UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

November 7, 2016

MEMORANDUM TO: John W. Lubinski, Director
Division of Engineering
Office of Nuclear Reactor Regulation

FROM: Brian E. Thomas, Director ***/RA/***
Division of Engineering
Office of Nuclear Regulatory Research

SUBJECT: ACCEPTANCE CRITERIA FOR USE WITH XLPR VERSION 2 CODE

The Office of Nuclear Regulatory Research (RES) has completed the enclosed technical letter report (TLR), titled "xLPR Acceptance Criteria." This TLR presents RES' recommendations to the Office of Nuclear Reactor Regulation (NRR) for its consideration in reviewing potential leak-before-break (LBB) analyses for nuclear power plants containing piping welds susceptible to primary water stress corrosion cracking (PWSCC). The TLR is part of the broader xLPR Version 2 (V2) developmental effort, and was conducted under Task 1, titled "Completion of Version 2 of the xLPR Code," of NRR's User Need Request NRR-2014-004, "Implementation of Probabilistic Fracture Mechanics Methods for Evaluating Leak-Before-Break of Nickel Based Alloys Exposed to Primary Water Environments." The code was developed to permit quantitative assessment of piping systems subject to active degradation mechanisms, such as PWSCC, for compliance with Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants," Criterion 4, "Environmental and Dynamic Effects Design Bases."

The TLR documents recommendations developed by the Acceptance Group, which was chartered as part of the xLPR V2 development effort to establish potential criteria and associated technical bases against which the results from the code could be compared in order to judge their acceptability. Members of this group included Robert Hardies, David Rudland, Tim Lupold, David Alley, Aladar Csontos, and Stephen Dinsmore from the NRC, and Robin Dyle and Craig Harrington from the Electric Power Research Institute. The group defined a failure as a leak that satisfies both of the following criteria: (1) exceeds 50 gpm in the time interval of a code iteration loop, and (2) was less than 10 gpm at the end of the previous code iteration loop time step. This definition is general, and the values may be changed for plant-specific applications with appropriate justification. The group also recommends 10^{-6} failures per year per plant as the acceptance criterion for failure frequency. The recommendations are consistent with the statement of considerations for 10 CFR Part 50, Appendix A, Criterion 4, which states that "…dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping."

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The recommendations captured in the TLR are the result of significant interactions among the members of the Acceptance Group and the broader xLPR V2 development team. A list of comments provided by these individuals and the Acceptance Group's responses are also enclosed in an effort to capture those interactions and provide additional rationale for the proposed criteria. Of note, the criteria are considered to be conservative overall, and some of the industry representatives on the xLPR V2 development team have expressed concerns that the criteria may be overly conservative. These individuals may elect in the future to further document their concerns using a process that is internal to the xLPR V2 development project and analogous to the NRC's Differing Professional Opinion Program. Should that process be used, RES will communicate the results to NRR in a follow-on memorandum.

Notwithstanding, RES views the acceptance criteria to be a sufficient starting point for the initial code application work outlined in Tasks 2, 3, and 4 of User Need Request NRR-2014-004. If that work identifies the need to revise the acceptance criteria, the staff will have the opportunity to do so before formally capturing the criteria in regulatory guidance. Separate memoranda will be sent to indicate when the remainder of the Task 1 efforts are complete. In the meantime, please communicate any questions or additional information needs to the RES technical contacts listed on the page 1 of this memorandum.

Enclosures:
As stated.

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As stated.

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xLPR Version 2.0

Technical Basis Document

Acceptance Criteria

October 28, 2016

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1.0 Objective

The xLPR (extremely low probability of rupture) Code is a probabilistic fracture mechanics (PFM) tool that will be used to estimate the frequency of failure for reactor coolant system components. This paper defines the characteristics of single xLPR realizations considered to be failures. Armed with a definition of failure, it is possible to use the xLPR code to establish time-to-failure distributions that can be converted to failure frequency. This paper also discusses the rationale for establishing failure frequency acceptance criteria for use in leak-before-break (LBB) evaluations.

2.0 Summary of Conclusions

2.1 Definition of Failure in xLPR

For xLPR, a failure is defined as a leak that satisfies both of the following criteria: (1) the leak rate exceeds 50 gallons per minute (gpm) in the time interval of a code iteration loop and (2) the leak rate was less than 10 gpm at the end of the previous code iteration loop time step. This definition is general. The values may be changed for plant-specific applications with appropriate justification.

The paper also discusses alternative failure definitions.

2.2 Acceptance Criteria

The recommended acceptance criterion for leak-before-break analysis for an individual plant is the total failure frequency of all exempted, high energy piping welds susceptible to primary water stress corrosion cracking (PWSCC) within all environmental zones that contain safe shutdown equipment shall be less than 10^{-6} failures per year. Actions that result in absolute plant piping failure frequencies less than 10^{-6} failures per year would be permissible. The actual acceptance criteria will be established by U.S. Nuclear Regulatory Commission administrative processes that occur outside this paper. The acceptance criteria ultimately approved may differ from the value recommended in this paper.

For applications of xLPR other than LBB, the processes and acceptance criteria described in Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis [Ref. 1]," may be applicable.

This paper does not address acceptability of the xLPR Code itself or acceptability of inputs for any future analyses made using the code. Acceptability of the code itself will be established by the Office of Nuclear Reactor Regulation (NRR) after the code is delivered for review. Extensive use of benchmarking, collaborative expert review and documentation from the software quality assurance program used during code development are expected to be the primary objective evidence to be reviewed for the acceptability of the source code. Acceptability of inputs for future analyses using the xLPR Code, where the results of the analyses are used in a future licensing submittal, will be subject to the normal NRR review processes.

2.3 Alternatives to Addressing Conservatisms Outlined in this Paper

Some of the approaches and criteria discussed in this paper incorporate conservatisms. Some of the conservatisms are adopted for convenience where it is believed they will not significantly affect the computed level of risk. However, sensitivity studies may be used to quantify the effects of this type of conservative assumption and, if found to be important, the approach can be modified to reduce or eliminate this type of conservatism. Other conservatisms arise out of a lack of information about relationships between causes and effects during piping failures. These conservatisms can be reduced when appropriate information is developed. Known conservative choices are discussed in subsequent sections and summarized in Section 8.

3.0 Introduction

3.1 Background

Nuclear reactors are designed to be able to be shut down safely even if the main coolant piping were to fail catastrophically. Mitigating systems such as the emergency core cooling systems (ECCS) supply reactivity control and heat removal capability in the event of reactor coolant piping failure. Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic

Licensing of Production and Utilization Facilities," Appendix A, "General Design Criteria for Nuclear Power Plants," General Design Criterion (GDC) 26, "Reactivity Control System Redundancy and Capability," and GDC 27, "Combined Reactivity Control Systems Capability," establish the requirements for reactivity control during postulated accidents such as main coolant piping failure. GDC 35, "Emergency Core Cooling," establishes the requirement for heat removal. During an accident involving a breach of the reactor coolant piping the ECCS maintains heat removal by supplying copious amounts of water to compensate for the loss of coolant inventory through the break and, in pressurized water reactors, supplies reactivity control via boron in the injected coolant. The ECCS is designed to be capable of mitigating the effects of a main coolant piping failure to permit the reactor to be placed in a safe shutdown condition.

