ABSTRACT

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Title: A Study on the Failure Analysis of the Irradiated Reactor Pressure Vessel Support using Finite Element Analysis
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One of the major degradation mechanisms in a nuclear power plant structural or mechanical component is the neutron embrittlement of the irradiated steel component. High energy neutrons change the microstructure of the steel, so the steel loses its fracture toughness. This neutron embrittlement increases the risk of the brittle fracture. Meanwhile, the reactor pressure vessel support is exposed in low temperature with high neutron irradiation environment which is an unfavorable condition for the fracture failure. This study conducted the failure assessment of a reactor pressure vessel support using the fitness-for-service failure assessment diagram of API 579-1/ASME FFS-1 with quantifying the structural margin under the maximum irradiation and extreme load events.

Two interrelated studies were investigated. The first investigation reviewed current analytical methods to estimate the embrittled properties, such as fracture toughness and the yield strength incorporates the low irradiation temperature. The analytical results indicated that the reactor pressure vessel support may experience substantial fracture toughness decrease during the operation near the lower bound of the fracture toughness. A three-dimensional (3D) solid element finite element model was built for the linear stress analysis. Postulated cracks were located in the maximum stress region to compute the stress intensity and the reference stress ratio. Based on the stress result and the estimated physical properties, the structural margin of the reactor pressure vessel support was analyzed in the failure assessment diagram with respect to the types of the cracks, level of the applied load and the level of the neutron influence.

The second study explored the structural stress analysis approaches at hot-spots which was found to be key parameter in failure analysis. Depending on the methods to remove the non-linear peak stress and the stress singularities, the accuracy of the failure assessment is subject to vary. As an alternative propose to evaluate the structural stress in 3D finite element analysis (FEA), the 3D model was divided into two-dimensional (2D) plane models. Five structural stress

determination approaches were applied in 2D FEA for a comparison study. Reconstructing the structural stress in 3D was carried by the 3x3 stress matrix and compared to the 3D FEA results. The difference in 2D FEA structural stress results were eliminated by the constructing the stress in 3D.

This study provides the failure assessment analysis of irradiated steel with prediction of the failure modes and safety margin. Through the failure assessment result, we could understand the effects of different levels of irradiation and loadings. Also, this study provides an alternative structural steel determination method for three-dimensional (3D) solid element model using the finite element analysis.