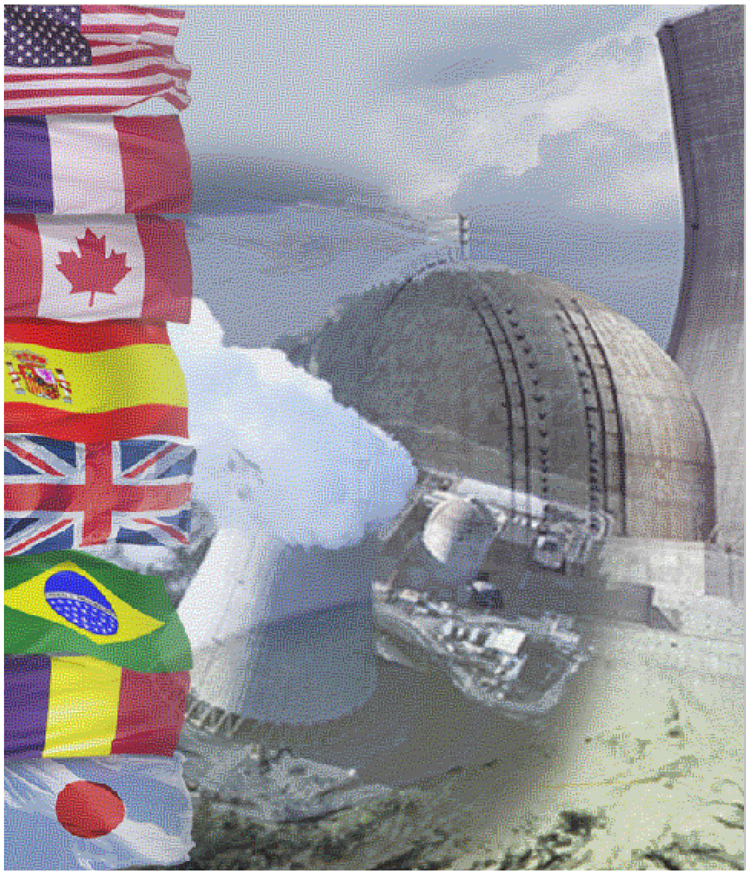
Section 2:
Session 1: Inspection Techniques, Results, and Future Developments



NDE of Austenitic Materials A Review of Progress and Challenges

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Conference on Vessel Head Penetration Inspection, Cracking, and Repairs

September 29-October 1, 2003

Gaithersburg, MD

Outline

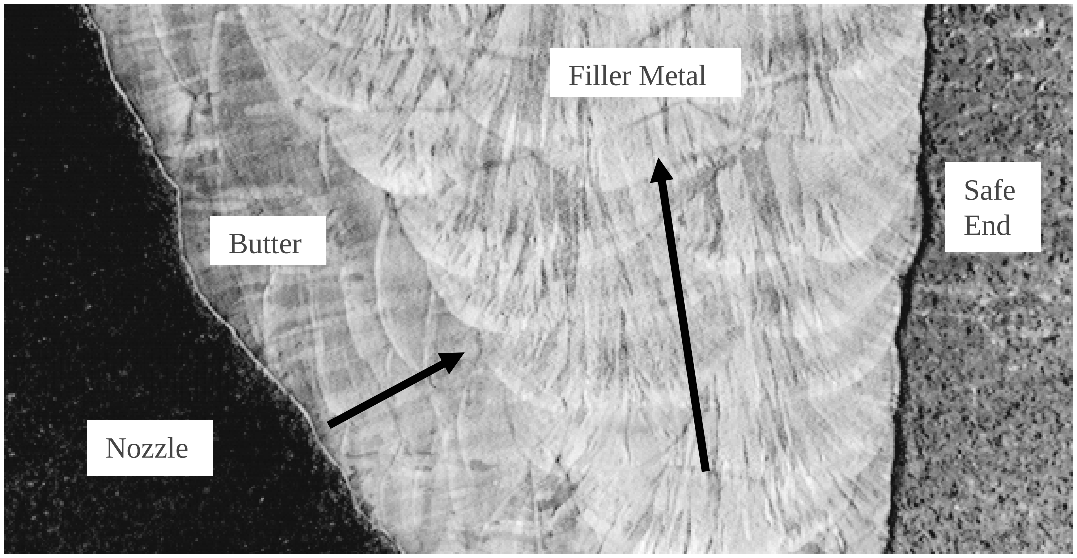
- NDE issues associated with austenitic materials
  - Piping Butt welds
  - Vessel head penetrations
- Activities in progress to address the issues
  - Technology development
  - Mockup considerations
  - Demonstration/Qualification

NDE Issues Associated with Austenitic Materials

- Ultrasonic techniques (UT) are used extensively for volumetric examination
- Austenitic weldments have particular characteristics that challenge UT
  - Coarse dendritic grain (scattering/attenuation/noise/beam steering)
  - Configuration (accessibility/interfering geometric features)
- Other NDE issues
  - Cost & availability of inspection resources
  - Qualification of procedures & personnel
  - Dose

Typical Austenitic Weld Structure-Nozzle-to-Safe End

- Interpretation
- Probe Contact
- Attenuation
- Scattering
- False calls



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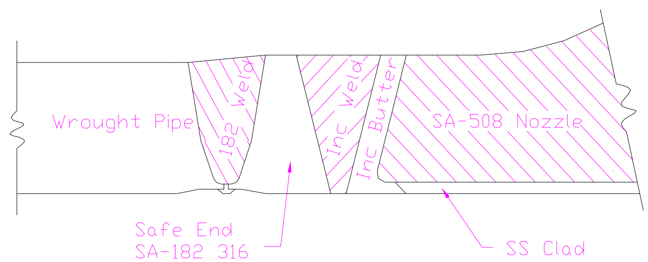
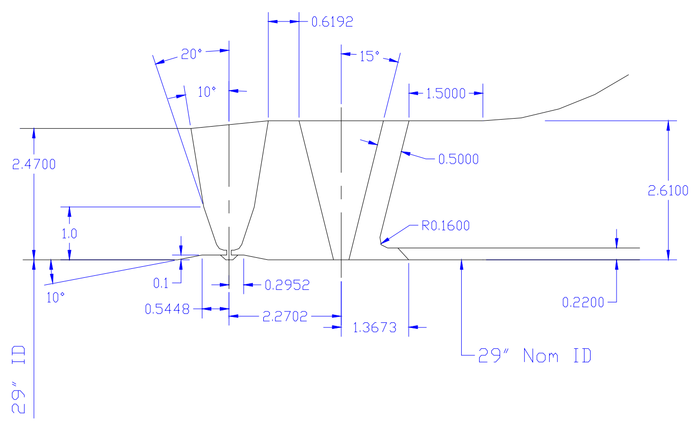
Dissimilar Metal Butt Weld Configurations



Some UT examinations are performed from Inside surface



Inside Surface Effects

•Detection of short axial cracks limited due to poor UT probe contact on inside surface

