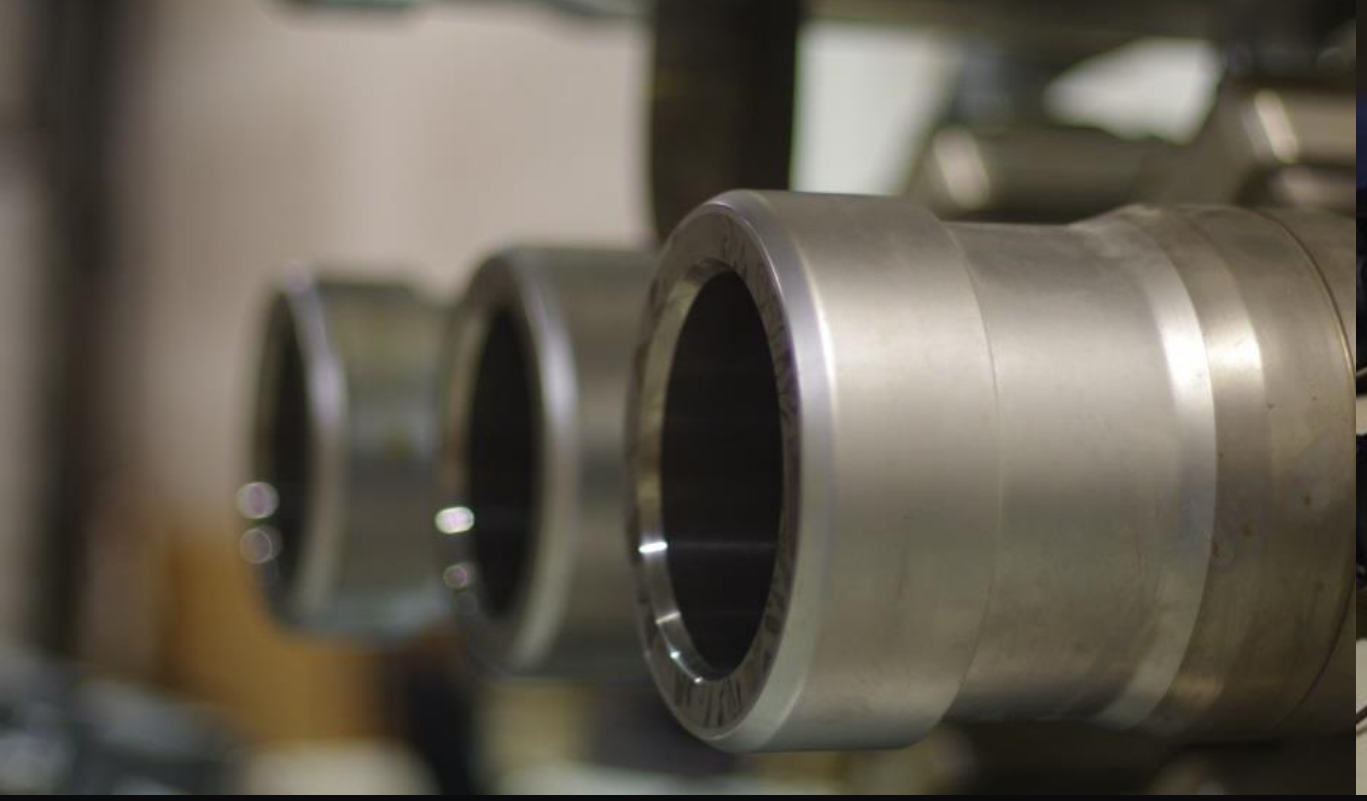


NDT in Canada
NDTiC 2017
Canada's NDT Conference
June 6 - 8
Centre des congrès de Québec
Québec City, Québec

NUCLEOM
INNOVATION • INTEGRATION

Used Fuel Containers NDE Inspection Program Report

Agenda

- **Historical Context**
  - NWMO – Role and Responsibilities
  - What is Canada's Used Nuclear Fuel?
  - National Infrastructure Project
- NDE Design and Development
- Results
  - Partial Penetration Weld Inspection Program
  - Copper Coating Inspection Program
- Conclusion

Historical Context

NUCLEOM
INNOVATION • INTEGRATION

NDT in Canada
NDTiC 2017
Canada's NDT Conference
June 6 - 8
Centre des congrès de Québec
Québec City, Québec

NWMO – Role and Responsibilities

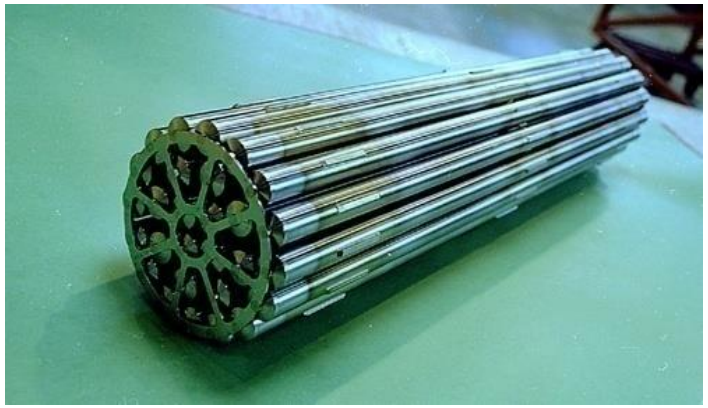
- NWMO: Nuclear Waste Management Organization (https://www.nwmo.ca)
- Formed in 2002 as required by the Federal *Nuclear Fuel Waste Act (NFWA)*
- Funded by Canada's nuclear energy corporations as required by the *NFWA*
- Operates on a not-for-profit basis

NWMO's mission is to develop and implement collaboratively with Canadians, a management approach for the long-term care of Canada's used nuclear fuel that is socially acceptable, technically sound, environmentally responsible, and economically feasible.

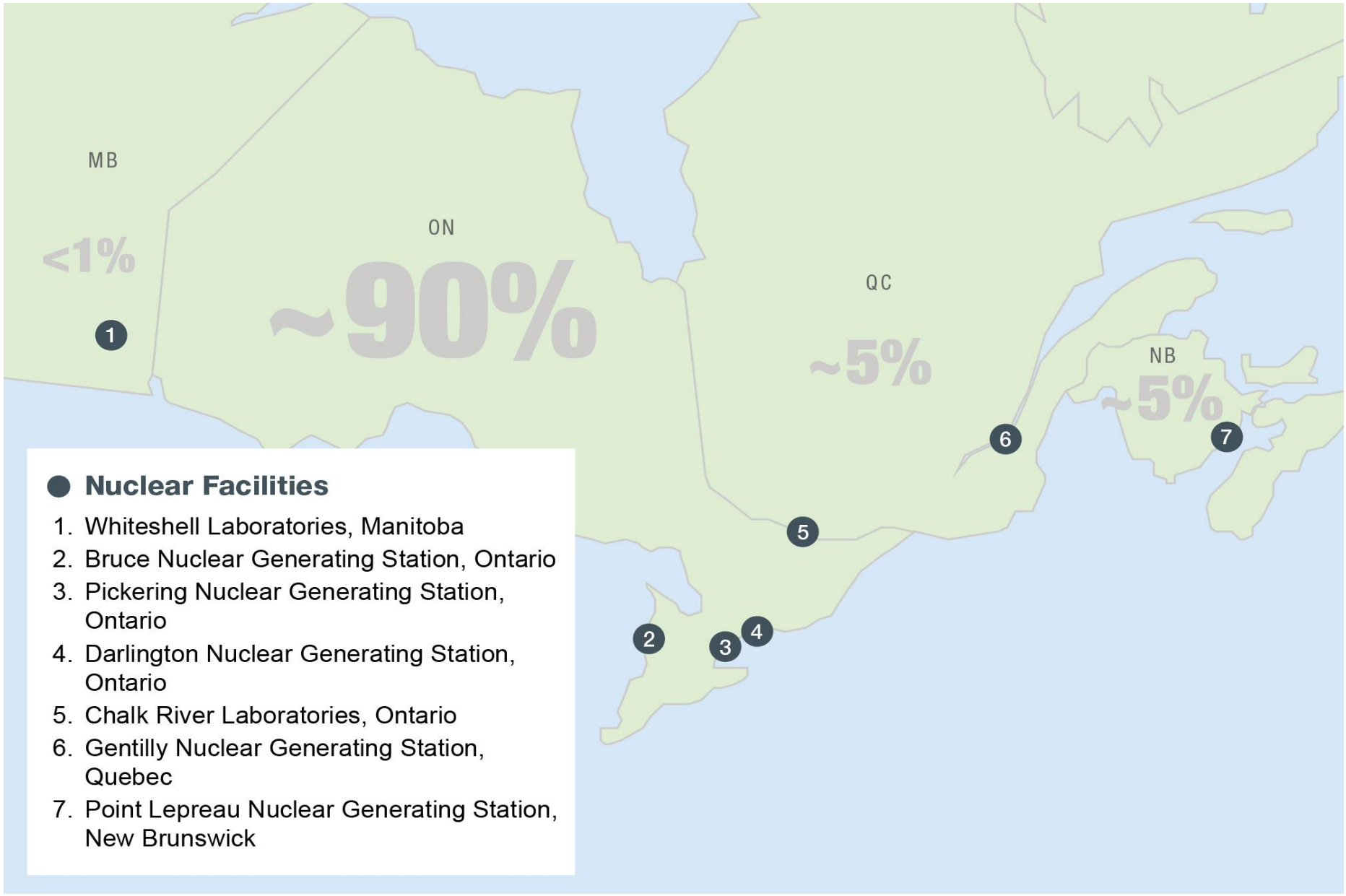
What is Canada's Used Nuclear Fuel?

- It is the result of using uranium to produce electric power in a nuclear reactor.
- It is typically a solid ceramic, encased in Zircaloy metal tubing.
- It is constantly generating heat, about 3-10 W per bundle, similar to an LED lightbulb.
- It contains high levels of radioactivity.

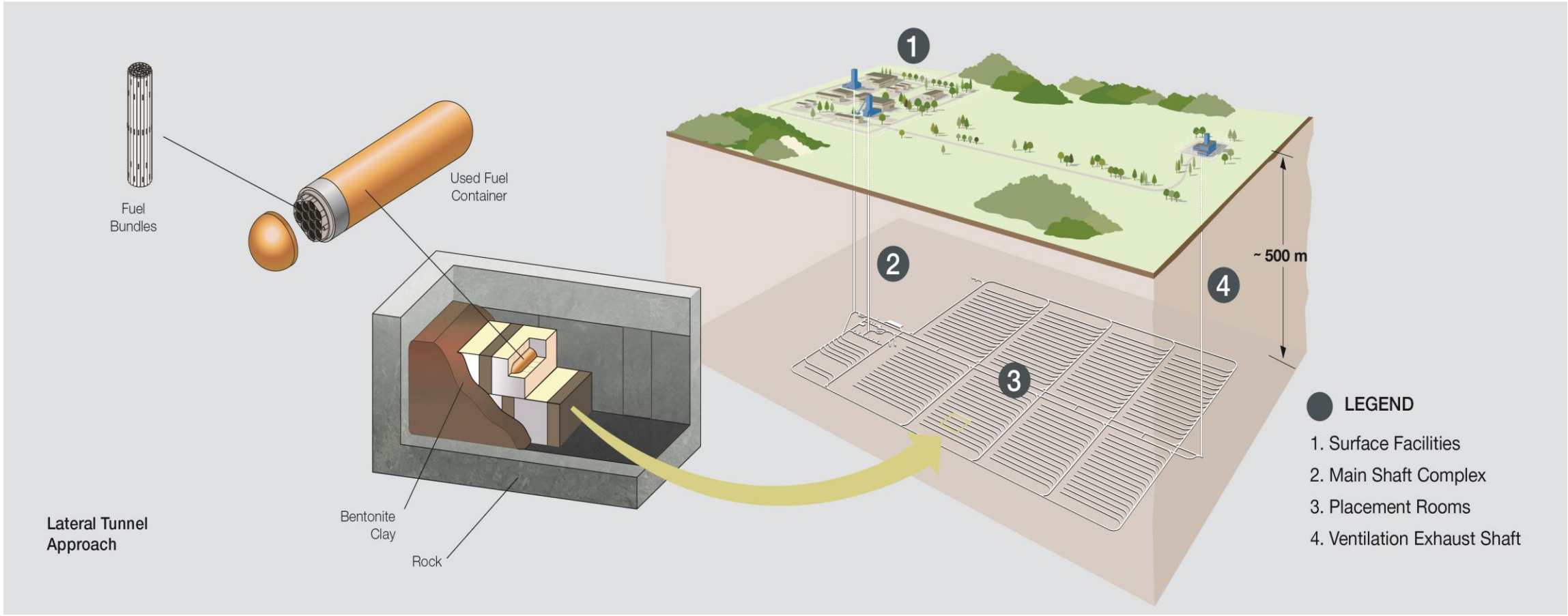
Fresh fuel	
Uranium dioxide (UO_2)	100%
Used CANDU fuel	
Uranium dioxide (UO_2)	98.5%
Non-radioactive products	1.0%
Radioactive products	0.5%



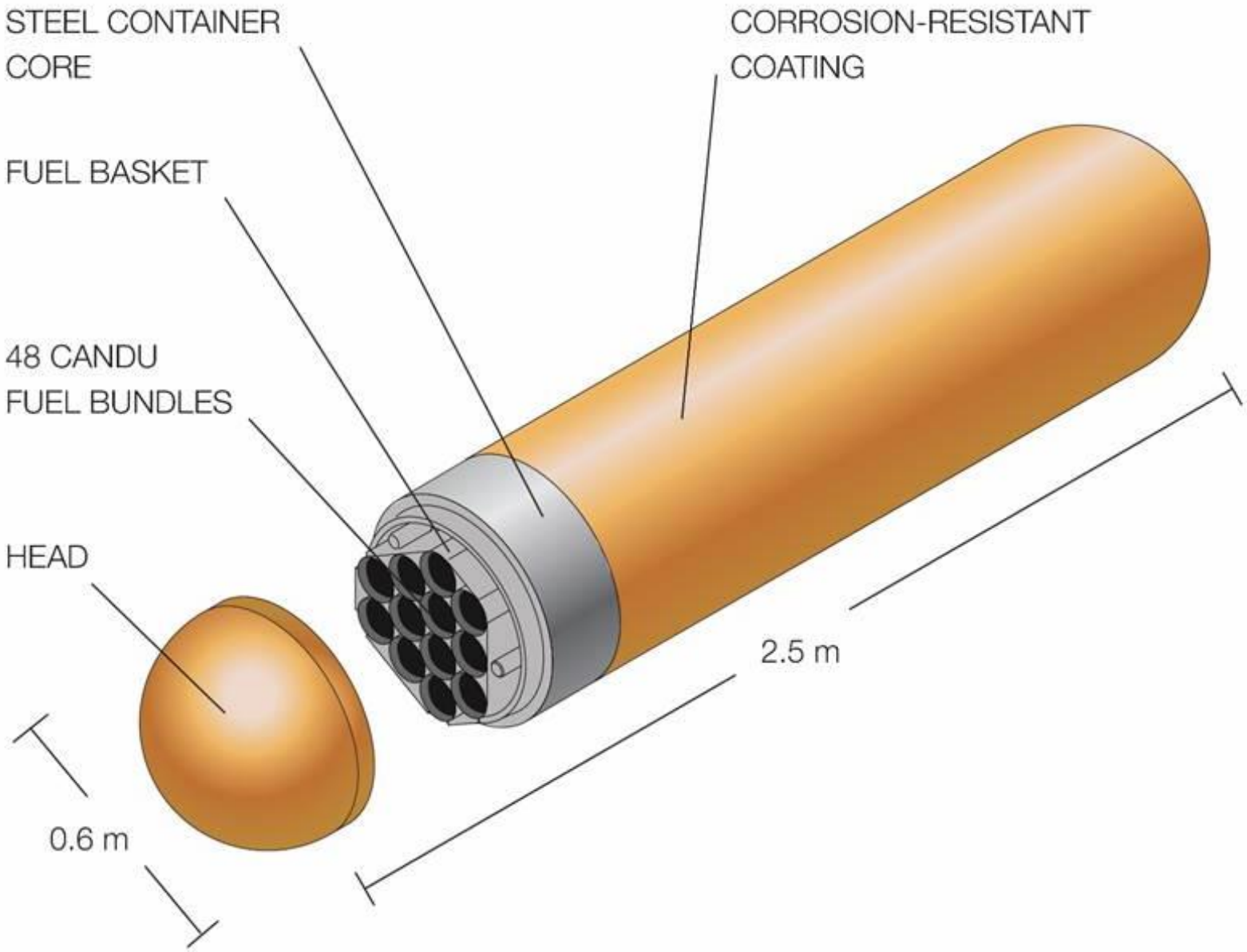
Over 2.6 Million Fuel Bundles Safely Stored



