U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Advanced Sensors and Instrumentation

Irradiation of Sensors and Adhesive Couplants for Application in LWR Primary Loop Piping and Components

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar
October 24 – 27, 2022

Principal Technical Leader, EPRI: Joe Wall, PhD

[National Laboratory, University/Department or Company Name]

Project Overview

- EPRI launched a project in 2020 to assess the feasibility of using semi-permanently mounted piezoelectric sensors to monitor existing cracks in primary loop piping and components.
  - Of particular interest is the stability of the piezoelectric sensors and the ability of adhesive couplants to transmit sound reliably under operational environment conditions.
    - Elevated temperature
    - Irradiation – Specifically at the hot and cold leg nozzle dissimilar metal welds.
  - The EPRI funded portion of the research focuses on elevated temperature effects.
  - The NSUF funded portion of the research focuses on irradiation effects.

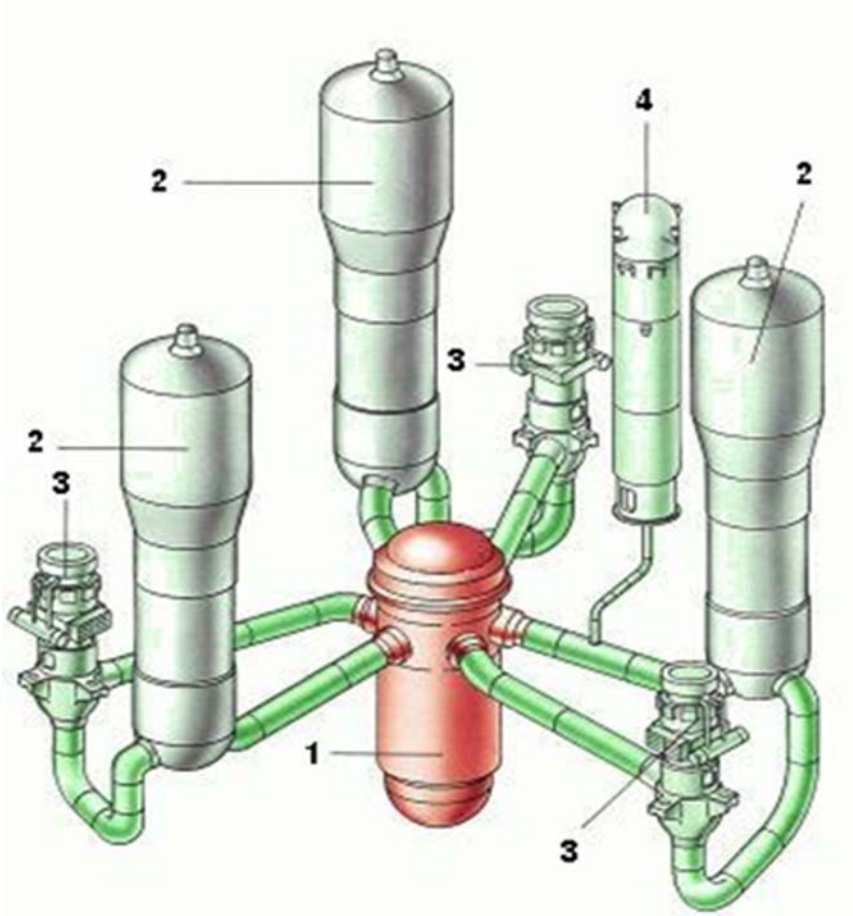


Illustration of the primary loop piping and components in a commercial PWR (primary loop piping is in green). 1 – Reactor Pressure Vessel; 2 – Steam Generator; 3 – Reactor Coolant Pump; 4 – Pressurizer.

Project Overview

Project Team

- Principal Investigator: Dr. Joe Wall, Principal Technical Leader, Nuclear Sector, EPRI
  - Overall responsibility for project
- Collaborator: Dr. Luke Breon, Senior Technical Leader, Nuclear Sector, EPRI
  - Subject matter expert – acoustic sensors, PI for the EPRI elevated temperature companion study
- Collaborator: Dr. Maria Guimaraes, Program Manager, Nuclear Sector, EPRI
  - EPRI program manager
- Collaborator: Dr. Josh Daw, Principal Researcher, INL
  - Consultant for irradiation experiment and capsule design
- Collaborator: Dr. Pradeep Ramuhalli, Distinguished R & D Staff Member, ORNL
  - Consultant for irradiation experiment and capsule design as well as post irradiation examination

