ISSUE STATEMENT

The ability to monitor and demonstrate the structural integrity of the reactor pressure vessel (RPV) through 80 years of operation is essential to ensure continued operation of the nuclear fleet. For an RPV subjected to years of neutron radiation, adequate demonstration of integrity will become increasingly difficult when applying existing analytical tools and correlations, many of which were established using technology and analytical capabilities dating from the 1970s.

Revisions to analytical tools, material property databases and embrittlement correlations are necessary to accurately predict the service life of the RPV. Technical advances are needed to:

• Ensure that necessary research data is available to identify and assess fluence- and flux-based damage mechanisms at the levels anticipated through 80 years of operation.

• Establish a damage mechanism-based definition of the region of the reactor vessel that must be evaluated for maintenance of structural integrity. Improving the understanding of these damage mechanisms could help inform regulations.

• Ensure that design materials, end-of-license fluence, and flux are considered to optimize design and fabrication practices for advanced light water reactors.

Ongoing research and regulatory interactions are needed to ensure that the appropriate analytical tools and correlations are developed to analyze and model vessel integrity for safe and efficient operation through 80 years.

RESULTS IMPLEMENTATION

The successful management of reactor vessel integrity issues helps ensure that regulations reflect known technical constraints, but also retain operational flexibility. The end product of this R&D will be EPRI reports that support the bases for ASME Code and NRC regulations affecting RPV asset management.

Additionally, within the next several years, EPRI will develop assessment tools for use in developing site-specific strategies for RPV management. Utilities will use these tools to address 80-year operation.

As data gathering and modeling proceed, the needs of the advanced light water reactor fleet will be considered to ensure that long-term plans envelope advanced designs. Moreover, where program results may affect design or fabrication practices, this guidance will be made available to vendors via the EPRI Utility Requirements Document.

PROJECT PLAN

The project plan is comprised of the following elements:

Operational Support Through 80 Years

• PWR utilities will implement EPRI’s coordinated reactor vessel surveillance program beginning in 2011. This program will generate the high-fluence surveillance data and irradiated material samples needed to support embrittlement correlation databases and damage mechanism assessments at fluences representative through 80 years of operation.

• EPRI and the PWROG will conduct R&D to determine whether the Code and regulatory requirements for RPV integrity could put plants at safety and economic risk in coming decades. This will be accomplished through technical support of ASME Code activities and collaboration with NRC Research in several areas:

  RPV surveillance issues, ASME Section XI Appendix G pressure-temperature (P-T) limit issues; RPV low upper shelf energy (USE) and equivalent margins analysis (EMA) issues; development of fracture toughness testing methods; and RPV “extended beltline” issues.

• EPRI and the PWROG will evaluate the operational impacts related to embrittlement correlations and environmental damage projections for materials and components in the “extended beltline.”
• BWR vessel embrittlement issues will be evaluated, including extension of the BWR Integrated Surveillance Program to support 80 years of operation.
• EPRI will conduct R&D to assess the generic impact of the Doel-3 RPV NDE experience (i.e., potential hydrogen flaking in core shell forgings and issues regarding potential nonhomogeneity of forging materials). As required, the technical bases for changes to the ASME Boiler & Pressure Vessel Code will be generated, to ensure that plants have the necessary Code tools and guidance to evaluate a large number of quasi-laminar flaws.

Data Modeling
• EPRI will support NRC development of an updated RPV database, the Radiation Embrittlement Archive Project, which will be a web-based tool available to the public for research on new embrittlement trend curves and surveillance data analysis.
• EPRI and the PWROG will assess appropriate stress intensity, flaw distribution and fluence attenuation models for use in assessing materials/components of the “extended beltline.”
• EPRI will work with its international partners (e.g., Materials Aging Institute) to develop advanced modeling tools and techniques (e.g., multiscale).
• EPRI will develop an RPV asset management tool (software) to enable utility RPV program managers to manage vessel embrittlement.
• EPRI will support efforts to assess and update the Industry-standard embrittlement trend correlation (ASTM E900). This will include examination of high fluence surveillance specimens using advanced microscopy techniques to identify new embrittlement mechanisms (if any) at high fluences.
• EPRI will develop a PWR Supplemental Surveillance Program, consisting of new surveillance capsules containing selected, previously-irradiated and tested, high-value PWR surveillance specimens. This capsules will be installed in high lead factor locations in volunteer PWR host plants and will provide significantly more high fluence surveillance data than a typical plant capsule. The PSSP capsule data will alleviate the need to use test reactor data for future generation ETCs, which will directly affect RPV operations through 80 years.
• EPRI will evaluate potential embrittlement of PWR nozzles by performing testing to characterize the through-thickness material properties of a Zion RPV nozzle. The testing will be conducted as a collaborative effort with other research organizations for the purpose of characterizing fluence attenuation and potential low flux embrittlement in PWR nozzle material.

Regulatory and Communications
• Since NRC is responsible for drafting and issuing regulations dealing with irradiation damage mechanisms, EPRI and the PWROG will regularly interface with the NRC Research and Regulation branches.
• EPRI will continue to integrate PWROG, BWRVIP and MRP activities relative to RPV integrity and regularly communicate their activities with the NRC.

RISKS
There are both economic and operational risks to the industry if this research is not conducted. Overly conservative RPV material damage mechanism models could lead to operational constraints, significant analysis, inspection, and mitigation costs.

Project risks are associated with the potential identification of new and/or more significant material damage than expected. For example, the data from the coordinated and supplemental PWR surveillance capsule programs may confirm additional embrittlement at fluences beyond $3 \times 10^{19}$ n/cm$^2$ for PWRs and flux effects (increased damage at lower flux) for BWRs limiting the ability to reach 80 years without aggressive mitigative management of the vessel. The embrittlement effects on nozzles, coupled with higher stress intensity factors, may make the nozzles controlling for pressure-temperature limits and require additional mitigative actions.
RECORD OF REVISION

This record of revision will provide a high level summary of the major changes in the document and identify the Roadmap Owner.

<table>
<thead>
<tr>
<th>REVISION</th>
<th>DESCRIPTION OF CHANGE</th>
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| 0        | Original Issue: August 2011  
Roadmap Owner: Timothy Hardin |
| 1        | Revision Issued: August 2012  
Roadmap Owner: Timothy Hardin  
Changes: Added the development of a PWR Supplemental Surveillance Program (PSSP) capsule as an element of the Program Plan under “Data Modelling”; added an element to assess and update ASTM E900 ETC. Revised the flowchart to reflect these additions; updated overall schedules; and corrected the program interactions indicated by some connectors. |
| 2        | Revision Issued: August 2013  
Roadmap Owner: Timothy Hardin  
Changes: Minor editorial changes. Clarified the research areas for collaborative research with NRC. Clarified description of the PSSP, which will consist of two capsules, not a single capsule. Added project to perform materials testing on a decommissioned RPV nozzle (Zion). Added Research and Development efforts to address issues raised by the Doel-3 RPV forging issue (potential hydrogen flaking). |