.**
Digital Image Correction Test Results Showing Strain Behavior on Concrete Surface.

Experimental data are still needed for both model development and validation. However, we cannot wait 20-40 years to collect the applicable aging data needed for a certification process planned for the next 10 years. Therefore, accelerated aging will be a critical component of our experimental measurements. Accelerated aging comes with certain risks. Questions remain as to whether higher dose rate experiments can be extended to lower dose rate applications; uncertainty exists in the applicability of elevated temperature experiments, which may increase the kinetics, to normal operating temperature conditions. These extrapolation uncertainties can be reduced through the development of improved science-based models.

*Advanced Instrumentation, Information and Control Systems Technologies*

This research pathway supports modernization of current nuclear power plant instrumentation and control (I&C) technologies through development/testing of new I&C technologies and advanced condition monitoring technologies for more automated and reliable plant operation. The R&D products will be used to design and deploy new I&C technologies and systems in existing nuclear power plants to provide a better understanding of plant operating conditions and available margins. These new technologies should also improve response strategies and capabilities for operational events. The goals are to enhance nuclear safety, increase productivity, and improve overall plant performance. This transformation is critical to addressing an array of issues facing plants, including the aging of legacy analog I&C systems, a potential shortage of technical workers, a continued focus on nuclear safety improvement, and relentless pressure to reduce costs.

A series of pilot projects are underway to enable a smooth transition to modernization of I&C technologies. The projects represent a means to transform the operating model of nuclear power plants from one that is highly reliant on a large staff performing mostly manual activities to an operating model based on highly integrated technology and a smaller staff.

*Risk Informed Safety Margin Characterization*

The Risk-Informed Safety Margin Characterization (RISMC) Pathway is developing a methodology to support the management of uncertainty in safety margins quantification to improve operator decision-making in nuclear power plant operations. The RISMC methodology is a combination of probabilistic and mechanistic approaches. The LWRS Program is developing a series of models to support the simulation elements of the RISMC toolkit, including a systems code that will simulate behavior at the plant level using advanced computational tools and techniques to allow faster and more accurate analysis (RELAP-7); a simulation module that provides input on the plant state to RELAP-7 to represent realistic plant behavior during normal and off-normal scenarios (RAVEN); a graphical user interface used to create, control, and interact with the various tools in the RISMC toolkit (Peacock); and an aging simulation model that simulates the physical processes related to time-dependent materials degradation and subsequent damage evolution.

**EPRI-DOE COOPERATION**

Because both DOE and EPRI conduct R&D in technologies that have application to establishing the feasibility of operating commercial light water reactors beyond the current 60-year license limits, it is important that their work be coordinated. An integrated approach to the planning and execution of this R&D will enable both DOE and EPRI to more efficiently establish and fund research projects and avoid duplication of efforts.

In October 2010, DOE and EPRI executed a memorandum of understanding to "establish guiding principles under which research activities (between LWRS and LTO) could be coordinated to the benefit of both parties." The primary focus of the memorandum of understanding is on R&D goals, objectives, and tasks.[9]

Although both programs were established based on the November 2007 LWR R&D Strategic Plan, each program proceeded with unique but complimentary R&D plans and projects. Despite these distinct approaches, both programs continue to cooperate on a range of R&D activities related to extended plant operations. Cooperation includes the sharing of responsibilities (leadership and financial) for conducting portions of large, multi-year R&D projects; the exchange of information on R&D work in areas of mutual interest; and participation (by either the LWRS Technical Integration Office Director or the LTO Manager) in periodic conference calls and meetings (technical and budget program reviews).

9 *Strategic Plan for LWR R&D*, jointly prepared by EPRI and INL for DOE-NE, November 2007; *Life Beyond 60 Workshop Summary Report,* February 19 2009; *The DOE-NE Light Water Reactor Sustainability Research and Development Program Plan,* December 2009; *The EPRI LTO Strategic Plan,* June 13, 2010; *The DOE-NE Light Water Reactor Sustainability Program and EPRI Long-Term Operations Program – Joint Research and Development Plan,* INL/EXT-12-24562, Rev. 2, April 2013.

