



U.S. DEPARTMENT OF
ENERGY

Nuclear Energy

**Office Of Nuclear Energy
Sensors and Instrumentation
Annual Review Meeting**

**Key Technology Demonstration
for Under Sodium Viewing**

**Hual-Te Chien
Argonne National Laboratory**

September 16-18, 2014



Work Package AR-14AN230101

Subtask: Under Sodium Viewing

Subtask Relevancy

- Re-establish U.S. technology leadership for advanced fast reactor technology and develop advanced I&C technologies for nuclear energy applications
 - Developing an enabling under sodium viewing (USV) technique for nondestructive examination (NDE) of SFRs:
 - Real-time operation or maintenance monitoring of SFR at high temperatures and high radiation in-sodium
 - In-service inspection and repair of components, structures, and systems within reactor core or steam generators

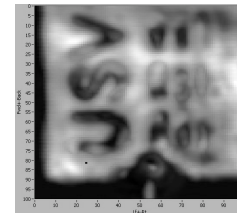
Technical Approach/Accomplishments/Results

- Constructed a USV test facility for automated in-sodium test and signal/image processing
- Successfully developed and demonstrated ultrasonic waveguide transduce (UWT) technique with real-time defect detection resolutions of 0.5 mm in both width and depth at temperature up to 650°F in sodium.
- Developed and tested a brush-type ultrasonic waveguide transducer (BUWT) phased array in water. Mockup for in-sodium testing is in-progress.
- Developed two submergible high-temperature transducers and successfully tested in hot oil up to 320°F with real-time defect detection resolutions of 0.5 mm in both width and depth.

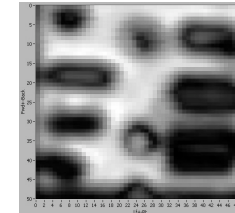
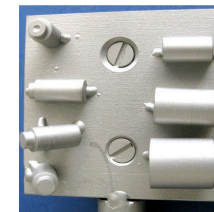
Real-Time Intensity Images

In-sodium Test @ 350°F

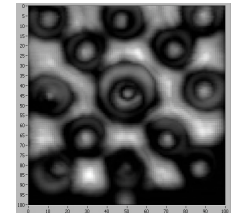
USV Target



Joyo Pin Target



Fuel-Pin Target



Expected Deliverable & Schedule

- Development of BUWT phased-array (3/15)
- Development of sodium-submergible high-temperature transducers (6/15)
- In-sodium test of BUWT phase array and submergible HT-transducers (9/15)
- Identify commercial partners and in-reactor USV system integration pathways (9/15)
- Continue CEA-DOE-JAEA collaboration on In Service Inspection and Repair (ISI&R)
- M3 and M2 progress reports (3/15 & 9/15)



Project Overview

■ Goal and Objectives

- Re-establish U.S. technology leadership in advanced fast reactor technology and develop advanced I&C technologies for nuclear energy applications
- Developing an enabling under sodium viewing (USV) system by using a novel ultrasonic waveguide transducer technique for
 - Real-time operation or maintenance monitoring of SFR under high temperatures and high radiation with high resolution in-sodium
 - In-service inspection and repair of components, structures, and systems within reactor core or steam generators

■ Participants

Hual-Te Chien, Dave Engel, William P. Lawrence, Shuh-Haw Sheen

Nuclear Engineering Division, Argonne National Laboratory

■ Schedule

Task Name	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Continue in-sodium test of UWT	●					→						
Develop brush-type waveguide phase array	●					→						
Mockup of brush-type waveguide phase array						M3	●					
Develop High-temperature transduce					●							
Conduct in-sodium test of phase array transducer											●	→
ANL M2 report and ANL/PNNL joint annual report												●



