Low Frequency Phased Array Methods for Crack Detection in Cast Austenitic Piping Components

Michael Anderson
Susan Crawford
Stephen Cumblidge
Aaron Diaz
Steven Doctor

6th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurised Components

October 8-10, 2007

Budapest, Hungary

Sponsored by: The U.S. NRC, Office of Research
Wallace Norris, Project Manager

Battelle

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Acknowledgements

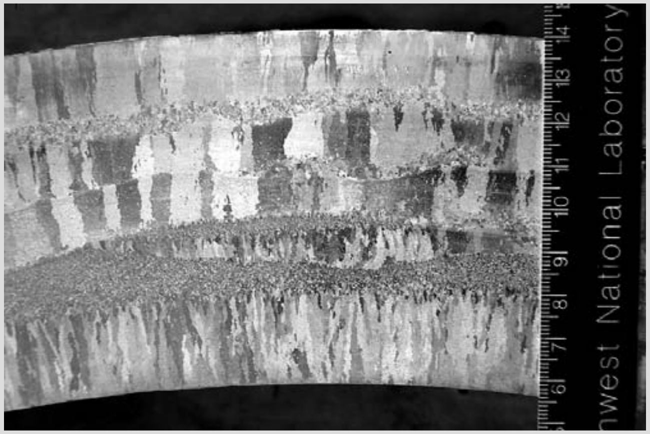
- Greg Selby at EPRI for use of Westinghouse Owners Group (WOG) “practice” and new vintage pipe specimens
- Michel DeLaide at AIB-Vincotte for use of 500 kHz prototype phased array
- Guy Maes at Zetec, Inc. for modifying Tomoscan III to enable operation at 500 kHz
- G. Lagleder at IHI Southwest, Inc. and D. Kurek at Westinghouse for vintage piping specimens
- Activities sponsored by: The U.S. NRC Office of Research, JCN-Y6604, Wallace Norris, Program Manager

Presentation Outline

- Inspection problems with cast materials
- Specimens
- Ultrasonic Phased Array Inspections
- Ultrasonic Conclusions
- Eddy Current Inspection
- Eddy Current Conclusions

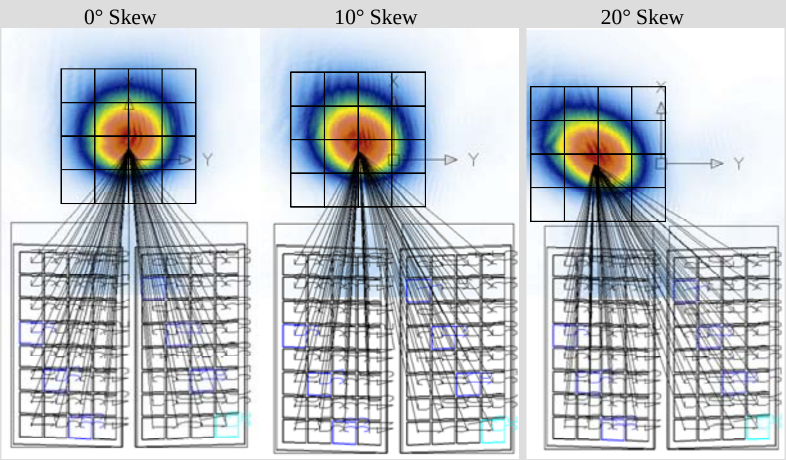
Coarse Grain Effects on UT

- FCC lattice structure in austenitic materials, coupled with large grains, cause very difficult inspection problems
- Refraction and reflection of ultrasound within these microstructures cause field skewing and partitioning, resulting in:
  - Decreased signal-to-noise ratio
  - Difficulty with signal interpretation
- Which can lead to:
  - Cracks not being detected
  - False reporting of defects
  - Incorrect reporting of defect locations
  - Specific volumes of material not being examined



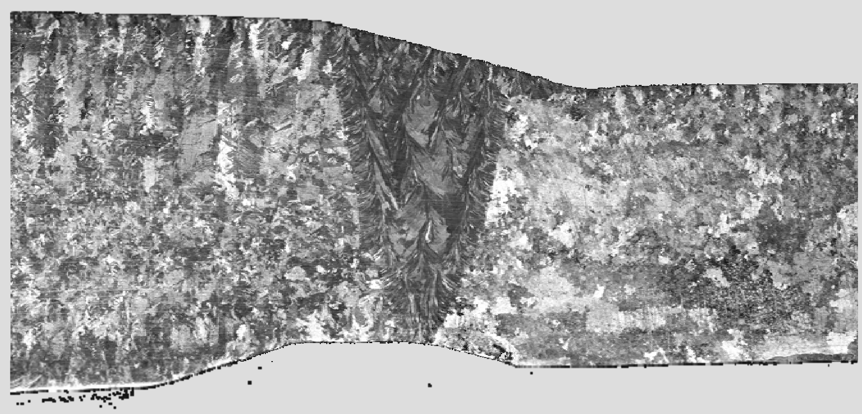
Ultrasonic Phased Array Inspection

- Phased Array:
  - Allows multiple, simultaneous angles with line scans for a decreased acquisition time
  - Inherent data fusion (multiple angles), so reduced analysis time;
  - Skewing



