U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Office Of Nuclear Energy Sensors and Instrumentation Annual Review Meeting

Key Technology Demonstration for Under Sodium Viewing

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DOE-NE ART-ICHMI

October 28-29, 2015

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Nuclear Energy

Work Package AT-15AN230101 Subtask: Under Sodium Viewing

Subtask Relevancy

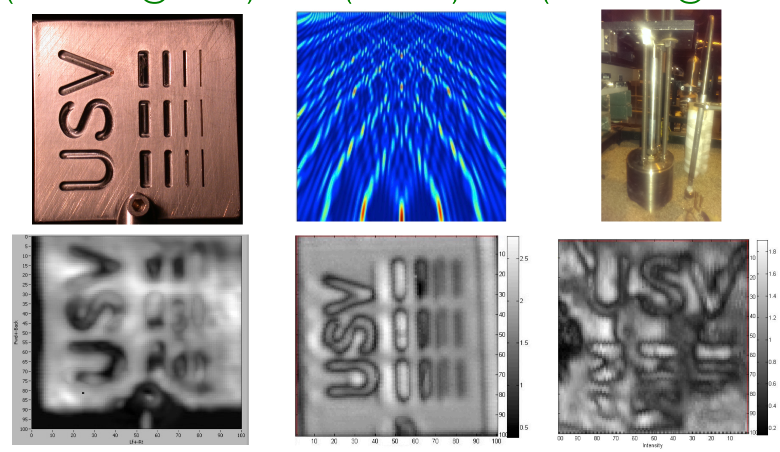
- **Re-establish U.S. technology leadership for advanced fast reactor technology and develop advanced I&C technologies for nuclear energy applications**
  - **Developing an enabling under sodium viewing (USV) technique for nondestructive examination (NDE) of SFRs:**
    - *Real-time operation or maintenance 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, signal/image processing, and defection detection.**
- **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.**
- **Successfully developed submergible high-temperature transducers and tested in hot oil up to 320°F with real-time defect detection resolutions of 0.5 mm in both width and depth. In-sodium testing is in-progress**
- **Developed and tested a brush-type ultrasonic waveguide transducer (BUWT) phased array in water. Mockup for in-sodium testing is in-progress.**

Real-Time Intensity Images

UWT (in Sodium @ 350°F) | BUWT-PA (in Water) | Submergible UT (in Sodium @ 320°F)



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 (3/31 & 9/30)**

Work Scope and Milestones

■ Work Scope and Schedule:

Task Name	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Development and Mockup of BUWT												
Development of BUWT phased array												
Development of HT submergible transducer												
In-sodium test of HT submergible transducer												
ANL semiannual M3 report							M3					
Mockup of BUWT phased array												
In-sodium test of BUWT phased array												
ANL/PNNL joint M2 annual report												M2

■ Funding:

FY14 carryover: $103.7K

FY15: $450K (FY16 carryover: $50K)

■ Milestones and Deliverables:

M3 Development of submergible BUWT and high-temperature ultrasonic transducers 3/31/2015 Completed

M2 Development of submergible BUWT and high-Temperature ultrasonic Transducers for Under-Sodium Viewing (ANL-PNNL joint report) 9/30/2015 Completed

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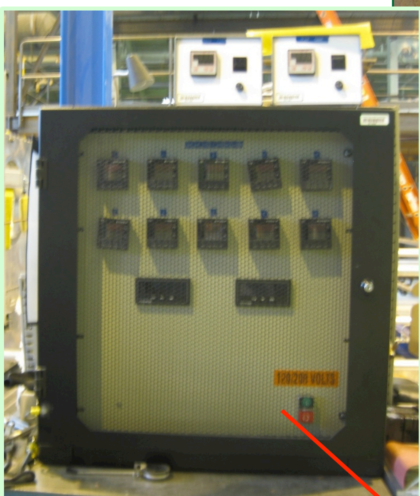
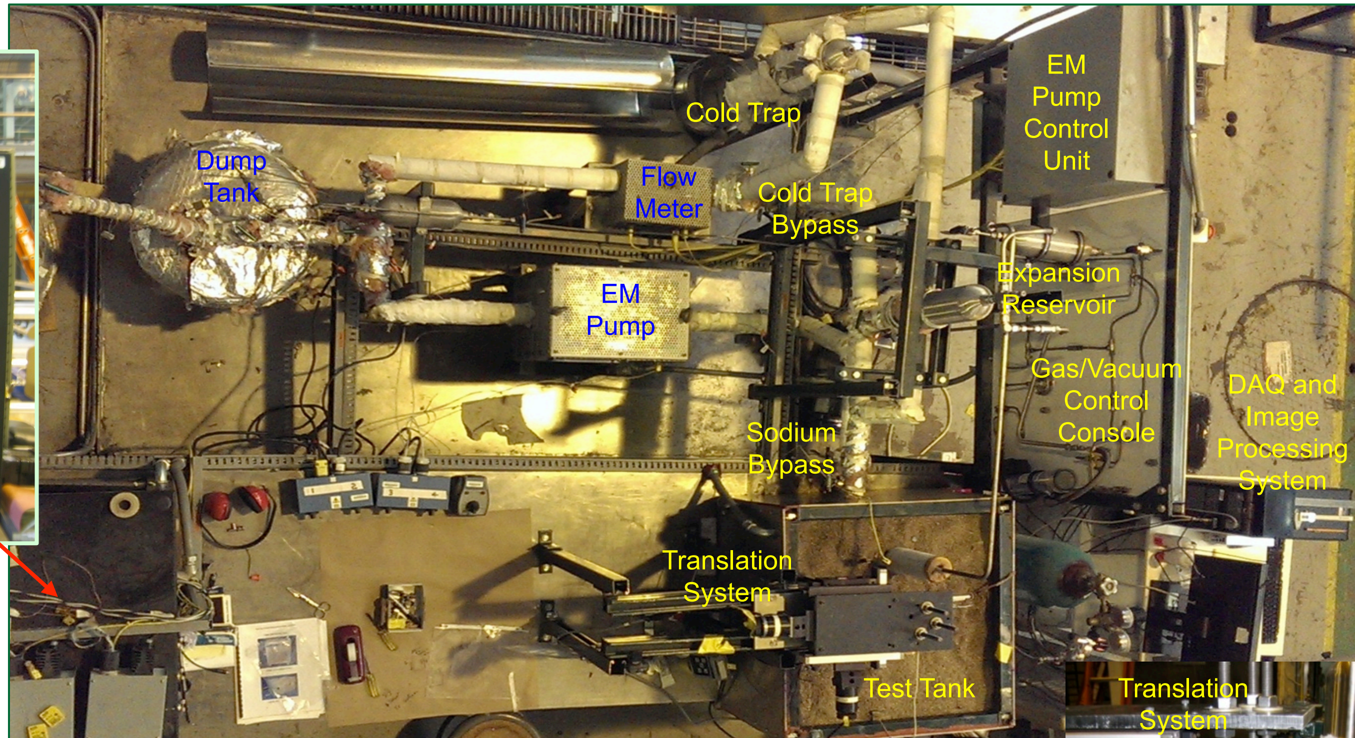
Accomplishments