Accomplishments

■ Milestones and Deliverables

M3 Linear-array waveguide transducer under-sodium tests 4/30/2014 **Completed**

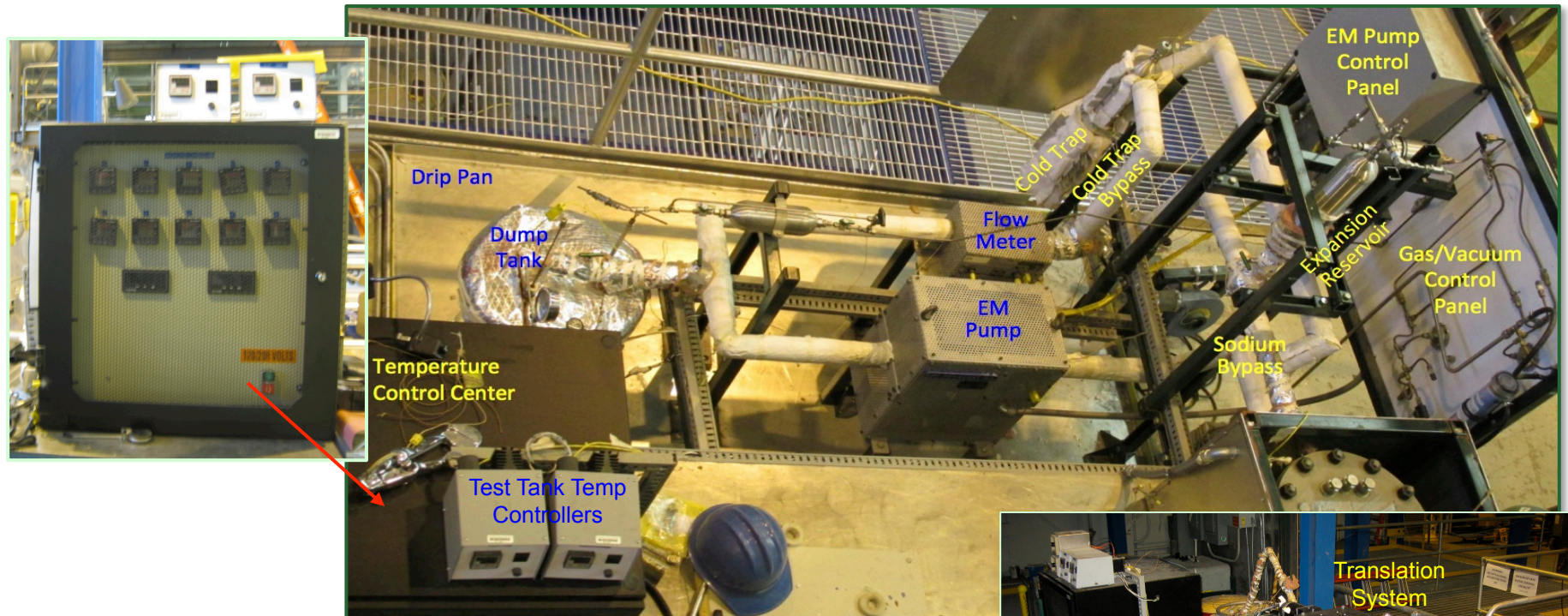
M2 Array-waveguide USV system development 9/30/2014

■ Accomplishments of FY14

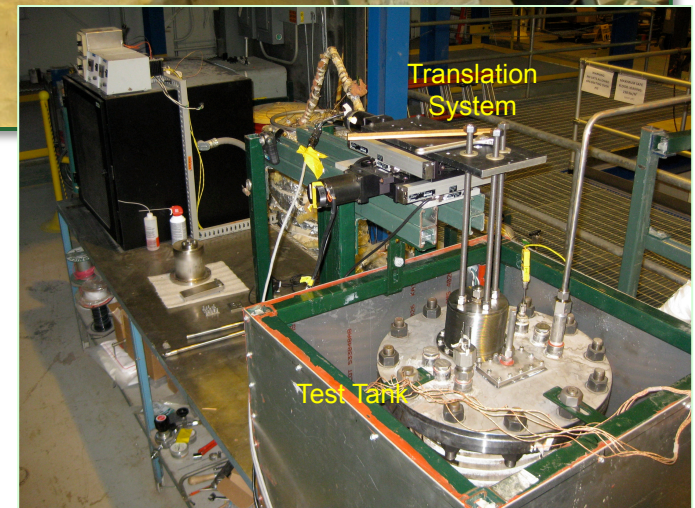
- Upgraded the USV test facility with automated real-time in-sodium monitoring/inspection and improved signal/image processing (Dec 2013)
- Successfully developed and demonstrated ultrasonic waveguide transducer (UWT) technique with real-time defect detection sensitivities of 0.5 mm in both width and depth at temperature up to 650°F in sodium. (May 2104)
- Developed and tested a brush-type ultrasonic waveguide transducer (BUWT) phased array in water. (July 2104) Mockup for in-sodium test is in-progress.
- Developed two submergible high-temperature transducers and successfully tested in hot oil up to 320°F with real-time defect detection sensitivities of 0.5 mm in both width and depth. (Aug 2104)



USV Test Facility



- ❑ Large straight-up tank to accommodate linear-array transducers
- ❑ Accept larger targets and components
- ❑ Better tank design, better fabrication, and safer operation
- ❑ Easier component/target setup, testing, and replacement
- ❑ Precise temperature control using digital temperature controllers
- ❑ Tanks sealed tighter and using cold trap to keep sodium clean
- ❑ EM pump to circulate sodium and reduce sodium wetting time
- ❑ Expansion reservoir to reduce loop stresses caused by sodium's thermal expansion





