INL/EXT-12-24562
Revision 1

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

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DOE Office of Nuclear Energy

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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

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Approved by

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SUMMARY

Nuclear power has 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 (NPPs) some of the most economical power generators available. Further, nuclear power remains the single largest contributor (nearly 70%) 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.

Nine commercial NPPs in the Unites States have passed their 40th anniversary of power operations, and about one-half of the existing fleet will reach the same 40-year mark within the next decade. While recent performance has been excellent (capacity factors approaching or exceeding 90%), the fleet is facing a number of technical challenges related to long-term operation. Those challenges include uncertainties in material safety margins and degradation rates under extended operating conditions, obsolescence of instrumentation and control systems, safety analysis methods that would benefit from updating, and others. A regulatory process exists (10 CFR Part 54) for obtaining approval from the U.S. Nuclear Regulatory Commission on extended NPP operations beyond 60 years. However, the U.S. Nuclear Regulatory Commission will require plants applying for license renewals to extend NPP service life to demonstrate that adequate design and operational safety margins will be maintained over the duration of the extended operations period.

If current NPPs do not operate beyond 60 years (due to owner decisions or regulatory restrictions), 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 (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), the costs for replacement generation capacity will be even higher.

Recognizing the challenges associated with pursuing commercial NPP operations beyond 60 years, 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 programs (DOE-NE's Light Water Reactor Sustainability [LWRS] Program and EPRI's Long-Term Operations [LTO]Program) to address these challenges. 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 LWRS and LTO) 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 first annual revision to the initial version (March 2011) of the plan as called for in the Memorandum of Understanding.

CONTENTS

ACRONYMS

CMC	ceramic matrix composite
DOE-NE	U.S. Department of Energy, Office of Nuclear Energy
EPRI	Electric Power Research Institute
IASCC	irradiation-assisted stress corrosion cracking
I&C	instrumentation and control
II&C	instrumentation, information, and control
IMT	Issues Management Table
INL	Idaho National Laboratory
LTO	long-term operations
LWR	light water reactor
LWRS	light water reactor sustainability
MDM	Materials Degradation Matrix
NDE	nondestructive examination
NPP	nuclear power plant
NRC	U.S. Nuclear Regulatory Commission
R&D	research and development
RISMC	risk-informed safety margin characterization
RPV	reactor pressure vessel
SiC	silicon carbide
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 the United States' energy, environmental, and energy security needs by resolving technical, cost, safety, proliferation resistance, and security barriers through research, development, and demonstration activities, as appropriate. R&D efforts under the Light Water Reactor Sustainability (LWRS) Program are managed by DOE-NE's Office of Light Water Reactor Technologies, NE-72, and the program Technical Integration Office, located at the Idaho National Laboratory (INL).

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 (NPPs). R&D efforts in the Long-Term Operations (LTO) Program are managed as a separate technical program operating in the Plant Technology Department of the EPRI Nuclear Power Sector with the guidance of an industry advisory Integration Committee.

1.3 Research and Development Cooperation

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

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

1. Strategic Plan for LWR R&D, jointly prepared by EPRI and INL for DOE-NE in November 2007 (this report has been superseded by the DOE-NE R&D Roadmap and the implementation plans for each R&D objective discussed on the roadmap)

2. Life Beyond 60 Workshop Summary Report, documenting a workshop jointly conducted by the U.S. Nuclear Regulatory Commission (NRC) and DOE on February 19 through 21, 2008 (a second workshop was held in February 2011)

3. The DOE-NE Light Water Reactor Sustainability Research and Development Program Plan, dated December 2009 (superseded by the Light Water Reactor Sustainability Program – Integrated Program Plan, January 2012)

4. The EPRI LTO Strategic Plan, dated June 13, 2010 (most recent update: July 2011).

Although both programs emerged from the November 2007 LWR R&D Strategic Plan, each program proceeded with development of individual program plans and more detailed R&D plans for individual technology pathways or projects. Still, both programs continue to cooperate on a range of R&D activities related to extended plant operations. Cooperation includes the sharing of responsibilities (leadership and financial) for conducting portions of large, multi-year R&D projects; the exchange of information on R&D work in areas of mutual interest; and participation (by either the LWRS Technical Integration Office Director or the LTO Manager) in periodic conference calls and meetings (technical and budget reviews) for the other program.

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

1. Materials Aging and Degradation

2. Advanced Light Water Reactor Nuclear Fuels

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

4. Risk-Informed Safety Margin Characterization (RISMC).

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

4. Advanced Safety and Risk Analysis Tools

5. Integrated Life-Cycle Management (data, methods, and tools)

6. Advanced Fuel Analysis and Design for Existing Plants (in Calendar Year 2012 there are no active projects in this work area)

7. Cable Aging

8. Aging Management Program Scope for Operation Beyond 60 Years

9. 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 beyond 60 years. LTO Technical Area 5, Integrated Life-Cycle Management, and LTO Technical Area 8, Aging Management Program Scope, currently are exceptions for which there are no corresponding LWRS Pathways. 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 the 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 LWRS and LTO to more efficiently and effectively meet the joint objectives.

2. DESCRIPTION OF RESEARCH AND DEVELOPMENT PROGRAMS

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

Sustainability in the context of LWRs is defined as the ability to maintain safe and economic operation of the existing fleet of NPPs for a longer-than-initially-licensed lifetime. It has two facets with respect to long-term operations: (1) manage aging of hardware so the NPP lifetime can be extended and the plant 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.

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 life of the current fleet of commercial NPPs. 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 operations of existing reactors

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

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

Programmatically, the LWRS Program depends on a sequence of four successful phases: (1) a utility's decision to invest in extending NPP life beyond 60 years; (2) regulatory and public confidence in NPP life extension; (3) implementation of NPP refurbishments and upgrades to meet licensing and enhanced performance requirements; and (4) safe and economic NPP operation for the intended period of the NPP life extension. While tightly coupled, each of the four sequential phases is critical to nuclear power generation on its own and with a specific set of challenges. The four phases span several decades, a feature important for planning and implementation of the supporting R&D program.

Through the LWRS Program, DOE collaborates with industry and NRC in appropriate ways to support and conduct the long-term research needed to inform major component refurbishment and replacement strategies, performance enhancements, 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. Cost-shared demonstration activities will be conducted when appropriate.

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

1. ***Materials Aging and Degradation*** with R&D to develop the scientific basis for understanding and predicting long-term environmental degradation behavior of materials in NPPs. The work will provide data and methods to assess the performance of SSCs essential to safe and sustained NPP operations. The R&D products will be used to define operational limits and aging mitigation approaches for materials in NPP SSCs that are subject to long-term operating conditions.

2. ***Advanced LWR Nuclear Fuels*** with R&D to improve the scientific knowledge basis for understanding and predicting fundamental nuclear fuel and cladding performance in NPPs and applying this information to development of high-performance, high burn-up fuels with improved safety, cladding integrity, and improved nuclear fuel-cycle economics. The R&D products will be used to deploy new fuel/core designs for the existing NPP fleet with improved safety and economic operational capabilities.

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 NPPs that provide an enhanced understanding of plant operating conditions and available margins and improved response strategies and capabilities for operational events.

4. ***RISMC*** develops and deploys approaches to support management of uncertainty in safety margins quantification to improve decision making for NPPs. This pathway will (1) develop and demonstrate a risk-assessment method tied to safety margins quantification and (2) create advanced tools for safety assessment that enable more accurate representation of an NPP safety margin. The R&D products will be used to produce state-of-the-art NPP safety analysis information that yields new insights on actual plant safety/operational margins.

2.2 Electric Power Research Institute Long-Term Operations Program

High capacity factors and low operating costs make NPPs some of the most economical power generators available. Even when major plant components must be upgraded to extend operating life, these plants often represent a cost-effective, low-carbon asset. The decision to extend NPP 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 NPP operation, EPRI launched the LTO Project in 2009. LTO is defined as being high-performance NPP operation to 60 years, 80 years, or beyond. 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 NPP operation to 60 years, 80 years, or beyond. Specifically, LTO Program projects must address one or more of the following:

1. License renewal beyond 60 years

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

3. Refurbishment and uprate decisions

4. 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 and uprate

   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 of 2014 to 2019.

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 DOE LWRS or NRC's Office of Nuclear Regulatory Research.

The R&D portfolio addresses the following nine 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 (MDM) and Issues Management Tables (IMTs) 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 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 and forensic concrete examination methods, prognostic modeling to determine remaining useful life, and investigate mitigation measures for issues important to long-term operations.

3. 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 highly integrated control room, highly automated 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.

4. 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.

5. Provide industry with ***integrated life-cycle management*** data, methods, and tools for key components that will improve the cost and certainty of high-performance operation and will support optimization of integrated refurbishment and uprate plans. Individual projects addressing this objective include the following:

a. Integrated Life-Cycle Management Data Resource and Method

b. Pilot Application of EDF Asset Management Tools

c. Identification and Assessment of Potential Life-Limiting Issues.

6. Support the investigation of ***silicon carbide (SiC) fuel cladding designs and reliability analyses*** that can lead to breakthroughs in the cost or performance of fuel in existing plants. Current work is specifically addressing technical barriers and potential benefits to the use of SiC fuel cladding.

7. 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.

8. Investigate ***aging management program scope*** for operation beyond 60 years. Research results and operating experience might identify additional components of concern, failure mechanisms, or conditions that would be part of aging management programs for operation beyond 60 years. 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.

9. Develop an ***integrated strategy, process plan, and demonstration plants*** to support license renewal, the decision to extend operation beyond 60 years, 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. Nuclear Plant Life-Extension Demonstration Project.

