15th International Conference on Fracture (ICF15)
June 11-16, 2023 Atlanta, GA USA

xLPR: A Probabilistic Code for fatigue and PWSCC analysis of weld in Nuclear Power Plant

Cédric Sallaberry[1], Robert Kurth[1*], Frederick Brust[1], and Elizabeth Kurth-Twombly[1]

[1]*Engineering Mechanics Corporation - 3518 Riverside Drive Suite 202 - Columbus OH 43221-1735, USA*
** Presenting Author email: bkurth@emc-sq.com*

Abstract
The US NRC and EPRI have developed a probabilistic fracture mechanics code through a memorandum of understanding. The code is called xLPR (extremely low probability of rupture) and can be used to evaluate a variety of structural integrity problems dealing with fatigue and primary water stress corrosion cracking (PWSCC) degradation. The code version 2 is now officially released and has been used by both NRC, EPRI and their contractors to perform a series of studies.

1. Introduction

In 2008, the NRC Office of Nuclear Regulatory Research signed a memorandum of understanding addendum with the Electric Power Research Institute (EPRI) to cooperatively develop a PFM code to analyze risks associated with nuclear power plant piping systems subject to active degradation mechanisms. The resultant PFM code was called "xLPR" [1]. The code was constructed by assembling a wide range of experts in fracture mechanics and probabilistic analysis of nuclear power plant piping systems. The requirements were that the state-of-practice for the deterministic models be incorporated, and the code must be modular to allow improvements to be implemented.

2. The xLPR code

xLPR Version 2 incorporates a set of state-of-practice deterministic models to evaluate both fatigue and PWSCC degradation mechanisms from crack initiation and growth until rupture. It also models weld residual stresses (WRS), leak rate detection, ISI, and seismic events. Additionally, it can model the various techniques employed in nuclear power plants to mitigate PWSCC. The various models are each implemented in a modular form and linked together by a central probabilistic framework that contains the logic for code execution. This version of the code was developed under a rigorous quality assurance program and independently reviewed by a panel of experts.

3. Example of xLPR application to fatigue problem

The xLPR probabilistic fracture mechanics code was used to demonstrate that a selected pressurized-water reactor (PWR) piping system exhibits an extremely low probability of rupture consistent with the requirements [2]. The piping system selected for this study is the primary or main loop piping in a Westinghouse four-loop PWR design. The base case analysis was supported by several sensitivity study challenging some of the assumptions and distributions. Some of these sensitivity analyses considered the impact of transients either coupled with PWSCC or treated separately. Transients generated by plant shut down and start up, as well as loading and unloading were considered.

a. Combined fatigue/PWSCC impact

A first sensitivity analysis set considered the addition of fatigue mechanisms due to transients to the PWSCC degradation. Figure 1 displayed the comparison of probability of crack initiation(black), leakage (blue) and rupture (red) between PWSCC only degradation (plain line) and when fatigue is added (dashed line). It can be noted that fatigue tends to increase the likelihood of having a crack and leakage but does not affect the probability for the pipe to rupture

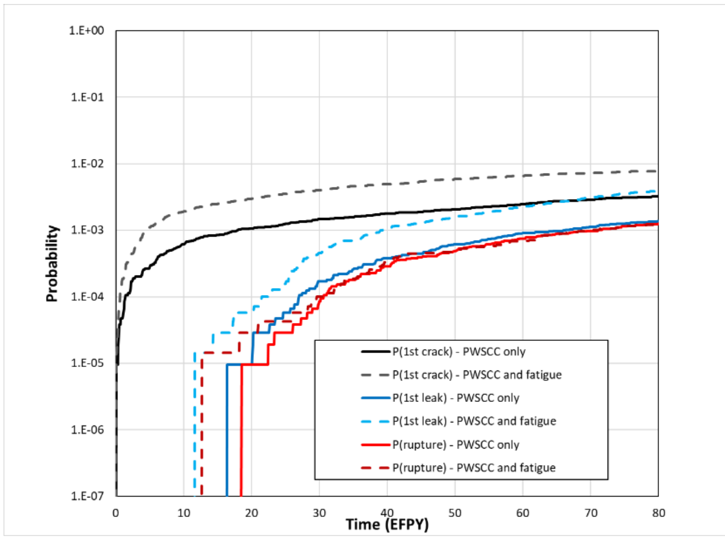

Fig.1 – Comparison between PWSCC only and PWSCC + fatigue results

a. Fatigue only mechanisms

A second sensitivity analysis set considered the impact of fatigue mechanisms by themselves. No initiation occurred over the 80 years period considered for 100,000 realizations, showing the extremely low probability of even crack occurring when no active degradation mechanisms are considered. This is in agreement with analysis previously performed using other deterministic or probabilistic codes [3].

4. Conclusions

Over the last 4 years, US-NRC, EPRI and their contractors have increasingly used the PFM code xLPR to perform analyses in support of risk-informed decision making. It is believed that the importance of a consistent treatment of uncertainty will be pursued in the future to provide more insights for regulatory decision making and that xLPR will be a key software in the structural integrity area.

5. References

[1] D. Rudland and C. Harrington, "xLPR Pilot Study Report (NUREG-2110)," U.S. Nuclear Regulatory Commission, Washington,DC 20555-0001, 2012.

[2] C. Sallaberry and others, "TLR-RES/DE/CIB-2021-XX, "Probabilistic Leak-Before-Break Evaluation of Westinghouse Four-Loop Pressurized-Water Reactor Primary Coolant Loop Piping using the Extremely Low Probability of Rupture Code, ADAMS Accession Number ML21217A088," NRC, Washington, DC, 2021.

[3] R. Tregoning, L. Abramson and P. Scott, "NUREG-1829 : Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process," U.S. NRC, Washington D.C., 2008.

Acknowledgements

This report was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for any third party's use, or the results of such use, of any information, apparatus, product, or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights. The views expressed in this paper are not necessarily those of the U.S. Nuclear Regulatory Commission.