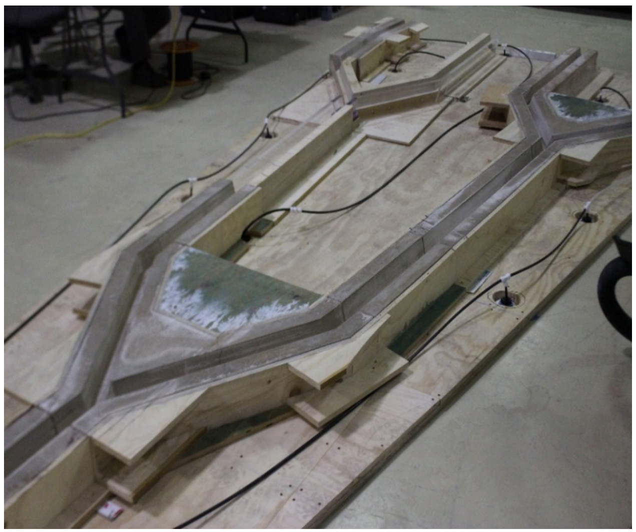
Under-Tank-Bottom Inspection Demonstration



Kayle Boomer

Closure Forum

September 10, 2019

Bottom Inspection

NDE Technology Engineering Program for Tank Bottom Inspection

Phase I

NDE Sensor Selection:

Identify and down-select NDE technologies based on flaw detection abilities only

Phase II

NDE Inspection System Maturation:

*Mature promising NDE technologies to adapt transducer hardware and robotic deployment **system to address** access challenges*

Phase III

Full-scale Demonstration of Integrated NDE System:

Demonstrate adapted NDE technologies in a cold test platform to challenge flaw detection and navigation abilities

Complete

In-progress

Inspection Approach

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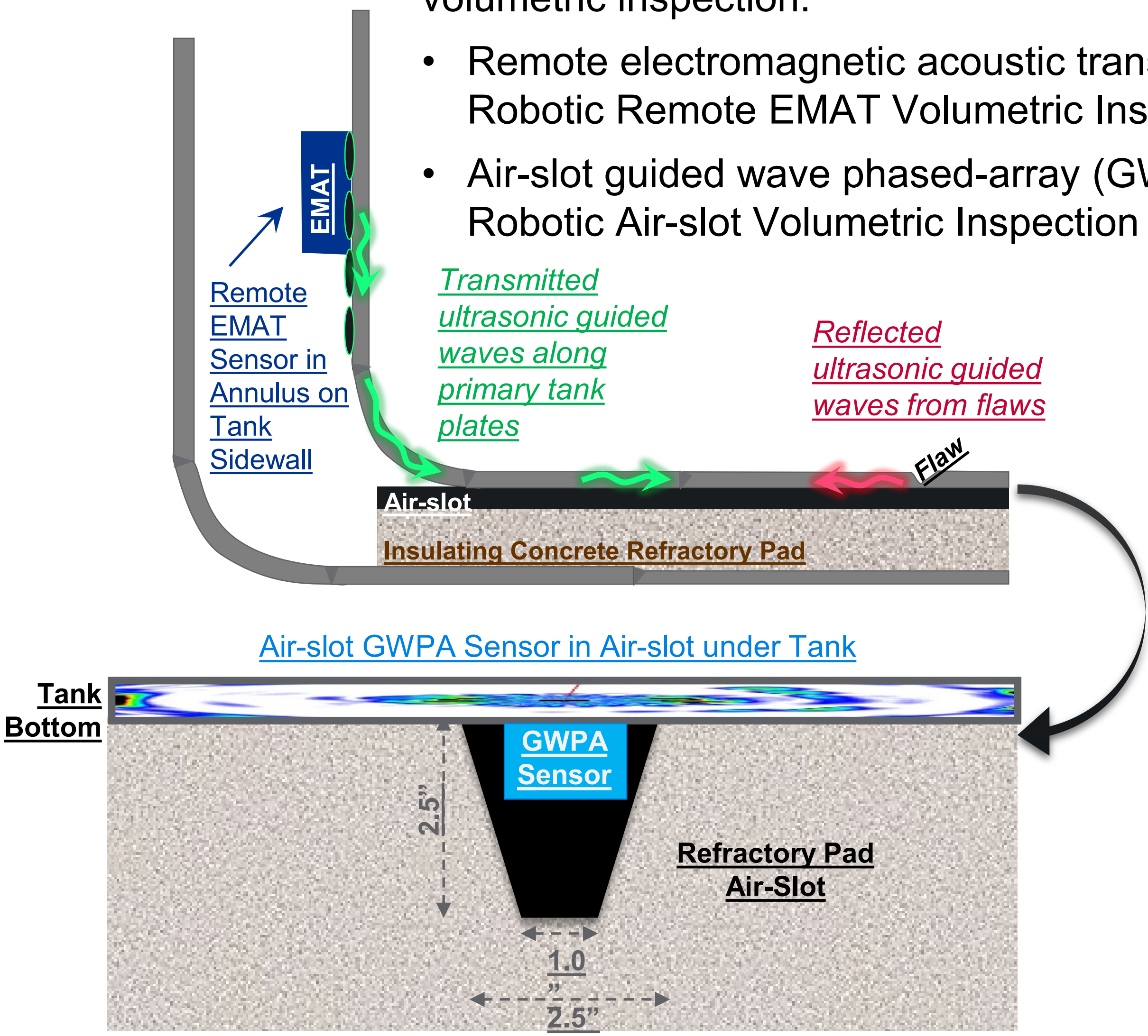
Ultrasonic inspection methods/technologies selected for tank bottom volumetric inspection:

- Remote electromagnetic acoustic transducer (EMAT) to be part of Robotic Remote EMAT Volumetric Inspection System (RREVIS)
- Air-slot guided wave phased-array (GWPA) sensor to be part of Robotic Air-slot Volumetric Inspection System (RAVIS)



RREVIS and RAVIS used in series can support a Dual Ultra-Sonic Tank Inspection (DUSTI) approach:

- Remote inspection with RREVIS to "flag" potential regions of degradation (low resolution)
- For high-resolution inspection, deploy RAVIS down air-slots under flagged tank bottom regions

Guided Waves

washington river protection solutions

Pacific Northwest NATIONAL LABORATORY

Eddyfi Technologies

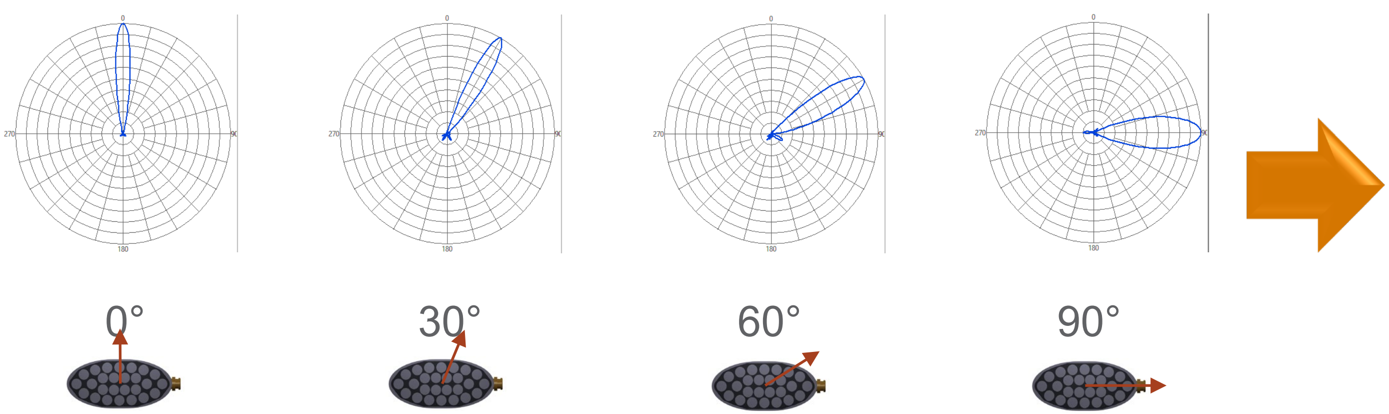
GUIDEDWAVE

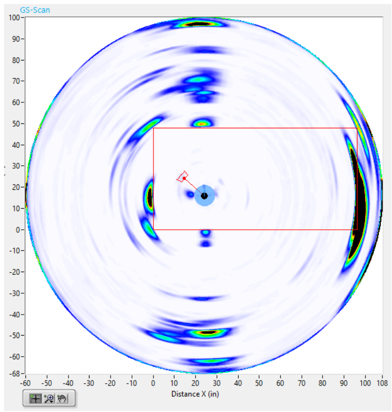
Phased-array Sensor Design

- 26 ultrasonic piezoelectric elements
  - Transmits: Applies different time delays to different sets of 16 elements to direct/steer an ultrasonic beam 360° around the sensor
  - Receives: All 26 elements used as receivers to detect ultrasonic reflections from welds, flaws
  - No rotation of sensor; Akin to sonar or radar
- Dry couplant used to transmit and receive ultrasonic energy from plates

Ultrasonic Guided Waves

- Employs fundamental shear-horizontal (SH_0) wave mode
  - Uses plate as "wave guide" to inspect plate/welds several feet away from sensor
  - Not damped by liquids (waste) touching plate
  - Non-dispersive for "clean"/interpretable signals
- Ultrasonic frequency specifically selected to be compatible with plate thickness
  - e.g., 150 kHz for 1/2 in. plates and welds





Crawler Testing

Testing for the Marsupial NDE Air-Slot Crawler included the following*:

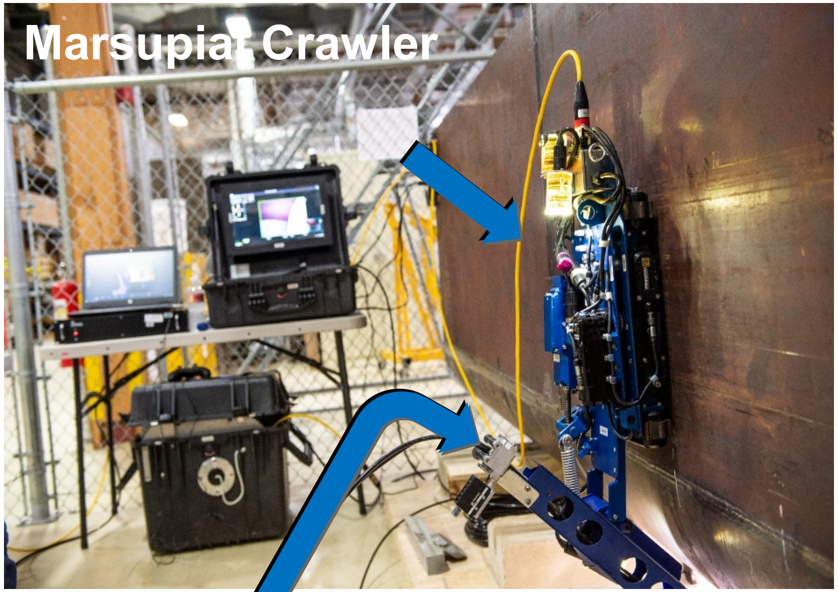
1) The ability of the vehicle to properly positon the UT probe and apply it to the underside of the tank with 150 lbs. of force.

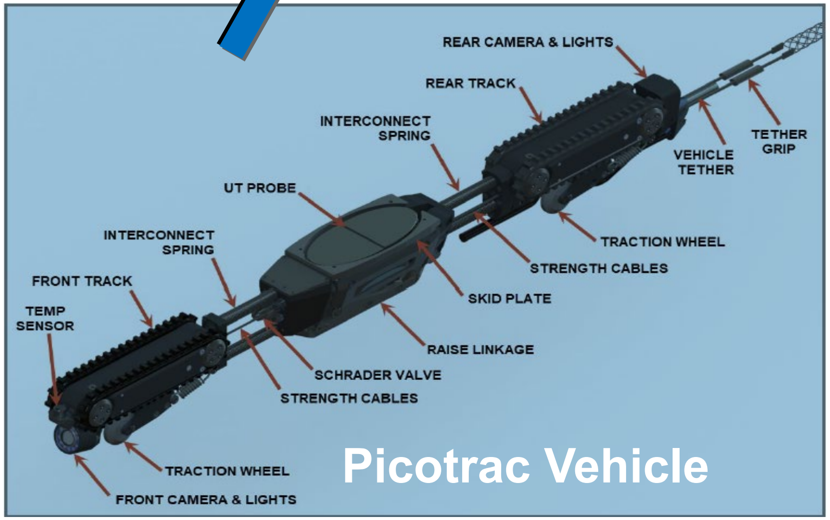
2) The ability of the vehicle to be retrieved in the event of a power loss by pulling on the tether and activating the linkage release mechanism.

3) The ability of the marsupial crawler to deploy the vehicle into the air slots

4) The ability of the vehicle to navigate the air slots

*** TESTING FOR MARSUPIAL NDE AIR-SLOT CRAWLER (SP931-015221), 2019 Eddyfi Technologies**





Force Testing

The ability of the vehicle to properly positon the UT probe and apply it to the underside of the tank with 150 lbs. of force.

Picotrac w/ext scissor lift

Expected Test Result: Actuator should press the UT probe up against the top plate with 150 lbs. of force. Difference between the shipping scale and on-board force sensor should not exceed 5%.

TEST RESULT						
Shipping scale reading (lbs)	147	134	214	175.5	150	190
On-board force sensing reading	159	146	214	175.6	152	199
Percent difference	7.8	8.6	0	0.06	1.34	4.6

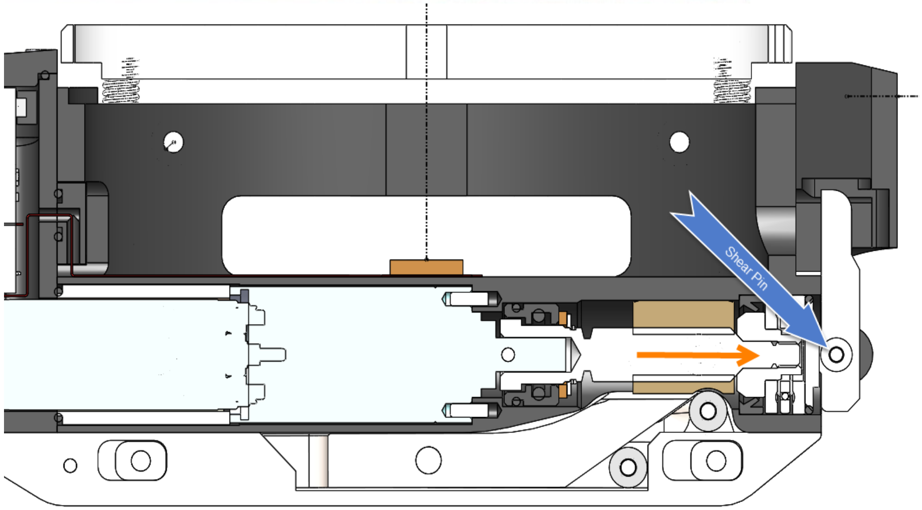
Vehicle Recovery

The ability of the vehicle to be retrieved in the event of a power loss by pulling on the tether and activating the linkage release mechanism.

