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Three-Dimensional NDE of VHTR Core Components via Simulation-Based Testing

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ABSTRACT

The very high-temperature reactor (VHTR) core will use nuclear graphite blocks as a moderator, reflector, and structural material. During the lifetime of a VHTR, individual graphite blocks will be exposed to significant (irradiation-induced) residual and thermal stresses, and will consequently undergo various levels of damage. In addition, the as-manufactured components may contain pre-existing defects that may likewise be detrimental to the performance of the reactor. To ensure the safety and functionality of VHTR, a high-fidelity, three-dimensional (3D) quantitative NDE of as-manufactured and replaceable in-service core components may provide an indispensable tool for the identification of damaged elements that need replacing.

To this end, a next-generation, simulation-driven-and-enabled testing platform is proposed for the 3D detection and characterization of defects and damage in nuclear graphite and composite structures in the VHTR. Centered around the novel use of (ultra-) sonic waves, this research will utilize a robust, non-iterative inverse solution for the 3D reconstruction and (material) characterization of damaged/defective zones together with a non-contact, laser-based approach to the measurement of mechanical waveforms generated in VHTR core components. In particular, this research aims to:

(1) Employ electronic speckle pattern interferometry (ESPI) as a means to accurately and remotely measure 3D displacement waveforms over the accessible surface of a VHTR core component excited by a vibratory source (operating at frequencies on the order of 104Hz)
(2) Generalize a powerful new inverse technique, based on the concept of topological sensitivity (TS), for non-iterative stress-wave imaging of internal heterogeneities to permit both 3D mapping and characterization of the severity of diffuse damage (arrays of microcracks) and discrete damage (fractures)
(3) Integrate the ESPI testing methodology with the TS imaging algorithm into a non-contact, high-fidelity NDE platform for the 3D reconstruction and characterization of defects and damage in VHTR core components
(4) Apply the proposed methodology to VHTR core component samples (e.g., hexagonal carbon blocks) with a priori induced, discrete, and diffuse damage
(5) Verify the fidelity and effectiveness of the ESPI-TS approach by comparison with existing NDE techniques, including x-ray computed tomography (CT).

A unique feature of the ESPI-TS “marriage” is that the ESPI approach to NDE is conducive to producing experimental data with only few vibratory, i.e., “illuminating,” sources and plentitude of observations (triaxial displacement fields over sizable surface patches)—a setup in which, in contrast to tomography applications, the TS-based imaging excels. Given the fact that the reactor core may tolerate certain levels of component damage, provided its functionality and safety (e.g., in terms of seismic analysis) are not compromised, an ability of the new technique to identify not only the 3D geometry but also the constitutive characteristics of

damaged regions would bring about a major tool toward safe, cost-effective, and environmentally responsible stewardship of the VHTR installations.