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## Physics-based Machine Learning Aided Multimodal NDT to Detect Internal Abnormalities in Sealed SNF Canisters

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### ABSTRACT

Dry storage of spent nuclear fuel (SNF) from commercial nuclear power plants (NPP) is likely to remain a solution to address the growing SNF inventory in the upcoming decades. These systems may develop internal degradation or other abnormalities due to long-term storage or during handling and transportation. Given the extended storage and the imminent need to transport these packages to longer-term (or interim) storage facilities, detecting such abnormalities without having to open the sealed SNF canisters is crucial for safe and efficient SNF management. A particular concern is the treatment of a package that undergoes a minor incident. Currently, there are few tools available to assess such a package following the incident.

To address these pressing questions, this project aims to develop a multimodal non-destructive testing (NDT) framework with hybrid data and physics-based machine learning (ML) algorithms to detect and quantify multiple internal abnormalities in sealed SNF canisters. Data will be collected from multiple types of NDT measurements, embedded in a low-dimensional latent space, and integrated through physics-based ML. This framework will be used to determine structural damage, impurity gasses, residual water, and abnormal thermal states in the canister. This information may then be used for risk assessment and decision making of sealed SNF packages. The proposed framework is designed to integrate data from other sources when additional data or NDT modalities become available. The project objective will be achieved through three main tasks. In the first task, the three NDT techniques previously developed by the PIs for SNF canister inspection will be further advanced, high-fidelity computational models will be developed and validated using the collected experimental data, and they will serve to inform physics-based ML models. In the second task, a multimodal NDT framework will be developed, which will allow for fusion of data from multiple sources (different experiments and physics-based simulations) into a single model, which can then be used to perform multiple inference tasks. Furthermore, by taking advantage of latent spaces, our framework will accept other data sources as they become available, accommodate missing information, and it will provide confidence bounds and uncertainties. In the third task, we will further advance the TRL of the proposed multimodal NDT framework through demonstrations on full-scale canisters mock-ups and by addressing any scaling up and feasibility issues that may arise. The main deliverable of this project will be the multimodal NDT framework to detect multiple interior abnormalities in sealed SNF canisters all-at-once.

The sealed nature and the difficulty to open SNF canisters for inspection makes it particularly challenging to characterize their internal environment. Therefore, the development of a multimodal NDT system capable of detecting various interior abnormalities simultaneously is essential. It is impractical to inspect thousands of packages that need to be transported using different detection methods one at a time. A multimodal approach that can detect multiple abnormalities all-at-once is needed, which is the overarching goal of this project. The proposed project aligns with the Topic Area 6-Storage and Transportation Research. The successful completion of this project holds significance for the SNF management because it will provide a robust method for early detection of abnormalities within SNF canisters, and thus, contribute to the longevity and reliability of dry cask storage systems (DCSSs). These capabilities contribute significantly to enhancing the safety and security of storage and transportation of canisters to interim or permanent facilities, aligning closely with the U.S. DOE's goals.