Modeling of neutron irradiation embrittlement of reactor pressure vessel steels

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Reactor pressure vessels (RPVs) of nuclear power plants are exposed to the fast neutron irradiation during plant operation, which causes reduction in fracture toughness of the RPV steels. This phenomenon is known as neutron irradiation embrittlement of RPV steels, and is a primary concern for the structural integrity analyses of the RPVs. The estimation of the reduction in fracture toughness, which is normally evaluated in terms of a shift in ductile-to-brittle transition temperature, is a key technology for the safe operation of nuclear power plants.

The initial process of the embrittlement is a displacement cascade of lattice atoms due to neutron bombardment. The lattice defects produced diffuse to cause structural changes of materials in a nano-meter scale such as precipitation, segregation and formation of point-defect clusters. Such nano-features affect the mobility of dislocations in a micron-meter scale, which results in the change in the fracture toughness of the materials in a centimeter scale. The whole process is a time-evolving multi-scale phenomenon, and the understanding and modeling of the whole process is essential for the development of an accurate and predictive method to estimate the amount of neutron irradiation embrittlement.

CRIEPI has been working on understanding the microstructural changes of neutron irradiated RPV steels as well as analyzing the mechanical property data of the Japanese surveillance materials from all the commercial nuclear power plants in Japan. Based on these results, a mechanism-guided embrittlement correlation method to estimate the amount of embrittlement was developed, which is now adopted in the Code of the Japan Electric Association to determine the plant operation conditions of the Japanese nuclear power plants. In this talk, the findings obtained by nano & micro scale experiments and computer simulations will be presented, followed by the modelling of microstructural changes and the link of micro- and macro- properties regarding the neutron irradiation embrittlement of RPV steels.