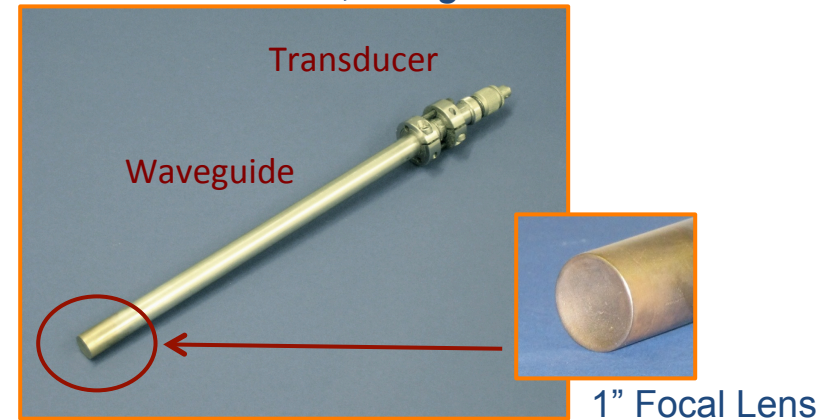
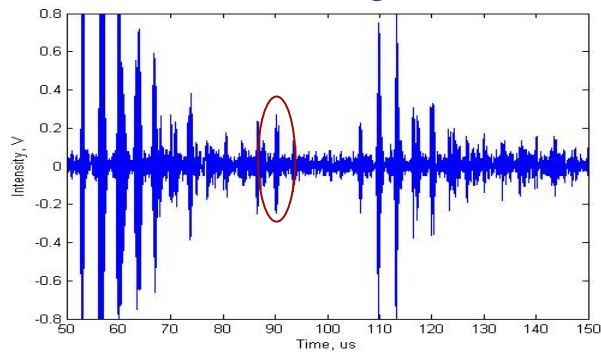
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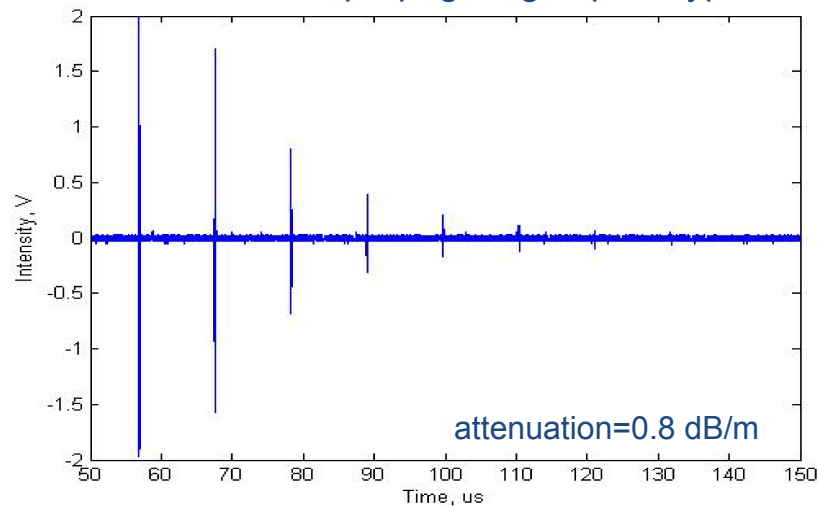
Argonne UWT Prototype

Diameter: 0.625", Length=12"

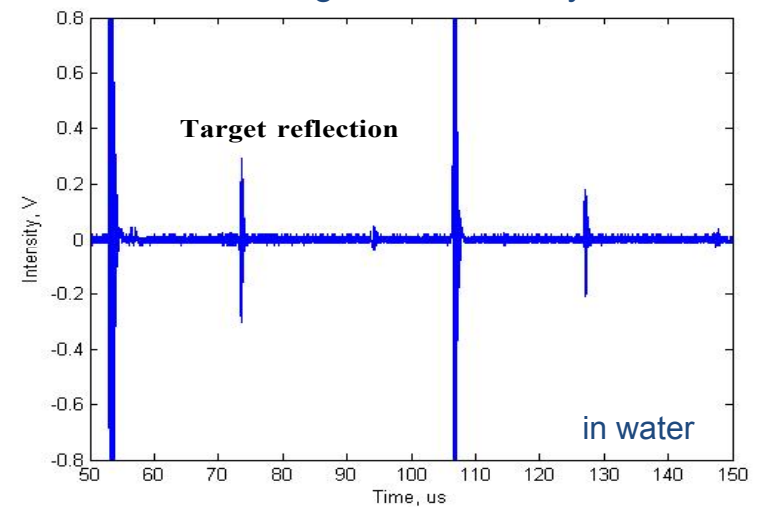
Ultrasonic signal from a conventional waveguide