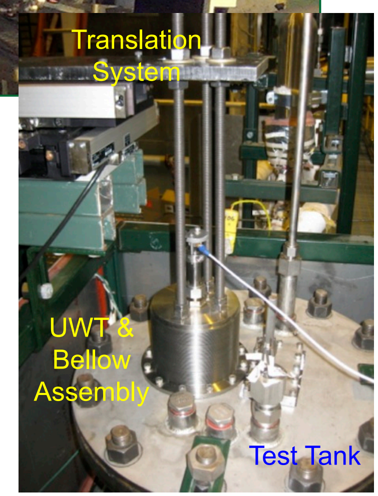
- Upgraded USV test facility for automated real-time in-sodium monitoring/inspection with improved signal/image processing. (Dec 2013)
- Successfully developed and demonstrated ultrasonic waveguide transducer (UWT) technique for in-situ, in-sodium defect detection with resolutions of 0.5 mm in both width and depth up to 650°F. (May 2014)
- Successfully developed and demonstrated ultrasonic waveguide transducer (UWT) technique for in-situ, in-sodium component recognition up to 650°F. (July 2014)
- Developed and tested a BUWT for side- and downward-view in water. (July 2014)
- Developed two HT submergible ultrasonic transducer (PZT-5A) prototypes and successfully tested in water and hot oil bath (up to 320°F) with in-situ defect detection resolutions of 0.5 mm in both width and depth. (Sep 2014)
- Sealed and tested HT submergible ultrasonic transducer (PZT-5A) in water (Oct 2014) and tested in hot oil bath for study of focal effect. (Dec 2014).
- Integrated BUWT and phased array (PA) techniques and conducted PA modeling. (April 2015) Mockup for in-sodium test is in-progress.
- Tested HT submergible ultrasonic transducer (PZT-5A) in sodium with potential in-situ defect detection resolutions of ~0.5 mm in both width and depth. (August 2015) . Additional in-sodium tests are in-progress.
- Developed two HT submergible ultrasonic transducer ($LiNbO_3$) prototypes and successfully tested in water and hot oil bath (up to 320°F) with in-situ defect detection resolutions of 0.5 mm in both width and depth. (Sep 2014)

USV Test Facility



System Temperature Controller Unit





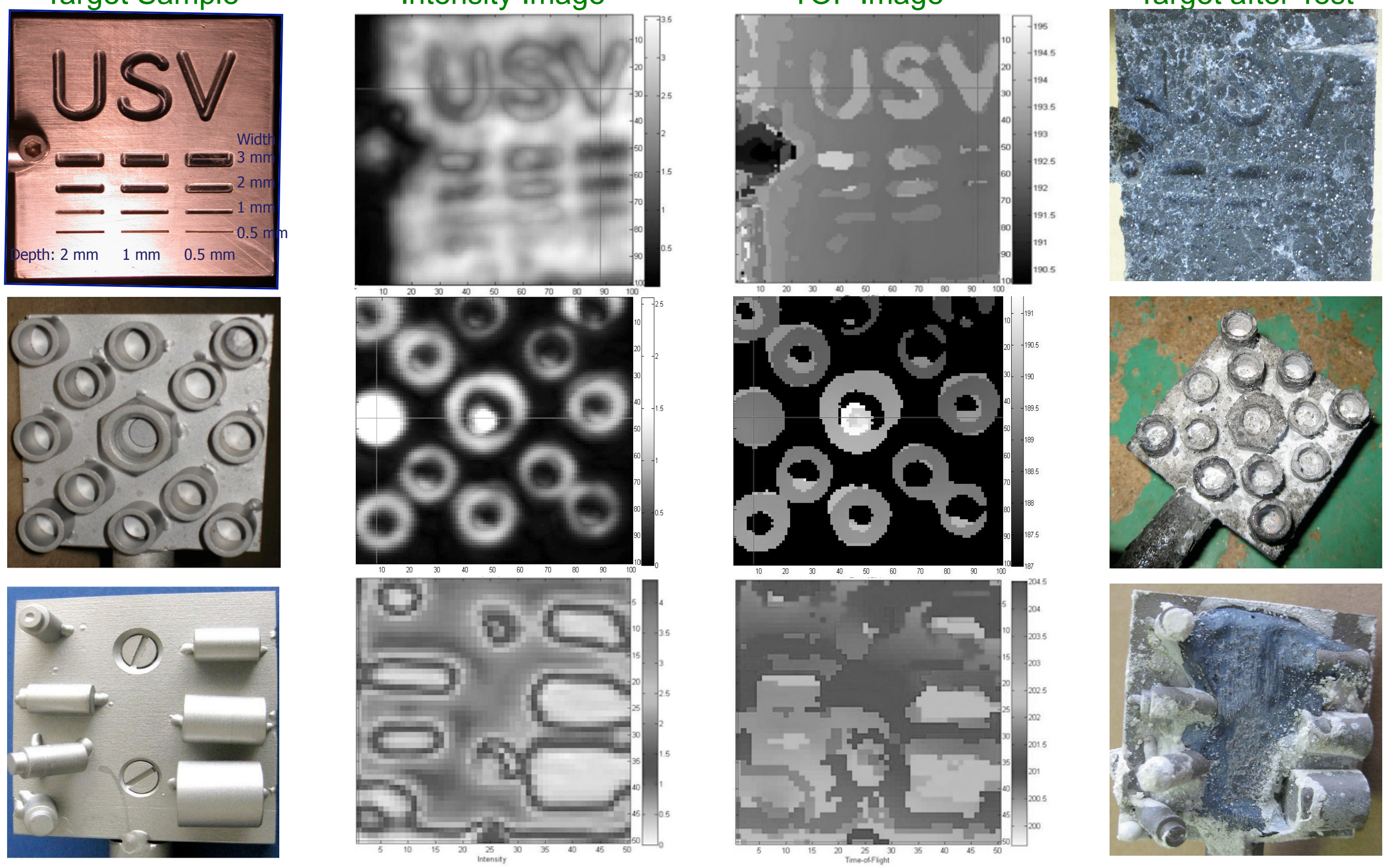
- Large straight-up tank to accommodate linear-array transducers and larger targets
- Better tank design for easier component/target setup, testing, and replacement
- Completely sealed test tank and bellow assembly for safer operation
- Cold trap to remove impurity and keep sodium clean
- EM pump to circulate sodium and potential speed up sodium wetting process
- Expansion reservoir to reduce loop stresses caused by sodium's thermal expansion

In-Sodium Test of UWT

Purpose: Evaluation of defect-detection capability and component detection and recognition capabilities of the UWT-USV system

Accomplishment: Achieved in-situ defect detection with resolutions of 0.5 mm in both width and depth at temperature up to 650°F
Capable of identifying components with complex geometry and thin tubing

Target Sample | Intensity Image | TOF Image | Target after Test



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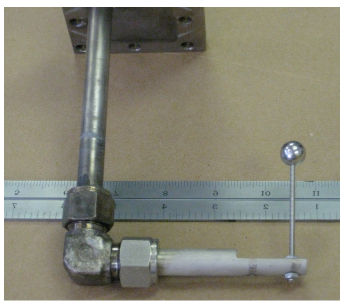
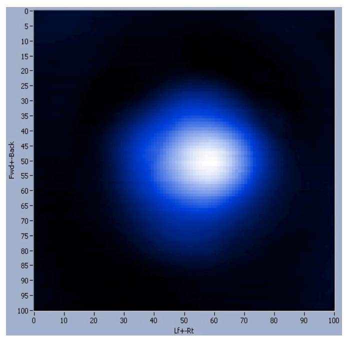
In-Sodium Focal Effect Test

Purpose: Determine beam diameters and shapes of the UWT at the focal point (FD = 1”) and at various distances from the focal point.

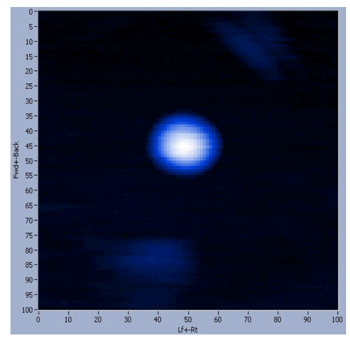
A better understanding and explanation of focal effect on defect detection resolution and component detection and recognition capabilities, especially for a component with complex 3D geometry

Accomplishment: Ultrasonic beam diameter converges in near field and reaches the minimum size (~0.255”) at the designed focal point

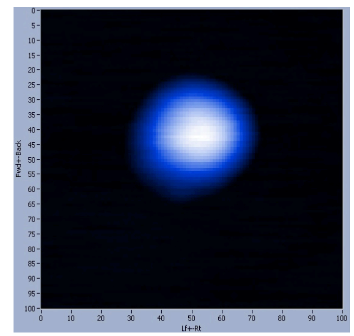




FD = 0.875”

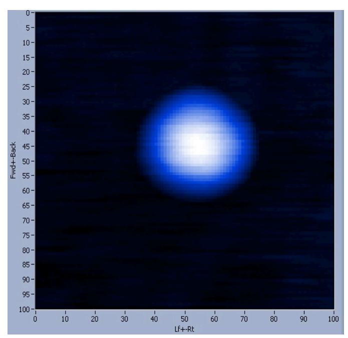


FD = 1.0”

