INL/EXT-12-24562
Revision 4

# DOE-NE Light Water Reactor Sustainability Program and EPRI Long Term Operations Program – Joint Research and Development Plan

April 2015

U.S. Department of Energy
Office of Nuclear Energy

INL/EXT-12-24562
Revision 4

# DOE-NE Light Water Reactor Sustainability Program and EPRI Long Term Operations Program – Joint Research and Development Plan

**April 2015**

**Idaho National Laboratory**
**Idaho Falls, Idaho 83415**

**http://www.inl.gov**

**Prepared for the**
**U.S. Department of Energy**
**Office of Nuclear Energy**
**Under DOE Idaho Operations Office**
**Contract DE-AC07-05ID14517**

# DOE-NE Light Water Reactor Sustainability Program and EPRI Long Term Operations Program – Joint Research and Development Plan

**Revision 4**

**April 2015**

**Approved by**

Kathryn McCarthy, Ph.D. — Date: 6-3-15
Light Water Reactor Sustainability Technical Integration Office Director, INL

Richard Reister — Date: 6/3/15
Light Water Reactor Sustainability Federal Program Director, DOE-NE

Sherry Bernhoft — Date: 6/3/2015
Long Term Operations Program Manager, EPRI

# SUMMARY

Nuclear power has safely, reliably, and economically contributed almost 20% of the total amount of electricity generated in the United States over the past two decades. High capacity factors and low operating costs make nuclear power plants some of the most economical power generators available. Further, nuclear power remains the single largest contributor (more than 60%) of non-greenhouse-gas-emitting electric power generation in the United States. Even when major refurbishments are performed to extend operating life, these plants continue to represent cost-effective, low-carbon assets to the nation's electrical generation capability.

At present, over three-quarters of the nuclear power plants in the United States have received a renewed operating license from the U.S. Nuclear Regulatory Commission (NRC), permitting those plants to operate up to 60 years. By the end of 2015, more than one-third of the existing domestic fleet will have passed their 40th anniversary of power operations, and about one-half of the fleet will reach the same 40-year mark within this decade. A regulatory process exists (10 CFR Part 54) for obtaining approval from NRC on extended nuclear power plant operations beyond 60 years. However, NRC will require nuclear power plants that choose to apply for a second renewal of their operating license (identified as "Subsequent License Renewal" by NRC; industry uses the term "Second License Renewal") to demonstrate that adequate design and operational safety margins will be maintained over the duration of the extended operations period.

While recent, overall performance has been excellent (average capacity factors exceeding 90%), the fleet is facing a number of technical challenges related to long-term operations. If current nuclear power plants do not operate beyond 60 years, the total fraction of domestic electrical energy generated from nuclear power will begin to decline—even with the expected addition of new nuclear generating capacity. Replacing these units will require long-lead planning periods (i.e., 10 to 15 years prior to unit retirement). In addition, significant capital investments (hundreds of billions of dollars) will be needed to design, construct, and commission the replacement generation capacity. Further, if the new capacity has to meet any carbon-neutral criteria (i.e., the replacement units must not produce more greenhouse gas emissions than the units being retired), costs for replacement generation capacity will be even higher.

Recognizing the challenges associated with pursuing extended service life of commercial nuclear power plants, the U.S. Department of Energy's (DOE) Office of Nuclear Energy (NE) and the Electric Power Research Institute (EPRI) have established separate but complementary research and development (R&D) programs (DOE-NE's Light Water Reactor Sustainability [LWRS] Program and EPRI's Long Term Operations [LTO] Program) to address these challenges. Since calendar year 2010, the LWRS and LTO Programs have cooperatively pursued extensive, long-term R&D activities related to the ability (from a material and economic perspective) of operating the existing fleet for periods up to 80 years and beyond. Contributions to date have advanced the state of knowledge on the measured and predicted performance of materials (e.g., metals, concrete, and cabling) used in nuclear power plant systems, structures, and

components; improved analysis methods and tools for understanding safety margins; and advanced instrumentation, information, and control technologies with no generic technical barriers identified that would make long-term plant operations infeasible. The R&D activities of both programs, including progress achieved and plans for continued work, are described herein.

To ensure that a proper linkage is maintained between the programs, DOE-NE and EPRI executed a memorandum of understanding in late 2010 to "establish guiding principles under which research activities (between the LWRS and LTO Programs) could be coordinated to the benefit of both parties." The memorandum of understanding calls for DOE-NE and EPRI to "provide and annually update a coordinated plan for the LWRS and LTO programs. The plan should provide for the integration of the separate LWRS and LTO Program Plans at the project level, showing project scope, schedule, budgets, and key interrelationships between the LWRS and LTO programs, including possible cost sharing." This document represents the fourth annual revision to the initial version (March 2011) of the plan, as called for in the memorandum of understanding.

# CONTENTS



# TABLES

# ACRONYMS

| | |
|---|---|
| AMP | Aging Management Program |
| ASR | Alkali Silica Reaction |
| BWR | Boiling Water Reactor |
| CASS | Cast Austenitic Stainless Steel |
| DOE | U.S. Department of Energy |
| EAF | Environmentally Assisted Fatigue |
| EMDA | Expanded Materials Degradation Assessment |
| EPRI | Electric Power Research Institute |
| IASCC | Irradiation-Assisted Stress Corrosion Cracking |
| I&C | Instrumentation and Control |
| II&C | Instrumentation, Information, and Control |
| ILCM | Integrated Life-Cycle Management |
| IMT | Issues Management Table |
| INL | Idaho National Laboratory |
| ITT | Issue Tracking Table |
| LTO | Long Term Operations |
| LWR | Light Water Reactor |
| LWRS | Light Water Reactor Sustainability |
| MAaD | Materials Aging and Degradation |
| MDM | Materials Degradation Matrix |
| MOOSE | Multi-physics Object Oriented Simulation Environment |
| NDE | Nondestructive Examination |
| NE | Office of Nuclear Energy |
| NEI | Nuclear Energy Institute |
| NRC | U.S. Nuclear Regulatory Commission |

| | |
|---|---|
| PWR | Pressurized Water Reactor |
| R&D | Research and Development |
| RAVEN | **R**eactor **A**nalysis and **V**irtual Control **EN**vironment |
| RELAP | **R**eactor **E**xcursion and **L**eak **A**nalysis **P**rogram |
| RIMM | Risk-Informed Margin Management |
| RISMC | Risk-Informed Safety Margin Characterization |
| RPV | Reactor Pressure Vessel |
| RST | Reactor Safety Technologies |
| SCC | Stress Corrosion Cracking |
| SLR | Second License Renewal (Subsequent License Renewal for NRC) |
| SSC | Systems, Structures, and Components |

# DOE-NE Light Water Reactor Sustainability Program and EPRI Long Term Operations Program – Joint Research and Development Plan

## 1. BACKGROUND

### 1.1 U.S. Department of Energy Office of Nuclear Energy

The U.S. Department of Energy Office of Nuclear Energy (DOE-NE) conducts research and development (R&D) on nuclear energy to advance nuclear power as a resource capable of meeting U.S. energy, environmental, and energy security needs by resolving technical, cost, safety, proliferation resistance, and security barriers through research, development, and demonstration activities, as appropriate. DOE-NE's Office of Light Water Reactor Technologies, NE-72, and the program Technical Integration Office, located at the Idaho National Laboratory (INL), manage R&D efforts under the Light Water Reactor Sustainability (LWRS) Program.

### 1.2 Electric Power Research Institute

The Electric Power Research Institute (EPRI) conducts R&D in the public's interest, mostly with funding provided by its membership and the electric utility industry, with respect to the production, transmission, distribution, and utilization of electric power, including research designed to improve the safety, reliability, and economy of nuclear power plants. R&D efforts in the Long Term Operations (LTO) Program are managed as a separate technical program operating in the External Affairs Department of the EPRI Nuclear Power Sector, with the guidance of an industry advisory Integration Committee.

### 1.3 Research and Development Cooperation

The DOE-NE and EPRI R&D activities directed at providing the technical foundations for licensing and managing the long-term safe and economical operation of commercial nuclear power plants are described in the following documents:

1. Light Water Reactor Sustainability Program Integrated Program Plan (April 2015)

2. EPRI Long Term Operations Program Plan (July 2014).

In late 2010, DOE-NE and EPRI executed a memorandum of understanding[a] to "establish guiding principles under which research activities (between the LWRS and LTO Programs) could be coordinated to the benefit of both parties." This 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 in periodic conference calls and meetings (technical and budget reviews) for the other program.

a. "Memorandum of Understanding Between United States Department of Energy (DOE) and The Electric Power Research Institute (EPRI) on Light Water Reactor Research Programs," dated November 1, 2010, and signed by John E. Kelly, Deputy Assistant Secretary for Nuclear Reactor Technologies, Office of Nuclear Energy, DOE and Neil Wilmshurst, Vice President Nuclear, EPRI.

The work funded and managed by DOE under the LWRS Program is laid out along the following R&D pathways:[b]

1. Materials Aging and Degradation (MAaD)

2. Risk-Informed Safety Margin Characterization (RISMC)

3. Advanced Instrumentation, Information, and Control (II&C) Systems Technologies

4. Reactor Safety Technologies (RST; added in 2014).

The work funded and managed by EPRI under their LTO Program is organized and managed in the following work areas:

1. Primary System Metals Aging

2. Concrete Structures, including Containment Degradation

3. Cable Aging

4. Instrumentation and Control (I&C) and Information Technology (including online monitoring of critical equipment)

5. Advanced Safety and Risk Analysis Tools

6. Aging Management Program Scope for Operation Beyond 60 Years

7. Integrated Strategy, Process Plan, and Demonstration Plants.

As acknowledged in the memorandum of understanding, "the technical areas above encompassing each participant's work scope are roughly the same;" that is, both organizations have the same objectives to deliver technology on critical issues in a timely manner to inform decisions on life extension and license renewal. LTO Technical Area 6, Aging Management Program Scope, currently is an exception for which there is no corresponding LWRS Program pathway. In a few cases, 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 are adaptation, validation, and implementation of technology with deliverables such as databases, guidelines, and pilot applications. EPRI brings global leadership in conducting public interest R&D with collaboration from nuclear utilities. Through joint planning and defined cooperation, the intent is to leverage the diversity between the LWRS and LTO Programs to more efficiently and effectively meet the joint objectives.

b. A fifth pathway, Advanced Light Water Reactor Fuels, was transitioned to the DOE-NE Fuel Cycle R&D Program under the advanced fuels activity at the beginning of Fiscal Year 2014.

# 2. DESCRIPTION OF RESEARCH AND DEVELOPMENT PROGRAMS

## 2.1 Department of Energy Office of Nuclear Energy Light Water Reactor Sustainability Program

For the LWRS Program, “sustainability” is defined as the ability to maintain safe and economic operation of the existing fleet of nuclear power plants for a longer-than-initially-licensed lifetime. It has two facets with respect to long-term operations: (1) manage the aging of hardware so the nuclear power plant lifetime can be extended and the nuclear power plants can continue to operate safely, efficiently, and economically; and (2) provide science-based solutions to industry to implement technology to exceed the performance of the current labor-intensive business model and practices.

In April 2010, DOE-NE’s R&D Roadmap was issued. The roadmap organized DOE-NE activities in accordance with four objectives that ensure nuclear energy remains a compelling and viable energy option for the United States. Objective 1 of the roadmap focuses on developing the technologies and other solutions that can improve reliability, sustain safety, and extend the life of the current fleet of commercial nuclear power plants. The LWRS Program is the primary programmatic activity that addresses Objective 1. The LWRS Program is focused on the following three goals:

1. Developing the fundamental scientific basis to understand, predict, and measure changes in materials and systems, structures, and components (SSCs) as they age in environments associated with continued long-term operation of existing nuclear power plants

2. Applying this fundamental knowledge to develop and demonstrate methods and technologies that support safe and economical long-term operation of existing nuclear power plants

3. Researching new technologies to address enhanced nuclear power plant performance, economics, and safety.

Through the LWRS Program, DOE collaborates with industry and interfaces with the U.S. Nuclear Regulatory Commission (NRC) in appropriate ways to support and conduct the long-term research needed to inform major component refurbishment and replacement strategies, performance enhancements, nuclear power plant license extensions, and age-related regulatory oversight decisions. The DOE role focuses on aging phenomena and issues that require long-term research and are generic to reactor type.

The LWRS Program consists of the following primary technical areas of R&D:

1. ***MAaD*** with R&D to develop the scientific basis for understanding and predicting long-term environmental degradation behavior of materials in nuclear power plants. The work will provide data and methods to assess the performance of SSCs essential to safe and sustained nuclear power plant operations. The R&D products will be used to define operational limits and aging mitigation approaches for materials in nuclear power plant SSCs that are subject to long-term operating conditions, providing key input to both regulators and industry.

2. ***RISMC*** with R&D to develop and demonstrate approaches to support the management of uncertainty in safety margins quantification to improve decision making for nuclear power plants. This pathway will (1) develop and demonstrate a risk-assessment method tied to safety margin quantification and (2) create advanced tools for safety assessment that enable more accurate representation of nuclear power plant safety margins and their associated impacts on operations and economics. The R&D products will be used to produce state-of-the-art nuclear power plant safety analysis information that yields new insights on actual nuclear power plant safety and

operational margins and permits cost-effective management of those margins during periods of extended operation.

3. ***Advanced II&C Systems Technologies*** with R&D to address long-term aging and modernization of current 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 II&C technologies and systems in existing nuclear power plants that provide an enhanced understanding of plant operating conditions, available margins, and improved response strategies and capabilities for operational events.

4. ***RST*** with R&D to improve understanding of beyond design basis events and reduce uncertainty in severe accident progression, phenomenology, and outcomes using existing analytical codes and information gleaned from severe accidents, in particular the Fukushima Daiichi events. This information will be used to aid in developing mitigating strategies and improving severe accident management guidelines for the current light water reactor fleet.

Public Law 109-58 (National Energy Policy Act of 2005, EPAct 2005) and Congressional language establish a clear expectation that the DOE-NE funding for LWRS Program activities will be supported by industry to "cost share" the overall R&D effort. Cost sharing of LWRS Program R&D projects by industry ensures that federal funding is leveraged on the most important technical challenges relative to long-term operations of the current reactor fleet. Each LWRS Program pathway considers cost-share contributions from industry as part of the R&D selection process. In 2015, the value of industry cost sharing for LWRS Program R&D activities is approximately $30.45 million. This compares to 2013 and 2014 values of $17.9 million and $22.0 million, respectively. The major elements of this cost sharing include the value of in-kind contributions of services/resources (subject matter expert involvement in R&D projects, shared test data, and donated/shared materials for testing). Details are provided in an appendix to this plan.

## 2.2 Electric Power Research Institute Long Term Operations Program

High capacity factors and low operating costs make nuclear power plants some of the most safe and most economical power generators available. Even when major plant components must be upgraded to extend operating life, nuclear power plants often represent a safe, cost-effective, low-carbon asset. The decision to extend nuclear power plant life involves inter-related technical, economic, regulatory, and public policy issues. Unknown or uncertain technical inputs impact the decision-making process both directly and indirectly: directly through design and operational contingencies and indirectly through impacts on regulatory actions and public policy.

Recognizing the many technical challenges confronting nuclear power plant operation, EPRI launched the LTO Project in 2009. LTO is defined as being high-performance nuclear power plant operation under extended service conditions. High performance is measured by reliability, availability, cost of operations, and safety.

The LTO Project at EPRI is justified by the potential benefits that long-term operations present to society and to member companies. In 2011, the EPRI LTO Project was elevated to program status and is funded by all EPRI Nuclear Sector members. However, success is contingent on timely and useful products. LTO products must provide a sound technical basis for decisions necessary to achieve high-performance nuclear power plant operation under extended service conditions. Specifically, LTO Program projects must address one or more of the following:

1. License renewal for long-term nuclear power plant operation

2. Aging management and life-cycle management throughout long-term operation

3. Opportunities for modernization and performance improvement.

Criteria for selecting technical areas and specific work scopes within technical areas are as follows:

1. Projects address one or more of the following needs:

    a. Identify and characterize (or dismiss) a potential life-limiting issue

    b. Support aging management and life-cycle management

    c. Provide opportunities for modernization

    d. Develop enabling technology (e.g., analysis methods) that will be needed to enhance performance or reduce cost.

2. Useful results are planned for the timeframe to 2019 to support the expected need for decision making.

3. It is unlikely that the planned R&D would be performed within other programs at EPRI.

4. EPRI involvement is necessary to provide industry input to R&D efforts with collaborating partners such as the DOE-NE LWRS Program or NRC's Office of Nuclear Regulatory Research.

The R&D portfolio addresses the following seven technical areas and associated principal objectives:

1. For ***primary system metals***, characterize the conditions and parameters associated with aging degradation, develop data resources and predictive models for remaining useful life, and provide methods to mitigate risk and extend component life. Individual projects addressing this objective include the following:

    a. Extension of Materials Degradation Matrix and Issues Management Tables to include Failure Mechanisms to 80 Years

    b. Evaluation of Crack Initiation and Propagation Mechanisms in LWR Components

    c. Identifying Mechanisms and Mitigation Strategies for Irradiation-Assisted Stress Corrosion Cracking of Stainless Steel in LWR Core Components

    d. Reactor Pressure Vessel (RPV) Embrittlement from Long-Term Fluence

    e. Welding of Irradiated Materials for Reactor Internals Repair and Replacement.

2. For ***concrete structures, including containment***, identify and prioritize degradation mechanisms and locations; establish methods for issue resolution, including new nondestructive examination (NDE) and forensic concrete examination methods; perform prognostic modeling to determine remaining useful life; and investigate mitigation measures for issues important to long-term operations.

3. Develop the ***technical basis for aging management and life-cycle management of cables***, specifically, identifying cable aging management activities, classes of cables that can be life limiting, and data and methods for life-cycle management of aging cables. Enhanced testing and end-of-life predictive methods will be investigated.

4. Through support of structured pilot studies, demonstrate and document ***advanced I&C and information technology*** to address obsolescence aging of components and systems. Pilot studies will address a highly integrated control room, highly automated nuclear power plant, integrated operations, human performance improvement for field workers, outage safety and efficiency, and centralized online monitoring and information integration. EPRI will participate on a working group that oversees these studies. EPRI also will document good practices and requirements for these studies into an accessible database. For mature applications with generic applicability, EPRI will develop guidelines for future applications.

5. Create ***advanced safety and risk analysis tools*** to address anticipated needs during the period of long-term operation and develop an approach for best estimate safety margins assessments that can identify the contributions of design and operational changes, aging effects, and key uncertainties.

6. Investigate ***aging management program scope*** for long-term operation. Research results and operating experience might identify additional components of concern, failure mechanisms, or conditions that would be part of aging management programs for long-term operation. R&D activities will be identified where risk-important gaps exist for aging management activities, including time-limited aging assessments, one-time inspections, and periodic inspections or monitoring.

7. Develop an ***integrated strategy, process plan, and demonstration plants*** to support license renewal, the decision to extend operation, and life-cycle management of assets. Demonstration plants will pilot applications of monitoring methods, inspection guidelines, testing methods, demonstrations of new technologies, and analyses. The principal projects addressing this objective are as follows:

    a. LTO Integration and Collaboration

    b. Plant support for second license renewal (SLR) by identifying issues and developing more accurate aging assessments of key components

    c. On-going linkage to the integrated life-cycle management (ILCM) software that was developed under LTO and transferred to EPRI Plant Engineering in 2015 for expanded use and long-term support.

In addition, a “living” Issue Tracking Table (ITT) maintains the status of all identified issues and assigned priorities. This table is regularly reviewed for accuracy and completeness by EPRI stakeholders, LWRS Program representatives, a working group of the Nuclear Energy Institute (NEI), and EPRI advisors. The objectives and associated projects listed in this document have been selected from high-priority issues in the ITT that meet the selection criteria and have received concurrence of the LTO Program Integration Committee. A copy of the latest ITT is included as Attachment A to this plan.

Finally, it is important to emphasize that considerable supporting R&D is pursued within EPRI that is driven by current operating nuclear power plant issues rather than by a specific LTO need. For example, buried and underground piping and tank research is an area where the impact is primarily directed at resolving issues for the operating fleet with respect to identifying the extent of in-service degradation and technology to detect and/or mitigate degradation. Additional areas are summarized in Section 5 and include ILCM, Technical Bases Updates to EPRI Technical Reports to Support SLR, Buried Piping and Tanks, Nuclear Plant Chemistry, and Steam Generator Management Program. If appropriate, work with an LTO focus and objective may be identified as the in-progress R&D efforts yield data and direction.

## 2.3 Reporting of Research and Development Projects

Consistent with the memorandum of understanding, the R&D projects described in the program plans for the LWRS and LTO Programs are presented in this joint plan using the following categories:

1. Section 3 discusses "Coordinated (but independent) Activities," meaning "in general, work in the category will be managed by either DOE or EPRI, using standard, approved processes for R&D management. Funding is also likely to be independent for work in this category. Coordination will be limited to joint planning and communications to limit possible overlaps and gaps that may exist in the planned activities."

2. Section 4 discusses "Collaborative Activities," meaning "DOE and EPRI intend work in the category to be planned and executed on a collaborative basis. The collaborative efforts between DOE and EPRI may involve, to a significant degree, joint funding as permitted by law and available appropriations. DOE and EPRI will determine which organization will lead each effort based on which party is positioned to most efficiently and effectively execute the work."[c]

3. Section 5 (added in 2014) discusses "Program Unique Activities," meaning R&D activities supported by DOE-NE (under the LWRS Program) or EPRI that are not considered (per the memorandum of understanding) to be coordinated or collaborative in nature, but yet add to the body of knowledge that may be consulted by nuclear power plant owners and operators as they weigh the technology, regulatory, and business factors involved with pursuing renewals of their plant's operating license from NRC.

In Sections 3 and 4, the work of the lead program for the R&D activity is described first, followed by a similar description of the work by the supporting program (in some cases, the lead for the activity is jointly shared by the LWRS and LTO Programs).

Table 1 represents a summary overview of the joint R&D plan. The table lists (beginning in the left column) the LWRS Program's R&D activities, the corresponding (coordinated or collaborative) LTO Program's R&D activities, and the program-unique R&D activities. For the purposes of this plan, multiple R&D activities are, in selected instances, rolled up under a single heading.

c. As committed to in the memorandum of understanding, "DOE and EPRI endeavor to plan, integrate, and prioritize nuclear R&D in Coordinated Activities and Collaborative Activities, and intend to keep each other informed of meetings, correspondence, and the status of work in order to strengthen the partnership." Further, the LWRS and LTO Programs are committed to maintaining an inventory of the relevant technical results from these R&D projects and sharing each program's R&D results with the other organization.