Pulse train propagating in prototype



Ultrasonic signal received by UWT





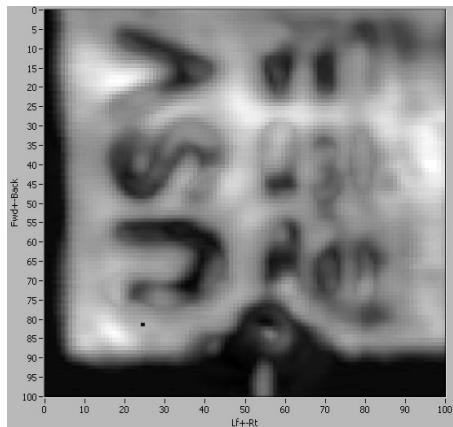
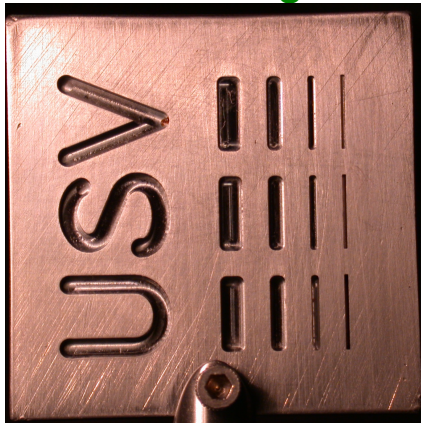
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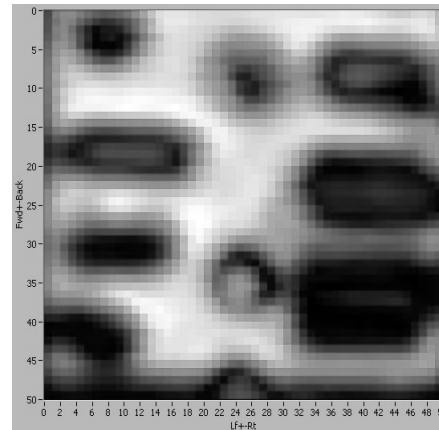
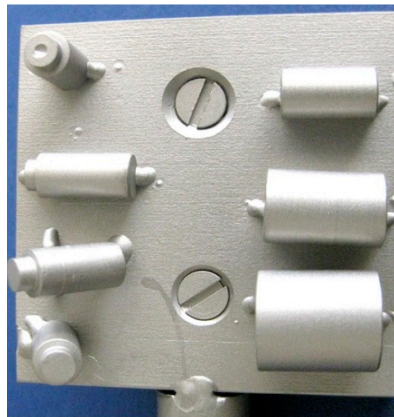
In-Sodium Test (350°F)

Real-time Intensity Images

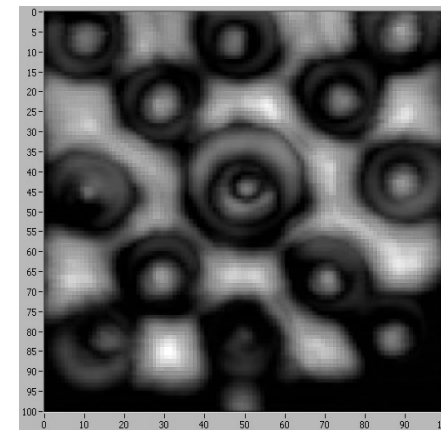
USV Target



Joyo Pin Target



Fuel-Pin Target



- ❑ Achieved real-time defect detection sensitivities of 0.5 mm in both width and depth at temperature up to 650°F in sodium.
- ❑ Capable of detecting Joyo pin laying under different orientations
- ❑ Capable of identifying components with complex geometry and thin tubing

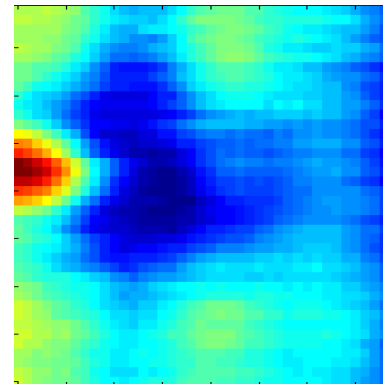
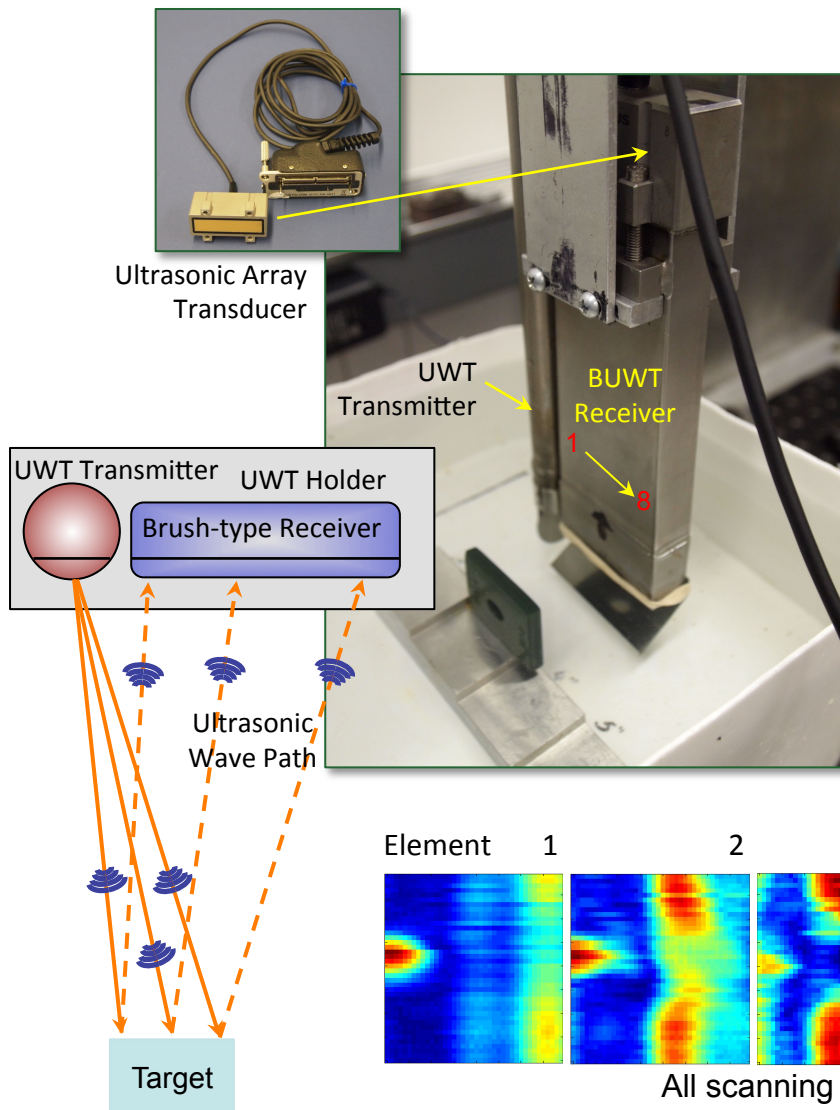