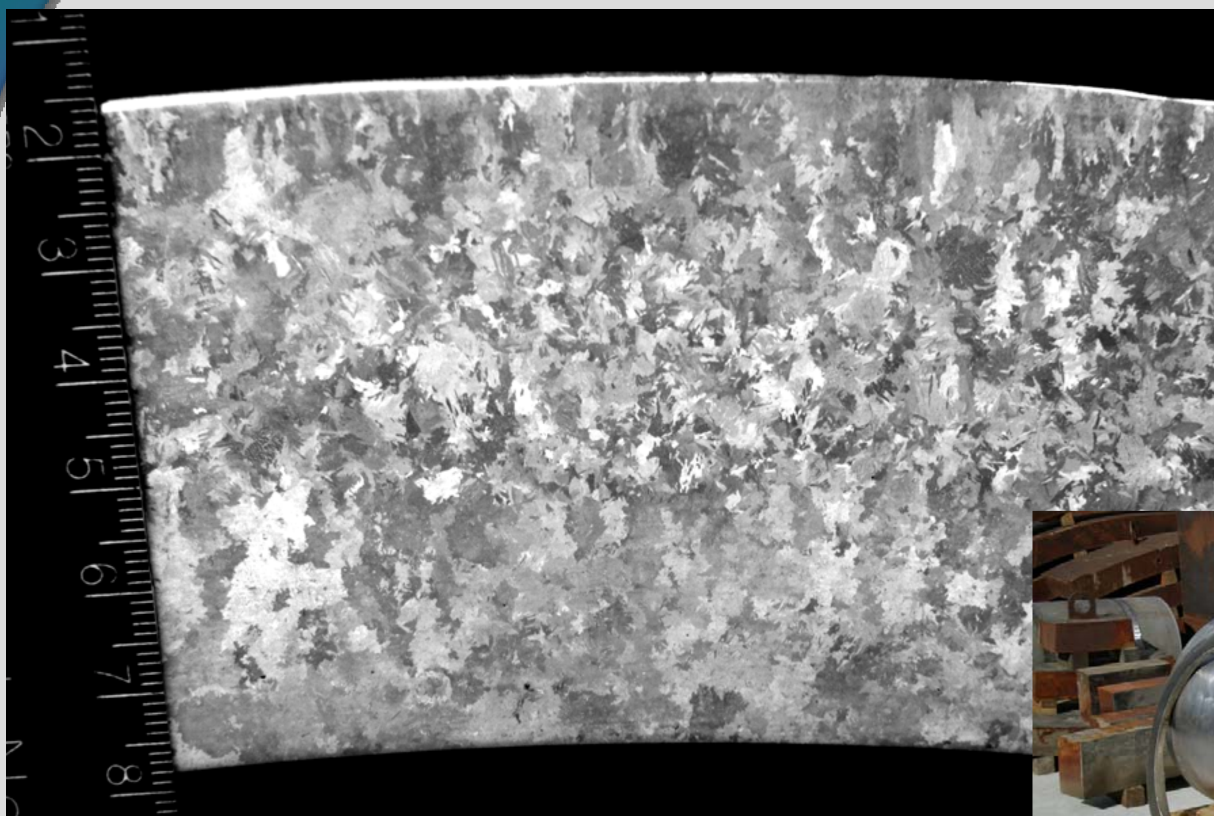
Westinghouse Owners Group Welded Specimens

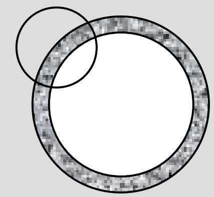
- Varied OD/ID geometries and weld configurations:
  - Elbow-to-safe end
    - (SCSS – FGSS)
  - Pipe-to-safe end
    - (CCSS – FGSS)
  - Nozzle-to-safe end-to -pipe
    - (CS – FGSS – CCSS)
  - Pipe-to-elbow
    - (CCSS – SCSS)
- Mixed/coarse grain structures in pipes and elbows
- Note OD/ID geometries
- Grain size 0.2 – 16.7 mm



Acronyms:
SCSS = statically cast stainless steel
FGSS = fine-grained stainless steel
CCSS = centrifugally cast stainless steel
CS = carbon steel

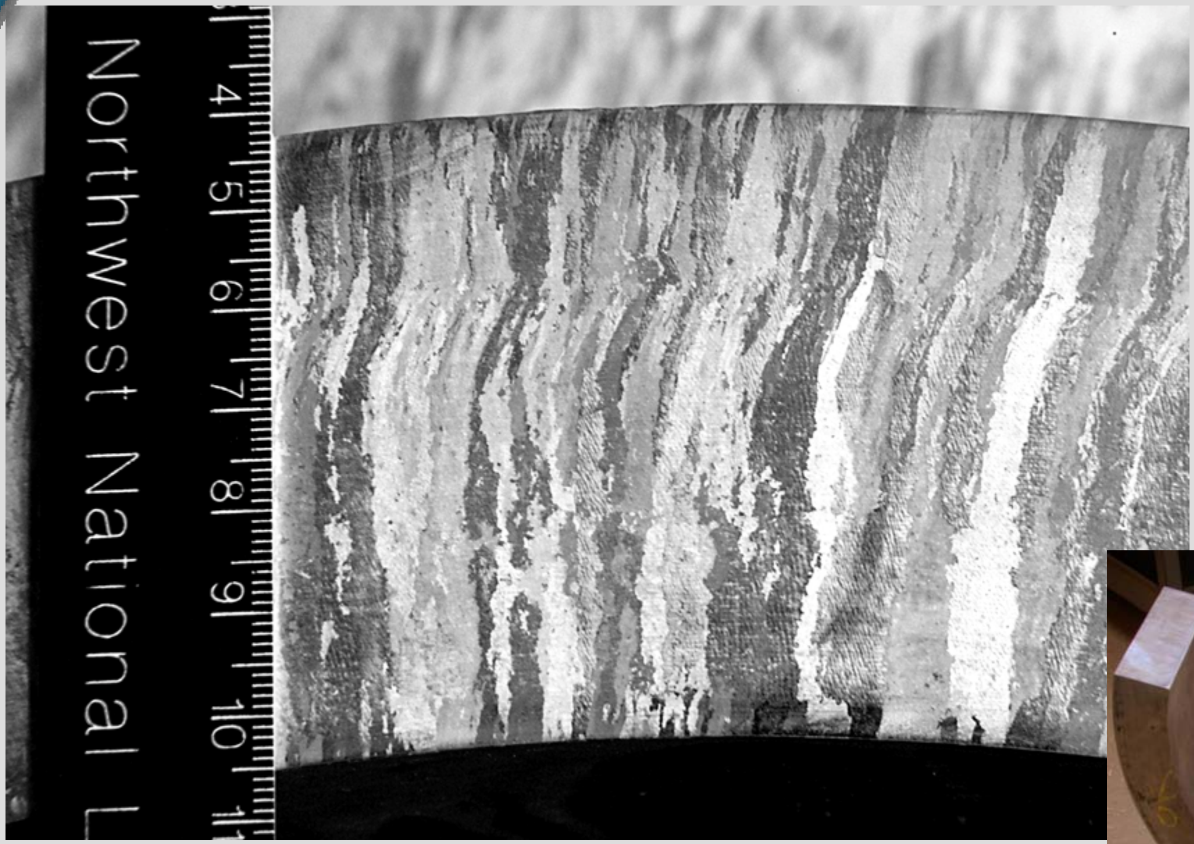
CSS Microstructure – EPRI Base Metal Specimen