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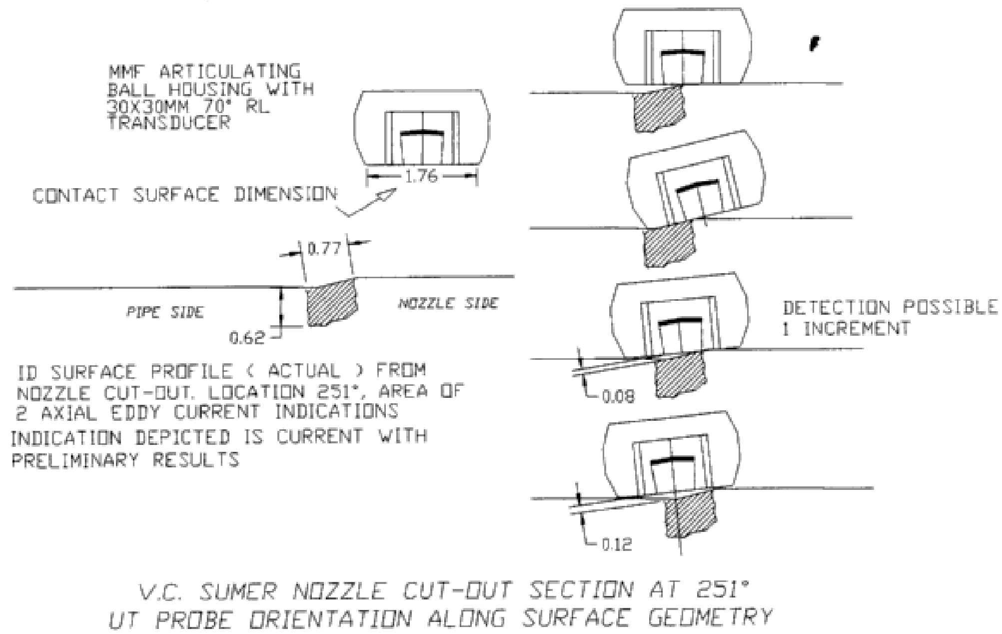


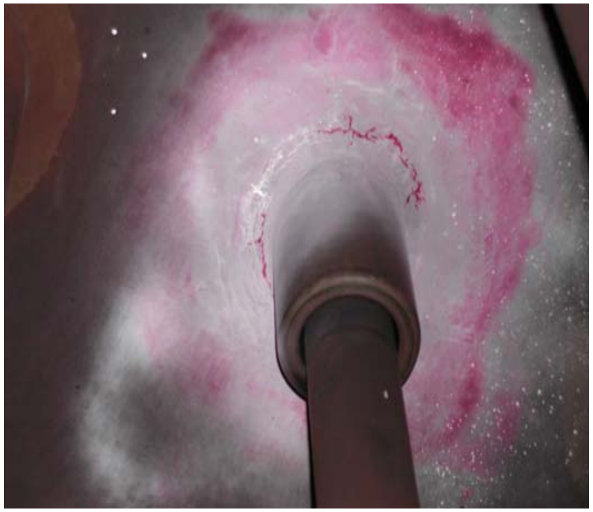
Source; Wesdyne presentation at VC Summer Public Meeting 12/6/2000

IGSCC Examination Approach

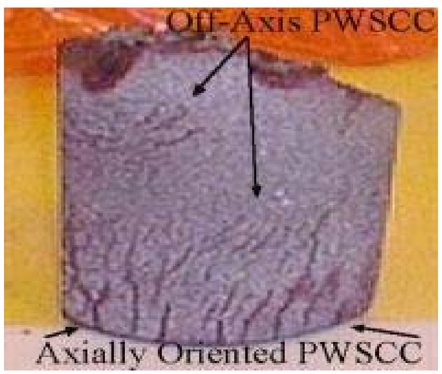
Extensive BWR NDE experience is helpful for PWR application, but not entirely transferable

	IGSCC	Dissimilar Metal Welds
Flaw Location	Heat affected zone	Weld metal (typical)
Detection Method	Shear waves	RL waves
Ultrasonic Responses	Root (typical)	ID surface contour
	Austenitic weld metal	Numerous metallurgical interface(s)
		Complex configurations
Flaw Sizing	Flaws located in base metal	Flaws located in weld metal

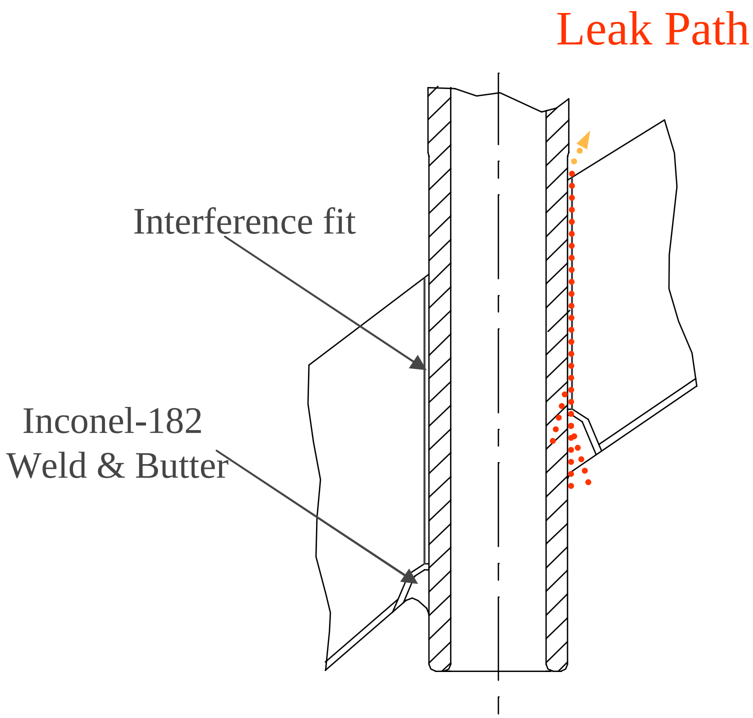
VHP Penetration, J-Groove Weld Cracking, & BMI Leak



Cracking in CRDM Penetrations

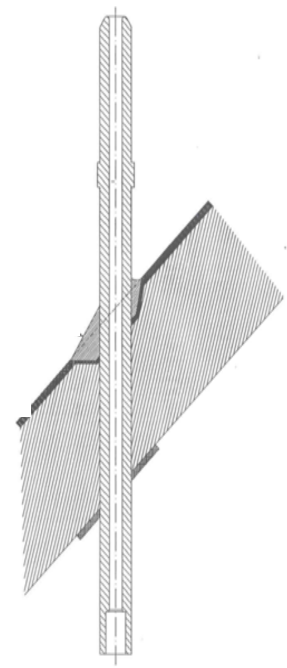


Leak Paths



Top Head

Consider leak path through base metal or through weld



Bottom Head

NDE Effectiveness & Productivity Improvement

- Modify butt weld ID transducer sled for more flexibility
  - Smaller probes for better contact on inside surface
- ID Profiling to improve sizing accuracy for butt welds
- Evaluate productivity improvements
  - Eddy Current array probes
  - Phased array UT
- Qualify procedures & personnel
  - Realistic Mockups
  - Realistic flaws
  - ASME Appendix VIII for butt welds , including dissimilar metals
  - MRP Program for VHPs

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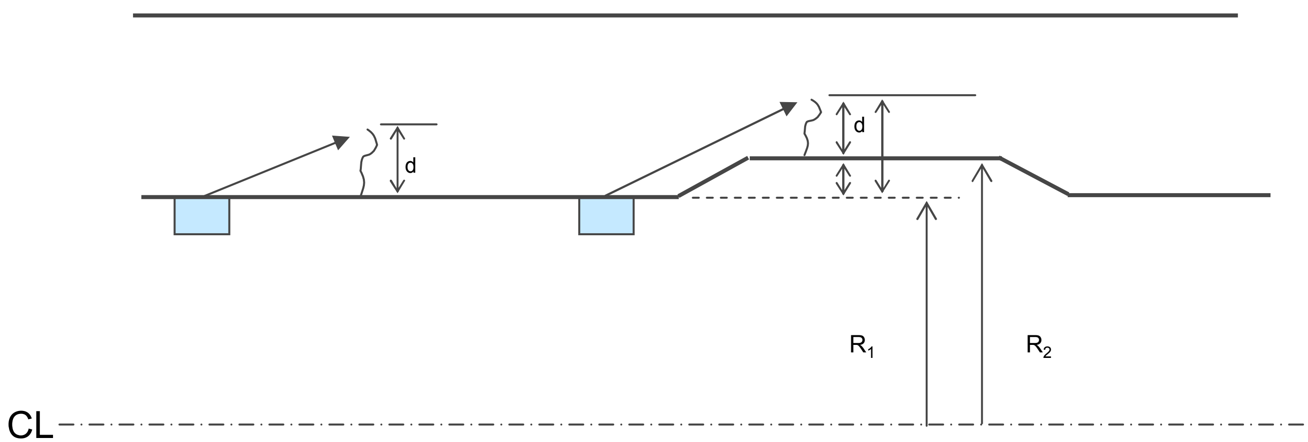
Flaw Depth Sizing-Compensation for Butt Weld Contours