BUWT for Sideway Scanning

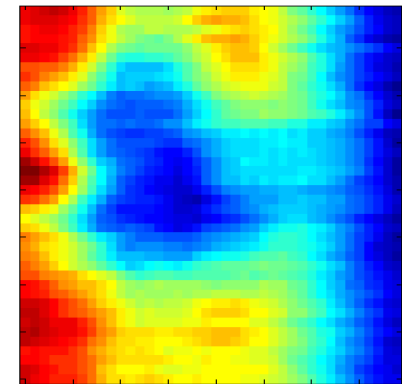
Mockup for in-sodium test is in-progress.

Further improvements:

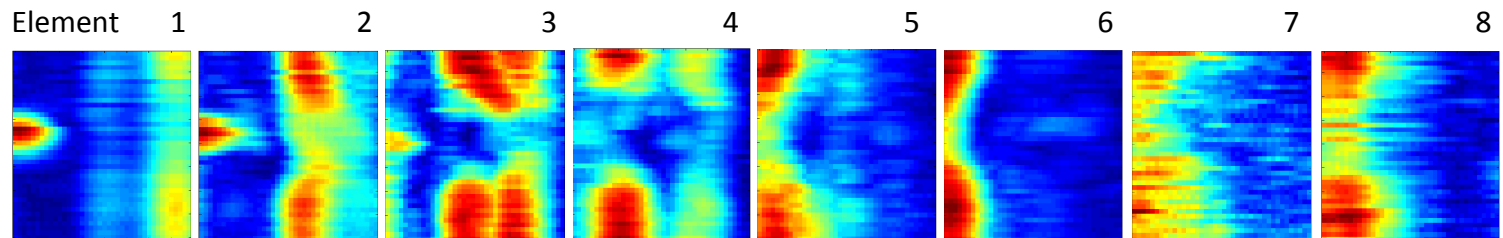
- ☐ TOF correction (testing)
- ☐ Intensity correction
- ☐ Pixel-size correction
- ☐ More accurate positioning (encoder added)



Sum-up of elements 1-8



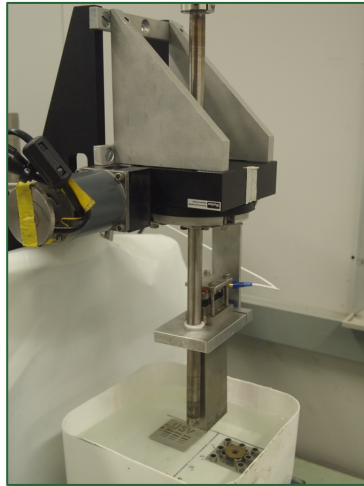
Sum-up of elements 2-8



All scanning images have been corrected to the right aspect ratio.

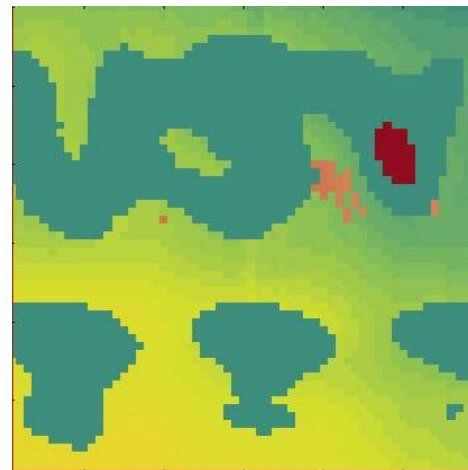
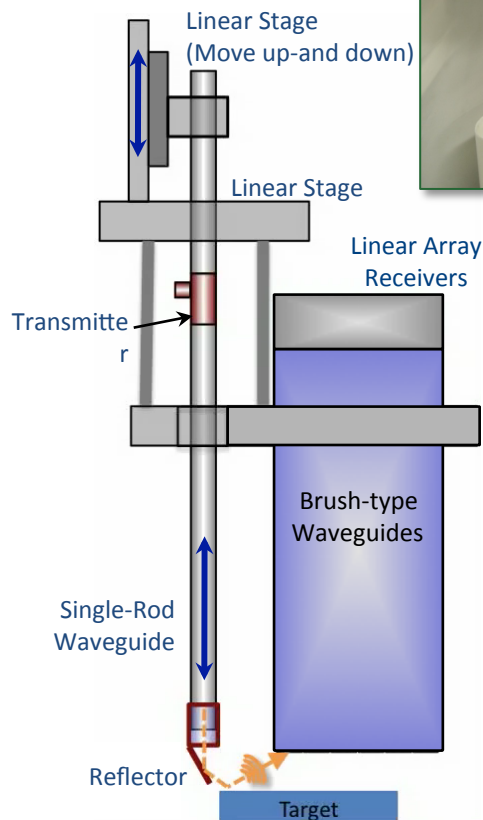


