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

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Nuclear Energy

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*

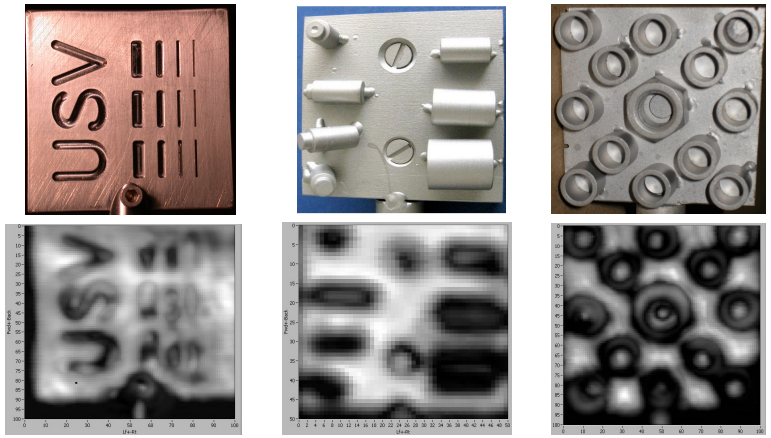
Technical Approach/Accomplishments/Results

- **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)**

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Project Overview

Goal and Objectives

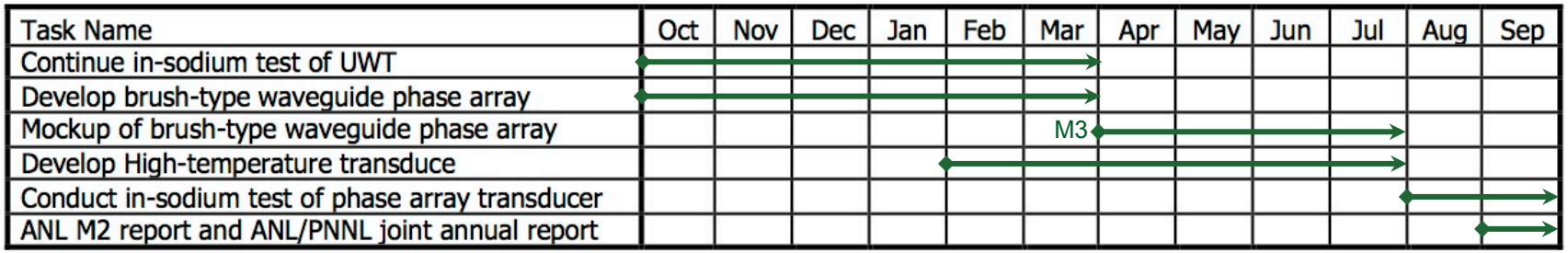
- Re-establish U.S. technology leadership in advanced fast reactor technology and develop advanced I&C technologies for nuclear energy applications
- Developing an enabling under sodium viewing (USV) system by using a novel ultrasonic waveguide transducer technique for
  - Real-time operation or maintenance 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



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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)