Catastrophic failure of high-energy main coolant piping could release a large amount of energy in the region close to the break. Water flashing to steam could create jets or plumes of steam affecting nearby equipment. Pieces of the fractured pipe could damage adjacent equipment and structures. Steam plumes from the break could create sufficient force to cause the end of the fractured pipe to whip around and affect adjacent components such as piping, valves, actuators, pumps, or control equipment. If these dynamic effects of piping rupture: jet impingement, missiles and pipe whip, affect ECCS equipment, then these effects could challenge the capability of the ECCS to mitigate the effects of the piping rupture. If a pipe break compromises the ECCS equipment, then it may not be possible to place the reactor in a safe shutdown condition. For this reason, 10 CFR Part 50, Appendix A, GDC 4, "Environmental and Dynamic Effects Design Bases," requires the plant design to include features accounting for and mitigating dynamic effects of pipe rupture. The plant must be designed such that a main coolant piping rupture will not damage the ECCS system so that the ECCS system can return the plant to safe shutdown in the event of main coolant piping rupture.

One method of addressing the potential for main coolant piping failure to affect ECCS equipment is to install physical barriers and restraints so dynamic effects from the break can be contained or directed away from ECCS components. Early plant designs employed physical barriers such as pipe whip restraints and jet impingement shields. Inclusion of these engineered features in plant design eliminated interdependency between main coolant piping break and ECCS failure, but their physical size and location complicates maintenance and

inspection activities, leading to additional accumulation of radiologic dose to workers, and eliminating access for some inspection activities, including examinations that are to confirm piping integrity [Ref. 2].

In the 1980s, as an alternative to installing physical engineered barriers, the nuclear industry developed an analytical approach to show that catastrophic failure of main coolant piping would be preceded by leakage of sufficient volume and duration that operators would identify the leakage (through routine surveillance activities) and place the plant into safe shutdown before catastrophic piping failure occurs. The analyses demonstrated the piping system is extremely unlikely to fail catastrophically. As a result, the design of the piping system did not need to have features installed to mitigate or localize the environmental effects of catastrophic failure. The NRC approved the approach, termed leak-before-break (LBB), and eventually revised GDC 4 to permit LBB analyses in lieu of installing physical barriers. GDC 4 was changed by adding the following words:

> …dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping.

All references to LBB in this paper refer to the analytical approach described in NUREG-0800, Standard Review Plan (SRP) 3.6.3, “Leak-Before-Break Evaluation Procedures” [Ref. 3]. The approach outlined in SRP 3.6.3 involves (1) determining the size of a crack that would leak enough to be identified by operators, (2) determining the critical crack size that could lead to catastrophic failure, and (3) ensuring the leaking crack size is much smaller than the size of a crack that would cause catastrophic failure.

The current approach in SRP 3.6.3 is a deterministic flaw tolerance approach. As such, it relies on the application of explicit margins to ensure the probability of rupture is extremely low. Margins used in the approach were established by engineering judgment to accommodate uncertainties in input variables such as material performance, material properties, applied stresses, and postulated crack leak rates as well as operator responses to leakage. A relative

lack of understanding of stress corrosion cracking (SCC) in the PWR environment at the time the SRP was created made it difficult to establish appropriate margin terms to apply in the assessment of SCC. As a result, the current SRP does not permit LBB assessment of active crack propagation mechanisms such as SCC.

Advances in PRA and PFM, in particular, during the 30 years since the original deterministic approach for LBB was established has made it possible to construct computer programs that explicitly address uncertainties, including uncertainties associated with SCC, making it possible to directly estimate the probability of failure of RCS piping components. Active PWSCC has been observed in pressurized water reactor (PWR) reactor coolant piping butt welds starting in 2000 [Ref. 4]. PFM can be used to quantitatively assess the safety risk associated with PWSCC.

3.2 The xLPR Code

The xLPR Code is a PFM tool that simulates initiation and growth of cracks in reactor coolant pressure boundary piping welds. The active degradation mechanisms currently modeled are PWSCC and fatigue. Its near-term application will be to evaluate the effects of PWSCC and fatigue on the frequency of failure of nickel-based alloy butt welds. The initial need for this code is to assess the LBB approach in SRP 3.6.3, in accordance with 10 CFR Part 50, Appendix A, GDC 4.

The xLPR Code models the effects of system operational and residual stress loads on piping system welds. The code uses a Monte Carlo approach to simulate many lifetimes of the piping system. Within each lifetime, the code evaluates whether the applied stresses interact with the simulated flaws in a manner leading to crack initiation and growth, piping leakage or piping system failure. Each lifetime involves a series of time loops: the system is modeled initially without flaws, then increments of time are added and some flaws initiate. Increments of time continue to be added; additional flaws may initiate and the simulated flaws (initiated in previous time steps) may grow. At each time step the system is evaluated for leakage and failure. During a single simulated lifetime some flaws arrest. Other flaws may grow to become through-wall cracks with leakage of some defined amount. The times to each type of outcome (no initiation, crack arrest, crack growth to leakage, or rupture) can be collected from multiple

simulated lifetimes to develop time-to-failure distributions. These distributions can be converted to the probability of failure over a given time period or failure frequency. The failure frequency can be expressed as an annual frequency (if results are uniform enough over the years). The xLPR Code annual failure frequency output can be used to quantify the risk associated with the deterministic approach in SRP 3.6.3. In order to do an evaluation, it is first necessary to explicitly define criteria for what constitutes failure and what annual failure frequency is adequately low.

4.0 xLPR Acceptance Criteria Development

The xLPR Code output can be used in decision making. Quantitative estimates of the likelihood of reactor coolant system piping failure can inform decisions related to piping system design, maintenance, inspection, degradation management, repair, replacement, or other courses of action. In order to create a useful code, the developers need to know what types and formats of output are needed. Under the xLPR Code development process an acceptance group addresses questions related to potential applications of the xLPR code and the types of outputs that would support those applications.

Development of the xLPR Code was a collaborative effort between the NRC and the Electric Power Research Institute (EPRI). The xLPR acceptance group includes Robert Hardies, David Rudland, Tim Lupold, David Alley, Aladar Csontos, Stephen Dinsmore from the NRC and Robin Dyle and Craig Harrington of EPRI. Tim Lupold and Aladar Csontos were original members who were replaced by David Alley and David Rudland due to organizational changes. The group focused on identifying how the output of the xLPR Code can best be used to support risk-informed decision making.

4.1 Acceptable Results versus Acceptable Inputs

There are two aspects of acceptance: results and inputs, which include the technical basis for the code calculations. The acceptance group will develop results criteria and the NRC will consider these criteria for use in concert with existing regulatory criteria. Each time an applicant or the regulator uses xLPR to evaluate results, the results would be compared to the acceptance criteria to determine whether the event/condition analyzed was acceptable. There

are a variety of types of applications envisioned for xLPR, so there may be a variety of acceptance criteria. The initial application of the xLPR Code is to evaluate the risk associated with PWSCC to determine whether the very low probability of failure as required by GDC 4 is achieved with current designs and inspections, or if changes are needed. Other applications of xLPR will eventually need to be explored, but only acceptance criteria related to evaluation of LBB are addressed in this document.

Acceptance of the inputs and the technical basis for the xLPR Code is different than the acceptance criteria for the outputs and refers to the process used to assess regulatory acceptability of a particular application of the xLPR Code. Specifically, when a licensee or the NRC uses xLPR to evaluate a proposed license or regulatory change (such as a plant-specific change to the licensing basis or a generic change to regulatory review approaches), NRR will evaluate the inputs and the technical basis for the license or regulatory application. An example would be an individual licensee's application to increase the length of time between inspections. In this case, NRR would review the inputs to xLPR and the xLPR Code itself. This aspect of acceptance needs to be defined and portions of it need to be planned, but will be addressed later in the project as part of a formal acceptance review of the proposed new Regulatory Guide describing acceptable application methods for licensees to use xLPR. The acceptance group will not define acceptable uses of the xLPR Code or establish any new regulatory acceptance process.

