Transducers for In-pile Ultrasonic Measurements of Fuels and Materials Evolution

Bernhard Tittmann – Pennsylvania State University – brt4@psu.edu

Figure 1. 3-D renderings of the ULTRA-capsule as constructed for the irradiation. The piezoelectric sensors are shown in yellow, the magnetostrictive sensors are shown in green, the piezoelectric drop in specimens are shown as gray disks, while the magnetostrictive drop-in samples are shown in a peach cylinder.

Current generation light water reactors (LWRs), sodium cooled fast reactors (SFRs), small modular reactors (SMRs), and Next Generation Nuclear Plants (NGNPs) produce harsh environments in and near the reactor core that can severely tax material performance and limit component operational life. To address this issue, several Department of Energy Office of Nuclear Energy (DOE-NE) research programs are evaluating the long-duration irradiation performance of fuel and structural materials used in existing and new reactors. To maximize the amount of information obtained from Material Testing Reactor (MTR) irradiations, DOE is also funding development of enhanced instrumentation that will be able to obtain in-situ, real-time data on key material characteristics and properties with unprecedented accuracy and resolution. Such data are required to validate new multi-scale, multi-physics modeling tools under development as part of a science-based, engineering driven approach to reactor development. It is not feasible to obtain high-resolution/microscale data with the current state of instrumentation technology.

Project Description

Ultrasound-based sensors offer the ability to obtain in-situ data if it is demonstrated that these sensors and their associated transducers are resistant to high-neutron flux, high-gamma radiation, and high temperature. To address this need, the Nuclear Science User Facilities (NSUF) funded an irradiation, led by Pennsylvania State University (PSU), at the Massachusetts Institute of Technology (MIT) Research Reactor to test the survivability of ultrasound transducers.

