xLPR External Review Board

Report on the First Review Meeting
Held on February 20, 2013
Washington, D.C.

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Prepared for:

Probabilistic Integrity Safety Assessment (PISA) Program

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xLPR External Review Board

Report on Review Meeting

Held at EPRI Offices
2000 L Street, NW, Suite 805, Washington DC
8:00 AM – 5:30 PM, February 20, 2013
8:00 AM – 12:00 PM, February 21, 2013

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Preamble

The External Review Board (ERB) met with managers and participants of the xLPR simulation project team for a full day of formal presentations, each followed by questions and extensive discussion. The Agenda (Attachment 1) lists the presentations and speakers. Presentations by xLPR project personnel at this meeting provided a retrospective on the goals, implementation details, and assessment of V1.0 in addition to plans in-progress for V2.0 to expand and refine the simulation capabilities.

This review occurred following completion of the pilot project to create Version V1.0 of the xLPR code, and approximately one year before projected completion of xLPR Version V2.0. Prior to this initial meeting of the ERB, members reviewed documentation on all aspects of the project leading to completion of V1.0. Attachment 2 summarizes questions submitted by the ERB prior to this review meeting. These items were addressed in large part during the formal presentations. Those that were not addressed make up in part the comments identified in this report. All items not yet answered will be followed up in future ERB meetings with the project team. Attachment 3 provides additional comments provided by Dr. Modarres's after the meeting. The ERB's charter is provided in Attachment 4.

SUMMARY AND DISCUSSION

The review board offers conclusions and identifies items for consideration and resolution. These conclusions and items are presented according to three generalized categories summarizing detailed objectives provided in the charter for the Review Board.

1. Is the xLPR project positioned to meet its stated objectives?

a. The review board agrees the project has been structured and managed in a way that will allow the objectives to be met. Specifically, the board notes that the personnel's technical qualifications and management capabilities are excellent. The board acknowledges the professional enthusiasm exhibited by the project team throughout the course of the review meeting.

b. The use of Sandia as the organization for software identification and development, overall software framework, and module integration within the framework was an appropriate choice. With the depth and breadth of expertise of participating personnel at Sandia, the board believes the project has a high probability of success.

c. The use of software code modules within an overall integrating framework for the project is excellent.

d. Since the project's acceptance criteria for the calculated values generated by the software code is assumed to be extremely low, *e.g.*, 10^{-7} rupture probability, other low probability phenomena not modeled can be important and should not be arbitrarily discounted. This issue should be thoroughly investigated by the project team.

e. The project has produced a number of conference papers. The Board encourages that this action continue when appropriate throughout the life of the project.

2. Is the xLPR project managed in a manner that meets its stated objectives?

a. The review board acknowledges that the project has met its milestones in a timely manner and is effectively managed.

b. The shared project leadership and decision making between the NRC (RES) and industry appears to have been an effective approach.

c. The review board agrees with the project leadership's initiative to have periodic status meetings with the ACRS. The meetings to date have been successful and should continue.

d. The functional groups defined within the project to accomplish the focused work and meet project's objectives are very effective.

e. The project's adaptation of modern, web-based tools to manage this highly complex project has been effective. Extensive documentation on the project has been produced to date, some of which is repetitive. In hindsight, a well-defined knowledge management utility could have more efficiently captured the information and knowledge generated by this project as it developed over time. Such information would have been useful to project personnel and to future users of the software if a more structured, but interactive web-based approach, such as a Wiki or even SharePoint, was used from the beginning of the project. Consideration should be given to instituting a robust knowledge management system during implementation of Version 2. In this way the project may be able to recover much of the technical decision making process that supported Version 1.

f. It does not appear there has been significant involvement in project technical decision-making by NRC (NRR) personnel. It may make sense for industry and NRC to formally apply this tool using a lead-plant approach in obtaining a SER. An example of this approach used previously is the pilot plant initiative for Pressurized Thermal shock (PTS).

g. The project provides excellent documentation for handling technical disagreements among the project participants via an "Alternate Professional Resolution Guide," that is similar in content to the NRC's Differing Professional Opinion (DPO) Guidance. We did not see similar documentation for a process to resolve managerial differences or conflicts. For example, differences among the project senior managers regarding project direction or allocation of resources. Such a process could be critically important as the project evolves.

3. <u>Are the technical aspects of the xLPR project appropriate and adequate to meet its stated objectives?</u>

a. The review board acknowledges this project must strike a balance between producing an engineering tool in a practical time period and an effort associated with a research and development project. The project team has successfully met this challenge.

b. The next challenge for the project's leadership is to successfully transition from Version 1 accomplishments, where some simplified approaches were used, to Version 2 incorporating more complete and sophisticated models and algorithms.

c. The following are some examples of the issue presented in item b for consideration by the project team.

    i. incorporating any evidence of a plant's prior operational experience including inspections, no pipe rupture or leakage to formally update the probability of such events by xLPR,

    ii. simulations may need to incorporate prior plant inspections that did not exhibit inspection PODs developed using today's more accurate inspection technology and inspection protocols,

    iii. incorporation of an uncertainty about a calculated leak rate may be necessary since considerable uncertainty exists on the resulting leak rate associated with the morphology of through-wall cracks,

iv. the Version 1 crack initiation model should be refined for Version 2 since crack initiation is a significant risk driver, and

v. it may be wise to reduce the effort on weld residual stress modeling (*e.g*., welding process simulation, etc.) since mitigation through surface stress modification may be the operative approach to mitigate crack initiation.

d. Version 2 of the code should identify as early as possible the major risk drivers of pipe rupture and leakage. This information can be used by the leadership team to identify where best to focus resources for the remaining life of the project.

e. Consideration should be given to forming an ad hoc project group to review possible synergistic effects and their importance to the code results. It does not appear that the project has overlooked a potentially, significant phenomenon in its modeling. But the project may have missed possible synergistic effects between a given phenomenon and that resulting from pipe loads. For example, stress corrosion cracking transition to corrosion fatigue, where fatigue is driven by pipe vibration or significant operational transients, has not been modeled.

f. Justification should be developed supporting the use of deterministic models and regarding them as truth, *e.g*., net section collapse equations. Using such models and applying uncertainty distributions to the model parameters *does not* capture the potential error involved in the functional model itself. That is, in most cases model uncertainty as opposed to parameter uncertainty is not properly addressed. The question that must be asked is, "how does the given mathematical model truly represent reality of the phenomena being addressed?"

g. There was not sufficient justification and explanation provided establishing the division between assignment of aleatory and epistemic uncertainties. This should be done for each uncertain variable or parameter based on a consistent guideline. Also, justification would be needed for treating certain critical parameters as constants rather than uncertainties, such as the power law exponent of crack growth models.

h. The review board encourages strongly the further development and refinement of the core models as appropriate — with associated uncertainties applied. The veracity of the modeling components in the software will define the eventual success of the project.

i. It is stated in paragraph 2, page 3-1 of NRC/EPRI report: Model and Inputs Developed for Use in the xLPR Pilot Study that, "………..crack initiation rate to be calculated outside of the time loop, such that at each run through the time loop, the distribution of initiated flaws is sampled as opposed to a probability of initiation being calculated for each time loop." Also, the 3rd paragraph states, "Loads, weld residual stresses, crack initiation rates, inspection, and mitigation/remediation are calculated outside of the time loop…. Calculation of loads and initiated flaws outside of the time loop may change in moving forward to future versions…" Justification must be provided for the allocation of items within or outside the time loop.