4.2 Regulatory Applications of xLPR

The type of xLPR application initially expected is an evaluation of the effect of new information or different proposed changes on risk. An example of new information would be the identification of a new degradation mechanism such as PWSCC. Proposed changes include possible new activities that might be required following the identification of PWSCC in a system not previously known to be vulnerable to PWSCC. The possible changes include physical or administrative modifications. An example of a physical modification is the removal of susceptible welds and replacement with welds of a different, non-susceptible material. In this case the change of interest would be the difference in risk between a plant that had susceptible material and the same plant without susceptible material. Other types of physical modifications include mitigation of welds by peening, overlays, or stress improvement. In these examples the

plant risk before and after the mitigations are evaluated. Examples of administrative modifications include changes to inspection programs or changes to operating procedures.

Generally, once a licensee has done xLPR analyses of new information and any physical or administrative modification, they would need to evaluate the change with respect to the approved LBB analysis contained in their current LBB licensing basis. 10 CFR Part 50, Appendix A, Criterion 4, specifies LBB analysis methods must be approved by the NRC. Licensees would review proposed actions in accordance with the provisions of 10 CFR 50.59, "Changes, Tests and Experiments." In most cases for LBB the 10 CFR 50.59 screening would reveal the need to submit the method for NRC review.

Alternatively, the NRC may use xLPR to develop a technical basis demonstrating it is acceptable to continue to use the current deterministic approach to LBB. In this type of application the staff would select some generic configurations to analyze. The results would be compared to acceptance criteria to determine if the total risk or the change in risk is small enough. The analysis could be generalized to apply to all plants. The advantage of this approach is that it enables the use of state-of-the-art probabilistic analytical technology without the need to change the current deterministic regulatory framework in a way that would require significant amounts of new licensing effort.

In summary, applications of xLPR output that may require NRC approval include: (1) new license applications, (2) license amendment applications, (3) NRC assessment of the effect of PWSCC on previously approved exclusions, and (4) licensee evaluations of facility changes. In the case of new and amended license applications, "low probability of rupture" is the regulatory basis for NRC approval. For NRC staff internally assessing the effect of PWSCC, the approach described in RG 1.174 could be used to generically understand the safety significance of PWSCC.

5.0 Risk Acceptance Criteria

A specific requirement of GDC 4 for NRC acceptance of analyses supporting exclusion of pipe rupture dynamic effects is <u>demonstration that the probability of fluid system piping rupture is</u>

extremely low. The difficulty is with defining criteria for "piping rupture" and for "extremely low," but the requirement is clear.

A convenient approach for establishing risk-informed acceptance criteria, for defining "extremely low," would be to use criteria already approved for use in the NRC regulatory framework. RG 1.174 offers an approved method for evaluating whether actions (including inaction after finding new information) affecting risk are acceptable. RG 1.174 establishes risk acceptance criteria defined in terms of changes to core damage frequency (CDF) and large early release frequency (LERF). In general, when overall plant risk is low enough, small increases in risk are acceptable. When overall plant risk is higher, relatively smaller increases in risk are acceptable. Decreases in risk are acceptable. Licensees use their plant-specific probabilistic risk assessment (PRA) to calculate CDF, ΔCDF, LERF, and ΔLERF values. An approach that uses RG 1.174 would take annual LOCA frequency from xLPR and use information from the plant-specific PRA to transform the LOCA frequency into CDF, LERF, ΔCDF, and ΔLERF values. The calculated values then would be compared to the acceptance criteria given in RG 1.174.

5.1 Interdependence between Piping System Rupture and Core Damage

Application of RG 1.174 acceptance criteria to xLPR output is not straightforward. Current PRAs assume the only effect of LOCAs inside containment is the loss of coolant from the LOCA itself. No equipment is assumed failed by dynamic effects because dynamic effects are required to have an extremely low probability in the licensing basis by GDC 4. The xLPR Code outputs leak rate, but does not give information about consequential effects like pipe whip. While it may be possible to develop a technical basis for finding combinations of leak rate and pipe size to screen out non-pipe-whip failures, such a technical basis does not currently exist. Essentially, LOCA output from xLPR quantifies the loss-of-coolant effect from the LOCA, but the associated potential for consequential effects that could compromise the ECCS and lead to core damage remain unquantified. The PRA assumes the consequential effect is zero. Therefore, straightforward input of xLPR LOCA frequency output into a plant PRA could yield PRA output that under predicts the risk metrics. In order to correctly calculate risk arising from piping failure when dynamic effects may occur it would be necessary to revise the PRA to address

consequential effects of piping system failure, which would be a significant, complex and potentially expensive exercise.

An alternative to explicit inclusion of the consequential effects of piping system rupture in the PRA is to bound them. If the calculated annual LOCA frequency is low enough, then even if every LOCA led directly to core damage, it would still be possible to show the CDF resulting from LOCAs was adequately low. This approach is consistent with the philosophy of GDC 4, which permits exclusion of the consideration of consequential effects from the design basis if the frequency of piping system rupture is extremely low.

5.2 Large Early Release Frequency

In order to use the acceptance criteria of RG 1.174 with xLPR output, it will be necessary to evaluate the relationship of CDF and LERF. As an example, since LBB involves the postulated failure of primary piping, establishment of the relationship between CDF and LERF involves demonstrating the primary system pipe failure would not directly increase the failure probability of steam generator tubes, feedwater or main steam piping or isolation valves, or otherwise affect containment integrity. When containment integrity is not directly degraded by the pipe failure, a relatively low containment failure probability is expected because LOCAs generally lead to core damage at low pressures and therefore containment is not challenged by vessel ruptures at high pressure. In other words, the effects of the break should not result in other common cause effects altering the relationship between CDF and LERF. If containment integrity is not affected by piping failures, then the traditional assumption of LERF being one-tenth as large as CDF (i.e., conditional containment failure probability of 0.1) could be justified (for PWRs).

5.3 Evaluations of Changes in Risk

RG 1.174 offers guidance on the use of PRA findings and risk insights in support of licensee requests for changes to a plant's licensing basis, as in requests for license amendments and technical specification changes under 10 CFR 50.92, "Issuance of Amendment." The RG describes an approach for a licensee to evaluate the change in risk associated with a proposed change in the licensing basis. The magnitude of the increased risk that is permitted is dependent on overall plant risk. If overall plant risk is low, licensing basis modifications

increasing risk slightly may be permissible. If overall plant risk is relatively higher, then only very small increases are permitted. For example, the RG states:

> When the calculated increase in CDF is in the range of 10^{-6} per reactor year to 10^{-5} per reactor year, applications (meaning proposals to change the plant licensing basis) will be considered only if it can be reasonably shown that the total CDF is less than 10^{-4} per reactor year.

When the calculated increase in LERF is in the range of 10^{-7} per reactor year to 10^{-6} per reactor year, applications (meaning proposals to change the plant licensing basis) will be considered only if it can be reasonably shown that the total LERF is less than 10^{-5} per reactor year. Normally, calculations of ΔCDF and ΔLERF would be made by running the xLPR Code in a baseline configuration, then running the code again with the configuration of interest enabled. In order to save calculation time it is permissible to assign a failure frequency equal to zero for the initial evaluation state (e.g., for LBB before PWSCC) since this situation has been established as an acceptable regulatory situation. This approach is conservative; assigning zero as the initial condition places the entire burden of the risk on the final condition being evaluated and takes no credit for any circumstance previously determined to be acceptable.

Furthermore, RG 1.174 states:

> When the calculated increase in CDF is very small, which is taken as being less than 10^{-6} per reactor year, the change will be considered regardless of whether there is a calculation of the total CDF.

When the calculated increase in LERF is very small, which is taken as being less than 10^{-7} per reactor year, the change will be considered regardless of whether there is a calculation of the total LERF.