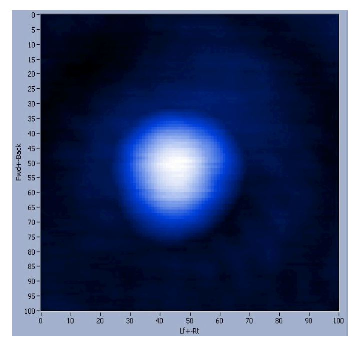


FD = 1.125”

Target after Test



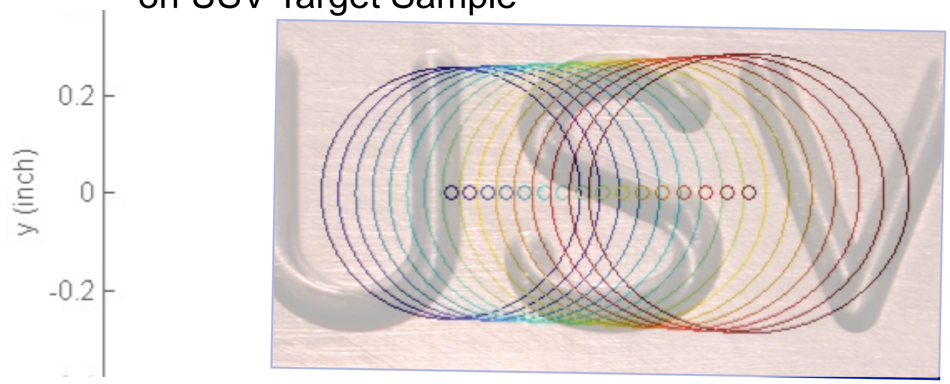
FD = 1.25”

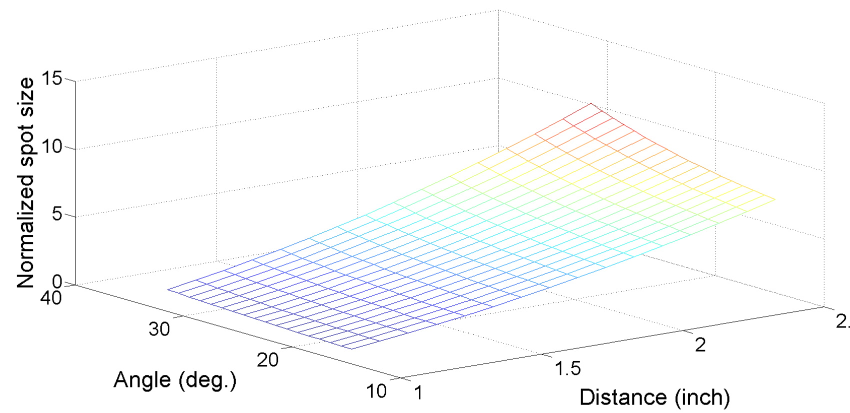


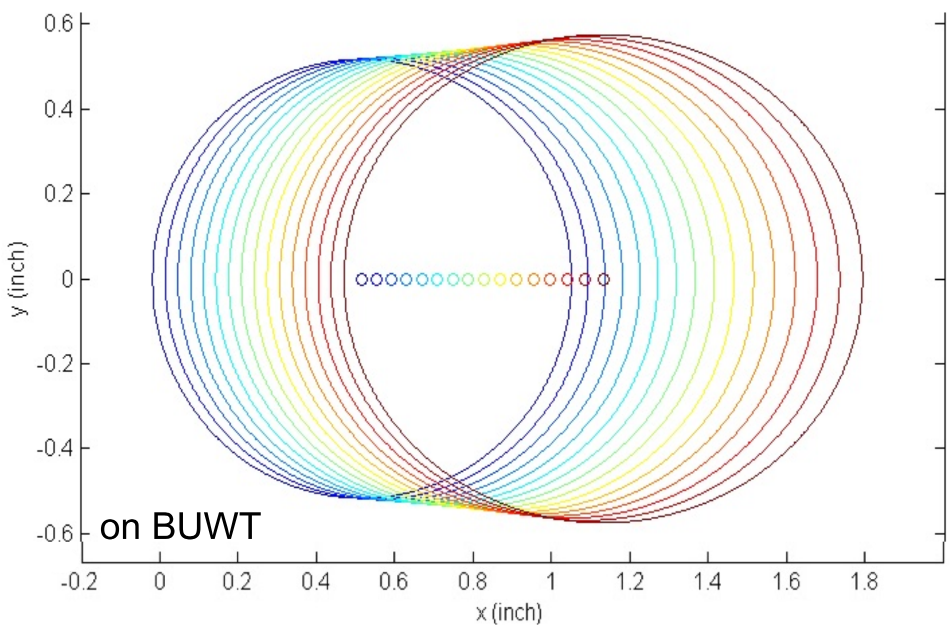
FD = 1.375”

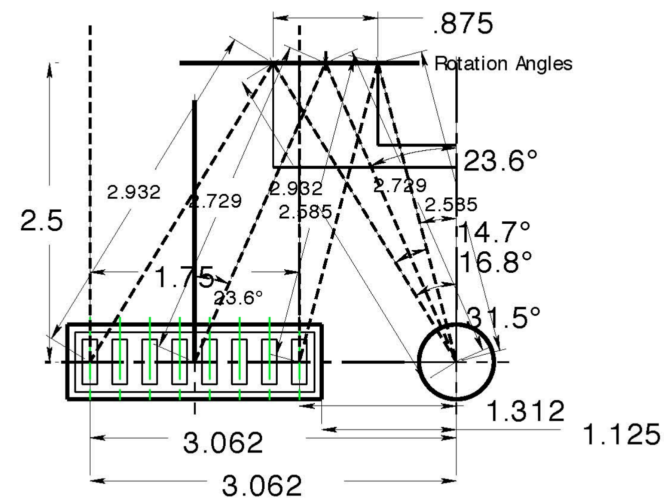
Sideway Scanning Setup-1
(Angled sideway-scanning)

on USV Target Sample









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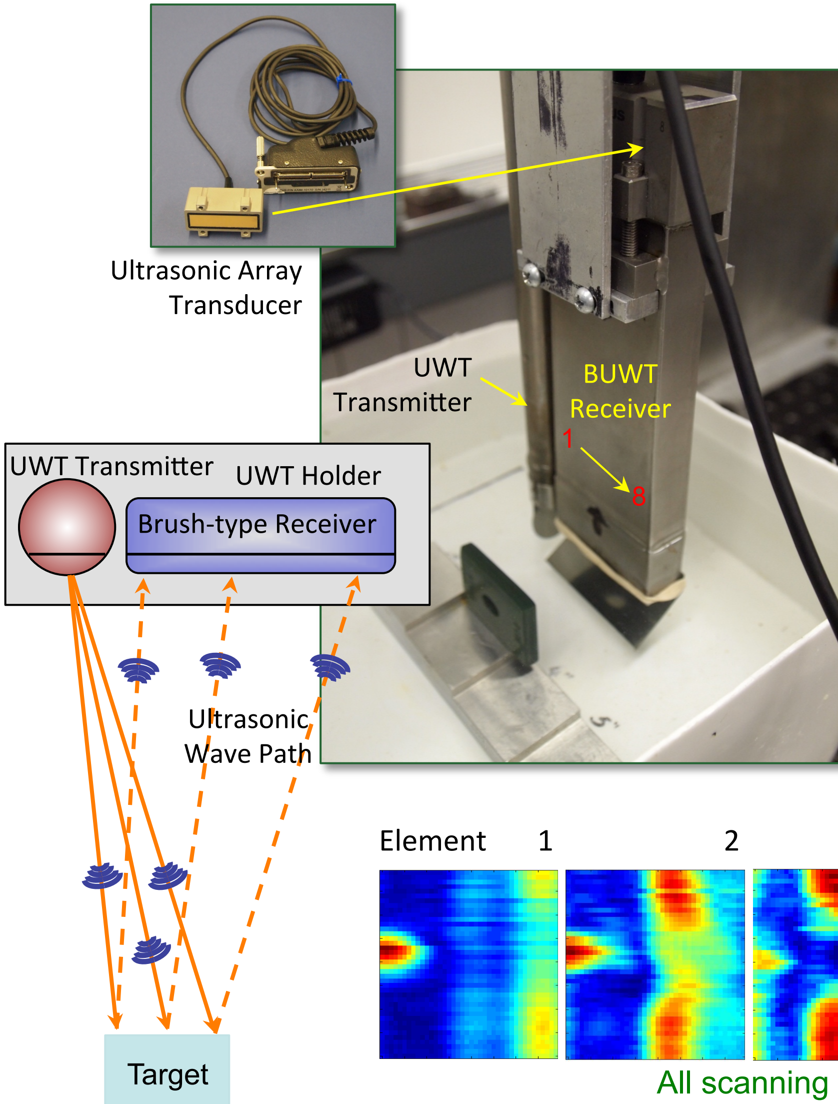
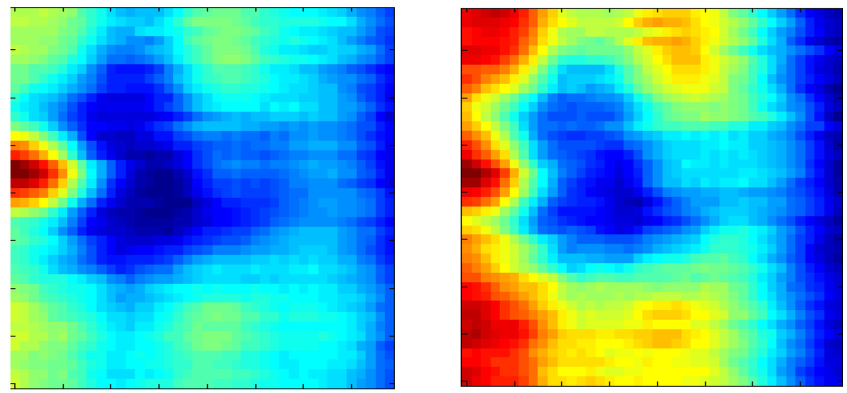
BUWT for Sideway Scanning