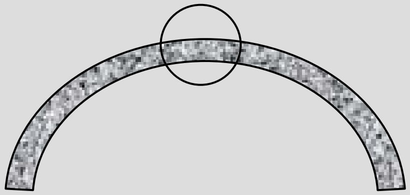




EPRI Pipe Sample @ 300° - shows mixed, but mostly equiaxed semi-coarse structure with 0.5 – 7.4 mm grain size

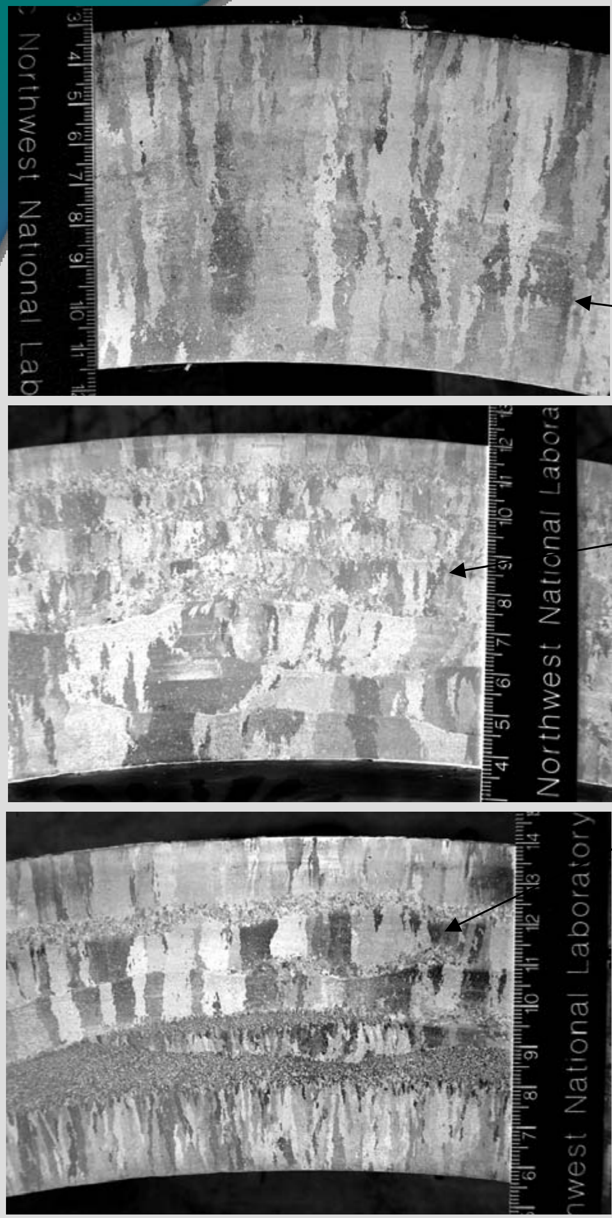
CSS Microstructure – Westinghouse Base Metal Specimen

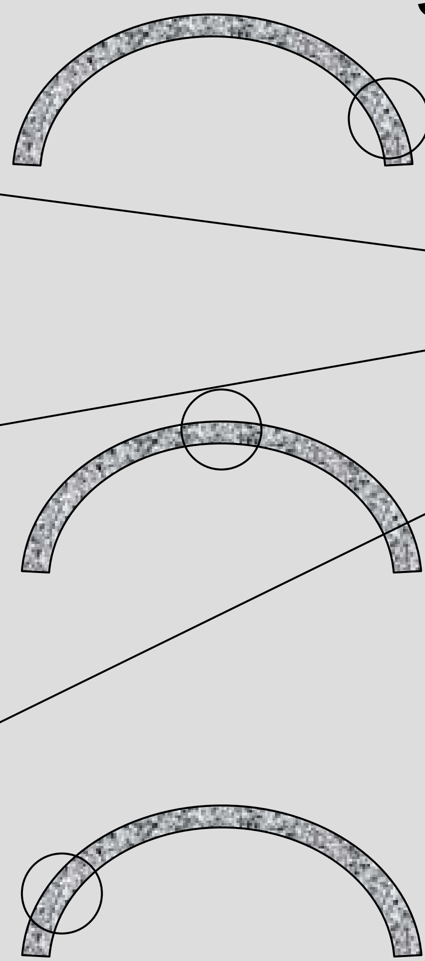




Westinghouse Sample in middle of arc; large dendritic grains from ID to OD, 0.6 – 16.3 mm grain size

CSS Microstructure – IHI Southwest Base Metal Specimen



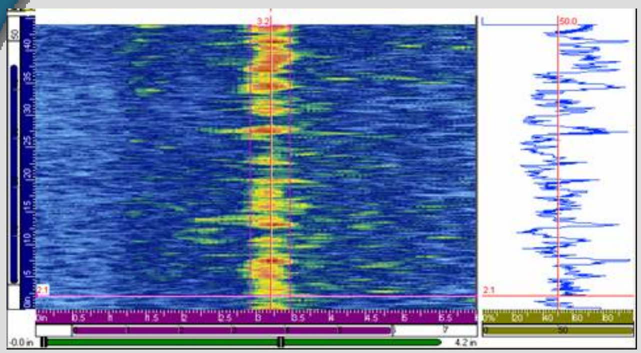


IHI Southwest specimen grain structure:

- Large dendritic
- Mixed large/smaller grains and layering
- Dendritic, large/small grains, many layers
- Grain size 0.2 – 25.0 mm

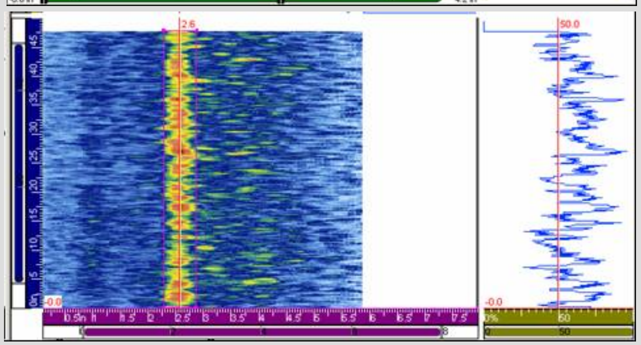
CSS Base Material Evaluation

Corner trap responses from end of blocks



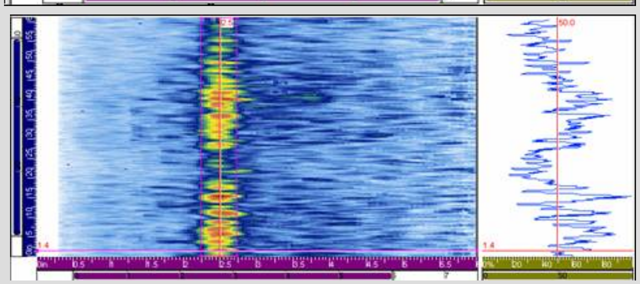
IHI Southwest

(49-inches)



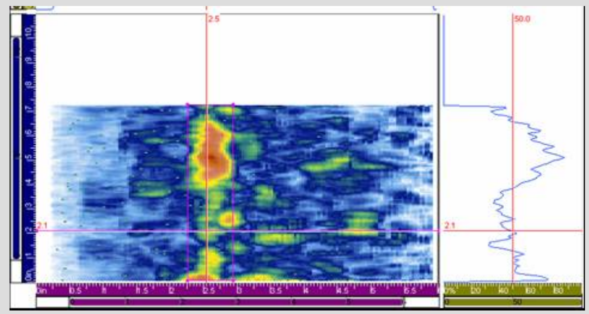
Westinghouse

(48 inches)



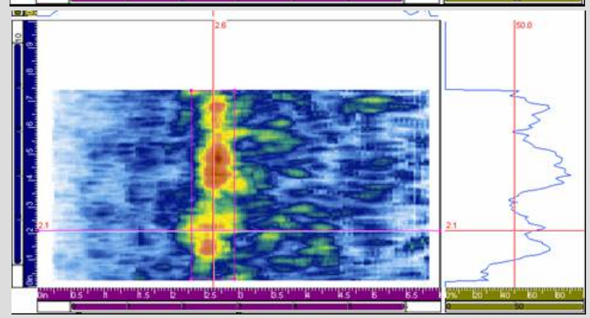
EPRI

(50 inches)



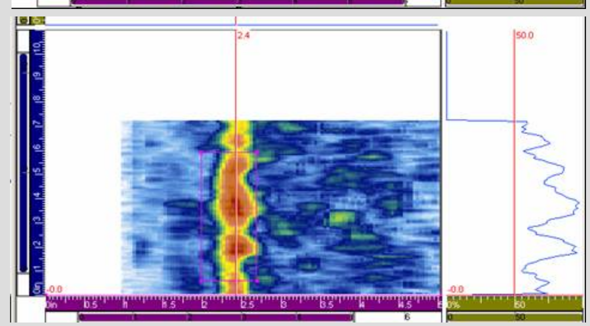
APE-1

(7 inches)



MPE-3

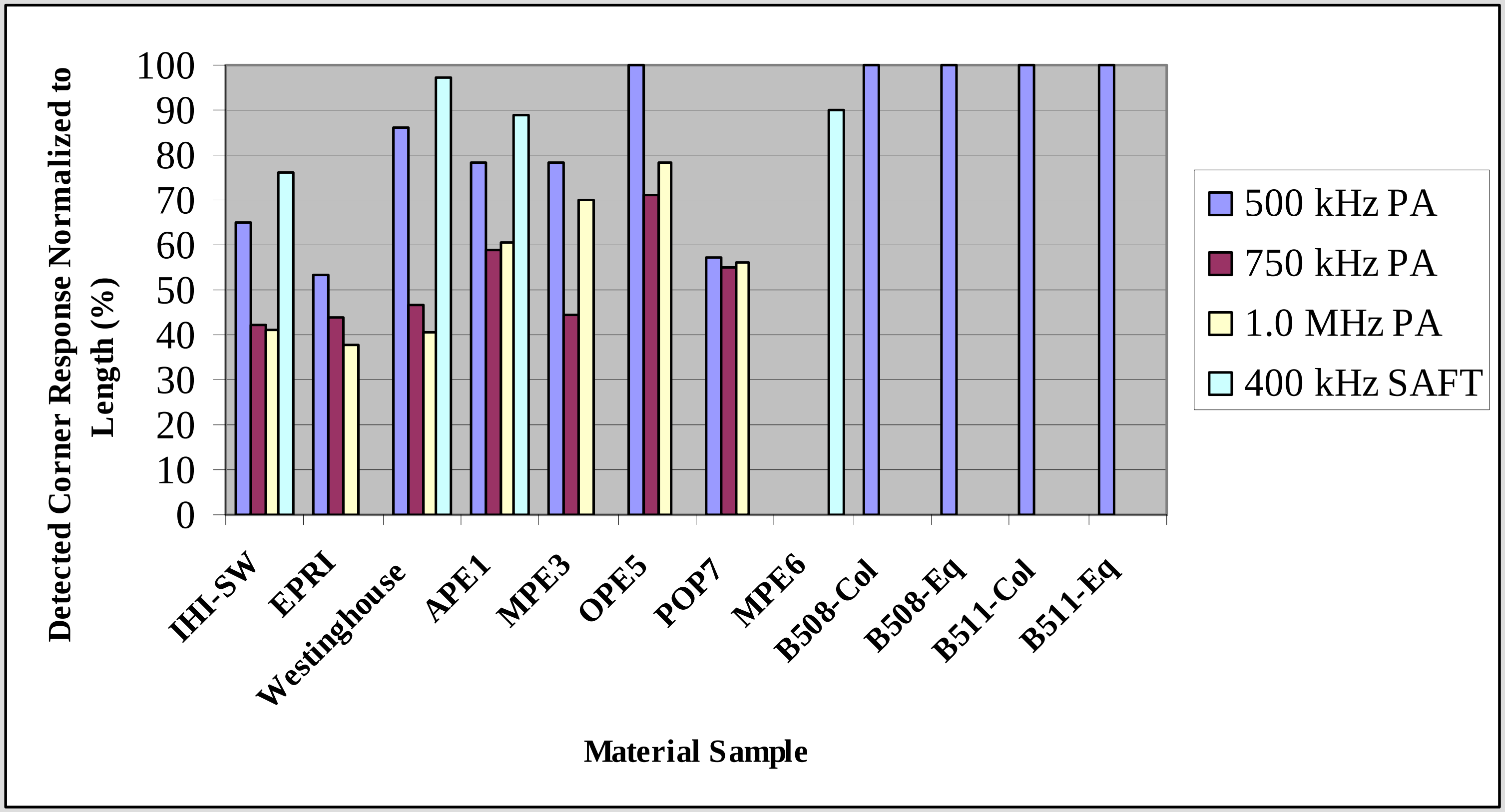
(7.5 inches)