Table 1. Summary overview of the joint research and development plan.

| LWRS Program R&D Activity | Related LTO Program R&D Activity | Coordinated Activity | Collaborative Activity | Program Unique Activity |
|---|---|---|---|---|
| Materials Aging and Degradation | Understanding, Prediction, and Mitigation of Primary System Aging Degradation | | | |
| Expanded Materials Degradation Assessment | | | | LWRS |
| | Materials Degradation Matrix and Issues Management Tables | | | LTO |
| Reactor Metals | | | | |
| RPV – High Fluence, Materials Variability, and Attenuation Effects on RPV Steels | RPV Embrittlement from Long-Term Fluence (focus on power reactor surveillance capsules irradiation and analyses) | LWRS-LTO joint lead | | |
| Mechanisms of Irradiation-Assisted Stress Corrosion Cracking (IASCC) | IASCC: Identifying Mechanisms and Mitigation Strategies for IASCC of Austenitic Steels and LWR Core Components | | LWRS-LTO joint lead | |
| Irradiation Effects (core internals – IASCC, swelling, and phase transformations) | Irradiation Effects (core internals – IASCC, swelling, and phase transformations) | LWRS-LTO joint lead | | |
| Crack Initiation in Ni-Base Alloys | Environmental-Assisted Cracking: Evaluation of Crack Initiation and Propagation Mechanisms in LWR Components | LWRS-LTO joint lead | | |
| Environmentally Assisted Fatigue (EAF) | EAF – Long-term focus; EPRI has a short-term focus effort (i.e., current operating plants) as well | LWRS-LTO joint lead | | |
| Thermal Aging of Cast Austenitic Stainless Steel (CASS) | Thermal Aging of CASS | LWRS-LTO joint lead | | |
| Concrete | Comprehensive Aging Management of Concrete Structures (Technology Roadmap) | | LWRS-LTO joint lead | |

Table 1. Continued.

| LWRS Program R&D Activity | Related LTO Program R&D Activity | Coordinated Activity | Collaborative Activity | Program Unique Activity |
|---|---|---|---|---|
| Cabling | Technical Basis for Aging Management and Life-Cycle Management of Cables | | LWRS-LTO joint lead | |
| Mitigation Strategies | | | | |
| Advanced Weld Repair | Advanced Welding Methods for Irradiated Materials | | LWRS-LTO joint lead | |
| Advanced Replacement Alloys | Advanced Radiation-Resistant Materials Program | | LWRS-LTO joint lead | |
| Thermal (Post-Irradiation) Annealing | | | | LWRS |
| Integrated Research – International Activities (Halden Project) | Participation in Halden Project | LWRS-LTO joint lead | | |
| Integrated Research – International Activities (Materials Ageing Institute) | Partnership in Materials Ageing Institute (EPRI Nuclear Sector) | LTO lead | | |
| Zion Materials Management and Coordination | | | | LWRS |
| NDE Technologies | Opportunities to Employ NDE Technologies for Automatic, Continuous, In-Situ Monitoring | LWRS-LTO joint lead | | |
| RISMC | | | | |
| Margins Analysis Techniques Modeling and Simulation Activities | Enhanced Safety Analysis Capability | | LWRS-LTO joint lead | |
| | Enhanced Risk Assessment and Management Capability | LTO lead | | |
| Advanced II&C Systems Technologies | | | | |
| New Instrumentation and Control and Human System Interfaces and Capabilities (including Advanced II&C Pilot Projects) | Requirements Database and Guidelines for Advanced I&C, Human System Interface, and Information Technology | | LWRS lead | |

Table 1. Continued.

| LWRS Program R&D Activity | Related LTO Program R&D Activity | Coordinated Activity | Collaborative Activity | Program Unique Activity |
|---|---|---|---|---|
| Halden Project | Halden Project | LWRS-LTO joint lead | | |
| Centralized Online Monitoring | Centralized Online Monitoring Methodology, Guidelines, and Pilot Studies (Part of Advanced II&C Pilot Projects) | | LTO lead | |
| Industrial and Regulatory Engagement | Requirements Database and Guidelines for Advanced I&C, Human System Interface, and Information Technology | | LTO lead | |
| RST | | | | |
| Gap Analysis | | | | LWRS |
| Accident-Tolerant Components | | | | LWRS |
| Severe Accident Analysis | | | | LWRS |
| Fukushima Inspection Plan | | | | LWRS |
| Other Projects | | | | |
| | Integrated Life-Cycle Management | | | LTO |
| | Technical Bases Updates to EPRI Technical Reports to Support SLR | | | LTO |
| | Buried Piping and Tanks | | | EPRI (Plant Engineering and NDE) |
| | Nuclear Plant Chemistry | | | EPRI (Water Chemistry) |
| | Steam Generator Management | | | EPRI (Steam Generator Management Program) |

# 3. LIGHT WATER REACTOR SUSTAINABILITY PROGRAM / LONG TERM OPERATIONS PROGRAM – COORDINATED RESEARCH AND DEVELOPMENT ACTIVITIES

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| **Reactor Metals** | |
| **LWRS – RPV: High Fluence, Materials Variability, and Attenuation Effects on RPV Steels** | **R&D Scope and Objectives:**<br><br>High-Fluence Effects – The last few decades have seen remarkable progress in developing a mechanistic understanding of irradiation embrittlement for RPVs. However, significant technical issues still need to be addressed to reduce the uncertainties in regulatory application. The objective of this research task is to examine and understand the influence of irradiation at high fluences on RPV embrittlement. Both industrial capsules and single variable experiments may be required to evaluate the potential for embrittlement and to provide a better mechanistic understanding of this form of degradation. Acquisition of samples from past programmatic campaigns (e.g., NRC programs), specimens harvested from decommissioned reactors (e.g., Zion Units 1 and 2), surveillance specimens from operating nuclear power plants, and materials irradiated in new test campaigns all have value in understanding high-fluence effects. Testing will include impact and fracture toughness evaluations, hardness, and microstructural analysis (i.e., atom probe tomography, small angle neutron scattering, and/or positron-annihilation spectroscopy). These research tasks all support development of a predictive model for transition-temperature shifts for RPV steels under a variety of conditions. This tool can be used to predict RPV embrittlement over a variety of conditions key to irradiation-induced changes (e.g., time, temperature, composition, flux, and fluence) and extends the current tools for RPV management and regulation to extended-service conditions. This model will be delivered in 2016 in a detailed report, along with all supporting research data. In addition, the library of assembled materials will be available for examination and testing by other stakeholders.<br><br>Materials Variability and Attenuation Effects – The subject of materials variability has experienced increasing attention in recent years as additional research programs have begun to focus on development of statistically viable databases. The objectives of this task involve developing new methods to generate meaningful data out of previously tested specimens. Embrittlement margins for a vessel can be accurately calculated with supplementary alloys and experiments using higher flux test reactors. The potential for non-conservative estimates resulting from these methodologies must be evaluated to fully understand the potential influence on safety margins. Critical assessments and benchmark experiments will be conducted. Harvesting of through-thickness RPV specimens may be used to evaluate attenuation effects in a detailed and meaningful manner. Testing will include impact and fracture toughness evaluations, hardness, and microstructural analysis (i.e., atom probe tomography, small angle neutron scattering, and/or positron-annihilation spectroscopy). The results of these examinations can be used to assess the operational implications of high-fluence effects on RPV. Furthermore, the predictive capability developed in earlier tasks will be modified to address these effects. |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| **LTO – RPV Embrittlement from Long-Term Fluence** | **R&D Scope and Objectives:**<br>Currently, RPV embrittlement is not considered to be a life-limiting factor for 60 years of operation because of the relatively low fluence level. However, for 80 or more years, refinement of analysis, testing, and validation of embrittlement models using irradiated samples will be needed. This project will design, fabricate, and irradiate two supplemental surveillance capsules that will provide high-fluence irradiated data in approximately 2027 to support future development of embrittlement trend curves applicable for LWR operation at high fluences. This project will perform mechanical property testing and then microstructurally characterize pressurized water reactor (PWR) surveillance materials that were irradiated in both PWR and Advanced Test Reactor irradiation environments to identify and quantify potential flux and dose effects. In addition, there is a need to develop new testing methods to extend the use of existing surveillance specimens to generate master curve fracture toughness data. This project will participate in a round robin test program to assess one such method that has been developed. |
| **LWRS – RPV: High-Fluence, Materials Variability, and Attenuation Effects on RPV Steels** | **Milestones:**<br>High-fluence effects:<br>• (2016) Provide validated model for transition temperature shifts in RPV steels.<br>Future milestones and specific subtasks will be based on the results of the previous years' testing, as well as ongoing, industry-led research. The experimental data and model are of value to both industry and regulators. Completion (in 2014) of data acquisition to permit prediction of embrittlement in RPV steels at high fluence is a major step in informing life extension decisions; high-quality data can be used to inform operational decisions for RPV by industry. For example, data and trends will be essential in determining operating limits. Data also will allow for extension of regulatory limits and guidelines to extended service conditions. The delivery (in 2016) of a validated model for prediction of transition temperature shifts in RPV steels will allow for estimation of RPV performance over a wide range of conditions. This will enable extension of current tools for RPV embrittlement (e.g., Fracture Analysis of Vessels: Oak Ridge[d]) to extended service conditions.<br>Materials variability and attenuation effects:<br>• (2016) Complete a detailed review of the NRC pressurized thermal shock re-evaluation project relative to the subject of material variability and identify specific remaining issues.<br>• (2019) Complete analysis of hardening and embrittlement through the RPV thickness for the Zion RPV sections.<br>Future milestones and specific subtasks will be based on the results of the previous years' testing, as well as ongoing, industry-led research. The analysis of hardening and variability through the thickness of an actual RPV section from service has considerable value to all stakeholders. These data will provide a first look at embrittlement trends through the thickness of the RPV wall and inform operating limits, fracture mechanics models, and safety margins. |

d. NUREG/CR-6854, ORNL/TM-2004/244, *Fracture Analysis of Vessels – Oak Ridge FAVOR, v04.1, Computer Code: Theory and Implementation of Algorithms, Methods, and Correlations*, P. T. Williams, T. L. Dickson, and S. Yin, Oak Ridge National Laboratory, October 2004.

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| **LTO – RPV Embrittlement from Long-Term Fluence** | **Milestones**:<br>This project involves irradiation of supplemental surveillance specimens to high fluence in a PWR. The follow-up testing and analysis must be performed in a laboratory with the capability of handling irradiated materials and reconstituting Charpy specimens. The project requires 10 or more years to complete the work. The work will be coordinated with ongoing and planned work within the PWR Materials Reliability Program and Boiling Water Reactor (BWR) Vessel and Internals Project to address RPV embrittlement after extended operation.<br>• (2015) Continuing participation in round robin testing of a new method to extend the use of existing surveillance specimens to generate Master Curve data. Having earlier tested base metal, the 2015 effort seeks to demonstrate efficacy of the method for weld metal.<br>• (December 2015) Design, fabricate, and insert a supplemental surveillance capsule in a host PWR.<br>• (2016) Develop an updated embrittlement trend correlation for prediction of the decrease in upper shelf energy with irradiation. |
| | |
| **LWRS – Irradiation Effects (core internals – IASCC, swelling, and phase transformations)** | **R&D Scope and Objectives:**<br>IASCC – The objective of this task is to assess high-fluence effects on IASCC for core internals. Crack growth-rate testing is especially limited for high-fluence specimens. Intergranular fracture observed in recent experiments suggests more work is needed. Also of interest is identification of high-fluence materials available for research and testing in all tasks. Research will involve a detailed plan for obtaining high-fluence specimens for IASCC testing from irradiation of as-received material to high fluence in a test reactor, obtaining high-fluence materials for sample manufacturing, or a combination of those two factors. In addition, both tests (i.e., crack growth and tensile tests) will be performed in simulated water environments in addition to complementary post-irradiation examination of irradiation effects. Results from this task can be used to investigate the potential for IASCC under extended service conditions, extend the mechanistic studies from other tasks in the LWRS Program, and be used to validate predictive models at high fluence.<br>Swelling – This task will provide detailed microstructural analysis of swelling in key samples and components (both model alloys and service materials), including transmission electron microscopy and volumetric measurements. These results will be used to develop and validate a phenomenological model of swelling under LWR conditions. This will be accomplished by extension of past models developed for fast reactor conditions. The data generated and mechanistic studies will be used to identify key operational limits (if any) to minimize swelling concerns, optimize inspection and maintenance schedules to the most susceptible materials/locations, and, if necessary, qualify swelling-resistant materials for LWR service.<br>Phase Transformations – This task will provide detailed microstructural analysis of phase transformation in key samples and components (both model alloys and service materials), including transmission electron microscopy, magnetic measurements, and hardness examinations. Mechanical testing to quantify any impacts on embrittlement also may be performed. These results will be used to |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| | develop and validate a phenomenological model of phase transformation under LWR conditions. This will be accomplished through use of computational thermodynamics and extension of models for radiation-induced segregation. The generated data and mechanistic studies will be used to identify key operational limits (if any) to minimize phase transformation concerns, optimize inspection and maintenance schedules to the most susceptible materials/locations, and, if necessary, qualify radiation-tolerant materials for LWR service. |
| **LTO – Irradiation Effects (core internals – IASCC, swelling, and phase transformations)** | **R&D Scope and Objectives:**<br>EPRI work on IASCC, swelling, and phase transformations is coordinated under the Materials Reliability Program for PWRs and under the BWR Vessel and Internals Program for BWRs. Significant work, including international cooperative programs, is funded under these two EPRI Programs. For example, the Gondole Project is a multi-national effort that includes EPRI funding that specifically seeks to develop data via test reactor irradiation of prototypical materials to characterize irradiation-induced swelling degradation effects in stainless steels. The current Phase 2 of the project seeks to drive irradiation to doses of 30 dpa. This phase is in progress, with completion expected in 2018.<br><br>Additionally, EPRI is performing thermal and irradiation embrittlement studies on weld material removed from the retired Zorita PWR in Spain. This information will be used to inform both PWR and BWR fracture toughness considerations. This effort is in progress and planned for completion in 2015. |
| **LWRS – Irradiation Effects (core internals – IASCC, swelling, and phase transformations)** | **Milestones:**<br>IASCC:<br>• (2015) Complete revised joint plan with EPRI for very high-fluence testing of core internals.<br><br>Future milestones and specific subtasks will be based on the plan initially developed in 2013 and partnerships developed in early 2014. Completing a detailed experimental plan for high-fluence IASCC testing was an essential first step in estimating the impact of IASCC at high fluence. This plan also is critical for building support and partnerships with industry and regulators.<br><br>Swelling:<br>• (2016) Deliver predictive capability for swelling in LWR components.<br>• (2016) Complete post-irradiation testing and examination of swelling in LWR components and materials.<br><br>Future milestones and specific tasks will be based on the results of the previous years' testing, as well as ongoing, industry-led research. Development and delivery of a validated model for swelling in core internal components at high fluence is an important step in estimating the useful life of core internal components. Understanding which components are susceptible to this form of degradation is of value to industry and regulators because it will permit more focused component inspections, component replacements, and more detailed regulatory guidelines.<br><br>Phase transformations:<br>• (2017) Deliver an experimentally validated, physically based thermodynamic and kinetic model of precipitate phase stability and formation in Alloy 316 |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| | under anticipated extended lifetime operation of LWRs.<br><br>Future milestones and specific tasks will be based on the results of the previous years' testing, as well as ongoing, industry-led research. Development and delivery of a validated model for phase transformations in core internal components at high fluence is an important step in estimating the useful life of the core internal components. Understanding which components are susceptible to this form of degradation is of value to industry and regulators because it will permit more focused component inspections, component replacements, and more detailed regulatory guidelines. |
| **LTO – Irradiation Effects (core internals – IASCC, void swelling, and phase transformations)** | **Milestones:**<br>• (2014) Published a report on improved void swelling model (MRP-391, EPRI report #3002003083).<br>• (2015) Interim results of IASCC crack growth and irradiation embrittlement studies on Zorita weld and HAZ material in BWR environments.<br>• (2015-2022) Additional irradiation of welds and HAZ from Zorita to assess crack growth and fracture toughness.<br>• (2018) Completion of Gondole Phase 2.<br>• (2019) Final report on Phase 2 Gondole Void Swelling Irradiation and Testing. |
| | |
| **LWRS – Crack Initiation in Ni-Base Alloys** | **R&D Scope and Objectives:**<br>The objective of this task is the identification of underlying mechanisms of stress corrosion cracking (SCC) in Ni-base alloys. Understanding and modeling the mechanisms of crack initiation is a key step in predicting and mitigating SCC in the primary and secondary water systems. An examination into the influence of surface and metallurgical conditions on precursor states and crack initiation also is a key need for Ni-base alloys and austenitic stainless steels. This effort focuses on SCC crack-initiation testing of Ni-base alloys and stainless steels in simulated LWR water chemistries, but includes direct linkages to SCC crack-growth behavior. Carefully controlled microstructure and surface states will be used to generate single-variable experiments. The experimental effort in this task will be highly complementary to efforts being initiated at the Materials Ageing Institute, which are focused primarily on modeling of crack initiation. This mechanistic information could provide key operational variables to mitigate or control SCC in these materials, optimize inspection and maintenance schedules to the most susceptible materials/locations, and potentially define SCC-resistant materials. |
| **LTO – Environmental-Assisted Cracking: Evaluation of Crack Initiation and Propagation Mechanisms in LWR Components** | **R&D Scope and Objectives:**<br><br>Environmental-assisted cracking of primary system components is the most prevalent degradation mechanism that directly impacts the sustainability of reliable operation of LWRs. To achieve long-term operation, it is imperative to extend the useful life of components in LWRs through better understanding of the crack initiation and propagation processes, improved predictive models, and identify effective countermeasures against SCC. The objectives of this project include the following:<br>• Determine the composition and impedance properties of metal surface oxides resulting from interaction with LWR environments, including the effects of |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| | $Fe^{2+}$, $Ni^{2+}$, and $Zn^{2+}$ cations, to identify the key process leading to cracking.<br>• Evaluate the effect of $Fe^{2+}$, $Ni^{2+}$, and $Zn^{2+}$ cations on oxide properties.<br>• Investigate the influence of hydrogen partial pressure on the damage processes prior to crack initiation in Alloy 600 in PWR primary water.<br>• Understand the mechanistic reasons for the superior performance of Alloy 690 relative to Alloy 600, particularly in the context of long-term performance; such a mechanistic basis will support proposals for optimizing the inspection frequency of Alloy 690 components.<br>• Participate in a collaborative research program in Japan to deepen the understanding of interface oxidation dynamics through the use of in-situ and ex-situ measurements by synchrotron x-rays at the Spring-8 synchrotron radiation facility in Japan.<br>• Identify the mechanisms leading to decreased fracture resistance in component materials in LWR environments.<br>• Develop improved prediction models of IASCC initiation and propagation and evaluation methodologies for assessing the reliability of LWR structural materials to support LTO and xLPR (Extremely Low Probability of Rupture) programs.<br>• Develop strategies to mitigate the risk of environmental-assisted cracking degradation and to extend component life, based on a sound mechanistic understanding. |
| **LWRS – Crack Initiation in Ni-Base Alloys** | **Milestones:**<br>• (2015) Complete Phase 1 mechanistic testing for SCC research.<br>• (2019) Deliver predictive model capability for Ni-base alloy SCC susceptibility.<br><br>Completing research to identify the mechanisms and precursor states is an essential step in predicting the extent of this form of degradation under extended service conditions. Understanding the underlying causes for crack initiation may allow for more focused material inspections and maintenance, new SCC-resistant alloys, and development of new mitigation strategies, all of which are of high interest to the nuclear industry. This mechanistic understanding also may drive more informed regulatory guidelines and aging-management programs. In the long-term, mechanistic understanding also enables development of a predictive model, which has been sought by industry and regulators for many years. |
| **LTO – Environmental-Assisted Cracking: Evaluation of Crack Initiation and Propagation Mechanisms in LWR Components** | **Milestones**:<br><br>Activity 1: In-situ surface oxide film characterization and correlation between oxidation and crack initiation:<br>• (2014) Summarize results of in-situ surface oxide film composition and impedance properties as functions of materials/LWR environment combinations, including the effects of cations (delayed, expected completion in 2016).<br>• (2013-2014) Damage Processes Prior to Crack Initiation in Ni Alloys (Published in 2013, EPRI report: 1025119).<br>• (2014) Summarize the results of in-situ surface oxide structure and oxidation kinetics. (Published in 2014 as part of POLIM project performed in Japan |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| | EPRI report: 3002003049).<br>• (September 2016) Establish correlation between oxidation and crack initiation.<br>Activity 2: Local strain-stress behavior associated with crack:<br>• (2016) Establish correlation between strain rate and crack growth rate.<br>Activity 3: Parametric study and development of mitigation strategy:<br>• (2015) Summary of parametric experiments on crack growth rate.<br>• (2017) Develop and validate mitigation strategies.<br>Activity 4: Modeling:<br>• (2012) Program on Technology Innovation: Hybrid Models of SCC Propagation for Nickel Alloy Welds in Low-Electrochemical Potential PWR Primary Water Environments (Published as 1024863, February 2012).<br>• (2016) Environmental-assisted cracking crack growth prediction model.<br>• (September 2019) Environmental-assisted cracking crack initiation model. |
| | |
| **LWRS – EAF** | **R&D Scope and Objectives:**<br>The objective of this task is to develop a model for EAF mechanisms. This will be supported by experimental studies to provide data for the identification of mechanisms and key variables and provide data for model validation. The experimental data will inform regulatory and operational decisions, while the model will provide a capability to extrapolate the severity of this mode of degradation to extended-life conditions. |
| **LTO – EAF (long-term focus)** | **R&D Scope and Objectives:**<br>The lack of definite design rules for EAF creates uncertainty for both new and operating nuclear power plants, where design compliance must be shown for the extended operating period (significant uncertainty for a potential 80-year life). To attain acceptable fatigue usage, design changes that increase design, construction, and operations costs without meaningful safety benefits may be required for previously certified designs, as well as designs currently under review by NRC. Affected items in the design may include materials selection, piping thickness, fitting tolerances, and number and locations of piping supports. Additionally, for license renewal, there is uncertainty as to the requirements that may be imposed by NRC because the scope of locations requiring environmental fatigue analysis is open to interpretation.<br>Several EPRI programs will combine expertise and share final EAF results to address the current data and analysis process. Upon completion of this work, EPRI intends to work through the American Society of Mechanical Engineers (ASME) code process to support effective code revisions that resolve the fatigue issue. These actions will include the following:<br>• Publication of reports and related documents that form the technical basis of code modifications in order to obtain code approval and regulatory acceptance, providing appropriate levels of conservatism.<br>• Development of EPRI guidance and code cases that provide evaluation procedures for assessing fatigue environmental factors that are accepted by |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| | regulatory authorities.<br>• Promoting an understanding of new procedures to provide for consistency of application by nuclear power plant vendors, construction firms, and utilities (new and operating plant owners).<br>• Supporting ASME Section III and XI code revisions that permanently include EAF procedures within the body of the code.<br>Note that EPRI continues to perform projects that address fatigue and EAF in the current operating fleet. EPRI is also now considering the potential impacts of fatigue related to flexible operations. |
| **LWRS – EAF** | **Milestones:**<br>• (2015) Complete base model development for EAF in LWR components.<br>• (2017) Complete experimental validation and deliver model for EAF in LWR components.<br>Completing research to identify the mechanisms of EAF to support model development is an essential step in predicting the extent of this form of degradation under extended service conditions. This knowledge has been identified as a key need by regulators and industry. Delivering a model for EAF will enable more focused material inspections, material replacements, and more detailed regulatory guidelines. |
| **LTO – EAF** | **Milestones:**<br>• (2012) Roadmap published (EPRI report 1026724).<br>• (2013) Publish guidance for EAF methodology. (Published as EPRI report 1025823, December 2012).<br>• (2014) Feasibility study to determine code margins versus EAF impact (EPRI report # 3002003922).<br>• (2013 through 2015) Continue international research collaboration with expert panel review and advice.<br>• (2013 through 2016) Initiate specimen testing and R&D to resolve EAF knowledge gaps – address inconsistencies in test data vs. operating plants experience on crack initiation.<br>• (2013 through 2015): Formulate and validate models of EAF enhancement and retardation in BWR and PWR environments based on fundamental understanding of EAF.<br>• (2016) Develop a stakeholder's database of all published data. |
| | |
| **LWRS – Thermal Aging of CASS** | **R&D Scope and Objectives:**<br>In this research task, the effects of elevated temperature service in CASS will be examined. The possible effects of phase transformations that can adversely impact mechanical properties will be explored. This task is expected to provide conclusive predictions for the integrity of the CASS components of nuclear power plants during extended service life. Mechanical and microstructural data obtained through accelerated aging experiments and computational simulation will be key input for prediction of CASS behaviors and for integrity analyses for various CASS components. While accelerated aging experiments and computational simulations will comprise the main components of the knowledge base for CASS aging, data |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| | also will be obtained from operational experience. These data are required to validate the accelerated aging methodology. Therefore, in addition to using existing data, a systematic campaign to obtain mechanical data from used materials or components will be pursued. Further, the detailed studies on aging and embrittlement mechanisms and on deformation and fracture mechanisms are performed to understand and predict the aging behavior over an extended lifetime. |
| **LTO – Thermal Aging of CASS and Stainless Steel Welds** | **R&D Scope and Objectives:**<br>Review and evaluate all available data on thermal aging in ferritic-austenitic stainless welds and CASS material and at LWR temperatures, as well as effects of thermal aging on mechanical properties and corrosion resistance. Additionally, EPRI is developing probabilistic fracture mechanics evaluation and acceptance criteria for use by currently operating nuclear power plants. A technical report has been developed and shared with ASME Code for incorporation into Code Case N-838. It is currently in the review/approval process. |
| **LWRS – Thermal Aging of CASS** | **Milestones:**<br>• (2017) Complete analysis of CASS specimens harvested from service conditions.<br>• (2018) Complete analysis and simulations on aging of CASS components and deliver predictive capability for CASS components under extended service conditions.<br>Completing research to identify potential thermal aging issues for CASS components is an essential step to identifying the possible synergistic effects of thermal aging (e.g., corrosion or mechanical) and predicting the extent of this form of degradation under extended service conditions. Understanding the mechanisms of thermal aging will enable more focused material inspections, material replacements, and more detailed regulatory guidelines. These data also will help close gaps identified in the EPRI Materials Degradation Matrix (MDM) and the Expanded Materials Degradation Assessment (EMDA) reports. |
| **LTO – Thermal Aging of CASS and Stainless Steel Welds** | **Milestones:**<br>• (2014) A technical report has been developed and shared with ASME Code as the basis into Code Case N-838. It is currently in the review/approval process of ASME. |
| **Mitigation Strategies** | |
| **LWRS – Integrated Research/ International Collaborations (Halden Project and Materials Aging Institute)** | **R&D Scope and Objectives:**<br>Participate in international collaborations that offer opportunities for a broader and more detailed research program than possible in an isolated research program. Coordinated research with international institutions (such as the Materials Aging Institute of which EPRI is a member) will provide more collaboration and cost sharing. In addition, research opportunities through information exchanges with the Halden Project are a planning element of the R&D collaboration. |
| **LTO – Integrated Research/ International Collaborations (Halden Project and** | **R&D Scope and Objectives:**<br>Participate in international collaborations (such as the Halden Project) that offer opportunities for a highly leveraged and more detailed research program than is possible in an isolated research program. Coordinated research with the Materials Aging Institute (of which EPRI is a member) will provide more collaboration and |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| **Materials Aging Institute)** | cost sharing. |
| **LWRS – Integrated Research/ International Collaborations** | **Milestones:**<br>LWRS milestones related to international collaborations are identified under the specific MAaD R&D areas. |
| **LTO – Integrated Research/ International Collaborations** | **Milestones**<br>EPRI membership is at a level above the specific LTO Program focus, such that LTO-relevant R&D is evaluated on a case-by-case basis. |
| | |
| **LWRS – NDE** | **R&D Scope and Objectives:**<br>NDE R&D is planned for the following MAaD R&D areas:<br>Concrete – Techniques for NDE of concrete provide new technologies to monitor material and component performance. This task will build on an R&D plan developed in 2012. Key issues for consideration can include new or adapted techniques for concrete surveillance. Specific areas of interest may include reinforcing steel condition, chemical composition, strength, or stress state.<br>Cabling – The objectives of this task include development and validation of new NDE technologies for the monitoring of cable insulation condition. This task will build on an R&D plan developed in 2012. In future years, this research will include an assessment of key aging indicators; development of new and transformational NDE methods for cable insulation; and utilization of NDE signals and mechanistic knowledge from other areas of the LWRS Program to provide predictions of remaining useful life. A key element underpinning these three thrusts will be harvesting of aged materials for validation. |
| **LTO – NDE** | **R&D Scope and Objectives:**<br>Identification and management of aging degradation for critical structures and components is fundamental to long-term operation. One-time inspections are specified to establish the extent of degradation; periodic inspections are specified as part of aging management programs. For quantitative and trendable results, NDE technology is used for these inspections. For some degradation mechanisms, in-situ online monitoring that employs NDE technology can provide quantitative and sometimes predictive results. These monitoring systems can have advantages over traditional periodic inspections (e.g., cost, accuracy, radiation exposure, and prognostic capability).<br>The EPRI NDE program provides NDE technology, procedures, validation, and training for identified materials, mechanisms, components, and locations of concern. This process is ongoing and robust and is expected to be effective for the life of the nuclear power plant, including SLR periods. Additionally, the NDE program continues to investigate new technologies that may provide enhanced detection and flaw characterization performance that may be incorporated into aging management programs.<br>The LTO Program investigates opportunities to employ NDE technologies that can be installed for automatic, continuous, in-situ monitoring for certain identified aging degradation concerns. The investigations will include identification of parameters, design of sensors and sensor configurations, data capture and analysis, |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| | validation of the NDE/monitoring system, and demonstration of the process in an operational environment. |
| **LWRS – NDE** | **Milestones:**<br>Concrete:<br>• (2016) Complete prototype proof-of-concept system for NDE of concrete sections.<br>• (2018) Complete prototype of concrete NDE system.<br>The development of NDE techniques to permit monitoring of the concrete and civil structures could be revolutionary and allow for an assessment of performance that is not currently available via core drilling in operating plants. This would reduce uncertainty in safety margins and is clearly valuable to both industry and regulators.<br>Cabling:<br>• (2015) Complete assessment of cable insulation degradation precursors to correlate with performance and NDE signals.<br>• (2017) Demonstrate field testing of prototype system for NDE of cable insulation.<br>• (2019) Deliver predictive capability for end-of-useful life for cable insulation.<br>Development of NDE techniques to permit in-situ monitoring of the cable insulation performance could be revolutionary and allow for an assessment of cable insulation performance at specific locations of interest and at more frequent intervals, which is a significant difference from today's methodology. This would reduce uncertainty in safety margins and is clearly valuable to both industry and regulators. |
| **LTO – NDE** | **Milestones**:<br>• (Ongoing) NDE-related work is reported under the topical areas as appropriate. |