4. High priority Items for Early Evaluation by the Project

The review board was requested by the project team to identify several high priority items that should be evaluated early during the development of xLPR Version 2. Also listed are items for later consideration. The suggested references provide additional details (all available in electronic form from B. Brickstad). Some of these items have been identified in prior sections.

a. As presented at the meeting, xLPR Version 2 does not account for plant experience prior to the first time of crack initiation in the xLPR simulation. For example, one should factor in plant experience for which no rupture or leakage has occurred. The current age of the plant can be factored into the analysis by incorporating the current operating time in which no rupture or leakage has taken place. This information can be used to adjust, for example, the crack initiation model. Suggested references [1] or [2]. In generalizing this concept, prior experience involves a range of phenomena including crack initiation rates, crack growth, loading, crack coalescence, and plant practices such as inspection, mitigation, etc. Probabilistic methods, such as Bayesian updating, provide the formal framework to accomplish the required modification. Neglecting a plant's prior experience can be conservative or non-conservative.

b. The treatment of secondary stresses in evaluating K-solutions, stability and crack opening displacement (COD) is not documented and justified in the project, especially for through-wall crack(s) (TWC). The adoption of a user input-scaling factor between 0 and 1 demonstrates an unclear treatment of secondary stresses. The models ignore potential redistribution of secondary stresses, such as weld residual stress, for large circumferential TWCs. This can be conservative or non-conservative effect. Suggested reference [3].

c. The combination of SCC and vibration fatigue can create a situation that will increase considerably the rupture probability if a surface crack caused by stress corrosion cracking grows through the pipe wall and remains undiscovered by leak-rate detection. To investigate this, it is suggested a model be developed to evaluate vibration fatigue, due to high frequency global bending stresses, on a TWC for which larger ΔK-values can be expected, especially for complex crack shapes. Even if this condition is shown not to be an issue for large diameter pipes (due to low vibration stresses), the project should consider this effect when expanding the scope to include smaller diameter piping systems. Neglecting vibration fatigue in combination with SCC can be non-conservative. Suggested references [2] or [4].

d. It is not clear how the code treats the leak rate caused by uncertainty in crack morphology. The review board interprets the current approach to leak rate as deterministic. That is, if the evaluated, average leak rate calculated by the code exceeds the leak-detection limit, then the crack is assumed detected and the sampled crack does not contribute to the rupture probability. An alternative evaluation would assume the leak rate as a random parameter with a certain distribution function. Then, there is always a non-zero probability that a TWC will be undiscovered by leak rate detection, even if the average leak rate exceeds the leak-detection limit. Treating the leak rate as deterministic can be non-conservative. Suggested references [1], [2] and [8].

e. When an ID initiated, semi-elliptical crack transitions to a TWC, its growth produces a complex shape with an outer pipe crack length often significantly smaller than the inner pipe crack length. The complex crack shapes affect K-values, crack growth rates, crack stability, critical crack size, COD and leak rates. Assuming a TWC with a straight crack front parallel to the pipe radius can be non-conservative for the rupture probability calculation, since the leak rate is overestimated when the surface crack turns into a TWC. The review board recommends further development of models for complex crack shapes that reflect real crack growth behavior for SCC and fatigue in piping systems. Suggested reference [4].

f. The interpretation of the review board is that through wall, off-center cracks are not evaluated. Consequently, a TWC is assumed to be located at the position of maximum global bending stress. An off-center crack will have different values of K, COD and leak rate compared to a center-crack position. The justification of neglecting off-center cracks should be documented by comparison with existing off-center crack solutions, since the assumption may be non-conservative. See reference [5].

g. Probability of Detection (POD) is important in modeling the influence of inspections. The review board believes there are reasons to use conservative assumptions in this modeling. When POD-data used in this project was generated, the NDE technician being tested is aware he/she is involved in an examination, and the inspected surface condition is generally clean and without exhibiting radiation that can hinder effective examination. Additionally, the assumption of independent inspections is non-conservative; if the project continues to assume independent inspections more justification on this topic is needed. Autocorrelation between inspection results should be modeled. Also, justification is needed to assume POD = 1 for a TWC since this situation can be non-conservative.

5. Secondary Priority Items for Later Evaluation by the Project

a. The project assumes that the pipe ends are free to rotate. In reality there are always some pipe end constraints, which may enable pipe cross sections to withstand very large TWCs before rupture occurs. Assuming free rotation of the pipe cross section in pipe systems is conservative; the amount of conservatism should be documented. Suggested references [5] and [7].

b. The code ignores the potential impact of weld residual stresses (WRS) for circumferential TWCs. The basis is that for an axisymmetric condition, axial WRS are in equilibrium over the pipe thickness which implies that the mean value of the axial WRS is zero over the pipe thickness. This may be a justified assumption, but the reasons for this simplified treatment of WRS, which can affect K, COD and leak rate, should be documented by comparison with published results. Ignoring WRS for circumferential TWCs can be conservative or non-conservative. Suggested reference [3].

c. Linear superposition is used for different load combinations — even if this assumption creates a stress above yield. This is generally a conservative assumption. It is not clear to the review board how the project will treat load combinations leading to excessive elastic stresses in future code versions. If a nonlinear stress correction factor is applied, this should be justified by comparing with existing solutions. There exist certain approximate solutions for high secondary stresses that elastically are above yield, *e.g*. the so-called Budden's method. Suggested reference [6].

d. Uncertainties assigned to input variables and parameters in most of the models were treated as independent. This could result in non-conservative estimates. Based on scatter and measurement errors in the original data from which the models were developed and/or based on expert judgment, any statistical dependencies between the parameters and variables should be identified. Monte Carlo sampling used in GoldSim should consider these dependencies.

6. References

[1] Brickstad, B., A Short Description of the NURBIT Piping Reliability Program for Stress Corrosion Cracking Analyses, NURBIM Report D4/Appendix D1, Det Norske Veritas, Stockholm, May 2004.

[2] Brickstad, B., Review and Benchmarking of SRMs and Associated Software, NURBIM Report D4/Appendix A1 SCC Benchmark Study, Det Norske Veritas, Stockholm, May 2004.

[3] Zang W. et al, Effect of Weld Residual Stresses on Crack Opening Displacement and Crack-Tip Parameters, Report 2009:17, Swedish Radiation Safety Authority, Stockholm, June 2009.