- Build UT probe Kart Test Assembly
- Pressurize Probe Kart with 80 psi nitrogen
- Place Probe Kart into a 2.5 in tall channel
- Restrain Kart from movement by blocking rear spring hanger plates
- Connect interconnect cables to a tension load cell via turnbuckle
- Tension the interconnects until the pin shears on the bearing cap anchor and the linkage is retracted tension

Expected Test Result: force to shear pin should be 60-90 lbs

Test Result: Typical values were 80 lbs. per pin



Deployment

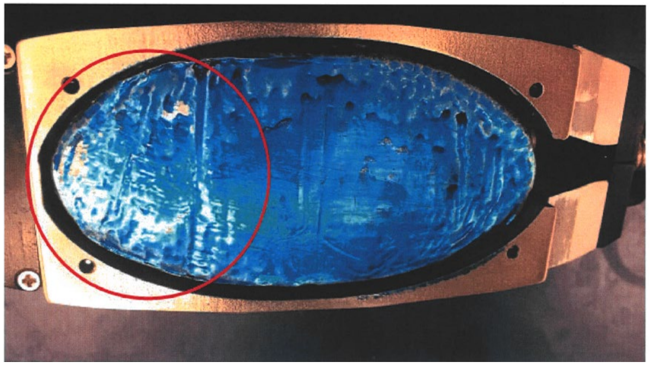
The ability of the original marsupial crawler to deploy the vehicle into the air slots

Verify that the completed vehicle can be deployed through the updated curved launch tube from the marsupial deployment crawler

Expected Test Result: the vehicle should travel down the launch tube into the air-slot

Test Result: deployed and retrieved several times successfully Some runs required multiple attempts at retrieval (tether can be used to retrieve as necessary)

- After 3 deploy/retrieve cycles, minimal surface abrasion and membrane was intact



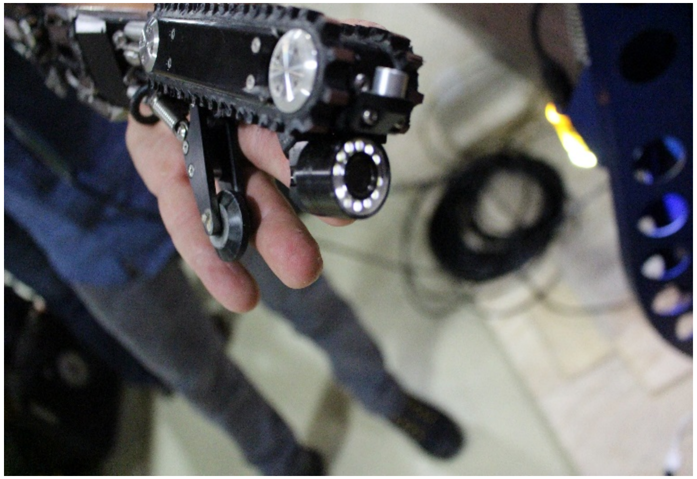
Air Slot Navigation

The ability of the vehicle to navigate the air slots, Verify the vehicle can maneuver through the air-slots and actuate the probe to the bottom of the tank

- Using tank bottom test apparatus run the vehicle through the whole air-slot and back again ensuring no hang-ups
- Midway between each straight run actuate the probe with 10 lbs. of force and make sure there is good contact on the bottom of the tank.

Expected Test Result: Vehicle travels down the air slot and back and can correctly apply the probe

Test Result: Crawler was successfully able to deploy, traverse the air slot from both front and rear video cameras (after gouging)



Camera mounted to picotrac

Traversed junctions only after gouging (8/7)

Exposed Air Channel

Crawler Testing Conclusions

- Original design was developed in 2017 and deployed for visual inspection of air slots
- 2018 redesigned Kart to replace DST temperature and radiation monitor with the guided wave sensor
  - Scissor mechanism to obtain 150 lbs. of force (over 200 lbs.)
  - Release mechanism to prevent blockage of the air slot
  - Reshaped sensor to allow better slot navigation
- Picotrac crawler was tested at the Inuktun Facility in Canada and demonstrated at the PNNL APEL Facility in Richland WA*.
  - Four performance goals were established and achieved
    - Probe positioning and application at 150 lbs.
    - Linkage release mechanism.
    - Ability of the marsupial crawler to deploy the vehicle into the air slots
    - The ability of the vehicle to navigate the air slots
  - Kart lift system showed Improved sensor signal over spring loaded coupler

TESTING FOR MARSUPIAL NDE AIR-SLOT CRAWLER (SP931-015221), 2019 Eddyfi Technologies

Probe/Sensor Testing

Guided wave phased array (GWPA) testing performance*

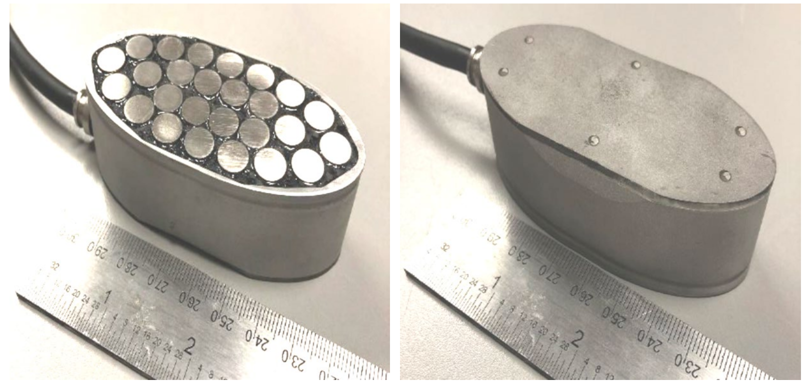
- Two primary tank mockups at the Pacific Northwest National Laboratory (PNNL)18-21 June 2019.
    - ➢ Flaw Detection and;
    - ➢ Rust and Dirt interference with signal transmission