| R&D Area | Advanced II&C Systems Technologies |
|---|---|
| **LWRS – International Collaborations (Halden Project)** | **R&D Scope and Objectives:**<br><br>The programs of the Halden Reactor Project (Halden) extend to many aspects of nuclear power plant operations; however, the area of interest to this R&D program is the human-machine interface technology research program in the areas of computerized surveillance systems, human factors, and man-machine interaction in support of control room modernization. Halden has been on the cutting edge of new nuclear power plant technologies for several decades and their research is directly applicable to the capabilities being pursued under the pilot projects. In particular, Halden has assisted a number of European nuclear power plants in implementing II&C modernization projects, including control room upgrades.<br><br>The Advanced II&C Systems Technologies Pathway will work closely with Halden to evaluate their advanced II&C technologies to take advantage of the applicable developments. In addition to the technologies, the validation and human factors studies conducted during development of the technologies will be carefully evaluated to ensure similar considerations are incorporated into the pilot projects. Bilateral agreements may be employed in areas of research where collaborative efforts with Halden will accelerate development of the technologies associated with the pilot projects. |
| **LTO – Halden Project** | **R&D Scope and Objectives:**<br><br>EPRI has established the Productivity Improvements through Advanced Technology Advisory Group. This group is looking at II&C enabled productivity improvements in nuclear power plants and is interacting closely with the LWRS Program's Advanced II&C Systems Technologies Pathway, including participating in the joint annual meeting (first meeting held August 2012). The Advanced Technology Advisory Group had the Halden Reactor Project give presentations in the June 2010 and April 2012 meetings. The intent is to identify opportunities to support productivity improvements in nuclear power plants, taking advantage of activities in Halden's Man-Machine-Technology Program. EPRI, as an associated member of the Halden Reactor Project, is providing input to Halden on their research activities in the man-machine-technology program. |
| **LWRS – International Collaborations (Halden Project)** | **Milestones:**<br><br>• Activities involving contributions from Halden are discussed under individual pilot projects. |
| **LTO – Halden Project** | **Milestones**:<br><br>EPRI membership is at a level above the specific LTO Program focus, such that LTO-relevant R&D is evaluated on a case-by-case basis. |

| R&D Area | RISMC (see "Margins Analysis Techniques" for LWRS cooperative R&D) |
|---|---|
| **LTO – Enhanced Risk Assessment and Management Capability** | **R&D Scope and Objectives:**<br><br>To achieve successful long-term operations of the current fleet of operating nuclear power plants, it will be imperative that high levels of safety and economic performance are maintained. Therefore, operating nuclear power plants will have a continuing need to undergo design and operational changes and manage aging degradation, while simultaneously preventing the occurrence of safety significant events and analytically demonstrating improved nuclear |

| R&D Area | RISMC (see "Margins Analysis Techniques" for LWRS cooperative R&D) |
| --- | --- |
| | safety. This portion of the EPRI LTO Program addresses the following two specific issues that are imperative to achieving these objectives:<br>(1) First, as the current fleet of operational nuclear power plants ages, it is anticipated that new challenges to plant safety will emerge. These challenges could be due to any number of causes such as a change in regulatory policy or the occurrence of an event at one or more operational nuclear power plants.<br>(2) Second, as new technologies and capabilities become available, it will be desirable to take advantage of these opportunities to enhance nuclear power plant technical and economic performance. Examples of such enhancements could include performing extended power uprates or implementation of new technologies or materials.<br>In each situation, a comprehensive and integrated assessment of the impact on nuclear safety will be required to support effective and efficient decision making.<br>This research project will develop and validate enhanced risk assessment and management capabilities and tools. A critical element of this research effort will be to integrate the results obtained from the EPRI PHOENIX software development effort, which is being conducted to develop an advanced probabilistic risk assessment and configuration risk management integrated tool suite. This research effort will support development of PHOENIX by integrating risk management analytical capabilities that are necessary for nuclear power plant long-term operations (e.g., RISMC/Risk Informed Margin Management [RIMM]) and providing for the capability of the PHOENIX software to link to the RELAP-7 software to permit its uses as a risk simulation tool. This project also provides significant interface and coordination of research efforts being conducted in safety analysis code development and safety margin analyses being performed by INL as part of the LWRS Program. |
| **LTO – Enhanced Risk Assessment and Management Capability** | **Milestones:**<br>In previous years, this LTO research effort has supported the Phase 1 and Phase 2 portions of the PHOENIX research effort. A key milestone provided by this research was development of the PHOENIX functional requirements document and roadmap (EPRI Report 1019207). During 2013, a "beta" version of the PHOENIX software was produced that concentrates on enhanced methods for configuration risk management applications. During 2015, the support of PHOENIX development, testing, and initial deployment will continue. The following activities are planned:<br>• (2014) Since the basic PHOENIX infrastructure has been developed with initial testing and deployment in 2015, the level of code development supports a more integrated interaction between the Phoenix/RAVEN/ RELAP-7 development teams. The primary activity in 2015 will be to identify and prioritize the appropriate linkages to the Reactor Analysis and Virtual Control ENvironment (RAVEN) controller being developed for use in the interface with the RELAP-7 systems analysis code being developed by INL.<br>• Initiate an evaluation of PHOENIX LTO for application to LTO-related issues and to integrate necessary capability development/external interfaces into the PHOENIX and RAVEN development plans. |

# 4. LIGHT WATER REACTOR SUSTAINABILITY PROGRAM / LONG TERM OPERATIONS PROGRAM – COLLABORATIVE RESEARCH AND DEVELOPMENT ACTIVITIES

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| **Reactor Metals** | |
| **LWRS – Mechanisms of IASCC** | **R&D Scope and Objectives:**<br>The objective of this work is to evaluate the response and mechanisms of IASCC in austenitic stainless steels with single-variable experiments. Crack growth rate tests and complementary microstructure analysis will provide a more complete understanding of IASCC by building on past EPRI-led work for the Cooperative IASCC Research Group.[e] Experimental research will include crack-growth testing on high-fluence specimens of single-variable alloys in simulated LWR environments, tensile testing, hardness testing, microstructural and microchemical analysis, and detailed efforts to characterize localized deformation. Combined, these single-variable experiments will provide mechanistic understanding that can be used to identify key operational variables to mitigate or control IASCC, optimize inspection and maintenance schedules to the most susceptible materials/locations, and, in the long-term, design IASCC-resistant materials. |
| **LTO – IASCC: Identifying Mechanisms and Mitigation Strategies for IASCC of Austenitic Steels and LWR Core Components** | **R&D Scope and Objectives:**<br>A better fundamental understanding of key parameters that affect IASCC is required to develop improved materials. For extended operation, IASCC is potentially a major failure mechanism that could impact the reliability of reactor core internal components due to higher fluence. The metallurgical modifications caused by neutron irradiation generally increase IASCC susceptibility of austenitic stainless steels.<br>Currently, this long-term LTO project is co-funded by EPRI and DOE. The project work is performed by the University of Michigan. The objectives of this LTO project include the following:<br>• Full assessment of high-purity solute addition alloys and, in particular, the roles of C, Mo, Ti, Nb, Cr+Ni, and P on crack growth rate and crack initiation.<br>• Full assessment of the roles of commercial alloy microstructure on crack growth rate and crack initiation.<br>• Linkage between irradiated microstructure and crack growth rate or crack initiation for solute addition and commercial alloys, as well as effects of cold work and dose.<br>• Relation between IASCC cracking susceptibility and neutron-irradiated alloys.<br>• Determination of the predictive capability of crack initiation due to proton irradiation by assessment against crack initiation due to neutron irradiation. |

e. EPRI, "Final Review of the Cooperative Irradiation-Assisted Stress Corrosion Cracking Research Program," Product ID. 1020986, June 3, 2010.