BUWT for Downward Scanning

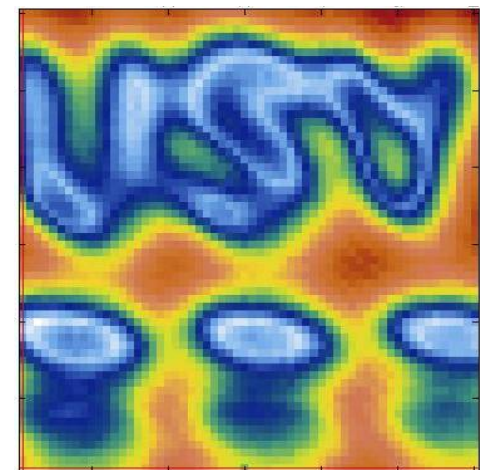


Further improvements:

- ☐ TOF correction (testing)
- ☐ Intensity correction
- ☐ More accurate positioning (encoder added)



Time-of-flight image



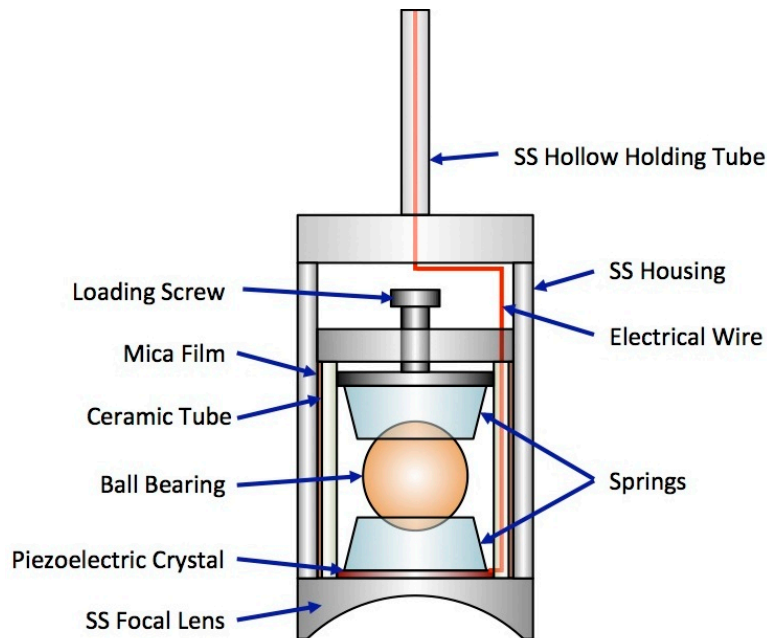
Intensity image



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High-Temperature Submersible Transducer Prototype



- HT Transducer prototype consists of
- Housing assembly (SS housing and focal lens)
 - Dry-coupling assembly
 - Mechanical loading assembly
 - PZT-5A piezoelectric element
- (Diameter: 0.5", operating frequency: 2.25MHz)

Max operating temperature: ~350°F

Dimensions: 1.125" in diameter and 2" in length



SS Focus Lens

SS Housing

Mica Film and
Ceramic Tube

Spring and Ball
Bearing

Loading
Assembly

Dry-coupling
Assembly

Housing Assembly

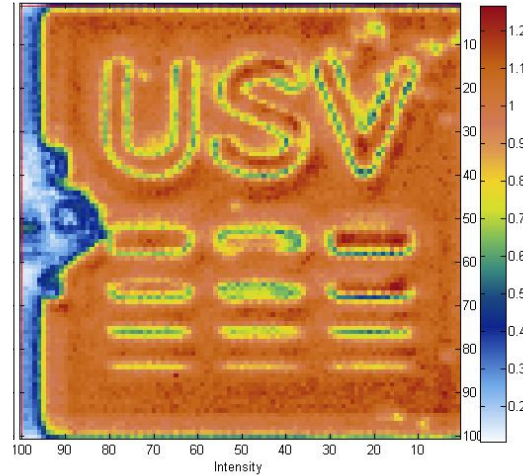
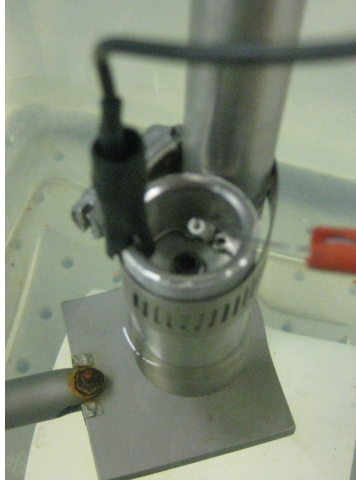