OPE-5

(7 inches)

Detected Corner Response Values for Base Material As Determined from Inspecting the End of CCSS Specimens



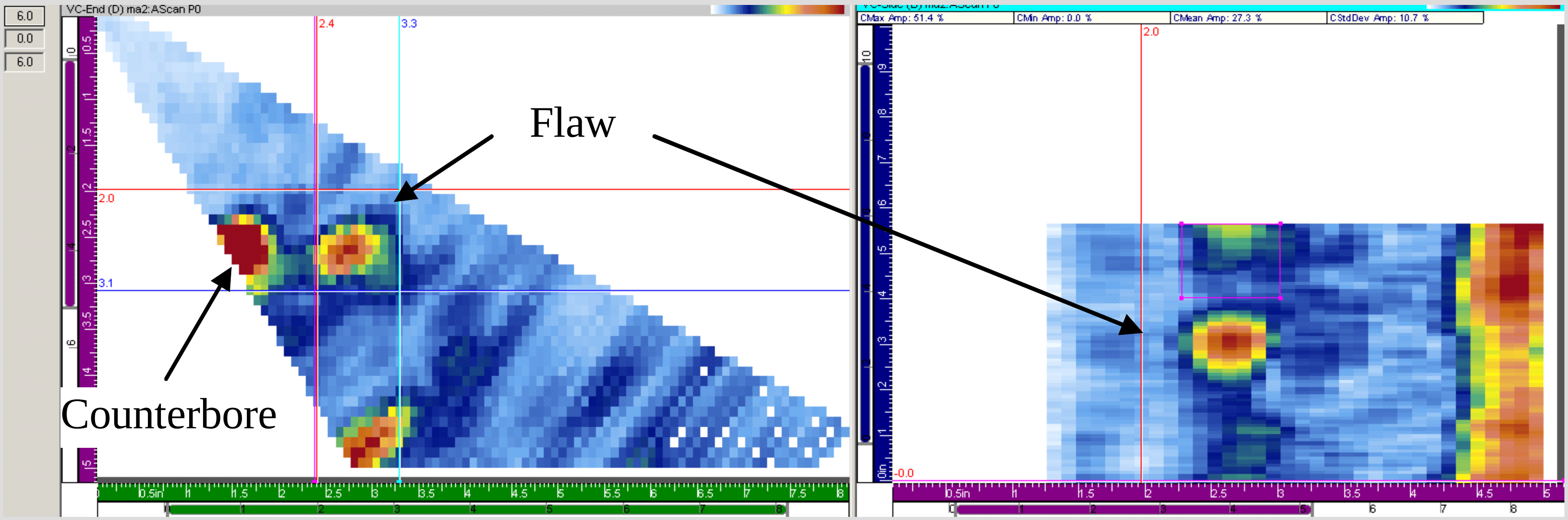
Regions of Diminished Signal Strength in Base Metal CCSS Specimens

Specimen	Number of Regions Observed	Measured Length of Diminished Signal Regions			
		Minimum	Maximum	Average	Median
EPRI	21	0.25 cm (0.10 in.)	11.43 cm (4.50 in.)	3.57 cm (1.41 in.)	2.29 cm (0.90 in.)
IHI-SW	27	0.25 cm (0.10 in.)	6.10 cm (2.40 in.)	1.55 cm (0.61 in.)	1.02 cm (0.40 in.)
Westinghouse	26	0.25 cm (0.10 in.)	3.05 cm (1.20 in.)	0.75 cm (0.30 in.)	0.51 cm (0.20 in.)
APE-1	4	1.02 cm (0.40 in.)	3.05 cm (1.20 in.)	1.78 cm (0.70 in.)	1.52 cm (0.60 in.)
MPE-3	5	0.25 cm (0.10 in.)	2.54 cm (1.0 in.)	0.91 cm (0.36 in.)	0.51 cm (0.20 in.)
OPE-5	0	0	0	0	0
POP-7	4	0.25 cm (0.10 in.)	4.32 cm (1.70 in.)	1.97 cm (0.78 in.)	1.65 cm (0.65 in.)