National Infrastructure Project



Used Fuel Container



Steel Shell

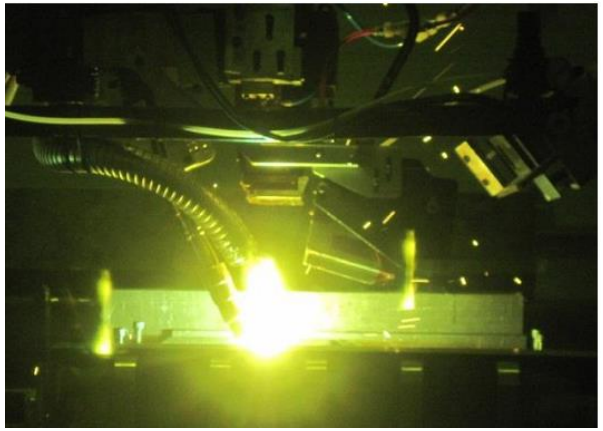
- Nuclear pressure vessel grade steel
- A/SA-106 Gr. C NPS 22” SCH 140 Seamless Steel Pipe

Steel Hemi-Head

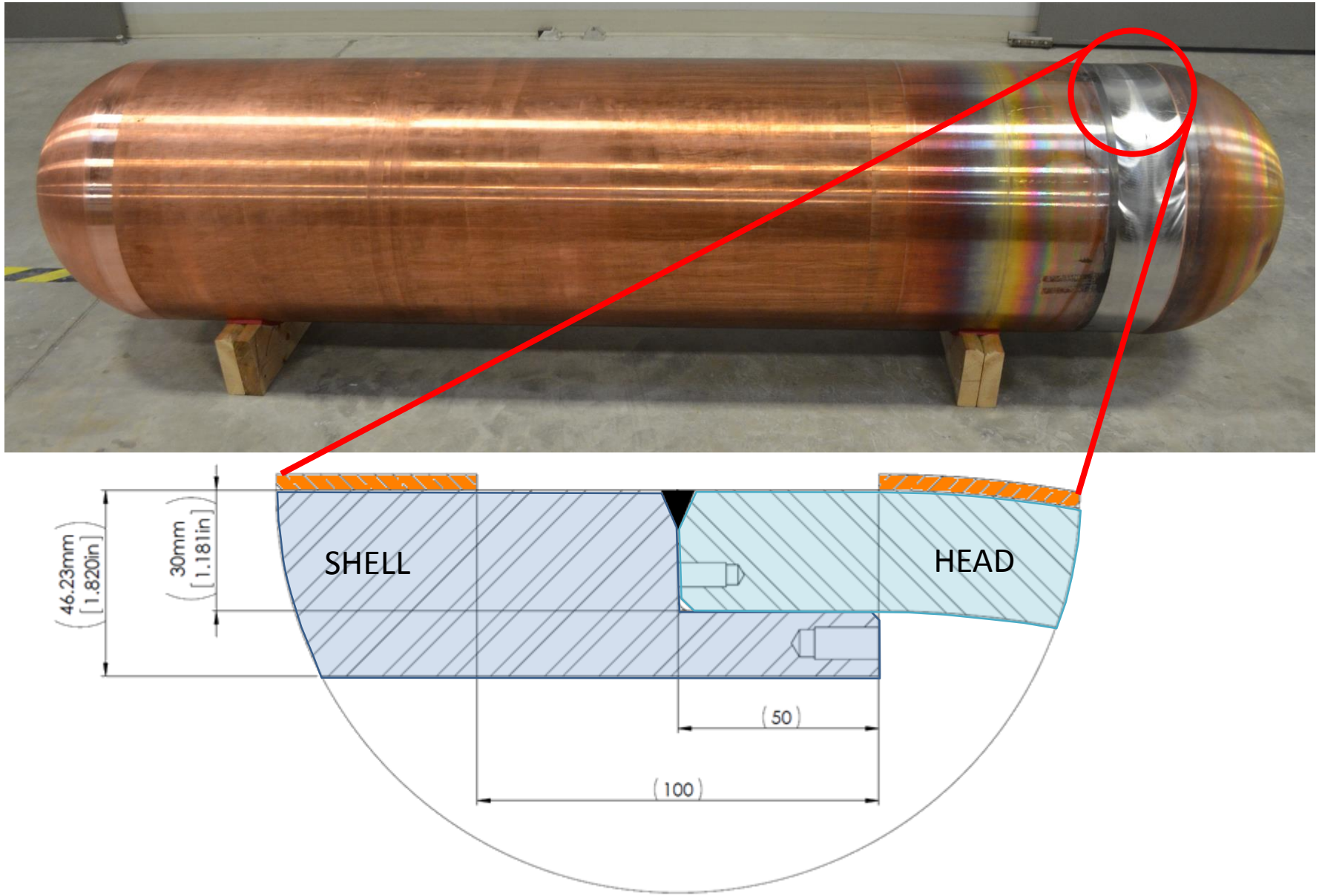
- Nuclear pressure vessel grade steel
- A/SA-516 Gr.70 plate, hot-formed

Welding

- Hybrid Laser Arc Welding (HLAW)



Used Fuel Container



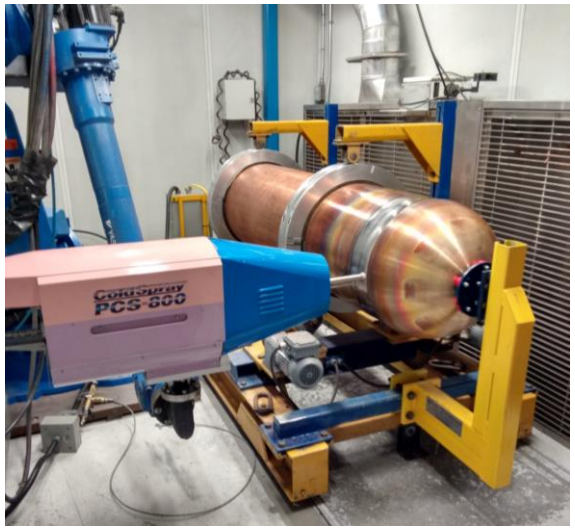
Copper Coating

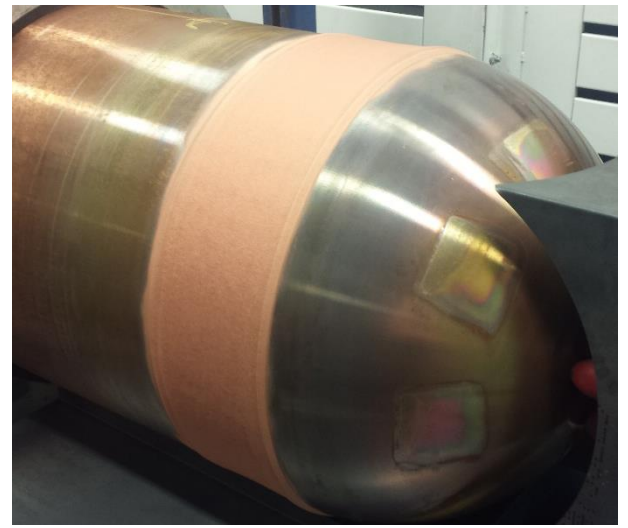
Electrodeposition for main body

- Reverse galvanic cell
- Nano-crystalline coating

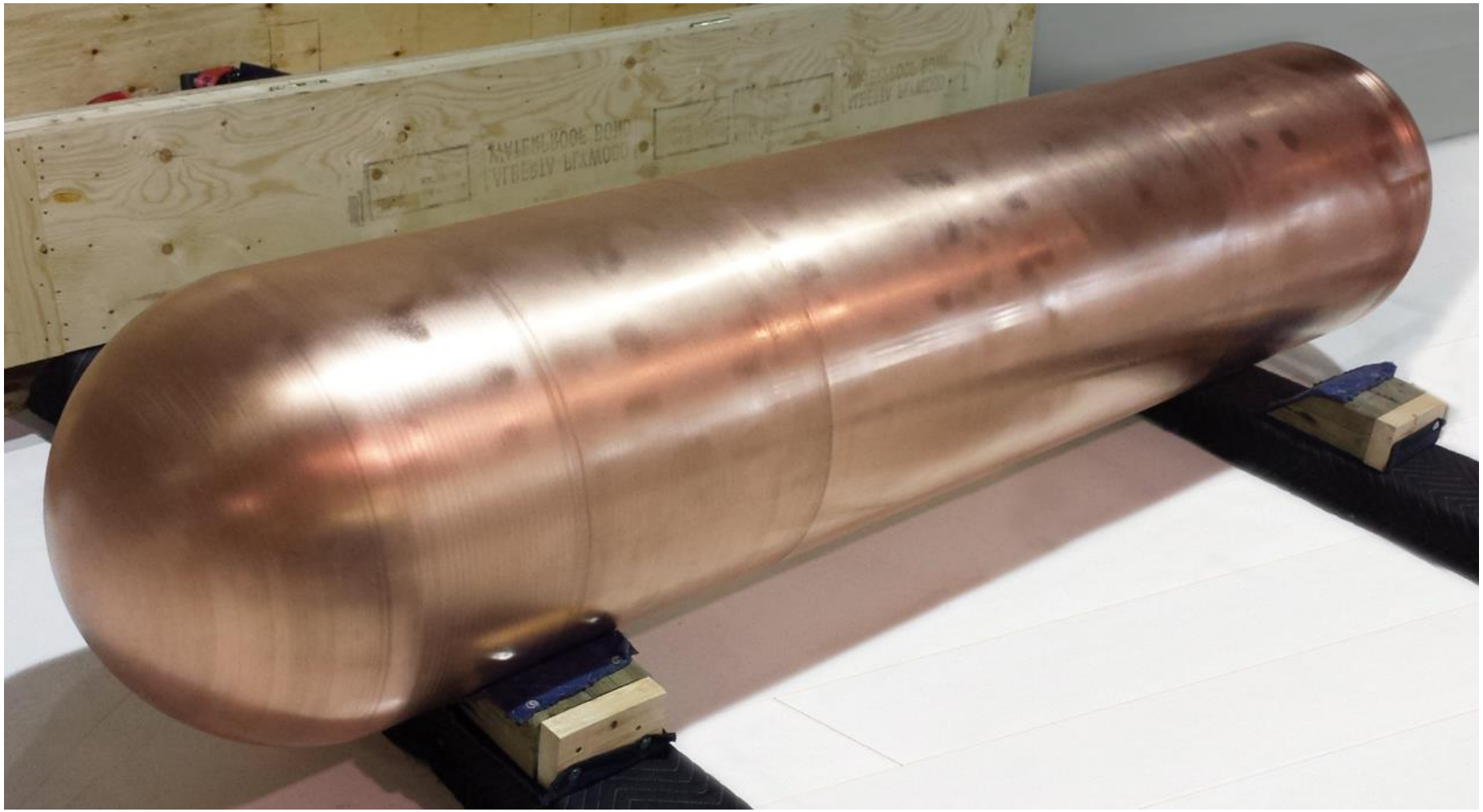
Cold spray for Closure Weld Zone

- Solid state high-speed spray of copper particles





Final Product



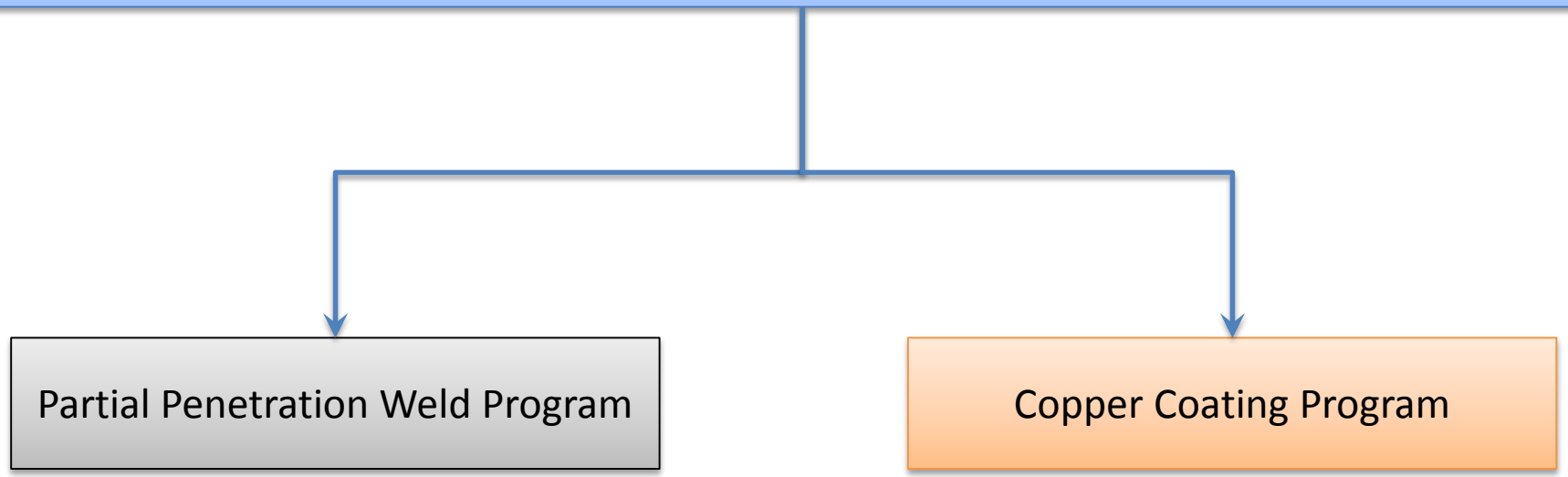
NDE Design and Development

NUCLEOM
INNOVATION • INTEGRATION

NDT in Canada
NDTiC 2017
Canada's NDT Conference
June 6 - 8
Centre des congrès de Québec
Québec City, Québec