With the establishment of xLPR output acceptance criteria as an absolute annual failure frequency less than 10^{-6} per reactor year, the RG 1.174 criterion for acceptable increases in CDF is always satisfied. With a conditional containment failure probability of 0.1, an absolute annual failure frequency less than 10^{-6} per reactor year also satisfies the criterion for acceptable

increase in LERF. This means the sole quantitative risk metric necessary for xLPR output in a RG 1.174 framework is the annual failure frequency of the final system configuration. This criterion is consistent with the risk acceptance criterion approved for through-wall cracking of the reactor pressure vessel and with the acceptance criteria established in the "Statement of Considerations" for rulemaking to change GDC 4 to permit LBB, "Modification of General Design Criterion 4 Requirements for Protection Against Dynamic Effects of Postulated Pipe Ruptures," 51 FR 12502, which states:

> The definition of "extremely low probability" of pipe rupture is given as of the order of 10^{-6} per reactor year for PWR primary coolant loop piping when all pipe rupture locations are considered. This is consistent with past NRC decisions relating to other postulated events. This value, which includes the probability of an initiating event occurring (such as an earthquake, abnormal transient or an accident), conforms with the implicit design goal of components and structures that are engineered on a deterministic basis. [Ref. 5]

Other acceptance guidelines may be developed and used. For example, NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," (SRP) Section 3.2.2 states that external events with a frequency less than 10^{-7} per reactor year (10^{-6} per reactor year if conservatively evaluated), need not be included in the design basis and it might be possible to extend the use of these criteria to LBB. In 2010, a rulemaking, 10 CFR 50.61a, "Alternate Fracture Toughness Requirements for Protection against Pressurized Thermal Shock Events," established that a frequency of through-wall cracks in the reactor vessel of up to 10^{-6} per reactor year was acceptable. Alternatively, the licensee may demonstrate the change in the risk associated with not installing dynamic pipe break protection is acceptable relative to a pre-approved risk metric, such as an acceptably small increase in leakage, LOCA or CDF. Alternative acceptance criteria would require justification and approval.

5.4 xLPR Acceptance Criteria

The xLPR acceptance group recommends 10^{-6} failures (to be defined in the following sections) per year as an acceptance criterion. This criterion is applied to the final system configuration under consideration with all changes from the baseline evaluation applied.

6.0 Definition of Piping Failure

6.1 The Difference between Leaks, Ruptures and Loss-of-Coolant Accidents

10 CFR Part 50, Appendix A, GDC 4, addresses piping rupture. Traditionally, rupture is defined as circumferential cracking leading to piping failure resulting in a double-ended guillotine break capable of discharging steam jets, causing pipe whip and creating missiles affecting the function of nearby structures, systems or components important for safety. However, xLPR is able to model failures that are not double-ended guillotine breaks which would nevertheless be able to discharge a large volume of steam with considerable force. Such failures, which would not be traditional ruptures, could create environmental conditions affecting nearby safety equipment. It is a goal of the probabilistic approach to model the system as accurately as possible, so it would not be appropriate to neglect an entire class of potentially contributing failures. Many piping failures would not damage the emergency core cooling system and, in particular, the potential for damage is expected to be a function of break size. It would be possible with additional work to exclude breaks of certain sizes in certain configurations from consideration as contributors to environmental effects. It is possible to categorize LOCAs to differentiate between LOCAs that cause local effects and LOCAs that do not, but the categorization exercise would require evaluation of each pipe break location and the surrounding equipment configuration. Such a categorization effort is beyond the scope of the current xLPR development effort, but could be accomplished. As a convenience for evaluating LBB, xLPR can treat all LOCAs as failures that lead to environmental effects in nearby safety equipment.

This definition of failure involves a large retained conservatism because it assumes all piping failures subsequently disable the ECCS and lead to core damage. The conservatism is expected to be greater for small LOCAs with potentially limited dynamic effects but configuration specific circumstances can also occur where smaller pipe whips could disable vital equipment.

The xLPR output can differentiate between different LOCA sizes and this information may be later used to refine the acceptance criteria as appropriate.

6.2 The Importance of Crack Growth Rate

The xLPR Code differentiates between cracks growing in a slow, stable manner and cracks propagating rapidly to large leaks or double-ended guillotine breaks. The xLPR code calculates the probability of leakage (and the associated leak rate) and the probability of guillotine breaks (and the associated leak rate) during each time step. Within the xLPR model some weld locations will never crack in any time step. At locations where cracks initiate, crack growth is affected by local applied stress, temperature and material composition variations. A primary contributor to crack driving force is weld residual stress, which can vary significantly through the thickness direction of a weldment. As a result, some welds may begin to crack in a time step, but the crack growth slows considerably or arrests in a stable configuration when it grows into a region with lower residual stress.

A crack may grow very slowly for some time before spreading into a region of higher tensile residual stress where it begins to grow more rapidly. Some cracks may continue to grow in successive time steps until they progress through-wall and begin to leak. Some of the through-wall cracks may arrest in stable configurations where the leak rate will never increase. Some may slowly grow to bigger cracks and bigger leaks, even to sizes that become LOCAs, while crack growth remains stable. Alternatively the cracks may grow over successive time steps until they are so large that double-ended guillotine break occurs.

Some cracks may grow very rapidly, potentially in a matter of moments, from small leaks (or even no leak at all) to complete piping break. The xLPR code integrates the contributions of all of these situations into a time-to-failure distribution from which the probability and magnitude of leakage as a function of time can be extracted. Double-ended guillotine breaks are clearly LOCAs, but some instances of stable crack growth and leakage can also be LOCAs. In order to calculate the total frequency of all LBB LOCAs it is necessary to define which instances of stable crack growth should be treated as LOCAs and which should not. The stable cracks that grow to act like LOCAs will be considered as failures that need to be added to instances of guillotine break, fishmouth and other kinds of ruptures to determine the total number of failures.

6.3 The Importance of the Rate of Increase of the Leak Rate

For cracks that the model predicts will grow relatively slowly and in a stable manner at first but may later grow in an unstable manner, there may be a point in time when plant operators identify leakage and shut the plant down to make repairs. For this reason, the leak rate and the increase in leak rate as a function of time should both be considered in defining when a LOCA occurs. The increase of the leak rate is important because a leak rate of 0.1 gallon per day (gpd) could be compensated for with a charging pump, but not if the crack responsible for the leak grew rapidly so a 0.1-gpd leak changed to a 10,000 gpm leak within, for example, 2 minutes. In this case operators could not diagnose the leak and shut the plant down to make repairs before the leak rate exceeded the LOCA leak rate. The rate of increase in the leak rate would be unacceptable because it eliminates the mitigating effect of leak detection.

6.4 One Failure Criterion Defined: Leaks that Exceed 50 GPM

All large break LOCAs and medium break LOCAs must previously be small break LOCAs, if even for a fraction of a second during a rupture, because the progression of degradation goes from crack, to leak, to bigger leak, and this process cannot happen in reverse. A LOCA should be defined as any leak with a rate that exceeds the leak rate of a small-break LOCA as defined in the PRA. This will vary from plant to plant, but will be approximately equal to the capacity of a single charging pump, which is typically greater than 50 gallons per minute. As a generic simplification for xLPR, it is proposed that when the calculated leak rate at the end of a time step exceeds 50 gpm, the leak be defined as a failure, irrespective of whether unstable crack growth or rupture occurred or not. This is conservative, and can be changed for specific analyses, and should be subject to sensitivity studies, but this offers a simple starting point for the failure metric.