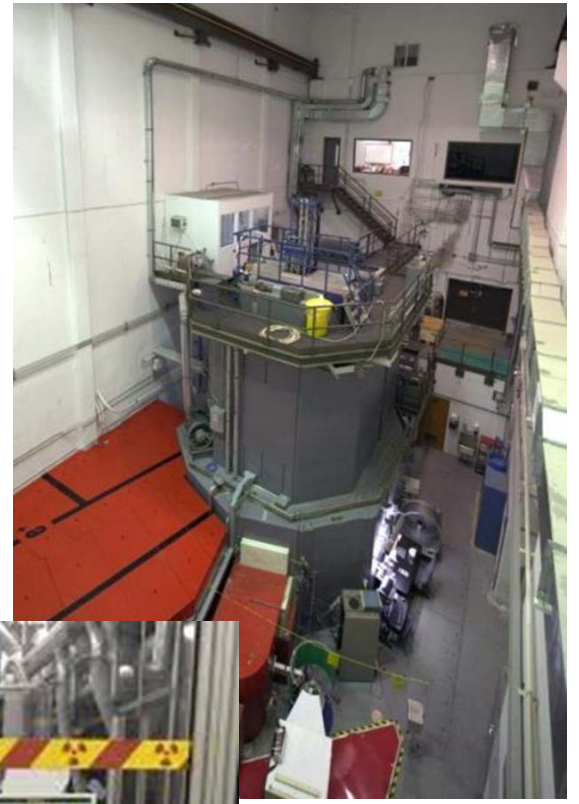
Project Overview

- The goal of the project is to characterize microstructural and acoustic property changes in piezoelectric sensors bonded to aluminum substrates (1” diameter x 3/8” thickness discs) using adhesive ultrasonic couplants.
- 3 types of transducers and 4 types of adhesive couplants are being irradiated and acoustic data (signal to noise ratio) is being collected in-situ.
- The target fluence is 5 x 10^{16} n/cm^2 (E > 1MeV) – estimated hot leg weld 80 year fluence (estimated using radiation transport simulations)

As Recieved	PULSTAR			
Sample ID	Adhesive Name	Sample ID	Adhesive Composition	Sensor Type
2	Zircar HITAC-4	EPRI-1	Aluminosilicate	Bismuth Titanate
4	Zircar HITAC-4	EPRI-2	Aluminosilicate	Lithium Niobate
8	Saureiusien Cement # 2	EPRI-3	Alumina Based	Lithium Niobate
5	Saureiusien Cement # 2	EPRI-4	Alumina Based	Bismuth Titanate
11	Contronics 904	EPRI-5	Zirconia Based	Bismuth Titanate
14	Masterbond EP17HT	EPRI-6	Epoxy	Bismuth Titanate
15	Masterbond EP17HT	EPRI-7	Epoxy	Lithium Niobate
16	Masterbond EP17HT	EPRI-8	Epoxy	Lithium Niobate

Project Overview

NSUF Facilities



PULSTAR Reactor

- The NC State University PULSTAR reactor was chosen for this study because it uses 4% enriched, pin-type fuel consisting of uranium dioxide pellets in zircaloy cladding which gives it characteristics that are similar to commercial light water power reactors.
- The PULSTAR reactor has been used for sensor irradiation studies in the past and we will leverage that experience in this research.
- Principal Contact: Dr. Ayman Hawari

LAMDA Laboratory

- The ORNL LAMDA facility is a multipurpose laboratory for evaluation of radioactive materials with low radiological threat without the need for remote manipulation. The LAMDA laboratories are equipped for analysis of samples at less than 100 mR/hr at 30 cm.
- Unirradiated sensor assemblies were sent to LAMDA in 2021 to develop sample preparation procedures for the irradiated assemblies.
- Principal Contact: Dr. Kory Linton