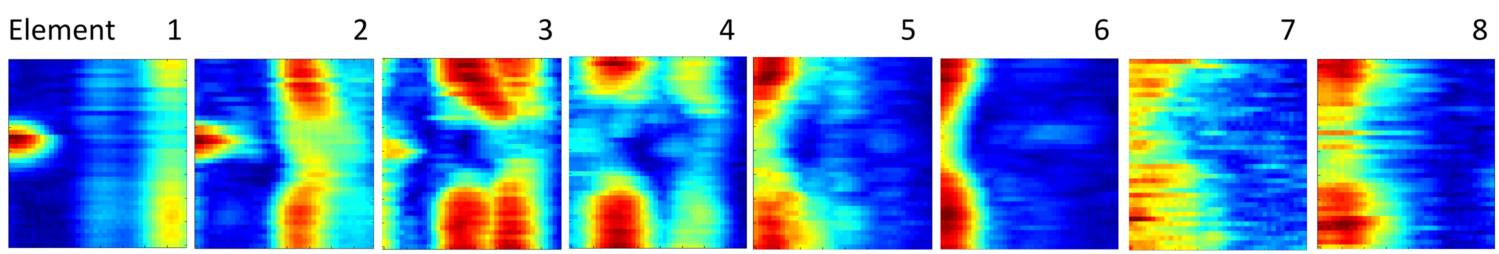
Mockup for in-sodium test is in-progress.

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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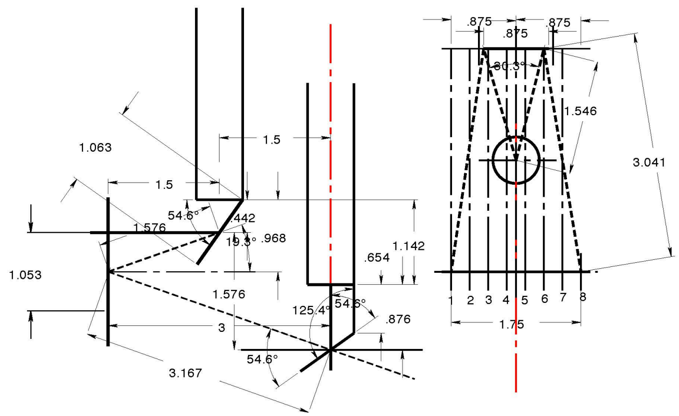
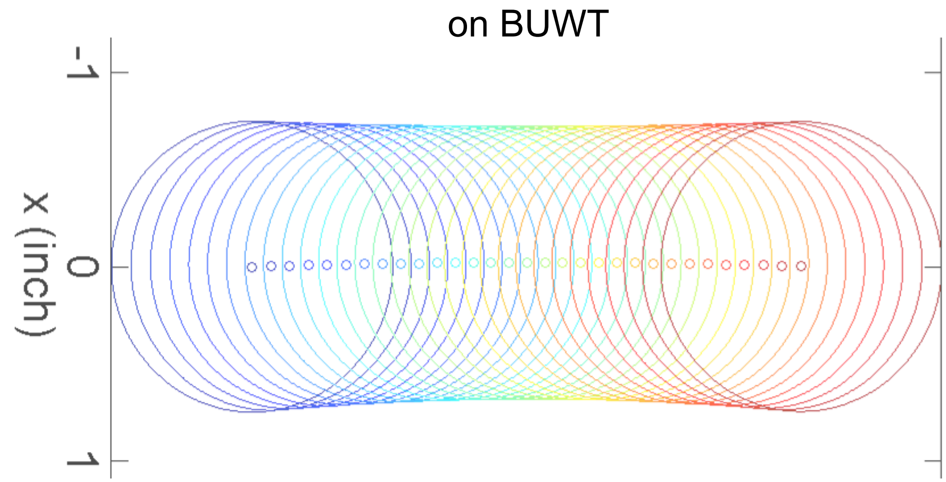
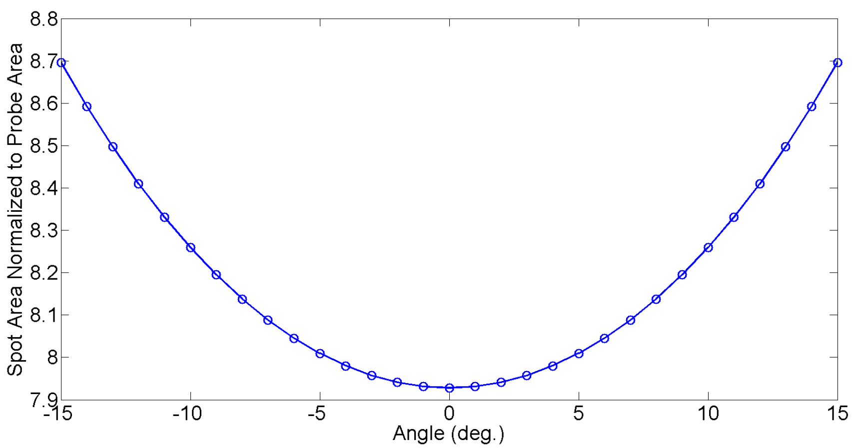
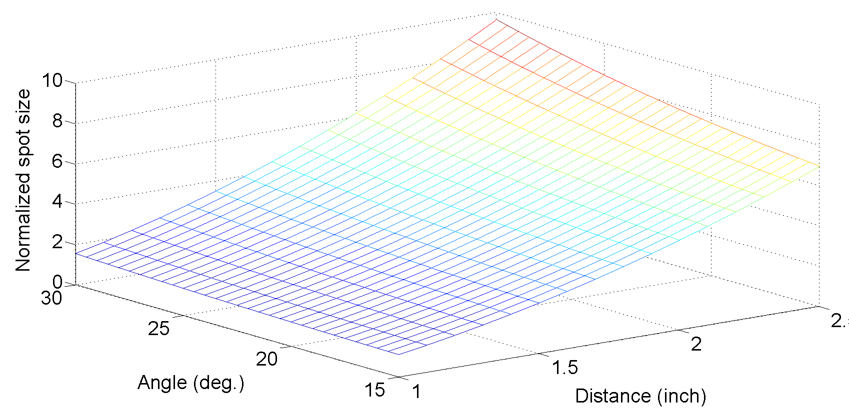
Sideway Scanning Setup-2
(Straight two-side scanning)

