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

ASI | Advanced Sensors and Instrumentation

Acoustic Sensors

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar

October 24 – 27, 2022

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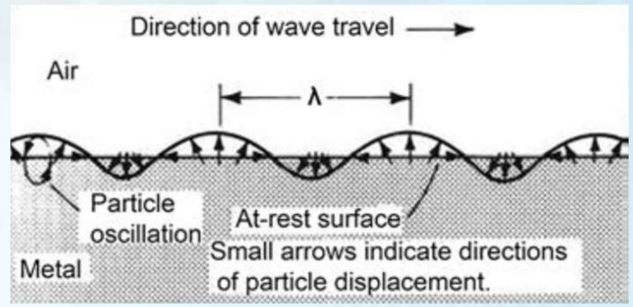
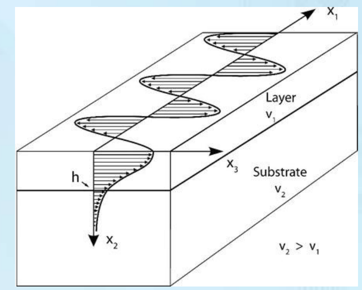
Idaho National Laboratory

Project Overview

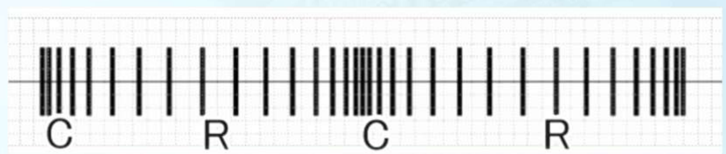
- Optimize and simplify UT fabrication process.
- Develop suitable electronics/DAS for UT through subcontract.
- Assessment of acoustic interrogation techniques for reactors operation and components health monitoring.
- Assess and select ASI sensors for inclusion in test at METL facility.
- Provide input for inclusion of UT in AS/NE sensor database.
- Participants: INL, ORNL, PNNL, ANL, BSU, OSU



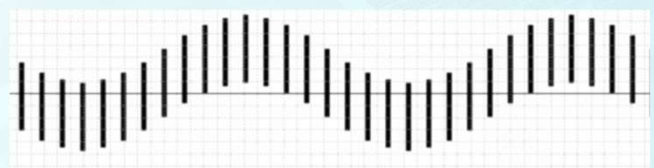
Raleigh



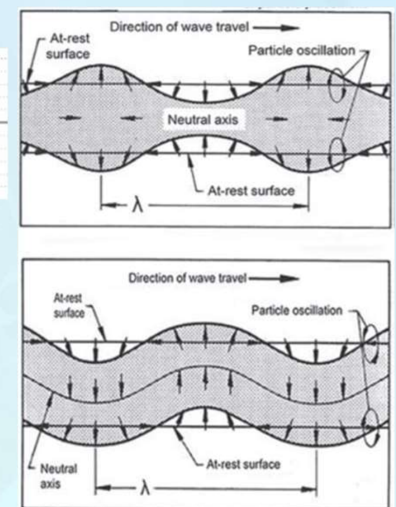
Love



Longitudinal



Shear



Lamb/SH

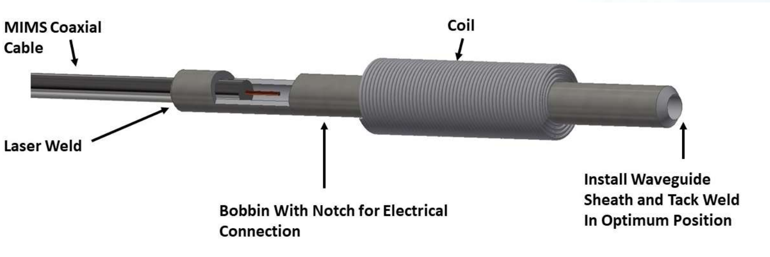
Figures from: ASM Handbook, Volume 17, Nondestructive Evaluation of Materials

Technology Impact

- Provide description of the technology application (i.e. where does it operate, who should be interested in this technology, and who are the stakeholders)
  - UT: In-core, multi-point temperature monitoring; Experiments in test reactors, core monitoring for high temperature advanced reactors
  - Acoustic Sensors: Too broad, depending on specific sensor they could be used anywhere
  - Stakeholders: Experimenters, Advanced Reactor Developers

- How does the technology support the nuclear energy industry?
  - UT: Accelerated development and acceptance of new fuels and materials through improved data density and testing in extreme conditions (ATF and High Temperature Concepts)
  - Acoustic Sensors (piezoelectrics, SAW, SHM): Enablement of online structural health monitoring of advanced reactors; monitoring of temperatures, pressures, level, flow, etc.; through vessel communications; etc.