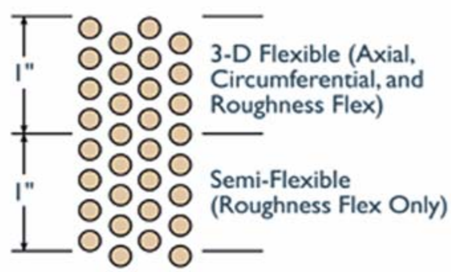
Profiling techniques can improve accuracy of depth sizing when the probe is not on the same surface as the crack

Eddy Current Array Probe for VHP J-Groove Welds

Advantages

- •Speed
- •Flexible membrane to accommodate contours
- •Multi-directional sensitivity

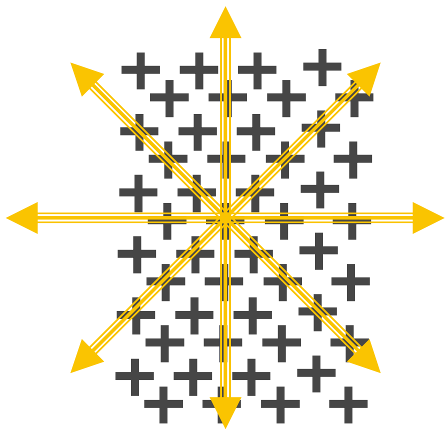
Comprehensive Configuration



Coil Type: Cross-Wound

 N

Eddy Current Array Probe Configuration



Array configuration allows switching between modes for multi-directional coverage at high speed

•Cross wound impedance mode for 0º, 90º directions

•Driver-pickup mode for ± 45º directions

NDE Mockup Considerations

- Mockups are used extensively
  - Technique development & demonstration
  - Training of personnel
  - Qualification of capability
- Mockup criteria
  - Realistic configuration
  - Sufficient number of intentional flaws with controlled & well known features
    - Size
    - Location
    - Shapes
  - Realistic flaw responses
    - Consistent with NDE techniques being used (UT techniques, ET, combination)
  - No "signposts"

NDE Mockup Considerations

Intentional flaws in mockups must have realistic NDE responses that reflect & challenge the techniques being applied

- Tip response
- Corner response
- Face response
- Examination surface

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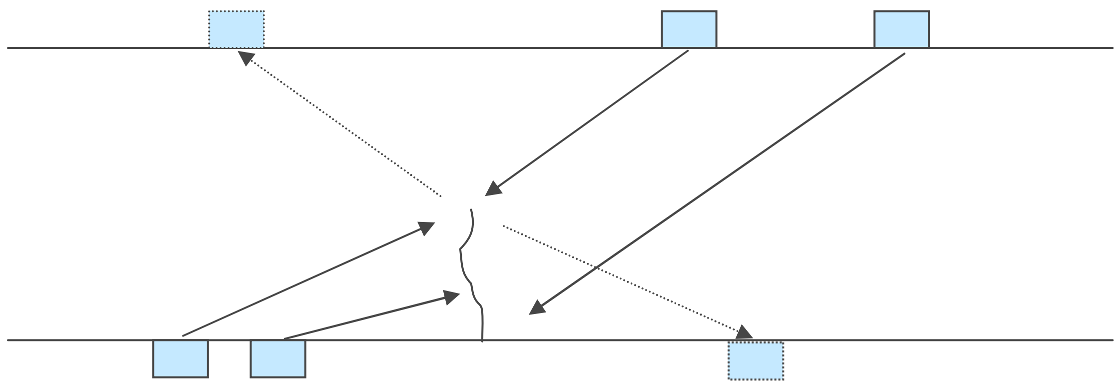

Mockup/Flaw Making

- Several methods can be used to produce flaws in mockups, e.g.:
  - Fatigue (mechanical & thermal)
  - Implantation
  - Weld contamination
  - Machining
  - Isostatic processing (HIP or CIP)
  - Combinations
- No one particular method addresses all the criteria
- Qualification of Mockups & flaws
  - Manufacturing surveillance
  - Comparison of responses with field removed samples
  - ISI experience

Qualification of Inspection

- Dissimilar metal butt welds
  - New requirement took effect November 22, 2002 for qualification of DM weld procedures/personnel
  - Applicable to all units-PWR and BWR
  - Applies to UT performed from inside or outside surface
  - Procedures & personnel being qualified through PDI program
- Vessel head penetrations (top head and BMI)
  - MRP inspection demonstration program
    - Volumetric Examination of base material
    - Examination of wetted surfaces
  - Demonstrations continuing
  - Tracking field results

Qualification of Inspection-DM Butt Welds

- Demonstration of Performance according to Supplement 10 of ASME SXI Appendix VIII
- Industry experience has indicated a need for improving inspection methods for dissimilar metal butt welds
  – Missed detections at VC Summer & Hope Creek
  – Appendix VIII qualification experience (supplement 10)
- VC Summer experience showed influence of ID contour on UT conducted from the inside surface
  – ID contour caused intermittent contact of the UT probe
- First attempts at qualification to Appendix VIII Supplement 10 identified some limitations for:
  – Detection of axial defects from ID
  – Depth sizing
  – Manual examination

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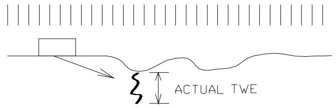
Status of Qualifications for DM Butt Welds

- Large effort by vendors and EPRI to improve capability
  - Closure weld (field weld) ID configurations added to qualification program to address ID contour problem identified at VC Summer
  - Vendors have made improvements such as more flexible ID transducer sleds, used smaller footprint probes, developed ID profiling
  - EPRI NDE Center evaluated essential joint parameters to design comprehensive mockup sets
  - Practice program initiated through PDI at the NDE Center to refine procedures and prepare personnel for qualification
  - Intense effort to qualify



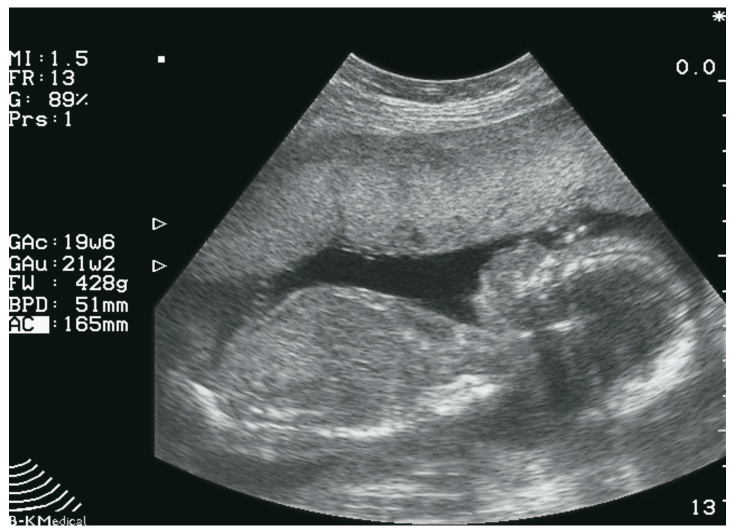
Status of Qualifications for DM Butt Welds