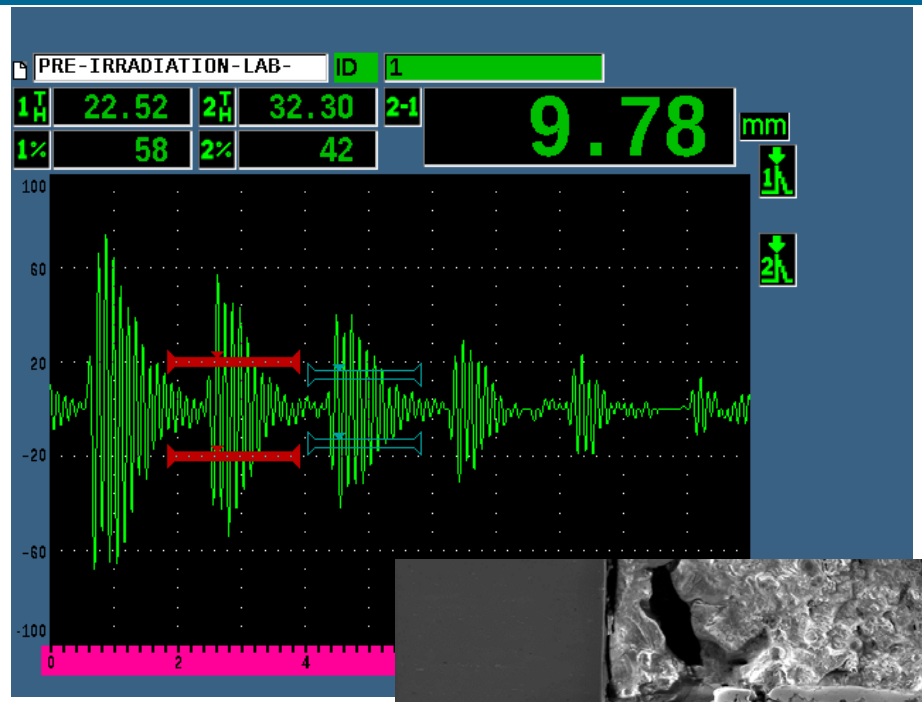
Technology Impact

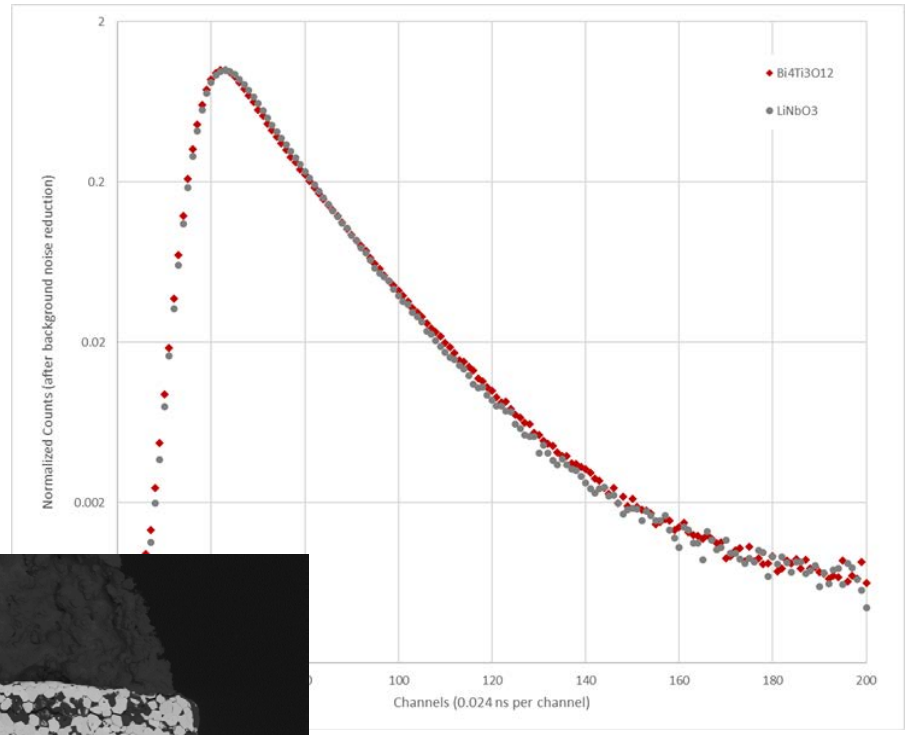
- Currently the majority of required nondestructive evaluations of LWR primary loop piping and components are performed manually.
- Going forward, it is in the interest of utilities to minimize manual inspections by development of online monitoring capabilities.
  - Minimization of human error
  - Reduction of dose to personnel
  - Real time inspection data
- To achieve this, semi-permanently installed sensors will have to operate at elevated temperatures and in radiation fields.
- This NSUF project will fill a gap in knowledge gaps associated with how piezoelectric ultrasonic transducers and, more specifically, adhesive couplants perform in a chronic radiation environment.
- This research will benefit both existing LWRs and advanced reactors
- EPRI is ideally positioned to utilize the NSUF research to facilitate sensor development and, subsequently, technology transfer to the industry.