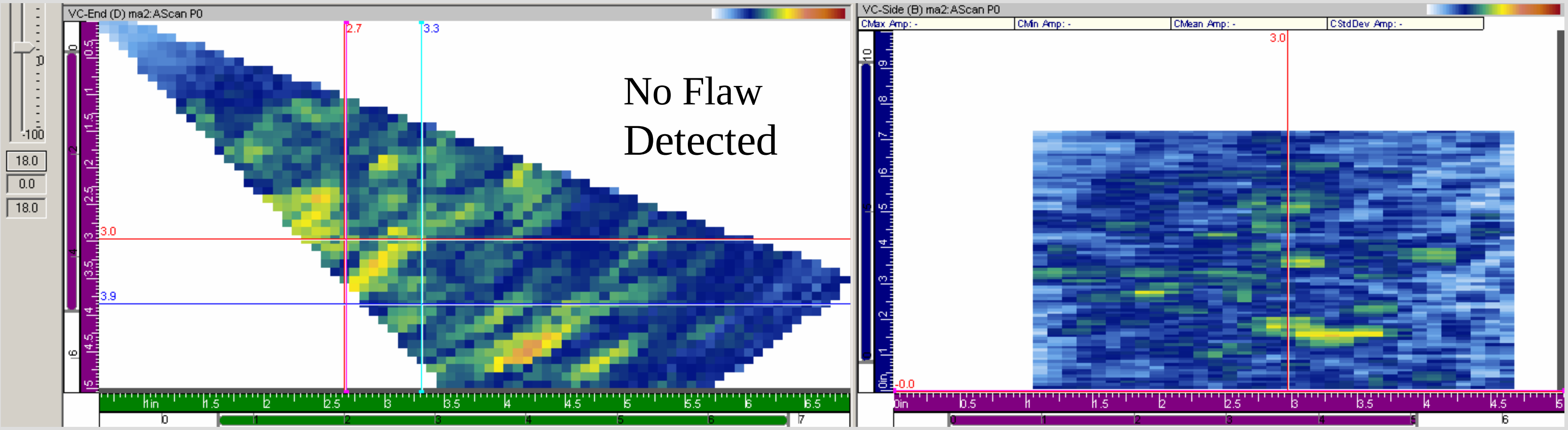
Largest area = 4.5 inches; median = 0.9 inches

No random noise to cause false calls

Detected Flaw: Mechanical Fatigue Crack in Specimen MPE-3 as Viewed From the SCSS Side at 500 kHz



Undetected Flaw: Mechanical Fatigue Crack in Specimen MPE-3 As Viewed from CCSS Side at 1.0 MHz



Crack Detection in WOG Specimens

500 kHz Phased Array

Crack Detections

Mechanical fatigue = 93%

Thermal fatigue = 57%

Combined = 75%

WOG Specimen	Mock-Up Configuration	Crack Type	Crack Through-Wall (%)	Crack Location (Side of Weld)
APE-1	CCSS pipe-to-SCSS elbow	MF	13	SCSS
APE-4	CCSS pipe-to-SCSS elbow	MF	14	SCSS
INE-A-1	SCSS elbow-to-WSS safe end	MF	42	SCSS
INE-A-4	SCSS elbow-to-WSS safe end	TF	29	SCSS
INE-A-5	SCSS elbow-to-WSS safe end	MF	34	WSS
MPE-3	CCSS pipe-to-SCSS elbow	MF	30	SCSS
MPE-6	CCSS pipe-to-SCSS elbow	TF	18	SCSS
ONP-D-2	CCSS pipe-to-WSS safe end	TF	28	CCSS
ONP-D-5	CCSS pipe-to-WSS safe end	MF	18	CCSS
ONP-3-5	CCSS pipe-to-WSS safe end	TF	28	WSS
ONP-3-8	CCSS pipe-to-WSS safe end	MF	28	WSS
OPE-2	CCSS pipe-to-SCSS elbow	MF	18	SCSS
OPE-5	CCSS pipe-to-SCSS elbow	TF	23	SCSS
POP-7	CCSS pipe-to-SCSS pump nozzle	MF	31	SCSS
POP-8	CCSS pipe-to-SCSS pump nozzle	TF	18	CCSS

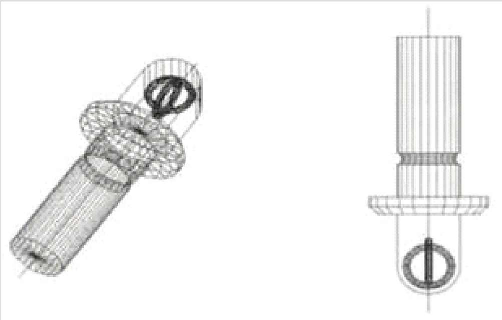
Phased Array Length Sizing Results

Frequency	Flaw Length-Sizing Error (RMSE)		
	CCSS	SCSS	Combined
500 kHz	2.54 cm (1.0 in)	2.22 cm (0.87 in)	2.37 cm (0.93 in)
750 kHz	3.81 cm (1.5 in)	2.37 cm (0.93 in)	3.00 cm (1.18 in)
1.0 MHz	2.07 cm (0.81 in)	1.93 cm (0.76 in)	1.98 cm (0.78 in)

Phased Array Ultrasonic Conclusions

- Use of lower frequency phased array can improve the effectiveness of UT for inspection of CSS from the OD surface of piping
- 500 kHz phased array – detected cracks greater than approximately 30% through wall
- Phased array line scans are fast and currently field deployable
- No tip signals detected for depth sizing – new methods being reviewed to address this issue.
- Length sizing RMSE is greater than currently allowed by ASME Code