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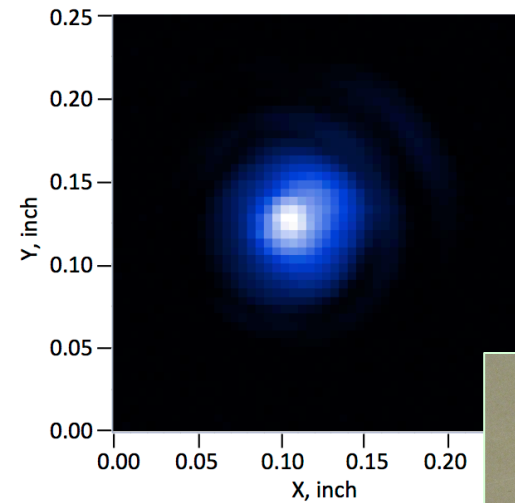
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High-Temperature Submersible Transducer (Under Ambient Condition)

Water Test

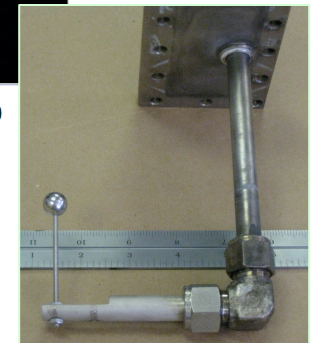


Intensity Image

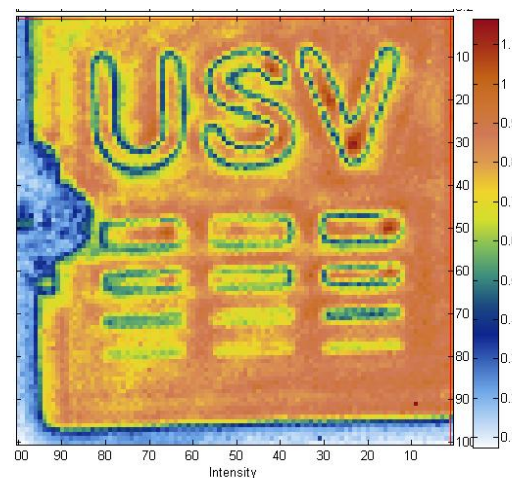
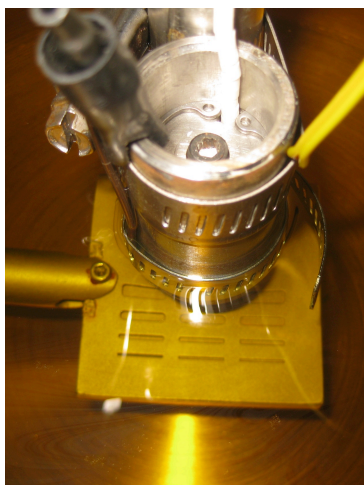


Beam Diameter

Ball target for
evaluation beam size



Oil Test



Intensity Image

- ❑ Achieved detection sensitivities of 0.5 mm in both width and depth
- ❑ Beam diameter < 0.2" @ FD=1" (Following the ASTM E1065-08 Test Std)



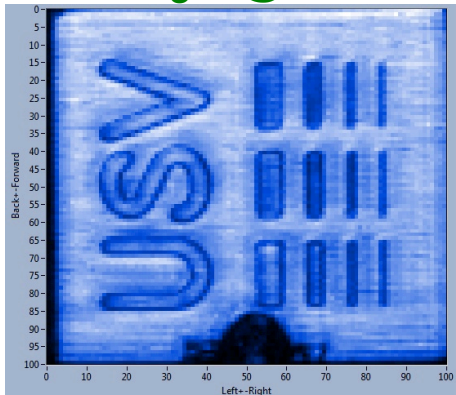
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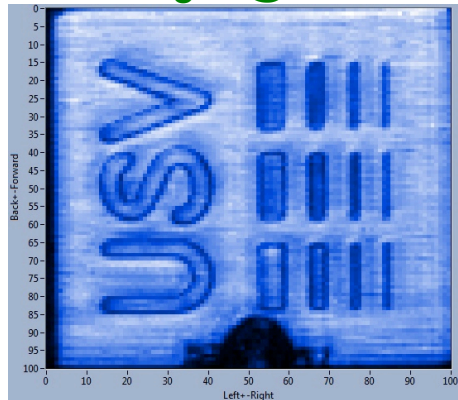
High-Temperature Submersible Transducer