[4] Brickstad, B. et al, Project NURBIM (Nuclear RI-ISI Methodology for Passive Components), Benchmarking of Structural Reliability Models and Associated Software, Proceedings of ASME Pressure Vessels and Piping Conference, San Diego, 2004.

[5] Rahman, S., Ghadiali, N., Wilkowski, G.M., Moberg, F. and Brickstad, B., Crack-opening area analyses for circumferential through-wall cracks in pipes – Part III: off-center cracks, restraint of bending, thickness transition and weld residual stresses, *Int. J. Pres. Ves. & Piping* 75, pp. 397-415, (1998).

[6] Sattari-Far, I., Constraint Effects on Behavior of Surface Cracks in Cladded Reactor Pressure Vessels Subjected to PTS Transients, *Int. J. Pres. Ves. & Piping* 67, pp. 185-197, (1996).

[7] Wilkowski, G. et al., Robust Analyses for Atucha II Nuclear Plant, Proceedings of ASME Pressure Vessels and Piping Conference, Baltimore, 2011.

[8] Ghadiali, N. and Wilkowski, G., Effect of Crack Morphology on Leak Rates (Coefficient of Variation), Report to SAQ Kontroll AB, Battelle, Columbus, USA, November 22, 1996.

Attachment 1

Agenda of xLPR Review Board Meeting

xLPR External Review Board

Initial Meeting – February 20 – 21
Washington, DC

1. Introductions– **Bass/Kirk 8:00-8:15**
    a. Charter review
    b. Focus of this meeting (focus on models and inputs – computational next meeting)
2. xLPR Background – **Rudland 8:15-8:30**
    a. Why xLPR?
    b. Broad goals
    c. Reason for cooperative approach
3. Pilot Study – **Rudland 8:30-9:15am**
    a. Purpose
    b. Scope
    c. Organization
    d. Code structure overview
    e. Results summary
    f. Recommendations
4. xLPR Version 2.0 – Management and Structure – **Harrington 9:15-9:45**
    a. Scope
    b. Organization & Funding
    c. Developmental Phase Software Quality Assurance / Configuration Management-Harrington
        i. Not fully Appendix B, basic NQA-1 compliance statement
        ii. Documentation structure
        iii. Web-based repository
        iv. Audits
    d. Project Management / Scheduling
        i. Schedule Development and Use -– **Make copy for everyone and attach to agenda**
5. Break – **9:45-10:00**
6. xLPR Version 2.0 – Technical Details
    a. Framework Overview – **Rudland 10:00-10:30**
        i. GoldSim
        ii. Flowchart – **Make copy for everyone and attach to agenda**
        iii. Pre-processor
        iv. Framework / Module Boundary Definition
        v. Sampling – advanced computational methods
    b. Inputs – **Stevens 10:30-11:00am**
        i. Selection of LBB locations for V2
        ii. Identification of Input Parameters
            1. Inputs Spreadsheet
            2. Attributes and Valid Ranges

        i. Material property Database development
        ii. Collection / Creation of Input Values for Code Development
            1. Plant & Vendor Data
            2. Consensus Data
    b. Models **– Erickson/Iyengar – 11:00-12:00pm (20 min each)**
        i. Stress Requirements
            1. Normal operation
            2. Operating Transients
            3. Seismic events
            4. Weld Residual Stress
            5. Tiffany
        ii. Uncertainty
            1. Characterization
            2. Worksheet
        iii. Crack Initiation
            1. General: Segmentation, orientation, crack size, placement, etc.
            2. PWSCC
                a. 3 model discussion
                b. Model calibration
                c. Expert panel
            3. Fatigue
2. Lunch **12:00-1:00**
3. xLPR Version 2.0 – Technical Details - Continued
    a. Models **– Erickson/Iyengar – 1:00-3:00pm (20 min each)**
        i. K-solutions
            1. Universal weight function
            2. ASME Section XI influence functions
        ii. Crack Growth
            1. Materials considered
            2. Development of Alloy 52/152 interim CGR
        iii. Crack Coalescence
            1. Circ crack
            2. Axial / Circ independence
        iv. Crack Transition – Surface to Thru Wall
            1. K and COD corrections
        v. COD
            1. Tension and bending solutions
        vi. Stability
            1. NSC and EPFM
            2. TWC and SC
4. Break – **3:00-3:15pm**
5. xLPR Version 2.0 – Technical Details - Continued
    a. Models **– Erickson/Iyengar – 3:15-4:15pm (20 min each)**
        i. Leak rate

1. Leak rate table development
        2. SQUIRT rewrite
    ii. ISI
        1. POD development
        2. Sizing model
    iii. Mitigation
        1. Methods Included
        2. Affected parameters for each

2. xLPR Acceptance Criteria Development – **Rudland – 4:15-4:30**
    i. General Status

3. Wrap-up and discussion – **Bass/Kirk 4:30-5:00pm**

Attachment 2

Questions Submitted by Review Board Prior to Meeting

xLPR Project – External Review Board – Comments and Questions

E. Hackett, 2/11/13

Overall

Outstanding job of integrating diverse technical elements and expertise to advance the state of knowledge on a very difficult subject and to develop practical tools to assess specific conditions in a comprehensive manner. The previous successful experience on the PTS project and the development of the FAVOR code, serves as an excellent model for this effort.

Technical

(1) The ACRS previously noted the difficulties inherent in development and refinement of the crack initiation module, even going so far as to suggest it could ultimately be "intractable." Given this, and the recognition that certain aspects of this modeling are aleatory, wouldn't it be prudent to not have the parameters all characterized as epistemic?
(2) In a similar manner, detailed characterization of weld residual stress distributions that may exist in specific operating plant configurations are extremely difficult to model. Given this difficulty, should NRC consider a regulatory position that would provide for stress mitigation (approaches for imparting surface compressive residual stresses) for primary system DSM welds susceptible to PWSCC?
(3) Suggest using ACRS more frequently (2X/year?) to obtain advisory feedback as was done throughout the PTS project.

Organizational

(1) I agree that propagation of the PIB model into Version 2 does not make sense – too large with no clear leader. I would suggest that any such Board in the future is smaller (4-6 members) and has an advisory function. Day-to-day decision making should be left to the line managers in the respective organizations and closely coordinated among them.
(2) I did not see any mechanism for resolution of significant conflicts over project direction? What are plans to address this for the future?
(3) Knowledge management is an important part of this effort. Responsibilities in this area should be explicitly spelled out in the project description with consideration given to careful documentation of the effort and to succession planning to the degree possible.

xLPR Project Pre-External Review Board Meeting Comments/Questions

M. Modarres (February 14, 2013)

General

xLPR modular probabilistic fracture mechanics project is timely, well organized and is being implement by an impressive team of experts. The results and progress so far are very encouraging with a high chance of attaining its ultimate goals.