NDE Design and Development

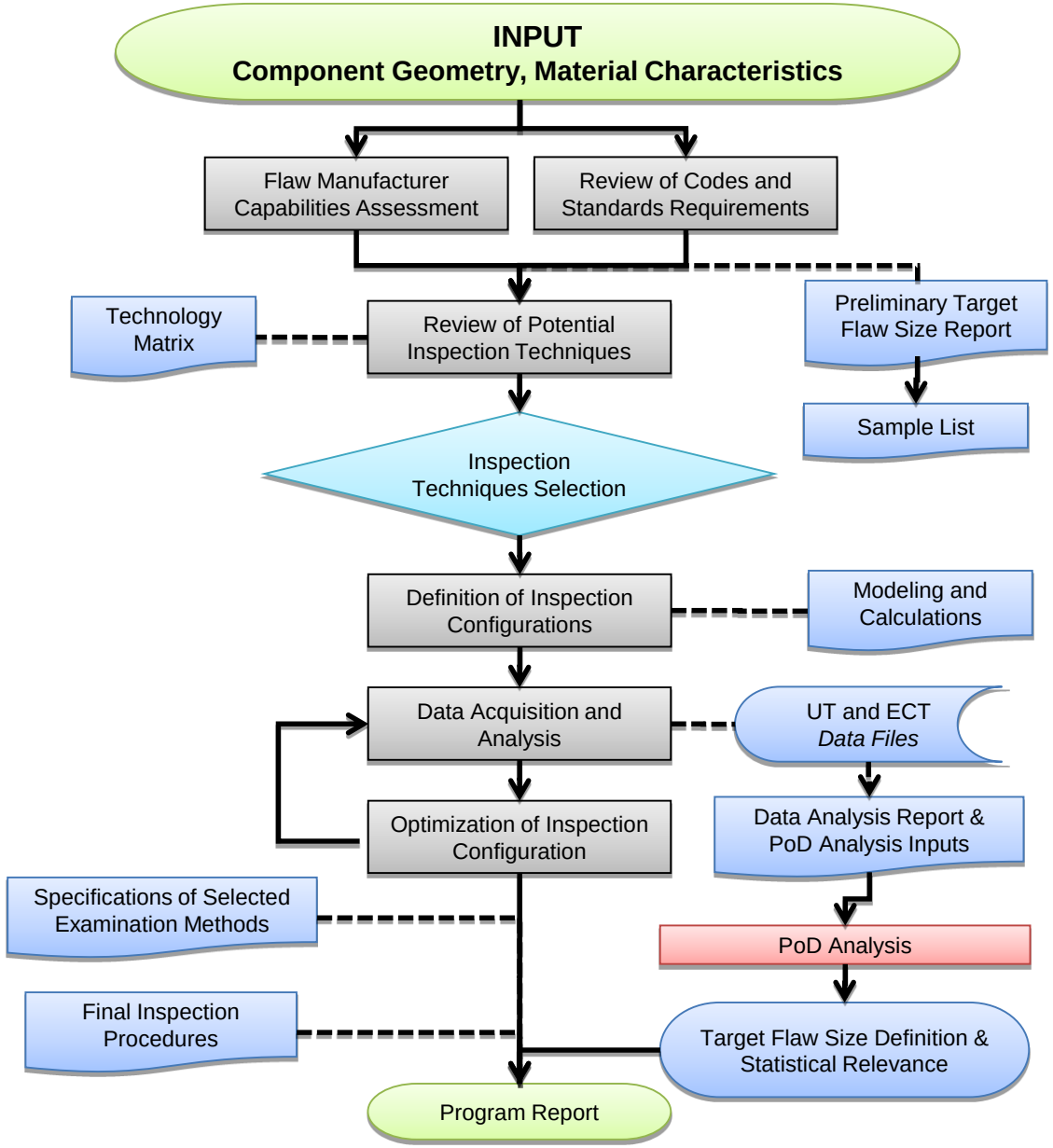
Define inspection techniques to achieve 100% coverage within applicable codes of all critical components at different stages of UFC manufacturing for increase reliability of the long storage life.



NDE Design and Development

Used Fuel Container

NDE Design & Development Flowchart



NDE Design and Development

1. Procurement of material;
2. Machining of shell and head components for assembly;
3. Welding of lower head assembly;
4. Machining of lower assembly weld cap;
5. **NDE**: 0°LW – Carbon steel wall thickness measurement;
6. **NDE**: Partial penetration weld examination;
7. If required, repairs of the partial penetration weld;

8. Copper Coating of the lower assembly and upper head (electrodeposition);
9. Machining of copper coating surface;
10. **NDE**: Eddy Current – Copper coating surface examination;
11. **NDE**: 0°LW – Copper coating examination;
12. If required, repairs of the copper coating surface;

13. Closure welding after fuel loaded;
14. Machining of closure weld cap;
15. **NDE**: Partial penetration weld examination;
16. If required, repairs of the partial penetration weld;

17. Copper coating of closure weld zone (cold spray);
18. Annealing of copper coating at the weld zone;
19. Machining of copper coating surface at the weld zone;
20. **NDE**: Eddy Current – Copper coating surface examination;
21. **NDE**: 0°LW – Copper coating examination.

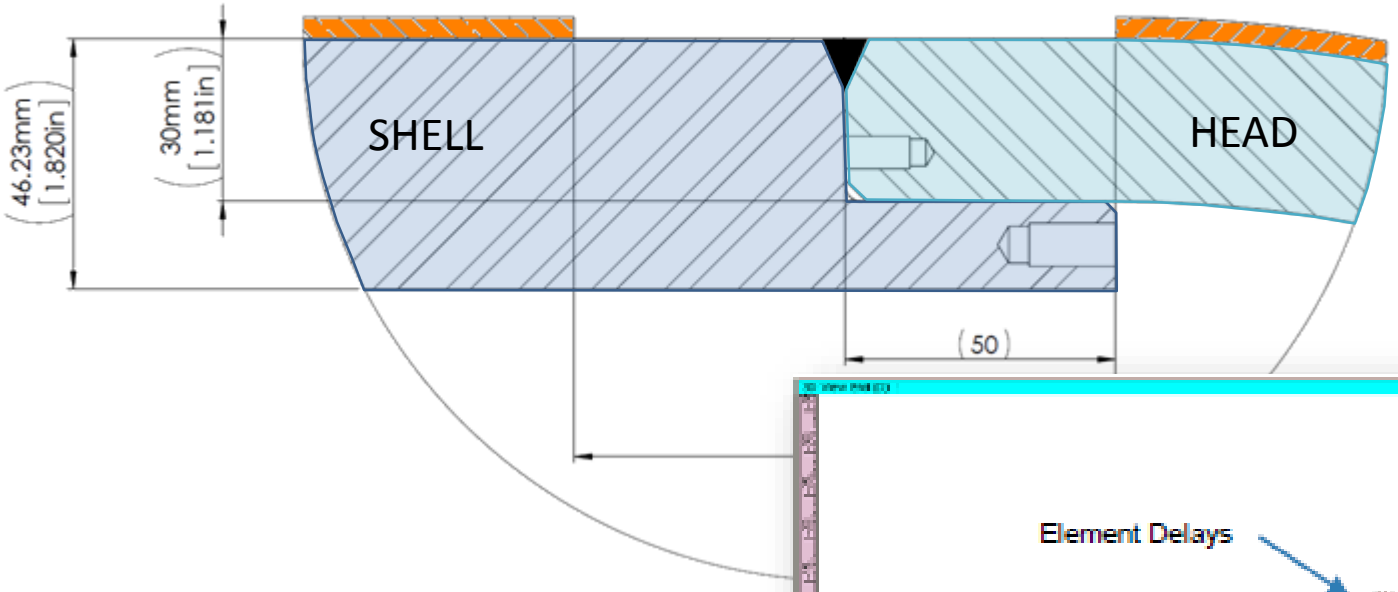
Used Fuel Container
Manufacturing Stages

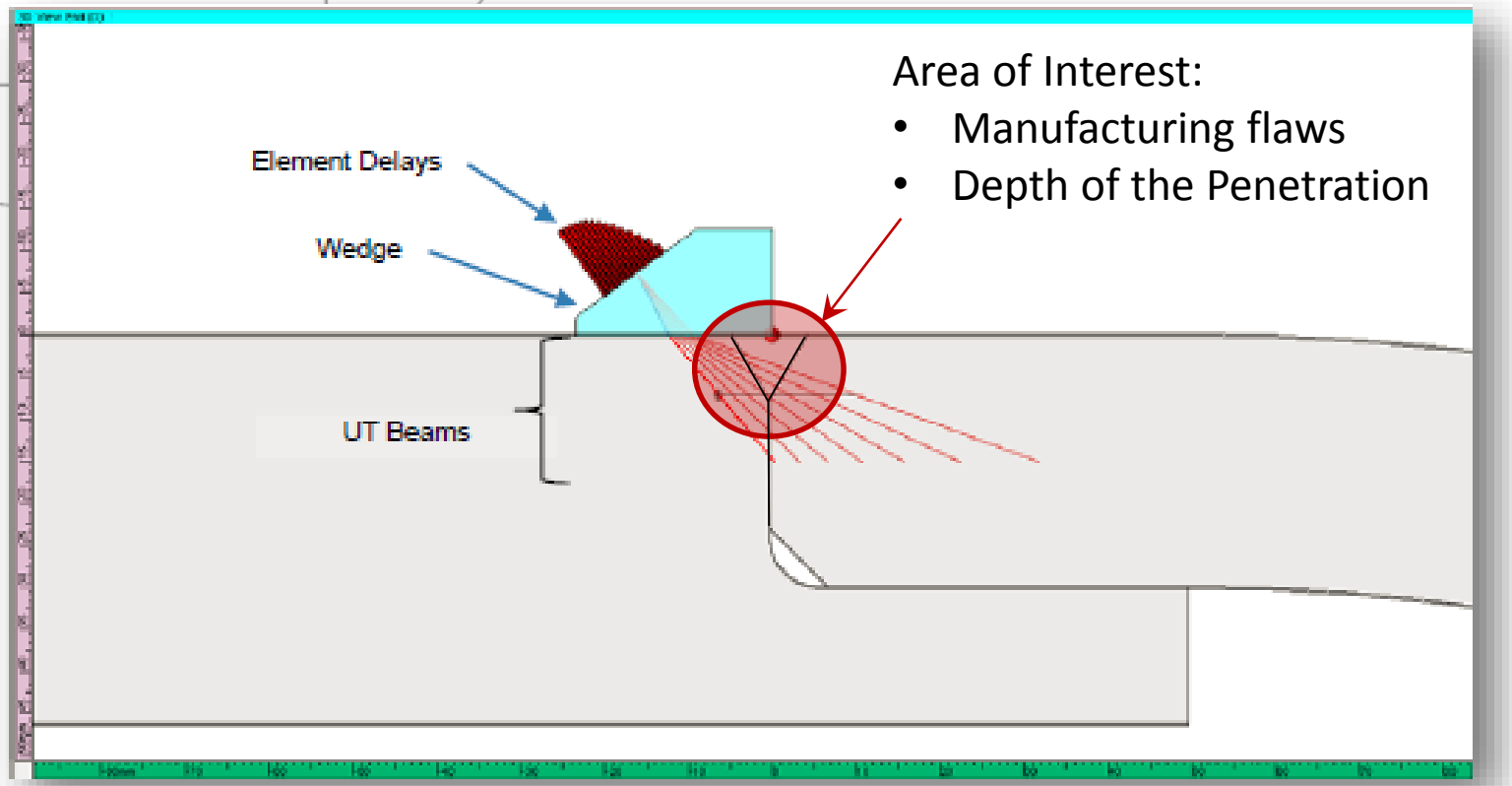
Results: Partial Penetration Weld

NUCLEOM
INNOVATION • INTEGRATION

NDT in Canada
NDTiC 2017
Canada's NDT Conference
June 6 - 8
Centre des congrès de Québec
Québec City, Québec

Partial Penetration Weld

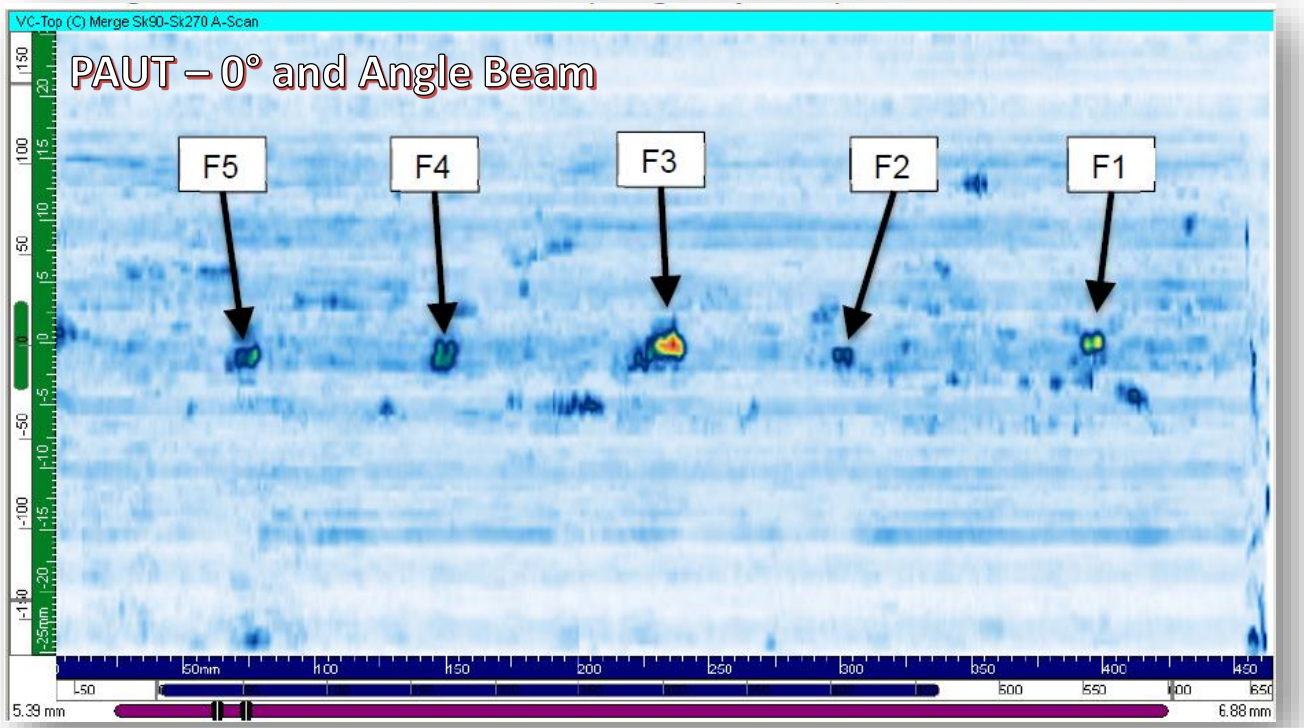


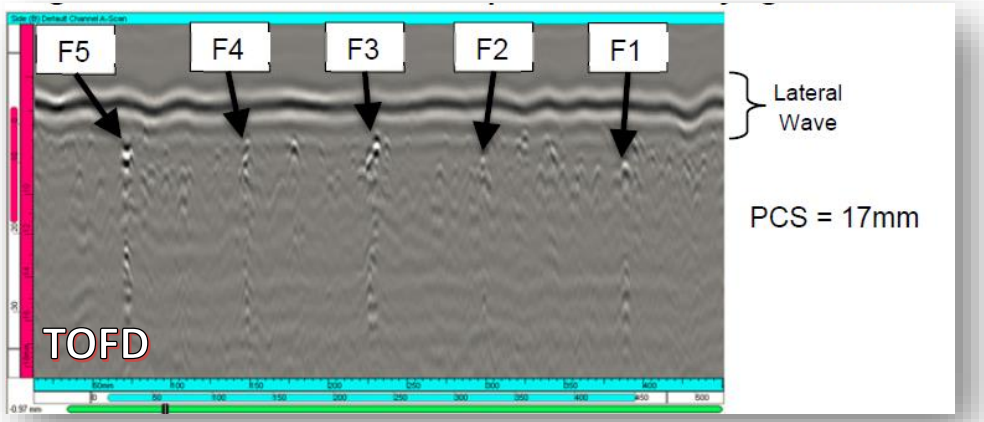


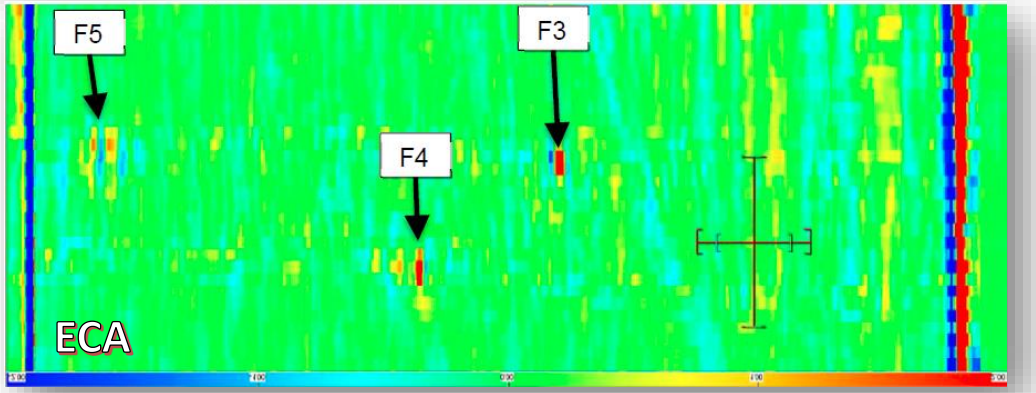
Area of Interest:

- Manufacturing flaws
- Depth of the Penetration

Partial Penetration Weld





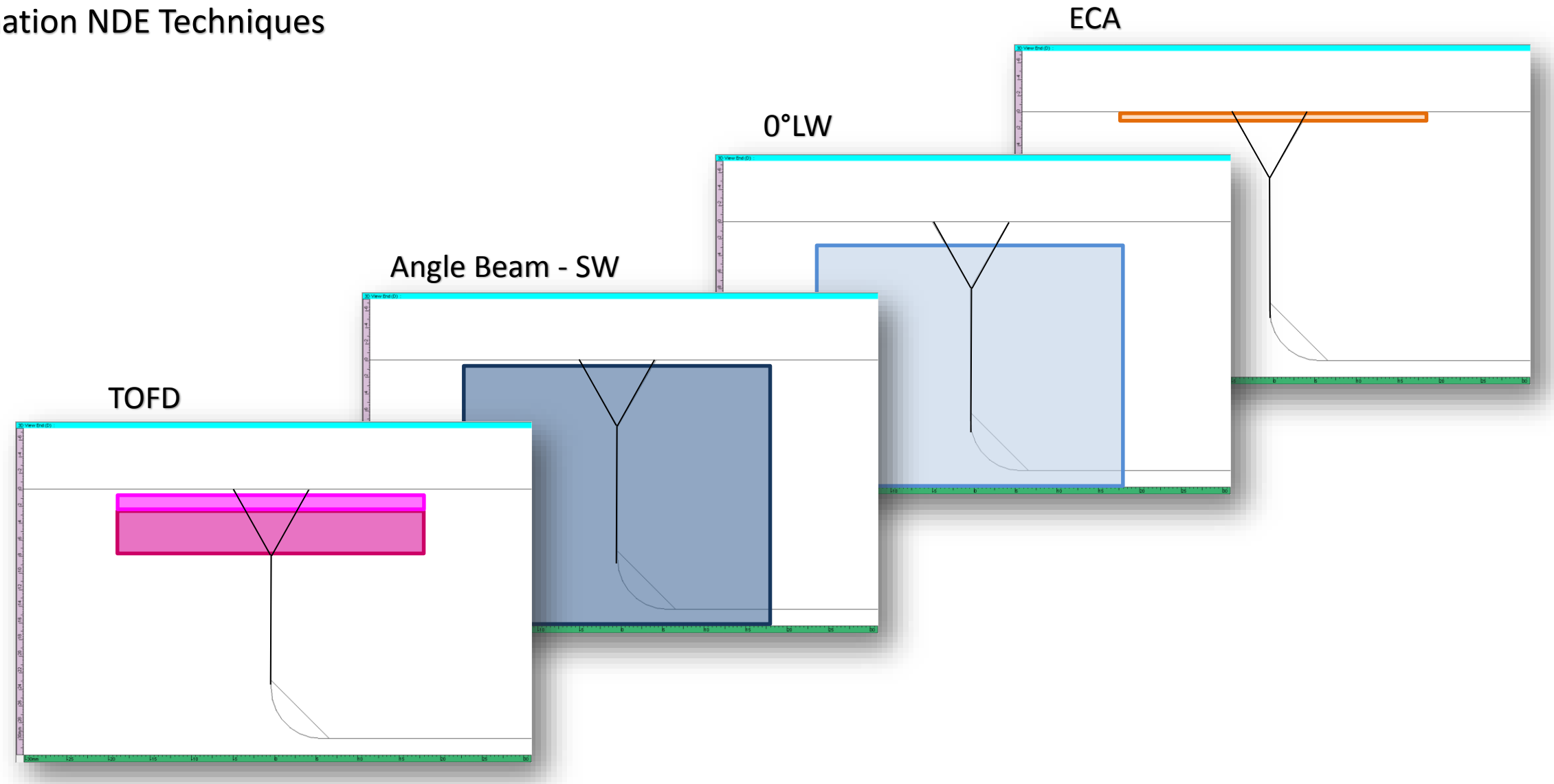


Looking for:

- Surface connected defects
- In-volume cracks/porosities
- Weld penetration depth

Partial Penetration Weld

Combination NDE Techniques



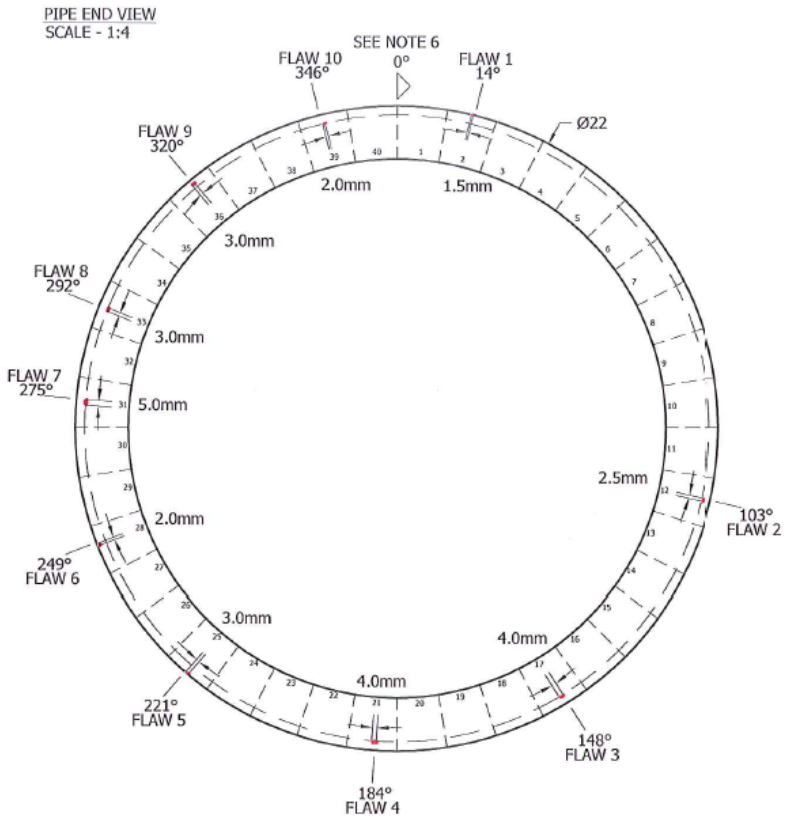
Partial Penetration Weld

100% Detection

Sample	Flaw Id	Description	Nominal Size		ECA	5MHz PAUT	10MHz PAUT		TOFD	Complete System
			Length	Depth Extent		45° to 70° SW	0° LW	45° to 70° SW		
Circ-W1 (C0870-NSC-001)	1	Toe crack	2.0mm (0.79in.)	0.4mm (0.0160in)	D	D	ND	D	ND	D
	2	Root LoP	2.8mm (0.110in)	1.0mm (0.0380in)	ND	D	D	D	D	D
	3	Root crack	4.1mm (0.162in)	1.2mm (0.047in)	ND	D	ND	D	D	D
	4	Root LoP	4.2mm (0.162in)	1.7mm (0.065in)	ND	D	D	ND	D	D
	5	Toe crack	3.3mm (0.130in)	1.0mm (0.0380in)	D	D	ND	D	D	D
	6	Porosity	2.1mm (0.084in)	1.1mm (0.044in)	ND	ND	D	ND	D	D
	7	Root crack	5.2mm (0.205in)	2.1mm (0.084in)	ND	D	D	D	D	D
	8	Root LoP	3.1mm (0.121in)	1.1mm (0.043in)	ND	D	D	D	D	D
	9	Side LoF	3.1mm (0.124in)	1.1mm (0.044in)	ND	D	D	D	D	D
	10	Root Crack	2.0mm (0.080in)	0.4mm (0.0140in)	ND	D	D	D	D	D
Circ-W2 (C0870-NSC-002)	1	Toe crack	3.8mm (0.150in)	0.9mm (0.0350in)	D	ND	ND	ND	D	D
	2	Porosity	3.2mm (0.127in)	1.6mm (0.062in)	ND	ND	ND	ND	D	D
	3	Root crack	2.6mm (0.102in)	0.5mm (0.0190in)	ND	D	D	D	D	D
	4	Side LoF	2.1mm (0.083in)	0.8mm (0.0320in)	ND	D	ND	D	D	D
	5	Toe crack	2.3mm (0.091in)	0.3mm (0.0120in)	D	ND	ND	D	D	D
	6	Root LoP	2.0mm (0.080in)	0.6mm (0.0240in)	ND	D	D	D	ND	D
	7	Side LoF	4.1mm (0.160in)	1.6mm (0.063in)	ND	D	ND	D	D	D
	8	Root crack	3.0mm (0.118in)	0.6mm (0.0240in)	ND	D	ND	D	D	D
	9	Toe crack	3.6mm (0.140in)	0.9mm (0.0340in)	ND	ND	ND	ND	D	D
	10	Root LoP	3.7mm (0.144in)	1.2mm (0.047in)	ND	D	D	D	D	D

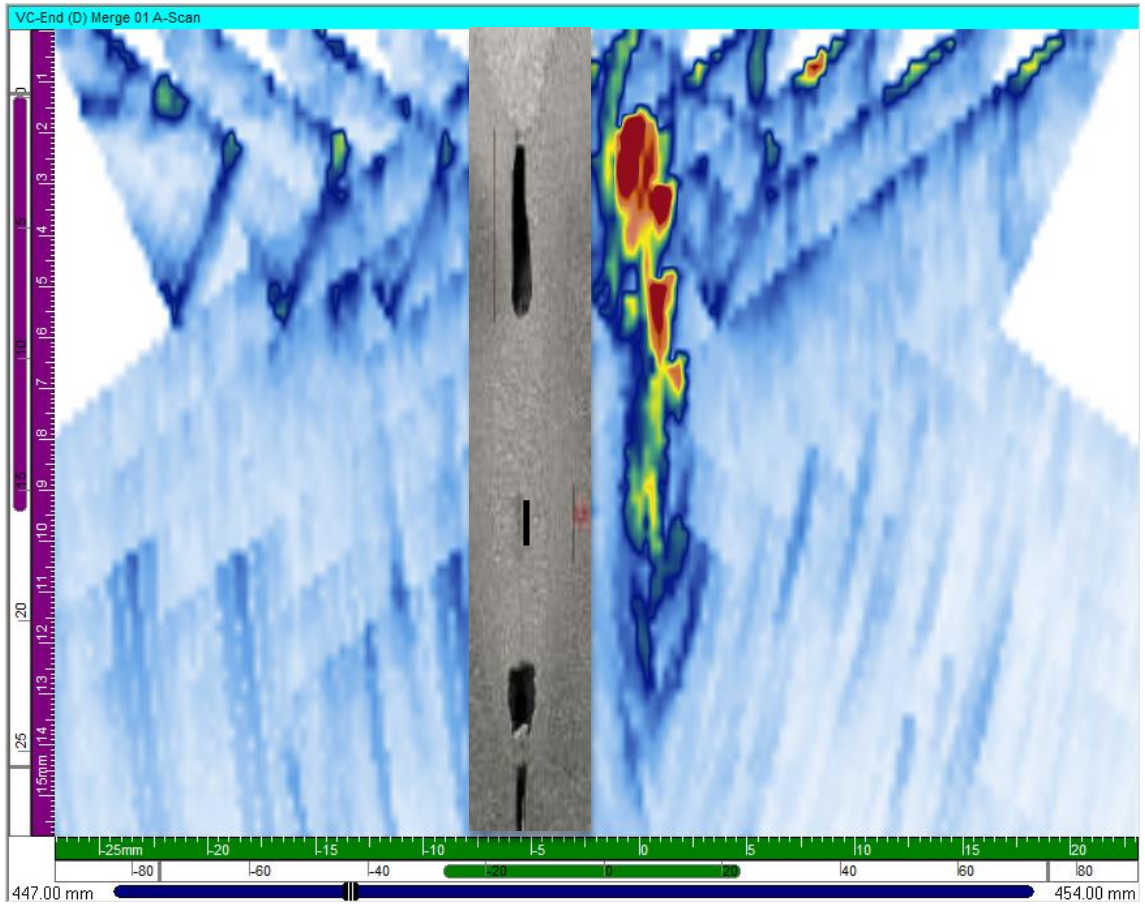
D: Detected

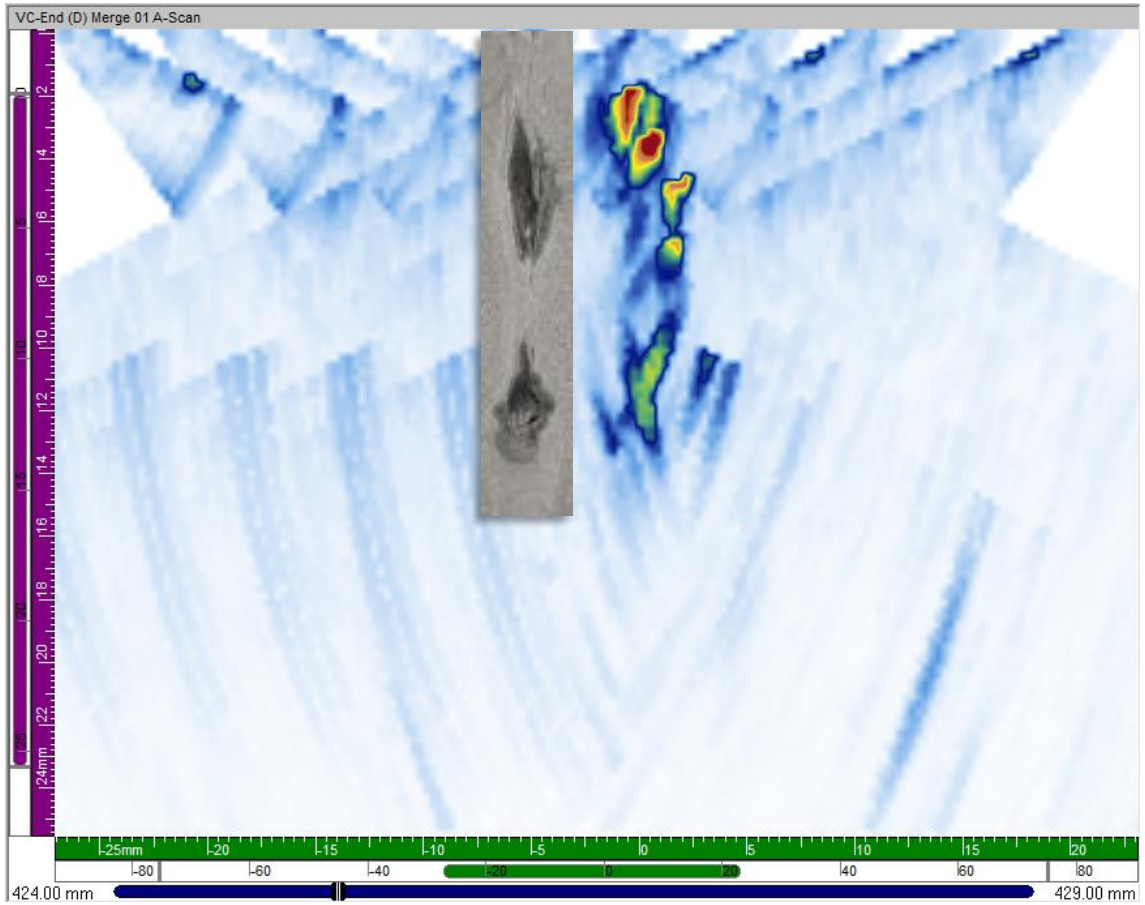
ND: Not Detected



Partial Penetration Weld

- Real Welding Defects (On-Purpose)