As acknowledged in the memorandum of understanding, "the technical areas…encompassing each participant's work scope are roughly the same." That is, both organizations have the same objectives to deliver technology on critical issues to inform decisions on life extension and license renewal beyond 60 years. In a few instances, activities are highly collaborative and co-funded—both organizations fund the same activity with the same deliverable. However, in most cases, as stated in the memorandum of understanding, "…the planned work in each program is distinctly different as the result of planning that reduces duplication of effort and takes into account each party's interests and strengths."

At the center of DOE's interest is work to develop new scientific knowledge, models, tools, and technology. DOE brings the strong expertise of national laboratory investigators, unique laboratory capabilities, and relationships with universities and other laboratories. At the center of EPRI's interest is the adaptation, validation, and implementation of technology with deliverables that include databases, guidelines, and pilot applications. EPRI provides global leadership in conducting public interest R&D in collaboration with nuclear utilities. Through joint planning and defined cooperation, the goal is to leverage the diversity between LWRS and LTO to more effectively meet the joint objectives.

The Committee finds that the LWRS and LTO programs have developed a useful pathway of research/surveillance/response that addresses the uncertainties associated with long-term nuclear plant operation. A significant portion of operating nuclear plants will benefit from these programs.

However, with the window of opportunity so short—a mere five years before plants begin facing renewal decisions—additional energy strategy and research pathways can be pursued that would make license renewal for a nuclear plant more feasible, thereby limiting the construction of alternative power generation capacity with other costs and risks, such as a coal or gas plant. Therefore, the Committee recommends three enhanced pathways.

## AN ENHANCED ENERGY STRATEGY PATHWAY

A utility's decision to renew a license will not be based solely on the results of technical evaluations. While an R&D program can provide an estimate of the risks and costs associated with long-term operation, a utility will balance these considerations against the costs of constructing new power generation, such as a coal or natural gas plant.

The decision to replace a nuclear plant with a coal or natural gas plant would have significant emissions consequences:

**Table 1.**
Emissions Produced by 1 Kilowatt-hour of Electricity Based on Life-Cycle Analysis.[10]

| Generation Option | Greenhouse gas emissions gram equiv. (in CO2/kWh) | Sulfur dioxide emissions (in milligrams/kWh) | Nitrogen oxide emissions (in milligrams/kWh) | NMVOC (in milligrams /kWh**) | Particulate matter (in milligrams /kWh) |
|---|---|---|---|---|---|
| Hydropower | 2 – 48 | 5 – 60 | 3 – 42 | 0 | 5 |
| Nuclear | 2 – 59 | 3 – 50 | 2 – 100 | 0 | 2 |
| Wind | 7 – 124 | 21 – 87 | 14 – 50 | 0 | 5 – 35 |
| Solar photovoltaic | 13 – 731 | 24 – 490 | 16 – 340 | 70 | 12 – 190 |
| Biomass forestry waste combustion | 15 – 101 | 12 – 140 | 701 – 1,950 | 0 | 217 – 320 |
| Natural gas (combined cycle) | 389 – 511 | 4 – 15,000[*] | 13 – 1,500 | 72 – 164 | 1 – 10 |
| Coal – modern plant | 790 – 1,182 | 700 – 32,321 | 700 – 5,273 | 18 – 29 | 30 – 663 |

Consequently, the energy strategy environment established by Congress, the Administration, and other institutions on issues such as clean energy or emissions standards can significantly impact a utility's decision on whether to renew a license. Consider three examples:

† For energy security and climate change reasons, the federal government or more individual states could enact a Clean Energy Standard (CES) that includes nuclear power. A CES is a type of electricity portfolio standard that requires electric utilities to supply specified percentages of their electricity sales from qualified energy sources. Some states (e.g. Ohio) have instituted electricity portfolio standards that set requirements for "clean" or "alternative" energy, including not only renewables but also certain non-renewable electricity generation technologies, such as new nuclear power.[11] Such a CES enhances lowest-carbon options over coal or gas plants. Thirty-one states and the District of Columbia have enacted energy standards for the power sector. Sen. Jeff Bingaman (D-NM) proposed a federal CES with the introduction of the Clean Energy Standard Act of 2012 on March 1, 2012, building on the state programs. President Obama has also called for a federal clean energy standard and a national goal of 80% clean energy by 2035.

10 "Hydropower-Internalized Costs and Externalized Benefits," Frans H. Koch. International Energy Agency (IEA)-Implementing Agreement for Hydropower Technologies and Programs, Ottawa, Canada, 2000.

