Paper Title:

Probabilistic Fracture Mechanics Codes for Piping International Benchmark – Part 1: Deterministic Comparisons

Abstract:

Probabilistic fracture mechanics (PFM) supports risk-informed decisionmaking. In PFM, fracture models are incorporated into a dynamic, Monte Carlo simulation environment to generate component failure frequency estimates with quantified uncertainties. A host of PFM codes have been developed within the Organisation for Economic Co-operation and Development (OECD) member states during the last four decades to support the continued safe operation of aging nuclear power plant components. However, these codes have been designed using different models and assumptions because there are no internationally accepted PFM standards. To understand the effects of the different modeling approaches, the metals sub-group of the Working Group of Integrity and Ageing of Structures of the Committee on the Safety of Nuclear Installation of the OECD's Nuclear Energy Agency is conducting a project to benchmark PFM codes for piping applications. The scope of the project involves 15 PFM codes from as many participating organizations. One of the initial objectives is to compare the deterministic fracture mechanics models used in the codes, because the deterministic crack growth results govern the subsequent stochastic analyses.

This paper describes the deterministic problems of the benchmark study and compares the results of the analyses of these problems using the PFM codes. The benchmark problems focus on determining the leak-before-break behavior of a nickel-based alloy weld in a large-bore piping system of a pressurized-water reactor. The modeled aging degradation mechanism is primary water stress-corrosion cracking. The benchmark problems were analyzed with the PFM codes using their models for normal operating and residual stresses, stress-intensity factors, crack growth rates, crack transition, crack-opening displacement, rupture, and leak rate. Several output quantities of interest relevant to leak-before-break behavior were compared among the codes. Other outputs were also compared, including the crack lengths and depths, stress-intensity factors at the crack tips, inner and outer diameter crack opening displacements, and leak rates as a function of the simulated component operating time. An interpretation of these comparisons is provided in relation to the underlying models to better understand the effects of the different modeling choices. Insights from this study will be used to inform probabilistic benchmark cases, which will be presented in a subsequent paper.

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