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| | • Role of localized deformation on the IASCC susceptibility in neutron-irradiated materials.<br>This LTO project on study of IASCC mechanisms has completed the Phase 1 study, and an EPRI report has been published to summarize the key results from the experiments on fast neutron irradiated alloys.<br>In 2015, EPRI and DOE have again jointly funded a follow-on study on IASCC mechanisms. The follow-on study focuses on identifying and modeling the mechanism of IASCC. The strategy for this program is to develop a model for IASCC initiation and growth based on localized deformation arising from irradiation-induced changes to the microstructure. The working hypothesis is to quantify the stress or strain at the dislocation channel-grain boundary intersection, which may induce fracture of the oxide film above the grain boundary. Determination of which process is responsible for IASCC will provide a pathway to a more physically based model for cracking.<br>In addition to testing the neutron-irradiated stainless steels, the similar stainless steels irradiated to the similar fluence by proton irradiation will be tested by constant extension-rate tensile tests. The cracking susceptibilities associated with neutron irradiation and with proton irradiation will be cross compared. The role of localized deformation on IASCC susceptibility will be investigated.<br>The additional EPRI-funded IASCC study includes the following:<br>• Investigate whether small-volume mechanical testing can provide an alternate method of assessing IASCC susceptibility to enable a potential strategy of retrieval and subsequent mechanical examination of materials from the field, in support of long-term operation.<br>• Compile crack growth rate data on irradiated stainless steels from several EPRI and international programs and convene an expert panel to screen the available crack growth rate data on irradiated materials using appropriate screening criteria and recommend crack growth disposition curves for BWRs and PWRs to support current and long-term operation.<br>• Testing in-service materials harvested from LWR plants. The results from testing these plant materials will be important to validate the findings from the mechanistic studies currently co-funded by EPRI and DOE. |
| **LWRS – Mechanisms of IASCC** | **Milestones:**<br>• (2019) Deliver predictive model capability for IASCC susceptibility.<br>Detailed testing and specific subtasks will be based on the results of the previous years' testing, as well as ongoing, industry-led research. Understanding the mechanism of IASCC will enable more focused material inspections, material replacements, and more detailed regulatory guidelines. In the long-term, mechanistic understanding also enables development of a predictive model, which has been sought for IASCC for decades. |
| **LTO – IASCC: Identifying Mechanisms and Mitigation Strategies for IASCC of Austenitic Steels and** | **Milestones**:<br>• (2015) Report on key factors in IASCC initiation and propagation of austenitic alloys in core internals and mitigation measures that could minimize IASCC in current LWR stainless steel components (actually published in 2014, EPRI report: 3002003105). |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| **LWR Core Components** | • (2014) Report on improved IASCC crack growth prediction models for BWRs and PWRs (published in 2014, EPRI report: 3002003103).<br>• (2018) Report on IASCC-resistant materials for repair and replacement. |
| **Concrete** | |
| **LWRS – Concrete** | **R&D Scope and Objectives:**<br>Large areas of most nuclear power plants have been constructed using concrete; there are some data on performance through the first 40 years of service. In general, the performance of reinforced concrete structures in nuclear power plants has been very good. Although the vast majority of these structures will continue to meet their functional or performance requirements during the current and any future licensing periods, it is reasonable to assume that there will be isolated examples where, primarily as a result of environmental effects, the structures may not exhibit the desired durability (e.g., water-intake structures and freezing/thawing damage of containments) without some form of intervention.<br>Although a number of organizations have sponsored work addressing the aging of nuclear power plant structures (e.g., NRC, Nuclear Energy Agency, and International Atomic Energy Agency), there are still several areas where additional research is desired to demonstrate that the structures will continue to meet functional and performance requirements (e.g., maintain structural margins). Structural research topics include (1) compilation of material property data for long-term performance and trending, evaluation of environmental effects, and assessment and validation of NDE methods; (2) evaluation of long-term effects of elevated temperature and radiation; (3) improved damage models and acceptance criteria for use in assessments of the current and future condition of the structures; (4) improved constitutive models and analytical methods for use in determining nonlinear structural response (e.g., accident conditions); (5) nonintrusive methods for inspection of thick, heavily reinforced concrete structures and basemats; (6) global inspection methods for metallic pressure boundary components (i.e., liners of concrete containments and steel containments), including inaccessible areas and the back side of liner; (7) data on application and performance (e.g., durability) of repair materials and techniques; (8) utilization of structural reliability theory, incorporating uncertainties to address time-dependent changes to structures to ensure that minimum accepted performance requirements are exceeded and to estimate ongoing component degradation of estimate end-of-life; and (9) application of probabilistic modeling of component performance to provide risk-based criteria to evaluate how aging affects structural capacity.<br>Complementary activities are being conducted under an NRC program at Oak Ridge National Laboratory, by EPRI and by the Nuclear Energy Standards Coordination Collaborative, which is headed by the National Institute for Standards and Technology.<br>Plans for research at EPRI and NRC will continue to be evaluated to confirm the complementary and cooperative nature of concrete research under the MAaD Pathway. In addition, formation of an Extended Service Materials Working Group for concrete issues will provide a valuable resource for additional and diverse input. |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| **LTO – Comprehensive Aging Management of Concrete Structures** | **R&D Scope and Objectives:**<br>Adequate understanding and (where necessary) inspection techniques of concrete civil infrastructure in commercial nuclear power plants is an essential need for comprehensive decision making for long-term operation. There are a variety of kinetic processes that can lead to degradation of civil structures and these may be accelerated by operating environments specific to nuclear power plants. It is important that industry understand the impact of accelerated aging of civil infrastructure, particularly for LTO, as individual utilities will be required to provide both sound technical and economic justifications for long-term operation.<br>The interim goal of this project is to create a project that looks at various degradation phenomena being experienced in operating nuclear power plants. The initial stage of the project compiled an Aging Reference Manual, which defined the physics of kinetic degradation processes and discussed operational issues dealt with by the industry over the past 40+ years. The manual contains a framework for identifying at-risk structures and applicable degradation mechanisms. More recently, the NRC published Volume IV of the EMDA (NUREG/CR-7153), which prioritized aging degradation issues in concrete. Building on these guiding documents, a number of individual research projects, aimed at further understanding of those degradation mechanisms and structures identified as "at-risk," have been and will continue to be undertaken. The results of the individual studies will be merged into an Aging Management Toolbox Platform, which will be an open-ended tool for operators to assess the severity of damage and explore repair or mitigation options. It is anticipated that these investigations will yield one or more industry examination guidelines for concrete aging assessment(s). Key areas of research will cover aging degradation due to irradiation and thermal environments, risks and impact of alkali silica reaction (ASR), and assessment of nuclear power plant risks due to concrete creep effects. Related work covering spent fuel pools, including boric acid corrosion assessment, will be addressed. |
| **LWRS – Concrete** | **Milestones:**<br>• (2015) Deliver unified parameter to assess irradiation-induced damage in concrete structures.<br>• (2018) Complete model tool to assess the impact of irradiation on structural performance for concrete components.<br>• (2020) Complete model tool to assess the combined effects of irradiation and alkali-silica reactions on structural performance for concrete components.<br>Future milestones and specific tasks will be based on the results of the previous years' testing, as well as ongoing, industry-led research. The database of concrete performance completed in 2013 is a high-value tool accessible to all stakeholders, is being used to focus research on the remaining knowledge gaps, and will enable more focused material inspections. In the long-term, completion of a concrete and civil structures toolkit may allow for more robust prediction of concrete performance over extended service conditions. These tools are of high value to industry, which is a partner in their development. |
| **LTO – Comprehensive Aging Management of** | **Milestones**:<br>• (2014) Initial report on preliminary findings of the effect of irradiation damage on reactor cavity concrete (Completed – EPRI Report 3002002676). |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| **Concrete Structures** | • (2013) Containment aging pilot plant investigation Outage 2011 and Outage 2012 reports (results of destructive examination/NDE at Ginna and Nine Mile Point); industry guideline(s) for examination of structures for concrete aging (Completed – EPRI Report 3002002335).<br>• (2014) Literature review of creep in concrete post-tensioned containment structures (Completed – EPRI Report 3002003220).<br>• (2016) Report on experimental study of the effects of boric acid corrosion on concrete.<br>• (2015) Report on risk screening for ASR in concrete structures in existing plants.<br>• (2016) Report on radiation damage effects on concrete.<br>• (2018) Complete concrete and civil infrastructure toolbox development with DOE and Materials Ageing Institute partners. |
| **Cabling** | |
| **LWRS – Cabling** | **R&D Scope and Objectives:**<br>Cable aging mechanisms and degradation is an important area of study. Nuclear power plant operators carry out periodic cable inspections using NDE techniques to measure degradation and determine when replacement is needed. Degradation of cables primarily is caused by long-term exposure to high temperatures. Additionally, stretches of cables that have been buried underground are frequently exposed to groundwater. Wholesale replacement of cables is economically undesirable for long-term nuclear power plant operation.<br>This task provides an understanding about the role of material type, history, and the environment on cable insulation degradation; understanding of accelerated testing limitations; and support to partners in modeling activities, surveillance, and testing criteria. This task will provide experimental characterization of key forms of cable and cable insulation in a cooperative effort with NRC and EPRI. Tests will include evaluations of cable integrity following exposure to elevated temperature, humidity, and/or ionizing irradiation. These experimental data will be used to evaluate mechanisms of cable aging and determine the validity or limitations of accelerated aging protocols. The experimental data and mechanistic studies can be used to help identify key operational variables related to cable aging, optimize inspection and maintenance schedules to the most susceptible materials/locations, and, in the long-range, design tolerant materials. |
| **LTO – Advanced Cable Testing Technology for Life-Cycle Management of Cables** | **R&D Scope and Objectives:**<br>In 2014, a technical update will be issued on progress made to-date on our radiation and temperature monitoring Phase II efforts. We are on track to install the first set of data loggers in a PWR in Fall 2015. This is a follow-up to the 2013 research to identify actual containment temperature; dose conditions in actual cable locations will continue. The 2013 collection of data did support the belief that cables see only a fraction of the dose used for environmental qualification, but the data could not be correlated to actual cable locations. The second major effort in 2015 is the harvesting of service-aged cables for accelerated cable aging research in the areas of inverse temperature, diffusion-limited oxidation, and fill gaps in the existing thermal and thermal/radiation models for the most often used cable types. |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| | Associated work of interest to LTO is being funded by EPRI's Plant Engineering group to develop the technical basis for aging management and life-cycle management of cable systems.* Specifically, EPRI is performing a submergence qualification for Kerite ethylene propylene rubber insulation and plans are to add pink Okonite ethylene propylene rubber to the project this year. An aging acceleration regime is being attempted in this project using high frequency (i.e., 450 Hz and 900 Hz), along with 2.5 times line voltage. Additionally, research on medium voltage water-related degradation is continuing in 2015 to identify causes of insulation breakdown. Analysis of member-provided Tan $\delta$ data and EPRI-recommended acceptance criteria has been validated to classify the degree of wet cable insulation degradation. A report on the data collected since the release of EPRI Report 1025262 in July 2012 will be issued later in 2015. EPRI's Plant Engineering group continues to support aging management implementation through the cable user group meetings. All of these projects support identifying cable system aging management activities, the portions of the cable system having limited life, and data and methods for life-cycle management of aging cable systems. Enhanced testing and end-of-life predictive methods will continue to be investigated.<br>* Cable systems include the field cables, their terminations and splices, and local wiring, as well as the support and protective systems such as trays, conduits, and ducts. |
| **LWRS – Cabling** | **Milestones:**<br>• (2016) Complete analysis of key degradation modes of cable insulation.<br>• (2017) Complete assessment of cable degradation mitigation strategies.<br>• (2019) Deliver predictive model for cable degradation.<br>Future milestones and specific tasks will be based on the results of the previous years' testing, as well as ongoing, industry-led research. Completing research to identify and understand the degradation modes of cable insulation is an essential step to predicting the performance of cable insulation under extended service conditions. These data are critical to developing and delivering a predictive model for cable insulation degradation. Both will enable more focused inspections, material replacements, and better-informed regulations. The development of in-situ mitigation strategies also may allow for an alternative to cable replacement and would be of high value to industry by avoiding costly replacements. |
| **LTO – Advanced Cable Testing Technology for Life-Cycle Management of Cables** | **Milestones:**<br>• (June 2015) Harvesting and distribution of service aged cables from Crystal River Unit 3 to research projects on EMDA gaps of will be completed.<br>• (August 2015) Finalize research needed based on analysis of existing cable aging research data gaps for major cable types needed to be addressed to qualify condition and remaining useful life.<br>• (September 2015) Technical update for Phase II of the radiation and temperature monitoring data collection will be issued on the methods and process for data collection. |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
| --- | --- |
| **Mitigation Strategies** | |
| **LWRS – Advanced Weld Repair** | **R&D Scope and Objectives:**<br>The objective of this task is to develop advanced welding technologies that can be used to repair highly irradiated reactor internals without helium-induced cracking. Research includes mechanistic understanding of helium effects in weldments. This modeling task is supported by characterization of model alloys before and after irradiation and welding. This model can be used by stakeholders to further improve best practices for repair welding for both existing technology and advanced technology. In addition, this task will provide validation of residual stress models under development using advanced characterization techniques such as neutron scattering. Residual stress models also will improve best practices for weldments of reactors today and under extended service conditions. These tools could be expanded to include other industry practices such as peening. Finally, advanced welding techniques (such as friction-stir welding, laser welding, and hybrid techniques) will be developed and demonstrated on relevant materials (model and service alloys). Characterization of the weldments and qualification testing will be an essential step. To realize this step, a unique facility (welding cubicle for hot cell service) has been constructed in partnership with EPRI to develop advanced welding techniques on irradiated materials. |
| **LTO – Advanced Welding Methods for Irradiated Materials** | **R&D Scope and Objectives:**<br>As the existing LWR fleet ages, the weldability of the structural material used to construct the RPVs and reactor internals may be diminished. The decrease in weldability is caused by formation of helium in the base material structure. This is caused by nuclear transmutation reactions of boron and nickel within the reactor materials and increases as neutron fluence accumulates. Helium-induced weld cracking is a complex phenomenon that is related to the concentration of helium in the material, heat input of the welding technique used, and stresses during cooling of the weld. Modest improvement in the weldability of irradiated material can be achieved by lowering the heat input using conventional laser beam welding, but once stainless steel components reach a certain fluence (typically at 20 to 30 years of exposure), some may be welded by current welding methods. As nuclear power plants age further (40 years and beyond) consideration of the embrittlement effect of helium on weld repair becomes critical. The development of advance welding processes (hybrid fusion and solid state) is needed to extend the weldability of these irradiated reactor components.<br>There is significant justification for development of advanced welding methods to repair irradiated reactor materials. However, development of advanced welding processes for repair of irradiated reactor components is a relatively complex task and will take both fundamental research related to welding of irradiated materials and refinement of existing welding technologies. This is a relatively long-lead-time development process and research needs to be started now if welding repair options are to be available for reactor material and internals as they age and require repair or replacement. Expected work includes the following:<br>• Perform review and prepare summary report on advanced welding processes and the potential application for welding of irradiated reactor components in the underwater environment. Processes being considered are<br>– Low force friction stir welding |

<table>
<tr><th>R&D Area</th><th>MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)</th></tr>
<tr><td></td><td>
<ul><li><ul>
<li>Low force friction stir cladding</li>
<li>Auxiliary beam laser welding</li>
<li>Low dilution laser beam welding</li>
</ul></li>
<li>Prepare a detailed project plan for the multi-year project
<ul>
<li>Sample irradiation plan</li>
<li>Welding hot cell design/fabrication/installation</li>
<li>Advanced welding equipment technical requirements and procurement specification</li>
<li>Welding experiments to benchmark models and provide process development/refinement</li>
<li>Budgeting and detailed task planning</li>
</ul></li>
<li>Design and procurement of a stainless steel sample set for irradiation.</li>
</ul>
Project tasks are funded by the LTO Program and the DOE LWRS Program, with some tasks being co-funded. LTO-related work supported by the LWRS Program is performed at Oak Ridge National Laboratory. The Oak Ridge National Laboratory scope will focus on development of fundamental science for developing predictive models and simulations for advanced welding processes and measurement of residual stress at high temperatures.
Oak Ridge National Laboratory has the following facilities to achieve the project goals:
<ul>
<li>High-Flux Isotope Reactor – Irradiation of the sample set will occur at this facility, as well as potential measurement of residual stresses at high temperature.</li>
<li>Material Process Hot Cell – Welding of irradiated material requires facilities that can remotely handle radioactive materials.</li>
<li>Advanced Microstructure Characterization Laboratory – Examination of radioactive material at the sub-grain level is a unique capability of Oak Ridge National Laboratory.</li>
</ul>
</td></tr>
<tr><td>LWRS – Advanced Weld Repair</td><td>
Milestones:
<ul>
<li>(2015) Demonstrate initial solid-state welding on irradiated materials.</li>
<li>(2018) Complete transfer of weld-repair technique to industry.</li>
</ul>
Future milestones and specific tasks will be based on the results of the previous years’ testing, as well as ongoing, industry-led research. Demonstration of advanced weldment techniques for irradiated materials is a key step in validating this mitigation strategy. Successful deployment also may allow for an alternative to core internal replacement and would be of high value to industry by avoiding costly replacements. Further, these technologies also may have utility in repair or component replacement applications in other locations within a nuclear power plant.
</td></tr>
</table>

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| **LTO – Advanced Welding Methods for Irradiated Materials** | **Milestones**:<br>• (2013) Completed sample set fabrication.<br>• (2014) Initial irradiation campaign for sample set.<br>• (2014) Complete fabrication of welding cubicle.<br>• (2014) Published three technical reports (3002003143, 3002003146, 3002002954).<br>• (2015) Installation of welding cubicle at Oak Ridge National Laboratory.<br>• (2015) Initial welding experiments on irradiated material sample set. |
| | |
| **LWRS – Advanced Replacement Alloys** | **R&D Scope and Objectives:**<br>Advanced replacement alloys for use in LWR applications may provide greater margins of safety and performance and provide support to industry partners in their programs. This task will explore and develop new alloys in collaboration with the EPRI Advanced Radiation-Resistant Materials Program. Specifically, the LWRS Program will participate in expert panel groups to develop a comprehensive R&D plan for these advanced alloys. Future work will include alloy development, alloy optimization, fabrication of new alloys, and evaluation of their performance under LWR-relevant conditions (e.g., mechanical testing, corrosion testing, and irradiation performance among others) and, ultimately, validation of these new alloys. Based on past experience in alloy development, an optimized alloy (composition and processing details) that has been demonstrated in relevant service conditions can be delivered to industry by 2020. |
| **LTO – Advanced Radiation-Resistant Materials Program** | **R&D Scope and Objectives:**<br>EPRI has initiated a new international collaborative project with DOE on development of radiation-resistant materials for LWR applications. EPRI and DOE have jointly prepared a comprehensive report on the state of current knowledge of radiation-induced degradation in LWRs and a roadmap to develop and qualify more radiation-resistant materials. The report was prepared by a team of world-class experts and widely reviewed by the international research community. The roadmap will be used to formulate a long-range R&D plan to develop improved materials for long-term operation of current and new nuclear power plants. |
| **LWRS – Advanced Replacement Alloys** | **Milestones:**<br>• (2017) Complete down-select of candidate advanced alloys following ion irradiation campaign.<br>• (2024) Complete development and testing of new advanced alloy with superior degradation resistance with Advanced Radiation-Resistant Materials partners.<br>Future milestones and specific tasks will be informed by EPRI's Advanced Radiation-Resistant Materials Program plan that was released in 2013 and joint assessment of partnerships and available funding. Completing the joint effort with EPRI on the alloy down-select and development plan is an essential first step in this alloy development task. This plan will help identify future roles and responsibilities in this partnership with EPRI. |

| R&D Area | MAaD (LWRS) / Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO) |
|---|---|
| **LTO – Advanced Radiation-Resistant Materials Program** | **Milestones:**<br>• (2015) Interim report on the results of Phase 1, documenting the results of microstructural, mechanical, and SCC studies on proton-irradiated commercial alloys to identify promising materials for further evaluation in Phase 2.<br>• (2017) Final report on the results of Phase 1, recommending alloys for further evaluation under neutron irradiation.<br>• (2019) Interim report on the results of Phase 2, documenting microstructural, mechanical, and SCC studies on neutron-irradiated commercial and advanced alloys.<br>• (2022) Final report on the results of Phase 2, identifying one or two radiation-resistant commercial alloys for LWR internals. |

| R&D Area | Advanced II&C Systems Technologies |
|---|---|
| **LWRS – New Instrumentation and Control and Human System Interfaces and Capabilities (including Advanced II&C Pilot Projects)** | **R&D Scope and Objectives:**<br>This research pathway will address aging and long-term reliability issues of the legacy II&C systems used in the current LWR fleet by demonstrating new technologies and operational concepts in actual nuclear power plant settings. This approach drives the following two important outcomes:<br>• Reduces the technical, financial, and regulatory risk of upgrading the aging II&C systems to support extended nuclear power plant life to and beyond 60 years.<br>• Provides the technological foundation for a transformed nuclear power plant operating model that improves plant performance and addresses the challenges of the future business environment.<br>The research program is being conducted in close cooperation with the nuclear utility industry to ensure that it is responsive to the challenges and opportunities in the present operating environment. The scope of the research program is to develop a seamless integrated digital environment as the basis of the new operating model.<br>A Utility Working Group, composed of leading nuclear utilities across the industry and EPRI, advises the program. The Utility Working Group developed a consensus vision of how more integrated, modernized plant II&C systems could address a number of challenges to the long-term sustainability of the LWR fleet.[f] A strategy was developed to transform the nuclear power plant operating model by first defining a future state of plant operations and support based on advanced technologies and then developing and demonstrating the needed technologies to individually transform the plant's work activities. The collective work activities are grouped into the following major areas of enabling capabilities:<br>1. Human performance improvement for nuclear power plant field workers<br>2. Outage safety and efficiency |

f. Long-Term Instrumentation, Information, and Control Systems (II&C) Modernization Future Vision and Strategy, INL/EXT-11-24154, Revision 3, November 2013.

| R&D Area | Advanced II&C Systems Technologies |
|---|---|
| | 3. Online monitoring<br>4. Integrated operations<br>5. Automated nuclear power plant<br>6. Hybrid control room.<br><br>In each of these areas, a series of pilot projects are planned that enable the development and deployment of new II&C technologies in existing nuclear power plants. A pilot project is an individual R&D project that is part of a larger strategy needed to achieve modernization according to a plan. Note that pilot projects have value on their own, as well as collectively. A pilot project is small enough to be undertaken by a single utility, it demonstrates a key technology or outcome required to achieve success in the higher strategy, and it supports scaling that can be replicated and used by other nuclear power plants. Through the LWRS Program, individual utilities and nuclear power plants are able to participate in these projects or otherwise leverage the results of projects conducted at demonstration plants.<br><br>The pilot projects conducted through this pathway serve as stepping stones to achieving longer-term outcomes of sustainable II&C technologies. They are designed to emphasize success in some crucial aspect of nuclear power plant technology refurbishment and sustainable modernization. They provide the opportunity to develop and demonstrate methods for technology development and deployment that can be broadly standardized and leveraged by the commercial nuclear power fleet. Each of the R&D activities in this program achieves a part of the longer-term goals of safe and cost-effective sustainability. They are limited in scope so they can be undertaken and implemented in a manner that minimizes technical and regulatory risk. In keeping with best industry practices, prudent change management dictates that new technologies are introduced slowly so that they can be validated within the nuclear safety culture model. |
| **LTO – Requirements Database for Advanced I&C, Human System Interface, and Information Technology** | **R&D Scope and Objectives:**<br><br>EPRI will participate in the LWRS Program working group for Advanced II&C Systems Technologies. This working group includes utility representatives from Exelon, Entergy, Duke, Southern, South Texas Project, Arizona Public Service, Constellation, Progress, Tennessee Valley Authority, and the STARS Alliance. Through the working group, the LWRS Program is sponsoring pilot studies of advanced applications of I&C and other information technology projects at individual utilities. The LWRS Program also has developed a Human Systems Simulation Laboratory to support these applications and to perform related R&D at INL. The Human Systems Simulation Laboratory employs 15 bench-board-style touch panels that resemble the control panels currently used in nuclear power plants. This equipment is capable of running nuclear power plant simulators to produce a high-fidelity control room environment for control room modernization R&D. EPRI will participate in these activities on behalf of the LTO project membership. EPRI will interact with the working group on the LTO requirements database activities. EPRI is making relevant EPRI technical reports available to INL for work in the LWRS Program Advanced II&C Systems Technologies area. |

| R&D Area | Advanced II&C Systems Technologies |
|---|---|
| **LWRS – New Instrumentation and Control and Human System Interfaces and Capabilities (including advanced II&C pilot projects)** | **Milestones:**<br>Human performance improvement for nuclear power plant field workers:<br>• (2015) Conclude the field evaluation of the added functionality and new design concepts of the prototype computer-based procedures system, evaluating at a host utility the revisions made to the system to ensure it encompasses a broad variety of procedures, instructions, and usage scenarios.<br>• (2015) Develop an automated work package prototype that supports paperless work flow and improved human performance.<br>• (2017) Integrate the automated work package with a wireless plant surveillance system and demonstrate self-documenting work packages for nuclear power plant surveillances.<br>• (2017) Publish a report on automated work package implementation requirements for both nuclear power plant field worker usage and self-documenting surveillances.<br>• (2017) Develop and demonstrate augmented reality technologies for visualization of radiation fields for mobile plant workers.<br>• (2018) Develop and demonstrate augmented reality technologies for visualization of real-time plant parameters (e.g., pressures, flows, valve positions, and restricted boundaries) for mobile plant workers.<br>• (2019) Publish a technical report on augmented reality technologies developed for nuclear power plant field workers, enabling them to visualize abstract data and invisible phenomena, resulting in significantly improved situational awareness, access to context-based plant information, and generally improved effectiveness and efficiency in conducting field work activities.<br><br>Outage safety and efficiency:<br>• (2015) Develop improved graphical displays for an Advanced Outage Control Center, employing human factors principles for effective real-time collaboration and collective situational awareness.<br>• (2016) Develop technology for real-time plant configuration status during outages to improve work coordination, efficiency, and safety margin.<br>• (2017) Develop and demonstrate (in the Human Systems Simulation Laboratory) technologies for detecting interactions between plant status (configuration) states and concurrent component manipulations directed by in-use procedures in consideration of regulatory requirements, technical specifications, and risk management requirements (defense-in-depth).<br>• (2018) Develop and demonstrate (in the Human Systems Simulation Laboratory) technologies to detect undesired system configurations based on concurrent work activities (e.g., inadvertent drain paths and interaction of clearance boundaries).<br>• (2019) Develop a real-time outage risk management strategy and publish a technical report to improve nuclear safety during outages by detecting configuration control problems caused by work activity interactions with changing system alignments.<br><br>Integrated operations:<br>• (2017) Develop and demonstrate (in the Human Systems Simulation |

| R&D Area | Advanced II&C Systems Technologies |
|---|---|
| | Laboratory) concepts for an advanced online monitoring facility that can collect and organize data from all types of monitoring systems and activities and can provide visualization of degradation where applicable.<br>• (2018) Develop and demonstrate (in the Human Systems Simulation Laboratory) concepts for real-time information integration and collaboration on degrading component issues with remote parties (e.g., control room, outage control center, systems and component engineering staff, internal and external consultants, and suppliers).<br>• (2019) Develop a digital architecture and publish a technical report for an advanced online monitoring facility, providing long-term asset management and providing real-time information directly to control room operators, troubleshooting and root cause teams, suppliers and technical consultants involved in component support, and engineering in support of the system health program.<br>• (2019) For chemistry activities, conduct a study and publish a technical report on opportunities to provide remote services from centralized or third-party service providers, based on advanced real-time communication and collaboration technologies built on the digital architecture for a highly automated plant. Demonstrate representative remote activities with a host plant.<br>• (2019) Develop and demonstrate (in the Human Systems Simulation Laboratory) concepts for a management decision support center that incorporates advanced communication, collaboration, and display technologies to provide enhanced situational awareness and contingency analysis.<br>• (2020) For maintenance activities, conduct a study and publish a technical report on opportunities to provide remote services from centralized or third-party service providers, based on advanced real-time communication and collaboration technologies built on the digital architecture for a highly automated plant. Demonstrate representative remote activities with a host plant.<br>• (2021) For radiation protection activities, conduct a study and publish a technical report on opportunities to provide remote services from centralized or third-party service providers, based on advanced real-time communication and collaboration technologies built on the digital architecture for a highly automated plant. Demonstrate representative remote activities with a host plant.<br>• (2022) Publish human and organizational factors studies and a technical report for a virtual plant support organization technology platform consisting of data sharing, communications (voice and video), and collaboration technologies that will compose a seamless work environment for a geographically dispersed nuclear power plant support organization.<br>• (2024) Develop and demonstrate (in the Human Systems Simulation Laboratory) concepts for advanced emergency response facilities that incorporate advanced communication, collaboration, and display technologies to provide enhanced situational awareness and real-time coordination with the control room, other emergency response facilities, field teams, NRC, and other emergency response agencies.<br>• (2025) Publish human and organizational factors studies and a technical |