In addition, a "living" IMT maintains the status of all identified issues and their priorities. This IMT is regularly reviewed for accuracy and completeness by stakeholders at EPRI, LWRS representatives, a working group of the Nuclear Energy Institute, and EPRI advisors. The objectives and associated projects listed in this document have been selected from high-priority issues in the IMT that meet the selection criteria and have received concurrence of the LTO Integration Committee.

2.3 Reporting of Research and Development Projects

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

1. Section 3 discusses "Coordinated (but independent) Activities," meaning that "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 that "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."[a]

Sections 3 and 4 provide a brief summary of the R&D activities. 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 Program and the LTO Program).

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[a] 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 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 and the corresponding (coordinated or collaborative) LTO Program's R&D activities. To provide more perspective on the total scope of R&D work, the table also identifies LWRS and LTO projects that do not meet the memorandum of understanding criteria for coordinated or collaborative activities. Details on those R&D projects can be found in the individual LWRS and LTO program R&D plans. For the purposes of this plan, multiple R&D activities are, in selected instances, rolled up under a single heading.

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

LWRS Project	Related LTO Project	Coordinated Activity	Collaborative Activity	Program Unique Activity
Materials Aging and Degradation	Understanding, Prediction, and Mitigation of Primary System Aging Degradation			
Expanded Proactive Materials Degradation Analysis	MDM and IMTs		LWRS-LTO joint lead	
Reactor Metals				
Mechanisms of Irradiation-Assisted Stress Corrosion Cracking (IASCC) Reactor Vessel Internals	IASCC: Identifying Mechanisms and Mitigation Strategies for IASCC of Austenitic Steels and LWR Core Components		LWRS-LTO joint lead	
Reactor Pressure Vessel (RPV)	RPV Embrittlement from Long-Term Fluence	LWRS lead		
Crack Initiation in Ni-Based Alloys	Environmental-Assisted Cracking: Evaluation of Crack Initiation and Propagation Mechanisms in LWR Components	LWRS-LTO joint lead		
Concrete	Comprehensive Aging Management of Concrete Structures (Technology Roadmap)		LTO lead	
Cabling	Technical Basis for Aging Management and Life-Cycle Management of Cables	LWRS-LTO joint lead		

LWRS Project	Related LTO Project	Coordinated Activity	Collaborative Activity	Program Unique Activity
Mitigation Strategies				
Weld Repair Techniques	Advanced Welding Methods for Irradiated Materials		LWRS-LTO joint lead	
Thermal (Post-Irradiation) Annealing				LWRS lead
Advanced Replacement Alloys and Fabrication Techniques				LWRS lead
Integrated Research – International Activities (Halden Project, International Forum on Reactor Aging Management)	Participation in International Forum on Reactor Aging Management	LWRS Lead		
Integrated Research – International Activities (Materials Aging Institute)	Partnership in Materials Aging Institute (EPRI Nuclear Sector)	LTO Lead		
Constellation Demonstration Project	Ginna and Nine Mile Point-1 Demonstration Plant Activities		LWRS-LTO joint lead	
Zion Materials Management and Coordination				LWRS lead
Nondestructive Examination (NDE) Technologies	Opportunities to Employ NDE Technologies for Automatic, Continuous, In-situ Monitoring	LWRS-LTO joint lead		
Advanced Light Water Reactor Fuels				
Advanced Design Concepts (SiC Cladding Design and Testing)	SiC Fuel Cladding Design and Reliability Analyses	LWRS lead		
Halden Project				LWRS lead
Mechanistic Understanding of Fuel Behavior				LWRS lead
Advanced Design and Measurement Tools				LWRS lead

LWRS Project	Related LTO Project	Coordinated Activity	Collaborative Activity	Program Unique Activity
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	
Halden Project		LWRS lead		
Centralized Online Monitoring and Information Integration In-Situ Continuous Monitoring for Degradation	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	
RISMC				
Margins Analysis Techniques Modeling and Simulation Activities	Enhanced Safety Analysis Capability		LWRS-LTO joint lead	
	Enhanced Risk Assessment and Management Capability	LTO lead		
Other Projects				
	Aging Management Program Scope for Operation Beyond 60 Years			LTO Lead
	Alternative Cooling Strategies			EPRI work outside LTO scope
	Case Studies for Large, Integrated Plant Refurbishments			EPRI work outside LTO scope

3. LIGHT WATER REACTOR SUSTAINABILITY/LONG-TERM OPERATIONS COORDINATED RESEARCH AND DEVELOPMENT ACTIVITIES

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
Reactor Metals	
LWRS – RPV	**R&D Scope and Objectives:** High-Fluence Effects on RPV Steels – Irradiation of RPV steels may cause embrittlement of the primary reactor vessel. Both industrial capsules and single variable experiments may be required to evaluate potential for embrittlement and to provide a better mechanistic understanding of this form of degradation. This effort also provides an opportunity for early programmatic success and can build on past efforts. Testing will include impact and fracture toughness evaluations, hardness, and microstructural analysis. Effects of Using Supplementary Alloys of High-Flux Irradiation on RPV Steels – New methods to generate meaningful data out of previously tested specimens will be developed. Embrittlement margins for a vessel can be accurately calculated using supplementary alloys and experiments such as 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.
LTO – RPV Embrittlement from Long-Term Fluence	**R&D Scope and Objectives:** Currently, the considerations of materials degradation for 60 years of operation do not include the fluence effect on RPV embrittlement as a life-limiting factor because of the relatively low fluence level. However, for 80 or more years, refinement of analysis, testing, and validation using irradiated samples will be needed. This project will design, fabricate, and irradiate a supplemental surveillance capsule that will provide high-fluence irradiated data and will develop and refine an embrittlement trend correlation using the Master Curve approach to convert the shift in Charpy V-notch energy data at different temperatures and irradiations to a fracture toughness equivalent shift. This embrittlement trend correlation is necessary to bridge the gap between the Charpy V-notch energy evaluation approach and the fracture toughness Master Curve approach. 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.

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
LWRS – RPV	**Milestones:** • Deliver mechanistic understanding for key materials and degradation modes, including the following: – (2015) Deliver the final model to predict RPV embrittlement over a variety of conditions for extended service (e.g., time, temperature, composition, flux, and fluence) together with all supporting research data. • (2017 to 2021) Deliver mechanistic understanding for the key materials and degradation modes, including the following: – Issue a final report on RPV attenuation and surrogate material issues (experimental results for replacement materials, attenuation studies, potential implications on operation and surveillance, and revisions to the RPV model). • (2017 to 2021) Deliver model capability for the key materials issues, including the following: – Develop additional modeling capabilities of RPV (substitute materials and attenuation and extending utility and accuracy).
LTO – RPV Embrittlement from Long-Term Fluence	**Milestones**: This project involves irradiation of supplemental surveillance specimens to high fluence in a pressurized water reactor. The follow-up testing and analysis must be performed in a laboratory with the capability of handling irradiated materials. The project requires 10 or more years to complete the work. The work will be coordinated with on-going and planned work within the Pressurized Water Reactor Materials Reliability Program and Boiling Water Reactor Vessel and Internals Project to address RPV embrittlement after extended operation. • (December 2014) Design, fabricate, and insert a supplemental surveillance capsule in a host pressurized water reactor. • (2014) Develop and refine an embrittlement trend correlation; report on revisions to embrittlement trend correlation. • (2013) Participate in a round robin test of a new method to extend the use of existing surveillance specimens to generate Master Curve data.
LWRS – Crack Initiation in Ni-Based Alloys	**R&D Scope and Objectives:** Identify underlying mechanisms of stress corrosion cracking in Ni-based alloys. Understanding and modeling the mechanisms of crack-initiation is a key step in predicting and mitigating stress corrosion cracking in the primary and secondary water circuits. An examination into the influence of surface conditions on precursor states and crack initiation also is a key need for Ni-based alloys and austenitic stainless steels. This effort would include crack-growth rate testing of Ni-based alloys and stainless steels in simulated LWR water chemistries. 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 Aging Institute (EPRI being a member), which are focused primarily on modeling of crack initiation.

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
LTO – Environmental-Assisted Cracking: Evaluation of Crack Initiation and Propagation Mechanisms in LWR Components	**R&D Scope and Objectives:** 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 effective countermeasures against stress corrosion cracking. The objectives of this project include the following: • Understand the evolution of metal surface resulting from interaction with LWR environments to identify the key process leading to cracking. • Understand the metallurgical evolution of component materials under LWR environments to identify the mechanisms leading to decreased fracture resistance in component materials. • Develop improved prediction models and evaluation methodologies for assessing the reliability of LWR structural materials. • Develop strategies to mitigate the risk of environmental-assisted cracking degradation and to extend component life.

LWRS – Crack Initiation in Ni-Based Alloys
 	
LTO – Environmental-Assisted Cracking: Evaluation of Crack Initiation and Propagation Mechanisms in LWR Components
	Milestones:
	• Deliver mechanistic understanding for key materials and degradation modes, including the following:
	  – (2016) Issue final report on crack initiation in nickel-based alloys for piping — data and mechanistic understanding.
	• (2017 to 2021) Deliver mechanistic understanding for key materials and degradation modes, including the final report on environmental fatigue — model and supporting data.
	• (2017 to 2021) Deliver model capability for the key materials issues, including the following:
	  – Develop a predictive model on Ni-based cracking (statistical analysis of crack probability as a function of time and composition).
	Milestones:
	Activity 1: In-situ surface oxide film characterization and correlation between oxidation and crack initiation:
	• (2012) Summarize results of in-situ surface oxide film as function of materials/LWR environment combination
	• (2014) Summarize results of in-situ surface oxide structure and oxidation kinetics
	• (September 2016) Establish correlation between oxidation and crack initiation.
	Activity 2: Local strain-stress behavior associated with crack
	• (2014) Results from in-situ synchrotron x-ray stress measurement
	• (2016) Establish correlation between strain rate and crack growth rate.