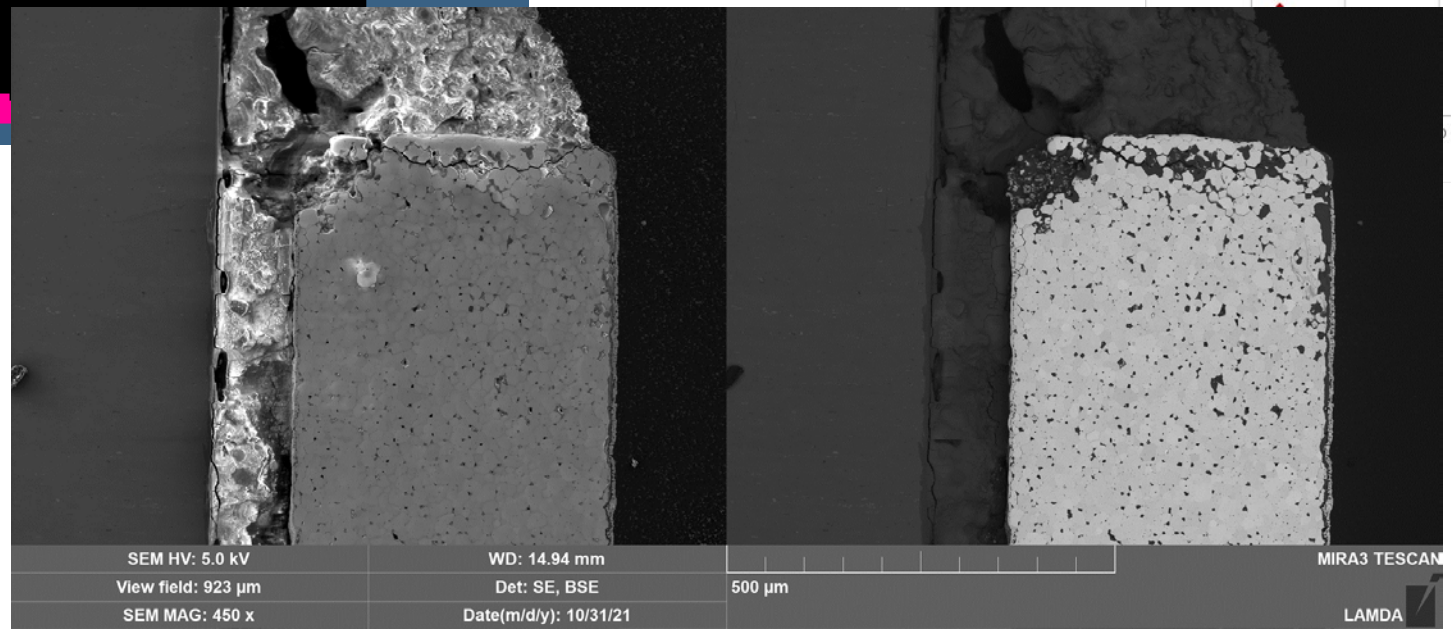
Results and accomplishments

- EPRI hosted a kick off meeting in Q1, 2021
- Acquisition of materials and equipment and construction of transducer/couplant/substrate irradiation assemblies were done in Q1 2021 – Q3 2021.
- Design and construction of the sample capsule was done in Q2 – Q4 2021.
- Baseline ultrasonic data for the unirradiated assemblies was acquired and analyzed.
- Irradiation of the sensor/couplant/substrate assemblies has been completed.
- In-situ ultrasonic data for the irradiated assemblies was acquired and analyzed.
- Destructive characterization of unirradiated assemblies is complete.
- PIE of the irradiated assemblies and piezoelectric crystal wafers is being done presently.

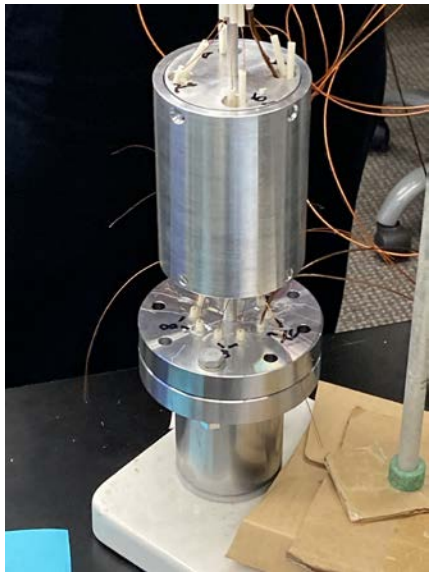
Results and accomplishments – Pre irradiation