| R&D Area | Advanced II&C Systems Technologies |
|---|---|
| | report for a management decision support center consisting of an advanced digital display and decision-support technologies, thereby enhancing nuclear safety margin, asset protection, regulatory performance, and production success.<br><br>Automated plant:<br>• (2015) Complete a digital architecture requirements report documenting the information technology requirements for the advanced digital technology envisioned to be applied to nuclear power plant work activities.<br>• (2015) Complete a digital architecture gap analysis report documenting the gap between current typical instrumentation & control and information technology capabilities in nuclear power plants versus those documented in the digital architecture requirements report.<br>• (2017) Complete a digital architecture implementation guideline, documenting a graded approach in applying the conceptual model to selected digital technologies and in determining the incremental information technology requirements based on a current state gap analysis.<br>• (2017) For nuclear power plant operations activities, analyze the staffing, tasks, and cost models to identify the opportunities for application of digital technologies to improve nuclear safety, efficiency, and human performance based on optimum human-technology function allocation. Demonstrate representative activities as transformed by technology, with results published in a technical report.<br>• (2018) For nuclear power plant chemistry activities, analyze the staffing, tasks, and cost models to identify opportunities for application of digital technologies to improve nuclear safety, efficiency, and human performance based on optimum human-technology function allocation. Demonstrate representative activities as transformed by technology, with results published in a technical report.<br>• (2019) For nuclear power plant maintenance activities, analyze the staffing, tasks, and cost models to identify opportunities for application of digital technologies to improve nuclear safety, efficiency, and human performance, based on optimum human-technology function allocation. Demonstrate representative activities as transformed by technology, with results published in a technical report.<br>• (2020) For nuclear power radiation protection activities, analyze the staffing, tasks, and cost models to identify opportunities for application of digital technologies to improve nuclear safety, efficiency, and human performance based on optimum human-technology function allocation. Demonstrate representative activities as transformed by technology, with results published in a technical report.<br>• (2021) Develop and demonstrate (in the Human Systems Simulation Laboratory) prototype plant control automation strategies for representative normal operations evolutions (e.g., plant start-ups and shut-downs, equipment rotation alignments, and test alignments).<br>• (2024) Develop and demonstrate (in the Human Systems Simulation Laboratory) prototype plant control automation strategies for representative plant transients (e.g., loss of primary letdown flow or loss of condensate pump).<br>• (2025) Develop the strategy and priorities and publish a technical report for |

| R&D Area | Advanced II&C Systems Technologies |
|---|---|
| | automating operator control actions for important plant state changes, transients, and power maneuvers, resulting in nuclear safety and human performance improvements founded on engineering and human factors principles.<br><br>Hybrid control room:<br>• (2015) Develop a distributed control system prototype. Using a participating utility's simulator plant model installed at the Human Systems Simulation Laboratory, develop a functional prototype for the turbine control system upgrade. Document the design, development, and functionality of the prototype replacement system.<br>• (2015) Develop prognostic software for control indicators. Provide demonstration and software for the prognostic system and display interface for installation at the Human Systems Simulation Laboratory.<br>• (2015) Develop operator performance metrics for verification and validation. Document the process of how simulator studies should be performed, including the various operator performance metrics that can be collected in support of control room upgrades.<br>• (2015) Develop a prototype of an advanced hybrid control room in the Human Systems Simulation Laboratory that includes advanced operator interface technologies such as alarm management systems, computerized procedures, soft controls, large displays, and operator support systems.<br>• (2015) Test Human Systems Simulation Laboratory systems in preparation for conducting benefits study with operators. Test Human Systems Simulation Laboratory systems in representative configurations to verify that systems are able to function reliably in operational sequences and scenarios, test data logging and collection systems, and verify the stability of different combinations of digital systems with human interactions in preparation for data collection with actual operating crews.<br>• (2017) Publish a report documenting the Control Room Upgrades Benefit Study that presents the data, findings, and conclusions on performance improvements that can be obtained through the technologies of an advanced hybrid control room.<br>• (2017) Develop concepts for using nuclear power plant full-scope simulators as operator advisory systems in hybrid control rooms and complete a technical report on prototype demonstrations in the Human Systems Simulation Laboratory.<br>• (2018) Develop concepts for a real-time plant operational diagnostic and trend advisory system with the ability to detect system and component degradation and complete a technical report on prototype demonstrations in the Human Systems Simulation Laboratory.<br>• (2019) Develop an operator advisory system fully integrated into a control room simulator (Human Systems Simulation Laboratory) that provides plant steady-state performance monitoring, diagnostics and trending of performance degradation, operator alerts for intervention, and recommended actions for problem mitigation, with application of control room design and human factors principles.<br>• (2020) Complete a technical report on operator attention demands and limitations on operator activities based on the current conduct of operations |

| R&D Area | Advanced II&C Systems Technologies |
| --- | --- |
| | protocols. This report will identify opportunities to maximize operator efficiency and effectiveness with advanced digital technologies.<br>• (2021) Develop an end-state vision and implementation strategy for an advanced computerized operator support system, based on an operator advisory system that provides real-time situational awareness, prediction of the future plant state based on current conditions and trends, and recommended operator interventions to achieve nuclear safety goals.<br>• (2023) Develop and demonstrate (in the Human Systems Simulation Laboratory) prototype mobile technologies for operator situational awareness and limited plant control capabilities for nuclear power plant support systems (e.g., plant auxiliary systems operations and remote panel operations).<br>• (2024) Develop and demonstrate (in the Human Systems Simulation Laboratory) new concepts for remote operator assistance in high activity periods (e.g., refueling outages) and accident/security events, allowing offsite operators to remotely perform low safety-significant operational activities, freeing the control room operators to concentrate on safety functions.<br>• (2025) Develop validated future concepts of operations for improvements in control room protocols, staffing, operator proximity, and control room management, enabled by new technologies that provide mobile information and control capabilities and the ability to interact with other control centers (e.g., emergency response facilities for severe accident management guidelines implementation). |
| **LTO – Requirements Database for Advanced I&C, Human System Interface, and Information Technology** | **Milestones**:<br>• (2013) Summary Report on Database Structure Capability Levels and Simple Prototype (Published – EPRI report 3002000503).<br>• (2014) Guidance for Developing a Human Factors Engineering Program for an Operating Nuclear Power Plant (Published – EPRI report 3002002770).<br>The following deliverables will be jointly developed by LWRS and LTO and are listed identically as milestones for each program:<br>• (2016) Publish interim guidelines to implement technologies for improved outage safety and efficiency.<br>• (2016) Publish revised interim guidelines to implement technologies for human performance improvement for nuclear power plant field workers.<br>• (2018) Publish interim guidelines to implement technologies for a hybrid control room.<br>• (2018) Publish final guidelines to implement technologies for improved outage safety and efficiency.<br>• (2019) Publish final guidelines to implement technologies for human performance improvement for nuclear power plant field workers.<br>• (2020) Publish interim guidelines to implement technologies for integrated operations.<br>• (2021) Publish interim guidelines to implement technologies for an automated plant<br>• (2021) Publish revised interim guidelines to implement technologies for a hybrid control room. |

| R&D Area | Advanced II&C Systems Technologies |
|---|---|
| | • (2022) Publish revised interim guidelines to implement technologies for integrated operations.<br>• (2025) Publish final guidelines to implement technologies for an automated plant.<br>• (2025) Publish final guidelines to implement technologies for integrated operations.<br>• (2025) Publish final guidelines to implement technologies for a hybrid control room. |
| | |
| **LWRS – Centralized Online Monitoring** | **R&D Scope and Objectives:**<br>As nuclear power plant systems begin to be operated during periods longer than originally licensed, the need arises for more and better types of monitoring of material and component performance. This includes the need to move from periodic, manual assessments and surveillances of physical components and structures to centralized online condition monitoring. This is an important transformational step in the management of nuclear power plants. It enables real-time assessment and monitoring of physical systems and better management of active components based on their performance. It also provides the ability to gather substantially more data through automated means and to analyze and trend performance using new methods to make more informed decisions concerning component health. Of particular importance will be the capability to determine the remaining useful life of a component to justify its continued operation over an extended nuclear power plant life.<br><br>Working closely with the MAaD and RISMC Pathways and EPRI, this pathway will develop technologies to complement sensor development and monitoring of materials to assess the performance of SSC materials during long-term operation for purposes of decision making and asset management. The MAaD Pathway is developing the scientific basis for understanding the modes of degradation and the physical phenomena that give rise to indications of damage and degradation. In addition, the MAaD Pathway is developing models of the degradation and degradation mechanisms, and sensors and techniques for NDE of materials during periodic inspections. The RISMC Pathway is developing tools that can guide sensor development and placement. The Advanced II&C Systems Technologies Pathway is developing in-situ methods to interrogate materials for indications of degradation, for monitoring components and materials in place, and for developing the tools to integrate indices that may be used to make assessments of structural and other aspects of material health in SSCs that are monitored. |
| **LTO – Centralized Online Monitoring** | **R&D Scope and Objectives:**<br>To achieve continued safe and economical long-term operation of the U.S. domestic and international nuclear power plants, it will be imperative that nuclear power plants maintain high levels of operational performance and efficiency. Nuclear power plants have a continuing need to undergo design and operational changes, as well as manage aging SSCs. Effective management of SSCs will require integration of advanced information monitoring and analysis capabilities into nuclear power plant operations, maintenance, and engineering activities.<br><br>Centralized online monitoring is a highly automated condition analysis and asset management system designed to capture and build in knowledge, experience, and intelligence from many diversified operating systems and monitoring environments. Domestic nuclear power plants have constrained resources to |

| R&D Area | Advanced II&C Systems Technologies |
|---|---|
| | support implementation of advanced technology programs not required for direct plant operation or regulatory issues. These constraints dictate that a comprehensive online monitoring capability will be an evolutionary development determined by the functional capabilities needed to support current operational requirements and to provide for long-term asset management. A key functional requirement of a well-developed monitoring program is its information interface with the operating nuclear power plant and associated staff.<br><br>To achieve the stated strategic goals of EPRI's LTO project, industry must develop an effective monitoring program that has a well-designed data and information integration platform with advanced technologies, including anomaly detection; automated diagnostic capabilities; a repository of equipment failure signatures captured from industry events; and, ultimately, prognostics-remaining useful life capabilities designed to evaluate critical nuclear power plant assets for optimized maintenance and investment decisions to support LTO. EPRI's research will build on previously developed monitoring technologies and leverage the LTO resources with our strategic partners. In support of implementation of nuclear power plant monitoring programs, EPRI has published comprehensive centralized online monitoring implementation guidelines, produced state-of-the-art diagnostics and prognostics technology developed by EPRI, with guidance based on early adopters and EPRI's Generation Division experience from the power industry's operational monitoring centers.<br><br>The continued development and execution of the required research must include broad and frequent interfacing with all of EPRI's strategic partners, including member advisors, technical specialists, and their commercial support organizations. Other partners include qualified vendors, universities, government laboratories, and utility research programs. |
| **LWRS – Centralized Online Monitoring** | **Milestones:**<br>• (2015) Develop select prognostic models for active components in nuclear power plants.<br>• (2015) Develop a passive component monitoring framework for aging effects in nuclear power plant materials.<br>• (2016) Develop a passive component monitoring framework for aging effects of piping and primary and secondary system components in nuclear power plant materials.<br>• (2017) Develop diagnostic and prognostic models for a second, large, passive plant component based on the information integration framework.<br>• (2018) Develop and validate a health risk management framework for concrete structures in nuclear power plants, demonstrate for illustrative concrete structures in the nuclear power plant environment, and develop an implementation strategy for nuclear power plants.<br>• (2018) Publish a technical report on measures, sensors, algorithms, and methods for monitoring active aging and degradation phenomena for a second, large, passive plant component, involving nondestructive examination-related online monitoring technology development, including the diagnostic and prognostic analysis framework to support utility implementation of online monitoring for the component type.<br>• (2020) Publish a technical report on tests of fiber optic systems and correlation of strain measurements with piping wall thickness, piping performance, and relationship with existing plant technical specifications for |

| R&D Area | Advanced II&C Systems Technologies |
|---|---|
| | risk-informed technical specification implementation.<br>• (2021) Publish a technical report on measures, sensors, algorithms, and methods for monitoring active aging and degradation phenomena for flow-accelerated corrosion and integration with industry standard guidance (e.g., EPRI CheckWorks, etc.). |
| **LTO – Centralized Online Monitoring** | **Milestones**:<br>• (2014) Complete EPRI prognostics and health management software installation at the pilot plant utilities (EPRI report 3002002762).<br>• (2014) Production release of EPRI's prognostics and health management software and access to the associated databases (EPRI report 3002004263).<br>• (2014) Complete joint research on diagnostics and prognostics (remaining useful life) application to critical plant assets (complete demonstration at INL).<br>• (2015) Proof-of-concept applications of in-situ monitoring of material degradation of passive assets (in progress at INL).<br>• (2015) Publish interim guidelines to implement technologies for centralized online monitoring and information integration.<br>• (2016) Pilot applications of in-situ monitoring of material degradation of passive assets.<br>• (2017) Complete transient analysis R&D.<br>• (2018) Publish final guidelines to implement technologies for centralized online monitoring and information integration. |
| | |
| **LWRS – Industrial and Regulatory Engagement** | **R&D Scope and Objectives:**<br>Nuclear asset owner engagement is a necessary and enabling activity to obtain data and accurate characterization of long-term operational challenges, assess the suitability of proposed research for addressing long-term needs, and gain access to data and representative infrastructure and expertise needed to ensure success of the proposed R&D activities. Engagement with vendors and suppliers will ensure that vendor expectations and needs can be translated into requirements that can be met through technology commercialization.<br>To ensure appropriate transfer of technology to the nuclear power industry, guidelines documents will be published for each of the areas of enabling capabilities, incorporating the specific technologies and technical reports produced under each of the pilot projects for the respective areas. EPRI has agreed to assume responsibility for development and publication of these guidelines, using their standard methods and utility interfaces to develop the documents and validate them with industry. The Advanced II&C Systems Technologies Pathway will support this effort by providing relevant information and participating in development activities. |

| R&D Area | Advanced II&C Systems Technologies |
|---|---|
| **LTO – Requirements Database for Advanced I&C, Human System Interface, and Information Technology** | **R&D Scope and Objectives:**<br>EPRI will develop a repository of advanced I&C, human system interface, and other information technology requirements and good practices from the pilot studies and from other industry activities. The purpose of this repository is to have a living resource for utilities to review state-of-the-art and good practices in the industry related to I&C enhancement projects. |
| **LWRS – Industrial and Regulatory Engagement** | **Milestones:**<br>Human performance improvement for nuclear power plant field workers:<br>• (2016) Publish interim guidelines to implement technologies for human performance improvement for nuclear power plant field workers.<br>• (2019) Publish final guidelines to implement technologies for human performance improvement for nuclear power plant field workers.<br>Outage safety and efficiency:<br>• (2016) Publish interim guidelines to implement technologies for improved outage safety and efficiency.<br>• (2018) Publish final guidelines to implement technologies for improved outage safety and efficiency.<br>Centralized online monitoring:<br>• (2016) Publish interim guidelines to implement technologies for centralized online monitoring and information integration.<br>• (2018) Publish final guidelines to implement technologies for centralized online monitoring and information integration.<br>Integrated operations:<br>• (2020) Publish revised interim guidelines to implement technologies for integrated operations.<br>• (2022) Publish final guidelines to implement technologies for integrated operations.<br>Automated plant:<br>• (2021) Publish interim guidelines to implement technologies for an automated plant.<br>• (2025) Publish final guidelines to implement technologies for an automated plant.<br>Hybrid control room:<br>• (2018) Publish interim guidelines to implement technologies for a hybrid control room.<br>• (2021) Publish revised interim guidelines to implement technologies for a hybrid control room.<br>• (2025) Publish final guidelines to implement technologies for a hybrid control room. |

| R&D Area | Advanced II&C Systems Technologies |
|---|---|
| **LTO – Requirements Database for Advanced I&C, Human System Interface, and Information Technology** | **Milestones**:<br>(2018, 2020, and 2025) Releases of repository of advanced I&C requirements based on pilot studies within the advanced I&C working group, other industry pilot studies, and LWRS Program user facility results.<br>(See also the LTO Program milestones listed earlier with the LWRS Advanced II&C Systems Technologies pilot projects.) |

| R&D Area | RISMC |
|---|---|
| **LWRS – Margins Analysis Techniques and Modeling and Simulation Activities in Support of RISMC** | **R&D Scope and Objectives:**<br>The purpose of the RISMC Pathway R&D is to support nuclear power plant decisions for RIMM, with the aim to improve economics and reliability and sustain the safety of current nuclear power plants over periods of extended operations. The goals of the RISMC Pathway are twofold:<br>1. Develop and demonstrate a risk-assessment method that is coupled to safety margin quantification that can be used by nuclear power plant decision makers as part of RIMM strategies.<br>2. Create an advanced RISMC Toolkit that enables more accurate representation of nuclear power plant safety margins and their associated impacts on operations and economics.<br>Margin Management Strategies:<br>One of the primary items inherent in the goals of the RISMC Pathway is the ability to propose and evaluate margin management strategies. For example, a situation could exist that causes margins associated with one or more key safety functions to become degraded; the methods and tools developed in this pathway can be used to model and measure those margins. These evaluations will then support development and evaluation of appropriate alternative strategies for consideration by key decision makers to maintain and enhance the impacted margins as necessary. When alternatives are proposed that mitigate reductions in the safety margin, these changes are referred to as margin *recovery* strategies. Moving beyond current limitations in safety analysis, the RISMC Pathway will develop techniques to conduct margins analysis using simulation-based studies of safety margins.<br>Central to this pathway is the concept of a safety margin. In general terms, a "margin" is usually characterized in one of two ways:<br>• A *deterministic* margin, defined by the ratio (or, alternatively, the difference) of an applied capacity (i.e., strength) to the load. For example, a pressure tank is tested to failure, where the tank design is rated for a pressure **C** and it is known to fail at pressure **L**, thus the margin is (**L – C)** (safety margin) or **L/C** (safety factor).<br>• A *probabilistic* margin, defined by the probability that the load exceeds the capacity. For example, if failure of a pressure tank is modeled where the tank design capacity is a distribution f(**C**), its loading condition is a second distribution f(**L**), the probabilistic margin would be represented by the expression Pr[f(**L**) > f(**C**)].<br>In practice, actual loads (**L**) and capacities (**C**) are uncertain and, as a consequence, |

| R&D Area | RISMC |
|---|---|
| | most engineering margin evaluations are of the probabilistic type. In cases where deterministic margins are evaluated, the analysis is typically very conservative in order to account for uncertainties. The RISMC Pathway uses the probability margin approach to quantify impacts to economics, reliability, and safety to avoid excessive conservatisms (where possible) and treat uncertainties directly. Further, this approach is used in RIMM to present results to decision makers as it relates to margin evaluation, management, and recovery strategies.<br><br>To successfully accomplish the pathway goals, the RISMC approach must be defined and demonstrated. The determination of the degree of a safety margin requires an understanding of risk-based scenarios. Within a scenario, an understanding of nuclear power plant's behavior (i.e., operational rules such as technical specifications, operator behavior, and SSC status) and associated uncertainties will be required to interface with a systems code. Then, to characterize safety margin for a specific safety performance metric[g] of consideration (e.g., peak fuel clad temperature), the nuclear power plant simulation will determine the time and scenario-dependent outcomes for both the load and capacity. Specifically, the safety margin approach will use the physics-based nuclear power plant results (the "load") and contrast these to the capacity (for the associated performance metric) to determine if safety margins have been exceeded (or not) for a family of accident scenarios. Engineering insights will be derived based on the scenarios and associated outcomes.<br><br>The RISMC methods are to be described in a set of technical reports for RIMM.<br><br>Margin Analysis Techniques:<br><br>This research area develops techniques to conduct margins analysis, including the methodology for carrying out simulation-based studies of safety margin, using the following generic process steps for RISMC applications:<br><br>1. Characterize the issue to be resolved in a way that explicitly scopes the modeling and analysis to be performed. Formulate an "issue space" that describes the safety figures of merit to be analyzed.<br><br>2. Quantify the decision maker and analyst's state-of-knowledge (uncertainty) of the key variables and models relevant to the issue. For example, if long-term operation is a facet of the analysis, then potential aging mechanisms that may degrade components should be included in the quantification.<br><br>3. Determine issue-specific, risk-based scenarios and accident timelines. The scenarios will be able to capture timing considerations that may affect the safety margins and nuclear power plant physical phenomena, as described in Steps 4 and 5. As such, there will be strong interactions between the analyses in Steps 3 through 5. Also, to "build up" the load and capacity distributions representing the safety margins (as part of Step 6), a large number of scenarios will be needed for evaluation. |

g. Safety performance metrics may be application-specific, but, in general, they are engineering characteristics of the nuclear power plant; for example, as defined in 10 CFR 50.36, "safety limits for nuclear reactors are limits upon important process variables that are found to be necessary to reasonably protect the integrity of certain of the physical barriers that guard against the uncontrolled release of radioactivity."