11 *Clean Energy Standards: State and Federal Policy Options and Implications,* Center for Climate and Energy Solutions, November 2011.

† The Environmental Protection Agency (EPA) has proposed numerous regulations implementing the pollution control statutes enacted by Congress. Particular attention is being paid to the Clean Air Act, under which EPA has moved forward with the first federal controls on emissions of greenhouse gases and also addressed emissions of conventional pollutants from a number of industries. The agency says that it is acting on a 2007 Supreme Court ruling that greenhouse gas emissions are air pollutants under the Clean Air Act's definition of that term[12].

† Some financial institutions assess a company's environmental performance using various methods, such as the Environmental Societal Governance (ESG) criteria. These criteria could be applied to license renewal decisions. For example, if a utility were to terminate a nuclear plant and replace it with a coal or natural gas plant, then financial institutions or funds that use ESG might downgrade the stock. Of course, this would only matter to investors who care about ESG, but a recent assessment determined that in 2012 $3.3 trillion in U.S. based assets select or analyze their portfolios based on ESG criteria.[13]

While the Committee does not take a position on the CES, EPA regulations, or ESG criteria, these options are identified as examples of many possible energy strategies that can make lowest-carbon options—including the long-term operation of a nuclear plant—as competitive a choice as the development of a coal or gas plant.

Therefore the Committee recommends:

- **Recommendation #1: An Enhanced Energy Strategy Pathway**

  For as long as licenses can be safely renewed, U.S. energy strategies should make renewal a feasible choice. For example: for energy security and climate change reasons the federal government or more individual states could enact policies that support lowest-carbon sources; or, financial institutions could weight environmental impact in valuating utilities.

### AN ENHANCED RESEARCH PATHWAY

The funding in the LWRS Program is highly leveraged, enabling important contributions to reactor long-term operation studies with modest costs. Providing information in the near term and reducing uncertainty associated with long-term operations are important to informing upcoming decisions on long-term operations. Decisions on extended operation—beyond 60 years—will ultimately rely on economic factors, but the economic outlook for renewing nuclear reactor licenses can be improved through technical advancements.

The current annual budget for the EPRI LTO program is $8 million. The current FY-13 Continuing Resolution (CR) budget for the Light Water Reactor Sustainability Program is $21 million. Note that 20% of the LWRS budget supports the Nuclear Energy University Program and about 2.5% supports various other DOE investments (small business awards, etc.).

Through discussions with independent experts and evaluation of program documents, the Committee found that under the current LWRS budget, the following important activities are not funded:

- Advanced Nuclear Materials Development: materials for use in LWR applications that may provide greater margin, performance, and support to industry partners in their programs

- Environmentally Assisted Fatigue Mechanisms: experimental activities supporting the development of a model for environmentally assisted fatigue

- Thermal Aging Behavior of Cast Stainless Steels: builds a systematic knowledge base for the thermal aging behavior of cast stainless steels

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12 CRS Report R40984, *Legal Consequences of EPA's Endangerment Finding for New Motor Vehicle Greenhouse Gas Emissions,* by Robert Meltz

13 The Forum for Sustainable and Responsible Investment, U.S. SIF, November 14, 2012.

- Verification and Validation (V&V) of RELAP-7: RELAP-7 is the primary safety code used in the Risk Informed Safety Margin Characterization Pathway; V&V is an important step in the development of new safety analysis tools, and development of a V&V plan is needed in the near term

Through discussions with independent experts and evaluation of program documents, the Committee also learned that under the current budget, the following activities are underfunded, thereby delaying the completion of these tasks that provide important input to decisions on long-term operation:

- Cable Performance: supports continued collaboration, analysis, and modeling as material harvesting increases in this high-priority area

- Nondestructive Examination Technologies Development: develops and tests technologies for nondestructive examination of reactor components, important for detecting anomalies before they become issues; the techniques are an important part of plant aging management plans

- Concrete Performance: supports experimental and modeling activities to understand the long-term behavior of concrete

- Instrumentation, Information, and Control Systems Technologies Pathway Pilot Projects: supports execution of a series of pilot projects designed to develop and demonstrate digital technologies to replace the currently-used aging analog technologies

- Safety analysis tools: the Risk Informed Safety Margin Characterization Pathway relies on state-of-the-art tools (including V&V and Uncertainty Quantification) to enable more accurate and efficient models for safety analysis

- Component Aging Modeling: provides a predictive capability for aging of important (and difficult/expensive to replace) components such as the reactor pressure vessel

- Accelerated testing: for developing a better understanding of irradiation and environmental degradation of core materials for long-term operation

The Committee also determined that the DOE program could benefit from deeper predictive capability—of when and how defects emerge and how materials fail—as well as more substantial development of detailed scaling laws that can be used to translate the environmental stresses in commercial reactors and the conditions that can be produced in material test facilities. Validated scaling laws would permit the development of rubrics for accelerated testing of materials that could predict how material properties evolve during the operational lifetime of a plant.

