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

# Applications of the Extremely Low Probability of Rupture (xLPR) Code

Christopher Nellis[1]* and Matthew Homiack[1]

[1]*U.S. Nuclear Regulatory Commission, Washington, DC, USA*
** Presenting Author email: Christopher.Nellis@nrc.gov*

## Abstract

To analyze the integrity of piping components in nuclear power plants (NPPs), the U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research and the Electric Power Research Institute jointly developed a probabilistic fracture mechanics computer code. The Extremely Low Probability of Rupture (xLPR) code simulates crack initiation and growth from fatigue and stress corrosion cracking (SCC) degradation mechanisms and other aspects of piping component structural integrity. This presentation provides an overview of the NRC staff's applications of the xLPR code since its public release in 2020 to assist in risk-informed regulatory evaluations of leak-before-break (LBB) analyses for pressurized water reactor piping systems with dissimilar metal welds susceptible to SCC. Potential use of the xLPR code to estimate loss of coolant accident (LOCA) frequencies and to interface with artificial intelligence machine learning (AI/ML) models are also discussed.

## 1. Introduction

Probabilistic fracture mechanics (PFM) is being increasingly utilized in aiding regulatory decision-making through policies that place emphasis on cost-benefit analyses and risk-based metrics. This emphasis makes PFM attractive as probabilistic methods can properly treat uncertainties, like stress distribution, and provide the statistical data to assess the risk of failure. Since its public release in 2020, the NRC staff has been applying the xLPR code to support safety decisions in the following areas:

- Leak-before-break analyses
- LOCA frequency estimation
- Sensitivity analysis through interface with AI/ML tools

Under the NRC's regulations in Title 10 of the *Code of Federal Regulations*, Part 50, Appendix A, General Design Criterion 4, structures, systems and components in an NPP are required to accommodate the effects of environmental conditions including postulated accidents; however, the dynamic effects from pipe ruptures may be excluded if the probability of rupture can be shown to be extremely low under design basis conditions. Extremely low probabilities of rupture have been demonstrated with deterministic LBB analyses, that compromises in piping integrity (leakage) can be detected before rupture. New information on SCC in nickel-based dissimilar metal welds prompted the NRC staff to develop a probabilistic approach to these analyses. In the first applications of the xLPR code, prior LBB analyses for approved piping systems were reevaluated by the NRC staff to determine whether the probability of rupture remains extremely low considering the effects of SCC.

LOCA frequency estimates are used to support several aspects of the NRC's regulatory framework. As examples, they have been used for initiating event frequencies in probabilistic risk assessment models, informing maintenance frequencies, and evaluating the design-basis pipe break size. Currently, the NRC staff use the LOCA frequency estimates in NUREG-1829, "Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process," issued April 2008. The NRC is investigating whether the xLPR code can be used to provide numerical insights that could be used to inform an update to this report.

Additionally, the NRC staff has issued Regulatory Guide 1.245, "Preparing Probabilistic Fracture Mechanics Submittals," in January 2022 to provide a framework to develop the contents of licensing submittals that the NRC staff considers acceptable when performing PFM analyses in support of regulatory applications. The guidance states that applicants should perform sensitivity analyses to identify the inputs that drive uncertainty in the quantities of interest. The NRC staff is investigating ways in which AI/ML models can be coupled with the xLPR code to conduct sensitivity analyses more efficiently and effectively.

## 2. Results

This presentation presents a selection of results from the NRC staff's applications of the xLPR code. In the area of LBB analyses, results from the xLPR code were used to demonstrate that the probabilities of piping system rupture remain extremely low when subject to SCC. The breadth of analyses also provides greater insights into the performance of dissimilar metal welds in pressurized water reactors. Exploratory results for generating LOCA frequency estimates for piping systems are also presented and compared with previous expert elicitation estimates. Finally, sensitivity analysis results from AI/ML tools are presented along with use of these for enhancing xLPR simulations.

## 3. Conclusions

The xLPR code has been extensively developed using mature, best estimate models. Initial uses of the xLPR code have demonstrated a usefulness for a broad range of nuclear regulatory applications, which include LBB analysis and LOCA frequency estimation. In addition, the flexibility of the xLPR code has been used to explore enhanced capabilities through the coupling with AI/ML models.

## 4. Acknowledgements

The authors would like to thank the team at Engineering Mechanics Corporation of Columbus—Dr. Cédric Sallaberry, Dr. Frederick Brust, Dr. Robert Kurth, and Ms Elizabeth Kurth-Twombly—for their efforts in conducting the leak-before-break and LOCA estimate analyses. The authors would also like to thank the team at Sandia National Laboratories—Mr. Steven Verzi and Mr. Joseph Lubars—for their efforts in exploring the use of AI/ML models.