Results and Accomplishments-UT w/ BSU

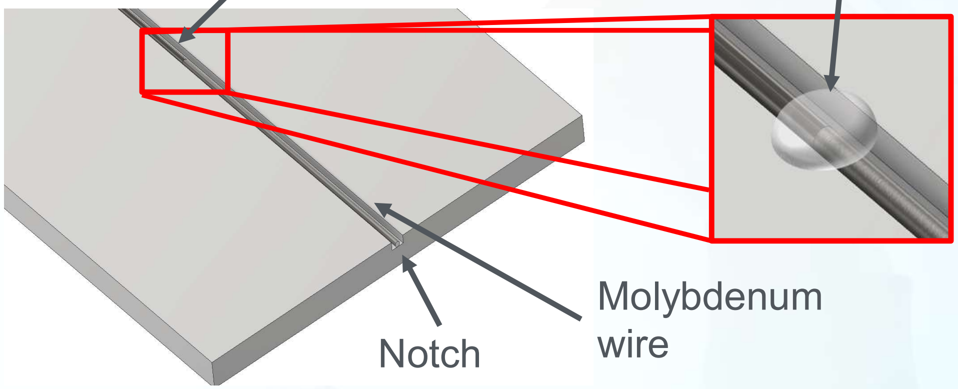


Redesigned coil bobbin to allow for easy signal optimization using a standard frequency coil

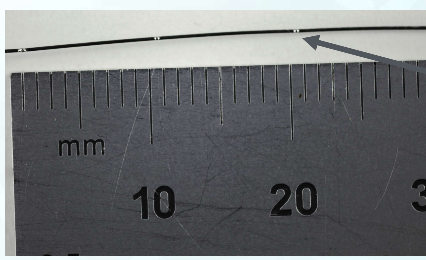
Concept design for a printed high-frequency (1 MHz), reactor-capable coil bobbin

Refined high-frequency coil bobbin after the first print attempt

Results and Accomplishments-UT w/ BSU

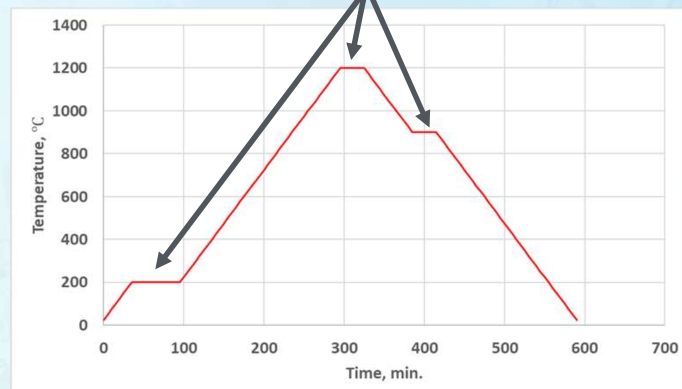


Stainless-steel (SS) weld platform



Laser-welded bump reflectors on the molybdenum waveguide become very brittle. A new heat treat restores ductility.

Temperature holds at 200, 1200, and 900℃. Heating and cooling rates of 5℃/min.



Molybdenum heat treat profile

Results and Accomplishments-UT w/ BSU

- ~200 kHz targeted as the typical UT operating frequency
- Three design elements tested
  - Sinusoidal plate (in both opposed and offset configurations)
  - Tapered and profiled wedges (to simulate a swaged tube profile)
  - Porous media closely matching the acoustic impedance of the waveguide (ultra-fine SS wool)
  - Tested in various combinations of the three elements

