**ISSUE STATEMENT**

Nuclear power plants must consider the catastrophic failure of reactor coolant system piping as a postulated event in developing the plant’s design basis. In the event of reactor coolant piping failure, mitigating systems such as the emergency core cooling system provide reactivity control and heat removal capability. Nuclear reactor design must also address the possibility that catastrophic failure of the high-energy coolant piping can create missiles, pipe whips, and blowdown effects that could affect vessel internals and impact mitigating system piping and equipment. In the United States (U.S.), General Design Criterion (GDC) 4, “Environmental and Dynamic Effects Design Bases,” addresses the potential for interdependence between failure of reactor coolant system piping and the functional requirements of the mitigating systems.

Although installation of physical barriers and restraints is an accepted resolution for pipe whips and other dynamic effects, GDC 4 allows the dynamic effects associated with pipe rupture to be excluded from the design basis if analyses demonstrate that the probability of piping system rupture is extremely low. The approved analysis methodology Described in Standard Review Plan (SRP) 3.6.3 is a deterministic evaluation commonly referred to as “Leak-Before-Break” (LBB). As an analytical simplification, this methodology requires a determination that there are no known active degradation mechanisms affecting the system. Subsequent to the approval of LBB at most U.S. pressurized water reactors (PWRs), primary water stress corrosion cracking (PWSCC) was identified and many systems previously approved for LBB are now known to be susceptible to an active degradation mechanism.

Existing deterministic analytical tools for assessing LBB compliance do not evaluate the effects of active degradation. The xLPR Code is a probabilistic fracture mechanics (PFM) computational tool that provides a best-estimate probability of failure with well characterized uncertainties for reactor coolant piping systems, including the effects of relevant active degradation mechanisms.

**DRIVERS**

The primary driver is to address the analytical limitations of the current deterministic LBB methodology that prevent evaluation of PWSCC. Since NRC and industry agree that appropriate programs are in place to manage the potential challenge to nuclear safety in the near term, nuclear safety is not considered an issue driver.

Potential opportunities for asset management applications beyond addressing PWSCC in LBB evaluations currently include:

- The ability to more accurately quantify RCS piping design margin to inform licensee and regulatory decisions regarding existing and new-plant issues.
- Improved flaw dispositions in operating plants considering a range of potential degradation mechanisms.
- Evaluation of mitigation, inspection, and repair options to determine the associated risk reduction either generically or in plant-specific implementation.

**RESULTS IMPLEMENTATION**

Following release of the completed xLPR Version 2.0 code, U.S. NRC plans to promulgate new regulatory guidance for the application of this analytical tool to address GDC 4 compliance, accommodating the existence of PWSCC as a reasonably characterized and managed active degradation mechanism. MRP will be actively engaged in the development of the technical basis for this regulatory guidance through a coordinated but independent series of NRC and MRP studies of increasing complexity using the xLPR Code.

xLPR V2.0 is a best-estimate code with characterized uncertainties and biases. The extensive set of inputs and user options provide many avenues for evaluating relevant aspects of LBB. However, determining how best to define appropriate analytical cases and interpret those results for real-world problems presents a significant challenge. Therefore, to ensure that the code can be effectively applied to address the PWSCC effect on LBB, the application phase of this project will occur in three steps. It will begin with a controlled set of sensitivity and analytical methodology evaluation studies to develop a knowledge base of experience with the released code and its output.
This practical working knowledge of the xLPR Code will then be applied in step two to select, describe, and investigate an appropriately representative set of real-world welds as a basis for an initial assessment of the failure probabilities associated with LBB where PWSCC may be active. Assessment of these results may identify a need for further refinement of the inputs, the methodology, or treatment of uncertainties to derive technically sound conclusions. Once a coherent evaluation methodology is established through step two, step three will perform a series of generalization studies to better define the boundaries of generic applicability and identify conditions that may require more focused evaluation.