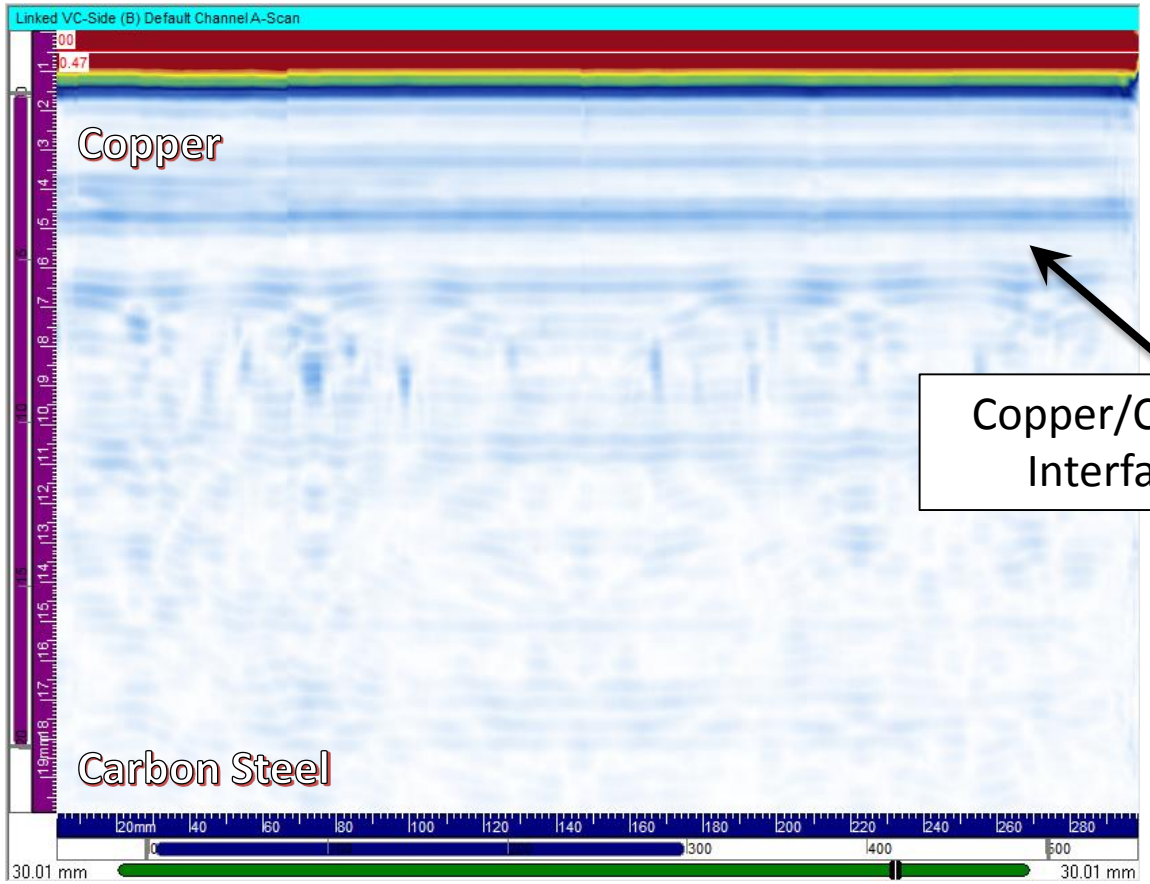
Results: Copper Coating

NUCLEOM
INNOVATION • INTEGRATION

NDT in Canada
NDTiC 2017
Canada's NDT Conference
June 6 - 8
Centre des congrès de Québec
Québec City, Québec

Copper Coating

Electrodeposition



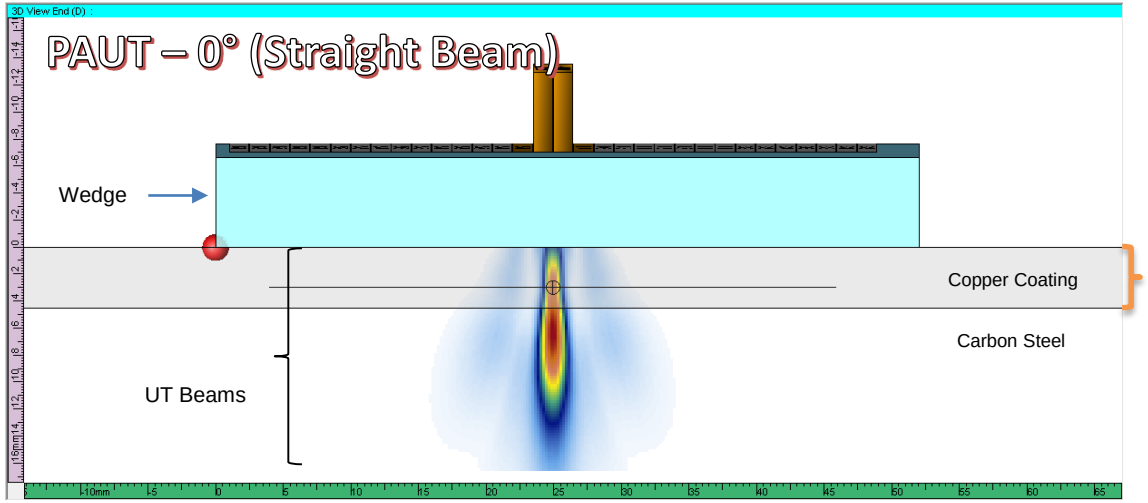
Cold Spray

Copper/Carbon Steel Interface Signal

Copper Coating Thickness : ~4.5mm

~23dB Amplitude Delta between Coating Techniques

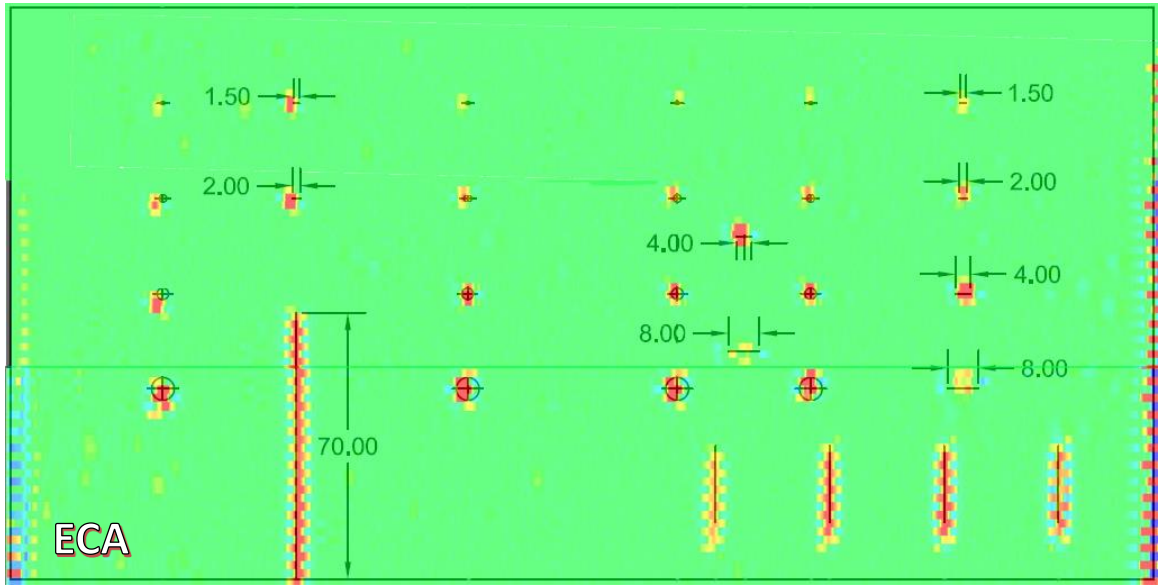
Copper Coating



~4mm

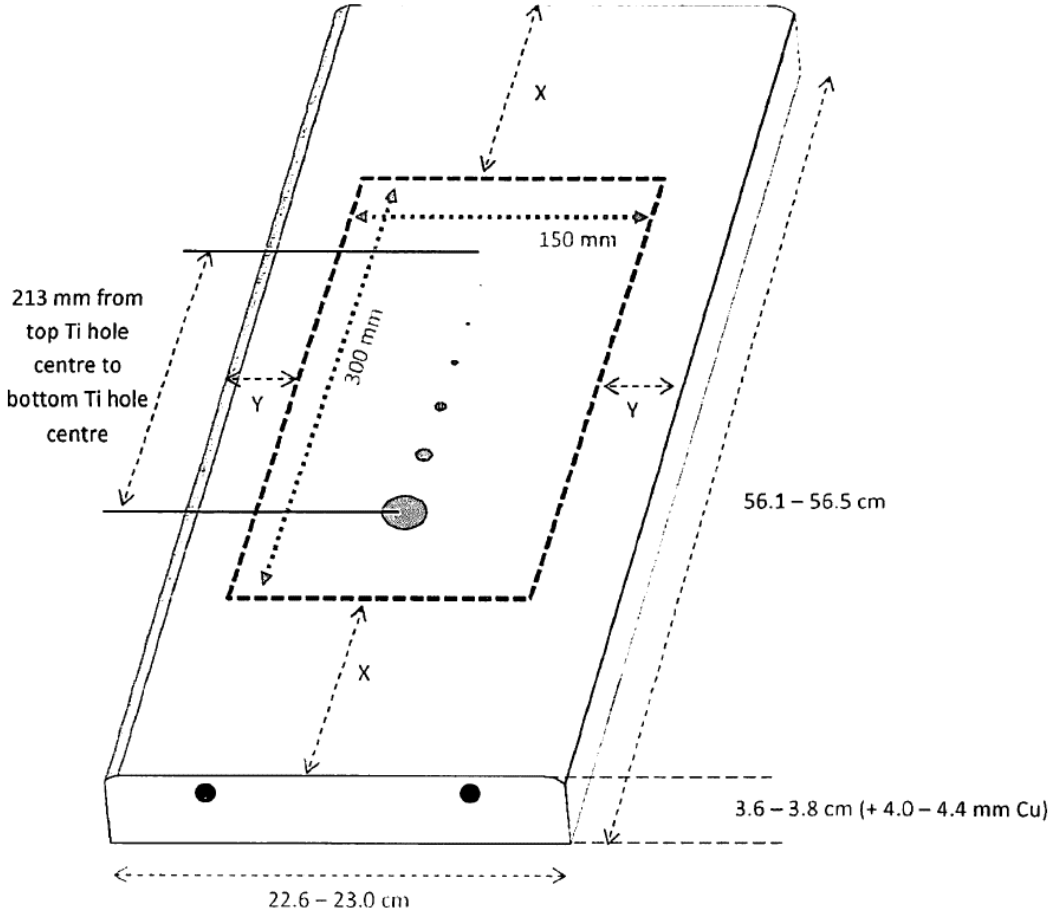
Looking for:

- Surface connected defects
- In-volume porosities
- Bonding issues with carbon steel
- Coating thickness

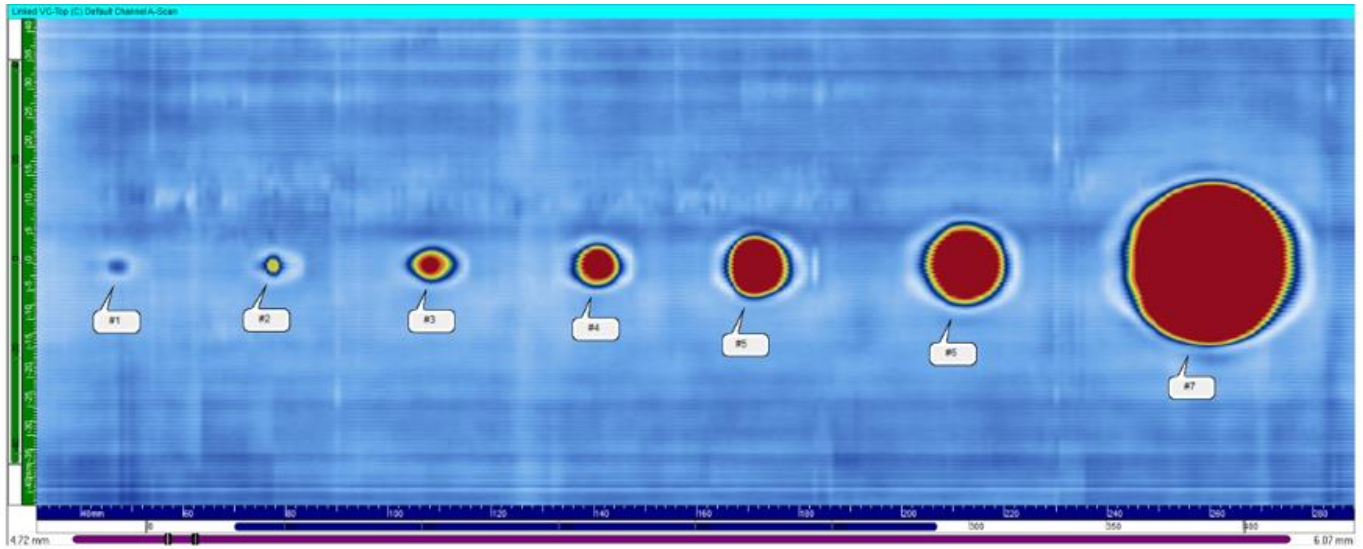


Copper Coating

- Bonding Issues



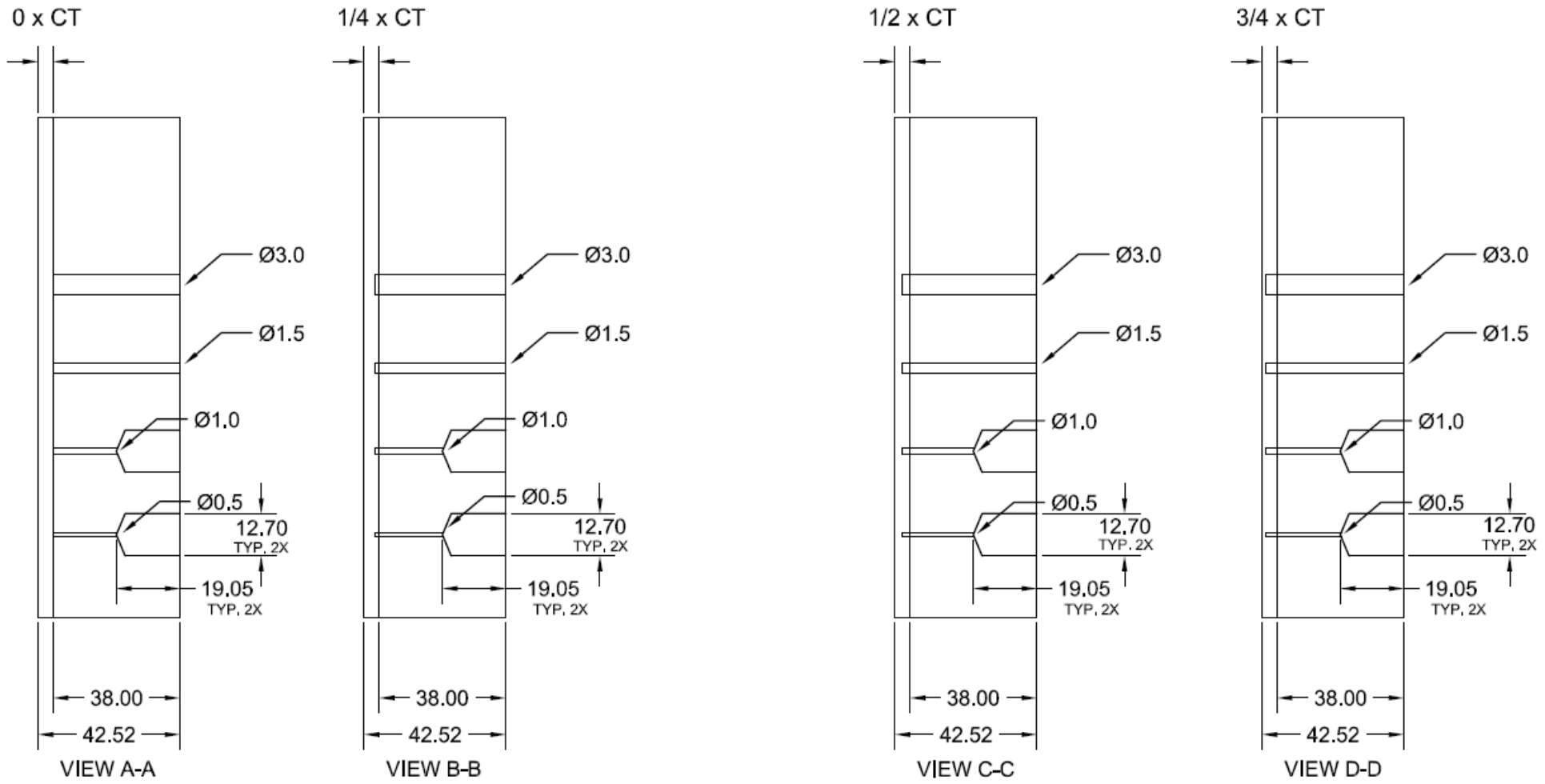
5MHz, 128 el. (Aperture: 16el.) – Linear Scan