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
	Activity 3: Parametric study and development of mitigation strategy • (2015) Summary of parametric experiments on crack growth rate • (2017) Develop and validate mitigation strategies. Activity 4: Modeling • (2016) Environmental-assisted cracking crack growth prediction model • (September 2019) Environmental-assisted cracking crack initiation model. Activity 5: Consolidation of Knowledge Base for Long-Term Operations • (2013, 2015, and 2018) Environmental-assisted cracking knowledge base updates for long term operations.
Cabling	
LWRS – Cabling	**R&D Scope and Objectives:** Cable aging is a concern that currently faces the operators of existing NPPs. The plant operators carry out periodic cable inspections using NDE techniques to measure degradation and determine when replacement is needed. Degradation of these cables is primarily 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 would likely be a "show stopper" for plant operation beyond 60 years because of the cost and difficulty in replacement. One of the primary activities for cable aging research in the LWRS Program involves identification of mechanisms of cable degradation to provide understanding of the role of composition, 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, ionizing irradiation, or a combination of these environmental elements. 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:** Develop the technical basis for aging management and life-cycle management of cable systems.* Specifically, 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 be investigated. Completion of technical basis is expected to frame R&D funding needs to resolve identified issues. * *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.

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
LWRS – Cabling	**Milestones:** • Deliver mechanistic understanding for key materials and degradation modes, including the following: – (2016) Issue a final report covering the controlling mechanisms for cable insulation, implications for extended service conditions, and supporting experimental data.
LTO – Advanced Cable Testing Technology for Life-Cycle Management of Cables	**Milestones**: • Initial aging method produced less aging than desired in a reasonable period. Alternate method to be tried in 2012. • (December 2013) Population of accelerated aged EPR cables and plan to evaluate and enhance testing methods. • (July 2013) Assess online continuous differential partial discharge test for medium voltage cable. • (2013) Assess cable system vulnerability by environment and service condition to estimate replacement needs for long-term operation.
Mitigation Strategies	
LWRS – Integrated Research/ International Collaborations (Halden Project and the International Forum on Reactor Aging Management)	**R&D Scope and Objectives:** 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. Research opportunities also can be explored through cooperative efforts with the International Forum on Reactor Aging Management, which facilitates the appropriate exchange of information among those parties and organizations around the world that presently are planning to address or are addressing issues of NPP SSCs aging management. 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 (Materials Aging Institute)	**R&D Scope and Objectives:** 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 the Materials Aging Institute (of which EPRI is a member) will provide more collaboration and cost sharing.
LWRS – Integrated Research/ International Collaborations (Halden Project and the International Forum on Reactor Aging Management)	**Milestones:** • (November 2012) Complete agreement for participation in the Materials Aging Institute activities coordinated with EPRI partners. • (January 2013) Initiate participation in one to two Materials Aging Institute-led tasks. • (September 2013 through 2018) Annual report on international collaborations.

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
LTO – Integrated Research/ International Collaborations (Materials Aging Institute)	**Milestones** • (2012) Participate in the International Forum on Reactor Aging Management meetings and activities. • (November 2012) Complete agreement for participation in the Materials Aging Institute activities coordinated with the LWRS Program.
LTO – Constellation Demonstration Project	**R&D Scope and Objectives:** Containment Assessments at Ginna and Nine Mile Point Unit 1 – Ginna assessment will include, pending plant site approval, application of fiber optics strain gages to tendon shims and digital image correlation to selected external surfaces to generate baseline and transient data during the planned Integrated Leakage Rate Test. Selected containment sites also will be subject to carbonation testing, and data from site planned inspection activities will be reviewed and evaluated for use and impact on greater than 60-year life. Nine Mile Point Unit 1 activities will be limited to data evaluation from site planned inspections. After the refueling outages of 2011 and 2012, a draft Comprehensive Containment Assessment Guideline will be developed for review by LTO members and testing at future outages. Internals Assessments at Ginna and Nine Mile Point Unit 1 – For Ginna, data from site planned inspection activities per guidance provided in EPRI MRP-227 will be reviewed and evaluated for use and impact on greater than 60-year life. A sample of stainless steel baffle bolts (about 150 to be removed from service during outage) will be destructively evaluated to assess damage progression at varying neutron fluence levels. A sample of inconel split pins also may be evaluated if current fluence levels subject potential damage. For Nine Mile Point Unit 1, data from site planned inspection activities per guidance provided by the EPRI Boiling Water Reactor Vessel and Internals Project will be reviewed and evaluated for use and impact on greater than 60-year life. Potential exists to remove samples containing known cracks from the stainless steel top guide. Cracks are believed to be examples of IASCC. Samples would be destructively evaluated to confirm crack morphology. After the refueling outages of 2011, draft guidance will be developed for review by LTO members and considered as incremental inspection/documentation recommendations for plants considering operations to 80 years. Vessel Assessments at Ginna and Nine Mile Point Unit 1– In addition to reviewing data from site planned inspection activities at Ginna and Nine Mile Point Unit 1, vessel-specific efforts are being developed. For Ginna, previously removed and tested (Charpy tests) vessel surveillance specimens may be reconstituted and subjected to further irradiation (DOE test reactor) to increase fluence levels per extended life operation. For Nine Mile Point Unit 1, one of two remaining surveillance capsules may be removed for specimen testing, pending a formal determination that testing the capsule will provide useful information for the Boiling Water Reactor Integrated Surveillance Program as it applies to LTO-estimated fluence. Note that evaluation activities would occur in 2012 to 2013. The results of these investigations will be input to a determination that suitable data, samples, and testing are available to support operations to 80 years. Identification of Additional SSCs for Demonstration and License Renewal

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
LWRS – Constellation Demonstration Project	Technical Issues –NRC is interested in this demonstration project and direct participation is a potential in 2011 and beyond. The focus of this effort will be on supporting the Nuclear Energy Institute and NRC on developing a template for license extension submittals to NRC. Work activities and results at both Ginna and Nine Mile Point Unit 1 will be reviewed to identify and pursue opportunities to improve life assessment efforts for other critical SSCs (e.g., cabling, spent fuel pool, and secondary piping) expected to be considered in extended-life license applications. **R&D Scope and Objectives:** The Constellation Pilot Project is a joint venture between the LWRS Program, EPRI, and the Constellation Energy Nuclear Group. The project utilizes two of Constellation's nuclear stations (R. E. Ginna and Nine Mile Point 1) for research opportunities to support future licensing of NPPs. Specific areas of joint research have included development of a concrete inspection guideline, installation of equipment for monitoring containment rebar and concrete strain, and additional analysis of RPV surveillance coupons. Opportunities for additional and continued collaboration will be explored in coming years.
LTO – Constellation Demonstration Project	**Milestones:** Demonstration Activities on Comprehensive Containment Examination: • Participation in 2011 and 2012 RFOs at Ginna and Nine Mile Point Unit 1 • (March 2013) Draft Comprehensive Containment Guideline • Participation in 2012 RFO at Ginna • Participation in 2013 RFOs at Nine Mile Point Unit 1 • (December 2013) Final Comprehensive Containment Guideline. Incremental Inspection and Examination of Reactor Vessel Internals: • Participation in 2011 RFOs at Ginna and Nine Mile Point Unit 1 • (December 2011) Draft Incremental Reactor Internals Inspection Guidance • Participation in 2012 RFO at Ginna • Participation in 2013 RFOs at Nine Mile Point Unit 1 • (December 2013) Final Incremental Reactor Internals Inspection Guidance. Task 3 • (December 2012) Draft Reactor Embrittlement Analysis and Validation Plan to 80 Years • Gap Analysis and Feasibility Study of Plan for Ginna and Nine Mile Point Unit 1 • Demonstration of Plan Elements for Ginna and Nine Mile Point Unit 1 • (December 2013) Final Reactor Embrittlement Analysis and Validation Plan to 80 Years. Task 4 • (December 2013) Report on Demonstration Plant Activities in Support of License Renewal Beyond 60 years.

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
LWRS – Constellation Demonstration Project	**Milestones:** • (2013) Complete Containment Inspection Guidelines for extended-service conditions through partnership with Constellation Energy and EPRI.
LWRS – NDE **LTO – NDE**	**R&D Scope and Objectives:** Techniques for NDE provide new technologies to monitor material and component performance. This task will deliver an R&D plan in 2012 for sensor development to monitor performance. An initial step in this R&D plan is to examine the key issues and available technologies. Key issues for consideration can include new or adapted techniques for surveillance. Expert panels will develop the R&D plan, ensuring broad input and discussion. In future years, sensor development will be performed, with a demonstration of key prototypes. **R&D Scope and Objectives:** 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 on-line monitoring employing 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). The EPRI NDE program provides NDE technology, procedures, validation, and training for identified materials, mechanisms, and locations of concern. This process is assumed to be effective for the life of the plant, including subsequent license renewal periods. 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, validation of the NDE/monitoring system, and demonstration of the process in an operational environment.

LWRS – NDE
 	
LTO – NDE
	Milestones:
	• (2016) Deliver prototype detection and monitoring tools for key material components, including cabling, concrete, RPV, and piping.
	• (2017 to 2021) Deliver validation data and use criteria for new detection and monitoring tools (technology transfer of NDE sensors).
	Milestones:
	• (2012) Reactor Building Tendon Monitoring Feasibility Study at Ginna
	   – Joint milestone with Online Monitoring Project
	• (2013) Pilot application of in-situ monitoring of material degradation of passive assets[1]
	   – Joint milestone with Online Monitoring Project
	• (2014) Pilot application of in-situ monitoring of material degradation of passive assets[1]

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
	– Joint milestone with Online Monitoring Project [1] At least one pilot application will employ NDE technology as part of the monitoring system.