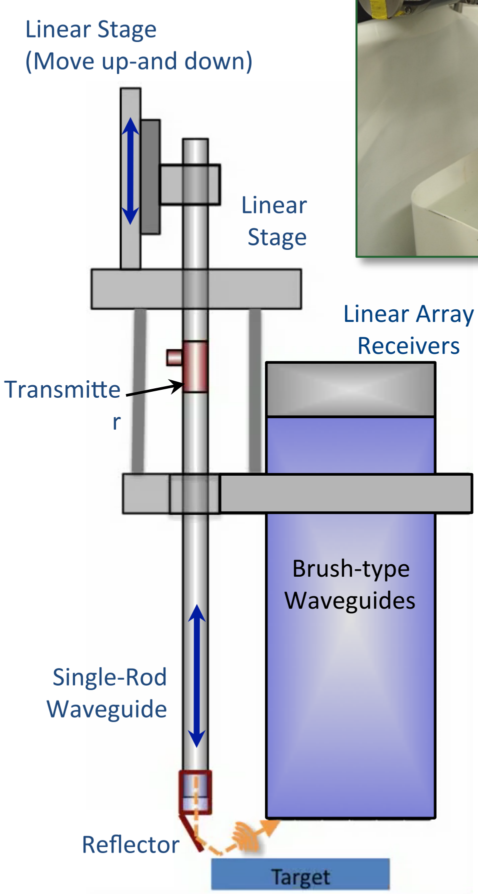


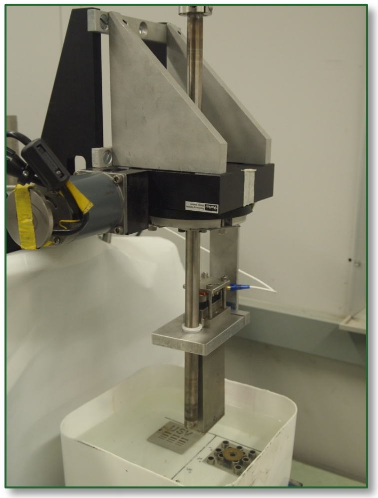


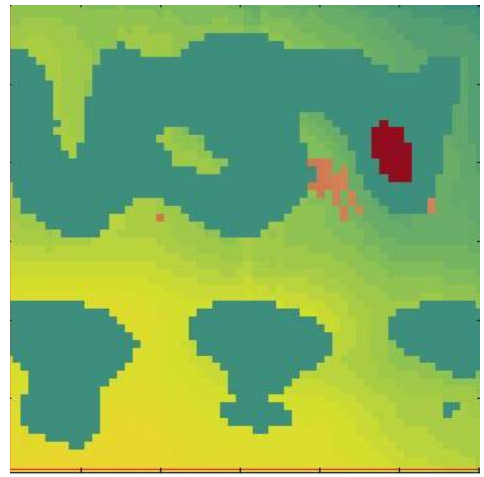




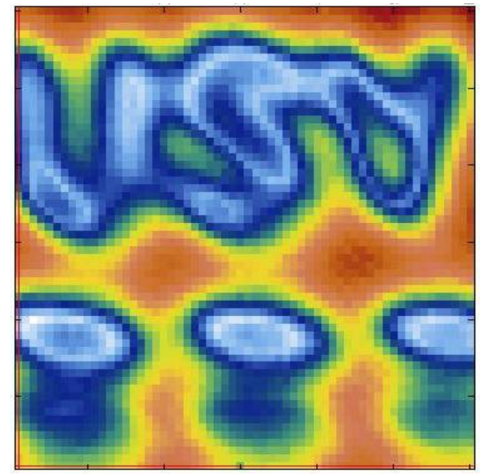
BUWT for Downward Scanning



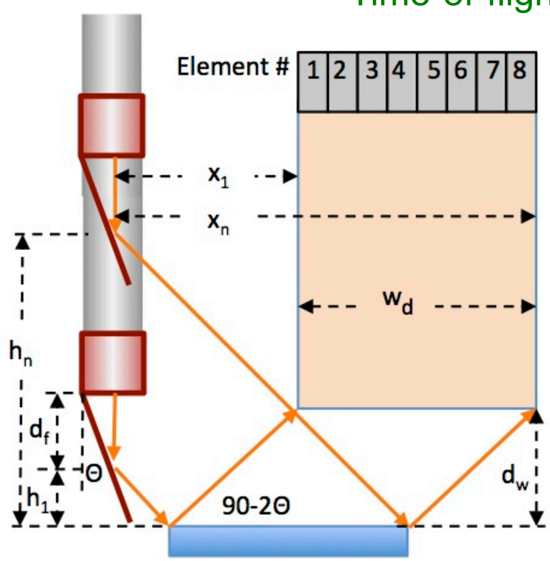




Time-of-flight image



Intensity image



Scanning geometry and corresponding positions of a SWGT, BWGT, and target

Beam divergence limits the detection resolution. (beam size increasing linearly to scanning distance)

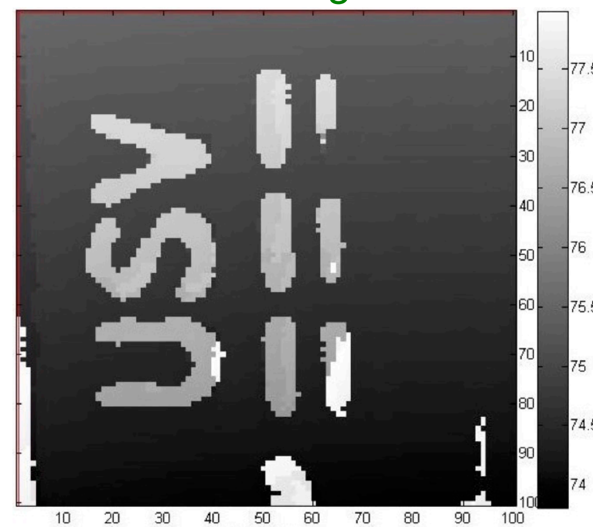
Beam shape stretched with scanning distance (become oval shape)

For each scan, TOF needs be corrected accordingly with the exact travel distance (D_i)