| R&D Area | RISMC |
|---|---|
| | 4. Represent nuclear power plant operation probabilistically using the scenarios identified in Step 3. For example, nuclear power plant operational rules (e.g., operator procedures, technical specifications, and maintenance schedules) are used to provide realism for scenario generation. Because numerous scenarios will be generated, the nuclear power plant and operator behavior cannot be manually created similar to current risk assessment using event and fault trees. In addition to the *expected* operator behavior (plant procedures), the probabilistic plant representation will account for the possibility of failures.<br>5. Represent nuclear power plant physics mechanistically. The nuclear power plant systems level code (RELAP-7) will be used to develop distributions for the key plant process variables (i.e., loads) and the capacity to withstand those loads for the scenarios identified in Step 4. Because there is a coupling between Steps 4 and 5, they each can impact the other. For example, a calculated high loading (from pressure, temperature, or radiation) in an SSC may disable a component, thereby impacting an accident scenario.<br>6. Construct and quantify probabilistic load and capacity distributions relating to the figures of merit that will be analyzed to determine the probabilistic safety margins.<br>7. Determine how to manage uncharacterized risk. Because there is no way to guarantee that all scenarios, hazards, failures, or physics are addressed, the decision maker should be aware of the limitations in the analysis and adhere to protocols of "good engineering practices" to augment the analysis. This step relies on effective communication from the analysis steps in order to understand the risks that *were* characterized.<br>8. Identify and characterize the factors and controls that determine the relevant safety margins within the issue being evaluated to develop appropriate RIMM strategies. Determine whether additional work to reduce uncertainty would be worthwhile or if additional (or relaxed) safety control is justified.<br>Case Study Collaborations:<br>Jointly with EPRI, the RISMC Pathway is working on specific case studies of interest to the nuclear power plant industry. During FY 2013 and FY 2014, the team performed multiple case studies, including a demonstration using the INL's Advanced Test Reactor, a hypothetical pressurized water reactor, and a boiling water reactor extended power uprate case study. Safety margin recovery strategies will be determined that will mitigate the potential safety impacts due to the postulated increase in nominal reactor power that would result from the extended power uprate. An additional task was to develop a technical report that describes how to perform safety margin-based configuration risk management. Configuration risk management currently involves activities such as the Significance Determination Process, which traditionally uses core damage frequency as the primary safety metric – the research will focus on how the safety margin approach may be used to determine risk levels as different plant configurations are considered.<br>RISMC Toolkit:<br>The RISMC Toolkit is being built using INL's Multi-physics Object Oriented |

| R&D Area | RISMC |
|---|---|
| | Simulation Environment (MOOSE) high-performance computing framework.[h] MOOSE is the INL development and runtime environment for the solution of multi-physics systems that involve multiple physical models or multiple simultaneous physical phenomena. Models built on the MOOSE framework can be coupled as needed for solving a particular problem. The RISMC Toolkit and roles are described as follows:<br>• RELAP-7: RELAP-7 (**R**eactor **E**xcursion and **L**eak **A**nalysis **P**rogram) will be the main reactor systems simulation tool for RISMC and the next generation tool in the RELAP reactor safety/systems analysis application series. RELAP-7 development will leverage 30 years of advancements in software design, numerical integration methods, and physical models. RELAP-7 will simulate behavior at the nuclear power plant level with a level of fidelity that will support the analysis and decision making necessary to economically and safely extend and enhance the operation of the current nuclear power plant fleet.<br>• RAVEN: RAVEN (**R**eactor **A**nalysis and **V**irtual Control **EN**vironment) is a multi-tasking application focused on RELAP-7 simulation control, reactor plant control logic, reactor system analysis, uncertainty quantification, and performing probabilistic risk assessments for postulated events. RAVEN will drive RELAP-7 (and other MOOSE-based reactor applications) for conduct of RISMC analyses.<br>• Grizzly: Grizzly will simulate component aging and damage evolution events for LWRS Program applications. Grizzly will be able to simulate component damage evolution for the RPV, core internals, and concrete support and containment structures subjected to a neutron flux, corrosion, and high temperatures and pressures. Grizzly will be able to couple with RELAP-7 and RAVEN to provide aging analysis in support of the RISMC methodology.<br>• Peacock: Peacock is a general graphical user interface for MOOSE-based applications. Peacock has been built in a very general fashion to allow specialization of the graphical user interface for different applications. The specialization of Peacock for RELAP-7/RAVEN allows both a graphical input of the RELAP-7 input file and online data visualization and is moving forward to provide direct user control of the simulation and data mining capabilities in support of probabilistic risk assessment analysis.<br>• External events tools: In 2014, the RISMC Pathway extended its analysis capabilities into additional initiating events, including external events (primarily focusing on seismic and flooding events). External events, such as flooding and seismic events, are being explored by leveraging existing tools (such as NEUTRINO for flooding) and by developing new tools (such as for seismic event evaluations). |
| **LTO – Enhanced Safety Analysis Capabilities** | **R&D Scope and Objectives:**<br>This research project will develop and validate an integrated framework and advanced tools for conducting risk-informed assessments that enable accurate characterization, visualization, and management of nuclear power plant safety |

h. Gaston, D., G. Hansen, and C. Newman, 2009, "MOOSE: A Parallel Computational Framework for Coupled Systems for Nonlinear Equations. International Conference on Mathematics," *Computational Methods, and Reactor Physics*. Saratoga Springs, NY: American Nuclear Society.

| R&D Area | RISMC |
| --- | --- |
| | margins. This LTO Program task is intended to develop an integrated methodology to assess plant safety margins and perform cost-effective, risk-informed safety analyses to meet these needs. It will achieve this objective through demonstration of effective and efficient application of the RISMC approach to issues important to the long-term operation of nuclear power plants. This project also provides significant interface and coordination of research efforts being conducted in safety analysis code development (via RELAP-7 and RAVEN) and safety margin analyses being performed by INL as part of the LWRS Program. |
| **LWRS – Margins Analysis Techniques and Modeling and Simulation Activities in Support of RISMC** | **Milestones:**<br>Margin management strategies:<br>• (2017) Complete the technical basis reports for RIMM.<br><br>Margin analysis techniques:<br>• (2016) Demonstrate margins analysis techniques by applying to performance-based emergency core cooling system cladding acceptance criteria.<br>• (2016) Demonstrate margins analysis techniques by applying to enhanced external hazard analysis (seismic and flooding).<br>• (2017) Apply margins analysis techniques to reactor containment analysis, including hardened reliable vents and shallow and deep-water flooding and seismic events.<br>• (2017) Complete a full-scope margins analysis of a commercial reactor power uprate scenario. Use margins analysis techniques, including a fully coupled RISMC toolkit, to analyze an industry-important issue (e.g., assessment of major component degradation in the context of long-term operation or assessment of the safety benefit of advanced fuel forms). Test cases will be chosen in consultation with external stakeholders.<br>• (2017) Demonstrate margins analysis techniques, including a fully coupled RISMC toolkit, for long-term coping studies to evaluate FLEX for extended station blackout conditions.<br>• (2019) Apply margins analysis techniques to evaluation of spent fuel pool issues.<br>• (2020) Ensure development and validation to the degree that by the end of 2020, the margins analysis techniques and associated tools are an accepted approach for safety analysis support to plant decision making, covering analysis of design-basis events and events within the technical scope of internal and external events probabilistic risk assessment.<br><br>RISMC toolkit:<br>• (2015) Release the beta version of RELAP-7, including limited benchmarking.<br>• (2015) Complete a report on advanced seismic soil structure modeling.<br>• (2016) Release the beta version 1.0 of Grizzly. This will include engineering fracture analysis capability for RPVs, with an engineering model for embrittlement, and a modular architecture to enable modeling of aging mechanisms.<br>• (2016) Complete the optimized and validated version of RELAP-7 that couples to RAVEN and to other applications (e.g., aging and fuels modules) for use as a balance-of-plant capability for multi-dimensional core simulators.<br>• (2016) Grizzly (RPV) is validated against an accepted set of data. |

| R&D Area | RISMC |
|---|---|
| | • (2016) RELAP-7 is validated against an accepted set of data.<br>• (2016) Release the beta version of initial flooding model.<br>• (2016) Beta 1.5 release of RELAP-7 with improved closure relationships and steam/water properties, completed LWR zero-dimensional components (such as jet pump and accumulator), improved LWR components (one to two-dimensional downcomer, one-dimensional pressurizer, and optional steam generator designs such as helical), tightly coupled multi-physics fuels performance (NEAMS code BISON), and single-phase three-dimensional subchannel flow capability.<br>• (2017) Release the beta version 2.0 of Grizzly. This version will include capabilities for modeling selected aging mechanisms in reinforced concrete and for engineering probabilistic RPV fracture analysis.<br>• (2017) Completed software that couples RAVEN to other applications (e.g., aging and fuels modules) for use as a balance-of-plant capability for multi-dimensional core simulators.<br>• (2017) Compete flooding fragility experiments for mechanical components.<br>• (2017) Release beta version of seismic probabilistic risk assessment model.<br>• (2017) Flooding model is validated against an accepted set of data.<br>• (2017) Beta 2.0 release of RELAP-7 with selected separate effects tests for validation data sets, validation of three-dimensional single-phase subchannel, preliminary three-dimensional two-phase (seven-equation) subchannel, multi-physics coupling to reactor physics (NEAMS codes Rattlesnake and MAMMOTH).<br>• (2018) Grizzly (concrete) is validated against an accepted set of data.<br>• (2018) Release advanced flooding analysis tool suitable for ocean and river-based flooding scenarios.<br>• (2018) Compete flooding fragility experiments for electrical components.<br>• (2018) Initial demonstration RPV steel embrittlement using a bottoms-up, lower-length scale model to capture causal mechanisms of embrittlement.<br>• (2018) Flooding fragility models for mechanical components are validated against an accepted set of data.<br>• (2018) Beta 3.0 release of RELAP-7 with additional validation and full multi-physics coupling, validated three-dimensional two-phase subchannel capability, and implementation of droplet model for BWR station blackout scenario, reflood phenomena under loss-of-coolant accident, and PWR feed-and-bleed process.<br>• (2018) Version 1.0 release of RELAP-7 with validation and selected integral effect tests, demonstration of large break loss-of-coolant accident, and three-field flow model, water, steam, droplets.<br>• (2019) Compete seismic experiments for critical phenomena.<br>• (2019) Release beta version 3.0 of Grizzly. This version includes capabilities for modeling selected aging mechanisms in reactor internals.<br>• (2019) Flooding fragility models for electrical components are validated against an accepted set of data.<br>• (2020) Implement RIMM module in RISMC toolkit that will perform analyst-augmented evaluation of facility safety to search for vulnerabilities and potential management strategies.<br>• (2020) Grizzly (core internals) is validated against an accepted set of data. |

| R&D Area | RISMC |
|---|---|
| **LTO – Enhanced Safety Analysis Capabilities** | **Milestones**:<br>In previous years, this LTO research effort successfully demonstrated that the RISMC methodology could be applied in an economical and efficient manner to analyze issues important to nuclear power plant safety. Key results of this research were documented in EPRI Report 1023032 (*Technical Framework for Management of Safety Margins - Loss of Main Feedwater Pilot Application*), which applied the RISMC methodology to evaluate the safety margins associated with a loss-of–all-feedwater event at a hypothetical PWR. An initial application of the RISMC approach to evaluate the impact on safety margins in the context of LTO decision making was conducted in 2012 and documented in EPRI Report 1025291 (*Pilot Application of Risk Informed Safety Margins to Support Nuclear Plant Long Term Operation Decisions: Impacts on Safety Margins of Power Uprates for Loss of Main Feedwater Events*). In 2013 (and continuing in 2014), the EPRI LTO portion of the RISMC research expanded and will continue to expand upon this research by performing additional analyses of safety-significant applications that have the potential to impact critical long-term operation decision making. The EPRI research also will engage nuclear power plant owners/operators to initiate transfer of the technology for application to relevant safety issues with impact on nuclear power plant LTO.<br>To support these objectives, the following activities will be conducted during 2015:<br>Project 1: RISMC Pilot Projects<br>• Conduct RISMC analysis of safety margins associated with decisions that are being pursued as part of nuclear power plant owner/operator LTO strategies. Work is planned to support both domestic (U.S.) and international applications. Work also will be initiated to integrate the results of RISMC evaluations into applicable utility decision processes using other LTO developed technologies (e.g. ILCM) as applicable.<br>• Support utility use of the RISMC approach to support utility and regulatory evaluations of the safety impact on nuclear power plant events as applicable.<br>Project 2: Socialize RISMC Approach Among External Stakeholders<br>• EPRI and EPRI member utilities will provide technical advice on RISMC/ RIMM development by participation on the RISMC Pathway Advisory Committee being formed by INL as part of the LWRS Program. This committee, which consists of a broad selection of risk assessment/ management technical experts, is being formed to provide external input and advice to the planned RISMC/RIMM development and deployment efforts.<br>• EPRI will continue engagement with NRC researchers who are involved with similar regulatory research into development and application of the RISMC methodology. This interaction will be conducted under the existing memorandum of understanding between EPRI and NRC'S Office of Nuclear Regulatory Research.<br>• EPRI also will continue to participate in external communication of RISMC research at appropriate venues, including conduct of EPRI industry workshops, presentations at applicable conferences, and reporting results of pilot applications in peer-reviewed scientific literature.<br>In addition to application of the RISMC methodology, EPRI will continue to support INL development of the next generation safety analysis software |

| R&D Area | RISMC |
|---|---|
| | (RELAP-7). Previously, EPRI provided important contributions to this work via EPRI Reports 1019206 (*Framework for Risk Informed Safety Margin Characterization*), which summarized the current state-of-the-art (as of 2009) for the RISMC methodology and deterministic safety analysis and probabilistic risk assessment software tools, and 1021085 (*Desired Characteristics for Next Generation Integrated Nuclear Safety Analysis Methods and Software*), which specified desired elements for the next generation safety analysis tool suite (from the perspective of a plant owner/operator). During 2014, EPRI provided a comprehensive and prioritized catalog of test data available to support the validation of the RELAP-7 code. The results of this effort were published in EPRI 3002003110 (*Data Sources for Capability Assessments of Next Generation Safety Analysis Codes*). Since code validation is an essential element for utility use of any safety analysis code, in 2015 and beyond, EPRI will continue to support INL's development of RELAP-7 by providing input to its development, validation, and deployment and supporting the conduct of trial applications as modules become available.<br><br>Project 3: RISMC Safety Margin Method and Tool Development (LWRS Program)<br><br>• Support development of RELAP-7 by closely working with the INL RELAP-7 development team to provide input to software development and by conducting testing on trial safety analysis applications as modules become available. EPRI also will work closely with INL to develop, prioritize, and conduct appropriate benchmarking and validation efforts as part of the planned RELAP-7 validation effort. |

# 5. LIGHT WATER REACTOR SUSTAINABILITY PROGRAM / LONG TERM OPERATIONS PROGRAM – PROGRAM-UNIQUE RESEARCH AND DEVELOPMENT ACTIVITIES

| | |
|---|---|
| **LWRS – EMDA** | **R&D Scope and Objectives:**<br><br>The objectives of this research task were to provide comprehensive assessment of materials degradation, relate to consequences of SSCs and economically important components, incorporate results, guide future testing, and integrate with other pathways and programs. This task provided an organized and updated assessment of key materials aging degradation issues and supported NRC and EPRI efforts to update the Proactive Materials Degradation Assessment or the MDM documents. Successful completion of this activity provides a valuable means of task identification and prioritization within this pathway, as well as identifying new needs for research.<br><br>An EMDA of degradation mechanisms for 60 to 80 years or beyond was identified as a useful tool in further prioritizing degradation for research needs. Based on joint discussions between DOE and NRC, it was decided that the EMDA would consist of separate and focused documents covering the key SSCs. This approach yielded a series of independent assessments (i.e., core internals primary and secondary piping, RPV, concrete civil structures, and electrical power and I&C cabling and insulation) that, when combined, created a comprehensive EMDA. The LWRS Program will use this as a tool for identifying and prioritizing research in future years. NRC will use the EMDA to inform the regulatory |

| | |
|---|---|
| | framework. The nuclear industry will use the EMDA results as a complementary tool to their MDM.<br>**Milestone:**<br>• (2014) Complete and deliver a gap analysis of the key materials degradation modes via the EMDA (NUREG/CR-7153, Volumes 1-5, October 2014). |
| | |
| **LTO –MDM and Issues Management Tables** | **R&D Scope and Objectives:**<br>EPRI's MDM, PWR Issues Management Tables (IMTs), and BWR IMTs are three key reference documents that are part of industry's materials initiative guided by NEI 03-08. The MDM and IMTs identify knowledge gaps based on likely degradation mechanisms and aging issues through an expert elicitation process. The MDM and IMTs also assess the state of industry knowledge worldwide, survey the laboratory data and field experience data, and prioritize the gaps for industry to resolve in the most effective way.<br>MDM results are used as direct inputs into the BWR IMT and PWR IMT. Degradation mechanisms identified in MDM are used as primary input for the set of degradation mechanisms considered by the IMT process. The MDM was first published in 2004 (Rev. 0), and it has been revised three times in 2007 (Rev. 1), 2010 (Rev. 2), and 2013 (Rev. 3). Sequentially, two IMTs were first published in 2005 (Rev. 0) and then revised in 2008 (Rev. 1), 2010 (Rev. 2), and 2013 (Rev. 3). Rev. 0 and Rev. 1 of MDM and the IMTs only addressed issues related to the current license period (40 years operation) and the license renewal period (from 40 to 60 years operation).<br>Long-term operation of nuclear power plants up to 80 years may pose additional materials degradation issues that may not be deemed to be life-limiting factors for 60-years operation. For example, the increased fluence level can be a serious concern to some of the reactor internal components. The increased fluence level not only can lead to changes in materials properties and cracking susceptibility, but also can be an issue in repairing the internal components.<br>In support of the LTO Program, an LTO 'flag' has been added to the MDM (starting with Revision 2 in 2010), indicating ongoing work or evaluation that is needed to support 60 to 80 years of operation. The objective of this addition to the MDM is to<br>1. Identify applicable degradation mechanisms and assess the extent to which applicable degradation mechanisms are understood<br>2. Evaluate the state of industry knowledge worldwide associated with mitigation of degradation mechanisms<br>3. Address any concerns related to regulatory and licensing renewal considerations.<br>MDM and IMTs are based on an expert elicitation process. A panel consisting of materials experts, industry personnel, and EPRI staff provided the key inputs for the ongoing revisions. The expert panel considered relevant operating experience, information from newly published and ongoing research projects worldwide, the consequence of failure, and the availability of mitigation strategies when developing the results.<br>1. Develop a fundamental understanding of the degradation phenomena/mechanisms and determine materials (and locations) that are known or can logically be assumed to be susceptible to aging/degradation phenomena when exposed to the operating environment. |

| | |
|---|---|
| | 2. Conduct generic operability and safety assessments for the locations of the various materials potentially susceptible to damage/degradation phenomena.<br>3. Develop inspection and evaluation guidelines and technology for the identified locations, starting with those for which the potential consequences of failure are most severe.<br>4. Evaluate available mitigation options and, if necessary, develop additional options.<br>5. Evaluate repair/replace options and, where necessary, encourage/support the development of additional options.<br>6. Monitor, evaluate, and feedback nuclear power plant operating experience.<br>7. Obtain regulatory acceptance of the items above and support licensees on nuclear power plant-specific applications as needed.<br>The MDM focuses on the development of a fundamental understanding of the degradation phenomena/mechanisms, based on the materials/environment combination. Expert elicitation, laboratory studies, and field experience were used to identify potential mechanisms by which each of the materials might degrade.<br>The PWR IMT and BWR IMT are component-based evaluations of the consequence of failure. This component-based approach also emphasizes the considerations of mitigation strategies, repair/replacement, inspection and evaluation guidelines, and regulatory requirements. All considerations will be captured in IMT gaps, which will then be prioritized. The prioritization of IMT gaps provides a basis for industry to prioritize R&D efforts to address materials' reliability issues and LTO concerns effectively.<br>The LTO Program will also support the current EPRI online Materials Information Portal. With built-in navigation and interlinks, the EPRI online Materials Information Portal integrates multiple EPRI resources (i.e., MDM, PWR IMT, BWR IMT, and the Materials Handbook). This portal provides a comprehensive, integrated view of materials issues and associated information necessary for materials aging management at nuclear power plants.<br>**Milestones:**<br>MDM and IMTs are living documents and they require updates and revisions periodically to reflect the knowledge gained and the evolving challenges. The MDM and IMTs are scheduled to be revised every three years, and more frequent interim updates of underlying information can be achieved through the maintenance of the Materials Information Portal. The Materials Information Portal maintenance frequency is semi-annual (twice a year). The LTO-supported work will be coordinated with the planned work within the Primary System Corrosion Research program to update and maintain the MDM and Materials Information Portal and work within the PWR Materials Reliability Project and BWR Vessel and Internals Project to update and maintain the IMTs.<br>• (2013) Update of the MDM complete (EPRI Report 3002000628, Rev 3).<br>• (2013) Update of the IMTs complete (EPRI Reports 3002000690 for BWRs and 3002000634 for PWRs).<br>• (2016 and 2019) Planned MDM Updates.<br>• (2016 and 2019) Planned IMT Updates for BWRs and PWRs. |

| | |
|---|---|
| **LWRS – Thermal (Post-Irradiation) Annealing** | **R&D Scope and Objectives:**<br>This task provides critical assessment of thermal annealing as a mitigation technology for RPV and core internal embrittlement and research to support deployment of thermal annealing technology. This task will build on other RPV tasks and extend the mechanistic understanding of irradiation effects on RPV steels to provide an alternative mitigation strategy. This task will provide experimental and theoretical support to resolve technical issues required to implement this strategy. Successful completion of this effort will provide data and theoretical understanding to support implementation of this alternative mitigation technology.<br>**Milestones:**<br>• (2021) Complete reirradiation on RPV sections following thermal annealing.<br>• (2025) Complete characterization of RPV sections (harvested from a reactor) that have been irradiated, annealed (post-harvesting) and then reirradiated in a test reactor.<br>While a long-term effort, demonstration of annealing techniques and subsequent irradiation for RPV sections is a key step in validating this mitigation strategy. Successful deployment also may allow for recovery from embrittlement in RPV, which would be of high value to industry by avoiding costly replacements. |
| | |
| **LWRS – Zion Materials Management and Coordination** | **R&D Scope and Objectives:**<br>The Zion Harvesting Project, in cooperation with Zion Solutions, is coordinating the selective procurement of materials, structures, components, and other items of interest to the LWRS Program, ERPI, and NRC from the decommissioned Zion 1 and Zion 2 nuclear power plants, as well as possible access to perform limited, onsite testing of certain structures and components. Materials of high interest include low-voltage cabling, concrete core samples, and through-wall thickness sections of RPV.<br>**Milestones:**<br>• (2015) Document the status of the Service Harvested Materials Database.<br>Discussions regarding continued harvesting of material (including cables, concrete, and RPV samples) are underway. Additional milestones will be identified once a revised decommissioning schedule is available. |
| | |
| **LWRS – RST (Gap Analysis)** | **R&D Scope and Objectives:**<br>Many of the activities associated with the RST Pathway represent DOE initiatives that had commenced shortly after the Fukushima accident. Thus, there remains a need for a more comprehensive review on what the industry has engaged for beyond design basis events subjects as well as what R&D activities NRC is supporting for this area. In 2015, a “gap” analysis will be completed using a team of reactor safety experts from industry (EPRI, BWR and PWR Owners Groups, U.S. vendors), DOE and its national laboratories as well as academe. The gap analysis report will help to inform an updated RST Pathway R&D plan (to be issued in the summer of 2015) and pathway activities beyond 2015.<br>**Milestones:**<br>• (2015) Complete a gap analysis on accident-tolerant components and severe accident analysis. |