- Considerable progress has been made, although some limitations still remain
- Qualifications to Supplement 10 have been achieved for some conditions:
  - Detection & length sizing of circ & axial defects from OD in range of wall thickness up to ~5”
  - Detection & length sizing of circ & axial defects from ID in configurations typical of shop welds, that is, no ID geometry
  - Detection & length sizing of circ defects from ID in configurations typical of closure welds with ID geometry
  - Depth sizing from OD in thicknesses up to ~2”

Status of Qualifications for DM Butt Welds

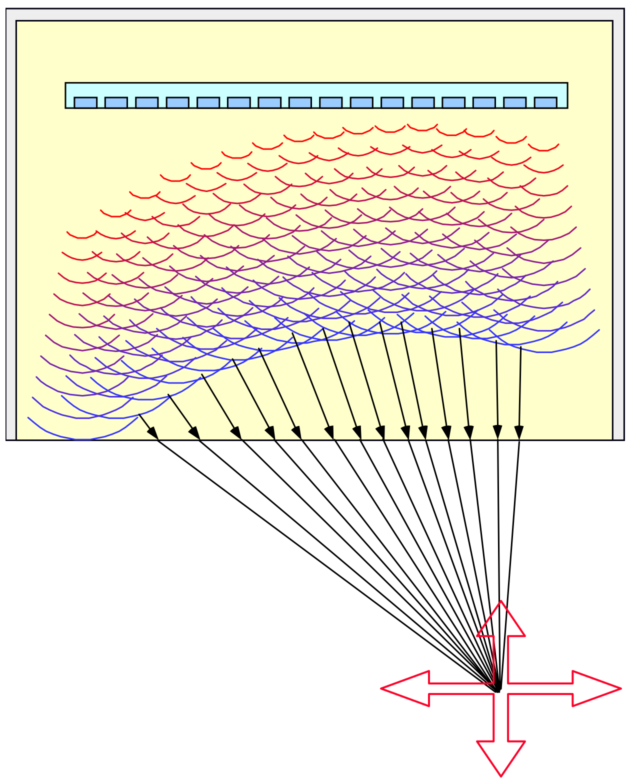
- Remaining limitations
  - Manual depth sizing
  - Detection of axial defects from ID in configurations with ID geometry (root, counterbore, etc)
  - Detection of defects from OD in configurations with OD tapers or limited scan surfaces
  - Depth sizing from ID surface (thick nozzle-safe end welds)
    - Sizing error is measurable, but exceeds code criterion
      - Some vendors have achieved errors ~ 8 -10% of wall thickness, but exceeding 0.125” (0.125” is ~ 2-5% of wall thickness)
- Efforts are continuing to eliminate or minimize limitations

Phased Array UT Technologies for Nuclear Pipe Inspection Productivity and Reliability



Phased arrays - Principles

Focused Angle Beam Mode



- Can focus & sweep the beam

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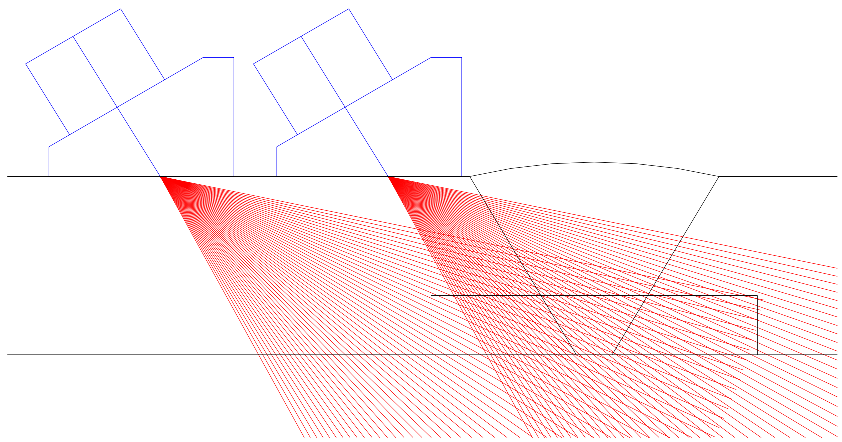
Phased arrays - principles

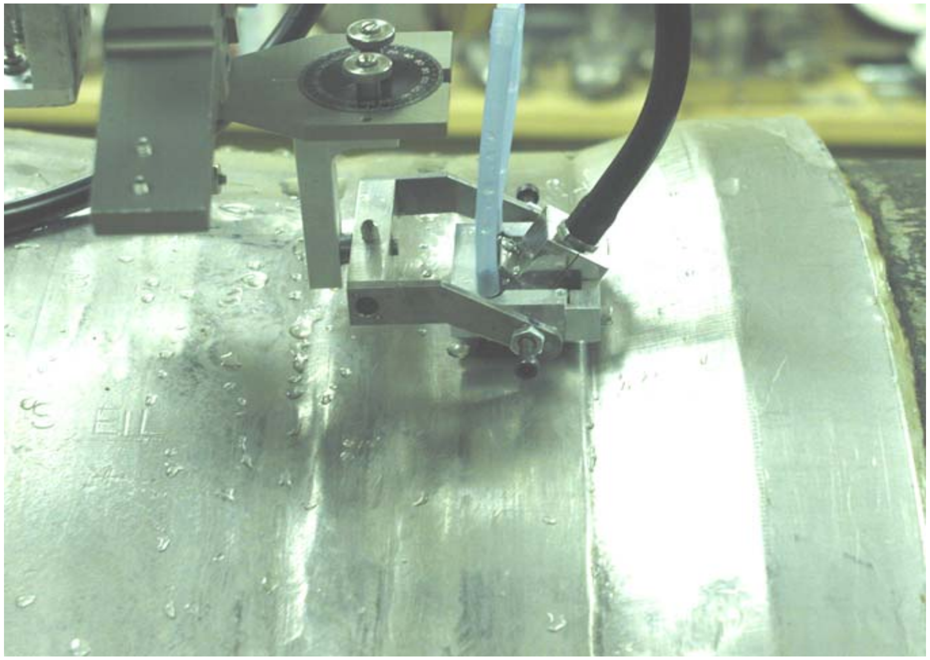
- Many angles produce a “sector scan” in milliseconds
- Provides good coverage from just one or two probe positions



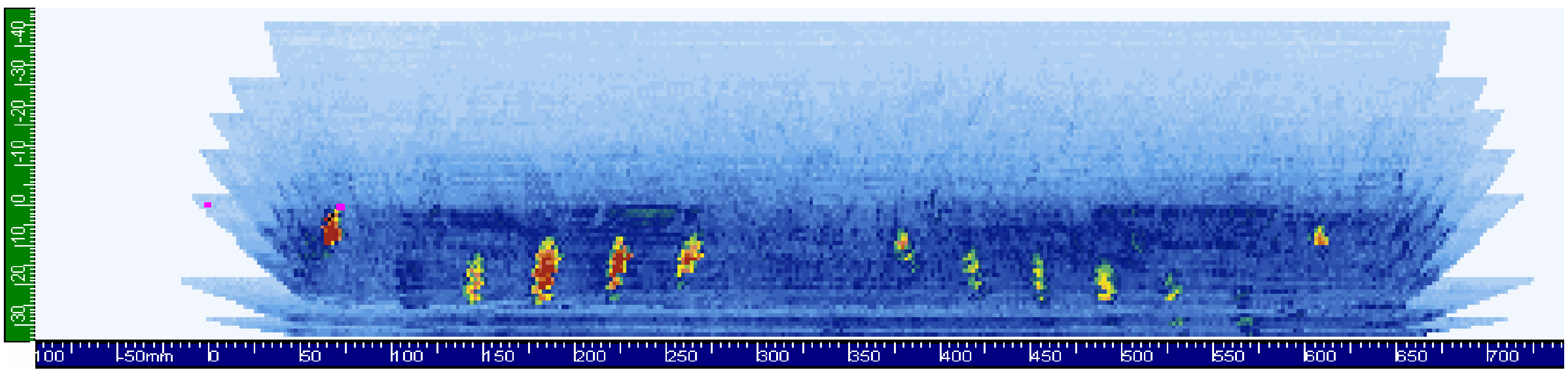
EPRI

Good Coverage with Poor Access

- Scanning a field-removed IGSCC specimen – only enough room for one stroke, but still get excellent data