- Guidedwave worked with Olympus Scientific Solutions Americas to modify the Hanford A probe design to correct the resonant frequency issues experienced during FY18;

- New probe was deemed Hanford A’ (A-prime). Additional changes to the probe design included
    - ➢ **a slimmer elliptical housing profile,**
    - ➢ **a groove for a membrane retention wire,**
    - ➢ **and a stiffer steel cap;**

These mechanical modifications were made to integrate the Hanford A’ probe with the Inuktun deployment robot.

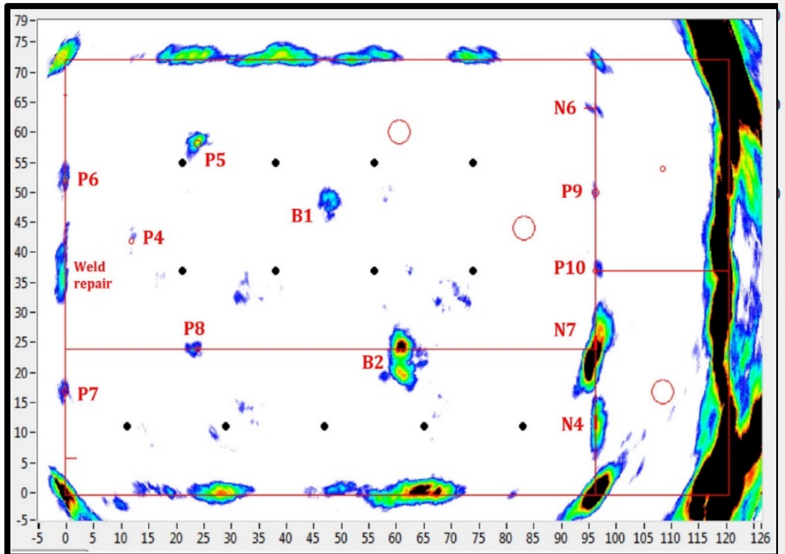
*****Report on FY19 Development of Guidedwave GWPA Hanford Probe Maturation Testing, 2019, GuidedWave***



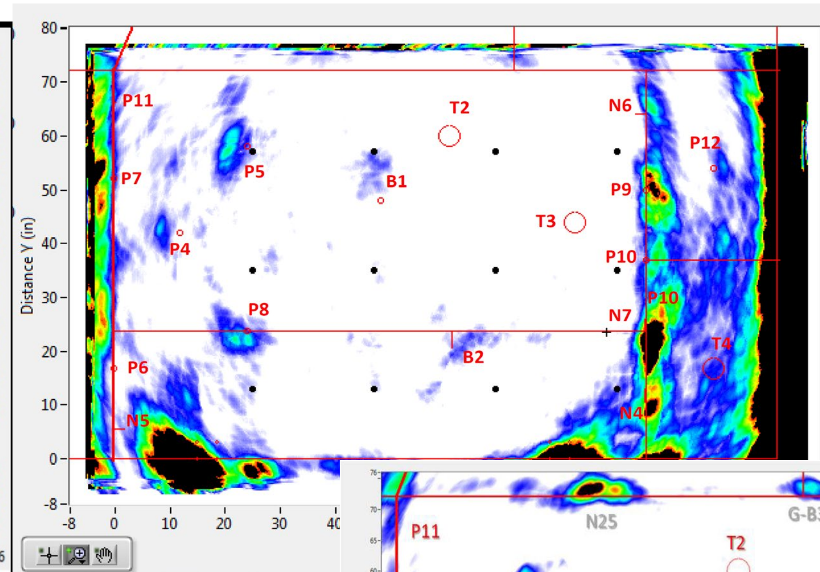
Top and Bottom of the A-Prime Probe

Kaolite dust on the surface of the mockup for the dirt testing.

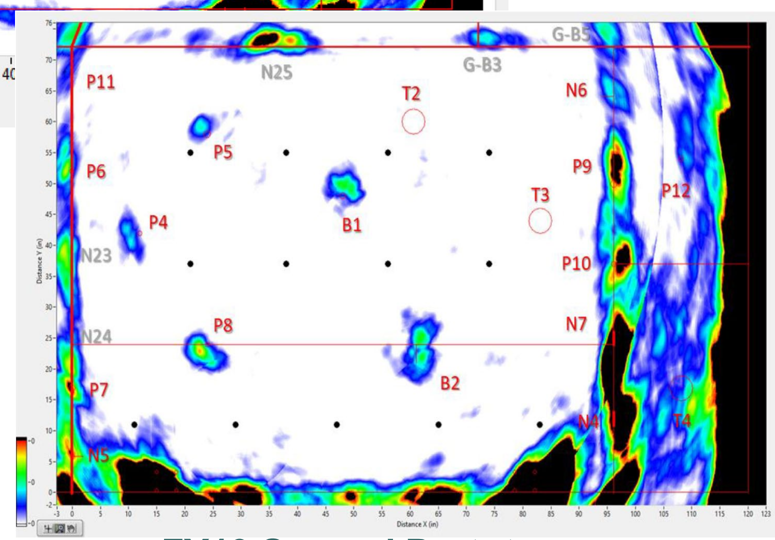
Probe/Sensor Performance



FY17 Baseline Case: Original Round GWPA NDE Sensor (standard commercial model)