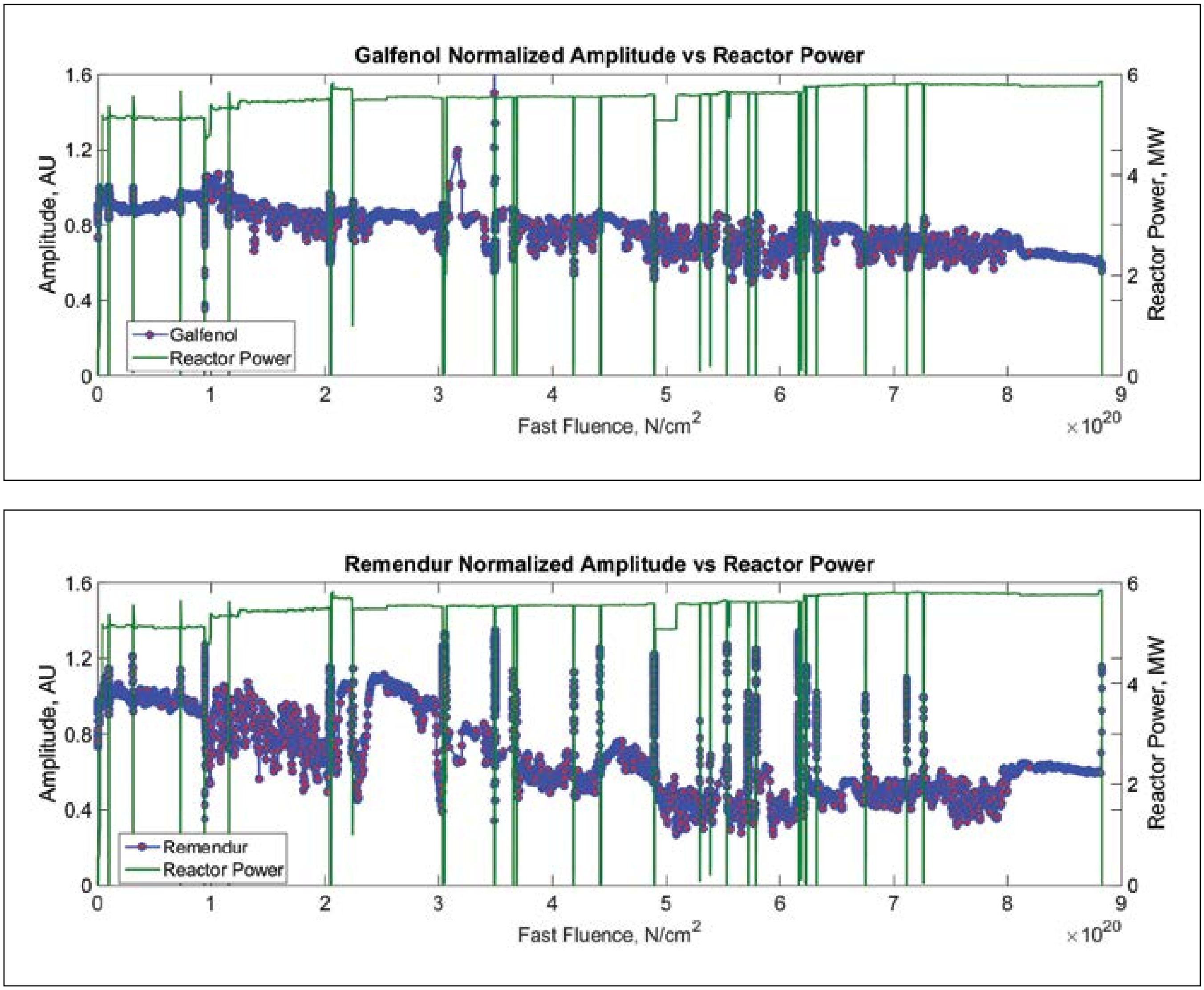

Figure 2. Pulse-echo amplitude for magnetostrictive transducers as a function of reactor power.

The feasibility of ultrasonic transducers in a nuclear reactor has been established. This opens the door to leave-in-place sensors for in-reactor conditions and materials.

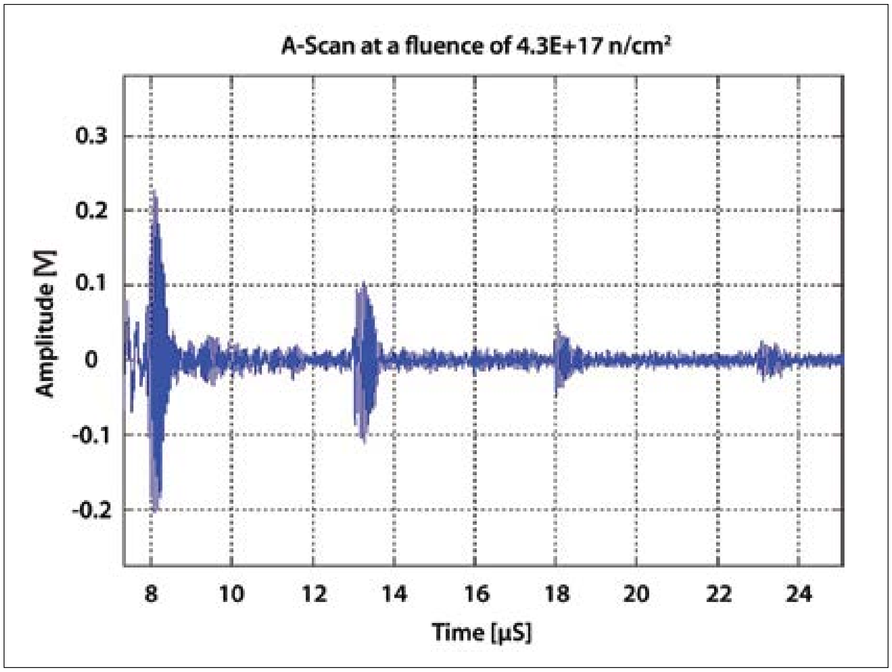

Figure 3. Example waveform from an elapsed time of 4 days.

AlN survived 18 months of irradiation.

— Bernhard Tittmann, Professor

As part of this effort, PSU and collaborators have designed, fabricated, and tested piezoelectric and magnetostrictive transducers that are optimized to perform in harsh, high flux environments. Four piezoelectric transducers were fabricated with aluminum nitride (AlN), zinc oxide (ZnO), and bismuth titanate (BiT) as the active elements and two magnetostrictive transducers were fabricated with remendur and galfenol as the active elements.

Accomplishments

The irradiation was performed in the MIT Reactor for a period of 18 months. First and most importantly, the successful operation of the transducers are shown at integrated neutron fluence of approximately 8.68 E+20 n/cm^2 for n >1 MeV, temperatures in excess of 420°C, and a gamma fluence of 7.23 Gy/cm^2. Although the sensors could perform in such environments, it was not without some troubles. Some of the sensors had issues with electrical connection and mechanical coupling to the waveguide. This is demonstrated and explained in the context of the pulse-echo signals. Overall, this is the longest exposure experiment conducted to the researchers' knowledge on the chosen sensor materials and the first instrumented lead test for many of these materials, aside for aluminum nitride, which had previously been tested at PSU's Brezeale Research reactor. The magnetostrictive transducers were monitored by Dr. Joshua Daw from INL and were found unaffected by the irradiation.

