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U.S. Department of Energy

Linear and nonlinear guided ultrasonic waves to characterize cladding of accident tolerant fuel

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Program: FC-2.1: NDE Techniques for assessing integrity of coated cladding tubes

ABSTRACT:

Offices within the U.S. Nuclear Regulatory Commission (USNRC) are preparing for anticipated licensing and use of accident tolerant fuels (ATF). Several vendors plan to seek and develop approval for various coated cladding designs with enhanced accident tolerance (i.e., increase of coping times during possible accident, while maintaining or improving the cladding performance during normal operations). While nondestructive evaluation (NDE) techniques are currently available for uncoated, zirconium-based alloys, the use of these coated fuels adds a new set of challenges for the characterization of ATF. The associated NDE needs are (1) verify the thickness and uniformity of the coating layers, (2) identify areas of missing coating layers, and (3) confirm the quality of the coating-substrate bond.

The thicknesses of coatings in ATF coated cladding concepts typically range between 2-20μm. Since these coatings are the primary source of protection from the extreme service conditions of temperature and irradiation, the ability to nondestructively inspect and characterize the quality of the cladding material and the associated bond properties of the coating to the substrate are of critical importance for the acceptance of these new ATF technologies.

To address these needs, ***we propose a combination of linear and nonlinear guided ultrasonic waves, integrated with newly established material behavior models to develop a reliable NDE approach for quality control and quality assurance (QC/QA) of the cladding thickness, uniformity and bond strength.*** There are no other exiting NDE techniques capable of characterizing bond strength.

The proposed research project has four specific Tasks: (1) Task 1 (Jacobs) Develop guided linear ultrasound techniques to verify the thickness and uniformity of cladding layers; (2) Task 2 (Jacobs and Qu) Develop guided nonlinear ultrasound techniques to characterize cladding-substrate bond quality; (3) Task 3 (Qu and Dingreville) Materials modeling to enable reverse-engineering of cladding-substrate bond properties from the measured nonlinear ultrasonic wave results; and (4) Task 4 (Qu and Dingreville) Develop methodologies to quantify uncertainties in the proposed NDE-based approaches for QC/QA.

Key to the success of this approach is the development and demonstration of a suite of innovative, high-throughput NDE-based inspection techniques capable of nondestructively characterizing the coating properties and bond strength. Linear guided, ultrasonic Lamb waves will provide a fast and efficient approach to determine the overall global material properties and uniformity of a cladded fuel rod – linear Lamb waves will separate conforming from nonconforming materials, and then guided nonlinear Lamb waves will determine the actual condition of any nonconforming ATF cladded fuel rods. An additional task develops material models to enable reverse-engineering for cladding bond strength properties.

To help bring these NDE results to industrial applications, uncertainties in the measurement system and in the materials models will be quantified. To determine the measurement uncertainty, we will develop the probability of detection curves for both the linear and nonlinear ultrasonic measurements. To quantify the uncertainties in the materials model, we plan to use conventional and non-conventional statistical analysis. Such capability will be essential for future (outside the scope of this research) mapping in-reactor performance and failure mechanisms to general design criterion (GDC) and Design Basis Accident (DBA) conditions for regulatory purposes.