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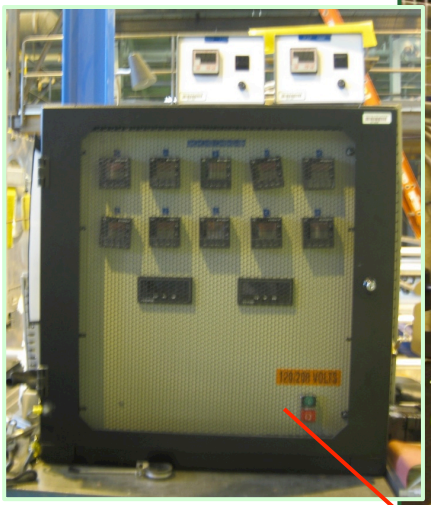
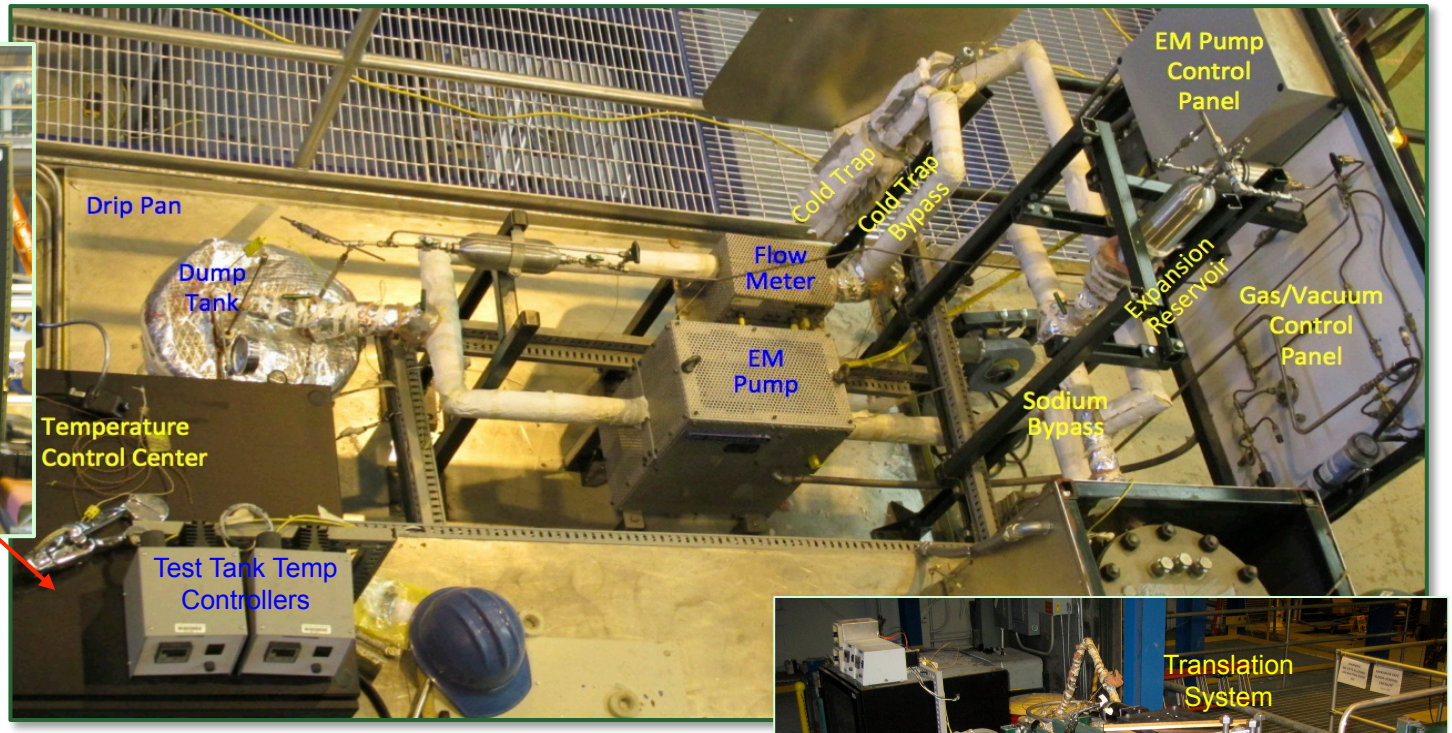
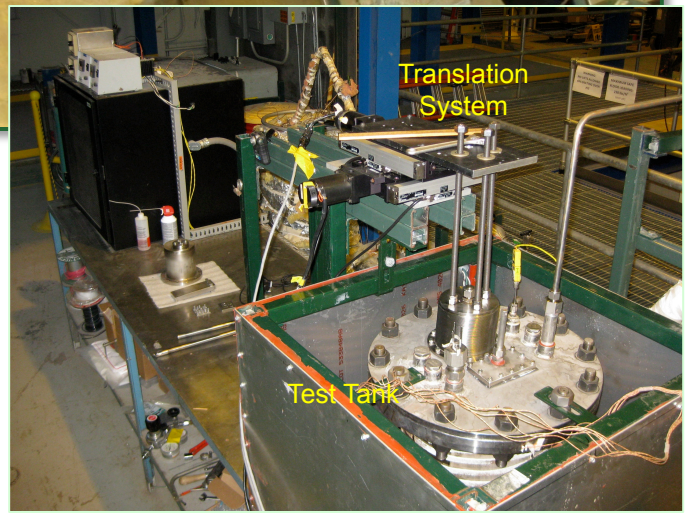
USV Test Facility







- 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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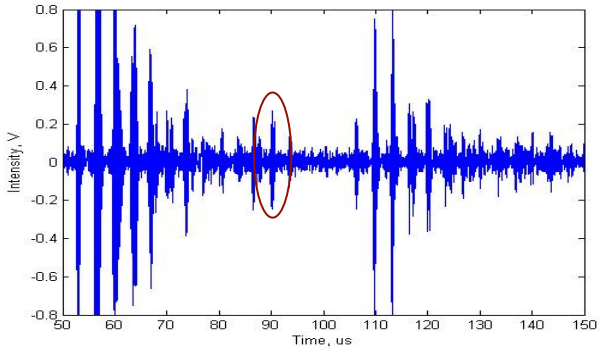
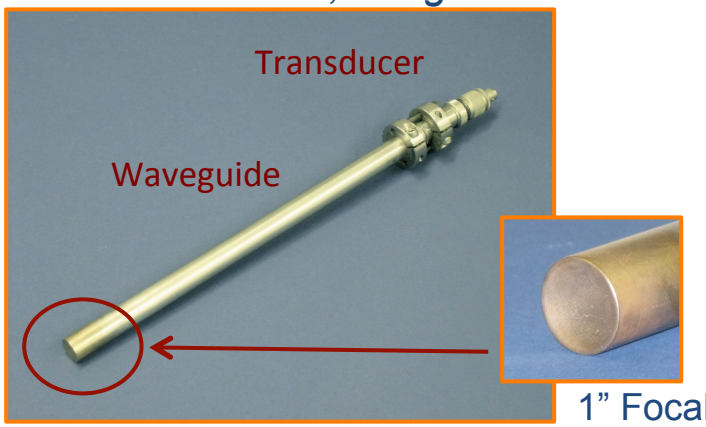
Argonne UWT Prototype