The reviews done by ACRS and comments by my colleagues in the review board address most of the key issues and I hope these comments would further benefit xLPR v.2 development efforts.

I read the xLPR documents with a special focus on the probabilistic treatments of the mechanistic and ISI models, as well as the algorithmic methods used and implemented in the GoldSim software.

Treatment of uncertainties, mainly separation and propagation of aleatoric and epistemic uncertainties are generally appropriate and computationally correct. A few detail areas that worth further discussing in our upcoming meeting follows.

Specific

1. **Consideration of model uncertainties and model errors.**
    a. Uncertainties in the experimental data (raw data) based on which the mechanistic models (e.g., crack initiation, crack growth, residual stresses, coalescence) were developed are missing.
    b. Uncertainties represented by probability density functions for the parameters of the mechanistic models appear to be treated as independent. Most of the models are empirical and fitted into the experimental data. Statistical correlation between these parameters should be quantified and accounted for in the simulation.
    c. Model error was not formally accounted for (i.e., any difference between "reality" and model estimation). It appears that experimental data were taken as representation of "reality". This may be true, but needs justification.
    d. When multiple models exist, formal "model averaging" or "model weighting" may be useful.
    e. Discussions on "completeness" uncertainty would be valuable. Why these are all the mechanisms that matter? What would be the contribution of other mechanisms not considered (creep, corrosion-fatigue, other types of SCC, etc.), particularly in light of uncertainties of the mechanisms considered?

2. **Consideration of model uncertainties associated with ISI.** This part can contribute significantly to the likelihood of any leak.

a. The POD model used is the so-called logistic model. It is not clear why this model was selected? Why not log-logistic or lognormal model? Depending on the ISI data type used (hit/miss or signal response) the choice of POD model would be different. The main difference between these is the way the lower tail is treated. The lower tail represents probability of detecting small flaws, and is the region that poses tremendous uncertainties and is often used in NDE. In analysis of small likelihood events, the devil is in the tails!
b. Parameters of the POD model are also correlated. xLPR v.1 treated these as independent. Also, POD models have detection threshold that should be accounted for.
c. Similar to mechanistic models, POD models involve model errors that should be treated probabilistically, for example by a normal distribution with mean of zero and a positive standard deviation.
d. I understand the probability of correct sizing and sizing error will be incorporated in xLPR v.2. Both systematic (bias) and random errors should be included in the sizing models. Some discussions of this in the upcoming review meeting would be useful.
e. Is there any probability of false call (POFC) or probability of miss call (POMC) involved?

2. **Computational uncertainties could be significant.**
    a. Standard errors in the Monte Carlo algorithm used by GoldSim should be accounted for (or ignored in light of other uncertainties). Some formal discussion will be useful.
    b. The xLPR v.1 algorithm estimates the likelihood at snapshots of time without regards to the autocorrelation between sequential ISI information. This can introduce major under or overestimation of the likelihood values. More formal methods such as the Sequential Bayes may be needed to address this critical issue.
    c. Another factor to consider in addition to the sequential ISI data would be formal accounting of the mitigation actions. The degree to which such mitigations renew the pipes should be factored into the integration of uncertainties.
    d. In the validation of the overall model the results of the validation (in form of difference between xLPR estimated and observed) can also be factored into assessment of uncertainties in an ad hoc manner.

xLPR Project – External Review Board – Comments and Questions

R. Dodds 2/13/13

Overall

The breadth, depth and quality of documentation for the xLPR project are truly outstanding. I have enjoyed reading the documents provided on the web site and learning details about aspects of the project.

The management of software design, implementation and verification across a wide range of technical issues and contributing teams is impressive.

I look forward to in-depth discussions at the panel meeting next week.

Technical

The documents provided to us place great emphasis on the *framework* aspects of the system (design, implementation strategies, configuration management, QA, etc.) Yet little information was provided about the deterministic models that define the core technologies on which the eventual validity of the framework rests for V1.0 and V2.0.

The Southwest report offers: (1) limited insights into technical details of the deterministic models and (2) a list of potential shortcomings. The Southwest report describes a rather in-depth verification of the deterministic models (the formulas are implemented correctly in working software) but does not attempt to validate the models.

My reading of the various reports suggests that the deterministic models are taken to provide results accepted as the truth (for lack of a better term) by the framework executing the probabilistic time loop. These models have varying degrees of reliability in predicting a truthful outcome for a specified set of input parameters. There exists a level of knowledge uncertainty in results produced by the deterministic models and used as the truth in the framework.

Example: the deterministic model for crack stability based on a J-R curve description of the phenomenon. The physical processes of elastic-plastic crack instability in a real pipe geometry are extraordinarily complex. The mathematical model has quite limited validation against experimental results (quality of experimental results?). In contrast, the deterministic model for stress-intensity factors within a limited range of crack sizes, locations, loading in a pipe should have substantially less knowledge uncertainty (the crack sizes, location, etc. are random variables appropriately handled by sampling of the framework).

Maybe I have simply missed the treatment of this issue in the documents – and look forward to a clarification.

End Users

I do not recall having read a description of the typical end-user of the xLPR system. What education level, engineering discipline(s), engineering analysis/design experience, software use experience, … is expected? What would a realistic scenario be like for an end-user session with the software?

Software Verification

For the software development team. As time moves forward, verification of the evolving source code base will be come ever more challenging. The source code for xLPR will itself change but so will all the supporting software, for example, Fortran compilers/loaders, numerical libraries, releases/patches of the Windows operating system, etc. with the GoldSim code topping the list.

Has an automated system been implemented/planned to execute such verification processes to assure continued production of known good solutions (the term we use in our software)? This process must be performed for each of the codes in the suite of deterministic models and for the integrated system framework as implemented in GoldSim. With the continuous release of new compiler versions, libraries, GoldSim, ... the verification process can become unwieldy rather soon.

Software Ownership

Application software developed using singe-vendor, proprietary toolsets (GoldSim) carries the distinct possibility that the toolsets may be abandoned, no longer supported, become too expensive or simply withdrawn from the marketplace at some point in the future. The escrow concept for GoldSim as described in the management plans would seem to be potential resolution. Has this process been executed? Are there known exemplars where this approach has been implemented and the escrowed code retrieved to sustain continued use of major application software?

What is the ownership status of the codes for the deterministic models? Are they open source (*e.g*. a Google code project with attendant licensing requirements), proprietary, etc ?

xLPR Project – External Review Board – Comments and Questions

B. Brickstad 1/18/13

Overall

I have been reading through the xLPR External Review Panel documents. I am impressed with the high ambition and the number of very experienced people involved in this project! Below you will find a number of questions, which I have noted when reading the documents. Some questions are more of a clarification nature, others questions are more fundamental. The purpose of these questions is to give time for people involved in the xLPR project to respond before or at the February meeting in Washington, DC. Below I sometimes refer to the NURBIM project. For those of you who are not familiar with this European sponsored project, I enclose an ASME PVP-paper on this project.