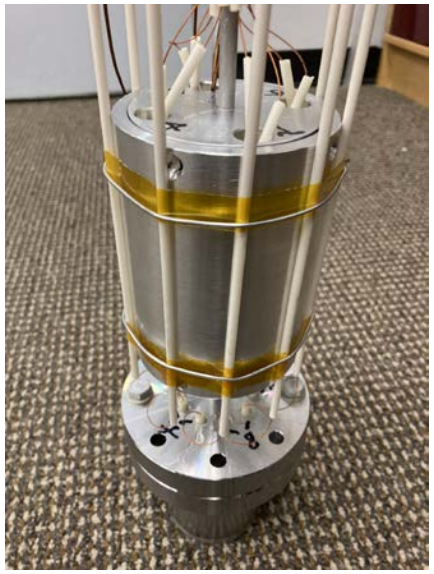


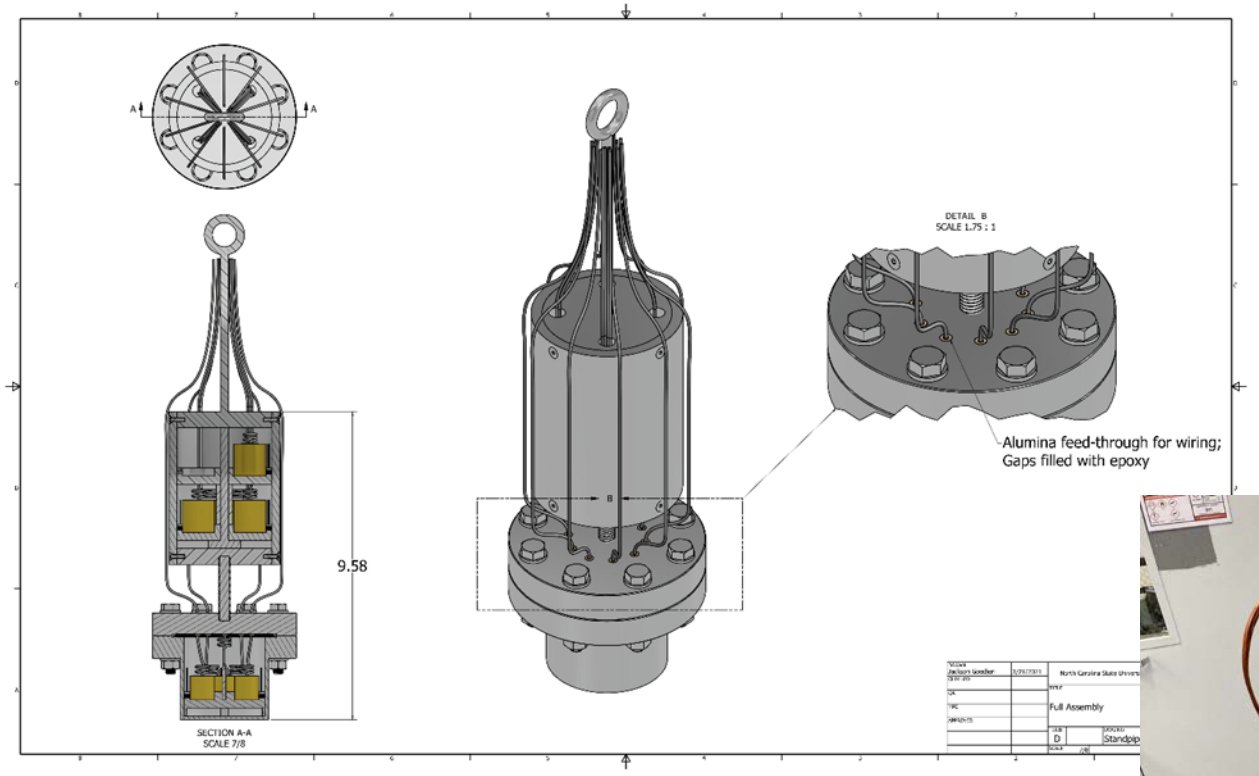


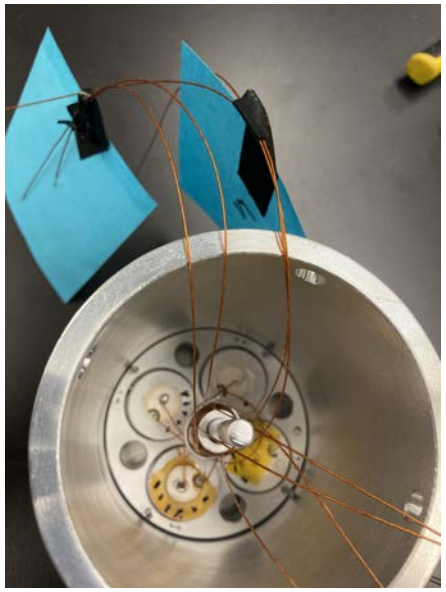


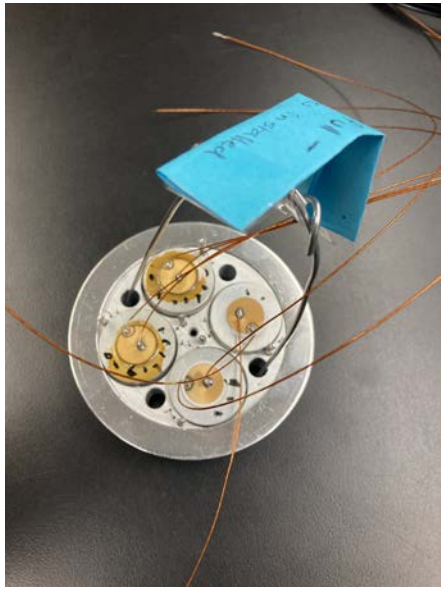
Results and accomplishments – Irradiation Capsule loading and irradiation