Ultrasonic signal from a conventional waveguide

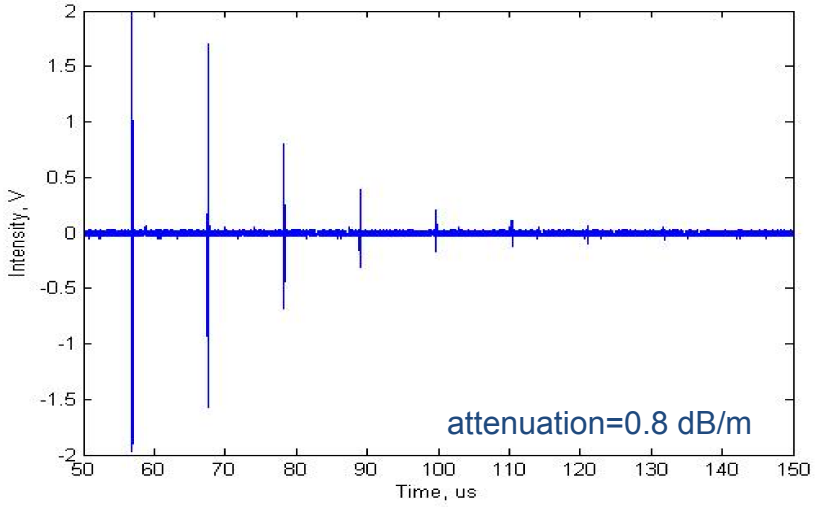


Diameter: 0.625", Length=12"

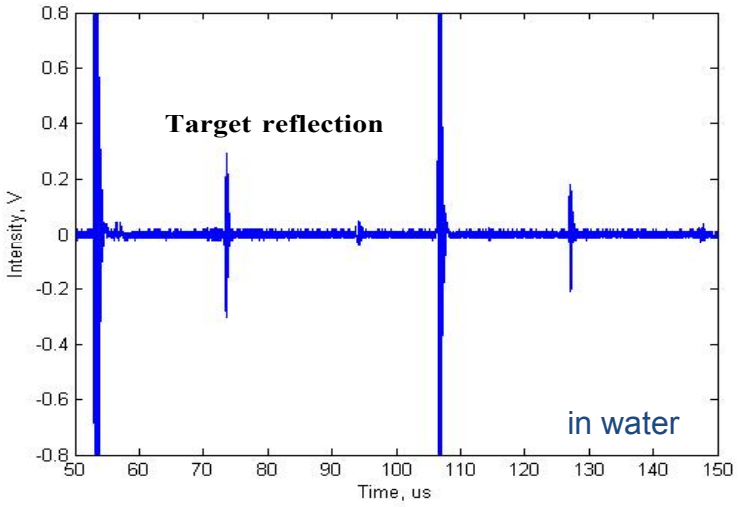


1" Focal Lens

Pulse train propagating in prototype



Ultrasonic signal received by UWT



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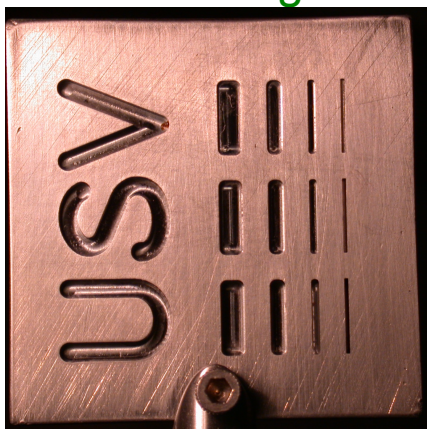
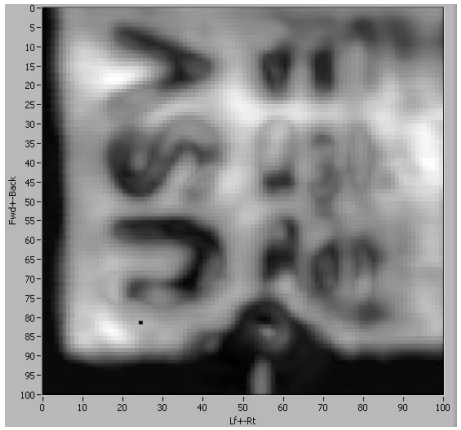
In-Sodium Test (350°F)