6.5 Time Increments

The xLPR code permits the user to establish the duration of time steps. Sensitivity studies should be performed around the time increment to ensure the code results are stable (e.g., do not change disproportionately) with respect to changes in the time increment. The minimum time increment is the time necessary for a plant to detect a leak and take action to put the plant

into a safe configuration. Therefore, the minimum time step is greater than the sum of the leak detection surveillance period and the time necessary for operators to do the plant configuration manipulations necessary to achieve a safe plant configuration. Decreasing the time steps increases xLPR computational time which would be unnecessary if results obtained using long time steps are acceptable. The xLPR code currently uses time increments of 1 month. If the time increments are changed from 1 month to some other increment, the proposed failure criteria would need to be validated or appropriately revised.

6.6 Detectable and Actionable Leaks

It is necessary to consider what happens in the time steps preceding failure. If a leak were large enough to be noticed, then operators could take corrective action before it progressed to failure. The leak rate through a crack varies with crack size, which varies with time. The xLPR Code uses the Leak Analysis of Piping - Oak Ridge (LEAPOR) Code to calculate leakage rates and there is appreciable uncertainty in the calculated leak rates for very small cracks. In order to minimize issues associated with estimation of leak rates for small crack sizes, it is convenient to consider large leak rates that are less than LOCAs that would be detected by leakage monitoring (and be removed from service before rupture could occur). It is considered that a leak rate above 10 gpm would certainly be detectable and would be removed from service. The probability of not detecting this leak rate should be set to zero in the xLPR code. In reality plant operators are required to detect much smaller leaks. Regulatory applications by licensees to use xLPR analyses should document that 10 gpm leaks would be detected, typically by referring to technical specification requirements. Leak rates above 10 gpm will be termed actionable leaks.

It may be very reasonable and justifiable to use lower leak rates to define actionable leaks. The choice of 10 gpm is conservative and for convenience. Use of a lower rate is not necessary if results using 10 gpm are acceptable.

6.7 Definition of Failure Criteria

After having defined an actionable leak rate (certainly detectable and requires action) and the largest leak rate that would not be a LOCA (equal to a single charging pump capacity), it is possible to fully define metrics for xLPR to use to differentiate between cracks that lead to

failures and those that do not. Nonfailures include: (1) pipes and welds that never leak at a rate larger than 10 gpm and (2) leaks that exceed 10 gpm at some point during a time increment but do not exceed 50 gpm during that same time increment. The first type of location will never be a LOCA; the second type of leak would be detected and would be removed from service before a LOCA occurs. Therefore, a failure is a leak that: (1) is a LOCA, which means its leak rate exceeds the capacity of a charging pump, set generically at 50 gpm and (2) was less than 10 gpm at the end of the previous time step. If the first condition is not satisfied then a LOCA has not occurred; if the second condition is not satisfied then operators will notice and take action to take the weld out of service before it progresses to a LOCA, preventing the LOCA.

Failures can be parsed into the appropriate category of small-, medium- and large-break LOCA as defined by plant-specific charging and low- and high-pressure safety injection pump capacities.

7.0 Full System Applicability, Interdependency and Duplicate Failures

According to SRP 3.6.3: "Approval of the elimination of dynamic effects from postulated pipe ruptures is obtained individually for particular piping systems at specific nuclear power units. LBB is applicable only to an entire piping system or analyzable portion thereof. LBB cannot be applied to individual welded joints or other discrete locations. Analyzable portions are typically segments located between piping anchor points." The xLPR code evaluates one weld at a time. Since LBB applies to an entire system (or analyzable portion), xLPR will need to address the entire system by direct calculation of frequencies, if they are interrelated, or by summing, if they are not. This can be illustrated by considering a system composed of two welds. The xLPR Code evaluates each weld separately, counting the number of times LOCAs occurred without being removed by leak detection (counting failures), dividing the number of failures by the number of trials, and converting the fraction to an annual frequency. If there are no interdependencies, then the annual failure frequency for each weld can be simply added together to determine the annual failure frequency for the system. However, if the welds are close together, perhaps inches apart if they are on opposite sides of a short safe end, then a leak detected on one weld would likely result in repair that would affect both welds. The failure frequency of the second weld should then be reduced in future trials. If a leak at one location

leads to augmented inspection of other welds, then the discovery of the leak results in a reduction in the frequency of failure of other welds because some augmented inspections may find cracks before they become through-wall cracks.

Failures in the xLPR code are assumed to lead directly to core damage. If duplicate failures are not addressed then it would be possible for a single piping system to be counted as failing more than once. If each weld in a system is analyzed independently, then one weld could experience failure at some particular time in life while another weld experiences failure at some later time, resulting in two failures in the same piping system. It is not reasonable, however, to expect a plant that experiences core damage to continue operating for the additional years necessary for subsequent failures to occur. The likelihood of more than one failure over the reactor lifetime can be estimated and subtracted from the sum of the failure frequencies if necessary or an alternative correction technique applied. However, given the low frequency estimates, the likelihood of more than one failure over the reactor lifetime is expected to be negligible, so a simple summing of the frequencies will yield a precise estimate.

If a plant has two piping systems, or multiple analyzable portions that are evaluated for annual frequency of piping rupture, the frequencies are summed for all welds in all subject systems for a cumulative total. This approach is consistent with the Statement of Considerations for the revision of GDC 4.

Finally, for analysis of LBB systems where the objective is to evaluate the effects of PWSCC, only the locations in the system or analyzable portion thereof that are susceptible to PWSCC need be considered. This is because it is permissible to assign a failure frequency equal to zero for the initial evaluation state (e.g., for LBB before PWSCC) since this situation has been established as an acceptable regulatory situation.

7.1 Application of Uncertainty Information

RG 1.174 uses mean yearly frequencies. xLPR is capable of generating mean annual (or maximum) frequencies of failure, and also the uncertainty in those means if the uncertainty of the inputs are, somewhat arbitrarily, separated into two classes of uncertainty. The acceptance criterion of 10^{-6} failures per year was developed with the understanding that it is to be assessed

against the 95% confidence level of mean results. When an analysis yields results that are close to the acceptance criteria it may be necessary to further address uncertainty. Methods to address uncertainty might include qualitatively describing the conservatism in the models, inputs, and assumptions used to calculate the mean result, or otherwise evaluating the distribution of the results. The objective of the evaluation of uncertainty is to document that the analysis is not systematically non-conservatively biased. Consideration of uncertainty does not mean that a deterministic margin or standard deviations needs to be added to results close to the acceptance criteria. Addition of conservatism when results are close to the acceptance criteria is not warranted. Appropriate methods to address non-conservative bias is to correct the source of the bias in the calculation rather than adjusting the analysis results.

Although the calculation of uncertainties will not normally be necessary for LBB, other applications of xLPR will benefit from knowledge of uncertainties. For example, when considering research funding, xLPR calculations could be used to reveal which type of research would have the greatest effect on reducing uncertainties.

7.2 Defense in Depth

Any application of the xLPR code shall also address safety margins and defense in depth. Potential approaches to address safety margins and defense in depth include tabulation of known conservatisms in the analytical approach, crediting mitigation actions, or evaluation of the likelihood of rapid crack growth versus slow crack growth.

8.0 Conservatisms in the xLPR Acceptance Approach

Some aspects of the criteria and approaches described in this paper represent purposefully selected conservative assumptions that could individually or collectively significantly affect calculated failure frequencies. These conservatisms were discussed previously but are repeated here for clarity. These conservative assumptions can be changed and less conservative assumptions could be made if the change were both valuable (had a measurable effect on results) and justifiable. The three major conservatisms include: (1) treating all LOCAs as failures that lead to environmental effects of nearby safety equipment, (2) selection of 1 month as the time step, and (3) selecting 10 gpm as an actionable leak rate.