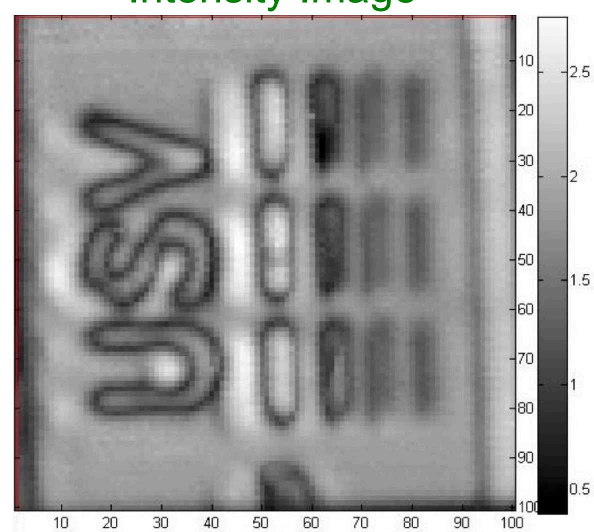
Water Mockup of BUWT-PA

Water test setup of feasibility study of BUW-PA technique

TOF Image

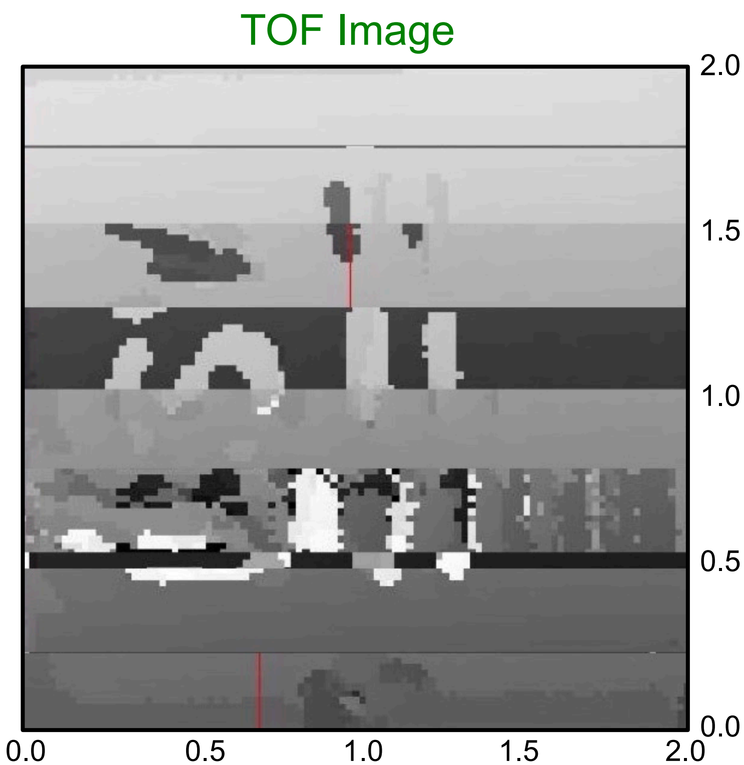


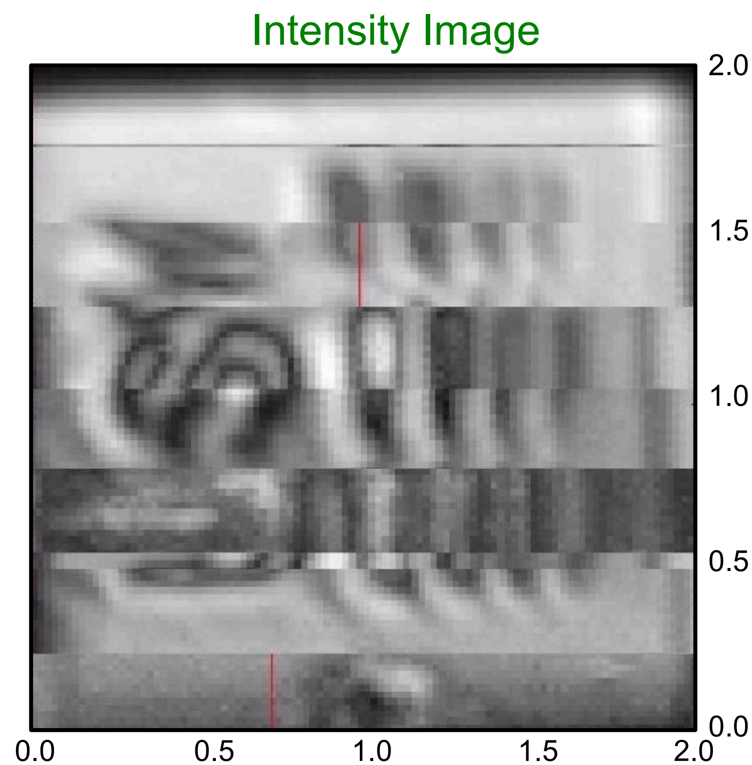
Intensity Image



- Images generated by using Channel 4 in water
- Real-time defect detection resolutions of 0.5 mm or better in both width and depth are achievable
- Cross-talk between adjacent waveguide regions < 2%, its effect on image construction is minimal
- Signal attenuation through the waveguide: ~0.78 dB/in at f = 2.25 MHz

Multiplexing of BUWT-PA





- Composite image of images generated by multiplexing from Channel 1 to 8 in water
- Normalization of the composite images based on transmission intensity of each channel
- Improvement of uniformity of the internal structure of the BUWT

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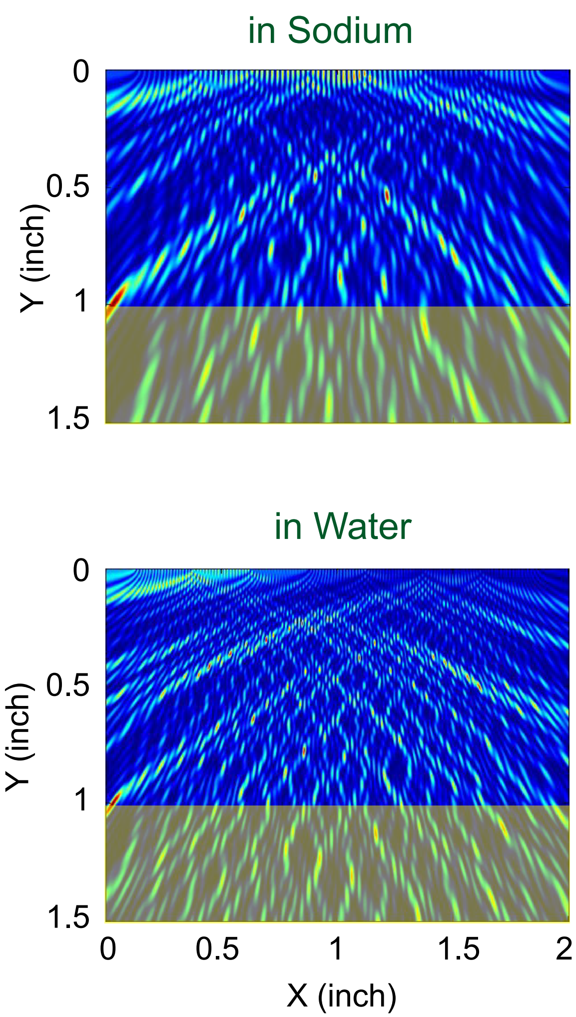
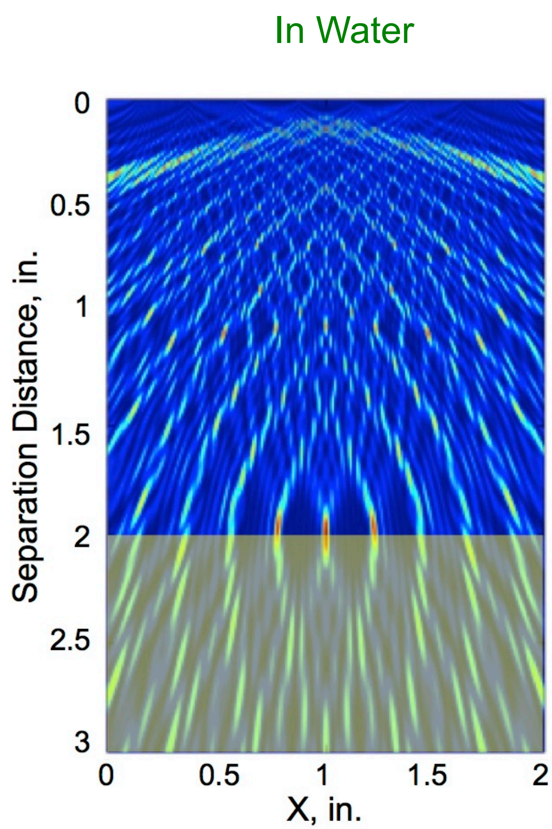
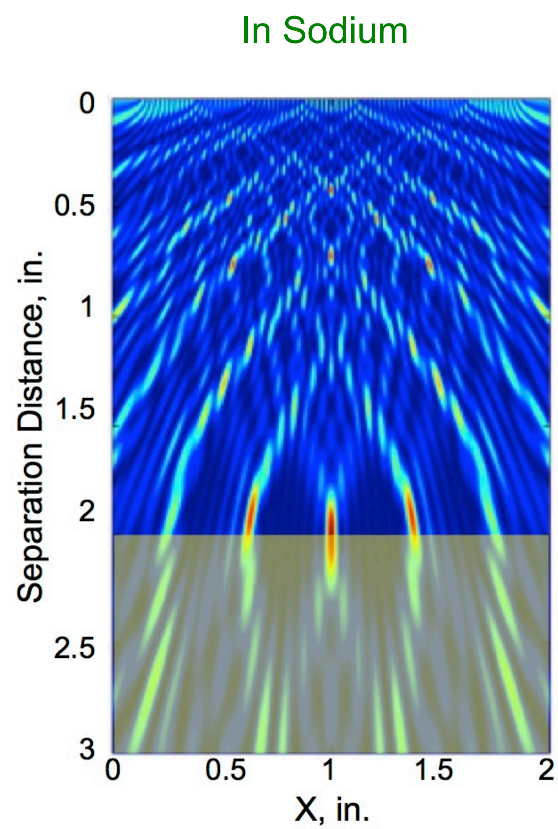
Wave Propagation of BUWT-PA