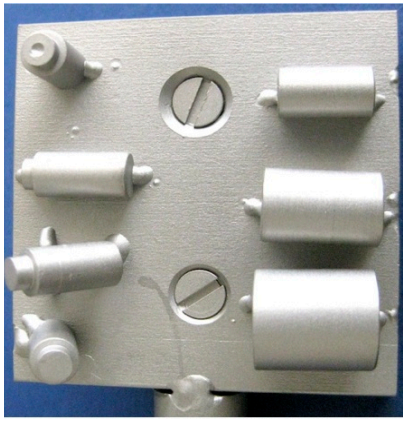
Real-time Intensity Images

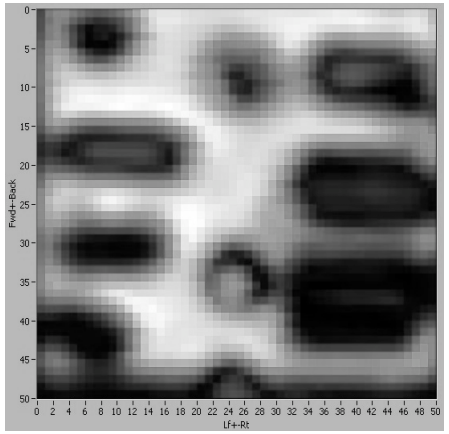
USV Target



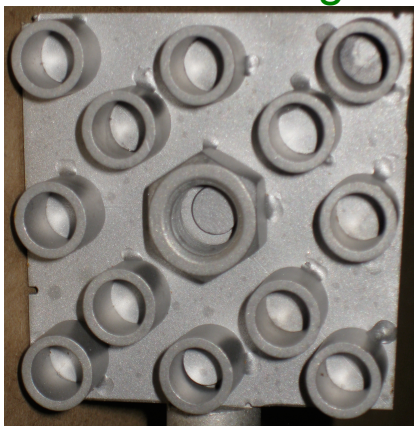


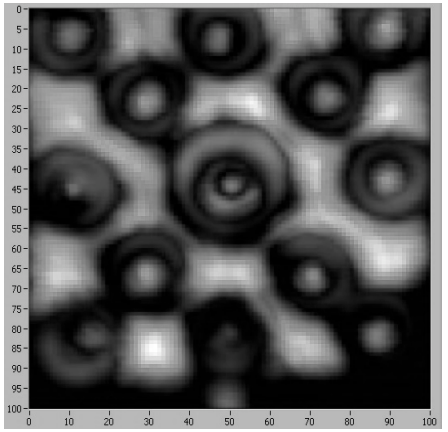
Joyo Pin Target





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

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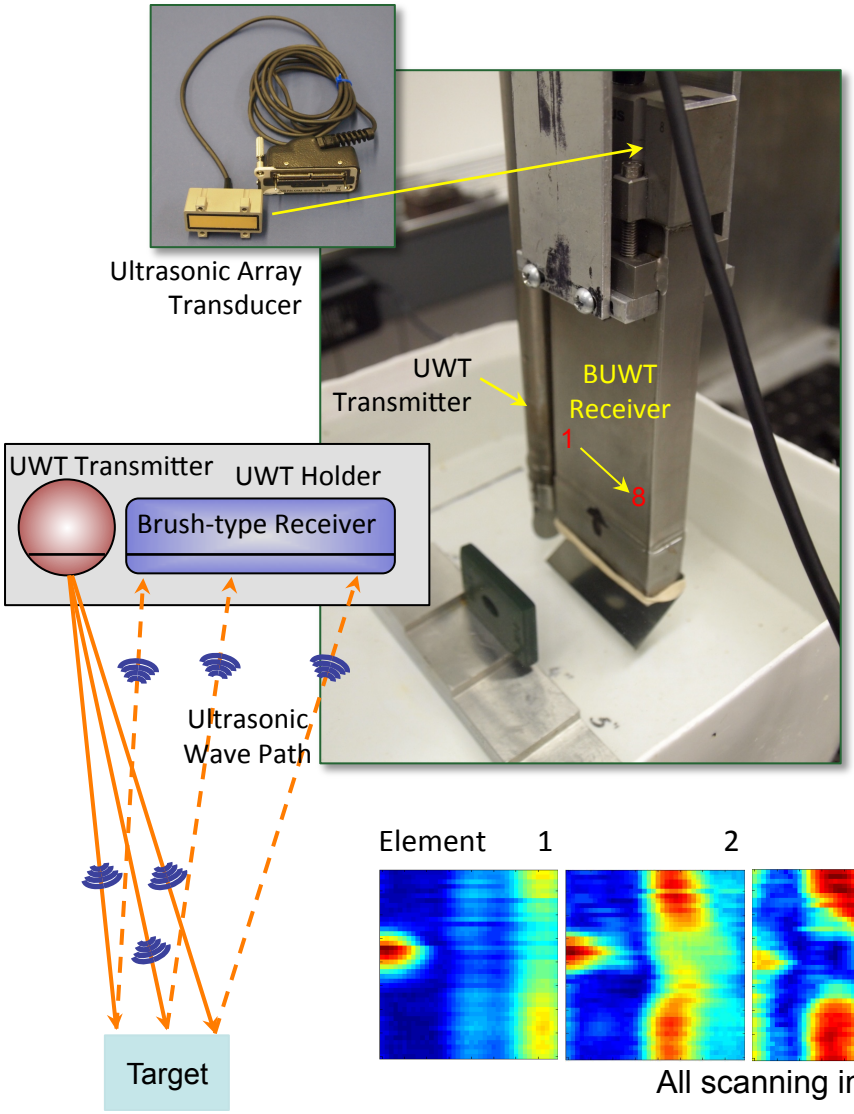
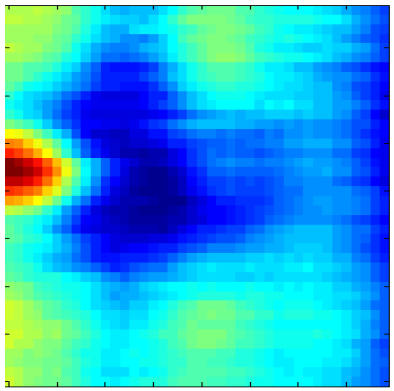
BUWT for Sideway Scanning