Questions

1. How does xLPR treat individual welds? I assume in the future development, it will be desirable to evaluate the collective rupture probability for an entire pipe system which may contain many welds. Will the properties of geometry, materials and pipe stresses be taken into account for individual welds?

2. How does xLPR treat different ages of plants? For a particular weld, let's denote the current time with t, the time at which a crack initiates with t_i and the time (after initiation) to rupture with t_r. Obviously, the probability of rupture will be different for a completely new pipe system (t = 0) compared to if t =30 years. In the latter case, you know there has been no rupture (so far) which means that the initiation time must be larger than $t - t_r$. (If $t_i < (t-t_r)$ then such cracks would have caused rupture before the current time t.) This information, that there has been no rupture up to the current time t, can be used to adjust the model assumptions about initiation. Also, the end of life of the plant should be a factor. If t = 30 years and if you <u>know</u> that the plant will be permanently shut down at time T, then the rupture probability will be different if T = 31 years compared to T = 60 years. The maximum initiation time for a crack will be $T - t_r$ if rupture is to occur before the end of service life T.

3. How does xLPR treat off-center cracks? Besides environmental conditions and material properties, stress corrosion cracking are initiated mainly due to WRS. This means that a circumferential crack may occur anywhere around the pipe circumference. This implies that the different bending components will have different impacts depending on the crack size and position. For through-wall cracks, this affects the values of K and COA and thereby the crack growth and leak rates.

4. How will xLPR handle the issue of complex crack shapes? It is not clear to me which strategy will be used in the later versions of xLPR. It is well-known that the shape of the crack as the surface crack transitions to a TWC and the subsequent growth of an undetected TWC will produce a

complex shape with an outer pipe crack length often significantly smaller than the inner pipe crack length. The issue of complex crack shape affects K-values, crack growth, crack stability, critical crack size, COA and leak rates. Assuming a TWC with a crack shape parallel to the pipe radius can be non-conservative for the rupture probability since the leak rate is overestimated when the surface crack turns into a TWC. On the other hand a complex crack shape will cause more stable cracks after the SC has become a TWC which tends to decrease the rupture probability.

5. How will xLPR consider WRS for TWCs? As I understand, in xLPR 1.0 for TWC only tension, linear through-thickness bending and global bending stresses are considered. In general, more complex WRS have features which cannot be represented by these stress components. This may influence K-values, crack growth, COA and leak rates. An even more complex situation may occur if a general WRS for complex crack shapes should be handled by future xLPR versions.

6. How is xLPR handling possible stress redistribution for large TWCs? For small cracks, the usual assumption of constant secondary stresses as the crack grows is generally a good approximation. If the TWC is large compared to the pipe section area, the displacement controlled stresses may redistribute. This will be the case both for thermal stresses as well as for WRS.

7. A general question on COA: how is plastic effects on COA taken into account? There exist solutions for simple crack geometries but what about off-center cracks and complex crack shapes?

8. How will xLPR treat transient loads? The question I have is that there can be a situation with e.g. an unplanned shutdown of the plant which creates additional loads on the pipe systems. Such loads can occur anytime during the plant life cycle. These loads do not contribute to SCC crack growth but may cause rupture of an undetected large crack.

9. How is xLPR considering vibration fatigue? Vibration fatigue as the only damage mechanism is normally not a problem since the stress amplitudes are too small to grow a manufacturing defect. The concern is when SCC and high cycle vibration fatigue occur at the same time. SCC may grow the crack to a certain point after which the threshold for vibration fatigue is passed, often predicted when the surface crack transitions to a TWC. Then rapid crack growth may follow until rupture and there may not be enough time to detect the crack by leak detection. Analyses made in Sweden within the NURBIM project indicate that the stress intensity factor for a global bending stress due to vibration for a TWC created by SCC, can be high enough to trigger vibration fatigue, especially for a complex crack shape with the outer pipe crack length smaller than the inner pipe crack length. The NURBIM project indicated that the combination of SCC, high cycle vibration fatigue and complex crack shapes did create quite high rupture probabilities, see Fig. 6 in the NURBIM PVP-paper.

10. My interpretation is that the leak flow rate is treated as a deterministic value in xLPR. What is the justification for this bearing in mind that for example the crack morphology parameters are random in nature?

11. In the pilot study, mainly the rupture probability versus time is evaluated and presented. As I understand xLPR also evaluates different leak probabilities corresponding to different leak rates. Are there plans in the future development to combine the different leak- and rupture probabilities

from xLPR with system barriers (or conditional core damage frequencies CCDF) from the plant specific PRA which enables the evaluation of risk?

12. What are the plans for consider axial cracks in xLPR version 2.0? It may reduce the rupture probability for circumferential crack if a leaking axial crack in a girth weld is detected and removed. But in a general risk evaluation, the risk may increase, depending on the different CCDF, because the leak probability is increased.

13. For the modeling of inspections, the information of POD is very important. In the xLPR documentation for the ERP, there is no detailed information given about the assumptions made of the POD curves used. What is the assumption of POD for small surface cracks?

Is it assumed that POD(1) = 1, i.e. are all TWCs assumed to be detected during an UT inspection? In my opinion, it can be questionable to assume POD = 1 for tight through wall cracks. Also other inspection methods than UT should perhaps be considered. Even a dye penetrant technique (PT) performed on the outside of a pipe weld can reduce the rupture probability. If nothing is detected with PT, then you know that there is no TWC during the time of inspection. This is expected to give some decrease of the rupture probability if the PT inspection is performed near the end of operation of the plant. In this case only surface cracks that have a shorter time between leak and rupture than the remaining plant life from the PT inspection will contribute to the rupture probability.

Another question about POD is if it is possible to have different PODs at different inspection times with xLPR, reflecting that over time POD is generally improved. My general opinion about POD-curves is that there are reasons to use somewhat conservative assumptions bearing in mind that when the POD-data was generated, the operator is prepared for that cracks exist, he is aware that this is an examination and the environment is generally clean without radiation.

14. My final question is about V&V. I am now referring to the experiences from the NURBIM project. In the NURBIM PVP-paper, a set of requirements and recommendations are given for which structural reliability models (SRM) and associated software should fulfill. In this list, it seems to me that many items are covered by xLPR. However, I have not seen a complete set of sensitivity analyses performed with xLPR. In the NURBIM project, for SCC we systematically varied each parameter from very small to very large values (keeping all other parameters constant at their baseline values) and studied if the results were consistent with expectations and justified with respect to the SRM theory. This proved to be very useful and in fact several code errors were discovered during this sensitivity analyses.