(8-element, f_c = 2.25MHz)







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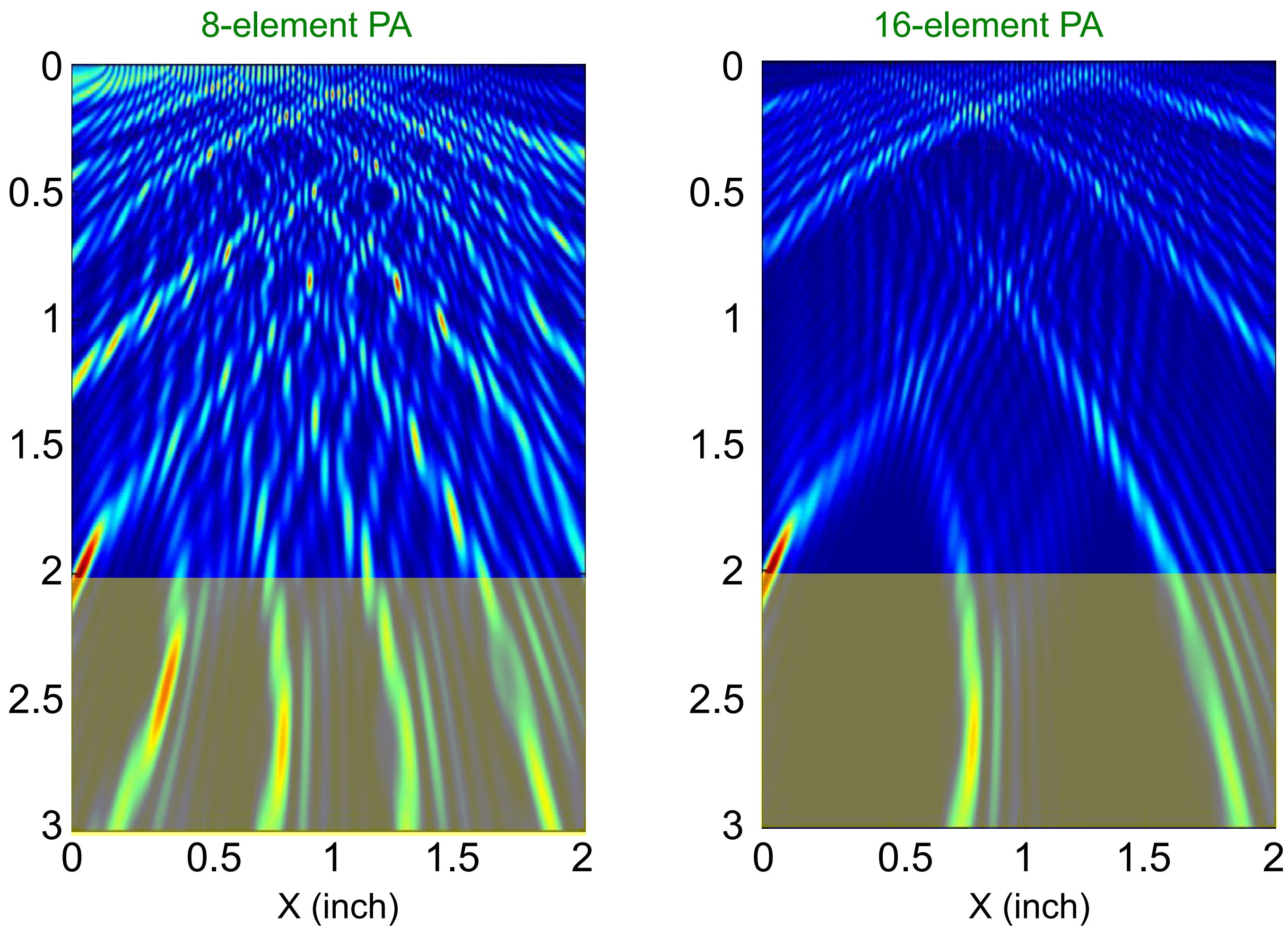
Wave Propagation of BUWT-PA

(in Sodium, f_c = 2.25MHz)



Target sample located 2” away from BUWT

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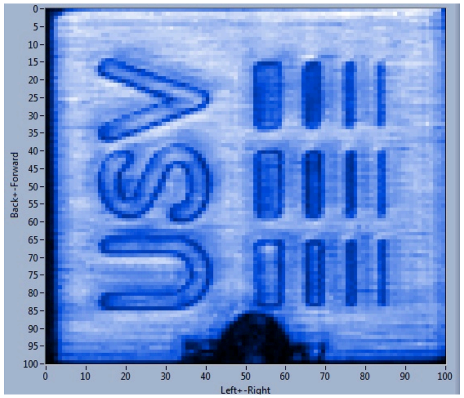
HT Submergible Transducer

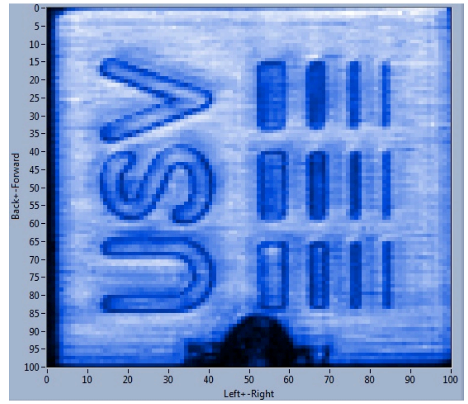
(PZT-5A, Oil Test @ 320°F)

HT-TD before and after sealed for in-sodium test

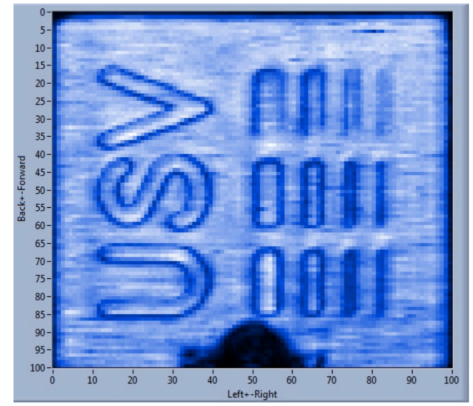
Target @ 1.0"

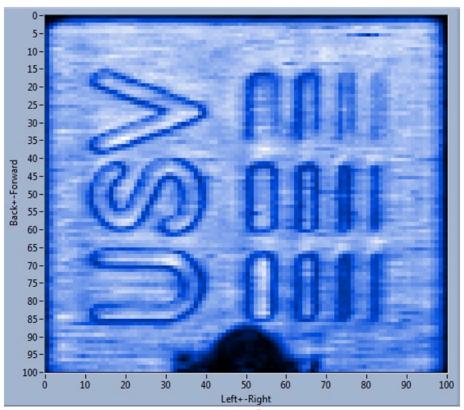


Target @ 1.25"

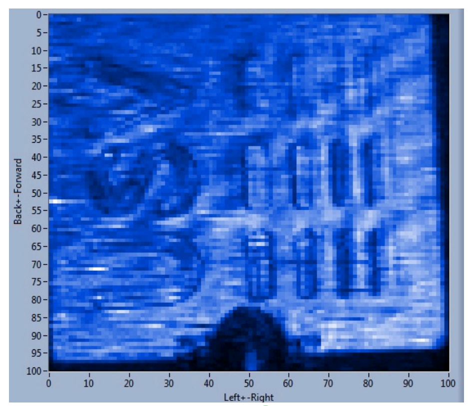


Target @ 1.375"

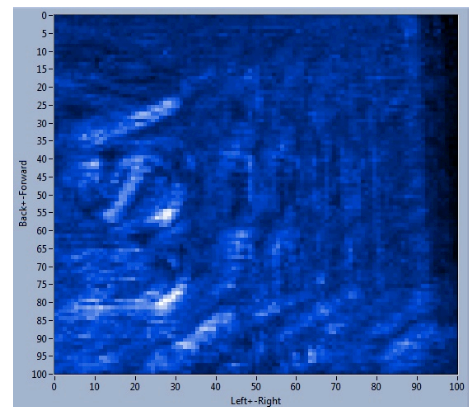




Target @ 1.5"