FY18 First Prototype: Elliptical GWPA air-slot NDE sensor *Hanford-Probe A*



- FY17 had the best result with round probe
- FY19 result was closer to the FY17 result than FY18

FY19 Second Prototype: Elliptical GWPA air-slot NDE sensor *Hanford-Probe A’*

Probe/Sensor Results

Open Flaw Detection (for flaws detected with high confidence):

- FY18 *Hanford-Probe A*: Confidently detected 17 of 27* open test flaws
- FY19 *Hanford-Probe A'*: Confidently detected 19 of 26* open test flaws

Blind Flaw Detection (using an initial, small set of blind flaws to get indication of accuracy):

- FY18 *Hanford-Probe A*: Detected 3 of "X" blind test flaws – with 5 false calls
  - FY8 test results indicated low accuracy flaw reporting – attributed to low signal fidelity
- FY19 *Hanford-Probe A'*: Detected 4 of "X" blind test flaws – with 2 false calls
  - FY19 test results demonstrated signal fidelity improvements facilitated more confident discrimination between test flaws and artifacts, resulting in **more accurate flaw reporting**
  - Results for initial set of blind flaws **warrants repeatability testing with full set of blind flaws** to characterize flaw reporting accuracy – needed in order to understand performance that can be expected during actual tank inspection

Probe/Sensor Testing cont.

[yellow/blue square] = used in testing

Yes = detected with high confidence

No = not detected or detected with low confidence

Flaw Type

Flaw Depth	*Machined Pit* FY18 *Hanford-Probe A*	*Machined Pit* FY19 *Hanford-Probe A'*	*Machined Notch (Weld Seam Opening/Crack)*[a] FY18 *Hanford-Probe A*	*Machined Notch (Weld Seam Opening/Crack)*[a] FY19 *Hanford-Probe A'*	*Machined Wall Thinning (general corrosion)* FY18 *Hanford-Probe A*	*Machined Wall Thinning (general corrosion)* FY19 *Hanford-Probe A'*
10% plate thickness					*(Reportable Level)* **No**	*(Reportable Level)* **No**
12% plate thickness	**No**	**No**				
20% plate thickness			*(Reportable Level)*[b] **Yes**, for *most* weld configs.	*(Reportable Level)*[b] **Yes**, for *all* weld configs.	*(Actionable Level)* **No**	*(Actionable Level)* **No**
25% plate thickness	*(Reportable Level)* **No**	*(Reportable Level)* **No**				
38% plate thickness	**No**	**Yes**				
50% plate thickness	*(Actionable Level)* **Yes**	*(Actionable Level)* **Yes**	*(Actionable Level)* **Yes**	*(Actionable Level)* **Yes**	**No**	**No**
75% plate thickness	**Yes**	**Yes**				

(a) Criteria for cracks were also applied to weld seam openings.

(b) A 20% through-wall crack specified for the actionable-level value is equivalent to the 0.1-inch through-wall depth specified for the reportable-level value when crack length is not a factor.

Probe/Sensor Test Conclusion

The FY19 testing demonstrated that the new Hanford A' GWPA probe design meets the dimensional requirements for integration with the Inuktun robotic deployment system and addresses the resonant frequency issues observed with the Hanford A probe from the FY18 effort*.

- Testing confirmed that the Hanford A' probe and dry coupling membranes are minimally affected by field-representative surface conditions such as rust and dirt.

- The FY19 Hanford A' capability testing results also demonstrated an improvement in sensitivity and accuracy over the FY18 Hanford A probe.