(Oil Test, Real-Time Intensity Images, 320°F)

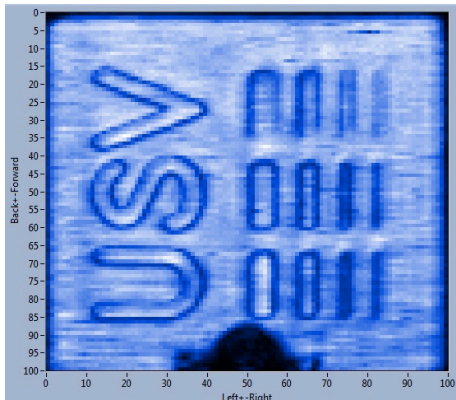
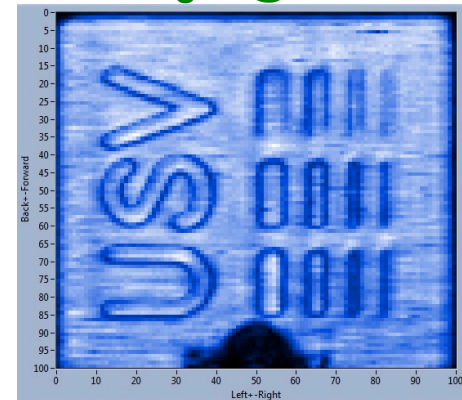
Target @ 1.0"



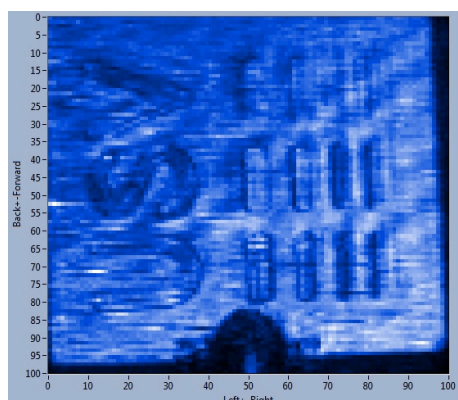
Target @ 1.25"



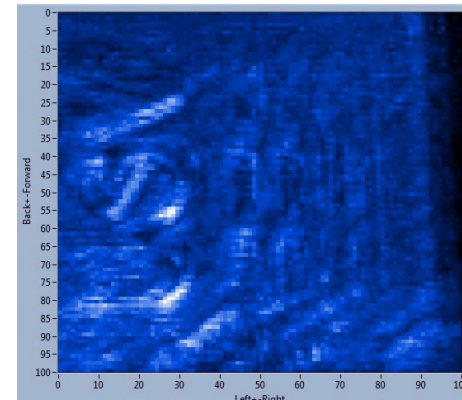
Target @ 1.375"



Target @ 1.5"



Target @ 1.75"



Target @ 2.0"

- ❑ Achieved detection sensitivities of 0.5 mm in both width and depth, even target is positing $\frac{3}{4}$ " away from the UWT's focal point (FD=1")
- ❑ Still maintaining same sensitivities after 2 weeks of hot oil tests (320°F)
- ❑ Will develop very HT-HR submersible transducers with ZnO (>1,400°F) and AlN (>1,800°F)



Future Plan

- Continue the development of sodium-submersible BUWT phased-array
- Development of sodium-submersible transducers (ZnO and AlN) with very high temperature and radiation resistances
- Evaluate detection sensitivities of submersible BUWT phase array and HT-HR transducers in sodium
- Conduct reliability and probability of detection (POD) with thermal cycling, signal, and imaging processing methodologies for loose-part detection and component inspection
- Identify commercial partners and in-reactor USV system integration pathways
- Continue CEA-DOE-JAEA collaboration on In Service Inspection and Repair (ISI&R)
- Complete M3 and M2 progress reports



Technology Impact

- *Currently there is no reliable inspection/monitoring method for reactor core of SFRs due to challenges associated with liquid metal cooled reactors (high temperature, high radiation, and corrosive environment) .*
- *The USV technology being developed under this project will play a critical role in safe operation of advanced reactor technologies.*
- *This enabling NDE technology will benefit other areas of reactor inspection needs, particularly those requiring inspection/monitoring in harsh environment.*
- *The data provided by USV system complements on-line monitoring data obtained by I&C system of future SFRs.*
- *Successful deployment of this technology will improve reliability, ensure safety, and reduce operational costs for nuclear stakeholders.*



Conclusion

- *Lead the USV technique development (between US, France, Japan, and Korea)*
- *Developed and demonstrated the UWT technique for USV with real-time defect detection sensitivities of 0.5 mm in both width and depth in sodium @ 650°F*
- *Developed and demonstrated high-temperature submersible ultrasonic transducers for USV with real-time defect detection sensitivities of 0.5 mm in both width and depth in oil @ 320°F*
- *Enable real-time monitoring of reactor core and in-service inspection, and complements on-line monitoring data obtained by I&C system of SFRs*
- *Constructed a under sodium test facility for in-sodium tests of materials and components, and study of sodium-water reaction*