UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

April 23, 2012

Mr. R.W. Borchardt
Executive Director for Operations
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: EXTREMELY LOW PROBABILITY OF RUPTURE PROJECT

Dear Mr. Borchardt:

During the 593rd meeting of the Advisory Committee on Reactor Safeguards, April 12-14, 2012, we completed our review of the Extremely Low Probability of Rupture (xLPR) project. We were briefed by the NRC staff during our 592nd meeting, March 8-10, 2012, and our Materials, Metallurgy, and Reactor Fuels Subcommittee also reviewed this research during a meeting on September 21, 2011. During these meetings, we had the benefit of discussions with representatives of the NRC staff and the documents referenced.

CONCLUSIONS

1. The project to develop the xLPR modular probabilistic fracture mechanics computer code is well structured, organized, and responsive to the Office of Nuclear Reactor Regulation (NRR) user need request.

2. The most challenging technical issue to be addressed in the xLPR code development will be the crack initiation phenomenon. Early development of the crack initiation module should be emphasized to determine whether a realistic crack initiation model is feasible.

3. Should the development of the crack initiation module prove to be intractable, the major advances in the xLPR code in fracture mechanics, the characterization of weld residual stresses, and treatment of uncertainties will greatly improve our capability to determine component rupture probabilities.

BACKGROUND

The NRR user need request for the development of an analytical method for evaluating the probability of leak before break (LBB) of nickel alloys exposed to primary water environments provides an excellent summary of the background and need for this research. In 1984, the NRC granted exemptions from the requirements of General Design Criterion -4 (GDC-4) by accepting LBB analyses. In 1987, GDC-4 was revised to allow dynamic effects associated with postulated pipe ruptures to be excluded from the design basis when analyses demonstrated that the probability of fluid system piping rupture was extremely low. The statement of considerations for the revision stated that "*the leak-before-break approach should not be considered applicable to fluid system piping that operating experience has indicated is particularly susceptible to failure from the effects of corrosion.*" Standard Review Plan (SRP) Section 3.6.3, "Leak-Before-Break Evaluation Procedures," states that "*evaluations must demonstrate that these [corrosion] mechanisms are not potential sources of pipe rupture.*" In practice, review criteria were implemented that excluded systems with potential corrosion degradation mechanisms.

SRP Section 3.6.3 describes the current methodology for LBB piping safety assessment. This section of the SRP is deterministic but seeks to demonstrate compliance with a probabilistic regulatory requirement. Because of the high level of conservatism and margins used in this approach, the staff is satisfied that adequate structural margins exist in all welds currently approved for LBB.

Operating experience has conclusively demonstrated that pressurized water reactor (PWR) reactor coolant pressure boundary (RCPB) components containing dissimilar metal (DM) welds fabricated from Alloy 82/182/600 are susceptible to primary water stress corrosion cracking (PWSCC). In response to observed leaks and nondestructive examination (NDE) indications of potential cracks attributed to PWSCC, the industry has performed a number of mitigating actions or has replaced the susceptible Alloy 82/182/600 with the more stress corrosion crack resistant Alloy 52/152/690. Although no PWSCC-related ruptures of LBB components have occurred, long-term operation may erode LBB margins. The staff has employed deterministic analyses to show that mitigation techniques applied to DM butt welds result in configurations that have extremely low probabilities of failure. Welds containing large defect indications have been repaired and very small indications have been determined to be acceptable in accordance with applicable codes. However, numerous small, acceptably sized indications may affect potential future propagation of PWSCC, particularly if the Alloy 52/152/690 replacement material exhibits PWSCC susceptibility after long-term operation.

In response to the user need request, a multi-task cooperative research program with industry has been initiated that will produce a flexible, modular probabilistic fracture mechanics code that can be used to assess the risk of pressure boundary rupture and compliance with GDC-4. The program will include the collection of data on material properties, fracture mechanics, PWSCC, NDE, welding, and the effects of water chemistry. The code will be updated based on reviews from a program integration board, an external expert review committee, and the staff. Currently, the research program and issuance of regulatory guidance is planned to be completed by the end of 2015.