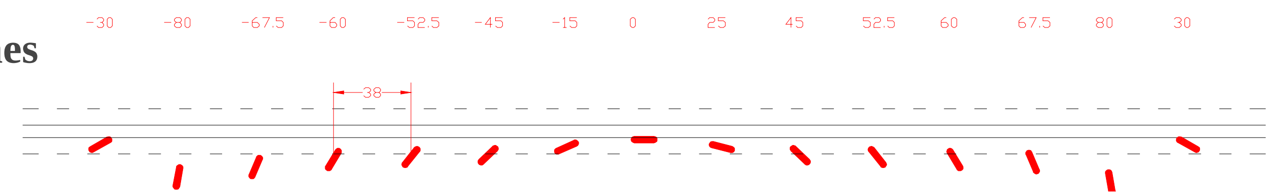
Next Step: Do It All with one 2D Array Probe



EDM notches

10mm long

5mm deep



SS pipe

30 mm

thick

EPRI

Summary

- Events in US and foreign plants highlighted NDE issues and focused industry attention on improving inspection technology & increasing productivity
  - PWSCC in Alloy 182 butt welds
  - Dissimilar metal welds
  - RPV head penetrations
- Complex configurations and materials associated with austenitic materials challenge NDE practitioners
- Considerable progress has been achieved in previous 12 months through demonstrations of capability
  - MRP
  - Appendix VIII
- New techniques & processes have been developed and are now being demonstrated to improve NDE performance & productivity
- Array probe technology shows promise for improving the reliability, effectiveness, and cost of inspection (UT and ET)
- Qualification has been achieved for many situations, with some limitations remaining to be addressed

Inspection Reliability of Reactor Vessel Head Penetrations

Presented by

Steven R. Doctor, PNNL

NRC Conference on VHP

September 29-October 2, 2003

Battelle

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

Acknowledgements

- Work being conducted under NRC programs
  - Y6534 – Carol Moyer NRC Program Manager
  - Y6604 – Debbie Jackson NRC Program Manager
  - Y6909 – Bill Cullen NRC Program Manager
- PNNL staff supporting work
  - George Schuster
  - Al Pardini
  - Randy Thornhill
  - John Abrefah

Presentation Outline

- Background
- History of degradation in high nickel alloys
- PWSCC in head penetrations
- NDE strategies for detecting PWSCC
- Programs addressing NDE effectiveness
- Conclusions

Background

- Inconel Alloy 600 selected because of its high strength, ductility and corrosion resistance
- Used in many applications: steam generators, pressurizer heater sleeves, instrumentation and sampling nozzles, head penetrations and DM piping welds – Alloy 600 historical failure experience addressed in paper by Bamford and Hall 2003
- PWSCC is a complex process that is not understood - many factors affect initiation and crack growth rate: environment (temperature), stresses (grinding or weld repairs) and susceptible microstructure

Historical Data

- NRC Lessons Learned Task Force – addressing the degradation of Davis-Besse Nuclear Power Plant
- Appendix E – Licensee Event Reports 1986-2002
- 89 LERs
  - 17% were CRDM leaks (most since 2000)
  - 15% were RCS instrumentation nozzle leaks
  - 10% were pressurizer instrumentation nozzle leaks
  - 8% were pressurizer heater penetration leaks
  - Remaining 50% from a variety of components and locations

Example of Early Leak

- San Onofre Unit 3 – leak detected February 27, 1986
  - Initially detected by subtle rise in radiation levels based on manually trending data
  - Sent staff member in to search for source of leak
  - No boric acid deposits found
  - Staff member perplexed and was trying to figure out what to look for when he heard hissing sound
  - Audible acoustic emission detection
  - Leak on pressurizer instrumentation nozzle, 0.15-0.2 gpm (0.57-0.76 lpm)
  - Confirmed to be PWSCC

CRDM Leak

- Bugey 3 – 9/1991during 10 year hydrotest - leak detected by acoustic emission with leak rate 0.003 gpm (0.7 L/h)
- Two through wall ID axial cracks confirmed by destructive testing (DT) to be PWSCC
- Two circumferential cracks on OD confirmed by DT
  - One located in the weld – hot crack created during fabrication
  - Other in the base metal and connected to the axial through wall crack on downhill side of nozzle just above the weld
- PT test of 754 J-groove weld crowns and buttering from 11 replaced heads – no cracks found (Amzallag et.al. 2002)

Overview of Degradation in Inconel – VHP

- Vessel head penetrations started to become a significant problem in the USA with the CRDM degradation in Oconee
- Ten plants have had cracking requiring repair based on data from 11/2000 to 2/19/2003
- Oconee Unit 1
  - 3 CRDMs requiring repair and 5 thermocouple nozzles
- Oconee Unit 2
  - 19 CRDMs requiring repair with one circumferential crack above the J-groove weld

Overview of Degradation in Inconel – VHP Cont'd

- Oconee Unit 3
  - 14 CRDMs requiring repair with four having circumferential cracks above J-groove weld
- ANO 1
  - 8 CRDMs requiring repair
- Surry 1
  - 6 CRDMs requiring repair
- North Anna 2
  - 14 CRDMs requiring repair and 6 with circumferential cracks – Head replaced

Overview of Degradation in Inconel – VHP Cont'd

- Davis-Besse
  - 5 CRDMs
  - 2 nozzles with significant wastage in ferritic head
- Three Mile Island 1
  - 6 CRDMs and 8 thermocouple requiring repair
- Crystal River 3
  - 1 CRDM with a circumferential crack
- Millstone 2
  - 3 CRDMs requiring repair