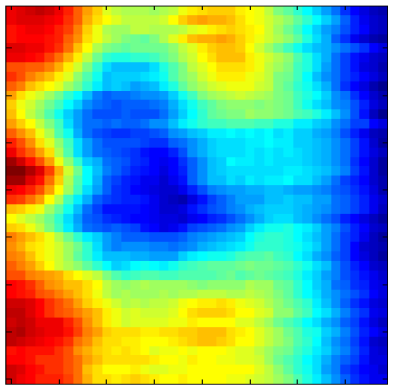
Mockup for in-sodium test is in-progress.

Further improvements:

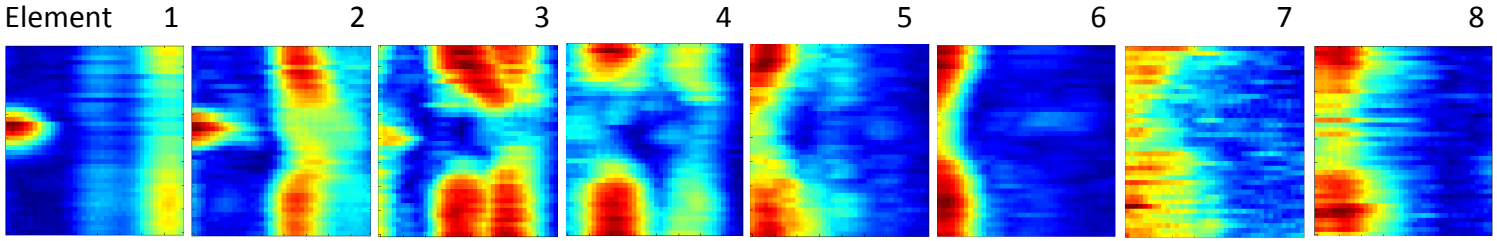
- TOF correction (testing)
- Intensity correction
- Pixel-size correction
- More accurate positioning (encoder added)