Treating all LOCAs as leading to environmental effects is believed to be very conservative because the maximum environmental effect is limited by the energy content of the pipe, so failure of a smaller pipe has a smaller maximum effect than failure of larger pipes. Quantifying the effect of this conservative assumption, or to justify using a different, less conservative assumption, would require use of a function that related pipe size to environmental effects. Such a function does not yet exist. For plant specific applications it may be possible to exclude environmental effects for certain welds where there are no nearby components subject to environmental effects.

Selection of a 1-month time step is conservative because cracks are only subject to leak detection at the beginning and end of time step, so longer steps permit more crack growth before leak detection. This conservatism could be quantified by varying the time step in a sensitivity study. Selection of 1 month is arbitrary. Therefore, if the effect is significant then use of a shorter time step (as short as the operator leak surveillance interval) could be applied.

Selection of 10 gpm as an actionable leak rate is conservative because in any simulation a crack with a smaller leak rate will typically have more time before it fails than a crack with a larger leak rate. The actionable leak rate was selected to avoid the need to address uncertainties in leak rate models. This conservatism could be quantified by varying the actionable leak rate in a sensitivity study. If the effect is significant then use of a smaller leak rate could be applied. Operator leak detection processes are capable of routinely detecting leaks two orders of magnitude lower than 10 gpm, so selection of a lower leak rate would be justifiable from the operator perspective. However, uncertainty in the xLPR leak rate calculations would need to be addressed.

9.0 Summary

For xLPR, a failure is defined as a leak that satisfies both of the following criteria: (1) the leak rate exceeds 50 gallons per minute (gpm) in a code iteration loop time step, and (2) the leak rate was less than 10 gpm at the end of the previous time step.

The recommended acceptance criterion for leak-before-break analysis is a failure frequency less than 10^{-6} failures per year.

10.0 References

1. Regulatory Guide 1.174, “An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis.

2. Scott, P. M., R. J. Olson and G. M. Wilkowski, “Development of Technical Basis for Leak-Before-Break Evaluation Procedures,” NUREG/CR-6765, Agencywide Documents Access and Management System (ADAMS) Accession No. ML021720594, May 2002.

3. Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition (NUREG-0800, formerly issued as NUREG-75/087), ADAMS Accession No. ML042080088.
4. Information Notice 2000-17: Crack in Weld Area of Reactor Coolant System Hot Leg Piping at V. C. Summer, October 18, 2000.

5. 51 FR 12502, “Modification of General Design Criterion 4 Requirements for Protection against Dynamic Effects of Postulated Pipe Ruptures,” published April 11, 1986.

APPENDIX A

COMMENTS AND RESPONSES

Comment Set 1

a) The first part of the document on NRR acceptance group actions are very open ended with no definitive commitments. This is exemplified by the last statement in Section 4.1, "The acceptance group will not define acceptable uses of the xLPR Code or establish any new regulatory acceptance process." However, the application to xLPR probabilistic analyses as prescribed in this document are detailed and overly conservative as discussed in the following comments.
Response: The initial sections describe the objective of the acceptance criteria document, which is to define what type of results should be produced by xLPR and to describe a framework in which to assess those results. The purpose is not to define all types of applications of the xLPR Code, so the document must be open ended with respect to types of applications. The latter sections of the document describe acceptance criteria for results of xLPR for leak-before-break evaluation, which is a single type of xLPR application.

b) Sections 5.1, 6.1 and 8.0 all refer to the assumed environmental effects of LOCA events. It should be noted that this was evaluated in detail and found to be acceptable for piping risk-informed ISI in Section 3.4.2, Indirect Consequences, of Topical Report WCAP-14572, Rev. 1-NP-A (NRC-ADAMS: ML042610469), including the effects of jet impingement on other piping. Also see the further discussion in comment g below regarding the unrealistic conservatism of this assumption.
Response: The work that the commenter describes may, if appropriately applicable, be used to establish a quantitative relationship between variously sized LOCAs and the consequential effect of the LOCAs on ECCS. The responsibility is with the applicant to demonstrate that the work described by the commenter justifies adjustment of the definition of piping failure.

c) Regarding the discussion about the possibility of double-ended guillotine break of the largest reactor coolant loop (RCL) piping occurring, there are two points that need to be considered. First, any RCL piping break could only be postulated to occur during non-normal operation. For xLPR, the most likely limiting non-normal event would be a safe-shutdown earthquake (SSE) seismic event, where the probability of the SSE occurring in a given year ($<10^{-3}$) would have to be considered in the analysis of change in risk. Second, the NRC and industry efforts on large-break LOCA redefinition found that a single ended transition break size (TBS, NRC-ADAMS: ML04320641) was much more realistic. Note that the TBS is the largest sized attachment to the RCL piping.
Response: The commenter is correct that the frequency of the earthquake should to be considered. The xLPR Code accounts for frequency of the earthquake in post-processing. The comment about the transition break size is not relevant to the acceptance criteria. If the frequency of a double ended guillotine break is extremely small, then it will not contribute significantly to the overall failure frequency. There is no reason to artificially truncate break sizes just because they are less likely. The very fact that they are less likely automatically truncates their effect.

d) In Section 6.3, the use of a 50 GPM leak for all LOCA events by xLPR is conservative relative to the SBLOCA of 100 GPM that is provided by NUREG/CR-4550 (NRC-ADAMS: ML072710062) and was previously reviewed and accepted by NRC for use in probabilistic fracture mechanics analyses for piping risk-informed ISI in Supplement 1 to WCAP-14572, Rev. 1-NP-A on Structural Reliability and Risk Assessment (NRC-ADAMS: ML042610375).
Response: The commenter is correct that 50 GPM is conservative. It is a value selected for convenience as being a lower bound for normal make-up capacity. It is a trivial exercise to change the value from 50 GPM, which was selected to apply generically, to the actual documented leak rate of a small-break LOCA that would be applicable to any non-generic analysis. It may be possible to justify a generic value larger than 50 GPM.

e) The detectable leak rate of 10 GPM in Section 6.5 is 10 times the plant technical specification limit (TSL) of 1 GPM for unidentified leakage. Since exceeding the TSL could have severe regulatory consequences, the leak detection capability is always much less (typically ≤0.1 GPM) of the TSL.
Response: The commenter is correct that 10 GPM is conservative and much lower leak rate detectability thresholds are applicable and defensible in plant service. It is a simple exercise to change the value to a more realistic value. If the more realistic value is appreciably smaller than 10 GPM then there may be a need to evaluate the effects of uncertainty in the leak rate model. There is no need to address the uncertainty in the leak rate model for leak rates of 10 GPM. The value of 10 GPM was selected for convenience so that uncertainty in the leak rate model did not need to be considered. If results of a particular set of xLPR analyses do not meet the proposed acceptance criteria, one of the first logical steps in improving the accuracy of the analyses may be to change the leak rate for detectability to a more accurate value.