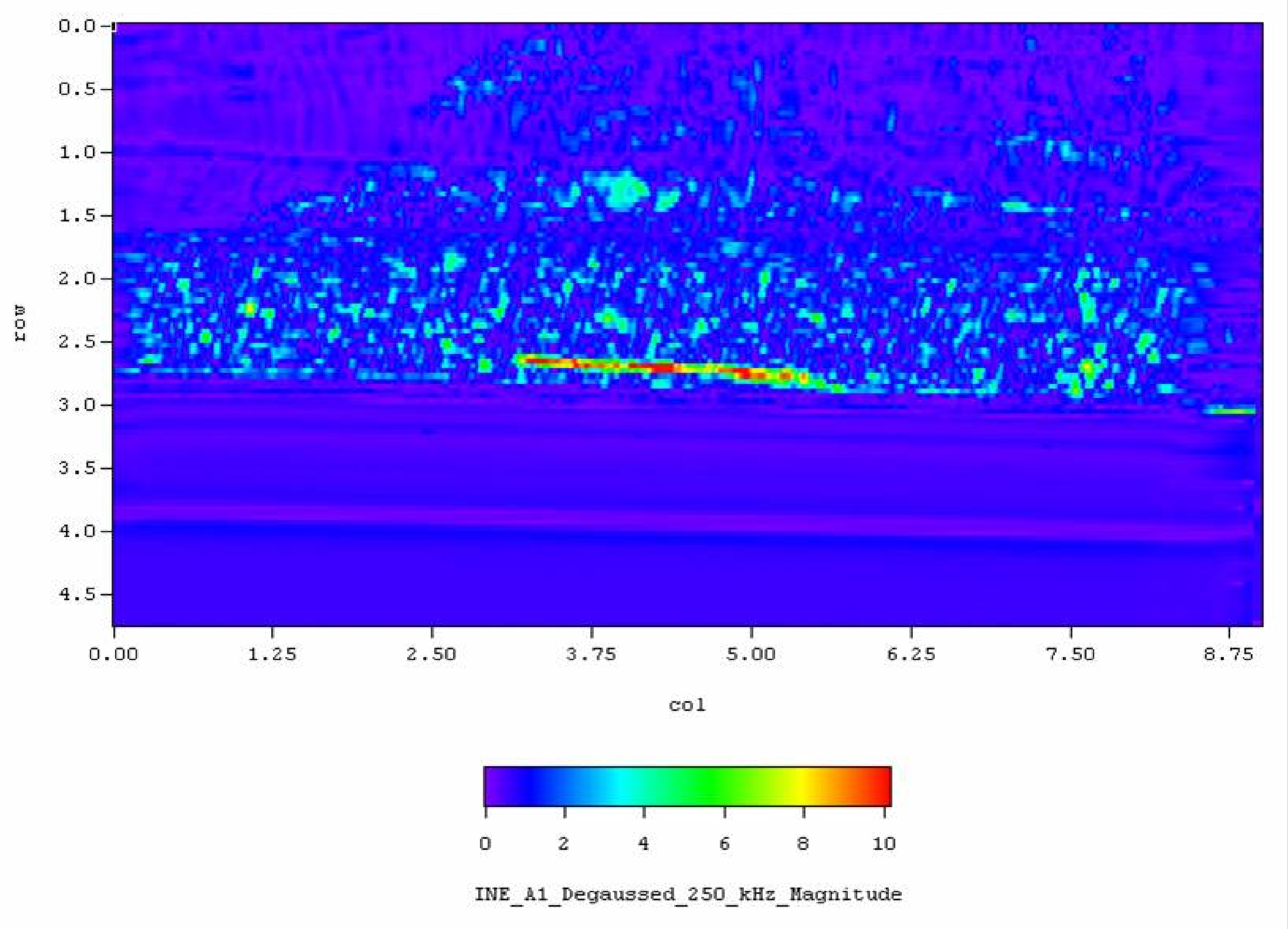
Eddy Current Inspection on the ID Using Plus-Point Probe



Eddy current testing (ET) from the inside surface of CSS pipe weld using a ZETEC MIZ-27SI instrument and a ZETEC Plus-point™ probe operating at 250 kHz; examined all WOG and selected PNNL specimens having MF and TF cracks

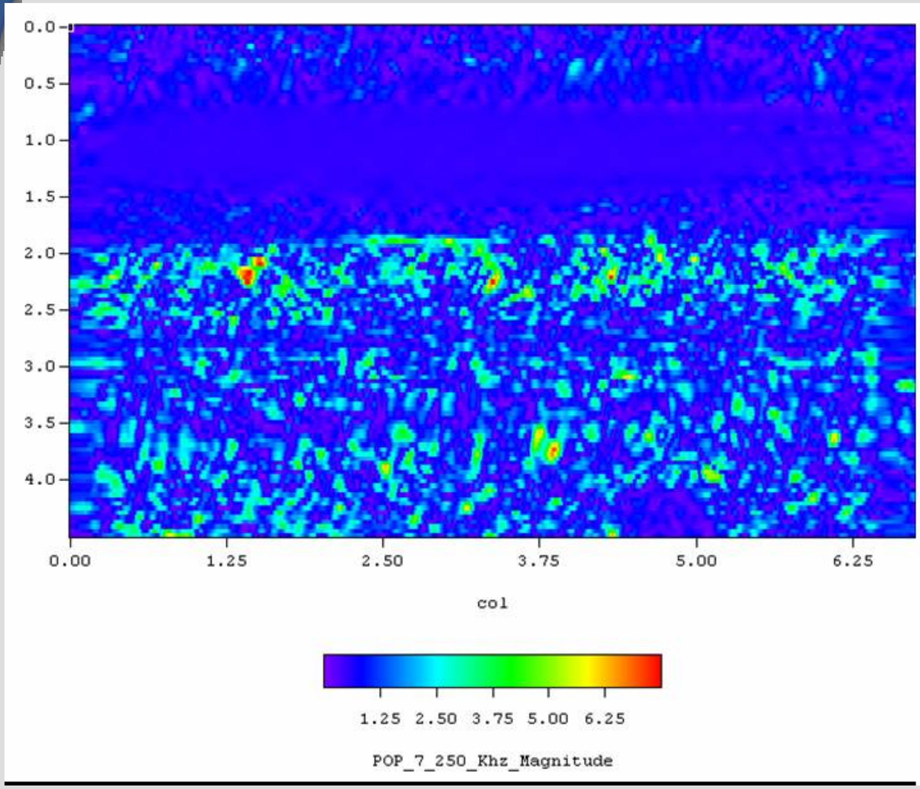
Examples of ET Data
(Scale on plot in inches)