Sum-up of elements 1-8



Sum-up of elements 2-8



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

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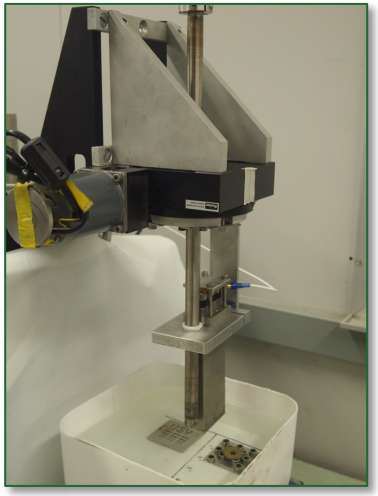
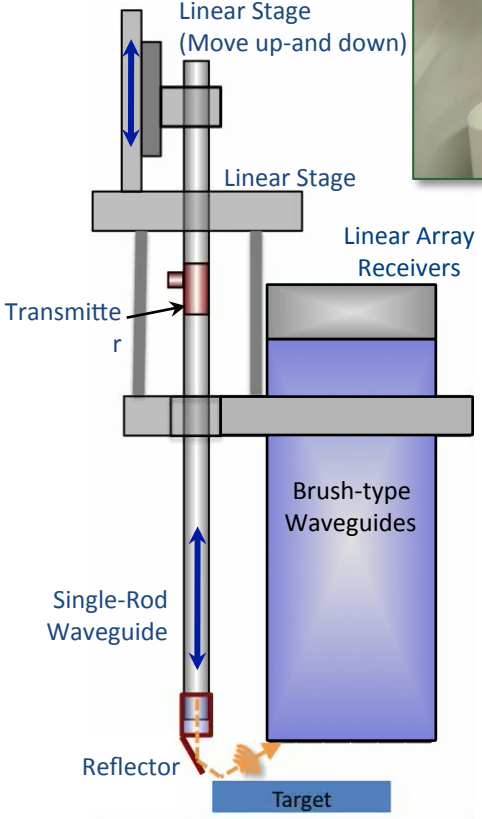
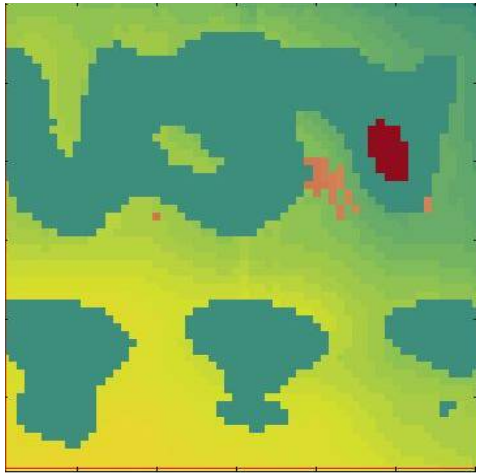
BUWT for Downward Scanning



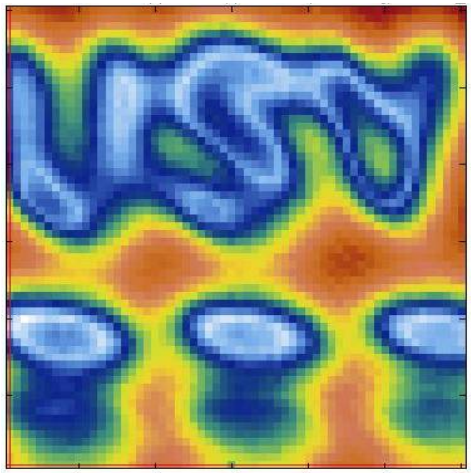


Further improvements:

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



Time-of-flight image



Intensity image

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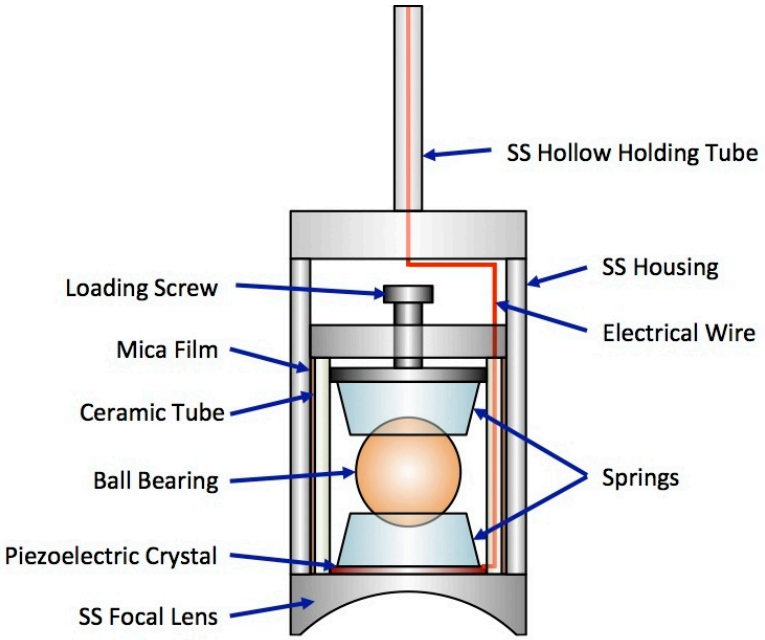
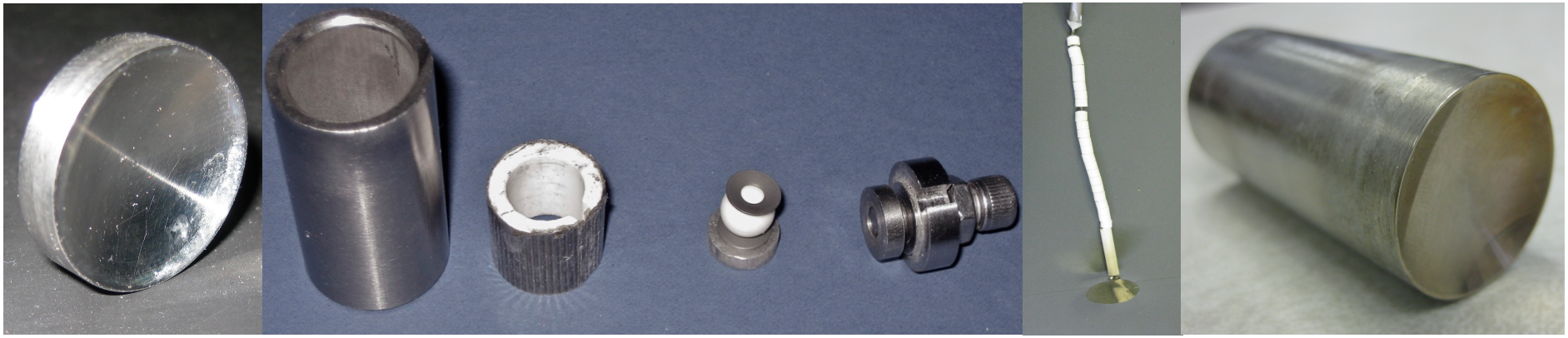
High-Temperature Submergible Transducer Prototype