15. In the Models and Inputs report (p. 3-14) it is mentioned that loads are applied using linear superposition and this may cause stresses larger than the yield stress. This will lead to conservative estimations of K or the J-integral. Rigorously, one should apply all loads assuming an elastic-plastic material in a FEM-model to evaluate the J-integral but this can be time-consuming. It would be interesting to learn what is planned for xLPR version 2.0 about this issue. At least for large thermal gradient stresses, there are approximate methods to account for large secondary stresses which exceed the yield stress.

16. In the Models and Inputs report (p. 3-121) it is mentioned that at this time independent inspections is assumed which means that the rupture probability is multiplied by (1-POD) during each inspection. The data for POD suggests quite high POD-values, of the order 0.95, which means that the rupture probability soon will be reduced to very small values. It seems to me that this can give non-conservative results. What future work is planned within xLPR to obtain more information on this issue?

17. It has been demonstrated that in some cases pipe cross sections can withstand very large TWCs before rupture occurs. This has to do with pipe end constraints which means that a flawed pipe section cannot rotate freely, see for example Wilkowski et al in PVP2011 "Robust LBB Analyses for Atucha II Nuclear Plant". A free rotating pipe cross section is often assumed in deterministic or probabilistic fracture assessments. Are there any plans for xLPR version 2.0 to explore this issue?

Also, I have not seen in the xLPR documentation a comparison with field data. Of course it is difficult to compare for rupture probabilities since hardly any pipe rupture (due to SCC) has ever occurred. However, several leaks have occurred and it should be possible to compare leak probabilities using xLPR with field data for leaks. If plans for xLPR version 2 is to use the detection of leaking axial cracks as a way to reduce rupture probability for circumferential cracks, then it is important to validate the leak probability.

xLPR Project – External Review Board – Comments and Questions

D. Steininger 2/15/13

Overall

Questions are required to be submitted a week ahead of the review meeting. Presented below are my comments and questions categorized according to the objectives of the Review Board's Charter. I think some of my questions are outside the criteria of the charter. I don't know how you will handle these .

Charter of xLPR Review Board: Objectives

1. *Assess whether the xLPR approach is adequate to meet the stated objectives of the project and whether the project work reflects a full understanding of the regulatory and industry needs.*

a. How was NRR regulatory objectives factored into the process development of xLPR? Does NRR have a target probability of pipe failure that is acceptable in regulatory space?

b. Did NRR personnel review the on-going development of the modeling and numerical techniques used in xLPR and provide comments? If so, how were these comments resolved?

c. What probability of pipe failure of a given confidence was targeted for xLPR to calculate? How does xLPR show that such accuracy and confidence level was obtained?

d. I could not find in the documentation an identification of the significant parameters that constrain accuracy of the solution and those that dominate the mean solution. Is there such a list or discussion on this topic? There was some discussion spread throughout the results of the pilot project. Section 6.3 of the xLPR Version 1 Report appears to briefly touch on this subject. Is there more than this discussion somewhere?

e. How does xLPR ensure that the code developed is user finally, that is, its more than a hard wired R&D code that is difficult to use by knowledgeable engineering personnel? I did not see this discussion in the documentation.

f. I could not find in one place where all of the independent parameters involved in the calculation that have uncertainty distribution assigned to them are listed with the uncertainty distribution identified, dispersion parameter stated if appropriate, and reference(s) from which the information supporting this uncertainty distribution is provided. Is there such a table?

g. What type of documentation will be provided to the code's user to allow relatively easy code implementation at the user's facility? Is this all provided by GoldSim and no additional documentation is needed other than discussion of additional inputs from the application development?

2. *Assess the organization and management adequacy of the xLPR project. Specifically:*

a. Are the qualifications and capabilities of the xLPR project staff appropriate to address all of the technical challenges identified for the project.

1. Project team capabilities appear to be excellent.

b. Are the analytical resources, facilities, and laboratory equipment appropriate to address the technical challenges identified for the project?

1. They appear adequate based on documentation provided.

c. Are the program management, communications, quality assurance, and other project management practices adequate to ensure the success of the project?

1. It is a complex and difficult software and engineering project, but it appears to have been handled quite well.

3. *Assess the technical adequacy of the xLPR project: Specifically:*

a. Is the engineering/scientific quality of the work comparable to the technical quality that exists in the leading federal, university, and/or industrial research and development efforts?

1. Will one document get published that will contain most of the information that is now allocated across multiple documents? The information is presently spread across multiple documents and contains duplicate information in some cases. There could exist contradictions between these documents, although I did not identify any. But I was not really looking that hard. A consolidation of this information would be appropriate.

4. *Does the xLPR project demonstrate a broad understanding of, and appropriate accounting for, the realities and constraints imposed by nuclear power plant design and operation?*

1. As usual, I am confused about aleatory and epistemic uncertainties and how they are handled. I am not sure that this division of uncertainties is really needed. I can't find in the documentation the criterion used to judge whether an uncertainty is either of the two or a hybrid. The documentation indicates that some analysis was performed with aleatory uncertainties becoming epistemic to see the effect. The change appears arbitrary. Is this the correct approach for handling and judging these uncertainties?

2. On the multiple crack simulation, are the uncertainty distribution applied to each crack (i.e, that associated with crack growth, etc) the same distributions. If so, doesn't this create a statistical correlation between the cracks. How is this handled?

3. In one of the documents it was stated that there would be an investigation concerning the appropriate stress strain curve to use for a dissimilar metal weld. I could not find the results of this investigation in the documentation. Please provide the results of this investigation in the review meeting.

4. It is stated in one report that an investigation is needed to resolve the SCC growth rate issue of higher growth rates associated with small SCC cracks. What action is being taken on this issue?

5. Please explain if there is a significant difference between corrected K's due to plasticity and K's used in linear fracture mechanics without correction.

6. I understand how the verification effort was performed. But did you calculate the best estimate probability of pipe rupture and compare it to the value one would obtain from evaluating actual field experience over the last 50 years of nuclear power plant operation? If not please develop this comparison.

7. Were the influence functions data provided in TWC Anderson.xism verified as being correct and accurate for the situation they were being applied?

8. In the paper by Rudland and Harrington it is stated that framework includes a robust design to insure that inputs used multiple times do not artificially increase (or decrease) the uncertainty. What does this mean? Why does multiple use possibly cause biased uncertainty?

9. At this point in the project, has the "Overall xLPR Development Schedule" been modified so that one can see where the issues associated with significant project delay are clearly identified? I would like to see this comparison between the original schedule and this modified one.

10. In the xLPR Pilot Study Report, Executive Summary, it is stated that "Even though the piping systems experiencing PWSCC have been shown through arguments to comply with regulations, no tool currently exists to quantitatively assess compliance with this criterion." Please explain the qualitative argument to me.

11. Even though code development followed a strict CM plan, the CM plan was not linked to a formal QA process. This will occur later at some point in time. How is this after the fact evaluation going to be performed and consistent with QA requirements. It is through some type of design review?