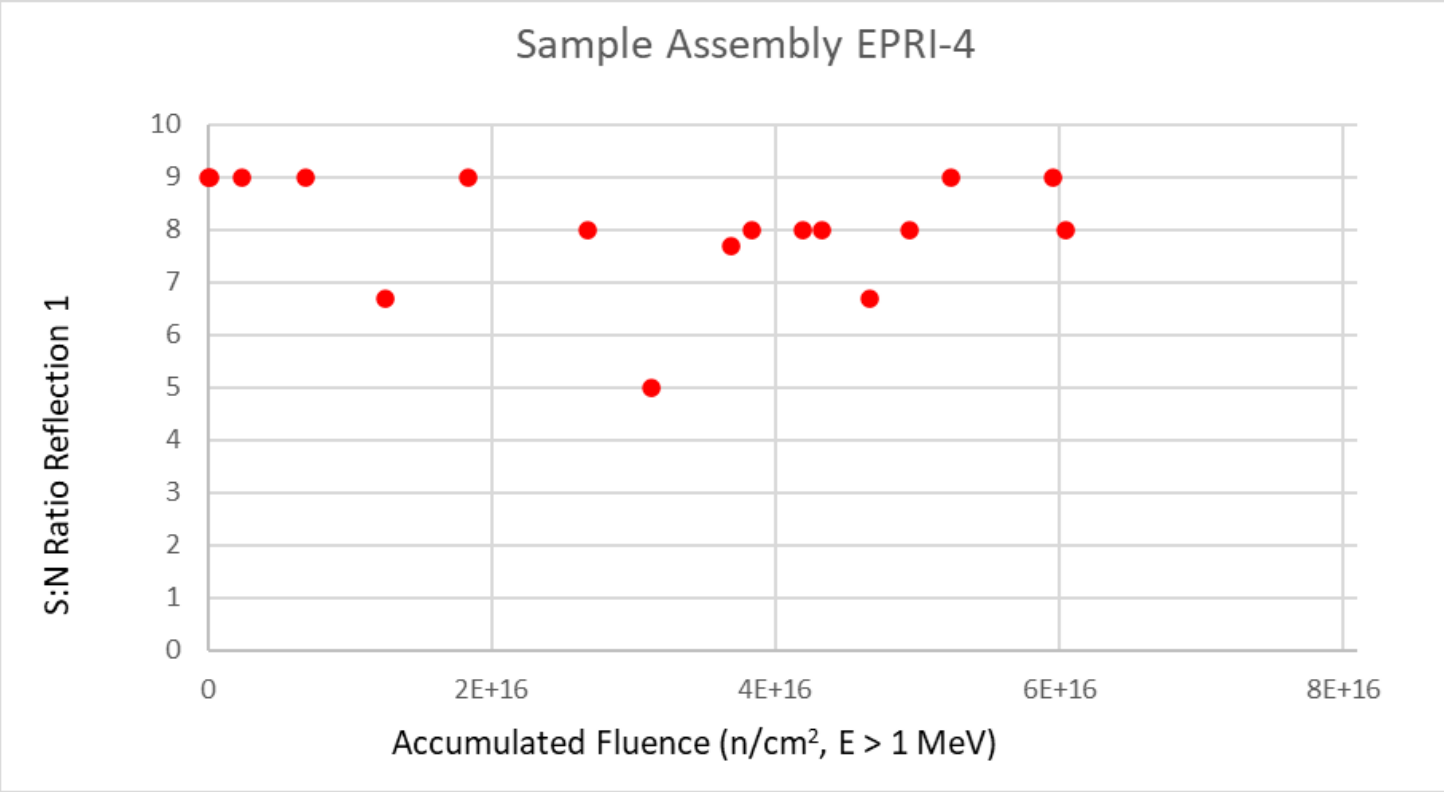


Results and accomplishments – In-Stu Acoustic Data

Sample ID	Adhesive Composition	Sensor Type	Result
EPRI-1	Aluminosilicate	Bismuth Titanate	Stopped generating usable data in early stages of irradiation
EPRI-2	Aluminosilicate	Lithium Niobate	Did not generate usable data before capsule insertion
EPRI-3	Alumina Based	Lithium Niobate	Did not generate usable data after capsule insertion
EPRI-4	Alumina Based	Bismuth Titanate	Generated usable data throughout irradiation
EPRI-5	Zirconia Based	Bismuth Titanate	Stopped generating usable data in early stages of irradiation
EPRI-6	Epoxy	Bismuth Titanate	Did not generate usable data after capsule insertion
EPRI-7	Epoxy	Lithium Niobate	Generated usable data throughout irradiation
EPRI-8	Epoxy	Lithium Niobate	Generated usable data throughout irradiation