The xLPR code is being developed in three distinct versions. Each code version is being developed to satisfy a specific user need. Version 1.0 is a pilot study to evaluate the feasibility of a code with a modular structure that can quantify uncertainties. Version 2.0 will be expanded to evaluate welds within primary system piping to provide a technical basis for LBB regulatory guidance. Phenomena to be addressed include fatigue, axial cracking, intergranular stress corrosion cracking (IGSCC), transition from surface cracking to through-wall cracking, and manufacturing defects. Version 3.0 will be applied to the entire reactor coolant pressure boundary including the piping, the reactor vessel, and the steam generator.

DISCUSSION

The staff has developed several fracture mechanics codes to evaluate specific structural issues caused by materials degradation. For example, the FAVOR code was successfully developed and used to evaluate reactor vessel integrity, and a specific fracture mechanics analysis was performed to evaluate the reliability of cladding on the Davis-Besse reactor vessel head. The technology for performing probabilistic fracture mechanics has advanced significantly during the past decade, and it is the staff's view that it is now possible to develop codes to directly calculate the effects of PWSCC on the probability of RCPB component rupture.

To complete the development of the xLPR code, the staff has assembled and organized an impressive NRC/national laboratory/industry team to address the many complex materials, mechanical, and computational issues that affect pipe rupture probability. The initial version of the xLPR code has been developed and applied to the evaluation of a Westinghouse-type pressurizer nozzle DM weld to demonstrate the feasibility of the project and to identify areas for improvement in the project approaches. This initial study has led to the recognition of the importance of the crack initiation phenomenon in the overall analysis. The staff has taken on the daunting challenge of developing quantitative methods to analyze the influence of the variables which control PWSCC crack initiation. While we support this initiative, it should be recognized that crack initiation is the least quantified of the phenomena which control stress corrosion cracking and ultimate rupture. While sophisticated test methods have been developed and used successfully to measure IGSCC crack growth rates in stainless steels exposed to boiling water reactor coolant environments and PWSCC crack growth rates in nickel alloys exposed to PWR environments, no generally accepted methods have been developed to measure crack initiation under prototypical conditions. It is often observed that stress corrosion cracks nucleate at heterogeneities caused by materials or fabrication variables. Also, variations in the aggressiveness of the water chemistry to which a component is exposed during startup, normal, or off-normal operation can significantly affect crack initiation. Because of these complexities as well as the probable lack of adequate experimental data, the development of a crack initiation module may prove more difficult than expected. Consequently, early development of the crack initiation module should be emphasized to determine whether a realistic crack initiation model is feasible.

Should the development of the crack initiation module prove to be intractable, the major advances in the xLPR code in fracture mechanics, the characterization of weld residual stresses, and treatment of uncertainties will greatly improve our capability to determine component rupture probabilities.

We would welcome the opportunity to review the staff's progress in the crack initiation module of the xLPR code.

Sincerely,

/RA/

J. Sam Armijo
Chairman

REFERENCES

1. NRR Memorandum, User Need Request on Development of A Probabilistic Method for Evaluating the Probability of Leak-Before-Break of Nickel Based Alloys Exposed to Primary Water Environments, dated August 26, 2010 (ML102140300)

2. NUREG-0800, Standard Review Plan, 3.6.3 Leak-Before-Break Evaluation Procedures, Revision 1, March 2007 (ML030280295)

3. xLPR Version 1.0 Report: Technical Basis and Pilot Study Program Results; xLPR Computational Group, February 2011 (ML110660292)

4. NUREG/CR-6854, Fracture Analysis of Vessels — Oak Ridge FAVOR v04.1, Computer Code: Theory and Implementation of Algorithms, Methods, and Correlations, August 2004 (ML051790408)

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1. NRR Memorandum, User Need Request on Development of A Probabilistic Method for Evaluating the Probability of Leak-Before-Break of Nickel Based Alloys Exposed to Primary Water Environments, dated August 26, 2010 (ML102140300)

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Letter to Mr. R. W. Borchardt, EDO, from J. Sam Armijo, ACRS Chairman, dated April 23, 2012

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