Hole Id	Diameter	Measured Diameter	Measurement Delta
1	3/64” (1.2mm)	--	--
2	3/32” (2.4mm)	3.0mm	0.6mm
3	9/64” (3.6mm)	5.00	1.4mm
4	7/32” (5.6mm)	7.0mm	1.4mm
5	21/64” (8.3mm)	10.0mm	1.7mm
6	29/64” (11.5mm)	13.0mm	1.5mm
7	1-1/32” (26.2mm)	27.0mm	0.8mm

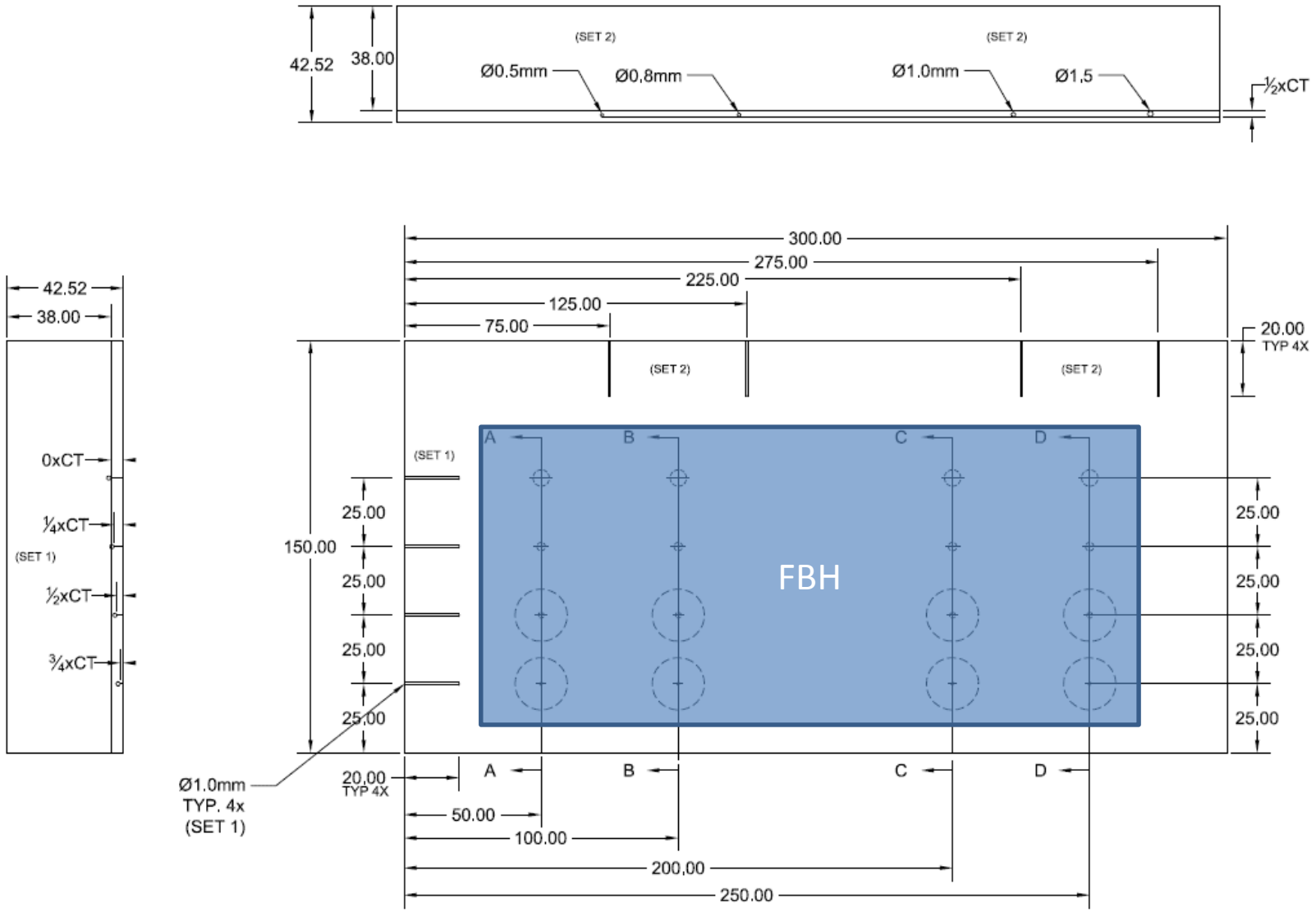
Copper Coating

- Samples with FBH (Electrodeposited and Cold Sprayed Coating)



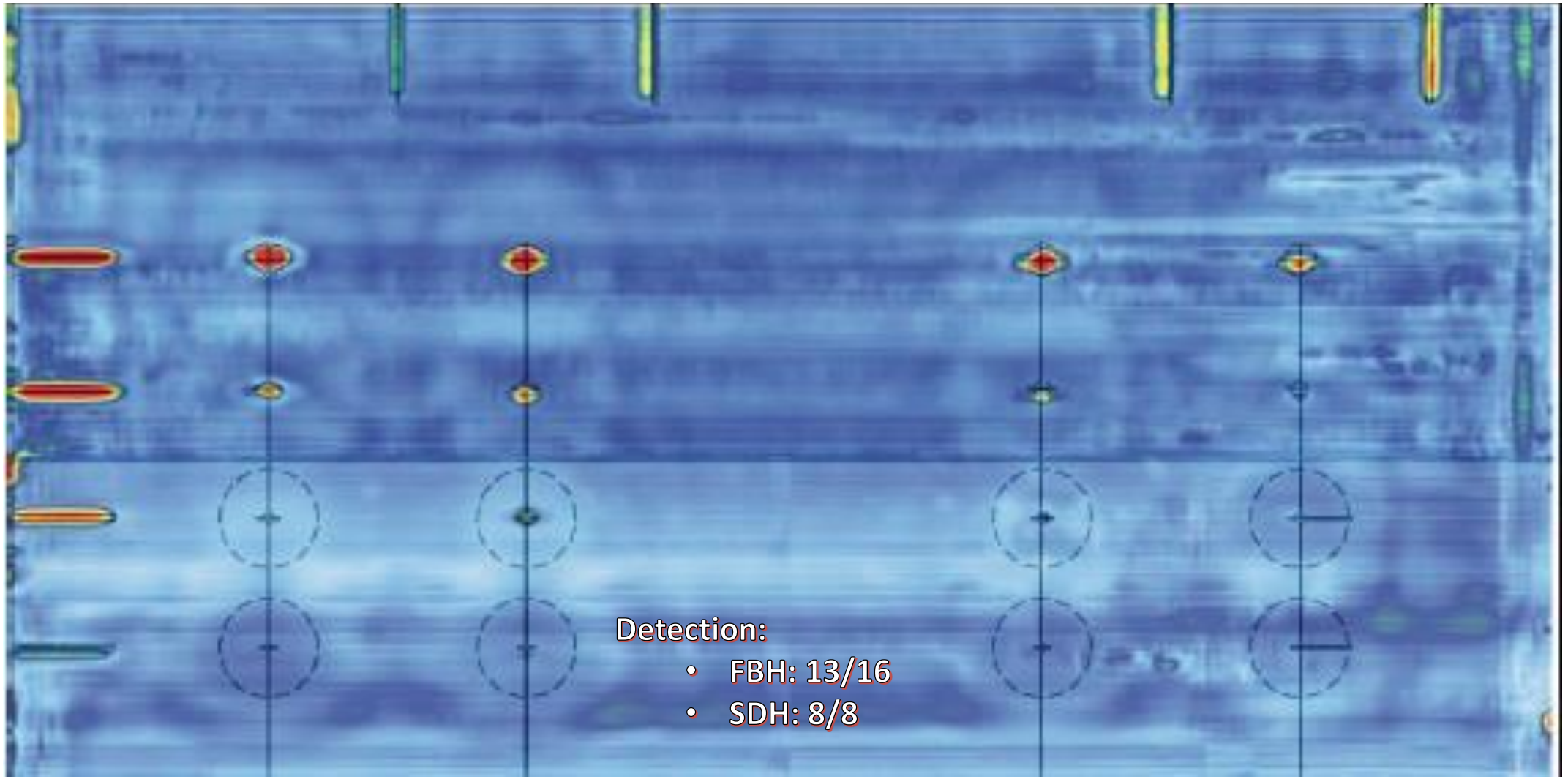
Copper Coating

- SDH of the Same Samples (Electrodeposited and Cold Sprayed Coating)



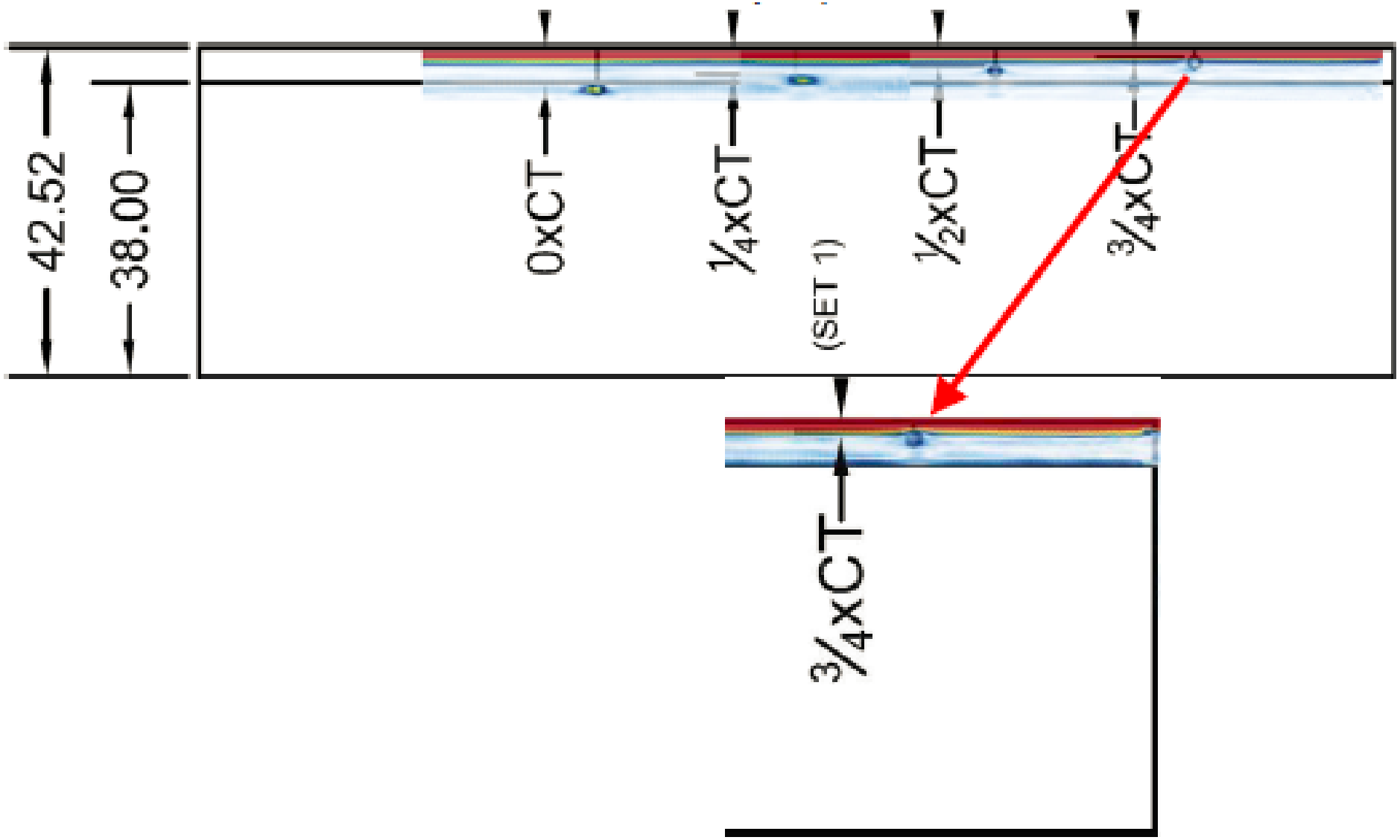
Copper Coating

- Typical UT Results (Straight Beam - Electrodeposited Copper)



Copper Coating

- Typical UT Results (Straight Beam - Electrodeposited Copper)

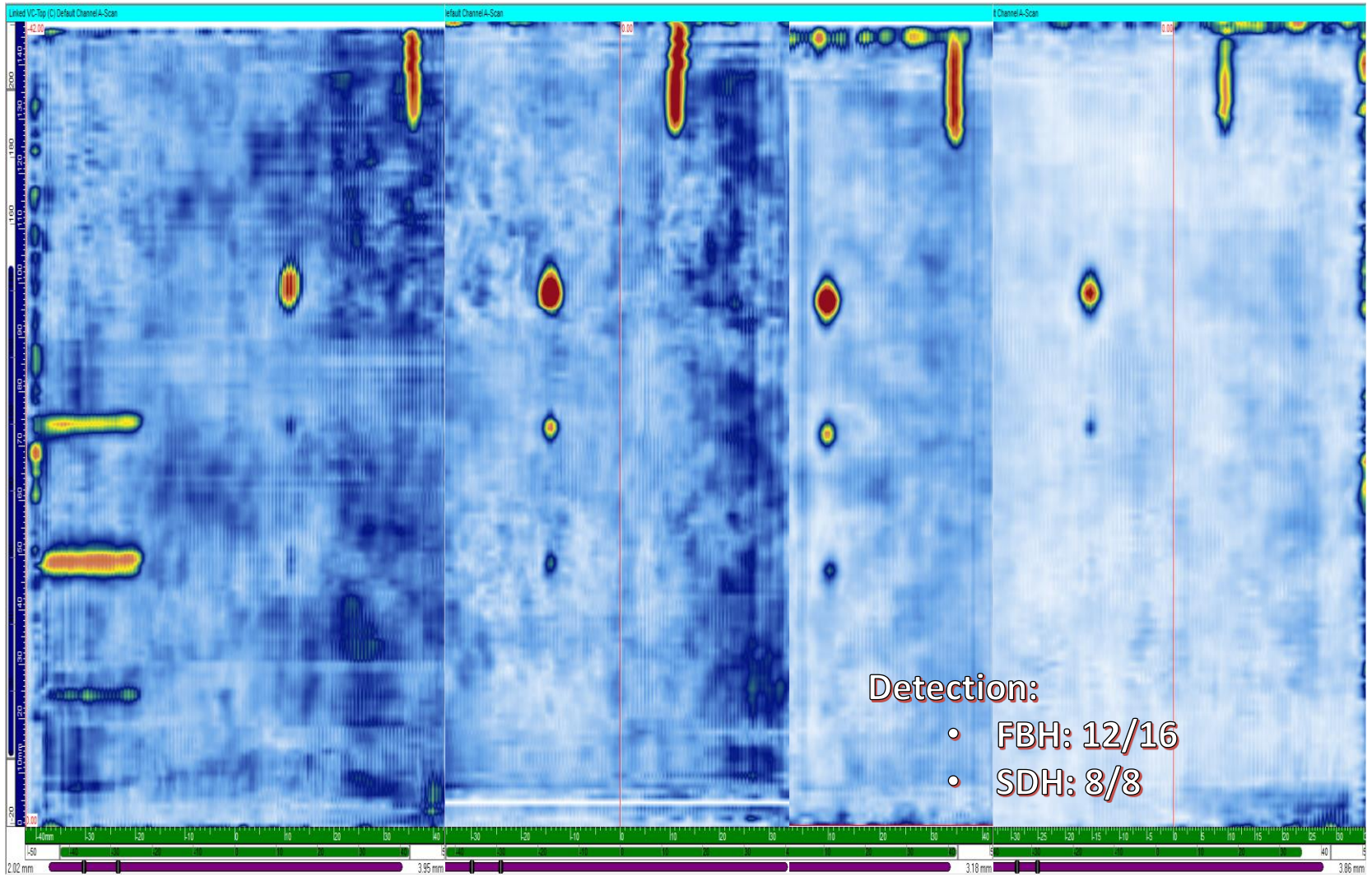


Copper Coating

- Typical UT Results (Straight Beam - Electrodeposited Copper)