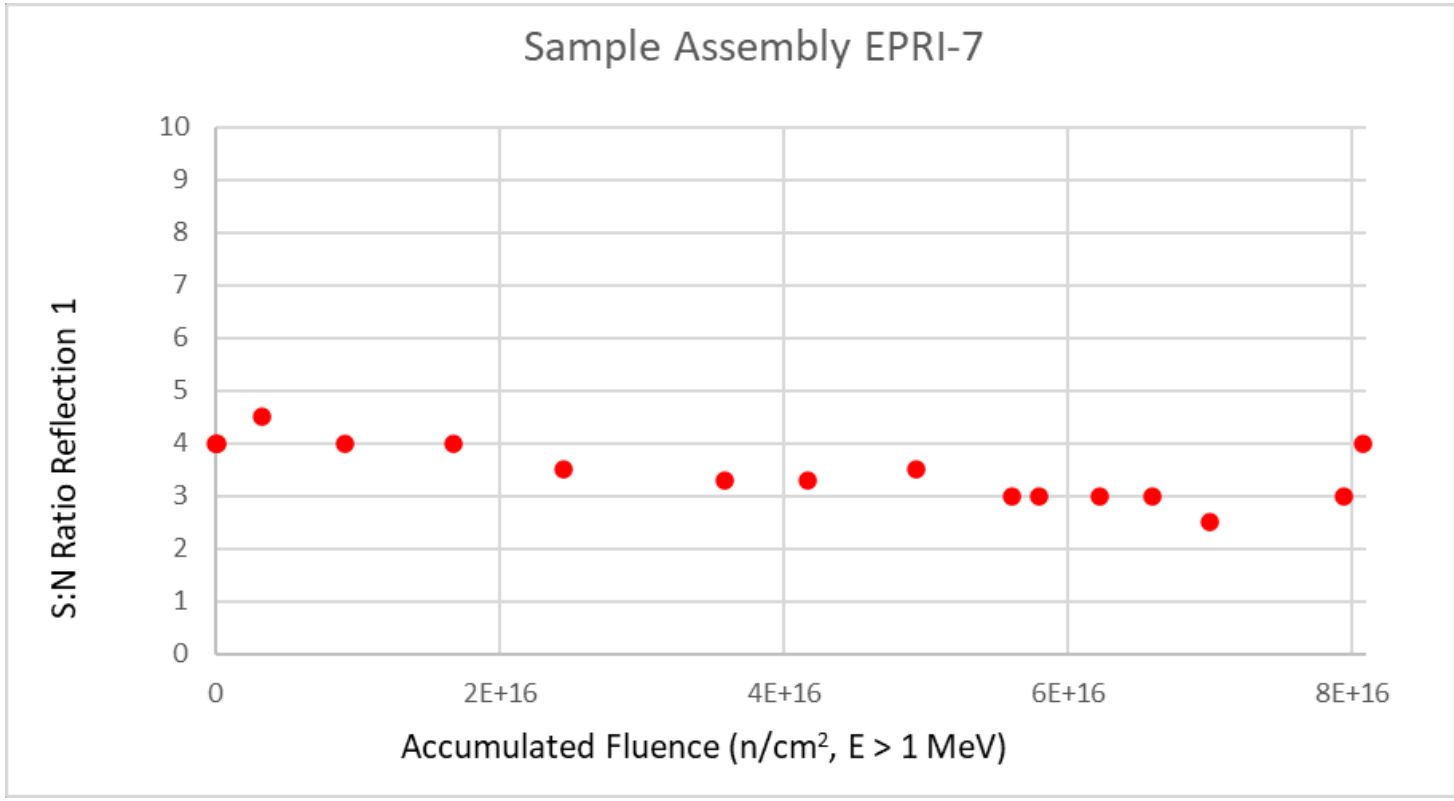
Results and accomplishments – In-Situ Acoustic Data

Analyzed S:N Ratio for reflection 1 as a function of fluence
EPRI-4
Bismuth titanate transducer bonded with alumina based cement