Overview of Degradation in Inconel – VHP Cont'd

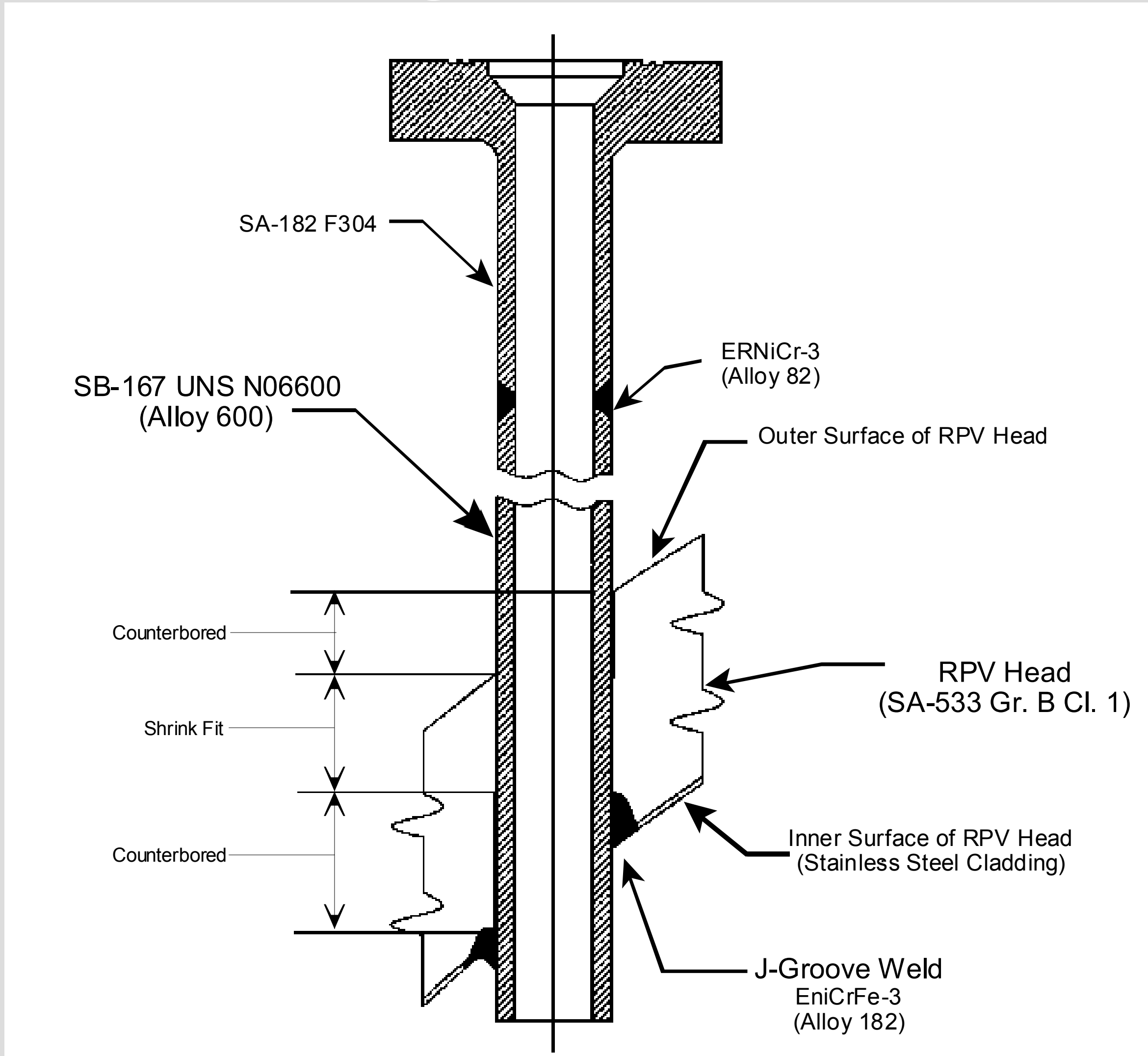
- LOWER HEAD PROBLEM
  - South Texas Project
    - 2 Bottom Mounted Instrument penetrations – visual detection of small boric acid deposits (3 mg and 150 mg)
    - Boric acid deposits were estimated to be 3 – 5 years old
    - Cracking along fusion zone of penetration tube and J-groove weld and into the penetration tube wall
    - Cracks confirmed by UT, ET and Helium Bubble Test
    - Boat samples taken
    - Not expected to crack because of low temperature

CRDM Degradation Locations

- Over time the problem has changed and NDE program has adapted to improve detection at each new location
  - Initially cracking was on ID of penetration tube
  - Cracking on OD of penetration tube at fusion zone of J-groove weld
  - OD initiated circumferential cracking above J-groove weld
  - Cracking in J-groove weld
  - Next had cracking associated with buttering
  - Large cavities in the ferritic steel
  - What is Next?

WNP-1

Design of B&W CRDM



NDE Methods - Visual Testing

- VT is conducted of the vessel head region to detect boric acid deposits
  - Need good access to the bare metal of the head in order to perform an effective examination
  - Other sources of leakage can obscure VHP leaks
  - Will not prevent leaks but only detects leakage
  - The goal of NDE should be to prevent leaks and VT should be used as back up in case degradation is missed by other NDE inspections

NDE Methods – Eddy Current Testing

- Is sensitive to the presence of surface breaking cracks on surface being inspected
- Provides crack length information
- If crack is near to the surface, the eddy current technique can still be effective
- Does not require coupling media but must be in contact with the surface for best test sensitivity
- Inspection of the J-groove weld crown and buttering is more challenging because of the curvature and surface preparation
- Inspection of the ID of the penetration tube is more reliable because of machined conditions

NDE Methods – Ultrasonic Techniques

- Primarily used for inspection from ID of the penetration tube testing for OD and ID flaws
- Most of the implementations use time-of-flight diffraction method
- Since flaws of interest are cracks – TOFD works well for detecting tips and perturbations of the surface signals (lateral wave and back surface)
- Over the fusion zone of the J-groove weld, there are no OD surface signals
- Works well for both axial and circumferentially oriented cracks
- Provides detection, length and depth sizing

NDE Methods – Penetrant Testing

- Primarily used for detection/confirmation of cracks on the crown of the J-groove weld or buttering
- Is an enhanced visual test
- Can be very effective but surface conditions and tight cracks degrade detection capability
- If done manually – high radiation exposure
- If cracks only break the surface in a limited number of locations, crack length will be undersized

Other NDE Methods

- Acoustic Emission for crack growth or leak detection
- Phased Arrays for detecting and characterizing wastage
- Helium Bubble test

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Programs Addressing NDE Effectiveness

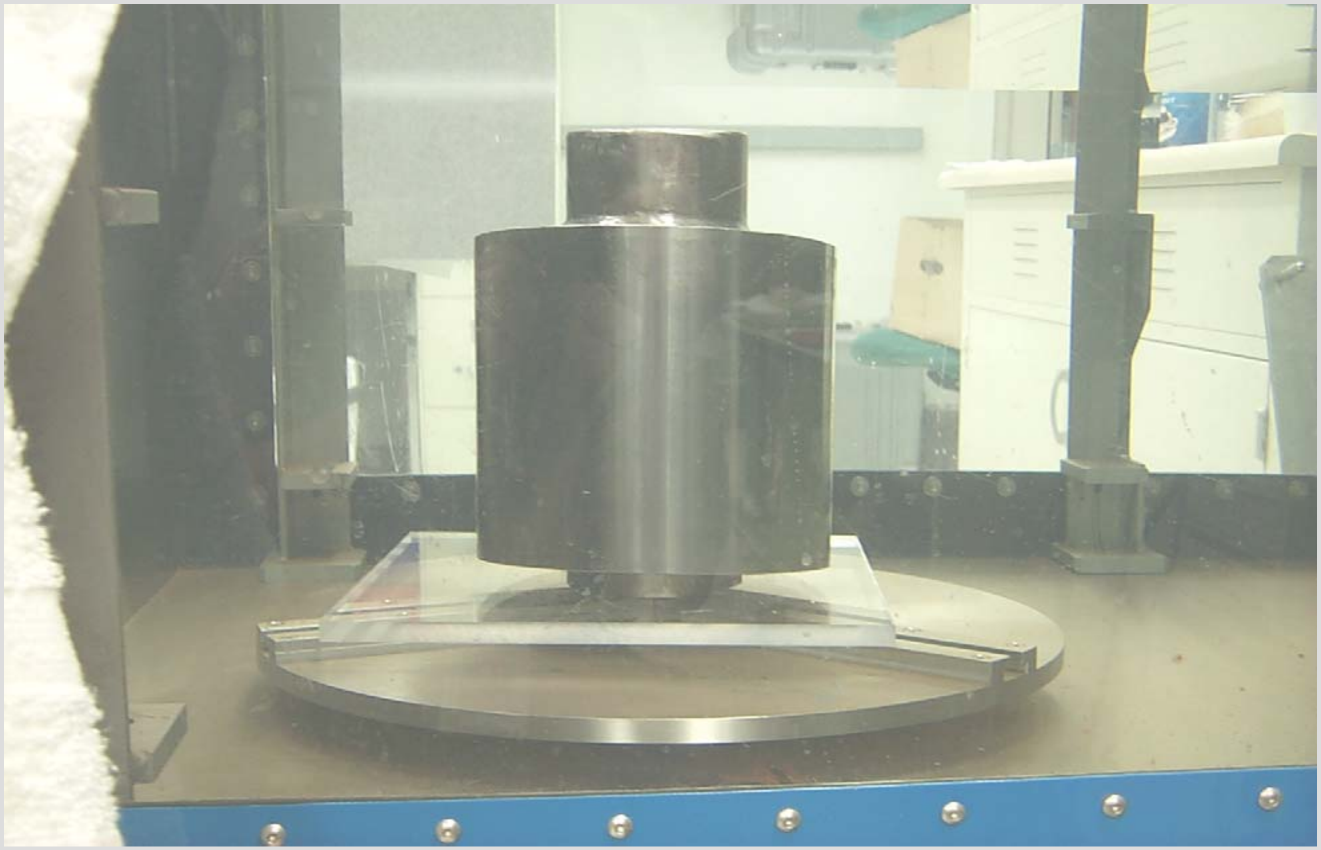
- NRC NDE programs
  - JCN Y6604
  - JCN Y6534
  - JCN Y6909
- EPRI/MRP
  - Developed mockups for NDE demonstration
  - Other research activities
- International Activities
  - Electricity de France
  - Sweden
  - JRC – Petten

