SUMMARY OF KEY RESULTS FROM THE HEAVY-SECTION STEEL IRRADIATION PROGRAM*

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ABSTRACT

The Heavy-Section Steel Irradiation (HSSI) Program at Oak Ridge National Laboratory, sponsored by the U.S. Nuclear Regulatory Commission (USNRC) , is assessing the effects of neutron irradiation on RPV material behavior, especially fracture toughness. Prototypic RPV materials are well characterized in the unirradiated condition, and following exposure to radiation under varying conditions; the effects of thermal annealing on mitigation of embrittlement and reirradiation are also studied. Mechanical property tests are conducted to provide data which can be used in the development of guidelines for structural integrity evaluations, while metallurgical examinations and mechanistic modeling are performed to improve understanding of the mechanisms responsible for embrittlement. The results of these investigations, in conjunction with results from commercial reactor surveillance programs, are used to develop a methodology for the prediction of radiation effects on RPV materials. This paper summarizes some of the key results from the HSSI Program in the area of irradiation effects on mechanical properties.

When the HSST Program was initiated in 1967, the United States Atomic Energy Commission had, in fact, already sponsored two irradiation effects projects, and the HSST Program assumed managerial responsibility for them and for the formulation of plans for extensions of those projects. It is important to note that the ASTM standard for fracture toughness testing was in the early stages of development. The results from those early programs were important in that they showed irradiation-induced degradation of fracture toughness, a strong temperature dependence of postirradiation fracture toughness, a need for larger specimens, and that the K_{Ic} temperature shift was about the same as the Charpy V-notch (CVN) 41-J shift. In 1972, a series of irradiation experiments was begun in response to the need for information regarding effects of neutron irradiation on the mechanical properties, particularly fracture toughness, of RPV steels. The eight completed projects included irradiation effects on (1) dynamic fracture toughness; (2) and (3) ductile tearing resistance; (4) state of the art welds; (5) and (6) temperature shift and shape of K_{Ic} and K_{Ia} curves; (7) stainless steel cladding; (8) commercial low upper-shelf welds; and (9) thermal annealing and reirradiation . Two ongoing projects include effects of irradiation on the shape of the fracture toughness master curve for highly embrittled steel, and the effects of irradiation and thermal annealing on the propensity for temper embrittlement in heat-affected-zones. All of the investigations have contributed results having significance to the integrity analyses of reactor vessels. The experimental programs have provided key results regarding the fracture behavior of RPV steels under conditions of irradiation, thermal annealing, and reirradiation, to include effects of copper and nickel content, relationships between Charpy impact toughness and fracture toughness (both initiation and crack-arrest toughness), specimen size effects, and statistical variability. Atom-probe field-ion microscopy, atom-probe tomography, and small-angle neutron scattering measurements have revealed detailed information regarding the chemical composition, size, and density of precipitates in irradiated and annealed steels. In the modeling studies, primary radiation damage simulation using molecular dynamics has provided input for the development of a kinetic embrittlement model which compares favorably with data from commercial reactor surveillance programs.

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