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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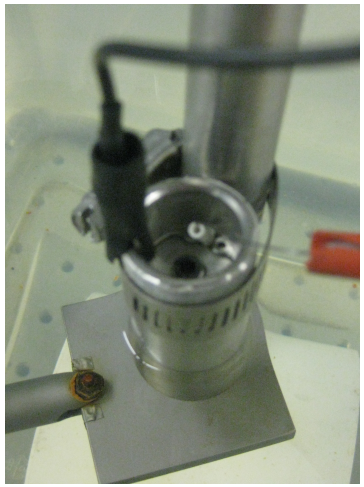
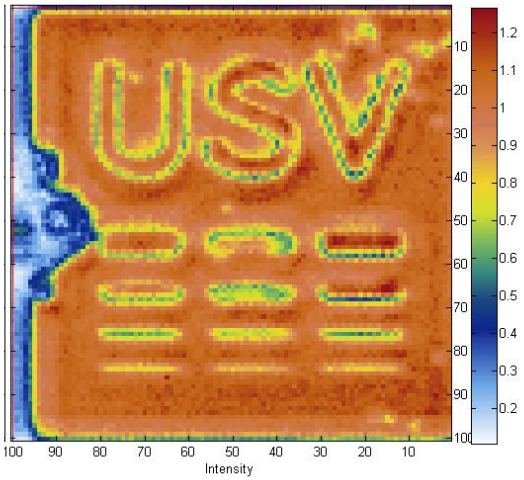
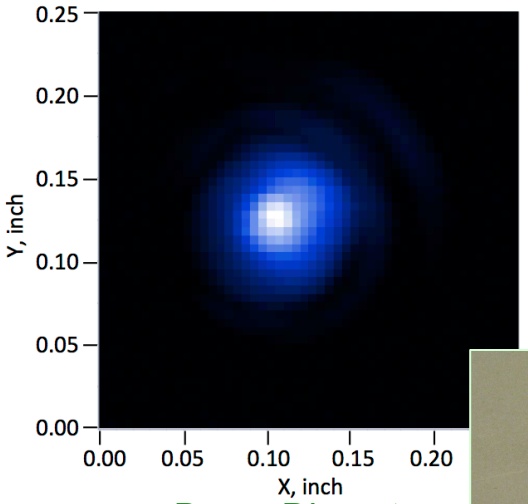
High-Temperature Submergible Transducer
(Under Ambient Condition)