12. The xLPR Pilot Study report states "relatively high mean probabilities of rupture using both codes were produced even for no inspection, mitigation, etc." Could this conclusion of relatively high" be more explicitly explained? Also please explain when the "safe end effect" is used and when it is not used.

13. Please more fully explain why in the base case evaluation (xLPR Pilot Study Report) why it is more likely to have at least one crack for each epistemic realization, but a smaller chance that all realizations within an epistemic set lead to rupture. It seems that if more cracks appear the rupture probability should increase. Obviously I am missing something here.

14. I would like some further discussion concerning the last paragraph on page 5-8 in the xLPR Pilot Study Report. I would like to better understand some of the statements made in this paragraph.

15. Is this computer code only to be given to organizations that have an acceptable QA program that has been reviewed and approved by NUPIC?

16. What maximum RCS pressure is used in the loading calculation for the fatigue crack growth and net section collapse? It doesn't appear that any accident transient pressure is used during any portion of the fatigue crack growth during normal operation (xLPR Version 1.0 Report).

17. SQUIRT is used for the leakage code. Is this code a QA program?

18. I don't understand why xLPR Version 1.0 report states there was no aleatory uncertainty effect on the realizations of the epistemic uncertainties for probability of crack initiation as a function of time for the base case (see Figure 16 of the report). Could this be better explained in the report.

19. How do the fracture mechanic models used in this effort compare to the BWR Pipe Burst/Cracking program results done in the 1980's? Shouldn't this be part of the validation effort?

20. Was there any uncertainty distribution assigned to the leak detection process?

21. There is a statement in section 7, page 69 of the xLPR Version 1.0 report that states "…..still addresses the differences in primary and secondary stresses should be considered." Wasn't this a significant issue during resolution of the Wolf Creek weld crack analysis. I believe the NRC at that time required that the secondary stresses be evaluated the same way as primary stresses. That is compliance was not considered as effective. Is this what is being referred to in the noted statement? How are secondary stresses handled in this work?

5. *Does the work performed employ an appropriate mix of theory, computation, and experimentation.*

1. My definition of "appropriate" in this context is probably different from the other team members. In any event, I believe this effort satisfies this requirement.

2. I would have liked to see a comparison of the results to historical evidence of plant pipe rupture and leakage events.

3. I would have liked to have seen a comparison of the fracture mechanics models against test data such as the BWR Pipe Rupture experiments performed in the 80's.

6. *Does the work performed include adequate and appropriate benchmarking of the analytical models to independent and rational metrics of truth?*

1. See my questions noted in item iii.

I hope this is sufficient for a start. I must say that I am impressed by the effort. It's very good work and the documentation was more than adequate. The participants have spent a lot of time writing up the effort. Hopefully, in the end, there will be one technical report that contains the pertinent information obtained during the complete investigation and code development. This document would fall under the QA umbrella. Additionally there must be code documentation for the user.

Attachment 3

Additional, Post-Meeting Comments from M. Modarres

1. **Consideration of model uncertainties and model errors.**

a. Experimental data and associated measurement uncertainties based on which the mechanistic models (e.g., crack initiation, crack growth, residual stresses, coalescence) were developed are the best source for analytically estimating model and parameter uncertainties. If not available, then conservative expert judgments may be used to assign model and parameter uncertainties. In all cases the choice of aleatory or epistemic uncertainty for each model parameter or input variable in the model should be justified by consistently using a preset guideline.

b. Uncertainties represented by probability density functions for the input variables and parameters of the mechanistic models appear to be treated as independent. Most of the models are empirical and fitted to experimental data. Often statistical correlation between these parameters may be prominent and should be quantified and accounted for in the simulation.

c. Model error was not formally accounted for (i.e., any difference between "reality" and model estimation). Usually one set of data is used to fit a model to estimate parameters and associated uncertainties, and another set of data (representing "reality") is used for validating the model and estimating the "model error". Model error is often treated in form of a normal or lognormal distribution function with a mean of zero and a standard deviation estimated from the difference between the model estimation and validation data. Only the measurement error model used in EPRI's POD/inspection included the model error, although not used in xLPR V.1. For a detailed example of model error calculations see: "V. Ontiveros, A. Cartillier, M. Modarres, *An Integrated Methodology for Assessing Fire Simulation Code Uncertainty*, Nuclear Science and Engineering, 166, 179–201 (2010).

d. When multiple models exist, formal "model averaging" or "model weighting" may be useful as an option in the code. In a number of cases multiple errors were used (e.g., crack initiation and crack growth).

e. Discussion on "completeness" uncertainty would be valuable. Why are these degradation modes the only mechanisms that matter? What would be the contribution of other mechanisms not considered (fatigue crack initiation and growth, pitting corrosion, corrosion-fatigue, other types of SCC, etc.), particularly in light of uncertainties of the mechanisms considered?

f. Crack initiation rate is preprocessed and is outside of the time step simulation in xLPR V.1. The rate should be updated in light of inspection, mitigation, and should be treated inside the time loop. Also, the criterion for transitioning to crack growth is not clear (it was stated at the meeting that the transition occurs for an initial crack of depth 0.1"). Ideally, for each realization of epistemic uncertainties associated with crack initiation and crack growth models, crack should be initiated (at random time with a random initial size) and be transitioned to crack growth (based on randomly selected transition crack size criterion). As such crack initiation rate should be part of the simulation time step from t=0 to the time of pipe break or to the final age of the plant (60 years or so) with no leak/break. A density function in this case will used to pick a realization of crack size representing transition criterion.

g. Only one initiated crack is associated with one segment. This can be true if segments are very small as compared to the size of the initial crack.

2. **<u>Consideration of model uncertainties associated with ISI. This part can contribute significantly to the likelihood of any leak.</u>**

a. Parameters of the POD model are also correlated. xLPR v.1 treated these as independent although Figure 3-60 and Table 3-16 of the report "Models and Inputs Developed for Use in the xLPR Pilot Study" clearly show a strong correlation between the parameters of the POD model. Also, POD models have detection threshold that was not considered in the logistic POD model.

b. Similar to mechanistic models, POD models involve model errors that should be treated probabilistically, for example by a normal distribution with mean of zero and a positive standard deviation.

c. I understand the probability of correct sizing and sizing error will be incorporated in xLPR v.2. Both systematic (bias) and random errors should be included in the sizing models. Some discussions of this in the upcoming review meeting would be useful. Eq. [3-78] of the report "Models and Inputs Developed for Use in the xLPR Pilot Study" correctly describes the sizing model without providing parameters and their uncertainties or discussing the interplay with the POD model.

d. The POD models can't reach POD=1 because there is probability of false call (POFC) or probability of miss call (POMC).