**Report on FY19 Development of Guidedwave GWPA Hanford Probe Maturation Testing, 2019, GuidedWave.*

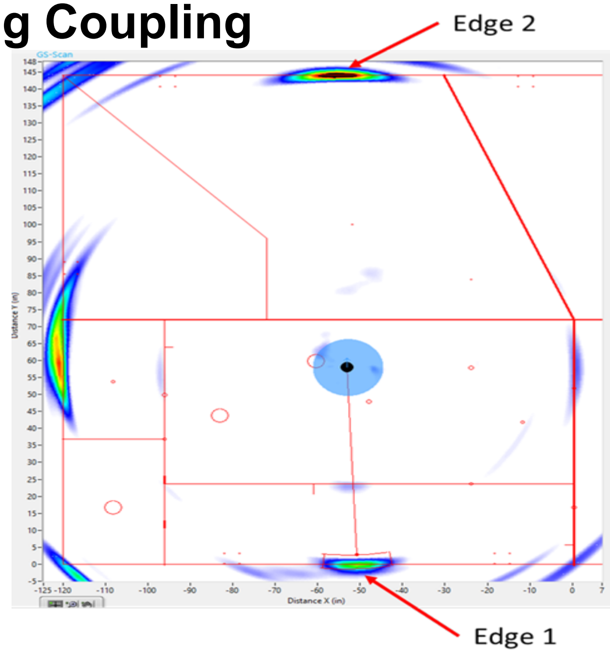
Questions

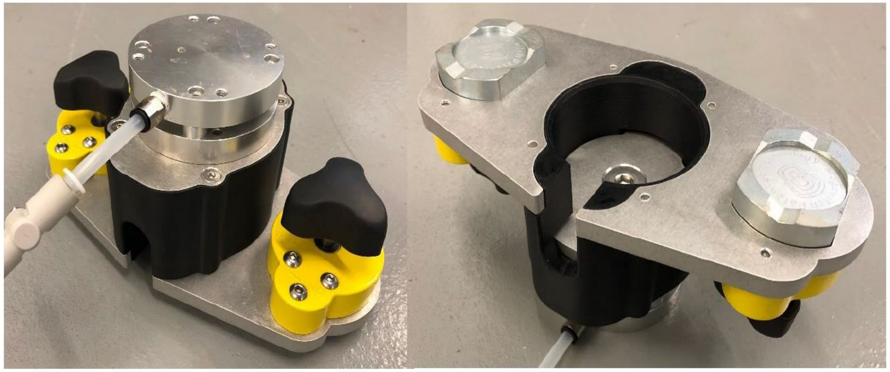
Backup Slides

Robotic Coupling vs. Spring Coupling

SNR Edge 1		
Location	**Robotic Coupler**	**Spring Coupler**
1	33.4	30.7
2	30.2	21.6
3	29.8	28.4
4	35.0	30.7
5	26.0	34.4

SNR Edge 2		
Location	**Robotic Coupler**	**Spring Coupler**
1	37.8	35.1
2	35.9	29.8
3	30.1	27.5
4	33.7	31.8
5	28.5	38.4