Water Test



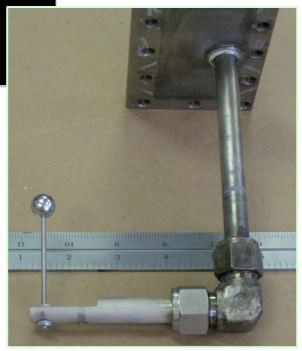


Intensity Image

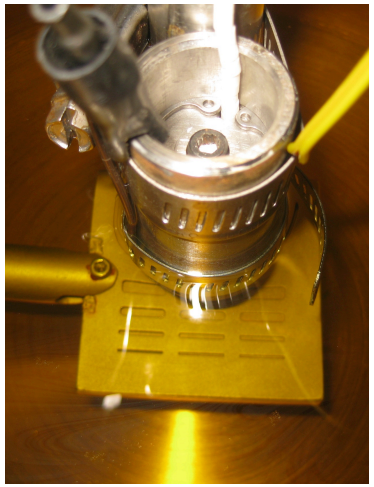


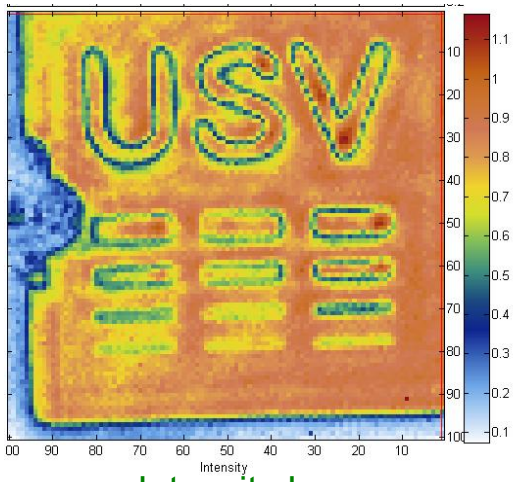
Beam Diameter

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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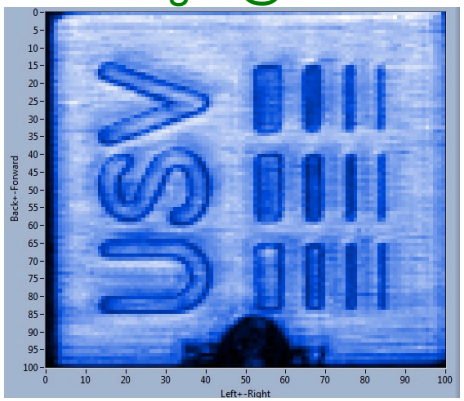
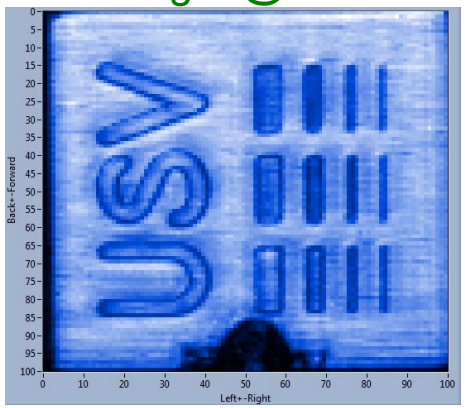
High-Temperature Submergible Transducer

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

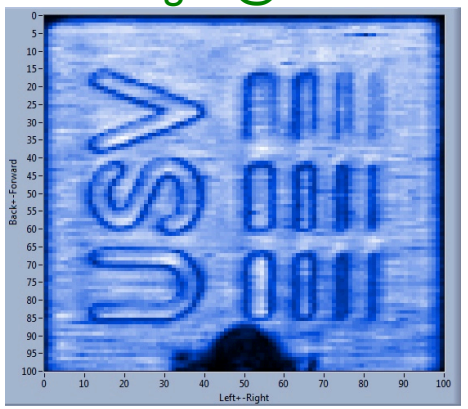
Target @ 1.0”

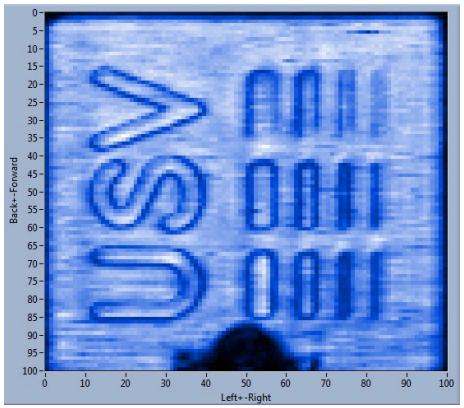


Target @ 1.25”

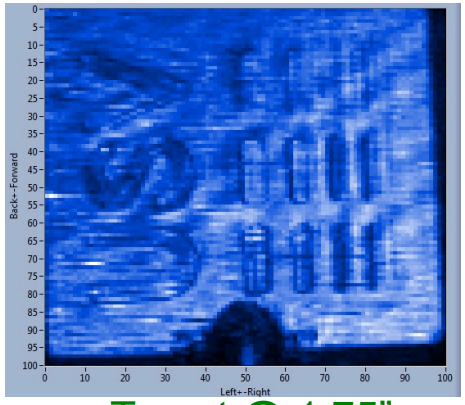


Target @ 1.375”

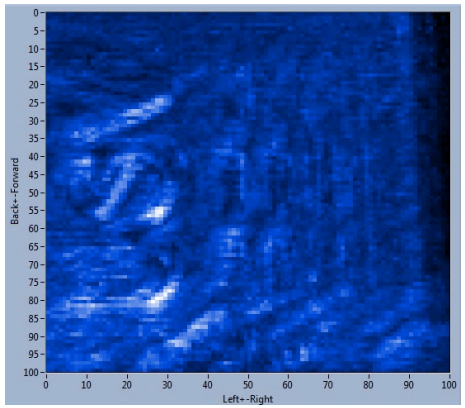




Target @ 1.5”



Target @ 1.75”



Target @ 2.0”

- Achieved detection sensitivities of 0.5 mm in both width and depth, even target is positing ¾” 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 submergible transducers with ZnO (>1,400°F) and AlN (>1,800°F)

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Future Plan

- Continue the development of sodium-submersible BUWT phased-array
- Development of sodium-submergible transducers (ZnO and AlN) with very high temperature and radiation resistances
- Evaluate detection sensitivities of submergible 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

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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.***

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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 submergible 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***