R&D Area	Advanced Light Water Reactor Fuels
Fuel Design	
LWRS – Advanced Fuel Design Concepts	**R&D Scope and Objectives:** The LWRS Program's Advanced LWR Nuclear Fuels Pathway is separated into three R&D tasks: (1) SiC CMC designs and concepts, (2) mechanistic understanding of fuel behavior, and (3) advanced tools. These tasks were selected to balance development of new knowledge, verify developed knowledge, and create new advanced fuel technology. • SiC ceramic matrix composite (CMC) designs and concepts – The purpose of this task is to increase the understanding of advanced LWR fuel design concepts and apply this understanding to create safer and more economic nuclear fuel. This development centers on use of new cladding materials to increase safety margins, fuel lifetimes, and expand the allowable fuel performance envelope. The advanced cladding material (SiC CMC) has the potential to maintain strength and resist chemical reactions at very high temperatures, allowing fuel performance-related plant operating limits to be optimized in areas such as operating temperatures, power densities, power ramp rates, and coolant chemistry. Accomplishing these goals will lead to increased operating safety margins and improved economic benefits. • Mechanistic understanding of fuel behavior – This task area includes the testing and modeling of specific aspects of LWR fuel, cladding, and coolant behavior. Examples include pellet cladding interaction, fission gas release, coolant chemistry effects on corrosion, and crud (oxide) formation. Improved understanding of fuel behavior can be used in fuel design, licensing, and performance prediction. • Advanced tools – This task uses increased understanding of specific fuel performance phenomena being integrated into encompassing fuel performance advanced tools that should help minimize the time required for materials development and fuel qualification. This task includes (1) engineering design and safety analysis tool, (2) mechanical models of composite cladding, (3) design studies of advanced SiC cladding, and (4) experiments to verify design and safety margin calculation tools.
LTO – Nuclear Fuel Designs and Fuel Analysis Enhancements	**R&D Scope and Objectives:** The overall objective of this work is to participate in the larger industry effort to identify advanced fuel designs that have potential for a full rod or assembly test in an operating plant and can be routinely loaded into existing NPPs within 20 years. This design must have significant cost and performance benefits such as enabling additional power uprates, operational flexibility, high fuel reliability, and accident tolerance. When a development roadmap exists for such an advanced design, the EPRI LTO Program will identify tasks within the roadmap to be performed by EPRI.

R&D Area	Advanced Light Water Reactor Fuels
LWRS – Advanced Fuel Design Concepts	**Milestones:** • (2012) Issue a fuel development plan for SiC CMC nuclear fuel systems, including technology challenges, development schedule, and approximate costs for implementation. • (2012) Complete an SiC CMC material technology tradeoff study on advanced LWR fuels cladding material to guide program development. • (2012) Complete the initial characterization of SiC CMC clad fuel performance to allow design activities. Characterization will allow an understanding of what technology is needed to meet the performance requirements. • (2013) Complete an analysis to support fueled SiC CMC matrix fuels in-pile testing to demonstrate practical operation. Demonstrate advanced cladding performance with simulated nuclear fuel heating. • (2013) Fabricate a second generation of advanced SiC CMC cladding that incorporates high-performance features. • (2013) Predict fuel interaction with cladding to demonstrate adequate performance for operating conditions using advanced fuel models of SiC CMC cladding. • (2014) Conduct transient testing of SiC CMC cladding with simulated nuclear fuel heating to define an operating envelope in advance of in-pile testing. • (2014) Fabricate extended-length fuel cladding that represents commercial nuclear fuel rods to demonstrate economic and technical practicality. • (2014) Deliver a computational model of an advanced SiC CMC fuel system to predict performance during accident scenarios in advance of in-pile demonstration tests. • (2014) Issue a report on licensing requirements and research program requirements to guide transfer to industrial development. • (2015) Perform accident scenario and reactivity insertion tests with simulated nuclear fuel heating to assess performance and provide data for verification and validation. • (2015) Perform in-pile testing of extended length SiC CMC cladding to demonstrate in-reactor performance of extended-length rods. • (2016) Perform in-pile testing of rods at higher exposure limits to demonstrate long-term performance of SiC CMC cladding. • (2016) Begin an evaluation of vendor-specific nuclear fuel rod features to establish critical operating limits for advanced commercial fuel designs. • (2017 to 2021) In cooperation with industry, obtain approval for lead test rod or assembly testing in a commercial reactor. • (2017 to 2021) In cooperation with industry, conduct analysis of vendor reload analysis capabilities to support licensing of advanced fuel reload. • (2022 to 2026) Industry receives first approval for a full core reload of advanced fuel in a commercial reactor.

R&D Area	Advanced Light Water Reactor Fuels
LTO – Nuclear Fuel Designs and Fuel Analysis Enhancements	• (2022 to 2026) Start evaluation to support increased enrichment/higher burn-up commercial fuel reloads. **Milestones**: • (2011) Project 1: Fuel Performance Modeling Final Report • (2011) Project 2: End Cap Demonstration Final Report • (2011) Project 3: Economic Analysis Final Report • (2011) Project 4: Boiling Water Reactor SiC Structural Applications Final Report • (2012) Participation of an EPRI nuclear fuel expert in industry meetings to identify viable advanced fuel designs. Participation in LWRS Program meetings to develop a roadmap for development and deployment of SiC cladded fuel for existing reactors.

R&D Area	Advanced II&C Technologies
LWRS – International Collaborations (Halden Project)	**R&D Scope and Objectives:** The Halden Reactor Project's programs extend to many aspects of NPP operations; however, the area of interest to this R&D program is the man-machine-technology research program that conducts research 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 NPP 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 NPPs in implementing II&C modernization projects, including control room upgrades. The II&C 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. Specific Halden developments of interest to the pilot projects are as follows: • Advanced control room layout • Computer-based procedures • Advanced, state-based alarm systems • Integrated operations • Plant worker mobile technologies. In addition, INL will enter into a bilateral agreement 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:** EPRI has established the Productivity Improvements through an Advanced Technology Advisory Group. This group is looking at II&C enabled productivity improvements in NPPs and is interacting closely with the LWRS Program's II&C Pathway, including having an upcoming joint meeting in August 2012. The Advanced Technology Advisory Group had the Halden Reactor Project give

R&D Area	Advanced II&C Technologies
	presentations in the June 2010 meeting and will have them give more presentations in the April 2012 meeting. The intent is to identify opportunities to support productivity improvements in NPPs, 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) **LTO – Halden Project**	**Milestones:** • (2011) Agreement between Halden and INL signed. **Milestones**: • EPRI membership is at a level above specific LTO Program focus such that LTO relevant R&D is evaluated on a case-by-case basis.

R&D Area	RISMC
LTO – Enhanced Risk Assessment and Management Capability	**R&D Scope and Objectives:** To achieve successful long-term operations of the current fleet of operating NPPs, it will be imperative that high levels of safety and economic performance are maintained. Therefore, operating NPPs will have a continuing need to undergo design and operational changes, as well as manage aging degradation while simultaneously preventing the occurrence of safety significant events and analytically demonstrating improved nuclear safety. This portion of the EPRI LTO Program addresses two specific issues that are imperative to achieving these objectives: (1) First, as the current fleet of operational NPPs ages, it is anticipated that new challenges to NPP 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 plants. (2) Second, as new technologies and capabilities become available, it will be desirable to take advantage of these opportunities to enhance plant technical and economic performance. Examples of such enhancements could include performing extended power uprates or implementation of new technologies or materials. In each situation, a comprehensive and integrated assessment of the impact on nuclear safety will be required to support effective and efficient decision making. 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 NPP long-term operations (e.g., RISMC) and providing for the capability for 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.

R&D Area	RISMC
LTO – Enhanced Risk Assessment and Management Capability	**Milestones:** 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 2012 and 2013, the support of PHOENIX development, testing, and initial deployment will continue. The following activities are planned: • (December 2012) Update of PHOENIX software development plan to incorporate LTO Program and LWRS Program requirements. This will include prioritization of LTO-related applications for inclusion into PHOENIX and the integration of these modules into the PHOENIX development plan and roadmap. • (Starting in 2013) Conduct a PHOENIX LTO pilot application and report results during 2014.

4. LIGHT WATER REACTOR SUSTAINABILITY/LONG-TERM OPERATIONS COLLABORATIVE RESEARCH AND DEVELOPMENT ACTIVITIES

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
LWRS – Expanded Proactive Materials Degradation Analysis	**R&D Scope and Objectives:** A proactive materials degradation analysis is a comprehensive evaluation of degradation modes for LWR applications, based on knowledge level, severity of degradation, and likelihood of occurrence. The degradation of core internals and primary piping for nuclear reactor applications was evaluated in considerable detail in the original NRC-led proactive materials degradation analysis (NUREG/CR-6923). This assessment has proven to be a very valuable resource in component aging management and regulation. Consequently, an expanded proactive materials degradation analysis-type activity is being performed to address extended service and include components beyond the primary piping and core internals. The proactive materials degradation analysis approach to extended service has the following key benefits: • Captures current knowledge base • Identifies gaps in knowledge for a component or material system that must be resolved • May help identify new forms of degradation • Identifies and prioritizes research needs and directions • Builds collaborations between industry, regulatory, and government • Is in a format familiar to industry. This Expanded Proactive Materials Degradation Analysis is being conducted in a cooperative partnership between NRC and DOE's LWRS Program.