f) The first paragraph of Section 7.0 states that "If there are no interdependencies, then the annual failure frequency for each weld can be simply added together to determine the annual failure frequency for the system." First of all, locations within one or several similar dissimilar metal (DM) welds susceptible to PWSCC in the RCL piping system would have essentially the same operating characteristics and environment within a relatively small band of uncertainty. Furthermore, in version 2 of xLPR, the maximum normal operating and transient stresses of a DM weld are conservatively assumed to apply simultaneously at one single limiting location, top dead center. Likewise, the weld residual stress does not vary around the circumference of the pipe. Therefore, this single limiting DM weld location would have the highest calculated failure (loss of pressure boundary integrity) probability due to the dominating failure mechanisms of PWSCC and fatigue and would be expected to fail first. Any locations with lower failure probabilities would then no longer be of concern because they can no longer contribute anything more to this first failure mode.
Section 3.2.3, Piping Failure Potential, in the NRC Safety Evaluation Report (SER) for piping risk-informed ISI (WCAP-14572, Rev. 1-NP-A, NRC-ADAMS: ML042610469) states the following: "WCAP-14572 methodology involves assigning all significant degradation mechanisms present in a segment to a single weld, and imposing operating characteristics and environment to that weld. The failure probability developed from the Monte-Carlo simulation of this weld is subsequently used to represent the failure probability of the segment, regardless of the number of welds in the segment, or the length of the segment." The version 2 xLPR approach of calculating the failure (leak) probabilities at the limiting top dead center location would certainly be consistent with this NRC accepted approach for piping risk-informed ISI.
Response: The application of xLPR that is the objective of the Acceptance Criteria document is General Design Criteria 4 rather than risk informed inservice inspection. Evaluation for leak-

before-break requires evaluation of the piping system, rather than evaluation of one spot on one weld.

g) The second paragraph of Section 7.0 states that “Failures in the xLPR code are assumed to lead directly to core damage.” If this statement means that the conditional core damage probability (CCDP) is 1.0 for all failures, then it is extremely conservative since the PWR plant safety and shutdown systems are designed to accommodate a small break LOCA (typically a 100 GPM leak rate per previous comment d) with no damage at all. However, there is always a small chance that the safety and shutdown systems will not perform as designed, but a bounding value of CCDP would still be less than 0.01.
Furthermore, the reason for the above statement in Section 7.0 is the following statement in Section 6.1: “As a convenience for evaluating LBB, xLPR can treat all LOCAs as failures that lead to environmental effects in nearby safety equipment.” However, it is physically impossible for a 50 or 100 GPM LOCA leak rate to produce the same dynamic effects, such a pipe whip, as a full pipe rupture, even if that postulated pipe rupture is limited to the TBS as discussed in previous comment c.
Response: The commenter is correct in stating that there is a small chance that the safety and shutdown systems will not perform as designed after a small break LOCA. The commenter is also correct in the assertion that a small break is less likely to cause damage to nearby safety equipment than a large break. If there were a documented quantitative relationship between break size and probability of the safety and shutdown system not performing as designed, then that relationship could be substituted for the proposed relationship (i.e., all LOCAs lead to ECCS failure). It is a appropriate to replace the proposed relationship with the actual quantitative relationship. It is not a trivial exercise to develop such a relationship.

h) Section 7.2 states that “When an analysis yields results that are close to the acceptance criteria it may be necessary to address uncertainty. Methods to address uncertainty might include qualitatively describing the conservatism in the models, inputs, and assumptions used to calculate the mean result, or otherwise evaluating the distribution of the results. The objective of the evaluation of uncertainty is to document that the analysis is not systematically non-conservatively biased. Consideration of uncertainty does not mean that a deterministic margin or a multiple of standard deviations needs to be added to results close to the acceptance criteria. The acceptance criterion of 10^{-6} failures per year was developed with the understanding that it is to be assessed against the 95% confidence level of mean results.”
Note that the third and fourth bullets of Section 1.2 (Background) in Regulatory Guide 1.174 (NRC-ADAMS: ML003740133) states that “PRA evaluations in support of regulatory decisions should be as realistic as practicable” and “The Commission’s safety goals for nuclear power plants and subsidiary numerical objectives are to be used with appropriate consideration of uncertainties”. Since version 2 of xLPR satisfies these requirements in all cases, any additional conservatism close to the acceptance criteria is not warranted. Furthermore, the last two sentences of the Section 7.2 requirements quoted above are conflicting in that the standard deviation on the mean value would be needed to calculate a 95% confidence bound.
Response: The document states: “Consideration of uncertainty does not mean that a deterministic margin or a multiple of standard deviations needs to be added to results close to the acceptance criteria.” The commenter opines that this statement is ambiguous. The following words will be added to the document in an attempt to reduce ambiguity: “Addition of conservatism when results are close to the acceptance criteria is not warranted.”
With respect to commenter’s second point, the sentence sequence will be revised to resolve the apparent conflict.

Comment Set 2

Comment 1: In section 2.1 the following words appear: “For xLPR, a failure is defined as a leak that satisfies both of the following criteria: (1) the leak rate exceeds 50 gallons per minute (gpm) in the time interval of a code iteration loop and (2) the leak rate was less than 10 gpm at the end of the previous code iteration loop time step. This definition is general. The values may be changed for plant-specific applications with appropriate justification.”
The commenter asks whether, with respect to the words “in the time interval of a code iteration loop” shortening the time interval can lead to disappearance of failures.
Response: In some cases shortening the time interval will eliminate failures. Consider a result where a LOCA occurred in time interval between iteration 50 and iteration 51. It does not matter how long the time interval is, after iteration 50 a leak was not observed, and at iteration 51 the crack had grown so the leak rate exceeded 50 GPM. This describes a failure because both criteria are met.
Now if the analyst decreases the duration of time steps by, for example, a factor of ten, then there would be ten times as many intervals. The same example would identify some iteration between iteration 500 and iteration 510 where the leak rate exceeded 50 gpm. The same example would identify some iteration between iteration 500 and iteration 510 where the leak rate was observed to exceed 10 gpm. If the iteration where the leak rate exceeded 10 gpm was at least one iteration before the one where the leak rate exceeded 50 GPM, then operators would notice the leak and the crack would never progress to a LOCA. This would not be a failure because the second criteria would not be met. So decreasing the length of the interval can eliminate LOCAs. If, on the other hand, the leak rate exceeded both 10 GPM and 50 GPM in the same time step, then the result would still be a failure.

Comment 2: Section 2.2 states: “For applications of xLPR other than LBB, the processes and acceptance criteria described in Regulatory Guide 1.174, “An Approach for Using Probabilistic Risk Assessment in Risk Informed Decisions on Plant-Specific Changes to the Licensing Basis [Ref. 1],” may be applicable.” The commenter asks: “Do we have any idea why the application of xLPR beyond LBB would not be acceptable under RG 1.174?”
Response: Two examples of types of xLPR applications where R.G. 1.174 is not applicable include: 1) applications where use of R.G. 1.174 is specifically prohibited and 2) applications where the xLPR output cannot be used to generate failure frequencies that can be converted into CDF or LERF. It is not known whether future applications of xLPR outside of LBB will include applications that fit either of these examples.

Comment 3: Section 2.2 states: “Acceptability of the code itself will be established by the Office of Nuclear Reactor Regulation (NRR) after the code is delivered for review.” The commenter states: “This seems to say if NRR is comfortable with a deterministic approach they can decide not to use the xLPR at all. I am a little concerned by this statement since NRR involvement in the xLPR construct has been limited and we are not sure it addresses all their concerns.”
Response: The intent of the statement is to reflect the temporal reality that NRR will not officially review the acceptability of xLPR until after it is presented to them for review. The intent of the statement is not to suggest that NRR will decline to review the code.

Comment 4: Section 3.1 states: “The current approach in SRP 3.6.3 is a deterministic flaw tolerance approach. As such, it relies on the application of explicit margins to ensure the probability of rupture is extremely low.” The commenter states: “If we know these margins would it not be helpful to demonstrate how these margins are addressed within xLPR.”

Response: Absolutely. Use of xLPR to identify the level of risk associated with the deterministic approach would be an enlightening exercise.

Comment 5: Section 4.1 states: “There are two aspects of acceptance: results and inputs, which include the technical basis for the code calculations.” The commenter states: “I think I understand that acceptance criteria for the results needs (to be) defined and laid out, but the inputs are data defining the stress, material properties, crack growth, etc. which should not be subject to acceptance.”
Response: When NRR reviews licensing actions NRR checks that the inputs used for analytical bases for the licensing action are appropriate. The sentence in the text describes normal NRR procedures for reviewing licensing actions.

