Multimodal Nondestructive Dry Cask Basket Structure and Spent Fuel Evaluation

PI: Dr. Joseph Gladden,
University of Mississippi

Collaborators: Prof. James Tulenko, University of Florida; Dr. Lingyu Yu, University of South Carolina; Dr. Haori Yang, Oregon State University; Mr. Ray Phan, AREVA Federal Services LLC; Dr. Jeremy Renshaw, EPRI

Program: IRP- FC - 3

ABSTRACT:

Above ground dry storage casks for spent nuclear fuel rods were employed starting in 1986 to the Surry Nuclear plant as a temporary solution for high level nuclear waste storage until a more permanent solution could be found. That permanent solution has proved elusive over the years and dry storage casks have become more of a semi-permanent solution as opposed to a temporary one. Because of the increased service life required of the casks, there is a concern about the integrity of the internal structures of the casks. A primary such structure is the basket in which the spent fuel rod clusters are placed. No internal sensors were part of the cask design and these casks cannot be opened for obvious reasons. This presents a difficult, although fairly common, problem for structural health monitoring (SHM): assessing structural integrity of a complex enclosed structure with only access to the outside.

Because of the difficulty of this problem, this specific team was assembled to bring in a range of technical approaches in the hope that the chances for success will be more than the sum of its parts. The team brings in expertise in emissions tomography (University of Florida (UF)), physical and structural acoustics (National Center for Physical Acoustics at the University of Mississippi), acoustic emissions and ultrasonic interrogation (University of South Carolina), and muon imaging (Oregon State University). Critically, we have also included two industry partners: AREVA Transnuclear who will provide expertise on cask design and provide access to full scale test casks, and Electric Power Research Institute (EPRI) who will help with industry contacts and plans for technology transition from the laboratory to the field. By bringing this diverse group together under a single project team, we hope to see real advances at the intersections. Specifically, these advances will come during at least quarterly video conferences to share results and discuss difficulties and "face to face" team meetings annually. This regular interaction and discussion will be a priority in the project management. The primary objective of this project is to develop a range of complimentary structural health monitoring technologies able to assess the structural integrity of dry storage casks for spent nuclear fuel rods.

Emission source tomography leverages penetrating residual radiation (gammas and neutrons) coming from the spent fuel rods to gather information about the source and about the medium between the source (inside the cask) and detectors (outside the cask). . This line of inquiry will be performed by the University of Florida. Scattering events and energy spectra are effected by the nature of the travel path and thus carry information about those structures. In this technology, UF intends to use the collected scattered radiation from the radiating fuel to reconstruct its inner structure. This line of research will explore the sensitivity of emission source tomography to the structural health of the cask fuel rod basket by studying gamma detector placements. An added factor to aid the scattered Radiation emission imaging is that the structure and the in place fuel assemblies are all know and a simulation can be set up to

compare to the reconstructed values. UF will accomplish the imaging objective by using a combination of theoretical and computational modeling and laboratory experimentation and evaluation. The University of Florida will receive $750,000 over the period of performance to support these activities.

Acoustics based methods have a long history in structural health monitoring. It is well known that inhomogeneities in a structure can change the acoustic wave speed and scatter ultrasonic waves. Broadly, acoustic methods in SHM fall into two categories. First is active acoustics which requires an input of acoustic energy into the structure using a shaker, a piezoelectric transducer, or impulsive source such as a hammer. An array of sensors, typically in the form of piezoelectric transducers or accelerometers, are used to detect the response of the structure. The second category is passive acoustics, or acoustic emissions, in which the acoustic energy originates from the structure itself, typically as a result of an advancing crack or strain induced grain boundary shifts. More recently, the production and interpretation of nonlinear contributions due to structural defects have been the subject of intense study. This proposal will explore both active and passive acoustics approaches to the problem. The University of Mississippi will focus on linear and nonlinear vibrational spectroscopy in which the structure will be excited through a range of frequencies and the modal response will be monitored by an array of acoustic sensors. Placement of sensors and actuators will be optimized and resonances associated with internal structures of interest will be identified through a detailed finite element analysis and experimentation on a laboratory scale model cask. The nonlinear response of these resonances will be of particular interest and a sensitivity analysis of shifts in frequencies, quality factors, and nonlinear parameters due to induced damage will be conducted. The University of South Carolina will focused on a coupled passive and active acoustics approach in which acoustic emissions will be monitored and inform subsequent ultrasonic interrogation using guided ultrasonic waves. The University of Mississippi will receive $825,000 to support vibrational spectroscopy activities as well as manage the program. The University of South Carolina will receive $675,000 to support acoustic emissions and ultrasonic interrogation activities.

A relatively new SHM technology is muon imaging. Muons are highly penetrating particles and muon imaging leverages naturally occurring muon sources from the upper atmosphere. Attenuation and scattering of muons in dense structures carries information about the structure. Much of the current research is focused in image reconstruction methods. Oregon State University is home to a leading research group in this field with current funding with a NEUP research grant which will be folded and integrated into our program. In the current proposed project, OSU will work with this team on the application of muon imaging to the dry storage cask NDE challenge problem. Muon technology is currently being used to look inside the reactor at the Fukushima Daiichi Nuclear Power station 1 and offers promise as an emerging technology. Oregon State University will receive $150,000 to support the application of muon imaging to dry storage cask monitoring.

The two industry partners will be critical to the ultimate success of this project. The structural details of the casks, including materials, is vital to each of the lines of proposed research, so having AREVA as part of the team will help insure laboratory experiments on the TN32 cask and to also have the opportunity of being transitioned to a successful field test. An important phase of this project will come in Year 3 in which field tests of each of the methods will be conducted in a full scale research cask which will be facilitated by AREVA. EPRI will bring important connections to power industry leaders for discussions about practical criteria important to eventual transfer of the resulting technologies. The team has received non-disclosure agreements from Areva so that the team can address the actual dimensions and materials of the TN32 spent fuel container system. This is the same container system which will be used by DOE/EPRI for a $50 million dollar high burnup spent fuel performance assessment. AREVA will receive $400,000 and EPRI will receive $200,000 to support this entire project.