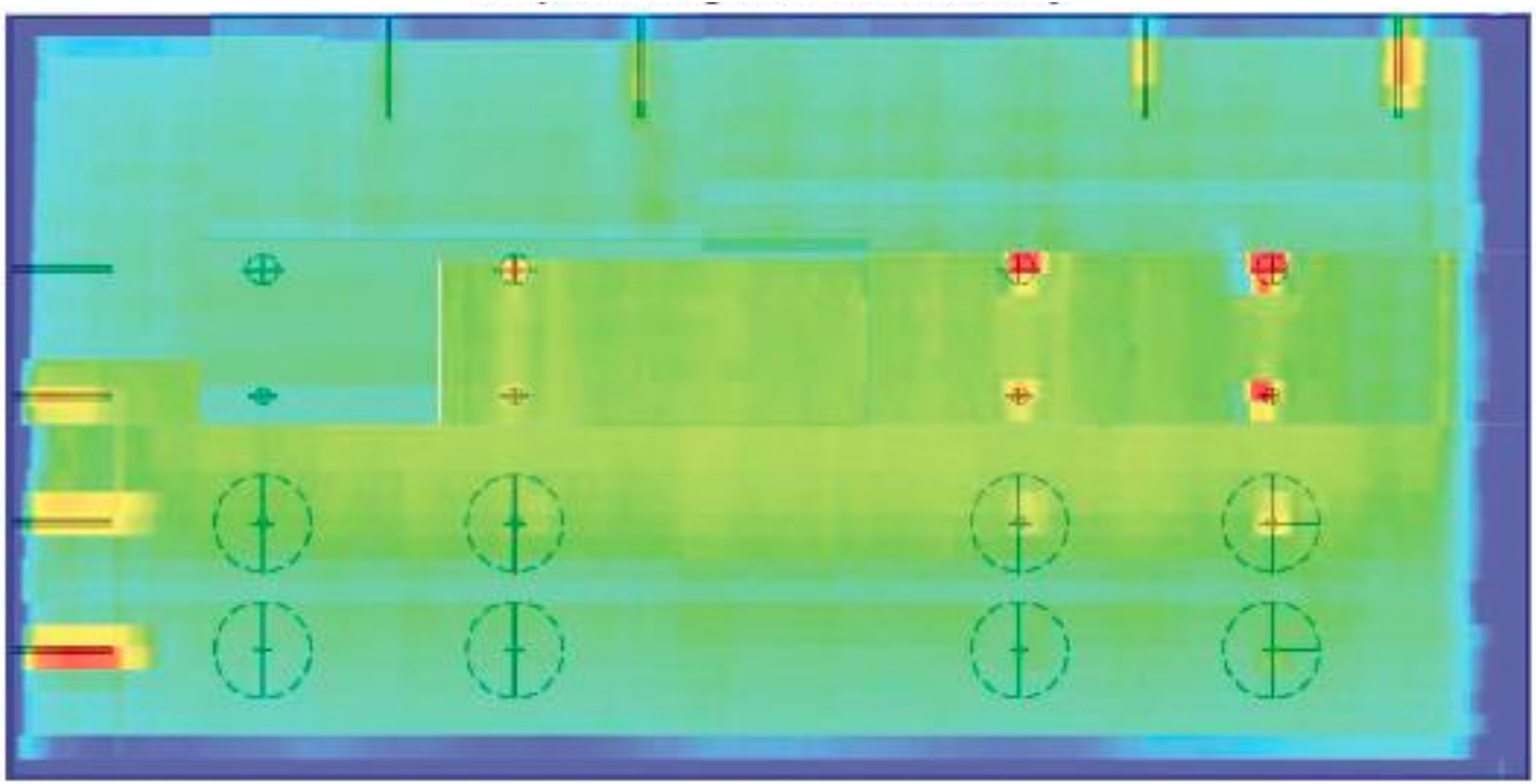
Copper Coating

- Typical UT Results (Straight Beam - Cold Sprayed Copper)



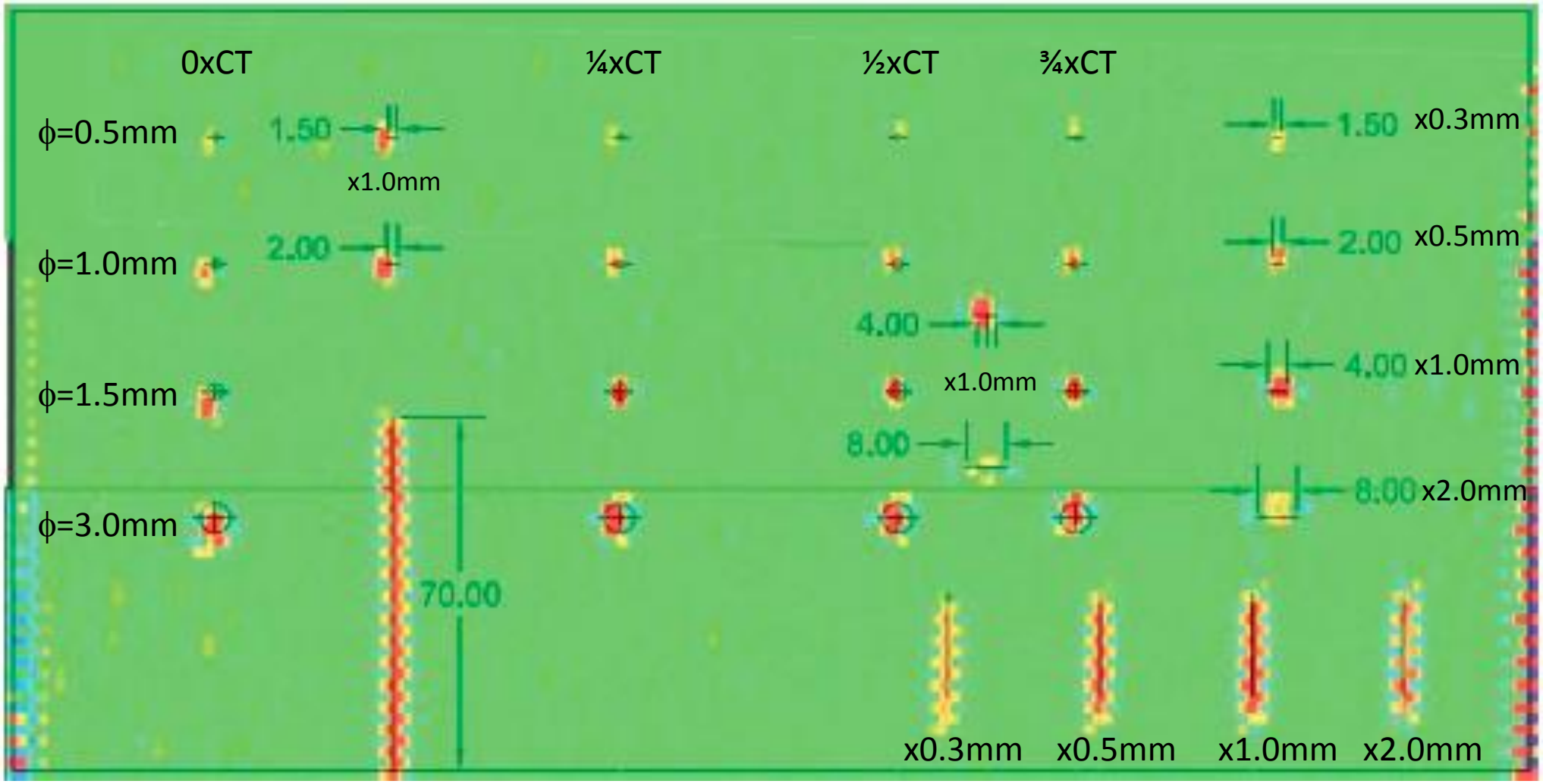
Copper Coating

- Typical ECA – Low Frequency Probe (In-Volume Features – SDH and FBH)



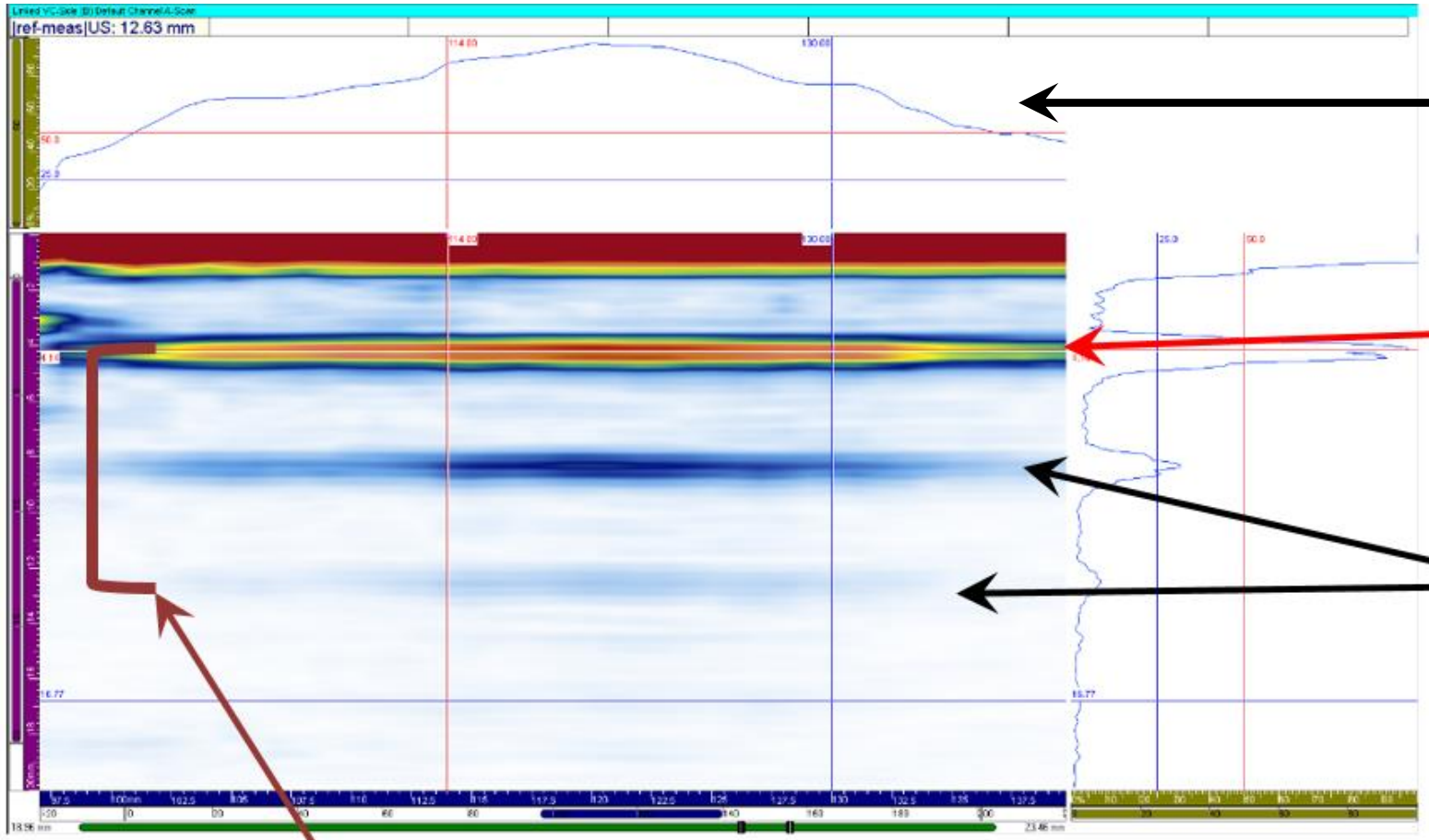
Copper Coating

- Typical ECA – Low Frequency Probe (Surface Breaking Features)



Copper Coating

- Coating Thickness (Part 1)