WOG Specimen with MFC on Elbow Side of Weld

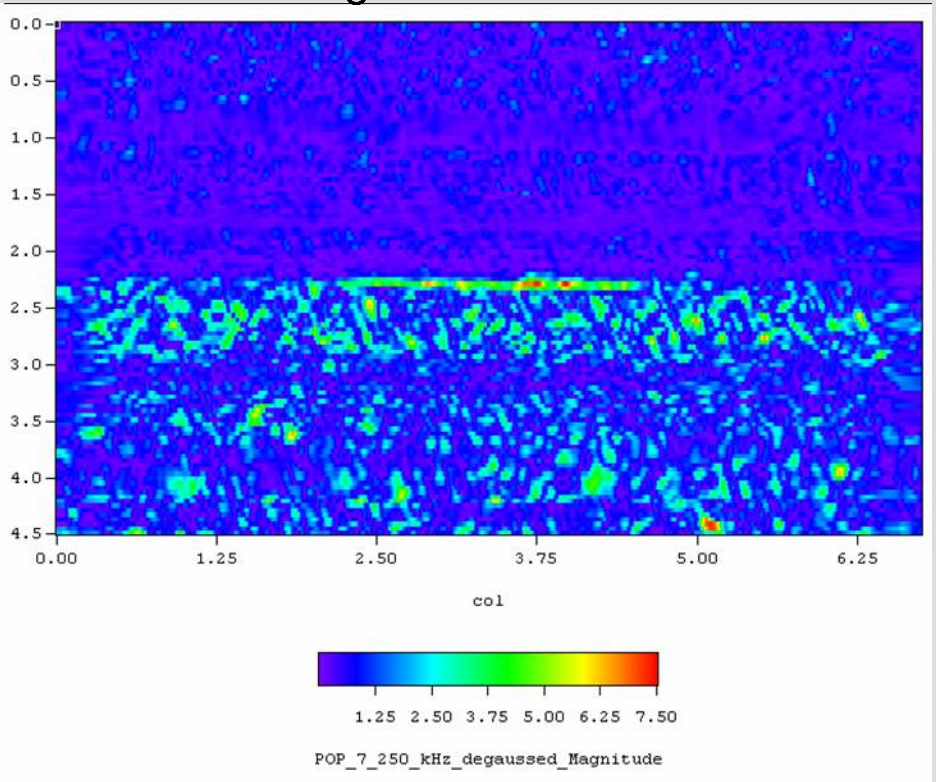


Examples of ET Data with Demagnetization

Normal Scan



Demagnetized Scan



ET Results from ID Studies

Specimen ID Descriptor	Was Flaw Detected?/ Did Degaussing Improve SNR?	Peak Mag. from Flaw (Volts) and SNR (dB)		Range of Phase Response from Flaw (deg.)	Measured Flaw Length (cm)	True State Flaw Length (cm)	True State Flaw Depth (cm)
		V	dB				
APE-1	Yes/No	9.77	11.8	92º - 97º	3.82 cm	3.94 cm	1.1 cm
APE-4	Yes/No	8.00	16.1	50º - 115º	4.11 cm	4.19 cm	1.27 cm
INE-A-1	Yes/Yes	10.12	10.6	275º- 292º	6.60 cm	6.99 cm	2.64 cm
INE-A-4	Yes/No	10.20	11.4	270º- 282º	5.90 cm	6.86 cm	1.85 cm
INE-A-5	Yes/Yes	10.0	15.1	200º- 290º	6.35 cm	6.73 cm	2.54 cm
MPE-3	Yes/No	10.11	14.1	270º- 285º	6.12 cm	6.73 cm	2.54 cm
MPE-6	Yes/No	8.42	10.5	270º- 285º	3.80 cm	5.92 cm	1.5 cm
ONP-3-5	Yes/No	5.75	21.2	70º- 110º	6.40 cm	6.60 cm	1.78 cm
ONP-3-8	Yes/Yes	1.20	10.7	50º- 120º	4.21 cm	5.13 cm	1.78 cm
ONP-D-2	Yes/Yes	9.18	13.9	250º- 285º	5.49 cm	6.60 cm	1.78 cm
ONP-D-5	Yes/No	6.58	16.4	260º- 275º	3.73 cm	4.06 cm	1.19 cm
OPE-2	Yes/Yes	6.25	8.0	105º- 130º 7º - 38º	4.37 cm	4.19 cm	1.27 cm
OPE-5	Yes/Yes	8.06	11.1	70º- 105º	5.58 cm	6.15 cm	1.63 cm
POP-7	Yes/Yes	7.52	11.5	273º- 280º	6.72 cm	6.78 cm	2.55 cm
POP-8	Yes/No	9.25	15.8	230º- 258º 80º- 150º	6.02 cm	5.72 cm	1.5 cm
B-501	Yes/No	8.42	12.5	45º - 130º	2.84 cm	2.92 cm	2.0 cm
B-504	Yes/No	6.47	14.3	260º- 285º	6.19 cm	6.15 cm	2.79 cm
B-515	Yes/Yes	5.86	13.4	85º - 105º	2.87 cm	2.92 cm	1.52 cm
B-519	Yes/No	4.90	16.3	260º- 285º	4.18 cm	5.72 cm	2.79 cm
RMSE					**0.77 cm**		

ET Conclusions from ID Studies

- All cracks were detected
- If calling nothing less than 12.5 mm then no false calls
- Demagnetizing the inspection zones was useful 42% of the time (improved SNR in 8 out of 19 specimens)
- For cast specimens, no correlation was found between background noise or clutter (magnitude or phase) and variables such as microstructural classification, grain size, orientation, etc.
- Loss of Signal was used for length sizing
  - 16 of 19 flawed specimens were undersized
  - Largest length difference (from undersizing) was 21.2 mm (0.83 in.)
  - 3 of 19 flawed specimens were oversized
  - Largest length difference (from oversizing) was 3 mm (0.12 in.)
  - Study yielded a length RMSE of 7.7 mm (0.30 in.), ASME Code acceptable