| | |
|---|---|
| **LWRS – RST (Accident-Tolerant Components)** | **R&D Scope and Objectives:**<br>The accidents at Three Mile Island Unit 2 and Fukushima demonstrate the importance of accurate, relevant, and timely information on the status of reactor systems during such an accident to help manage the event. While significant progress in these areas has been made since Three Mile Island Unit 2, the accident at Fukushima suggests that there may still be some potential for further improvement. Recognizing the significant technical and economic challenges associated with plant modifications, it is important to deploy a systematic approach, which uses state-of-the-art accident analysis tools and plant-specific information to identify critical data needs and equipment capable of mitigating the effects of any risk-significant accident.<br>The objective of this R&D activity is to identify opportunities to improve nuclear power plant capability to monitor, analyze, and manage conditions leading to and during a beyond-design-basis event. Availability of appropriate data and the operator's ability to interpret and apply that data to respond and manage the accident was an issue during the Fukushima accident. The damage associated with the earthquake and flooding inhibited or disabled the proper functioning of the needed safety systems or components.<br>There are compelling reasons for pursuing this area of R&D both for our domestic reactor fleet and for international collaborations. Results could provide useful information to industry regarding possible post-Fukushima regulatory actions related to sensor and equipment reliability and/or operability. Additionally, results and processes developed from this research could benefit Design Certification and Combined Operating License applicants as they are challenged to meet new requirements related to equipment survivability during severe accidents. Finally, analyses and experiments in support of industry initiatives may reveal additional margin in reactor safety systems and components.<br>**Milestones:**<br>• (2015) Develop recommendations for accident-tolerant sensor development, based on evaluation of a PWR severe accident scenario.<br>• (2015) Develop recommendations for accident-tolerant sensor development, based on evaluation of a BWR severe accident scenario.<br>• (2015) Complete reactor core isolation cooling analytical model and a draft testing program.<br>The recommendations for accident-tolerant sensor development will be provided to the Nuclear Energy Enabling Technologies Program for their consideration. Development of an accident-tolerant sensor is not currently planned under the LWRS Program. Exploration in 2015 into possible testing of a reactor core isolation cooling turbine-pump under beyond design basis conditions will inform a future decision as to whether such a test will be carried out under the LWRS Program. |

| | |
|---|---|
| **LWRS – RST (Severe Accident Analysis)** | **R&D Scope and Objectives:**<br>After Fukushima, DOE and other domestic and international groups initiated severe accident analysis efforts aimed at reconstruction and analysis of the Fukushima reactor units. While useful insights were gained as to accident progression, these activities also highlighted where the existing computer system models being used did not always produce consistent results. If such tools were to be used to aid in effective severe accident management guidelines and associated training, further work was needed on identifying the sources of uncertainties and inconsistencies, in order to have greater confidence in the use of these tools.<br>The objective of this R&D activity is to improve understanding of and reduce uncertainty in severe accident progression, phenomenology, and outcomes using existing analytical codes, and to use the insights from this improved understanding of the accident to aid in improving severe accident management guidelines for the current LWR fleet. Information gathered from the application of existing codes to the scenario at Fukushima Daiichi could be used to inform improvements to those codes. However, at this time, the LWRS Program does not plan to fund the improvement of legacy codes. Analysis efforts can aid in preparations and planning for examination of the damaged Fukushima units.<br>**Milestones:**<br>• (2015) Complete a MELCOR/MAAP comparison of analyses of the events at Fukushima Daiichi.<br>• (2015) Complete analysis of uncertainties in MELCOR calculations as applied to the events at Fukushima Daiichi.<br>• (2017) Complete MAAP-MELCOR crosswalk Phase 2 with collaboration between EPRI, DOE laboratories, NRC, and possibly French and Japanese partners.<br>• (2019) Complete water management severe accident analysis in support of BWR ex-vessel mitigating strategies. |

| | |
|---|---|
| **LWRS – RST (Fukushima Forensics and Inspection Plan)** | **R&D Scope and Objectives:**<br>The Fukushima accident provides the nuclear industry with opportunities to incorporate lessons learned into the operation of current plants and the design of future plants. Forensic examination of post-accident conditions at Fukushima will provide valuable insights into severe accident phenomena progression and an opportunity to improve severe accident analysis tools and accident management guidance and training for plant staff.<br>Experience from the Three Mile Island Unit 2 accident in the United States suggests that critical information can be lost if not obtained as soon as feasible during the cleanup and decommissioning process. Experience also suggests that R&D needs must be fully incorporated early in cleanup and decommissioning plans in order to minimize the impact on decommissioning cost and schedule. Japan has already begun planning the decommissioning of the damaged Fukushima reactors; therefore, this is an appropriate time to identify inspection and sampling needs, prioritize them, and sequence them most efficiently into the planning process.<br>The objective of this R&D activity is to provide U.S. insights into severe accident progression and the status of reactor systems through early data collection, visual examination of in-situ conditions of the damaged Fukushima units, and collection and analysis of material samples and radionuclide surveys (e.g., within the reactor building, the drywell, and the vessel). U.S. consensus insights will be obtained from severe accident experts and plant operations experts from national laboratories, academia, and industry (including plant staff, PWR and BWR Owners Groups, and EPRI), and informed by interactions with representatives from NRC and TEPCO. These insights will also contribute to synergistic international efforts, such as the CSNI (Committee on the Safety of Nuclear Installations, under the Office for Economic Cooperation and Development's Nuclear Energy Agency) safety research opportunities post-Fukushima (SAREF). SAREF is establishing a process for identifying and following up on research opportunities to address safety research gaps and advance safety knowledge related to Fukushima. The ultimate goal of this activity is to use knowledge gained from Fukushima to inform model enhancements to safety analysis codes and to apply lessons learned based on these insights to plant systems and procedures. Lessons learned may also help improve the design of future reactor safety systems.<br>**Milestones:**<br>• (2015) Complete U.S. input towards a forensics examination plan for Fukushima Daiichi.<br>This plan will be updated periodically. Future milestones will be informed by activities in 2015. |

| | |
|---|---|
| **LTO – Integrated Life-Cycle Management** | **R&D Scope and Objectives:**<br><br>To achieve long-term operation, nuclear power plant operators must maintain and/or enhance high levels of safety, reliability, and economic performance as are typical today. Nuclear power plant operators will need to be equipped with sound scientific and consistent technical knowledge bases to provide them the optimum information in support of their plant asset extended operation decisions of 60 years and beyond. Refurbishment and/or replacement of large capital assets not normally considered during the original licensed life may now come into play. This project will identify those large capital assets. Some of these assets may not have the operating experience and research sufficient for providing technical bases input into operators' business models. The project will develop methods that nuclear operators can utilize in the determination of the likelihood of failure for selected large capital assets that is supported by science and enabling technology and operating experience. This methodology is ILCM and will provide consistency of information nuclear power plant operators can utilize in support of the optimization of their long-range nuclear power plant and/or fleet strategic technical and business decision models. For example, what large capital assets will be required to be refurbished and/or replaced, when they will be required to be addressed in the life cycle and how much it will cost?<br><br>The design phase of work will be complete in 2013, with technical transfer scheduled for 2015/2016 to EPRI Plant Engineering.<br><br>• The initiative commenced in 2010 with the following accomplishments:<br>– Project requirement documents (database and methods)<br>– Likelihood of failure methodology<br>– Proof of concept for likelihood of failure methods using actual site data for initial components<br>– Governance and communication through quarterly advisor meetings and periodic LTO Program executive committee presentations<br>– Completion of failure curves for 2010-scoped SSCs<br>– Completion of life-limiting and Constellation Energy Nuclear Group demonstration projects<br>– Entering into a memorandum of understanding with Électricité de France to proceed with collaboration<br>– Publication of EPRI Technical Update 1021188, *Integrated Life Cycle Management Status Report*, December 2010.<br><br>• Using the results from prior year work, develop the modified optimization tools and document them as a production report and user guide by 2014 (EPRI report 3002003010).<br><br>• EPRI Software Engineering to complete the ILCM optimization framework that incorporates a failure calculator and ILCM modified IPOP (Investments Portfolio Optimal Planning into a single software package. Formal release after pilot applications and user beta testing is planned for 2014 (EPRI report 3002004656).<br><br>• Establish the necessary code support, users group, and training for the |

| | |
|---|---|
| | optimization tools. In 2015 and beyond, it is anticipated that the users group would not only provide for continuity of the optimization tool, but would also provide for continuous improvement.<br>• In 2015, technical transfer through workshops and/or seminars, failure curve ongoing development, and final report. It is anticipated that an ILCM users group will be created to foster continued component data, failure curve development, and refinement to the methods. |
| | |
| **LTO – Technical Bases Updates to EPRI Technical Reports to Support SLR** | **R&D Scope and Objectives:**<br>The Aging Management Program (AMP) Assessment Project focused on the technical bases of the currently defined AMPs per the NRC report "Generic Aging Lessons Learned" (NUREG-1801, Revision 2). Technical bases are the data and associated implementation tools (e.g., guidelines, analytical models, evaluation bases, etc.) that provide reasonable assurance that the current condition of the subject SSC is assessed to allow safe, continued operation as is through a defined period prior to reassessment or to allow remedial actions prior to risk of failure.<br><br>Under this project, the current set of AMPs reviewed for their applicability to a period of extended operation (i.e., 60 to 80 years) that may be allowed via a successful SLR. The review process is intended to help define additional technical needs and/or changes to allow the AMPs to be successfully used for the period from 60 to 80 years of operation. The AMP reviewers included subject matter experts drawn from both EPRI staff and external sources, utility staff involved in the design and implementation of AMPs at operating nuclear power plants, and appropriate third parties such as owner's groups and vendors. The review focused on binning AMPs according to the future technical bases required or gaps in those technical bases. The key points of the review were as follows:<br>• Are there changes in the aging mechanisms, their rates, or their extent that may occur after operation to 60 years?<br>• Are such changes after 60 years being addressed by current or planned R&D efforts?<br>• Are there technical tools required to effectively address new or changed aging management requirements?<br><br>The project identified significant potential "gaps" in the industry technical bases support eight AMPs for the operating period from 60 to 80 years. As somewhat expected, the affected AMPs covered reactor internals for both BWR and PWR designs, RPV, the behavior of nickel alloy CASS subject to extended exposure to operating environments, the monitoring of concrete structures, and the remaining useful life assessment for plant cables. Such information will then be used to refine industry R&D efforts and to reduce the uncertainties for utility decision making concerning SLR for a specific nuclear power plant.<br><br>An additional follow-on effort is focused on the review of EPRI technical documents that form the foundation for AMP actions to assess their applicability through the extended operating period. Where appropriate, the need for technical updates will be identified and then incorporated into a schedule for such updates to be completed. Consideration will be given in the process to supporting potential utility licensing decision making as expected to occur in the 2015 through 2019 timeframe. |

| | |
|---|---|
| | |
| **Buried Piping and Tanks (work not directly in LTO scope due to near-term, nuclear power plant operational impact)** | **R&D Scope and Objectives:**<br>This research area is under the NEI 09-14 initiative. EPRI buried pipe research is focused on furthering state-of-the-art technologies for inspection, analysis, repair, and mitigation of ongoing corrosion in buried infrastructure. This includes the following:<br>• Development and delivery of appropriate reference documents and training to support broad knowledge awareness for buried and underground piping.<br>• Development and transfer of new buried pipe inspection technologies, such as remote field NDE inspection robotics.<br>• Identification and evaluation of existing technologies that may be directly applied or easily adapted for nuclear power plant buried piping inspection.<br>• Improved understanding regarding the usefulness of guided wave acoustic NDE technologies for buried piping inspections.<br>• Availability of repair and replacement alternatives for buried pipe applications, including high-density polyethylene.<br>• Enhanced buried pipe risk-ranking technologies through updates to existing software.<br>Research activities are coordinated across EPRI's Plant Engineering and NDE Programs.<br>The Plant Engineering Program provides buried pipe program owner guidance documents, reference materials, and upgraded risk ranking software (BPWORKS™) and also supports the development of various ASME Code Cases for repair/replacement activities. Training courses are offered for newly assigned Buried Pipe Program owners to help ensure buried pipe management guidance is appropriately deployed in the field. Reference materials on cathodic protection and coatings have been developed to address buried and underground pipe program needs. Through the Buried Pipe Integrity Group, EPRI provides a forum for information exchange among nuclear power plant personnel, vendors, and other stakeholders to identify and transfer best practices for buried pipe inspection and assessment.<br>The NDE Program is pursuing the identification and assessment of existing robotic and inspection technologies, as well as the development of new robotic inspection technologies using remote field detection technology. Efforts continue to identify, demonstrate, evaluate, and qualify inspection technologies suitable for buried pipe applications, with special emphasis on guided wave ultrasonic technologies. |
| | |
| **Nuclear Plant Chemistry (work not directly in LTO scope due to near-term, nuclear power plant operational impact)** | **R&D Scope and Objectives:**<br>No specific water chemistry program LTO-related R&D gaps were identified. The benefit of water chemistry technologies is generally time independent. Although mitigation through chemical means is vital to long-term aging management, any changes to program implementation over time are not likely to be related to time-dependent factors.<br>Importantly, implementation of the water chemistry program is specifically within the scope of NEI 03-08. A robust industry program exists to ensure that water |

| | |
|---|---|
| | chemistry guidelines are periodically reviewed and updated and that related R&D gaps are proactively addressed. Opportunities for AMP implementation improvements may be realized from these ongoing research efforts.<br>Key existing EPRI reports include the following:<br>• BWRVIP-190: BWR Vessel and Internals Project, BWR Water Chemistry Guidelines – Revision 1. EPRI, Palo Alto, CA: 2014, 3002002623.<br>• Pressurized Water Reactor Primary Water Chemistry Guidelines – Revision 7. EPRI, Palo Alto, CA: 2014, 3002000505.<br>• Pressurized Water Reactor Secondary Water Chemistry Guidelines, Revision 7. EPRI, Palo Alto, CA: February 2009, 1016555. |
| | |
| **Steam Generator Management Program (work not directly in LTO scope due to near-term, nuclear power plant operational impact)** | The EPRI Steam Generator Management Program provides guidelines for inspection, repair, monitoring, and flaw evaluation of steam generator components and tubing materials. The Steam Generator Management Program includes aging management activities for the steam generator tubes, plugs, sleeves, and secondary side components that are contained within the steam generator. Program implementation is consistent with nuclear power plant technical specifications and includes commitments to NEI 97-06. The NDE techniques used to inspect tubes, plugs, sleeves, and secondary side internals are intended to identify components (e.g., tubes and plugs) with degradation that may need to be removed from service or repaired. The program additionally provides for degradation assessments, condition monitoring (assessment of past performance), and operational assessments (forward-looking assessment of anticipated performance until the next inspection). The Steam Generator Management Program is based on these six EPRI guidelines:<br>• PWR Steam Generator Examination Guidelines<br>• PWR Primary-to-Secondary Leak Guidelines<br>• PWR Secondary Water Chemistry Guidelines<br>• PWR Primary Water Chemistry Guidelines<br>• Steam Generator Integrity Assessment Guidelines<br>• Steam Generator In-Situ Pressure Test Guidelines.<br>These guideline documents are supported by both evaluation handbooks (e.g., flaw evaluation and foreign object evaluation) and by technical reports that document the results of EPRI research. Reports are periodically updated using the latest R&D results. |

# Attachment A
# Long Term Operations Issue Tracking Table

**Long Term Operations (LTO) Issue Tracking Table (ITT)**

| LEGEND |
|---|
| Active on-going work |
| Planned work |
| No planned work; potential scope |
| Not within LTO scope |
| Complete |

**The purpose of the LTO ITT is to identify and prioritize the R&D projects needed to support safe, reliable and economic long-term operations of nuclear plants. The ITT is the result of an expert solicitation process and is maintained as a living document. It is reviewed on an annual basis by stakeholders from EPRI, NEI, DOE, national laboratories and EPRI utility advisors to ensure accuracy and completeness. The R&D projects are colored coded to indicate their status and assigned to one of the following categories:**

**A – An industry developed program *or* R&D results are needed for a utility to submit an application for Second License Renewal (SLR) to the NRC.**

**B – Sufficient information exists to submit a SLR application, but continued R&D projects are needed to provide informed insights for aging management, inspection intervals and repair/replacement decisions.**

**C – R&D projects are not needed for SLR, but the projects support long-term sustainability based on addressing obsolescence and economic improvements for extended operations.**

**The EPRI-LTO and the DOE-LWRS Program use the ITT to ensure the necessary R&D projects being performed at the right time to support long-term operations of nuclear power plants by plant owners and operators.**

**In 2014, the ITT was revised to link with an EPRI Technical Report (3002000576) that identified R&D technical needs to support specific Aging Management Programs (AMPs) as they could be applied for SLR. The report noted three categories of R&D efforts:**

1. **R&D support to address knowledge gaps for 60 to 80 years operation to better understand and manage materials performance.**
2. **R&D supporting role where aging degradation is well-characterized.**
3. **No new R&D role identified.**

**Category 1 broadly represents the highest priority area for R&D supporting LTO. The revised table now links issues to the R&D need category for AMPs from the report. It is important to note, however, that each AMP includes a range of activities and that not all activities in the AMP may benefit from additional R&D. The descriptions in the ITT have been modified to focus on the specific information needs. It is also useful to note that issues have been modified or added to provide correspondence to the issues identified in the Expanded Materials Degradation Assessment (EMDA) published by the NRC (NUREG/CR-7153, Volumes 1-5, October 2014). This report utilized a Phenomena Identification and Ranking Table (PIRT) process to highlight key technical issue areas for metal components (reactor vessel, internals, steam generators, and piping systems), concrete structures, and electric cables.**