NRC Program JCN Y6604

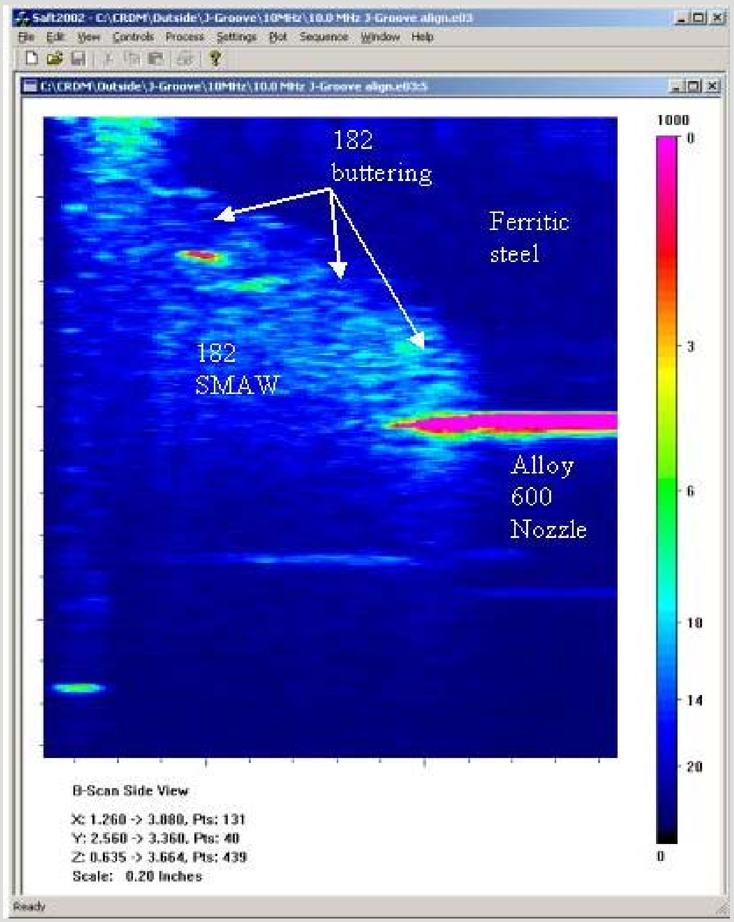
- Studies conducted on a Midland CRDM specimen
- Initial focus of work - detection of fabrication flaws in the J-groove weld and buttering
- Can detect fabrication flaws (1-2 mm)
- Can not effectively detect fabrication flaws on far side of J-groove weld
- Future work will quantify what can be detected

Midland CRDM Nozzle – Head Segment

CRDM prepared for Inspection



SAFT-UT Images from the Outside Machined Surface: 10 MHz



Normal incidence using 10MHz spherically focused, F8

Image is SAFT processed using a shallow processing angle

Four product forms are imaged

- Ferritic steel
- 182 buttering
- 182 Shielded metal arc weld (SMAW)
- Alloy 600 nozzle

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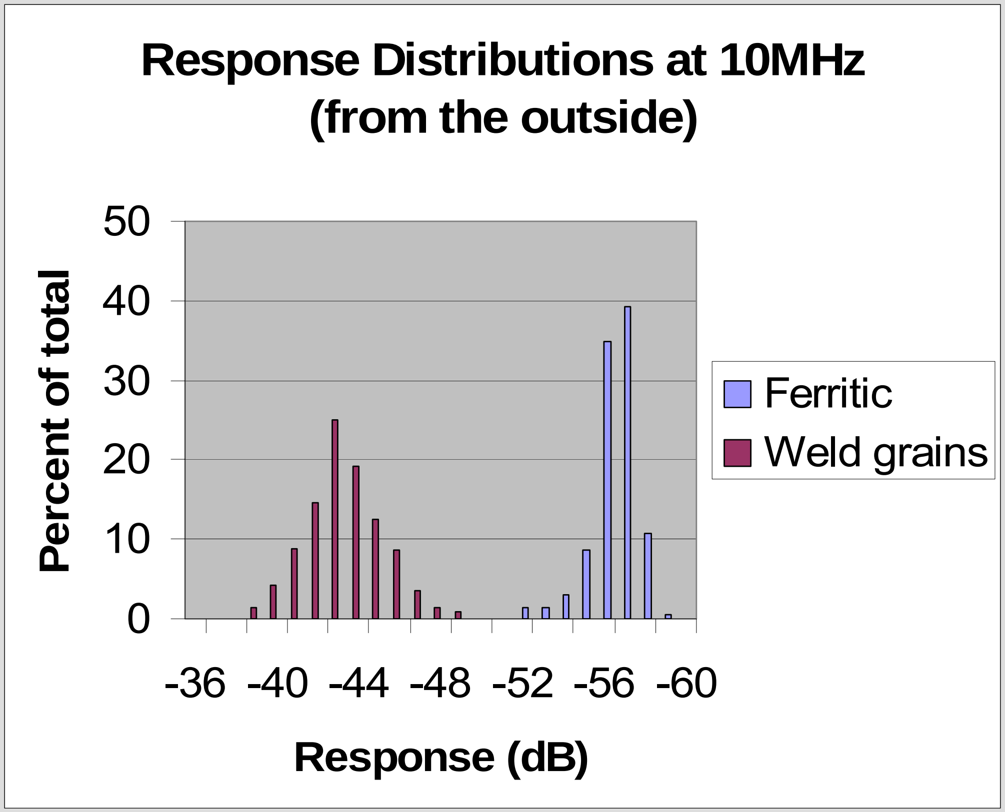
Comparison of Response Distributions



NRC Program JCN Y6534

- International Cooperative on PWSCC and NDE of DMW and Nickel Base Alloys
  - Carol Moyer is leading this effort
  - Produce an atlas of metallography documentation on PWSCC cracks and NDE responses
  - Organize and conduct round robin study to assess nondestructive evaluation (NDE) techniques for detecting and characterizing PWSCC
  - Other options being considered such as modeling, assessing conditions affecting NDE effectiveness, etc.

NRC Program JCN Y6909

- North Anna 2 CRDMs containing real cracks
- Joint program with EPRI/MRP
- 7 nozzles flame cut from head – Shipped to PNNL
- Being decontaminated for study – Note extreme care being taken to keep cracks pristine
- ISI vendors to conduct NDE inspections
- Will provide an assessment of what was and was not detected and how accurately characterized
- Destructive validation and study of cracking process planned – PWSCC or Hot Tears?