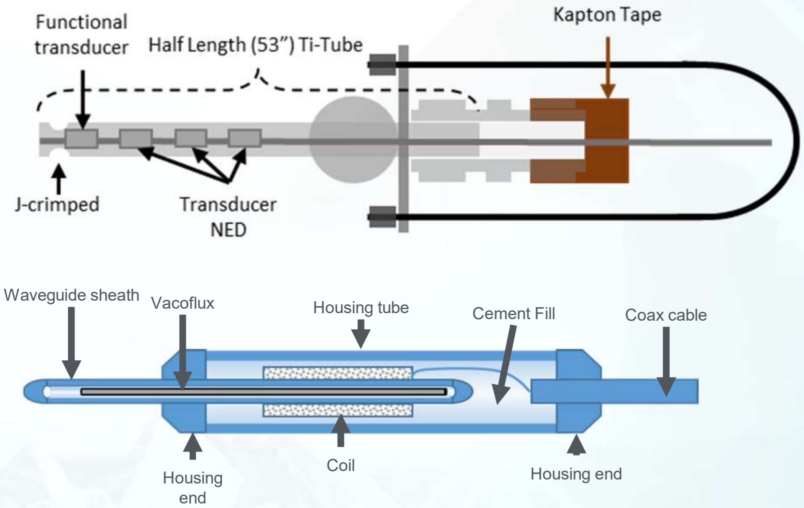
Sinusoidal Plate in Opposed Configuration

Sinusoidal Plate in Offset Configuration

Flat Tapered and Profiled 3-D-printed Wedges

	5 deg. wedge, with media	5 deg. wedge, with media and sinusoidal plate	10 deg. wedge, with media	10 deg. wedge, with media and sinusoidal plate	Parabolic wedge, with media	Parabolic wedge, with media and sinusoidal plate
% Reduction in 1st echo	**99.12**	98.30	97.47	89.27	98.95	98.70
Note:	**Adds very small artifact**	Adds small artifact	Adds large artifact	Adds small artifact	Adds very small artifact	Adds small artifact

Results and Accomplishments-UT



Some in-core UT failures are thought to be attributable to degradation of the fill cement causing coil wire mobility and shorting or open-circuit failure of the coil. In addition to the currently used Sauereisen, three other cements with desirable properties have been identified:

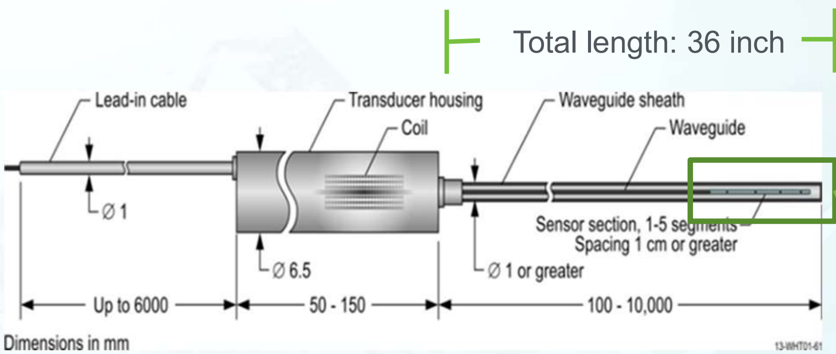
- Saueresen Electrotemp Cement No. 8
- Aremco 538 N
- Aremco 575 N
- Aremco 675 N-Likely will not be tested

Sauereisen No. 8, Aremco 538 N, and Aremco 575 N have been included as concurrent tests in several TREAT transients. This testing is ongoing and has yet not produced an obvious “best” candidate.

Results and Accomplishments-UT

SPHERE is an electrically heated non-nuclear testbed used to test heat pipes

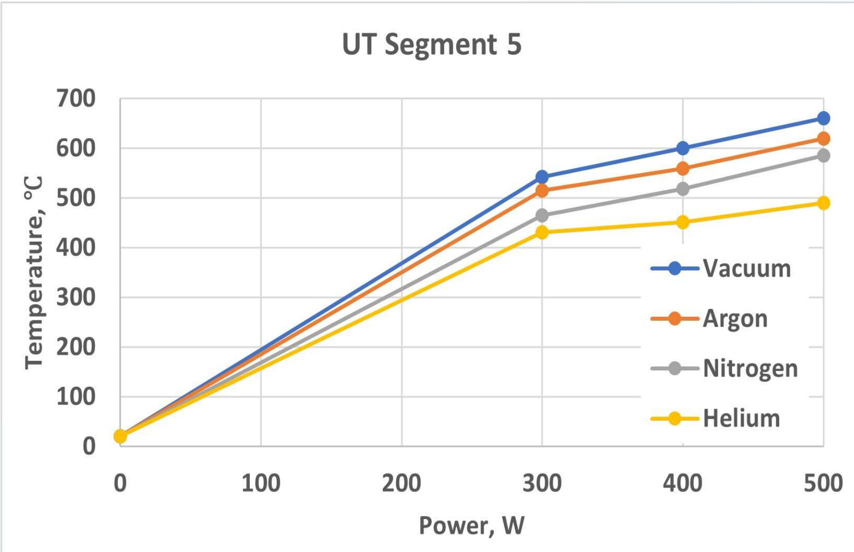
- 2 UTs were fabricated for SPHERE/MAGNET testing
  - Vacoflux-50 magnetostrictive material welded to waveguides
    - A new technique (previously described) was used to maintain ductility
  - 316-stainless-steel waveguides in a 316 SS sheath
  - Molybdenum waveguides in a 316 SS sheath
- Each sensor uses three waveguides, with welded bump reflectors for segmentation
  - The molybdenum waveguides were heat treated using a new annealing process
- Due to space constraints within the SPHERE assembly, only the SS UT was tested