In addition, experimental understanding and diagnostic instrumentation and facilities tools should be supplemented with extensive development of petascale computational tools that will permit combining models for assessment of simultaneous degradation modes including microstructural and microchemistry evolution under prototypic reactor neutron spectra.

Finally, several classes of facilities located in the United States will be needed, as more of the installed U.S. nuclear capacity reaches the point of subsequent licensing:

- Hard X-ray (100–300 keV) and neutron scattering beamlines, capable of handling radioactive materials, to characterize samples of engineering-sized samples pre- and post- reactor irradiation. A full science-based program in support of renewed licensing should have the capability to experimentally characterize, irradiate, and model a prioritized set of controlled materials in multiple environments. Meso-scale samples with a characteristic dimension of 10–30 μm should be measured with resolution at the <10 nm scale.

- At least one test facility for the development and testing of in-situ NDE instruments.

- Facilities for test and evaluation of accelerated aging techniques including an evaluation of energy scaling of damage mechanisms with high- and low-energy ion beams and hadron beams.

- Capability and funding to support large component testing to microstructural examinations at national user facilities capable of handling irradiated samples to provide a range of data from engineering performance to validation of advanced models. Facilities for a demonstrated scientific understanding of the performance, safety & reliability, and degradation phenomena associated with new technology.

A more substantial fundamental research effort would better inform the assessments that will drive a decision whether or not to seek long-term operation. With additional federal resources and matching support from industry, the current $21 million-per-year program at DOE could be made both deeper and broader. It could provide more accurate predictions, leading to a more targeted response that can be expected to buy down risk, reduce uncertainties, and thereby make license renewal more feasible. The research would also provide critical information to establish the necessary regulatory framework for long-term nuclear plant operation. The research would also provide critical information to establish the necessary regulatory framework for long-term nuclear plant operation.

Consequently, the Committee recommends:

- **Recommendation #2: An Enhanced Research Pathway**

  A more substantial fundamental research effort, with a long-term commitment, would better inform the assessments that will drive a decision whether to seek continued operation beyond the current license period. With additional resources, the current program at DOE would grow both deeper and broader serving to buy down risk, and reduce uncertainties.

The Committee strongly supports the integrated DOE-EPRI Joint R&D plan. This plan shows significant coordination between the two agencies in defining research areas that are complementary and not duplicative. To ensure that performance prediction models are at the most advanced state for making cost-risk decisions by power utility companies, the Committee believes that there should be a clearer connection of fundamental R&D milestones in the DOE roadmap to the EPRI milestones in order to maximize the benefits of both programs.

## AN ENHANCED LEADERSHIP PATHWAY

Safe, reliable, clean, low-cost electricity is the objective of countries world-wide, and many are turning to nuclear energy to reach this goal. The U.S. has led the development of commercial nuclear energy since its inception, and today stands as the gold standard in safe and reliable operation of its plants. In 2011, the operational nuclear plants in the U.S. accounted for 63% of the country's emission-free electricity[14]. With a capacity factor of nearly 90% across the entire fleet[15], nuclear plants are producing electricity more of the time than any other power source in the country. This high availability has contributed to nuclear energy being the lowest-cost source of electricity in the U.S. through 2011. This successful U.S. leadership in the development and operation of commercial nuclear power programs has made it a focus of global attention.

Safe and reliable use of this valuable energy resource is a result of over 50 years of experience, reinforced by a sustained research effort on the part of the U.S. government and industry. It is imperative that new entrants into commercial nuclear power are guided by the best practices developed over the last half decade in the U.S. The investment in nuclear energy in some countries is impressive and growing. Leading the list is China, with 17 nuclear power reactors in operation, 28 under construction, and more about to start construction[16]. Countries that are building reactors are new to the commercial nuclear power field and would benefit greatly by drawing on U.S. experience. More importantly, U.S. presence in these programs is vital to ensuring safety not only in the operation of the plants, but in neighboring countries that may be affected by lapses in operational vigilance. Perhaps most important to U.S. and international security is continuing U.S. leadership in safeguarding against proliferation. However, none of this is possible unless the U.S. remains a leader in commercial nuclear power operations and development.

