Nondestructive Evaluation of Fracture Properties in Irradiated Light Water Reactor Pressure Vessel Steels

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ABSTRACT:

Extended operation of existing light water reactors will be critical to meet the demand for baseload electricity generation as the US transitions to cleaner sources of electric power. As such, the US Department of Energy Light Water Reactor Sustainability (DOE LWRS) Program and Electric Power Research Institute (EPRI) are focused on performing research to address materials aging issues that could affect operation of commercial nuclear power plants beyond the period of initial license renewal (> 60 years of operation for US units). A significant issue identified that could impact the long-term operability of light water reactors is longer term irradiation embrittlement of reactor pressure vessels (RPVs). Microstructural changes caused by fast neutron displacement cascades generally result in an increase in ductile to brittle transition temperature (DBTT), a decrease in upper shelf energy (USE) and reduced fracture toughness in ferritic RPV steels. Traditionally, irradiated reactor vessel mechanical properties, which are highly composition dependent, have been quantified by removing RPV surveillance samples, which are sacrificial samples that sit inside the reactor during operation and are subjected to representative temperature loading and neutron flux, by destructively testing them to periodically obtain fracture properties of the vessel during its operational life. Historically and presently, Westinghouse has been supporting the industry on destructive mechanical property characterization of reactor-specific surveillance samples. One challenge that the industry is currently facing, and will face more so in the future, is that reactor life extension will result in a shortage of high fluence RPV surveillance samples, necessitating other methods to qualify aging light water RPVs for continued safe operation.

There are currently no pedigreed in-service nondestructive evaluation (NDE) methods capable of directly characterizing the evolution of microstructures and mechanical properties of RPV Steels. To address this gap, we propose a benchmarking study to determine if it is possible to characterize irradiation embrittlement in RPV steels using a variety of NDE methods. The proposed approach is to select and benchmark candidate advanced NDE techniques on a subset of the library of irradiated reactor surveillance specimens housed at the Westinghouse Churchill Site hot cell laboratory, which represent > 90% of the US fleet of operating and decommissioned light water reactors for which the microstructures and fracture properties will be known a-priori. Candidate advanced ultrasonic and electromagnetic NDE techniques, which are sensitive to microstructural and physical properties, have been selected based on their sensitivity of the microstructural features that influence embrittlement, e.g., dislocation density, dislocation/precipitate interactions. The NDE techniques of interest will be adapted to be deployed in the Westinghouse hot cells, which the PI has done with several advanced NDE techniques in unrelated investigations successfully. The data obtained will then be compared to the fracture properties to determine if there are correlations that can be exploited to subsequently develop an inspection tool and procedure(s) to supplement traditional surveillance program data. This work is timely for the industry as lead plants have recently been granted subsequent license renewal authorization by the US Nuclear Regulatory Commission (NRC) and more plants are expected to follow.