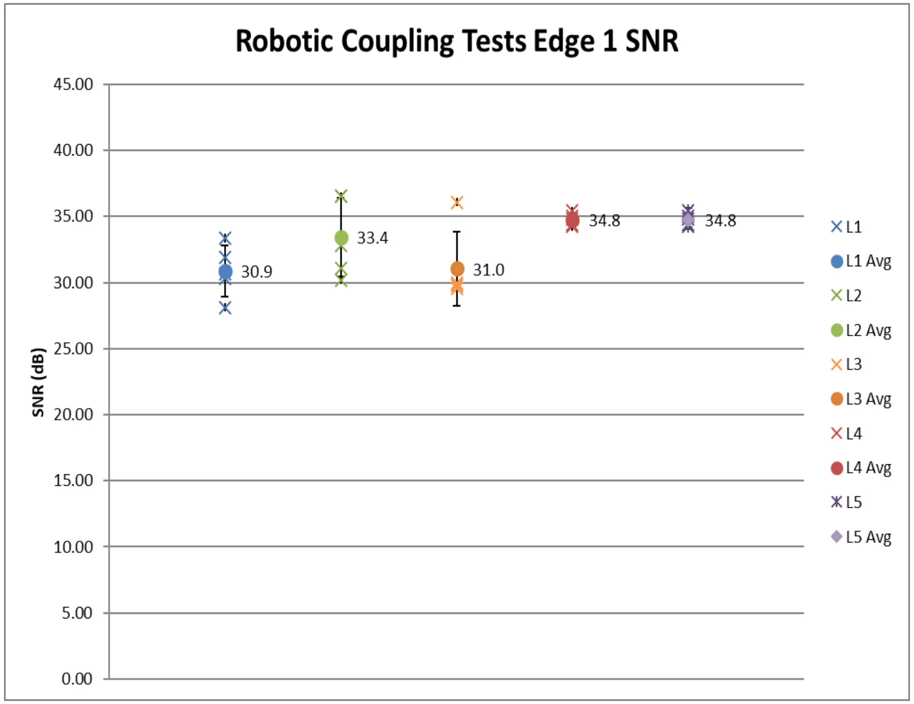


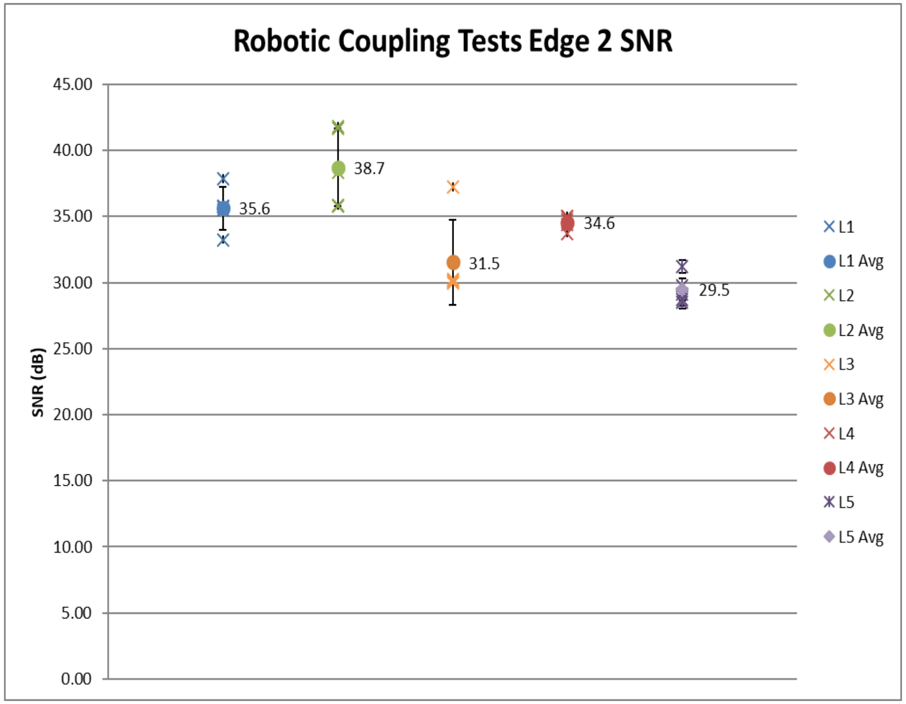


Spring loaded Coupler

Robotic Coupling Tests

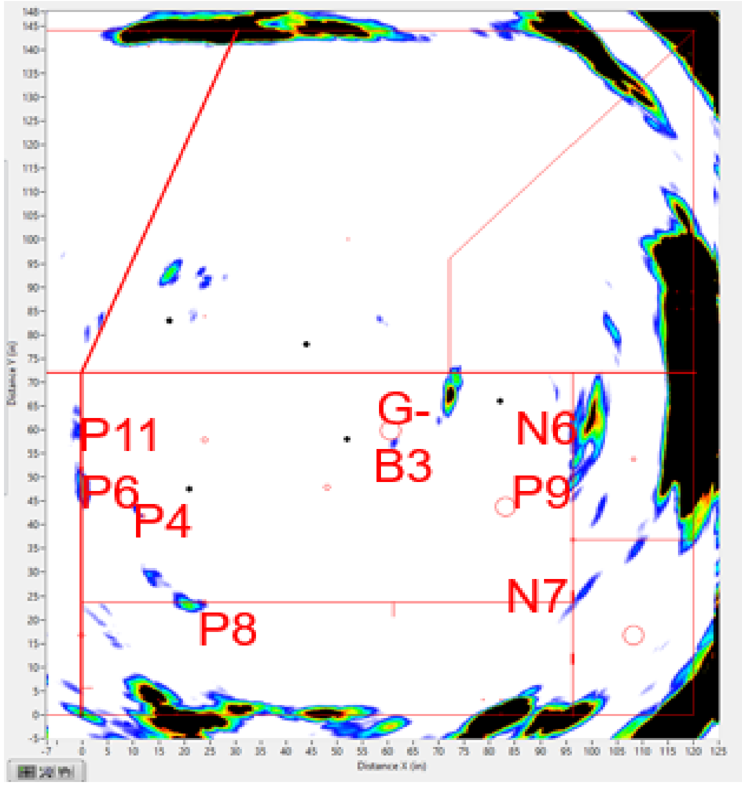
5 sensor deployments were performed at each location using robotic crawler



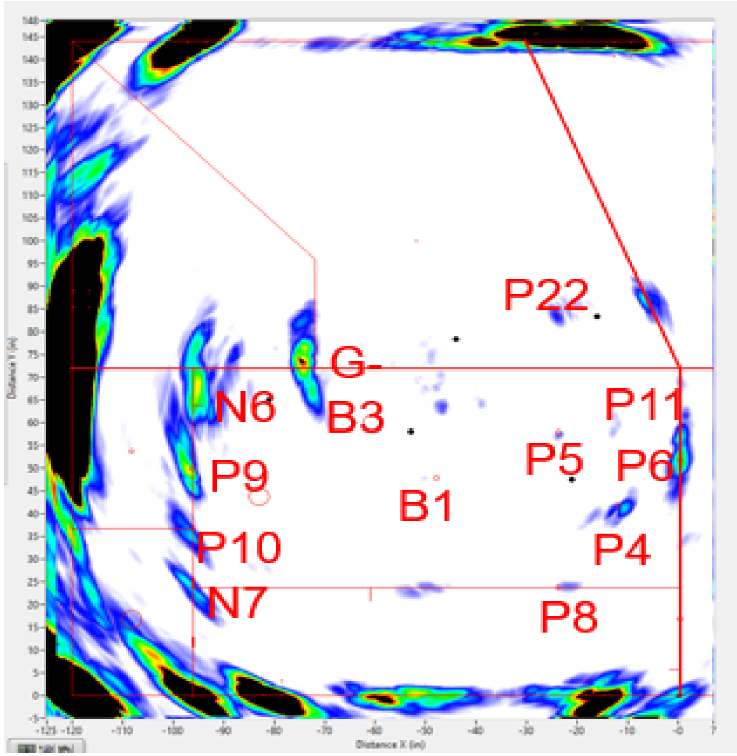


Composite Test Results

Robotic Coupling vs. Spring Coupling



Spring Coupler
(Topside)



Robotic Deployment
(Underside)