14 Young, G. (February 14, 2013, APS POPA Nuclear Reactor Lifetime Extension Study Committee Workshop) *License Renewal Process Status and Technical Needs* [PowerPoint slides]

15 90% capacity factor (NEI, ANS)

16 World Nuclear Association, updated 19 February 2013. http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/China--Nuclear-Power/#.UTuFzRklh0A.

As nuclear power programs around the world mature, commercial power providers will look to the U.S. to provide leadership in reactor sustainability. Yet U.S. leadership in today's light water reactors is insufficient to maintain the lead in nuclear technology. India is building several fast reactors using technology developed in the U.S. in the 1980s. China has recently commissioned its first fast-spectrum test reactor to join the increasing international interest in this reactor design for future nuclear power program development.

It is essential that the U.S. have the technical expertise and appropriately skilled workforce in order to lead. The need for a continuous and enduring supply of well-trained and educated experts is essential to ensuring the country's safety, security, and power supply. Nuclear workforce needs are well documented.[17]

U.S. leadership also requires a concentrated federal effort to continue nuclear development, in areas such as small modular reactors.[18] This can be done as part of other programs such as the Advance Manufacturing Partnership that President Obama proposed expanding in his 2013 State of the Union Address.

Whatever pathways are pursued, the renewal of licenses is not an end in itself. The current fleet of nuclear reactors cannot be indefinitely renewed. However, while renewal is not a long-term solution, these reactors operate safely and reliably, and renewal of their licenses does provide valuable time to establish a balanced and durable energy future for the nation. That time must be used to develop a clean energy future that should include, in part, the re-establishment of U.S. leadership in nuclear energy technology as urged by the American Physical Society,[19] so that the U.S. remains at the forefront of nuclear energy practice and understanding.

The Committee therefore recommends:

- **Recommendation #3: An Enhanced Leadership Pathway**

  The U.S. government should have a concentrated program to support the development, manufacturing and licensing of new nuclear reactors that can be built, operated, and eventually decommissioned in a manner that is safe, environmentally sound, and cost-effective.

## IN SUMMARY

Safe and economical long-term operation of the nation's nuclear plants accomplishes several things: it keeps an essential, clean and secure energy asset available and sustains the operational infrastructure needed to re-establish the nation's leadership position in nuclear power. This report identifies three distinct actionable pathways to achieve these critical national goals.

17 Readiness of the U.S. Nuclear Workforce for 21st Century Challenges, June 2008, http://www.aps.org/policy/reports/popa-reports/upload/Nuclear-Readiness-Report-FINAL-2.pdf; Human Capitol Crisis Task Force Report, http://hps.org/documents/ManpowerTaskForceReport.pdf; Statement by the NEA Steering Committee for Nuclear Energy on a government role to ensure qualified human resources in the nuclear field, 2007, http://search.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=NEA/COM(2007)5&docLanguage=En World Nuclear Association, updated 19 February 2013. http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/China—Nuclear-Power/#.UTuFzRklh0A.

18 Blue Ribbon Commission on America's Nuclear Future, January 2012.

19 APS, Statement on Nuclear Energy, 1993, http://www.aps.org/policy/statements/93_7.cfm

# APPENDIX A: CONDUCT OF THE STUDY

The impetus for the present study originated from discussions in the APS Panel on Public Affairs (POPA) Subcommittee on Energy and Environment on the need for a technical study to examine renewing the operating licenses for U.S. nuclear power reactors, timeliness of such a study, and the appropriateness for APS/POPA to sponsor it. A steering group was formed of POPA members Dahlberg, Rosner, and Schwitters and POPA Advisor Slakey, charged to develop a specific proposal to POPA to conduct such a study.

The steering group met with U.S. government officials involved in nuclear energy to assess the most important areas that a study might consider and canvassed prominent members of the research community active in power plant aging. As part of this background effort, the steering group identified nationally prominent experts in materials and operations of nuclear plants who were invited to serve on the Study Committee. Everyone we invited to join agreed to serve and all made substantial contributions to this report. The key input-gathering event proposed for the study was a workshop for Study Committee members where other experts would be invited to present their views on topics selected by the Study Committee.