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
LTO – Extension of MDM and IMTs to Include Failure Mechanisms to 80 Years	**R&D Scope and Objectives:** The EPRI MDM, Pressurized Water Reactor IMT, and Boiling Water Reactor IMT are three key reference documents that are part of the 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. MDM results are used as direct inputs into the Pressurized Water Reactor IMT and Boiling Water Reactor 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 (Revision 0), and revised in 2007 (Revision 1). Sequentially, two IMTs were first published in 2005 (Revision 0) and then revised in 2008 (Revision 1). The Revision 0 and Revision 1 of MDM and the IMTs only addressed issues related to the current license period (40 years of operation) and the license renewal period (from 40 to 60 years of operation). The goal of the LTO Program is to extend MDM and the IMTs to 80 years of operation. The objectives of ongoing revision (Revision 2) of MDM and the IMTs are as follows: • Identify applicable degradation mechanisms and assess the extent to which applicable degradation mechanisms are understood • Evaluate the worldwide state of industry knowledge associated with mitigation of degradation mechanisms • Address any concerns related to regulatory and licensing renewal considerations. The MDM and IMTs are living documents and they require updates and revisions periodically to reflect the knowledge gained and the evolving challenges.
LWRS – Expanded Proactive Materials Degradation Analysis **LTO – MDM/IMTs**	**Milestones:** • (2012) Complete the Expanded Proactive Materials Degradation Analysis gap analysis of the materials degradation modes. **Milestones**: • (2012, 2015, and 2018) MDM revision every 3 years. • (2013, 2016, and 2019) IMTs revision every 3 years.
Reactor Metals	
LWRS – Mechanisms of IASCC	**R&D Scope and Objectives:** Mechanisms of IASCC in stainless steels provide understanding of the role of composition, history, and the environment on IASCC and model capability. This will be accomplished through a partnership with EPRI by performing tests in simulated water environments (both crack growth and tensile tests) in addition to complementary post-irradiation examination of irradiation effects on a series of service materials and model alloys. Combined, these single variable experiments will provide mechanistic understanding that can be used to identify key operational variables to mitigate or control IASCC, to optimize inspection and

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
	maintenance schedules for the most susceptible materials/locations, and to design IASCC-resistant materials. The final results of this study (i.e., data and mechanistic understanding) will be delivered in a detailed report in 2014, with preliminary results provided at interim points.
LWRS – Reactor Vessel Internals	**Scope and Objectives:** • High-Fluence Effects on IASCC of Stainless Steels — Assess high-fluence effects on IASCC for core internals. Work on crack growth-rate testing on high-fluence specimens and on intergranular fracture will be undertaken. Work also will include identification of high-fluence materials available for research and testing in all tasks. **Note:** *The activities described below are included within the scope of LWRS R&D work concerning reactor internals. While the activities do not specifically address IASCC concerns, they are being listed here to reflect the broader scope of LWRS R&D in this area.* • Evaluation of Swelling Effects in High-Fluence Core Internals — Assess the extent of potential swelling in reactor core internals. While swelling is typically a greater concern for fast reactor applications where it can be life-limiting, voids have recently been observed in LWR components such as baffle bolts. Longer reactor component lifetimes may increase the need for a more thorough evaluation of swelling as a limiting factor in LWR operation. A critical assessment of key components and experimental validation of trends using core components or specimens irradiated in test reactors will be provided. • Irradiation-Induced Phase Transformations in High-Fluence Core Internals — Assess the extent of potential embrittlement due to high-fluence irradiation of core internals. A predictive model will be developed to provide insight into embrittlement caused by microstructural changes. High-fluence thimble tubes will be sought as an important resource of existing irradiated material for examination. The relation between microstructure, hardening, and embrittlement also will be explored.
LTO – IASCC: Identifying Mechanisms and Mitigation Strategies for IASCC of Austenitic Steels and LWR Core Components	**R&D Scope and Objectives:** 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. 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: • 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. • Full assessment of the roles of commercial alloy microstructure on crack growth rate and crack initiation.

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
	• 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. • Relation between IASCC cracking susceptibility and neutron irradiated alloys. • Determination of the predictive capability of crack initiation due to proton irradiation by assessment against crack initiation due to neutron irradiation. • Role of localized deformation on the IASCC susceptibility in neutron irradiated materials. 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. This LTO project is a 5-year effort that started in 2009. The scope of this LTO project can be summarized as investigating the following: • Role of solutes in crack initiation • Role of solutes in crack propagation • Role of starting microstructure in crack initiation • Role of starting microstructure in crack propagation • Effectiveness of proton irradiation in forecasting relative crack growth rate behavior • Comparison of crack initiation following proton and neutron irradiation • Comparison of crack initiation and crack growth in neutron-irradiated samples as a function of solute addition or starting microstructure • Structure-property relationship for neutron irradiated alloys • Effect of alloy, alloy purity, heat, and dose on crack growth and crack initiation. In addition, EPRI will initiate a new international collaborative project with DOE on development of radiation-resistant materials for LWR applications. EPRI and DOE will jointly prepare a comprehensive report on the state of current knowledge of radiation-induced degradation in LWRs and prepare a roadmap to develop and qualify more radiation-resistant materials. The resulting roadmap will be used to formulate a long-range R&D plan to develop improved materials for current and new NPPs.
LWRS – Mechanisms of IASCC **LWRS – Reactor Vessel Internals**	**Milestones:** • Deliver mechanistic understanding for key materials and degradation modes, including the following: – (2014) Issue a final report on IASCC (data and mechanistic understanding). • (2013) Prepare a comprehensive report on the state of current knowledge of radiation-induced degradation in LWRs and prepare a roadmap to develop and qualify more radiation-resistant materials. (This effort links

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<tr><th>R&D Area</th><th>Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)</th></tr>
<tr><td>LTO – IASCC: Identifying Mechanisms and Mitigation Strategies for IASCC of Austenitic Steels and LWR Core Components</td><td>with the LTO Knowledge Base Report scheduled for 2013 listed below.)

(2015) Deliver model capability for key core internal issues, including the following:

Issue a final report on the experimental results and details of the predictive model of swelling of core internal components.
Issue a final report on the experimental results and details of the predictive model for phase transformations of core internal components.

(2017 to 2021) Deliver mechanistic understanding for the key materials and degradation modes, including the following:

Issue a final report on high-fluence IASCC (detailed experimental results and an evaluation of the effects).

(2017 to 2021) Issue a final report on the validation of modeling capabilities for swelling and phase transformations.
(2017 to 2021) Deliver model capability for the key materials issues, including the following:

Develop a predictive model on IASCC (function of fluence and material properties).

Milestones:

(December 2013) IASCC knowledge base for long-term operations
(Mid-2014) Correlation for crack initiation and growth and mitigation strategies
(2016) Crack growth prediction model
(2018) Report on IASCC-resistant materials for repair and replacement.
</td></tr>
<tr><td>Concrete</td><td></td></tr>
<tr><td>LWRS – Concrete</td><td>R&D Scope and Objectives:
Large areas of most NPPs have been constructed using concrete, and there are some data on performance through the first 40 years of service. However, currently, there is little or no data on long-term concrete performance in these plants. Long-term stability and performance of concrete structures within an NPP is a potential concern. As such, the objective of this task is to assess the long-term performance of concrete in nuclear applications. Research task evaluation and prioritization will be performed on an ongoing basis. Plans for research at EPRI and NRC will continue to be evaluated to confirm the complementary and cooperative nature of concrete research under the Materials Aging and Degradation Pathway. In addition, the formation of an Extended Service Materials Working Group for concrete issues will provide a valuable resource for additional and diverse input.
One of the primary activities in this R&D area involves identification of mechanisms of concrete degradation to provide understanding of the role of composition, history, and the environment on concrete degradation; development of a concrete performance database; and support to partners in modeling activities, surveillance, and testing criteria. This task is being performed in</td></tr>
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R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
	cooperation with NRC, EPRI, and the Materials Aging Institute. The overall objective of the concrete task is to provide assurances that the NPP concrete structures will continue to meet their functional and performance requirements and maintain adequate structural margins during the current licensing period, as well as for continued service periods beyond the initial operating license period that may extend plant operation to 60, 80, or more years. In meeting this objective, several tasks where concrete-structures-related research is required have been identified: (1) compilation of material property data, including data on irradiation and high-temperature performance, which are currently sparse and where National Institute of Standards and Technology and other databases will be a key resource; (2) assessments of the current condition and estimates of the future condition of the structures (e.g., improved condition assessment methodologies and development of damage models and acceptance criteria for use in condition assessments); (3) improved constitutive models and analytical methods for use in determining nonlinear structural response (e.g., accident conditions); (4) nondestructive methods for thick, heavily reinforced concrete and global inspections of the containment metallic pressure boundary; (5) data on application and performance (e.g., durability) of repair materials and techniques; and (6) utilization of the structural reliability theory, incorporating uncertainties to address time-dependent changes to structures to assure minimum-accepted performance requirements are exceeded, to forecast ongoing component degradation for end-of-life estimations, and to apply probabilistic modeling of component performance to provide risk-based criteria to evaluate how aging affects structural capacity. Activities under the LWRS Program presently are being conducted under Tasks 1, 2, 4, and 6. Complementary activities are being conducted under an NRC program at the Oak Ridge National Laboratory, addressing Task 2. EPRI has activities under Tasks 2, 3, and 4. Task 5 is being addressed by the Nuclear Energy Standards Coordination Collaborative headed by the National Institute for Standards and Technology.
LTO – Comprehensive Aging Management of Concrete Structures	**R&D Scope and Objectives:** Without an adequate understanding and (where necessary) inspection, concrete civil infrastructure in commercial NPPs is a potential “show-stopper” in lieu 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 NPPs. 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. The interim goal of this project is to create a project that looks at various degradation phenomena being experienced in operating NPPs. The initial stage of the project will be to compile an Aging Reference Manual, which will clearly define the physics of kinetic degradation processes and discuss operational issues dealt with by the industry over the past 40+ years. The manual will contain a framework for identifying at-risk structures and applicable degradation mechanisms. Building upon this, a number of individual research projects, aimed at further understanding of those degradation mechanisms and structures