Comment 6: Section 4.1 states: “There are a variety of types of applications envisioned for xLPR, so there may be a variety of acceptance criteria.” The commenter states: “…if the Acceptance Criteria is tied to the risk metrics of RG 1.174, would not the acceptance criteria be the same or very similar?”
Response: The xLPR Code is adaptable to many different types of problems. When xLPR is used to evaluate the frequency of events that have the potential to lead to core damage, the risk metrics of R.G. 1.174 would typically be applicable. In cases where xLPR is used to calculate something that is not related to core damage, R.G. 1.174 would not typically be applicable.

Comment 7: Section 4.1 states: “The acceptance group will not define acceptable uses of the xLPR Code or establish any new regulatory acceptance process.” The commenter states: “If xLPR is used to addressed LBB and GDC 4, would that approach not be considered an acceptable approach or protocol for other applications?”
Response: If xLPR is used to addressed LBB and GDC 4, that approach would be considered an acceptable approach or protocol for other applications if the other applications are sufficiently similar.

Comment 8: Section 5.1 states: “The xLPR Code outputs leak rate, but does not give information about consequential effects like pipe whip.” The commenter states: “Agreed but failure in xLPR is defined as leakage not rupture and if xLPR shows the probability of leakage is very low does this matter?”
Response: The rhetorical question posed by the commenter is answered in the follow-on paragraph in the same section: “If the calculated annual LOCA frequency is low enough, then even if every LOCA led directly to core damage, it would still be possible to show the CDF resulting from LOCAs was adequately low.” The answer to the commenters question is no.

Comment 9: Section 6.1 states: “Traditionally, rupture is defined as circumferential cracking leading to piping failure resulting in a double-ended guillotine break capable of discharging steam jets, causing pipe whip and creating missiles affecting the function of nearby structures, systems or components important for safety.” The commenter states: “I assume that if xLPR attempts to model a double-ended break the frequency of occurrence would be extremely low since two independent pipe welds would be required to develop and grow a crack to rupture at exactly the same moment in time, if one ruptures earlier many of the forces associated with the double-ended rupture would be lessened.”
Response: An example of a double-ended guillotine break is a single weld with a circumferential crack that propagates entirely around the weld, followed by displacement of the pipe so that coolant is able to escape from both broken ends of the pipe. Failure of a second weld is not necessary for a double- ended guillotine break.

Comment 10: Section 6.1 states: “However, xLPR is able to model failures that are not double-ended guillotine breaks which would nevertheless be able to discharge a large volume of steam with considerable force. Such failures, which would not be traditional ruptures, could create environmental conditions affecting nearby safety equipment.” The commenter states: “True but would not the consequences of non-double guillotine ruptures be smaller since the xLPR recognizes that 'failure' of the piping is not instantaneous. The pipe leaks and starts to relieve pressure which should mitigate these effects.”
Response: The comment is accurate, but there is no consequential damage module in xLPR or in the PRA. The transfer function between leak size and consequential damage does not exist a manner or format that is currently useful for xLPR.

Comment 11: Section 6.4 states: “If the time increments are changed from 1 month to some other increment, the proposed failure criteria would need to be validated or appropriately revised.” The commenter stated: “Does this imply that shorter time steps would be bounded by the longer time step outputs? Thus the 1 month tie step is a conservative feature of the Code.”
Response: Yes, shorter time steps are bounded by longer time steps. The user selects the time step. A one month time step is conservative. There is no technical basis for use of 1 month time steps or shorter or longer time steps. The initial selection of 1 month was arbitrary. Use of shorter steps would require justification for operator action times if the time step became shorter than about a day or two.

Comment 12: Section 7.0 states: “However, if the welds are close together, perhaps inches apart if they are on opposite sides of a short safe end, then a leak detected on one weld would likely result in repair that would affect both welds.” The commenter stated: “If a safe-end is used there would not be two DM welds close together so I do not see why the frequency of the second weld would be reduced sine we are addressing PWSCC of DM welds.”
Response: This is a hypothetical example constructed to illustrate how repair of one weld prior to rupture could lead to repairs of similar welds on the same system that would prevent their subsequent rupture. In this hypothetical example there are two dissimilar metal welds close together. They were hypothetically installed close together for the express purposes of making the point made in the statement.

Comment 13: Section states: “Failures in the xLPR code are assumed to lead directly to core damage.” The commenter stated: “This is really conservative. Failure is defined in 2.1 as leakage not rupture. One gets core damage when the make-up systems cannot keep the core covered, so the leakage would need to exceed make-up capacity. Once the plant is depressurized and on secondary cooling or drawing from the sump, core damage should not occur.
I could agree with this if the phrase, 'exceeding the make-up capacity of the ECCS'.”
Response: Section 6.3 states: “A LOCA should be defined as any leak with a rate that exceeds the leak rate of a small-break LOCA as defined in the PRA. This will vary from plant to plant, but will be approximately equal to the capacity of a single charging pump, which is typically greater than 50 gallons per minute.’ This statement provides the condition that the commenter sought.

Comment 14: Section 8 is titled: “Conservatisms in the xLPR Acceptance Approach.” The commenter stated: “Additional conservatisms may include the assumption that all xLPR failures lead to Core Damage, the computational codes used are based upon the ASME formulas and equations which are conservative and material properties used tend to be lower bound.”

Response: The first additional conservatism the commenter identifies is the same conservatism identified in the paragraph that follows the title. With respect to the other suggested additions, the computational codes are supposed to use best estimate models and material property inputs, so these should not be sources of significant conservatism.

Comment Set 3

Comment 1: In the first paragraph under section 2.2, we talk about the need to ensure that the probability of 'all applicable welds in a plant' is less than 1E-06. I think this is a good time to tighten that up a bit so we all have the same scope in mind. I would propose something more like: 'the total rupture probability of all exempted, high energy piping welds within all environmental zones that contain SSD equipment shall be less that 1E-6'. I understand what I have proposed may not be what we want; I just wanted to identify some of the boundaries behind the 10E-6.
Response: The recommended changes will be incorporated.

Comment 2: I like the explanation for how we (conservatively) chose to use a default rupture probability of 1E-6/y, and the implication that licensees might use similar logic on a plant specific basis. I just think we should be clear that NRC approval needs to be based on an acceptable rupture probability (and not a PRA CDF/LERF number) since rupture probability is the only variable that 10CFR50 allows the NRC to use in granting exemptions for equipment protection. (I may be mistaken on this but, I don't think the NRC can approve exemption from piping restraints based on a PRA risk number – I think we would need a CFR50 change to do that).
Response: Section 9.0 states: "For xLPR, a failure is defined as a leak that satisfies both of the following criteria: (1) the leak rate exceeds 50 gallons per minute (gpm) in a code iteration loop time step, and (2) the leak rate was less than 10 gpm at the end of the previous time step. The recommended acceptance criterion for leak-before-break analysis is a failure frequency less than 10^{-6} failures per year." It is believed that these statements clearly refer to piping failure frequency rather than CDF.

Comment 3: I didn't expect to see 50.59 discussed (late in section 4.2). I have difficulty envisioning any situation where 50.59 would allow a licensee could adopt the xLPR method of analysis without obtaining NRC approval. The text seems to imply that potential. It's good to get these issues on the table, but do we want to get into that area in this document?
Response: It agreed that it is unlikely that a 50.59 screening would result in anything other than a determination for the need to submit for NRC approval. Therefore, the wording in the section will be revised to reflect that the screening must be performed, but will probably result in the need for a submittal.