Knowledge gained by U.S. NRC from this series of evaluations will then form the technical basis for development of the planned regulatory guidance approximately 18 – 24 months following release of xLPR V2.0. Likewise, knowledge gained by MRP can be applied during the public comment period to engage the regulator if necessary. Whether the LBB - PWSCC issue will be resolved on a substantially generic basis through this process or will require further action by industry in accordance with newly promulgated guidance cannot be predicted at this time.

In the longer-term, asset management uses for xLPR (independent from the LBB-PWSCC application) may be realized on an as-needed basis through plant-specific issue resolutions and flaw dispositions. The xLPR probabilistic platform potentially can support resolution of other challenging analytical issues involving pipe rupture (e.g., environmental fatigue and GSI-191) through subsequent code releases with expanded capabilities. However, such extended generic applications are not included within the current scope and are not presently funded.

**PROJECT PLAN**

EPRI’s Materials Reliability Program (MRP) is cooperating with NRC Office of Regulatory Research (RES) to develop a probabilistic assessment tool (computer software) that can be used to directly assess piping system rupture probabilities relative to the 10CFR50 App-A GDC-4 “extremely low probability of rupture” acceptance criteria. Points of interface and interaction within this NRC/MRP cooperative project have been formally defined in a Memorandum of Understanding (MOU) Addendum addressing code development that provides for close interaction where appropriate and regulatory independence as necessary.

The production version of the code is expected to be complete by the end of 2015. MRP and NRC are providing technical experts as members of the jointly staffed technical task groups responsible for computational module development, documentation preparation, and module integration into a comprehensive computer software tool. The final product will be in the public domain, although use of this analytical tool will generally be by qualified experts.

The code models the effects of active degradation mechanisms and the inspection and mitigation activities that are being undertaken to manage PWSCC degradation in particular. It will be comprehensive, thoroughly vetted, flexible, and adaptable to accommodate evolving and improving knowledge.

NRC/MRP interaction during the LBB - PWSCC application phase of the project will be addressed within a separate MOU Addendum. This Addendum will define a cooperative process conducted within a public, peer-reviewed forum to ensure appropriate regulatory independence while still benefiting from the synergy of sharing methods and results. During this project phase, technical exchanges will primarily occur within the context of noticed public meetings.

Obtaining the full benefit of the developmental investment in this probabilistic analytical tool requires that it be productively applied to resolve a broader range of challenges. To this end, a scoping study will be proposed to MRP to leverage the knowledge and experience gained in initially applying the code to begin identifying applications for xLPR beyond the LBB problem. The most viable candidate issues will be developed into formal project proposals for funding consideration within MRP or other Issue Programs as appropriate.

**RISKS**

At this point in the project, code development risk is minimal although consequential deficiencies could still be identified as code development and testing is completed and application begins. Risks associated with application of xLPR to address LBB - PWSCC are difficult to assess. There is some expectation that despite the presence of PWSCC, GDC 4 compliance will be demonstrated. However, until appropriate and controlled analyses are conducted, the results cannot be easily predicted.
**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:** Craig Harrington |
| 1        | **Revision Issued:** August 2012  
**Roadmap Owner:** Craig Harrington  
**Changes:**  
- Issue Statement: minor wording changes primarily to clarify original intent regarding conservatism in original LBB analysis methodology.  
- Drivers: editorial changes primarily to refine schedule needs.  
- Results Implementation: significantly reworded to better reflect completed project activities and major future milestones. This version provides better clarity regarding the broad activities presently anticipated for resolving LBB – PWSCC and these are now described in better detail.  
- Project Plan: text has been rearranged and modified to better reflect the structure, activities, and deliverables from the project.  
- Risks: completely revised to better reflect risk to industry if the project is not successful or is not completed in a timely manner.  
- Flowchart: revised to reflect refined project schedule, details, and milestones. |
| 2        | **Revision Issued:** August 2015  
**Roadmap Owner:** Craig Harrington  
**Changes:** Extensive revision to incorporate plans to apply xLPR to address the LBB - PWSCC issue |