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
	identified as “at-risk,” will be commenced. 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 this investigation will yield one or more industry examination guidelines for concrete aging assessment.
LWRS – Concrete	**Milestones:** • (2013) Complete Containment Inspection Guidelines for extended-service conditions through partnership with Constellation Energy and EPRI. • (2016) Deliver a detailed database containing relevant and validated data for extended service, high-temperature effects, and irradiation effects on concrete performance.
LTO – Comprehensive Aging Management of Concrete Structures	**Milestones**: • (2011) Complete and publish a Concrete Structures Aging Reference Manual • (2011) Issue report on leaking spent fuel pools (structural significance of boric acid degradation of reinforced concrete) • (2012) Issue reports on chloride attack case study (Palo Verde Nuclear Generating Station) • (2012 and 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 • (2016) Report on radiation damage effects on concrete.
Mitigation Strategies	
LWRS – Weld Repair Techniques	**R&D Scope and Objectives:** Weld repair provides understanding and modeling of helium effects under welding, validation of residual stress models currently under development, and deployment of advanced repair welding techniques. This task for developing and demonstrating advanced welding technology for repair applications is being performed collaboratively with EPRI. 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 NPPs 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.

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
LTO – Advanced Welding Methods for Irradiated Materials	**R&D Scope and Objectives:** 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 aged 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 using conventional laser beam welding, but once stainless steel components reach a certain fluence (typically at 20 to 30 years of exposure) some may not be welded by current welding methods. As 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 and solid state) is needed to extend the weldability of these irradiated reactor components. 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: • Perform review and prepare summary report on advanced welding processes and the potential application for welding of irradiated reactor components in the underwater environment. • Prepare detailed project plan for the multi-year project: – Sample irradiation plan – Welding hot cell configuration/design – Advanced welding equipment technical requirements and procurement specification – Welding experiments test matrix design – Budgeting and detailed task planning. • Design and procurement of stainless steel sample set for irradiation. 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:

R&D Area	Materials Aging and Degradation (LWRS)/Understanding, Prediction, and Mitigation of Primary System Aging Degradation (LTO)
	• 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. • Material Process Hot Cell – Welding of irradiated material requires facilities that can remotely handle radioactive materials. • Advanced Microstructure Characterization Laboratory – Examination of radioactive material at the sub-grain level is a unique capability of Oak Ridge National Laboratory.
LWRS – Weld Repair Techniques **LTO – Advanced Welding Methods for Irradiated Materials**	**Milestones:** • (2016) Issue a final report on the technology transfer of advanced weld repair techniques (mechanistic studies, model development, supporting data, and development). **Milestones**: • (2012) Project status report for 2010 and 2011 and detail project plan for the remainder of project (EPRI Technical Update Report) • (2013) Hybrid and Solid State Welding: Methods and Technical Basis Report • (2014) Hybrid and Solid State Welding: Guidelines and Validation • (2015) Final Report.

R&D Area	Advanced II&C Technologies
LWRS – New Instrumentation and Control and Human System Interfaces and Capabilities (including Advanced II&C Pilot Projects)	**R&D Scope and Objectives:** R&D activities are being proposed to develop needed capabilities through digital technologies to support long-term NPP operations and management. The supporting technologies will enable the large integrated changes that industry cannot achieve without direct R&D support. This includes comprehensive programs that achieve the following: • Support creation of new technologies that can be deployed to address the sustainability of today's II&C systems technologies • Improve understanding of, confidence in, and facilitate transition to these new technologies • Support development of the technical basis needed to achieve technology deployments • Create or renew infrastructure needed for research, education, and testing This research program will address the 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 NPP settings. This approach drives the following two important outcomes: • Reduces the technical, financial, and regulatory risk of upgrading the aging II&C systems to support extended plant life beyond 60 years. • Provides the technological foundation for a transformed NPP operating model that improves plant performance and addresses the challenges of the future business environment.

R&D Area	Advanced II&C Technologies
	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. The program is advised by a utility working group composed of leading nuclear utilities across the industry and EPRI. The utility working group developed a consensus vision of how a more integrated approach to modernizing plant II&C systems could address a number of challenges to the long-term sustainability of the LWR fleet. A strategy was developed to transform the NPP 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 work activities. The collective work activities were grouped into the following major areas of enabling capabilities: • Highly integrated control room • Highly automated plant • Integrated operations • Human performance improvement for field workers • Outage safety and efficiency • Centralized online monitoring and information integration. Within these areas of enabling capabilities, a series of 18 pilot projects were defined as the roadmap for industry to collectively integrate new technologies into NPP work activities. Presently, for online monitoring, two broad areas of development have been defined, which will be further defined into a series of additional pilot projects. A pilot project is an individual demonstration that is part of a larger strategy needed to achieve modernization according to a plan. It 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 plants. The pilot projects were defined as the appropriate points to introduce enabling technologies across the spectrum of plant work activities. These technologies serve as the stepping stones to the eventual seamless digital environment that enables a transformed NPP operating model. In a September 2011 workshop, the utility working group prioritized the pilot projects in terms of value to the utilities and validated the development order. The sequence of development is designed to achieve progressively greater benefits as the growing aggregate of integrated technologies enables higher degrees of automation and innovation.
LTO – Requirements Database for Advanced I&C, Human System Interface, and Information Technology	**R&D Scope and Objectives:** EPRI will participate in the LWRS working group for Advanced II&C. This working group includes utility representatives from Exelon, Entergy, Duke, Southern, SONGS, STP, APS, Constellation, Progress, TVA, 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 is developing an advanced I&C user facility to support these applications and to perform related

R&D Area	Advanced II&C Technologies
	R&D at INL. 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 Advanced II&C area.
LWRS – New Instrumentation and Control and Human System Interfaces and Capabilities (including advanced II&C pilot projects)	**Milestones:** **Note:** *Some references to technical reports in the following milestones were previously referred to as guidelines in the milestones listed in the current revisions of the LWRS Integrated Program Plan (INL/EXT-11-23452, Revision 0) and the LWRS Long-Term Instrumentation, Information, and Control Systems Modernization Future Vision and Strategy (INL/EXT-11-24154, Revision 1). These documents will be updated at the next revision. Also, there have been some milestone consolidations and minor date changes in this revision of the joint LWRS/LTO plan.* • (2012) Publish a technical report for implementing digital technologies that facilitate communications, coordination, and collaboration in obtaining accurate outage activity status, managing the flow of information through the outage control center, and enabling the resolution of emergent problems in an efficient and effective manner, resulting in improved work efficiencies, production success, and nuclear safety margins. • (2012) Publish a technical report for implementing integrated mobile technologies for NPP field workers that provide real-time connections to plant information and processes, thereby reducing human error, improving human performance and productivity, enabling distance collaboration, and maximizing the "collective situational awareness." • (2012) Develop a digital full-scale mockup of a conventional NPP control room in the Human Systems Simulation Laboratory. • (2013) Publish a technical report for an optimized, human-factored control board layout for integrating digital operator interface screens with analog controls and indicators. • (2013) Implement an upgrade of the Human Systems Simulation Laboratory, enabling research on function allocation, staffing, situational awareness, and workload in multiple-unit control rooms. • (2014) Publish interim guidelines to implement technologies for human performance improvement for NPP field workers. • (2014) Publish a technical report for an advanced alarm management system in an NPP control room and a methodology for integrating diverse alarms and annunciators across all systems and digital platforms. • (2014) Develop human factors evaluations and an implementation strategy for deploying automated field activity work packages built on mobile technologies, resulting in more efficient and accurate plant work processes, adherence to process requirements, and improved risk management. • (2014) Develop human factors studies and publish a technical report for an advanced outage control center that is specifically designed to maximize the usefulness of communication and collaboration technologies for outage coordination, problem resolution, and outage risk management.

R&D Area	Advanced II&C Technologies
	• (2015) Publish a technical report for computer-based procedures that enhance worker productivity, human performance, plant configuration control, risk management, regulatory compliance, and nuclear safety margin. • (2015) Develop an advanced digital architecture that integrates plant systems, plant work processes, and plant workers in a seamless digital environment, and publish a technical report describing the architecture. • (2015) Publish interim guidelines to implement technologies for improved outage safety and efficiency. • (2016) Develop an end-state vision and strategy, based on human factors engineering principles, for the implementation of both a hybrid and a full highly integrated control room as new digital technologies and operator interface systems are introduced into traditional control rooms. • (2016) Publish revised interim guidelines to implement technologies for human performance improvement for NPP field workers. • (2016) Publish interim guidelines to implement technologies for a highly integrated control room. • (2017) Publish a technical report on augmented reality technologies for NPP 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. • (2017) 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. • (2017) 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. • (2017) Publish interim guidelines to implement technologies for a highly automated plant. • (2018) Publish final guidelines to implement technologies for human performance improvement for NPP field workers. • (2018) Develop an end-state vision and implementation strategy for an advanced computerized operator support system, providing real-time situational awareness for operators and prediction of the future plant state, based on current conditions and trends. • (2018) Publish final guidelines to implement technologies for human performance improvement for NPP field workers. • (2018) Publish final guidelines to implement technologies for improved outage safety and efficiency.