The final proposal, including membership and details of the study schedule and deliverables, was approved by POPA in October 2012. Working with the full Study Committee, the study workshop was planned and nationally prominent participants were selected. Again, the interest in this question and importance of having an up-to-date independent technical assessment of the issues led to unanimous acceptance of our invitations to participate. The workshop was held February 14-15, 2013 in Washington, DC. The workshop speakers and their topics are listed in Appendix II.

The basic objective for the study, as identified in the proposal, was to "produce a POPA report that: 1) identifies technical challenges associated with extending nuclear reactor lifetimes from the current 60 years to 80 years; and, 2) determine whether the nascent federal R&D program or, indeed, other possible technical approaches in this area would be sufficient and appropriate to address those challenges."

The study's main deliverable was to "produce a report of no more than 25 pages with actionable policy recommendations. The primary audiences would be: 1) the Members of Congress and staff on the relevant Committees; and 2) the relevant staff within the Administration including the Office of Science and Technology Policy and the office of Nuclear Energy within the Department of Energy. If the report considers any appropriations recommendations, they will be vetted by the APS Physics Policy Committee."

The Study Committee Chair invited Marvin Adams, Director of the Institute of National Security Education & Research, Nuclear Engineering, Texas A&M University; Richard Meserve, President, Carnegie Institution for Science; and Victor H. Reis, Senior Policy Advisor, U.S. Department of Energy, to review and comment on a nearly final draft version of the report. The Committee acknowledges their critical contributions and insights to this report.

The report was supported and overseen by the APS Panel on Public Affairs. The findings and recommendations contained in this report do not necessarily represent the views of the APS Council or the APS membership.

## APPENDIX B: WORKSHOP TOPICS & GUEST EXPERTS

**U.S. Department of Energy Perspective & Plans**
Peter Lyons, U.S. Department of Energy
Rebecca Smith-Kevern, U.S. Department of Energy
Richard Reister, U.S. Department of Energy

**U.S. Nuclear Regulatory Commission Perspective**
Richard Meserve, Former NRC Chairman
Allen Hiser, Jr., NRC

**Technical Needs—An Industry Perspective**
Garry Young, Entergy
Raj Pathania, EPRI
Steve Fyfitch, AREVA, Inc.
Peter Andresen, GE

**The Role of Government in Supporting Lifetime Extension R&D**
Pete Miller, Bipartisan Policy Center

**Research Community Perspective**
Sherry Bernhoft, EPRI
Jeremy Busby, ORNL
Dan Naus, ORNL
Ron Balinger, MIT

## APPENDIX C: GLOSSARY OF ACRONYMS

| | |
|---|---|
| **AEA** | Atomic Energy Act of 1954 |
| **AMP** | Aging Management Program |
| **EMDA** | Expanded Materials Degradation Assessment |
| **EPRI** | Electric Power Research Institute |
| **I&C** | Instrumentation & Control |
| **LTO** | Long-Term Operation (program) |
| **LWRS** | Light Water Reactor Sustainability |
| **NEPA** | National Environmental Policy Act |
| **NPPs** | Nuclear Power Plants |
| **NRC** | Nuclear Regulatory Commission |
| **PEO** | Period of Extended Operation |
| **POPA** | APS Panel on Public Affairs |
| **RISMC** | Risk-Informed Safety Margin Characterization |
| **SLR** | Subsequent License Renewal |
| **SSCs** | Structures, Systems, and Components |

In accordance with the Atomic Energy Act of 1954 (AEA), the U.S. Nuclear Regulatory Commission issues licenses to owners of commercial power reactors for operation up to 40 years. The term in the original license was set by Congress for economic and anti-trust reasons, not due to limitations in nuclear technology or design.

The AEA allows reactor operators to renew their operating licenses after the initial 40-year license period. As such, NRC regulations permit holders of operating licenses for commercial reactors to apply for renewed licenses to operate their plants for up to 20 years beyond the initial 40-year license. The decision to pursue license renewal rests solely with the plant owners. The decision is typically based on the plant's ability to both satisfy NRC requirements and remain economically competitive in the local electric power generation market. The NRC's review of a license renewal application focuses not on economics, but on providing reasonable assurance that the plant's current licensing basis (i.e., the set of requirements upon which the plant license was issued) will maintain an acceptable level of safety for the period of extended operation (PEO).