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Primary System Metals Aging | PWR Surveillance capsules with fluence representa-tive of 60-plus years of operation | Coupons placed in reactors to represent fluence to 60 years are important to validate analytical predictions of vessel embrittlement.<br><br>The Materials Reliability Program (MRP) has two projects in place to generate high fluence PWR surveillance data to 80 years operation;<br>1) optimize the withdrawal schedules of the remaining capsules to provide data coverage to high fluences<br>2) fabrication and irradiation of supplemental surveillance capsules (slated for insertion in 2 PWRs in Fall 2016). | LTO | Materials Reliability Program (MRP) | NA | A<br><br>B likely for Westing-house designs and A for B&W pending specimen program plan. | XI.M31<br>TLAA<br><br>Category 1 for M31 | Commitment to or implementation of the surveillance capsule program is needed for an SLR application.<br><br>Will be collecting data to 80 years operation. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 2 | Primary System Metals Aging | BWR Surveillance capsules with fluence representa-tive of 60-plus years of operation | Coupons placed in reactors to represent fluence to 60 years are important to validate analytical predictions of vessel embrittlement.<br><br>The Boiling Water Reactor Vessel and Internals Program (BWRVIP) has a planned project to develop a replacement for or an extension of the existing Integrated Surveillance Program (ISP) from 60 to 80 years of operation. This work is planned to start in 2015. | LTO | Boiling Water Reactor Vessel and Internals Program (BWRVIP) | NA | A | XI.M31<br>TLAA<br><br>Category 1 for M31 Specific EPRI Project started in 2015 to address needs and potential actions. | BWRVIP:<br>Task 2.1<br>Task 2.11<br>Task 2.35<br>Task 2.36<br><br>Commitment to or implementation of the surveillance capsule program is needed for compliance with 10CFR50 and therefore an SLR application. Extension to 80 years will consider development of new capsule specimens, use of alternate means to monitor RPV. |
| 3 | Primary System Metals Aging | Analysis of reactor pressure vessel embrittle-ment from long-term neutron fluence | Understand and assess the performance trends of RPV embrittlement effects impacting the nozzle course for PWRs. | | MRP | | B (for PWRs) | Category 1 for M31 | Related to Items 1 and 2 for vessel specimens. PWROG effort to utilize a Master Curve process for fracture toughness. Tied to industry effort on BTP 5-3. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 4 | Cable Aging | Understand the potential synergistic effects of radiation and temperature on cable insulation for long-term operations | Gather actual in-plant radiation and temperature data to determine the actual radiation exposure and temperature environment for assessing cable performance for 60 to 80 years. | LTO | | DOE LWRS | B | Category 1 for E1 and E2 Category 3 for E3 Specific EPRI Project started in 2014 and continuing to develop actual plant data on radiation and temperature environments . | Long-term R&D to support continued improvement of the basis for the AMPs. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 5 | Primary System Metals Aging | Environmentally assisted cracking (EAC) of nickel alloy base and weld materials | Extend data on and predictions of crack growth from EAC of Ni alloy base material and weld materials (600, 690, 82/182, 52/152) for operating environments and fluence conditions to 80 years of operation. | LTO | Primary System Corrosion Research (PSCR) | DOE LWRS | B | Category 1 for M11B<br><br>Develop data to update MRP-227 to address 80 years. RAI impact possible depending on timing of MRP-227 revision for 80 years.<br><br>Category 2 for M1, M2, M4, M7, M8, and 19<br><br>Category 3 for M32 | PSCR:<br>Task 8<br>Subtask 9a<br><br>Long-term R&D to support continued improvement of the AMPs and appropriate locations, if any, to monitor based on fundamental understanding of mechanism. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 6 | Primary System Metals Aging | Environmentally assisted cracking (EAC) of stainless steel base and weld materials | Extend data on and predictions of crack growth from EAC of stainless steel base material and weld materials for operating environments and fluence conditions to 80 years of operation | LTO | PSCR | NA | B | Category 1 for M9<br><br>Develop data to update BWR technical bases to address performance to 80 years.<br><br>Category 2 for M1, M2, M4, M7, M8, M19, M25, and M35.<br><br>Category 3 for M32. | PSCR: Task 8<br><br>Long-term R&D to support continued improvement of the AMPs.<br><br>Revision to EPRI Technical Report on Divider Plate Cracking to address impact to 80 years for M19. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 7 | Primary System Metals Aging | Irradiation assisted stress corrosion cracking (IASCC) of austenitic and cast stainless steel; Irradiation-induced creep of reactor internals | Extend data on IASCC of austenitic stainless steel internals (shrouds, baffle bolts,…) and cast stainless steel for operating environments and fluence conditions to 80 years of operation. Currently includes testing of high fluence sample components as well as irradiation and testing of X-750 and XM-19 shroud repair materials in the future.<br><br>DOE-LWRS is performing swelling evaluations and investigation of irradiation-induced phase transformations. | LTO | BWRVIP MRP PSCR | DOE LWRS | B | Category 1 for M9 and M16A<br><br>Category 2 for M2<br><br>Specific EPRI Project to identify EPRI technical reports that may be impacted by operation beyond 60 years. | PSCR:<br>Task 1<br><br>BWRVIP:<br>Task 2.5<br>Task 2.6<br>Task 2.7<br>Task 2.15<br>Task 2.34<br><br>Long-term R&D to support continued improvement of the AMPs.<br><br>This effort will include updates to EPRI technical reports. |
| 8 | Primary System Metals Aging | Thermal aging of cast austenitic stainless steel (CASS) and Stainless Steel Welds | Investigate fundamental mechanisms and extend data on thermal aging of ferritic-austenitic stainless welds and CASS materials at LWR temperatures and the effects of thermal aging on mechanical properties and corrosion resistance for operating environments and fluence conditions to 80 years of operation. | LTO | PSCR BWRVIP and MRP | DOE LWRS | B | Category 1 for M12 | Long-term R&D to support continued improvement of the AMPs. Continuing effort with NRC on screening criteria. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 9 | NDE Technology Advance-ments | Flaw detection methods for cast austenitic stainless steels | Need to develop a method for NDE of CASS. Current inspection method is enhanced VT-1. | | Non-destruc-tive Evaluation (NDE) Program | | C | Category 1 for M12 Qualification and acceptance required for NDE | Activities will be impacted by screening process for CASS materials. |
| 10 | Primary System Metals Aging | Analysis of reactor pressure vessel embrittle-ment from long-term fluence | Continued R&D projects to expand data sources for embrittlement trend correlations and direct measurement of fracture toughness to assure accurate assessment of embrittlement behavior at high fluences characteristic of 80 years operation. DOE-LWRS has irradiated a large number of specimens at ATR-2. These specimens will be tested over a period from 2015 to 2017.<br><br>EPRI supplemental surveillance capsules will also contribute data. | LTO | BWRVIP MRP | DOE LWRS | B | Category 1 for M31<br><br>Develop data to update technical bases to address performance to 80 years. | BWRVIP:<br>Task 2.1<br>Task 2.11<br>Task 2.35<br>Task 2.36<br><br>Long-term R&D to support continued improvement of the AMPs.<br><br>This work is fully coordinated with specimen surveillance programs. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 11 | Concrete and Concrete Aging | Concrete issues resolution, guidelines and analysis tools | Concrete issues resolution guidelines and analysis tools for managing alkali silica reaction (ASR), including testing and inspection techniques. | LTO | NDE | DOE LWRS | B | Category 1 for S6<br><br>Develop data to update technical bases to address performance to 80 years. | Limited current guidance for ASR management. LTO funded efforts to address need and if further evaluation indicates a need for aging management program. |
| 12 | Concrete and Concrete Aging | Concrete issues resolution, guidelines and analysis tools | Concrete issues resolution guidelines and analysis tools for managing boric acid degradation on the spent fuel pool (SFP) concrete and rebar. Pilot study of concrete cracking of fuel pools at liner connections. The issue is corrosion of metal reinforcement from boric acid. | LTO (co-funded with MAI for pilot study) | NDE | | B | Category 1 for S6<br><br>Develop data to update technical bases to address performance to 80 years. | Current R&D project in progress expected to provide understanding of significance to LTO. Project report in 2016. |
| 13 | Concrete and Concrete Aging | Evaluation of concrete structures subject to external stressors (radiation and temperature) | Concrete exposed to external stressors may age at an accelerated rate. Research will extend the data on rate of degradation to encompass potential operation to 80 years or beyond for radiation and temperature damage to the reactor support structure and biological shield. | LTO | NDE | DOE LWRS | B | Category 1 for S6<br><br>Develop data to update technical bases to address performance to 80 years. | Long-term R&D to support continued improvement of the basis for the AMPs.<br>Project in LTO to fund additional work to assess radiation effects and if further evaluation indicates a need for aging management program. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 14 | Concrete and Concrete Aging | Evaluation of concrete structures subject to creep aging degradation | Assess potential for post-tensioned concrete structures to experience creep degradation over time that impacts structural integrity and performance. | LTO | | | B | Category 1 for S6<br><br>Develop data to update technical bases to address performance to 80 years. | Project in LTO to fund additional work to assess effects and risks. |
| 15 | Cable Aging | Testing and aging management of cables (submerged/ wetted, EQ/non-EQ, medium and low voltage) | Testing and aging management of cables including submerged / wetted cables, EQ and non-EQ, medium and low voltage to extend data for operating environments to 80 years of operation. | LTO | Equip-ment Reliability (ER) Program | DOE LWRS | B | Category 1 for E1 and E2<br><br>Category 3 for E3 | Long-term R&D to support continued improvement of the basis to assess remaining useful life. |
| 16 | Cable Aging | Understand factors impacting qualified life of cables | Conduct research to assess impact of diffusion limited oxidation (DLO) on cable qualification and assess conditions capable of producing inverse temperature effects on cable aging. | LTO | | DOE LWRS/ NRC Re-search | B | | Impact to EQ cable basis. Current R&D funding under NRC-RES and DOE. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 17 | Cable Aging | Condition Monitoring for Cables | Continue to develop the state-of-technology on methods for condition monitoring of installed cables to allow improved accuracy in tracking actual aging rates relative to predictive results from test data. | LTO | ER Program | DOE LWRS | C | Category 1 for E1 and E2<br><br>Category 3 for E3 | Supports long-term sustainability by addressing obsolescence and economic improvement. |
| 18 | Primary System Metals Aging | Analysis of potential thermal embrittle-ment effects on PWR vessel nozzles | Determine if thermal embrittlement is a significant aging phenomenon for PWR nozzles in LTO. | | MRP | | C | | Currently assessing as a potential issue through ASTM E10.02 working group. PWROG effort also likely in 2017 using specimens removed from reactor head. |
| 19 | Primary System Metals Aging | Post-irradiation annealing of reactor pressure vessels | Issues associated with annealing must be investigated before it can be considered as a mitigation option for RPV embrittlement. | LTO | | DOE LWRS | C | Category 1 for M31 Lower priority item due to low likelihood of usage | Supports long-term sustainability by addressing obsolescence and economic improvement. Not a likely implementation process for SLR. |
| 20 | NDE Technology Advance-ments | Non-destructive evaluation methods for irregular welds, cast austenitic stainless steels, J-grooves, etc. | NDE methods (irreg. welds, vol. exam of CASS and J-grooves, eddy current of SGs). | | Materials/ NDE Program | | C | Category 1 for M12 Qualification and acceptance required for NDE | Dependent on current discussion on screening criteria for CASS concerns. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 21 | NDE Technology Advance-ments | Detection method for corrosion on backside of containment liner | Potential need to develop an efficient method to assess corrosion damage to containment liner. Current inspections are VT. | | NDE Program | | | | No current requirements.<br><br>Defer to ASME Code Requirement, if any. |
| 22 | Concrete and Concrete Aging | Detection of degradation in inaccessi-ble concrete | Potential need for both NDE and evaluation process to confirm structural integrity of concrete structures without direct surface access. | LTO | NDE Program | DOE LWRS | B | N/A | Potential area of concern per NRC presentations on Structural AMP changes for SLR. |
| 23 | Primary System Metals Aging | Expansion of MDM and IMT for primary metals to 80 years | Expansion of Materials Degradation Matrix (MDM) and Issue Management Tables (IMT) to include mechanisms acting beyond 60, to 80 years for primary metals.<br>Expansion of the PMDA into the EMDA. | LTO | Materials Program | NRC Re-search<br><br>DOE LWRS EMDA | A | N/A | MDM has been expanded to include 60 to 80 years of operation and is reviewed and updated on a routine cycle. NRC EMDA was published in October 2014. |
| 24 | Primary System Metals Aging | Environmen-tal effects on fatigue life for nickel alloys and stainless steel | Conservative assumptions in Reg Guide for EAF creates uncertainty for long-term operation. Upon completion of the work EPRI plans to work through the ASME code on needed code revisions | LTO | Materials Program | DOE | B | TLAA<br><br>Category 2 for M1 Develop data to update technical bases to address performance to 80 years. | Long-term R&D to support continued improvement of the basis for the AMPs. Key R&D focus on reconciliation of laboratory test results to actual in-service material performance. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 25 | Concrete and Concrete Aging | Concrete issues identification | Concrete issues identification, prioritization from operating experience, expert elicitation, and consideration of experience and analysis from other industries. | LTO | NDE | DOE LWRS | B | | Initial documentation completed subject to periodic updates. |
| 26 | Neutron Absorber Materials | Neutron Absorber materials for long-term operations | Follow guidance for the management of BORAL and performance accelerated aging tests. | | High Level Waste (HLW) | | B | Category 2 for M40 | Long-term R&D to support continued improvement of the basis for the AMPs. |
| 27 | Under-ground and BOP Equipment Aging | Testing and inspection methods for buried piping | Develop advanced methods for testing, inspection, and assessment of buried piping. | | ER Program | | B | Category 2 for M41 | NEI Initiative 09-14 was completed in 2014.<br><br>Long-term R&D to support continued improvement of the basis for the AMPs. |
| 28 | Under-ground and BOP Equipment Aging | Mitigation of corrosion via cathodic protection | Develop technical bases and guidance for the effective application of cathodic protection to mitigate corrosion of buried piping. | | ER Program | | B | Category 2 for M41 | Address demonstration of cathodic protection effectiveness for range of soil conditions and piping lay-out. |
| 29 | Under-ground and BOP Equipment Aging | New materials and methods for balance-of-plant replacement/ refurbish-ment | New materials and methods for BOP system replacement or refurbishment. | | ER Program NDE Program | | C | Category 2 for M41 | Supports long-term sustainability by addressing obsolescence and economic improvement in management processes. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 30 | Coatings | Coatings issues that could impact long-term operations | These issues might be risks such as coatings which could block containment sumps or coating performance issues for containment liners and buried piping. Issues could be opportunities, such as new coatings which have desirable properties that could enhance safety or reduce costs. Current efforts in ER Program. | | ER Program | | B | Category 2 for S8 | Recent NRC Interim Staff Guidance effort suggests that this is an issue area for LTO. Aging of coatings will need to be addressed by developing NDE and testing processes to confirm coating integrity. |
| 31 | Under-ground and BOP Equipment Aging | Application of BPWORKS methodology to estimate remaining useful life | Monitoring, assessment of degradation, and estimation of RUL using the EPRI BPWorks methodology. | | ER Program | | | Category 2 for M41 | BPWorks is a released EPRI software product that will be maintained and updated. |
| 32 | Under-ground and BOP Equipment Aging | Selective leaching of buried metal piping | Selective leaching of elements from buried metal piping (define types) is a form of aging degradation. R&D could be directed at monitoring, aging management and lifetime estimation methodology for susceptible piping. | | ER Program<br>NDE Program | | B | Category 3 for M33 | Plant specific impact that will likely require new NDE techniques to replace sampling and destructive testing approach. |
| 33 | SSC Monitoring Diagnostics and Prognostics | On-line monitoring, diagnostics, and prognostics for active components | On-line monitoring, diagnostics, and prognostics for active components including guidelines for monitoring, automated diagnostic advisory tools, and database of fault signatures. | LTO | | | C | N/A | Initial guideline report issued by EPRI.<br><br>Supports long-term sustainability by addressing obsolescence and economic improvement. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 34 | SSC Monitoring Diagnostics and Prognostics | On-line monitoring, diagnostics, and prognostic pilot studies for transformers and generators | On-line monitoring, diagnostics, and prognostic pilot studies: transformers and emergency diesel generators. | LTO | Instrumen-tation & Control (I&C) Program Genera-tion | DOE LWRS | C | N/A | Duke and Exelon pilot plant projects.<br><br>Supports long-term sustainability by addressing obsolescence and economic improvement. |
| 35 | Asset Manage-ment and ILCM | Life-cycle management tools to support decisions on continued operation, refurbish-ment and replacement of large components | Developing life cycle management guidelines and analysis tools to support decisions on continued operation, refurbishment, and replacement of large components including timing, costs, and engineering options. | LTO & EDF | | | C | N/A | Supports long-term sustainability by addressing obsolescence and economic improvement. This product will has been released for use and will be maintained through a software user group process. |
| 36 | Risk-informed Safety Margins Characteri-zation | Identification of technical gaps in safety assessment with respect to long-term operations | Investigation of safety assessment applications that are expected to be important to long term operations, and identification of technology gaps that could jeopardize the success of these applications. | LTO | | | C | N/A | Case studies completed. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 37 | Risk-informed Safety Margins Characteri-zation | Development of enhanced safety analysis codes to address technical gaps | Based on an inventory and functional mapping of current safety analysis tools and on the technology gaps identified in issue 6.1, enhanced safety analysis codes and capabilities will be specified and developed.<br><br>INL is taking the lead in development of next generation code for mechanistic simulation of transients and accidents. | LTO | | DOE LWRS | C | N/A | Supports long-term sustainability by addressing obsolescence and economic improvement. |
| 38 | Welding technology | Welding of irradiated reactor internals | Repair technique- welding of irradiated reactor internals materials and weld repair. | LTO | Welding & Repair Technol-ogy Center (WRTC) | DOE LWRS | C | N/A<br><br>He issues at high fluence per operation to 80 years will require new techniques to allow internals repairs. Plant specific impact. | WRTC:<br>2010-009<br>2010-037<br><br>Supports long-term sustainability by addressing obsolescence and economic improvement. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 39 | Digital I&C Moderni-zation and Enhanced Functional-ity | Next-generation I&C, human /system interface, and information technology architecture and capabilities | Pilot studies and Industry Guidelines for next generation I&C, human/system interface, and information technology architecture and capabilities. | LTO | | DOE LWRS | C | N/A | Supports long-term sustainability by addressing obsolescence and economic improvement. |
| 40 | SSC Monitoring Diagnostics and Prognostics | On-line monitoring, diagnostics, and prognostics for passive components | On-line monitoring, diagnostics, and prognostic for passive components. | LTO | | DOE LWRS | C | N/A | Supports long-term sustainability by addressing obsolescence and economic improvement. In progress work focused on concrete structures. |
| 41 | NDE Technology Advance-ments | Investigate techniques for NDE that can provide new technologies to monitor material and component performance. | DOE-LWRS program has developed roadmaps for future sensor and NDE enhancements. EPRI NDE Program works continues to advance the ability to detect and monitor for various forms of degradation and provide Industry leadership for NDE qualification and testing. | | NDE | DOE LWRS | C | May impact multiple AMPs after qualification and acceptance processes are complete. | Supports long-term sustainability by addressing obsolescence and economic improvement. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 42 | Digital I&C Moderni-zation and Enhanced Functional-ity | Dedicated user facility to support development, testing, modeling, and verification of advanced information and I&C systems | Establish an Information and I&C (IIC) user facility to support the development, modeling, verification, and testing of advanced IIC systems. | | | DOE LWRS | C | N/A | |
| 43 | Risk-informed Safety Margins Characteri-zation | Enhanced probabilistic risk assessment capabilities | Enhance PRA capabilities and tools to perform risks assessment. | LTO | | | C | N/A | Supports long-term sustainability by addressing obsolescence and economic improvement. |
| 44 | Risk-informed Safety Margins Characteri-zation | Development of margin-based safety case framework and calculation tool | Formulation of margin-based safety case framework, analysis capability, and calculation tool (RELAP-7). | LTO | | DOE LWRS | C | N/A | Supports long-term sustainability by addressing obsolescence and economic improvement. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| 45 | Methods to mitigate or improve stresses | Develop methods for stress improvement and repair options | Continue development and demonstration work on peening and other techniques for stress improvements. Continue work on weld overlays as a repair technique for long-term operations. | | Materials Programs | | C | N/A | Supports long-term sustainability by addressing obsolescence and economic improvement. |
| 46 | Fuel Pool Internals | Fuel pool internals aging and deterioration | Fuel pool liner cracking is an aging degradation issue that can lead to radiation leakage to groundwater or other clean areas and deterioration of the fuel pool structure. Methods to identify, mitigate and repair liners could address this issue. | | NDE Program | | C | N/A | Supports long-term sustainability by addressing obsolescence and economic improvement. |
| | Plant Security | Terrorism threat and risk assessment | Following the terrorist attacks of September 11, 2001, every U.S. plant conducted a risk assessment against a suite of threats using a nuclear specific, some considerably beyond the Design Basis Requirements of the plant. This exercise confirmed the resiliency of the plants against these threats or identified opportunities to increase this resiliency or plant response. Realistic threat scenarios evolve, and it is appropriate to perform this RAMCAP analysis and other assessments periodically. | | Risk & Safety Manage-ment | | | N/A | |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | Nuclear Fuel Design and Perfor-mance | Hydrogen embrittle-ment of on-site spent fuel storage installations | ISFSI licenses are generally for 20 years but must be extended much longer for long term operations. An important aging mechanism is hydrogen embrittlement that could affect the ability to transport the fuel or repackage it for transport. | | Used Fuel Manage-ment & High Level Waste Program | | | N/A | |
| | Nuclear Fuel Design and Perfor-mance | Silicon carbide cladding for improved nuclear fuel performance | SiC Cladding for Improved Operations. | | Fuel Reliability Program | DOE - FCR&D | | N/A | |
| | Equipment Qualifica-tion Improve-ments | Reduction in scope and costs associated with equipment qualification due to less conservative technical assumptions | A better technical representation of the containment conditions that are used for specifying equipment qualifications could allow equipment to operate longer without repair or replacement and could reduce the procurement costs. A commitment to perform containment temperature monitoring is one consideration; use of a smaller, more accurate source term is another. | | ER Program | | | N/A | |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | Seismic Issues | Potential plant modifications in response to greater seismic hazards frequencies or to a seismic event change flexibility in the future | Potential plant modifications in response to greater seismic hazards frequencies or to a seismic event was identified in the EPRI study of Life Limiting Issues. It had a relatively high priority among external conditions that could impact life extension. The seismic hazard distribution for plants in the Eastern U.S. has increased in recent years. This increase will increase the seismic risk at plants which could limit operational and design change flexibility in the future. | | Risk & Safety Manage-ment | | | N/A | EPRI SQUG Program. |
| | Nuclear Fuel Design and Perfor-mance | Advanced design, safety analysis and simulation tools for new nuclear fuel approaches | Advanced design, safety analysis and simulation tool. This tool includes incorporation of results from issue 5.2, models of composite cladding and other advanced fuel designs, advanced mathematical methods, and the experimental campaign to verify the tool. | | Consor-tium for Advanced Simula-tion of Light Water Reactors (CASL) | DOE CASL | | N/A | |
| | Nuclear Fuel Design and Perfor-mance | Advanced nuclear fuel designs (geometries, fuel content, high burnup) | Advanced fuel designs including new geometries, high enrichment, high power, and high burn-up fuels. This issue is related to the potential benefits from a next series of extended power uprates. | | Fuels | DOE – FCR&D | | N/A | |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | Environ-mental Interface | Water availability and quality and enhanced cooling technologies | Plant cooling depends on the continued availability of cooling water of suitable temperature, quantity, and quality. In addition, licenses to use the water must be maintained even as other stresses on the watershed increase and environmental expectations for plant discharge could be more challenging. Enhanced cooling technologies, water availability management, and better technical understanding of the plants impact can all contribute to the assurance of long term plant cooling capability. | | Environ-mental | | | N/A | EPRI Environmental Sector has the lead in developing a strategy for this issue. |
| | Primary System Metals Aging | Advanced alloys and fabrication methods for reactor internals replacement | Plant uprates and long term operations place additional stress on reactor internals. Repairs are complicated by radiologically induced changes in the metals and by the radioactive environment inside the reactor. This issue includes construction methods for shroud replacement. | | PSCR | DOE LWRS | | N/A<br><br>May impact multiple AMPs if new materials are qualified and implemented | Initial screening efforts are in progress. |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | Low Level Waste | Impact of Plant Life Extensions on Low Level Waste (LLW) Management and Decommis-sioning Planning | Currently, 85% of U.S. utilities lack the ability to dispose of higher activity low-level waste (Class B and Class C wastes). The lack of off-site disposal options and added storage requirements can be used as an argument against long term operation. With longer operation, activity content may increase due to increased contact time and activation of metal components or, alternatively, increase waste volumes as a result of component replacements. Many plants have replaced components with Inconel materials (e.g. Alloy 690, Alloy 800). However, it is uncertain how operation with the new material will affect waste characterization and ultimate disposal of that waste stream. Generation of Nb-94 is a major concern for some Inconel materials and may affect disposal during decommissioning. A plant must develop a long term waste management plan that properly accounts for future waste liabilities. Source term estimates and a material handling plan will be needed. | | Chemistry and Low Level Waste (LLW) | | | N/A | |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | Digital I&C Moderni-zation and Enhanced Functional-ity | Development of I&C compatibility equivalency database | I&C Compatibility Equivalency Database. | | I&C Program | | | N/A | |
| | Digital I&C Moderni-zation and Enhanced Functional-ity | Long term operations of 7300 I&C Systems | Addressing obsolescence concerns and providing technical justification for long term reliable operation of 7300 I&C Systems in lieu of replacement. | | I&C Program | | | N/A | |
| | Nuclear Fuel Design and Perfor-mance | Advanced understand-ing, analysis, and modeling of nuclear fuel degrada-tion mecha-nisms | Advanced understanding, analysis, and modeling capability of degradation mechanisms for nuclear fuel. Specifically, issues include changes in mechanical properties with exposure, pellet clad interaction, coolant crud chemistry interactions, and mesoscale modeling. | | Fuel Users Group | | | N/A | |
| | Nuclear Fuel Design and Perfor-mance | Effect of water chemistry on fuel behavior over extended operation | Water chemistry is known to have both positive and deleterious effects on plant materials (including fuel behavior). There are also opportunities to improve operations, perhaps by innovative chemistry changes or nanoparticle addition. | | Fuels Program | DOE CASL | | N/A | |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | Environ-mental Interface | Identify and propose technical solutions to hydro-dam re-licensing issues that could jeopardize long term operation. | Continued operation of hydro-dams on the same watersheds can jeopardize long-term operations if conditions of FERC re-licensing are unfavorable. This activity could identify and propose technical solutions to hydro-dam re-licensing issues that could jeopardize long-term operation. | | | | | N/A | Plant licensing issues |
| | Integrated, Phased Refurbish-ments and Uprates | Assessment of large component manufac-turing capabilities | Manufacturing capabilities (large components, etc.). | | Advanced Nuclear Technol-ogy (ANT) | | | N/A | |
| | NDE Technology Advance-ments | Risk-informed sampling for in-service inspection | Total in-service inspectability using NDE methods cannot always be achieved due to inaccessibility of the components. Risk informed sampling procedures can be developed and validated where access issues exist. | | NDE Program | | | N/A | |
| | NDE Technology Advance-ments | Analytical framework for extremely low probability of rupture | Extremely low prob. of failure (xLPR – risk informed analysis for hidden welds, etc.). | | Materials / NDE Programs | | | N/A | |

| Issue ID (New) | Primary Issue Description | Sub-issue Description | Detailed Description | EPRI LTO Status | EPRI Program (Other) | DOE-LWRS | ITT Category | AMP Impact and Category | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | Emergency Prepared-ness | | No LTO issues identified. | | | | | N/A | |
| | Personnel knowledge Capture | | No LTO issues identified. | | ER Program | | | N/A | |
| | Public Education about Current Fleet vs. New Plants | | No LTO issues identified. | | | | | N/A | |

# Appendix A

## Industry Cost Sharing

**(This appendix is proprietary and has special access requirements.)**