R&D Area	Advanced II&C Technologies
	• (2018) Publish interim guidelines to implement technologies for integrated operations. • (2019) Develop a transformed NPP operating model and organizational design derived from a top-down analysis of NPP operational and support activities, quantifying the efficiencies that can be realized through highly automated plant activities using advanced digital technologies. • (2019) Publish revised interim guidelines to implement technologies for a highly integrated control room. • (2020) Develop the strategy and priorities and publish a technical report for 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. • (2020) Publish revised interim guidelines to implement technologies for integrated operations. • (2021) 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. • (2021) Develop the strategy and priorities and publish a technical report for improving plant control algorithms, based on greater availability of sensed and derived plant parameters through the advanced digital architecture, resulting in more anticipatory, adaptive, and resilient control functions. • (2021) 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 NPP support organization. • (2021) Publish human and organizational factors studies and a technical report for a management decision support center consisting of advanced digital display and decision-support technologies, thereby enhancing nuclear safety margin, asset protection, regulatory performance, and production success. • (2021) Publish final guidelines to implement technologies for a highly automated plant. • (2022) Publish final guidelines to implement technologies for integrated operations. • (2022) Publish final guidelines to implement technologies for a highly integrated control room.
LTO – Requirements Database for Advanced I&C, Human System Interface, and Information Technology	**Milestones**: • (2010) Report on Project Plan for Framework for an Advanced I&C Requirements Database • (2012) Summary Report on Database Structure Capability Levels and Simple Prototype.

R&D Area	Advanced II&C Technologies
	The following deliverables will be jointly developed by LWRS and LTO and are listed identically as milestones for each program: • (2014) Publish interim guidelines to implement technologies for Human Performance Improvement for NPP Field Workers. • (2015) Publish interim guidelines to implement technologies for improved outage safety and efficiency. • (2016) Publish revised interim guidelines to implement technologies for human Performance Improvement for NPP field workers. • (2016) Publish interim guidelines to implement technologies for a highly integrated control room. • (2017) Publish interim guidelines to implement technologies for a highly automated plant. • (2018) Publish final guidelines to implement technologies for human performance improvement for NPP field workers. • (2018) Publish final guidelines to implement technologies for improved outage safety and efficiency. • (2018) Publish interim guidelines to implement technologies for integrated operations. • (2019) Publish revised interim guidelines to implement technologies for a highly integrated control room. • (2020) Publish revised interim guidelines to implement technologies for integrated operations. • (2021) Publish final guidelines to implement technologies for a highly automated plant. • (2022) Publish final guidelines to implement technologies for integrated operations. • (2022) Publish final guidelines to implement technologies for a highly integrated control room.
LWRS – Centralized Online Monitoring and Information Integration	**R&D Scope and Objectives:** As NPP systems are operated during periods longer than originally anticipated, the need arises for more and better types of monitoring of material and system performance. This includes the need to move from periodic, manual assessments and surveillances of physical systems to online condition monitoring. This represents an important transformational step in the management of NPPs. 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 about NPP management and safety management. Of particular importance will be the capability to determine the "remaining useful life" of a component to justify its continued operation over an extended plant life. Working closely with the Materials Aging and Degradation Pathway 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. This

R&D Area	Advanced II&C Technologies
	includes development of algorithms, methods, and automated tools to process sensor signals to derive parameter estimates of specific aging and performance features and analytic capabilities to characterize the state and condition of material properties. These developments will be used to produce new types of assessments of "diagnostic" accuracy about material aging and degradation. This will yield new capabilities that enable a move from mechanisms of change, their progression in materials, and a description of the specific transformations that affect a material or system's ability to achieve its design function, in turn, leading to "prognostic" assessments of the rate of degradation and the types and timing of needed interventions. A series of pilot projects will be conducted to develop the diagnostic and prognostic analysis framework for a representative set of large plant components, both active and passive, for which extended life is highly important to LWR sustainability. This will include the ability to predict the remaining useful life for these components. These capabilities will enable industry to implement online monitoring for these components and will establish the methodology for industry to extend the concept to other plant components, where aging and degradation mechanisms must be managed for extended life. The product of the pilot projects will be technical reports that describe the technical basis and analysis framework to enable online monitoring for these components. These technical reports will be used further to develop guidelines for utilities to implement centralized online monitoring and information integration for the components/structures important to plant life extension. Included in these guidelines will be a survey of additional sensors, NDE technologies, and signal processing techniques that will need development to enable the industry to extend online monitoring to other important components/structures.
LTO – Centralized Online Monitoring	**R&D Scope and Objectives:** To achieve continued safe and economical long-term operation of the U.S. domestic and international NPPs, it will be imperative that NPPs maintain high levels of operational performance and efficiency. NPPs 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 plant operations, maintenance, and engineering activities. 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 NPPs can be described as having constrained resources to support 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 plant and associated staff. 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

R&D Area	Advanced II&C Technologies
	signatures captured from industry events; and, ultimately, prognostics-remaining useful life capabilities designed to evaluate critical 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. The EPRI LTO project completed an in-depth industry analysis of monitoring capabilities and identified the needed analytical and programmatic capabilities (gap analysis). These results provide the foundation to define project priorities, identify needed technologies, project the costs and schedule, obtain required funding to execute the research, and manage all the implementation phases through successful implementation. In support of implementation of plant monitoring programs, EPRI has published comprehensive centralized online monitoring implementation guidelines, based on the current state-of-the-art diagnostics and prognostics technology developed by EPRI, with guidance based on early adopter and generations experience from the power industry's operational monitoring centers. Development and execution of the required research must include broad and frequent interfacing with all of EPRI's strategic partners, including member advisors and technical specialists and their commercial support organizations. Other partners include qualified vendors, universities, government laboratories, and utility research programs.
LWRS – Centralized Online Monitoring and Information Integration	**Milestones:** • (2013) Publish a technical report on measures, sensors, algorithms, and methods for monitoring active aging and degradation phenomena for generation step-up transformers as an important passive component, including the diagnostic and prognostic analysis framework to support utility implementation of online monitoring for the component type. • (2014) Publish a technical report on measures, sensors, algorithms, and methods for monitoring active aging and degradation phenomena for a large active component, including the diagnostic and prognostic analysis framework to support utility implementation of online monitoring for the component type. • (2015) Publish a technical report on measures, sensors, algorithms, and methods for monitoring active aging and degradation phenomena for a large passive plant component/structure, involving NDE-related online monitoring technology development and including the diagnostic and prognostic analysis framework to support utility implementation of online monitoring for the component type. • (2015) Publish interim guidelines to implement technologies for centralized online monitoring and information integration. • (2016) Publish a technical report on measures, sensors, algorithms, and methods for monitoring active aging and degradation phenomena for a second large active plant component, including the diagnostic and prognostic analysis framework to support utility implementation of online monitoring for the component type. • (2018) Publish final guidelines to implement technologies for centralized online monitoring and information integration.

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<tr><th>R&D Area</th><th>Advanced II&C Technologies</th></tr>
<tr><td>LTO – Centralized Online Monitoring</td><td>Milestones:
(2012) Reactor building tendon monitoring feasibility study.
(2012) Integrate the diagnostic advisor and remaining-useful-life prognostics applications and databases.
(2012) Complete software development and deliver the final version Asset Fault Signature Database software.
(2012) Complete and publish the Bruce Power Maintenance Optimization Monitoring application prototype results.
(2013) Report on results of cooperative research with industry partners to expand research on (1) diagnostics R&D, 2) industry database research to support Asset Fault Signature Database signature capture, (3) develop design-derived fault signatures to support Asset Fault Signature Database selected components, (4) prognostics remaining-useful-life application and database development.
(2013) Pilot applications of in-situ monitoring of material degradation of passive assets.
(2014) Complete joint research on diagnostics and prognostics (remaining useful life) application to critical plant assets.
(2015) Publish interim guidelines to implement technologies for centralized online monitoring and information integration.
(2017) Complete transient analysis R&D.
(2018) Publish final guidelines to implement technologies for centralized online monitoring and information integration.</td></tr>
<tr><td>LWRS – Industrial and Regulatory Engagement

LTO – Requirements Database for Advanced I&C, Human System Interface, and Information Technology</td><td>R&D Scope and Objectives:
Nuclear asset owner engagement is a necessary and an 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.
R&D Scope and Objectives:
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 the state-of-the-art and good practices in the industry related to I&C enhancement projects.</td></tr>
<tr><td>LWRS – Industrial and Regulatory Engagement</td><td>Milestones:
Included in discussion on “New Instrumentation and Control and Human System Interfaces and Capabilities (including advanced II&C pilot projects).”</td></tr>
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R&D Area	Advanced II&C Technologies
LTO – Requirements Database for Advanced I&C, Human System Interface, and Information Technology	**Milestones**: • (2014, 2016, and 2018)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 user facility results.