As illustrated in the diagram below, the license renewal process involves two separate review tracks —a safety review and an environmental review.

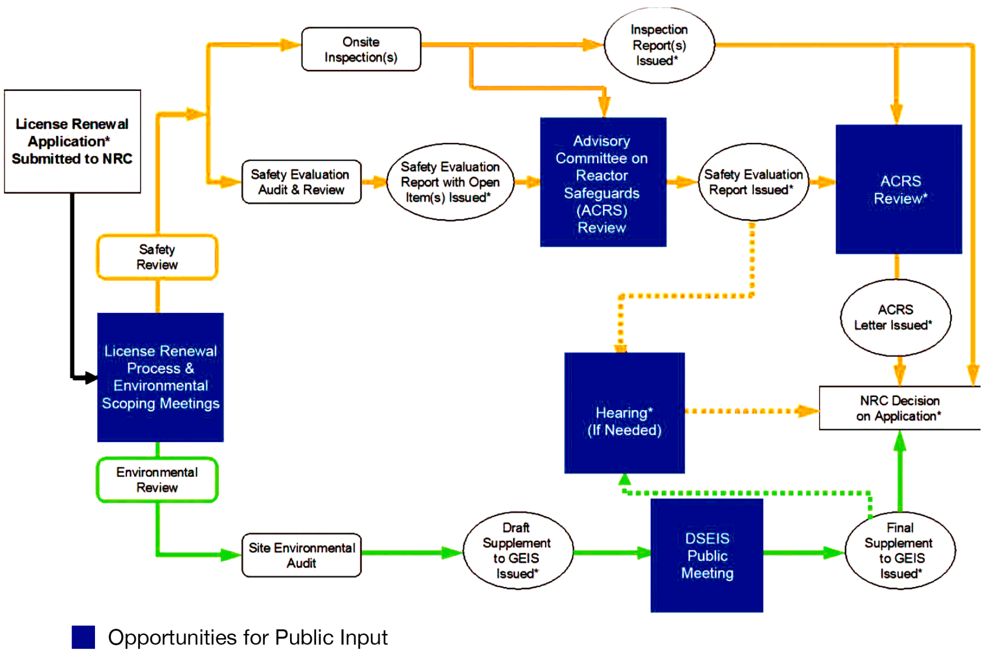


**Figure D1.**
The License Renewal Process.[20]

The regulatory requirements for a license renewal safety review are provided in Title 10 to the Code of Federal Regulations, Part 54 (10 CFR Part 54). Those requirements emerged from more than a decade of research on nuclear plant aging effects and safety demonstration activities with industry, which helped to focus the review requirements on managing the adverse effects of plant aging. Applicants for renewed licenses must identify all plant systems, structures, and components that are safety-related, whose failure could affect safety-related functions, and that are relied on to demonstrate compliance with the NRC's regulations for fire protection, environmental qualification, pressurized thermal shock, anticipated transients without scram, and station blackout. The license renewal safety reviews are primarily concerned with long-lived components that are not part of ongoing maintenance and replacement activities. Aging management programs must be in place to ensure these components undergo inspection, testing, or other verification to ensure that they can perform important safety functions during the PEO. The applicant for a renewed operating license must also provide information demonstrating that critical plant calculations have been updated to reflect additional years of operation.

20 Available at http://www.nrc.gov

Plant-specific reviews of the environmental impacts of license renewal are performed by the NRC in accordance with the National Environmental Policy Act (NEPA) and the NRC's own environmental regulations (10 CFR Part 51). Some issues are evaluated generically for all plants, rather than separately in each plant's renewal application. These generic evaluations assess the scope and impact of environmental effects that would be associated with license renewal at any nuclear power plant site, such as impacts the facility will have on endangered species, and particularly the impacts of cooling water systems on fish, shellfish, and overall ground water quality. A plant-specific supplement to the generic evaluation is required for each application for license renewal.

The conclusions from the safety and environmental reviews are subject to public participation through open meetings to discuss the license renewal application and NRC review results and, where required, hearings to address legal contentions. The Advisory Committee for Reactor Safeguards performs an independent assessment of the NRC's safety review. The license renewal work is also supported by plant inspections, both during the application review and before the plant begins operations beyond 40 years.