5 Sensor Segments: 3 inches each
3 Segments within heat pipe

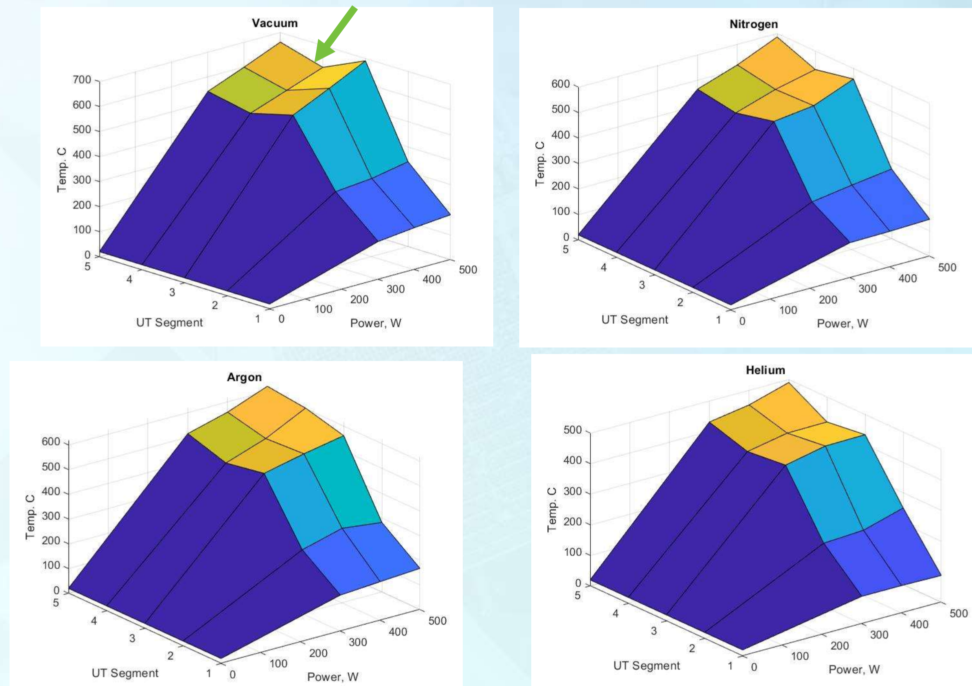
Results and Accomplishments-UT

- Data collected for 4 environments, at 0–500 W
- At over 500 W, the signal became unusable



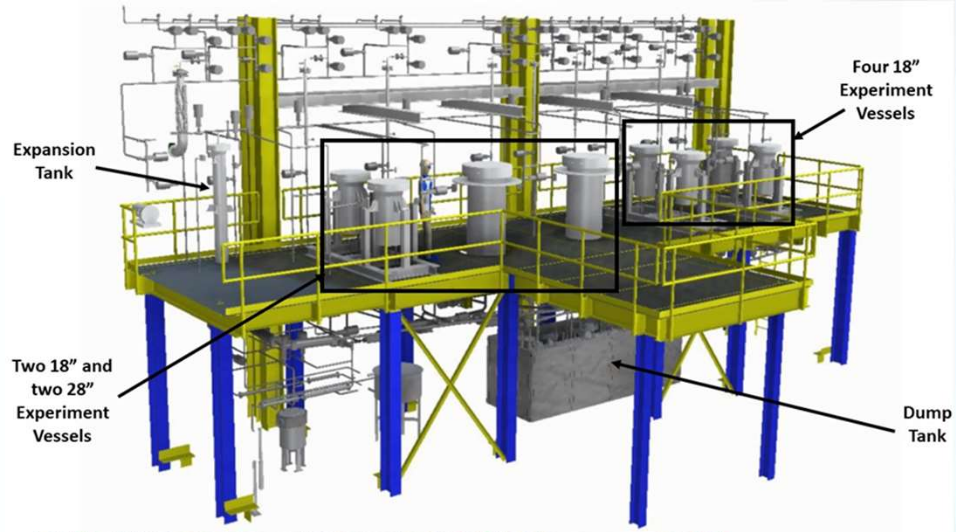
Temperature vs. power for the UT segment nearest the center of the SPHERE experiment