R&D Area	RISMC
LWRS – Margins Analysis Techniques and Modeling and Simulation Activities in Support of RISMC	**R&D Scope and Objectives:** This research area develops techniques to conduct margins analysis, including methodologies for carrying out simulation-based studies of safety margins using generic process steps for RISMC applications. The following provides an overview of the steps required to conduct an RISMC analysis to evaluate impacts on plant safety margins. Also, two example applications of margins analysis follow. 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 NPP safety figures of merit to be analyzed and the model parameter space that needs to be sampled. 2. Quantify the decision-maker and analyst's state-of-knowledge (uncertainty) of the key variables (and models) relevant to the issue. 3. Determine issue-specific, risk-based scenarios and event timelines. 4. Represent plant operation probabilistically using the scenarios identified in Step 3. For example, 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 plant and operator behavior cannot be manually created like are in current risk assessments using event/fault trees. In addition to the expected operator behavior (e.g. from plant procedures and operator training), the probabilistic plant representation will account for the possibility of failures. 5. Represent plant physics mechanistically. Plant systems level codes (e.g., RELAP-7) will be used to develop distributions for the loads applied to the subject SSCs and their capacities 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 pressure in an SSC may disable a component, thereby impacting an accident scenario. Thus, in the conduct of RISMC evaluations, Steps 4 and 5 likely will be iterative. 6. Construct and quantify probabilistic load and capacity curves relating to the figures of merit analyzed to characterize the safety margin. 7. Based on the outcomes from the previous steps, determine and evaluate, to the degree possible, options on how to best manage the risk (both those that were specifically evaluated and those that may not have been quantified / characterized). Because there is no way to guarantee that all scenarios, hazards, failures, or physics are addressed, the decision maker should be

R&D Area	RISMC
	aware of limitations in the analysis and adhere to protocols of "good engineering practices" to augment analysis. The intent of this step is to provide the decision-maker with relevant information and a process to evaluate alternatives and arrive at a decision that is both cost effective and technically defensible. 8. Identify and characterize the factors and controls that determine safety margins within the issue being evaluated to determine (and support) the safety case. Determine whether additional work to reduce uncertainty would be worthwhile or if additional (or relaxed) safety control is justified. Modeling and simulation activities: Although incremental advances have been made continuously over the past two decades to improve modeling of plant components and transient/accident phenomena, the system (plant) analysis tools currently used to address industry engineering applications are still based on a decades-old modeling framework and computational methodology that do not take advantage of modern developments in computers and in computational science and engineering. Although the current generation of codes have served as an adequate basis to address traditional safety margin analysis, significant enhancements will be necessary to support the challenges of plant decision-making on extended and enhanced plant operations. RELAP-7 is a systems code that will simulate behavior at the plant level. Simulation of a time history of plant performance requires a thermal-hydraulics simulation that is carried out conditionally, based on the postulated states of the plant components (e.g., which pumps are working, which pumps are not working, the positions of the various valves, and so on). The thermal-hydraulics portion of this will be performed by RELAP-7, with the determination of plant component states done by the simulation controller. The RAVEN controller will determine component states based on the following: • Plant control system actions (e.g., control logic generating a safety injection signal and ensuing component changes of state) • Operator performance, considering procedurally required actions and operator responses to technical specifications • Component reliability coupled to current plant conditions. To determine and manage these states, the controller will need to store plant physical properties, including SSCs. Inside the controller will be a component library, which stores component information such as component type, dimensions, materials, age, and failure models. Aging simulation - Because aging phenomena will be an increasingly important element in both safety management and effective economic decision making as plant lifetimes are extended, development of a simulation tool to evaluate the impact of plant SSC aging will be a necessary enabler of achieving the objectives of the LWRS and LTO Programs. To achieve this objective, an aging management simulation tool called Grizzly will be developed to model component aging and damage evolution in LWRs. Grizzly will couple with RELAP-7 and RAVEN to provide aging analysis in support of the RISMC methodology.

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<tr><th>R&D Area</th><th>RISMC</th></tr>
<tr><td>LTO – Enhanced Safety Analysis Capabilities</td><td>R&D Scope and Objectives:

To achieve successful long-term operations of the current fleet of operating NPPs, it will be imperative that high levels of safety and economic performance are maintained. Thus, operating NPPs will have a continuing need to undergo design and operational changes, as well as manage aging degradation while simultaneously preventing the occurrence of safety-significant events and analytically demonstrating improved nuclear safety. This portion of the EPRI LTO Program addresses two specific issues that are imperative to achieving these objectives.

(1) First, as the current fleet of operational NPPs ages, it is anticipated that new challenges to NPP 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 plants.

(2) Second, as new technologies and capabilities become available, it will be desirable to take advantage of these opportunities to enhance plant technical and economic performance. Examples of such enhancements could include performing extended power uprates or implementation of new technologies or materials.

In each situation, a comprehensive and integrated assessment of the impact on nuclear safety will be required to support effective and efficient decision making.

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 NPP plant safety margins. This LTO 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 by demonstration of effective and efficient application of the RISMC approach to issues important to the long-term operation of NPPs. 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.</td></tr>
<tr><td>LWRS – Margins Analysis Techniques and Modeling and Simulation Activities in Support of RISMC</td><td>Milestones:
• (2012) Deliver software development and quality assurance plans for RELAP-7.
• (2012) Demonstrate the RISMC approach using a test case based on the INL Advanced Test Reactor.
• (2012) Assist EPRI in defining the station blackout conditions for a postulated event in a boiling water reactor with analysis focusing on the impact on safety margins associated with an extended power uprate.
• (2013) Develop a reactor loop capability in RELAP-7 for two-phase flow, including the representation of several simplified major physical components for a boiling water reactor’s primary and safety systems.
• (2013) Demonstrate RELAP-7’s capability to simulate boiling water reactor station blackout with the RAVEN system controller.
• (2013) Deliver the RELAP-7 verification and validation plan.</td></tr>
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	• (2013) Demonstrate RELAP-7's capability to simulate loss-of-coolant accident of both small and large break events. • (2014) Complete software structure, allowing rapid and scalable development. At this time, RELAP-7 can be fully controlled by RAVEN for complete systems analysis. RELAP-7/RAVEN will have the capability to be coupled to other applications (e.g., aging and fuels modules) and perform as a balance-of-plant capability for the multidimensional core simulators under development in other DOE programs. • (2014) Demonstrate current safety margins analysis techniques on selected case studies using the completed software structure. The case studies will be selected in consultation with external stakeholders and will be chosen based on their potential to address an issue important to LWR sustainability or to achieve widespread stakeholder acceptance of the RISMC approach. • (2015) The safety margins analysis techniques will be sufficiently mature to enable industry to conduct margins quantification exercises for their own plants, including using RELAP-7/RAVEN/Grizzly (component aging module)/others (multiscale system analysis of plant performance, such as coupling to localized fuel behavior for a boiling water reactor station blackout and other defined LWR scenarios). • (2015) RELAP-7 will be validated against an accepted set of data. • (2016) Complete full-scope analysis of a power uprate using RELAP-7/ RAVEN (test case will be chosen in consultation with external stakeholders). • (2016) Use safety margins analysis techniques, including use of RELAP-7/ RAVEN/Grizzly (component aging module)/others, to analyze an industry important issue (e.g., assessment of major component degradation in the context of life extension or assessment of the safety benefit of advanced fuel forms). Test case will be chosen in consultation with external stakeholders. • (2020) Ensure development and validation to the degree that by the end of 2020, RELAP-7 and the safety margins analysis techniques developed as part of this collaborative research program are the generally accepted approach for safety analysis to support plant decision-making, covering analysis of design-basis events and events within the technical scope of internal events probabilistic risk assessment.
LTO – Enhanced Safety Analysis Capabilities	**Milestones**: 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 NPP 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 pressurized water reactor. In 2012 and 2013, the EPRI LTO portion of the RISMC research will expand upon this research by performing a comprehensive analysis of a safety significant event that has the potential to impact critical long-term operation decision making.

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	Also, the EPRI LTO Program will undertake to socialize the RISMC methodology and applications among key external stakeholders. To support these objectives, the following activities will be conducted during 2012 and 2013. Project 1: RISMC Pilot Projects • Conduct RISMC analysis of safety margins associated with an extended station blackout event at a large boiling water reactor that desires to implement an extended power uprate. This project will obtain and publish interim results in an EPRI Technical Update Report during 2012, with final results provided in an EPRI Technical Report in 2013. • Assess the potential for the RISMC approach to be used to support utility and regulatory evaluations of the safety impact on NPP events by application of the RISMC approach to one or more previous events that resulted in a regulatory significance determination process analysis. Project 2: Socialize RISMC Approach Among External Stakeholders • An EPRI Technical Advisory Group will be formed of industry experts to review and guide the application of RISMC to issues of importance to NPP safety management and long-term operation. This group also will provide input to EPRI's continuing interaction with RISMC research activities being conducted by INL for the LWRS Program. It is envisioned that this Technical Advisory Group will include both United States and international participation from ERPI's nuclear sector members. • EPRI will initiate engagement with NRC researchers who are involved with similar regulatory research into development and application of the RISMC methodology. It is envisioned that this interaction will be conducted under the existing memorandum of understanding between EPRI and the NRC'S Office of Nuclear Regulatory Research. • EPRI also will participate in external communication of RISMC research at appropriate venues, including conduct of EPRI industry workshops, presentation at applicable conferences, and reporting results of pilot applications in peer-reviewed scientific literature. In addition to application of the RISMC methodology, EPRI will continue to support INL development of the next generation safety analysis software (RELAP-7). Prior to this year, EPRI has provided important contributions to this work via EPRI Reports 1019206 (Framework for Risk Informed Safety Margin Characterization) that 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) that specified desired elements for the next generation safety analysis tool suite (from the perspective of an NPP owner/operator). During 2012 and 2013, EPRI will continue to support INL's development of RELAP-7 by providing input to its development and conducting trial applications as modules become available.

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	Project 3: RISMC Safety Margin Method and Tool Development (LWRS) • Support development of RELAP-7 by closely working with the INL RELAP-7 development team to provide input to the software development and conducting testing on trial safety analysis applications as modules become available. In particular, it is intended that the RELAP-7 software will be applied to support/confirm results from RISMC analysis of the station blackout event for a boiling water reactor, with an extended power uprate being conducted by EPRI during 2012 to 2013.