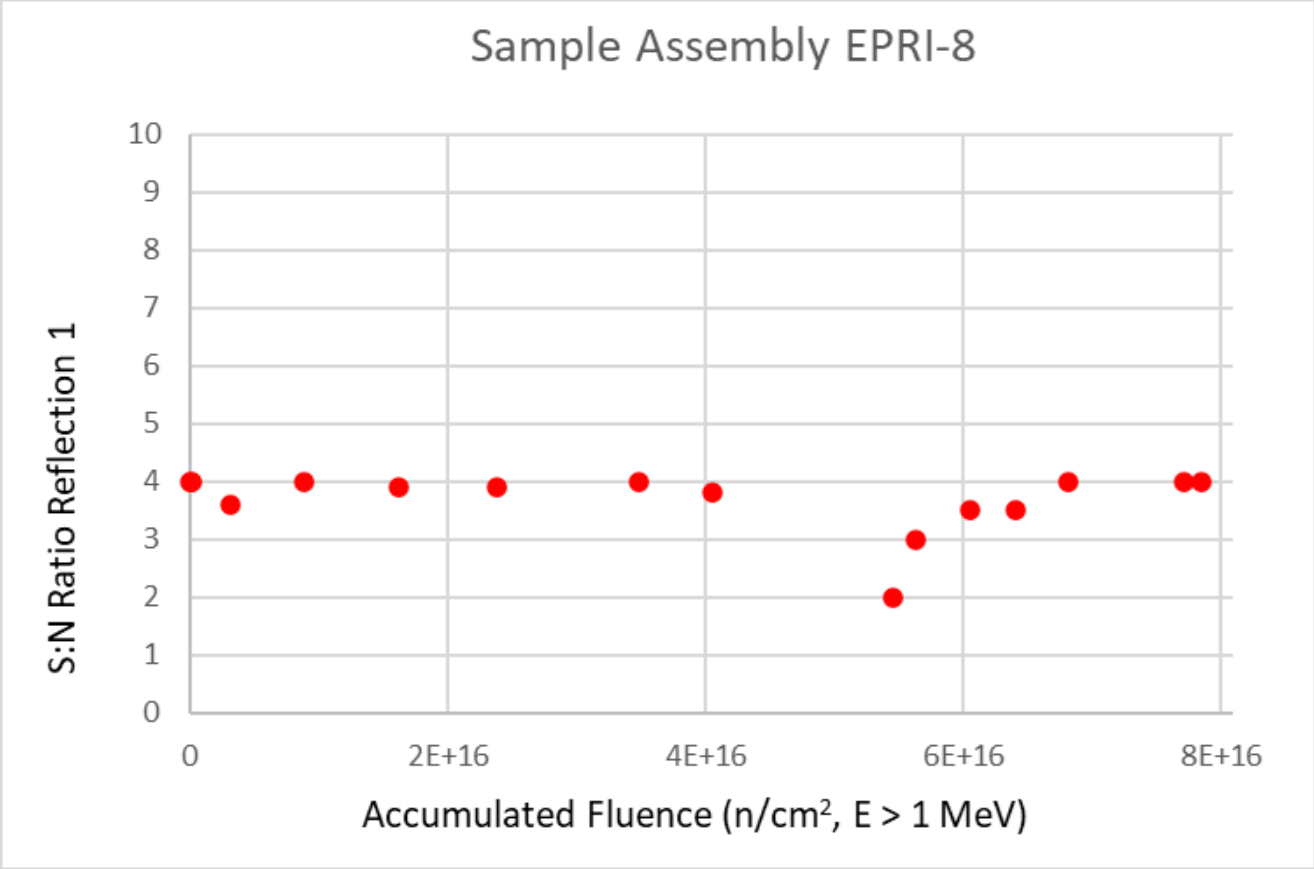
Results and accomplishments – In-Situ Acoustic Data

Analyzed S:N Ratio for reflection 1 as a function of fluence
EPRI-7
Lithium niobate transducer bonded with epoxy



Results and accomplishments – In-Situ Acoustic Data

Analyzed S:N Ratio for reflection 1 as a function of fluence
EPRI-8
Lithium niobate transducer bonded with epoxy



Conclusion

- DOE NSUF funding was awarded to characterize radiation effects in piezoelectric sensors and adhesive couplants.
- 3 types of sensors and 4 types of adhesive couplants were tested.
- The samples were irradiated at the NC State University PULSTAR reactor.
- 3 of the samples generated usable ultrasonic data throughout irradiation, one with alumina-based cement and two with epoxy
- The microstructure of the sensors themselves, as well as sensor-couplant-substrate interfaces are being characterized using light and electron microscopy and positron annihilation spectroscopy at the ORNL LAMDA laboratory and PULSTAR Intense Positron Beam facility.
- The results will be utilized immediately for an industry initiative

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Thank You