Transmission of Information by Acoustic Communication Along Metal Pathways in Nuclear Facilities
Project Overview

• Goal and Objective
  – Demonstrate ability to transmit information through physical boundaries at a nuclear facility

• Participants (2019)

• Schedule
  – Y1: developed system requirements and implemented ultrasonic communication setup on a pipe
  – Y2: demonstrated ultrasonic data transmission on room temperature pipe
  – Y3: demonstrated ultrasonic data transmission on elevated temperature pipe
Accomplishments

• **Deliverables**
Accomplishments Y1

• Developed System Specification
  – Focused on acoustic transmission of information in an out of the containment building
  – Containment walls are 4 to 5 feet thick concrete with steel liner
    • Blocks RF transmission
  – Proposed acoustic communication system at a nuclear facility would transmit information on steel pipes already in place for nuclear reactor operation
Accomplishments Y1

• Developed System Specification
  – Identified charging line stainless steel pipe of chemical volume control system (CVCS) as viable conduit for information transmission in and out of containment building
  • Pipe penetrates containment wall through a tunnel in concrete sealed on both ends by steel plates
  – Transducer operating conditions are specified by containment isolation function

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal</th>
<th>Accident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>50-120 °F</td>
<td>300 °F</td>
</tr>
<tr>
<td>Pressure</td>
<td>atmospheric</td>
<td>70 psig, max</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>30-100 %</td>
<td>100 %</td>
</tr>
<tr>
<td>Radiation</td>
<td>50 rads/hr</td>
<td>150 Mrads/hr</td>
</tr>
</tbody>
</table>
Accomplishments Y1

- Developed test article for proof-of-principle studies
  - Schedule 160 stainless steel pipe with baffle plates to simulate mechanical constraints at actual NPP
  - Demonstrated resilience of ultrasonic data transmission over pipe to low frequency noise
    - Experimentally simulated process noise with mechanical shaker vibrating a pipe
    - Vibrated pipe with 100Hz, 1KHz, 10KHz
    - Observed no interference effect on ultrasonic 2MHz shear wave information-carrying signal
Accomplishments Y2

- Developed Nuclear Pipe Ultrasonic Communication System

1. Digital computer with GNURadio software
2. RedPitaya transmitter board
3. Power amplifier,
4. Angled-wedge mounted PZT transmitting refracted shear waves
5. Stainless steel pipe
6. Angled-wedge mounted PZT receiving shear waves
7. Low noise amplifier
8. RedPitaya receiver board
9. Digital oscilloscope
Accomplishments

- Ultrasonic image transmission on a pipe at room temperature
  - Developed ASK communication protocol in GNURadio environment
  - Transducers are separated by 170cm on a pipe
  - Carrier frequency is 1.8MHz
  - 2Kbps data rate (bit pulse duration is 500 µs)
  - BER~$10^{-3}$

32KB image
Accomplishments Y3

• Developed Ultrasonic Communication System on Elevated Temperature Pipes

(1) Digital computer with GNURadio software
(2) RedPitaya transmitter board
(3) Power amplifier
(4) LiNbO$_3$ ultrasonic transmitter
(5) Stainless steel pipe
(6) Thermal insulation layer
(7) LiNbO$_3$ ultrasonic receiver
(8) Low noise amplifier
(9) RedPitaya receiver board
(10) Digital oscilloscope.
Accomplishments Y3

- Ultrasonic image transmission on a heated pipe
  - Used the ASK transmission protocol implemented in GNURadio environment
    - ISI suppressed with RRC filter
    - Pipe heated to 50°C and 150°C
    - Transducers separated by 170cm on a pipe
    - Carrier frequency is 728 kHz
    - 10KBps data rate (bit pulse duration is 100µs)
    - BER ~$10^{-3}$
Accomplishments Y3

• Complex piping topology in representative environment
  – Developed bent piping test article for signal transmission evaluation

  – Demonstrated signal transmission with time-reversal modulation
Accomplishments

• **Publications/Presentations**
  - One paper under review in *IEEE Transactions of Ultrasonics, Ferroelectrics and Frequency Control*
  - One paper to be submitted to *Nuclear Technology*
  - Four papers in Proceedings of *IEEE International Ultrasonics Symposium (IUS)*
  - Four papers in *Proceedings of IEEE International Conference on Electro/ Information Technology (EIT)* (including *Best Paper Award*)
  - One paper in *Proceedings of Nuclear Plant Instrumentation, Control, and Human-Machine Interface Technologies (NPIC&HMIT)*
  - One paper to appear in *Transactions of ANS Winter Meeting*
  - Submitted **R&D100** application
  - Project work profiled **twice** by ANL Media Office
Technology Impact

• **Advances the state of the art for nuclear application**
  – Provides capability to transmit information across physical barriers at a nuclear facility using in-place piping infrastructure

• **Supports the DOE-NE research mission**
  – Develops new means of secure and accident-resilient communication at a nuclear facility applicable to different reactor types

• **Impacts the nuclear industry**
  – Helps to increase safety of existing and future nuclear power plants

• **Will be commercialized**
Conclusion

• *Demonstrated information transmission on nuclear grade stainless steel pipe using ultrasonic transducers*
  – *Demonstrated high-bitrate ultrasonic transmission of images on a pipe at simulated normal and post-accident conditions*
  – *Conducted preliminary studies for ultrasonic communication over piping manifolds*

• **Contact Information**
  – *aheifetz@anl.gov*
  – *630-252-4429*