In addition to 10 CFR, Parts 51 and 54 cited above, a number of regulatory guidance documents have been developed as a result of the collective efforts of the NRC and industry to prepare, evaluate, and make decisions on license renewal applications.[21]

This substantial body of requirements and guidance, combined with the NRC's commitment to complete reviews of license renewal applications within two years, has provided the regulatory stability needed to implement the license renewal process. As of the end of 2012, nearly three-quarters of the U.S. commercial reactor fleet has received renewed 20-year operating licenses from the NRC.

As the initial round of license renewals enters its concluding phase, attention is turning to investigating the feasibility of commercial power reactors receiving a follow-on renewal to the once-renewed operating licenses (i.e. operation beyond 60 years). The first commercial power reactor 60-year operating license will expire in 2029. However, plant owners must begin planning years in advance of the license expiration date to either pursue a second 20-year renewal of the license (now referred to as Subsequent License Renewal, [SLR]), or to develop or acquire new baseload power generation sources while, at the same time, initiating work that will lead to reactor decommissioning.

Early planning and decision-making are especially important when plant owners are faced with the possible need to replace large components (reactor vessel heads, steam generators, turbines, transformers, etc.); in those instances, lead times of several years are required to receive the components when they will be needed. Further, additional years of plant operations allow the owners to amortize and depreciate the costs. However, it is important to note that, far from being unique to the license renewal decision-making process, such activities are already part of the day-to-day operations of a single nuclear plant or a fleet of reactors. For example, in 2011 alone, capital investments to upgrade and maintain plant systems exceeded $7 billion.

Still, the challenge remains for industry to satisfy itself and the NRC that nuclear power plants can be safely operated beyond 60 years. Efforts during development of the first license renewal process to establish necessary and sufficient AMPs for managing the aging process are expected to provide a sound technical basis for SLR. However, all parties involved recognize the need for a more thorough understanding of materials degradation, management of aging components, and the technical basis for continued safety during an additional 20 years of operation.

21 NUREG-1412, "Foundation for the Adequacy of the Licensing Basis – A Supplement to the Statement of Considerations for the Rule on Nuclear Power Plant License Renewal (10 CFR Part 54)"; NUREG-1437, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants"; NUREG-1555, "Standard Review Plans for Environmental Reviews for Nuclear Power Plants: Environmental Standard Review Plan (with Supplement 1 for Operating Reactor License Renewal)"; NUREG-1800, "Standard Review Plan for Review of License Renewal Applications for Nuclear Power Plants"; NUREG-1801, "Generic Aging Lessons Learned (GALL) Report"; NEI 95-10, "Industry Guidelines for Implementing the Requirements of 10 CFR Part 54 – The License Renewal Rule"; Regulatory Guide 1.188, "Standard Format and Content for Applications To Renew Nuclear Power Plant Operating Licenses" (endorses NEI 95-10, Revision 6); Regulatory Guide 4.2, Supplement 1, "Preparation of Supplemental Environmental Reports for Applications to Renew Nuclear Power Plant Operating Licenses"

The NRC and the DOE are producing an Expanded Materials Degradation Assessment (EMDA), which builds on the earlier Proactive Materials Degradation Assessment (NUREG/CR-6923) to include longer time frames and passive long-lived structures and components. Memoranda of understanding between DOE, NRC, and EPRI help to ensure that the research activities are coordinated and the results are shared. DOE and NRC held joint workshops in February 2008 and February 2011 to facilitate discussion among these agencies, the nuclear industry, national laboratories, academia, and the public. The workshops focused on such areas as SSC aging, materials degradation, diagnostic and prognostic technologies, and future technical and research requirements for supporting plant operation beyond 60 years. Finally, collaborations with international groups (Materials Aging Institute, International Forum for Reactor Aging Management, etc.) are in progress to exchange information on operating experience, best practices, and emerging knowledge.

As for the regulatory framework supporting SLR, the nuclear industry believes the current framework for the first round of license renewals, combined with effective implementation of AMPs and plant operating experience, should suffice. However, the NRC has indicated that a reassessment of the regulatory framework and requirements to be applied for SLR is in progress. Public workshops and webinars were held in 2012 to collect information on technical and policy issues, and will be considered in preparation for the expected receipt of SLR applications from licensees.