3. **<u>Computational uncertainties could be significant.</u>**

a. Standard errors in the Monte Carlo algorithm used by GoldSim should be accounted for (or ignored in light of other uncertainties). Some formal discussion will be useful.

b. The xLPR v.1 algorithm estimates the likelihood at snapshots of time without regards to the autocorrelation between sequential ISI test information. This can introduce major under estimation of the likelihood values. For example, suppose the POD is near one for two consecutive tests concluded with no crack detection. In this case only the last test information is useful, because it includes the information contained in the first test. More formal methods such as the Sequential Bayes may be needed to address this critical issue. More explanation and references on this topic can found in: M. Rabiei, M. Modarres, *A recursive Bayesian framework for structural health management using online monitoring and periodic inspections*, Reliability Eng. & System Safety J., Vol. 112, 2013, pp 154-164.

c. Another improvement to consider in addition to the sequential inspection data would be a formal quantitative accounting of quality of repair and mitigation actions. The degree to which such repairs or mitigations renew the pipe's reliability should be factored into the integration of uncertainties. Also, the criteria for timing and performance of such repair and mitigation actions in the simulations are unclear. Choice of predetermined mitigation intervals is not justified.

d. The inspection data and associated POD values are used to update estimated values of the probability of rupture (i.e., the model outputs). There is an opportunity to fold such inspection information and other plant-specific experiences to update the models too (that is to revise the epistemic uncertainties of xLPR models and parameters). If done, this would revise xLPR models to better represent a specific plant, based on the plant's age and experience. The process may be computationally burdensome, but worth considering for long-term plans of the xLPR code.

e. Validation of the overall xLPR model would also be useful. The results of the validation (in form of difference between xLPR code estimation and observed) can also be factored into assessment of uncertainties in an ad hoc manner. This may not be possible since actual pipe rupture events don't exist.

Attachment 4

Charter for External Review Board

Charter of xLPR External Review Board

Background

Since 2008, the NRC and the commercial nuclear power industry (working under the auspices of EPRI) have been engaged in a project whose objective is to develop a probabilistic assessment methodology for use in assessing compliance with 10CFR50 Appendix A, General Design Criteria (GDC)-4. GDC-4 specifies that the *"probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping."* This requirement has traditionally been fulfilled by following the NRC's Standard Review Plan (SRP) 3.6.3. SRP 3.6.3 describes a deterministic procedure for leak-before-break (LBB) assessment. Also, it contains an entry requirement that no active degradation can be present in the systems approved for LBB. The discovery in 2000 that primary water stress corrosion cracking (PWSCC) is active within these piping systems called into question their compliance with GDC-4. Through a quantitative approach which includes the industry's inspection and PWSCC mitigation program the NRC has determined that these susceptible piping systems are presently in compliance with GDC-4. However, in the long term, a quantitative approach is required to demonstrate the continued compliance of these systems with GDC-4. As a consequence, the xLPR project was undertaken. A more detailed description of the xLPR project is provided as an attachment to this Charter.

Objectives

The objectives of the external review Board are to perform periodic oversight reviews of the xLPR project and to provide non-binding recommendations to the NRC concerning the following matters:

1. Assess whether the xLPR approach is adequate to meet the stated objectives of the project and whether the project work reflects a full understanding of the regulatory and industry needs.
2. Assess the organization and management adequacy of the xLPR project. Specifically:
    a. Are the qualifications and capabilities of the xLPR project staff appropriate to address all of the technical challenges identified for the project?
    b. Are the analytical resources, facilities, and laboratory equipment appropriate to address the technical challenges identified for the project?
    c. Are the program management, communications, quality assurance, and other project management practices adequate to ensure the success of the project?
3. Assess the technical adequacy of the xLPR project. Specifically:
    a. Is the engineering/scientific quality of the work comparable to the technical quality that exists in leading federal, university, and/or industrial research and development efforts?
    b. Does the xLPR project demonstrate a broad understanding of, and appropriate accounting for, the underlying scientific principles? Are these principles appropriately applied?
    c. Does the xLPR project demonstrate a broad understanding of, and appropriate accounting for, the realities and constraints imposed by nuclear power plant design and operation?
    d. Does the work performed employ an appropriate mix of theory, computation, and experimentation?
    e. Does the work performed include adequate and appropriate benchmarking of the analytical models to independent and rational metrics of truth?

Review Periodicity

Reviews are requested twice annually, with the first review requested in January 2013.

Review Board Members

The Board will be comprised of five members, as follows:

- EPRI manager or senior technical staff
- NRC manager or senior technical staff
- Risk assessment expert
- Large-scale computational expert
- Materials expert

To ensure the impartiality of the reviews performed by the xLPR External Review Board, the EPRI and NRC manager/staff positions shall not be in a management chain responsible for either (a) the practical motivation for performing the xLPR project, or (b) the staff working on the xLPR project. Additionally, the EPRI and NRC manager/staff positions shall be filled with individuals who possess technical expertise relevant to the xLPR project. The three technical experts shall not be EPRI or NRC staff, nor shall they be current contractors to the NRC or EPRI, or have provided contract support since January 1, 2009. Board members shall serve for two-year terms.

Format for Reviews

Reviews shall consist of one day of briefings provided to the Board by the following individuals:

- The xLPR Technical Leads
- The xLPR Project Manager
- The Computational Group Lead or Co-Lead
- The Models Group Lead or Co-Lead
- The Inputs Group Lead or Co-Lead
- The Acceptance Group Lead or Co-Lead

Read ahead material shall be provided to the xLPR External Review Board members no less than three weeks prior to each meeting. No less than one week prior to each meeting, the xLPR External Review Board members shall send the xLPR Technical Leads a list of any questions they want to have addressed during the meeting. The one day of briefings shall be followed by half-day sessions during which the xLPR External Review Board members may compare notes and begin to prepare their assessments.

The xLPR External Review Board's assessments and recommendations shall be made to the xLPR Project in an advisory sense only; addressing the Board's recommendations by the NRC is not mandatory. The Board's recommendations shall contain the consolidated views of the entire xLPR External Review Board; they may also contain the individual views of each xLPR External Review Board member if the Board views this as beneficial. Each recommendation made by the xLPR External Review Board shall be tied to a one of the Board's objectives, which are defined by this Charter.

The xLPR External Review Board's recommendations will be provided to each of the following individuals no less than two weeks following the conclusion of each review:

- xLPR Technical Leads
    - Dave Rudland, NRC
    - Craig Harrington, EPRI
- The Chairman of the Materials Subcommittee of the Advisory Committee on Reactor Safeguards (ACRS[1]).
- Chairman of the Materials Reliability Program Integration Committee (currently Mr. Tim Wells, Southern Company)

Responsibilities of xLPR External Review Board Members

The xLPR External Review Board Members shall:

1. Prepare for all meetings by reading the material provided in advance, and providing questions on critical issues in advance of the review.
2. Attending and participating in all reviews.
3. Providing output and assessment to the xLPR Technical Leads within two weeks of the conclusion of all meetings.

[1] The xLPR External Review Board's reviews will supplement the reviews performed by the ACRS, since other duties prevent the ACRS from following the xLPR project in a close and detailed manner.