Target @ 1.75"

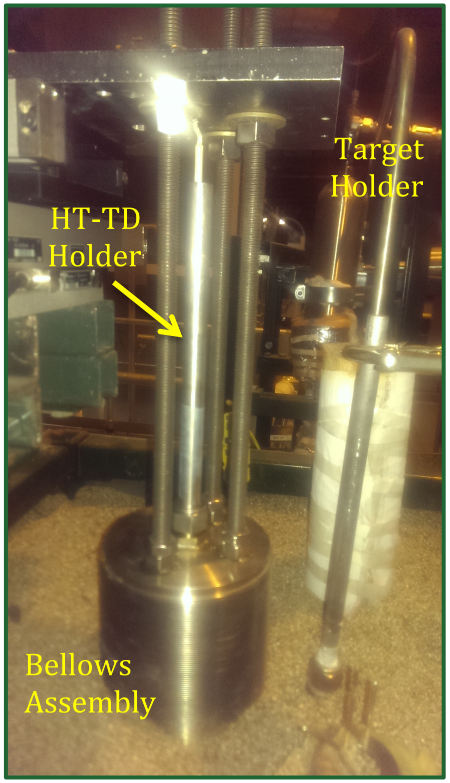


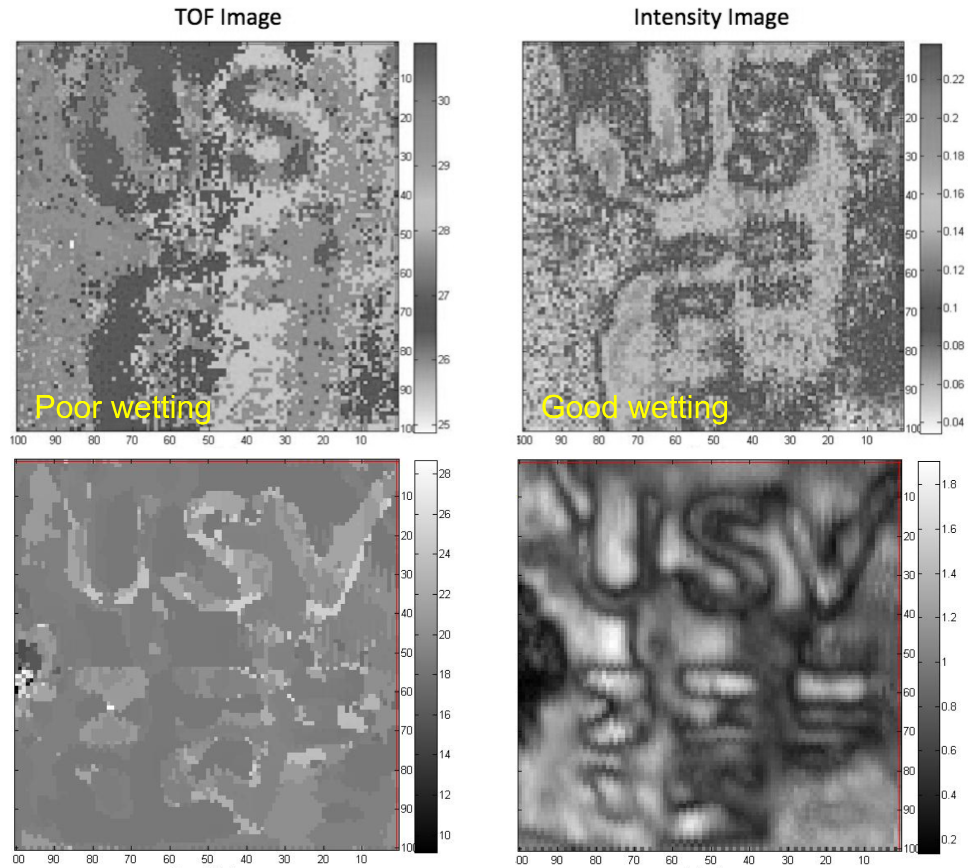
Target @ 2.0"

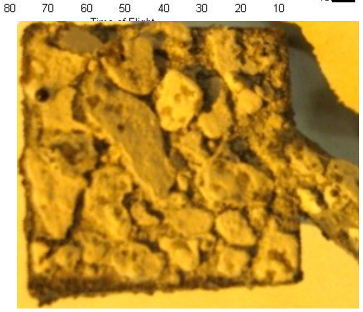
- Achieved detection resolutions of 0.5 mm in both width and depth, even target is positing ¾" away from the UWT's focal point (FD=1")
- Still maintaining same detection resolutions after thermal cycling for weeks (daily from 65°F to 320°F)

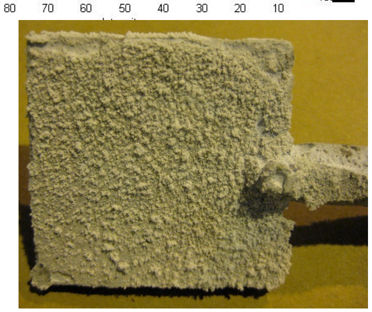
HT Submergible Transducer

(PZT-5A, In-sodium Test @ 320°F)









- Sodium wetting of target is still an issue for lab test (not an issue for reactor)
- Demonstrated detection resolutions of 0.5 mm or better in both width and depth are achievable

Tours and Visiting of Potential Commercial Partners

- DOE NE Program Manager Suibel Schuppner– Oct 21, 2014
- DOE NE-5 Program Manager BP Singh – Oct 24, 2014
- Generation IV International Forum – Nov 5, 2014
- Civil Nuclear Working Group (CNWG) – Jan 28, 2015
- SFRA/KAERI-CEA Technical Group – Feb 14, 2015
- Westinghouse (WEC) – March 17, 2015
- DOE NEAC Facilities Subcommittee – April 15, 2015
- General Electric Hitachi (GEH) – April 23, 2015
- DOE NE-ART Program Director Tom O'Connor – April 24, 2015
- Westinghouse (WEC) – May 8, 2015
- DOE-NE Office Assistant Secretary John Kotek – June 23, 2015
- ORNL Associate Laboratory Director Alan Icenhour – June 24, 2015
- General Electric Hitachi (GEH) – July 21, 2105
- GenIV International Forum– September 16, 2105

Future Plan

- Continue the integration of BUWT and ultrasonic phased-array Techniques
- Conduct mockup and in-sodium tests of BUWT phased-array
- Continue the evaluation of detection resolutions of submergible transducers (PZT-5A and $LiNbO_3$) in sodium
- Develop and evaluate very high temperature and radiation resistance (HT-HR) submergible transducers
- 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)

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.
- The USV technology being developed could be applied for other I&C applications of SFRs, such as in-situ, real-time passive or active steam generator leak detection/location and sodium boiling detection/ location for fuel-pin failure and reactor core monitoring.
- This enabling NDE technology will benefit other areas of reactor inspection needs, particularly those requiring inspection/monitoring in harsh environment.
- Successful deployment of this technology will improve reliability, ensure safety, and reduce operational costs for nuclear energy stakeholders.
- The data provided by USV system complements on-line monitoring data obtained by I&C system of future SFRs.

Conclusion

- **Upgraded the USV test facility for in-sodium tests of materials and components, and potential use for the study of sodium-water reaction**
- **Demonstrated the capability of UWT technique for in-situ, in-sodium defect detection with high resolution up to 650°F**
- **Demonstrated the capability of UWT technique for in-situ, in-sodium detection and recognition of components with complex geometry**
- **Integrated BUWT and phased array (PA) techniques and conducted BUWT-PA modeling.**
- **Developed and demonstrated high-temperature submergible UT for real-time defect detection with high resolution in hot oil bath and in sodium up to 320°F with potential in-situ defect detection resolutions of 0.5 mm in both width and depth.**
- **Enable real-time monitoring of reactor core and in-service inspection, and complements on-line monitoring data obtained by I&C system of SFRs**

Questions?

Thanks