Nonlinear Ultrasonic Techniques to Monitor Radiation damage in RPV and Internal Components

PI: Lawrence Jacobs – Georgia Institute of Technology

Collaborators: Jianmin Qu – Northwestern University

Jin-Yeon Kim – Georgia Institute of Technology

James Wall – Electric Power Research Institute

Pradeep Ramuhalli – Pacific Northwest National Laboratory

Program: Instrumentation and Controls

ABSTRACT

A new nondestructive evaluation (NDE) and monitoring method based on nonlinear ultrasonic (NLU) techniques is proposed that will quantitatively characterize the current state of material damage in the reactor pressure vessel (RPV) and stainless steel reactor core internal components. Specific damage types to be monitored are irradiation embrittlement and irradiation assisted stress corrosion cracking (IASCC). Currently there are no appropriate nondestructive evaluation methods to reliably monitor such radiation damage in RPVs and their internals.

Our vision is to develop a technique that allows operators to assess damage by making a limited number of NLU measurements in strategically selected critical reactor components during regularly scheduled outages. This measured data can then be used to determine the current condition of these key components, from which remaining useful life can be predicted. Our recent studies have shown that NLU is sensitive to damage mechanisms such as irradiation embrittlement and stress corrosion cracking. The unique advantage of the proposed research is that NLU is an absolute measure of material state which can be performed in situ, thus measured acoustic nonlinearity can be used to predict life well before failure is imminent. This study is timely since the US fleet of operating light water power reactors has entered the period of life extension, and components will see more neutron exposure and duty cycles than were originally anticipated.

Methods to unambiguously characterize radiation related damage in reactor internals and RPVs remain elusive. NLU technology has demonstrated great potential to be used as a *material sensor* – a sensor that can continuously monitor a material's damage state. The physical effect being monitored by NLU is the generation of higher harmonic frequencies in an initially monochromatic ultrasonic wave. The degree of nonlinearity is quantified with the acoustic nonlinearity parameter, β, which is an absolute, measurable material constant. Recent research has demonstrated that *nonlinear* ultrasound can be used to characterize material state and changes in microscale characteristics such as internal stress states, precipitate formation and dislocation densities. Radiation damage reduces the fracture toughness of RPV steels and internals, and can leave them susceptible to IASCC, which may in turn limit the lifetimes of some operating reactors. The ability to characterize radiation damage in the RPV and internals will enable nuclear operators to set operation time thresholds for vessels and prescribe and schedule replacement activities for core internals. Such a capability will allow a more clear definition of reactor safety margins.
The proposed research consists of three tasks: (1) materials sensing and monitoring; (2) physics-based materials and damage evolution modeling; and (3) remaining life estimation by integrating sensing, modeling and uncertainty.