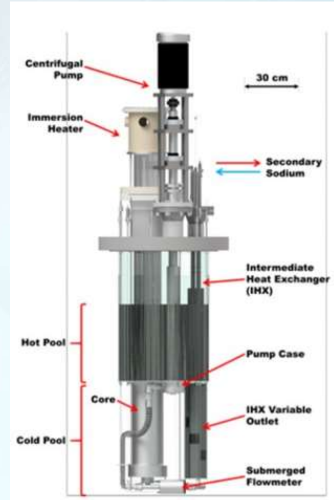
Looking into the cause of the apparent dip (real or a processing artifact?)

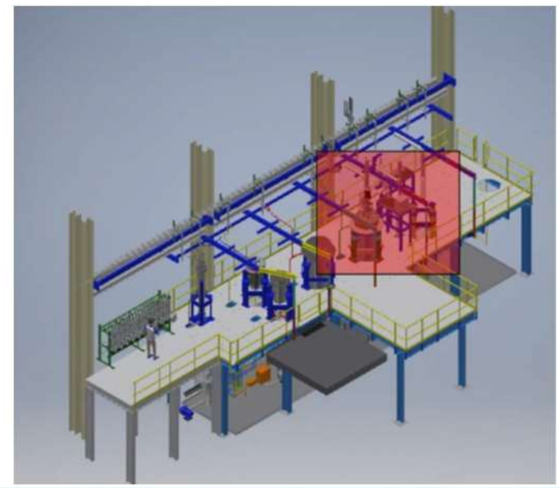


Temperature vs. power vs. segment for 4 different atmospheres

Results and Accomplishments-METL w/ ANL







Results and Accomplishments-METL w/ ANL

Parameter	Sensor	Developer	Test Position
Temperature, etc.	Wireless SAW	ORNL	Flow pipe exterior
Flow	High Temperature Flow Sensor	Sporian	“HT’s Loop”
Temperature Sensors	UT	INL	12 inch vessel
	Versatile Acoustic and Optical Sensing	VT	12 inch vessel
	Distributed Fiber Sensors	U-Pitt/Westinghouse, INL, ORNL, VT, OSU. Etc.	12 inch vessel
	HTIR TC	INL	12 inch vessel
Level	Optical Fiber Gamma Thermometer	OSU	Expansion tank
Pressure	Optical Fiber Pressure Sensor	INL	12 inch vessel
Thermal Properties	Thermal Conductivity Needle Probe	INL	12 inch vessel

Report in export review

Results and Accomplishments-SHM w/ ORNL, PNNL, EPRI

- Developer conversations held with Flibe, NuScale, BWXT
- Also contacted: Radiant, Oklo, Westinghouse, Terrapower, Framatome, Kairos; no response
- Reviewed: Piezoelectric, Magnetostrictive, EMAT, and Laser-based technologies; wave modes for SHM; commercial availability
- Major outcomes:
  - Research still needed on:
    - Transducer material identification and characterization
    - Signal analysis
  - Most ARDs are still looking at base instrumentation and not at on-line health monitoring
  - ARDs have not engaged regulators to determine need for SHM
    - Recommend holding workshop in near future to get these conversations happening

Concluding Remarks

- The UT design has been refined and will be tested in early FY23
- An assessment of ASI developed sensors has been performed with the goal of including them in a future test at the ANL METL facility
- An assessment of ultrasound based SHM technologies and needs has been performed and will be used to guide future R&D work
- FY 23 work will focus on finishing development and transfer of the UT to commercial partner, evaluating and developing pressure and acoustic emission sensors

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Thank You