Future Activities

Additional funding has been sought from Bettis and obtained for post-irradiation examination of the ultrasonic transducers to obtain detailed measurements after the capsules have been dissassembled. Physical appearance, electrical impedance values, ultrasonic pulse-echo amplitudes, piezoelectric performance, and vibrational Q values will be obtained.

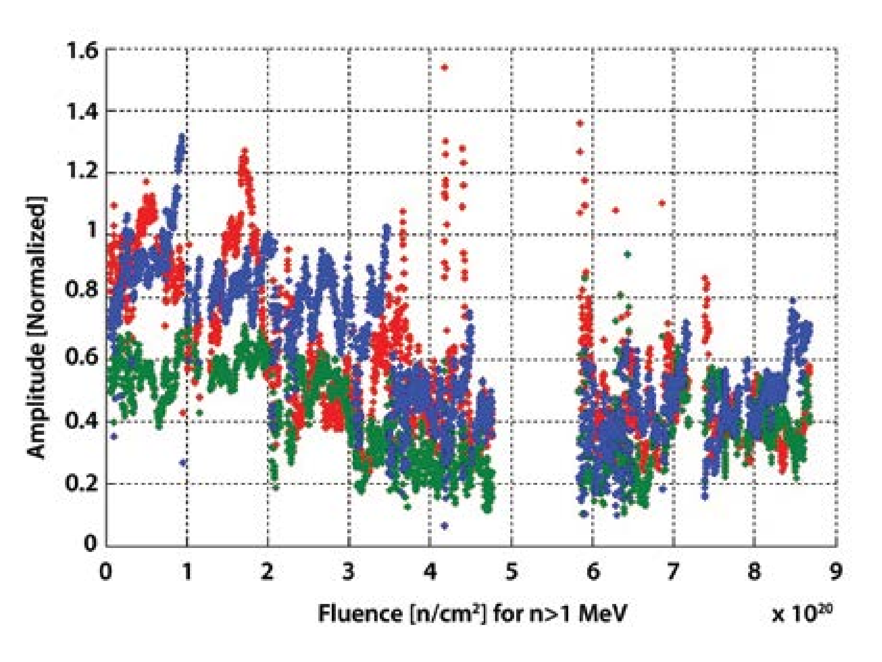

Figure 4. Change in ultrasonic pulse echo amplitude as a function of fluence for AlN transducer; only data points for which the power was greater than 5 MW are shown. The gap in data occurred during extended shutdown of the reactor.

Publications and Presentations*

1. Reinhardt, B., B. Tittmann, and A. Suprock, 2015, "Nuclear Radiation Tolerance of Single Crystal Aluminum Nitride Ultrasonic Transducer," *Physics Procedia*, 2015, in press.

2. Daw, J., J. Palmer, P. Ramuhalli, P. Keller, R. Montgomery, H-T. Chien, B. Tittmann, B. Reinhardt, G. Kohse, J. Rempe, J-F Villard, 2015, "Updated Results of Ultrasonic Transducer Irradiation Test," *4th Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA 2015) Lisbon, Portugal, April 20–24, 2015.*

3. Daw, J., J. Rempe, J. Palmer, P. Ramuhalli, R. Montgomery, H-T. Chien, B. Tittmann, B. Reinhardt, and G. Kohse "Ultrasonic Transducer Irradiation Test Results," *9th International Conference on Nuclear Plant Instrumentation, Control & Human–Machine Interface Technologies (NPIC & HMIT 2015), Charlotte, North Carolina, February 21–26, 2015.*

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Distributed Partnership at a Glance

NSUF and Partners	Facilities and Capabilities
Massachusetts Institute of Technology	Nuclear Reactor Laboratory
Collaborators	
Argonne National Laboratory	H.T. Chien (collaborator)
Bettis	Ben Wernsman (collaborator)
Commissariat à l'Energie Atomique	Brian Reinhardt (collaborator)
Idaho National Laboratory	Joy Rempe (principal investigator), Joshua Daw (co-principal investigator)
Massachusetts Institute of Technology	Gordon Kohse (collaborator)
Pacific Northwest National Laboratory	Pradeep Ramuhalli (collaborator)
Pennsylvania State University	Bernhard Tittmann (principal investigator)