Interface Signal Amplitude

Carbon Steel / Copper Interface Signal

Carbon Steel / Copper Boundary Repeat Signals

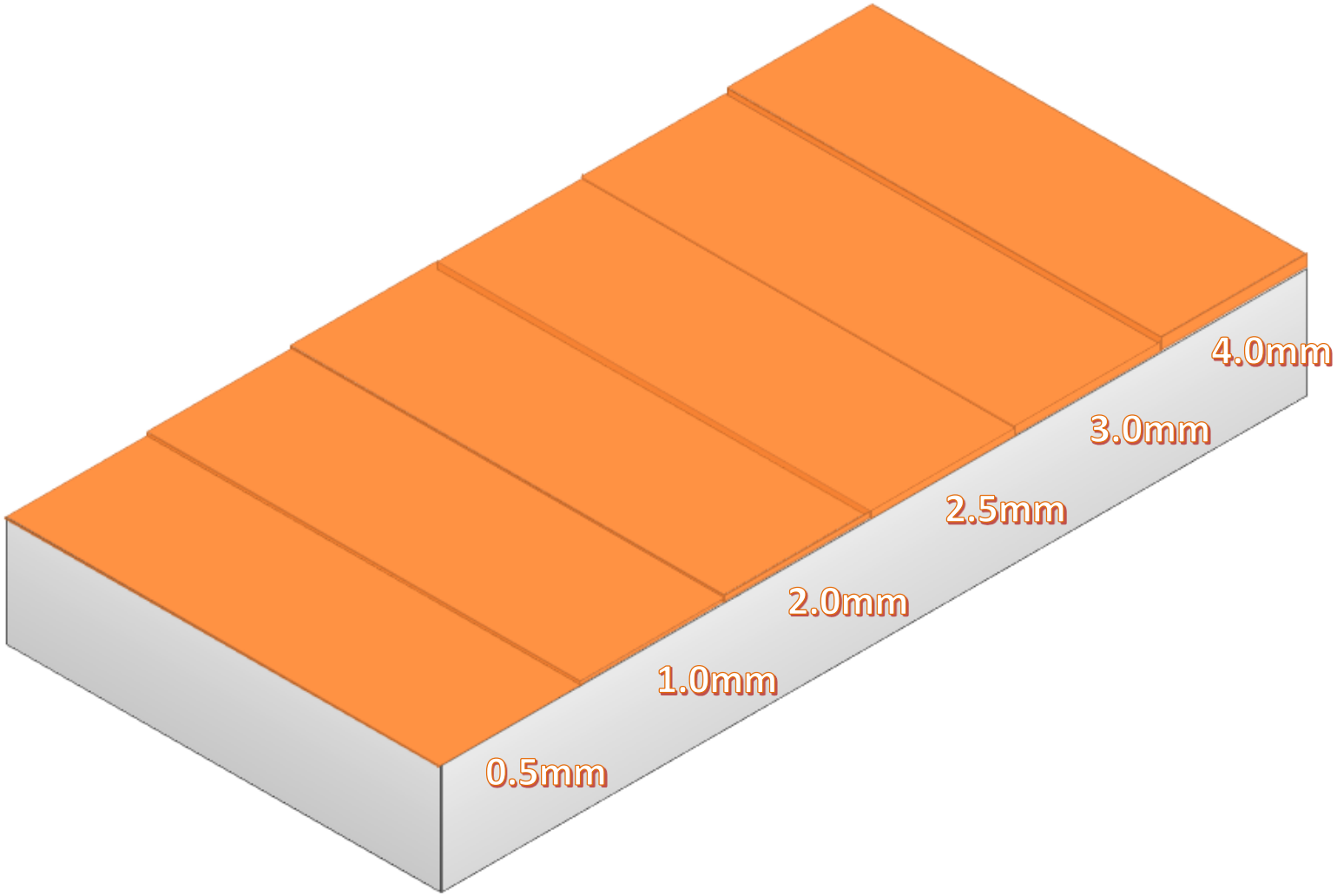
Depth Measurement Distance

Cold Spray ✓

Electrodeposition ✗

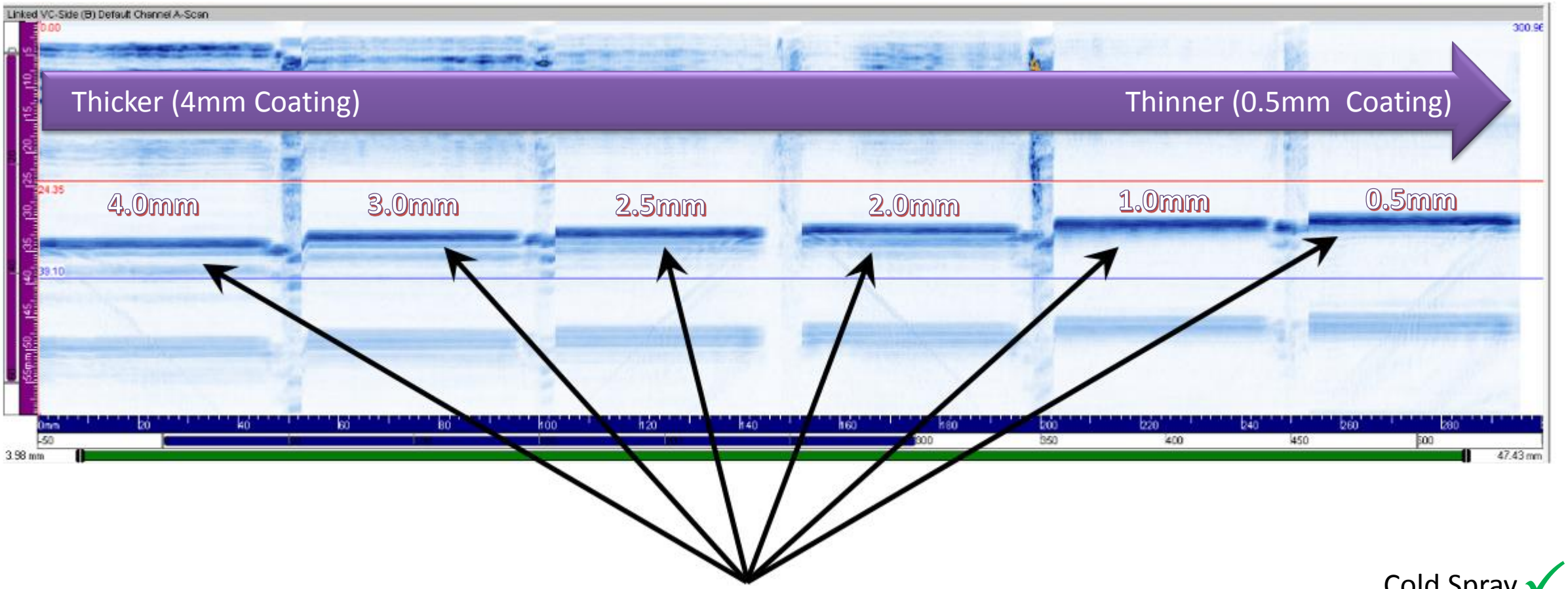
$$\text{Coating Thickness} = \frac{\text{Depth Measurement Distance}}{\text{Number of Repeat Signals}}$$

Coating Thickness Demonstration Sample



Copper Coating

- Coating Thickness (Part 2)



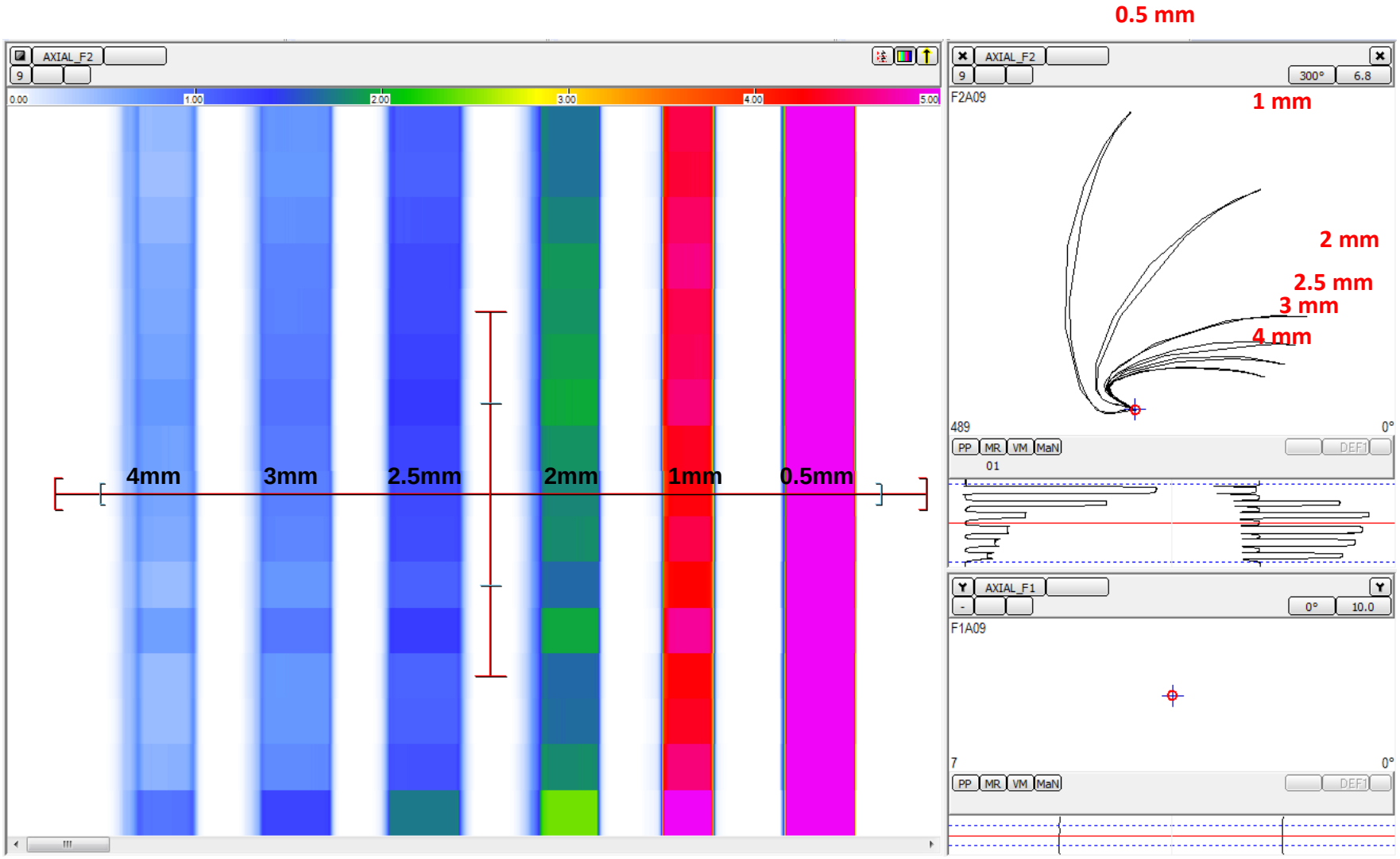
Carbon Steel Back-Wall
Signal Monitoring
(0° LW Examination)

Cold Spray ✓

Electrodeposition ✓

Copper Coating

- Coating Thickness (Part 3)

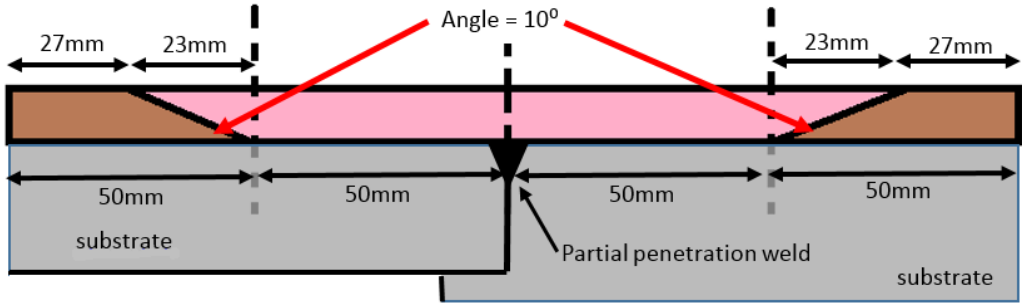


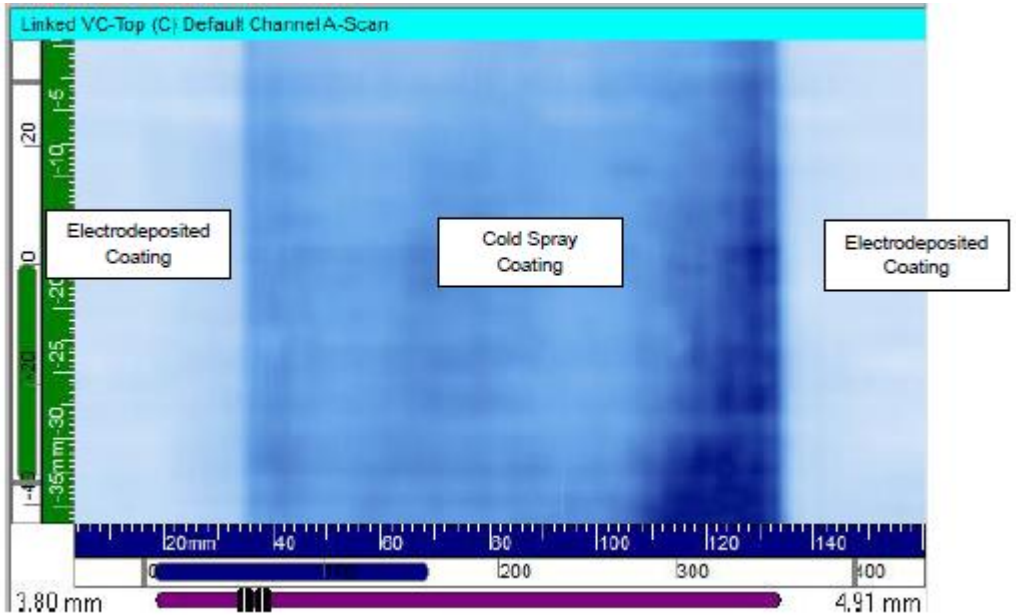
Cold Spray ✓

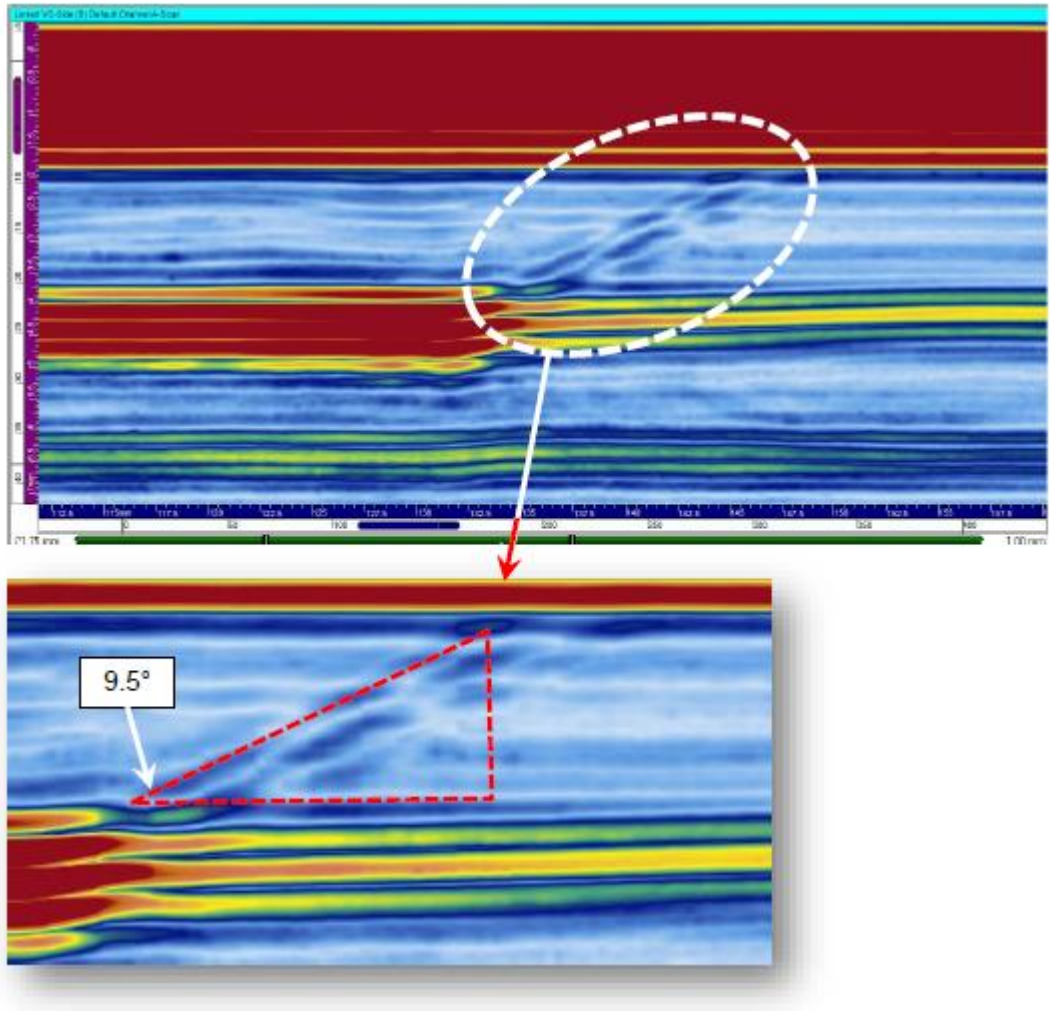
Electrodeposition ✓

Copper Coating

- Coating Thickness (Part 4)







Conclusions

NUCLEOM
INNOVATION • INTEGRATION

NDT in Canada
NDTiC 2017
Canada's NDT Conference
June 6 - 8
Centre des congrès de Québec
Québec City, Québec

Conclusion

- Identified NDE Techniques
  - Partial Penetration Weld
  - Copper Coating
- Identified the Challenges
- NDE System Specifications

Question