North Anna 2 Nozzle #51

Battelle

NRC Program JCN Y6909 Cont'd

- Davis-Besse material received at PNNL
  - Some of this material is being destructively characterized under a DOE program by Stephen Bruemmer at PNNL
  - Remaining material to be studied during FY 04 and 05

Davis Besse Head Degradation

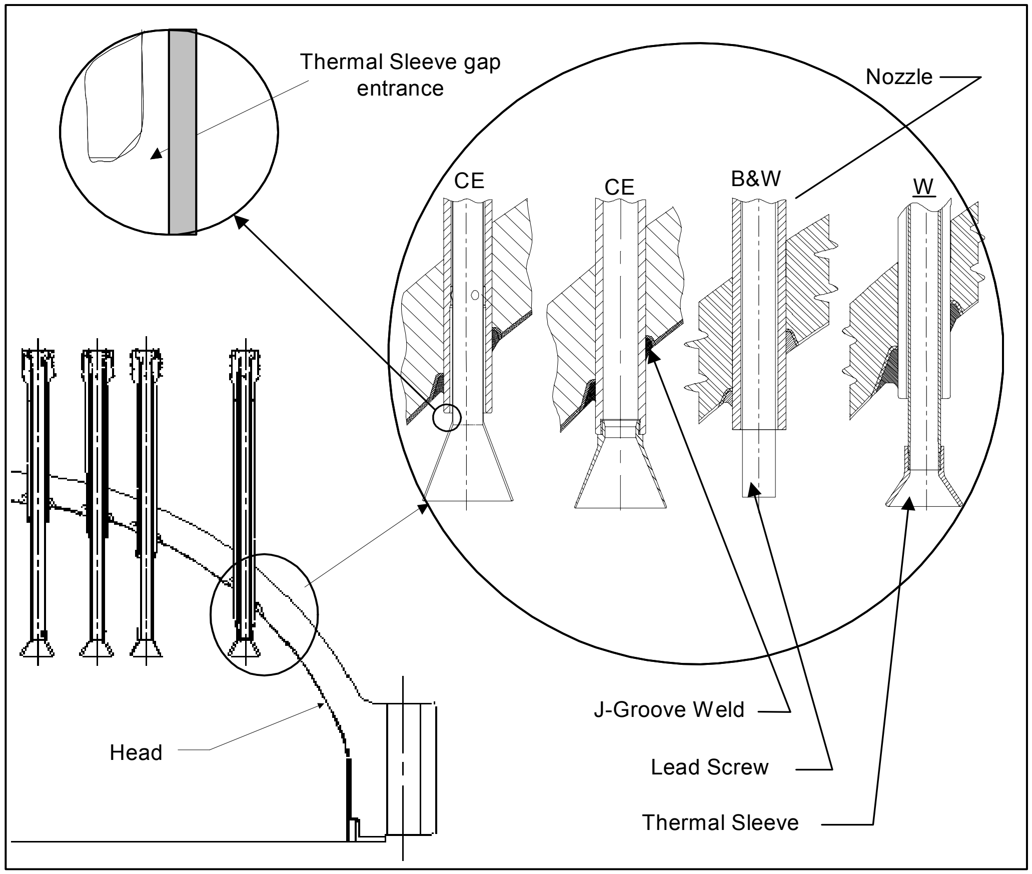
Conclusions

- Failure of Alloy 600/182/82 is a generic problem
- Dominant failure mode is PWSCC
- Most cracking has been detected by leakage because of ISI strategy - that is how areas of potential failure are located
- Goal of NDE program should be to prevent leaks
- How effectively can the J-groove weld be inspected? Classic coarse grained ISI problem
- Overall effectiveness of NDE is unknown
- A number of studies and programs (NRC, industry, international) are in progress or are being planned to address these issues and should bring closure to some of them

The Evolution of Inspection and Repair Approaches for Reactor Vessel Head Penetrations

D. Schlader

Typical CRD Nozzle Configurations



FANP RV Head Inspection Experience

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RVH Inspection Experience at Westinghouse Designed Plant

Utility Name Station Name	Date Insp.	Nozzle Types (#)	Bare Head By	UT [1]	PT [2]	ET [3]	Contact
RG&E Ginna	March 1999	CRDM (36) Vent Line (1)	Utility	1 BUT	0	28 BET 5 RET	Brian Flynn (716) 771-3734
FirstEnergy Beaver Valley 1	Fall 2001	CRDM (65)	FANP	0	0	0	Tim Heimal (724) 682-5470
Dominion Surry 2	Fall 2001	CRDM (60)	FANP	0	0	0	Dean Price (804) 237-2684
FP&L Turkey Point 3	Fall 2001	CRDM (65) ICI (8) Vent Line (1)	FANP	0	0	0	John Manso (305) 246-6622
Dominion Surry 1	Fall 2001	CRDM (60)	FANP	26 BUT	16 MPT	0	Dean Price (804) 237-2684
FP&L Turkey Point 4	Spring 2002	CRDM (65) Vent Line (1)	FANP	0	0	0	John Manso (305) 246-6622
FirstEnergy Beaver Valley 1	Spring 2002	CRDM (65)	FANP	0	0	0	Tim Heimal (724) 682-5470
Wisconsin Electric Point Beach 2	Spring 2002	CRDM	Utility	0	0	0	Tim Olson (920) 755-7435
British Energy Sizewell B	Spring 2002	CRDM	FANP	0	0	0	
Southern Company Farley 2	Fall 2002	CRDM (69) Vent Line (1)	Utility	69 BUT 1 RUT	0	0	David Gambrell (205) 992-6480
Wisconsin Electric Point Beach 1	Fall 2002	CRDM (49) Vent Line (1)	Utility	33 BUT 20 RUT 1 RUT	0	0	Tim Olson (920) 755-7435
Dominion North Anna 2 (Baseline for new head)	Fall 2002	CRDM (65) Vent Line (1)	NA	65 BUT 1 RUT	66 MPT	0	
Dominion North Anna 1 (Baseline for new head)	Fall 2002	CRDM (65) Vent Line (1)	NA	65 BUT 1 RUT	66 MPT	0	
Dominion Surry 1 (Baseline for new head)	Fall 2002	CRDM (65) Vent Line (1)	NA	65 BUT 1 RUT	66 MPT	0	
FP&L Turkey Point 3	Spring 2003	CRDM (65) Vent Line (1)	FANP	65 BUT 1 RUT			John Manso (305) 246-6622
TVA Sequoyah 1	Spring 2003	CRDM (6)	Utility	6 BUT	2 MPT		Tommy Hale (423) 365-3538

FANP RV Head Inspection Experience (cont'd)

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RVH Inspection Experience at CE Designed Plants

Utility Name Station Name	Date Insp.	Nozzle Types (#)	Bare Head By	UT [1]	PT [2]	ET [3]	Contact
Consumer Power Palisades	May 1995	ICI (8)	Utility	0	0	8 RET	Anand Gangadharan (616) 764-8913
FP&L St. Lucie 2	Fall 2001	CEDM (66)	FANP	0	0	0	John Manso (305) 246-6622
BG&E Calvert Cliffs 1	Spring 2002	CEDM (65) Vent Line (1)	FANP	0	0	0	Joe Richards (410) 495-6575
Dominion Millstone 2	Spring 2002	CEDM (69) ICI (8) Vent Line (1)	FANP	69 RUT 8 RUT 1 RUT	4 MPT	0	Tim Petit (860) 447-1791 x0509
FP&L St. Lucie 1	Fall 2002	CEDM (69) ICI (8) Vent Line (1)	FANP	69 BUT 8 RUT 1 RUT	0	0	John Manso (305) 246-6622
BG&E Calvert Cliffs 2	Spring 2003	CRDM (65) ICI (8) Vent Line (1)	FANP	65 BUT 8 RUT 1 RUT			Tim Lupold (410) 495-2283
FP&L St. Lucie 2	Spring 2003	CEDM (91) ICI (10) Vent Line (1)	FANP	91 BUT 10 RUT 1 RUT	0	0	John Manso (305) 246-6622

RVH Inspection Experience at B&W Designed Plants

Utility Name Station Name	Date Insp.	Nozzle Types (#)	Bare Head By	UT [1]	PT [2]	ET [3]	Contact
Duke Energy Oconee 2	Oct. 1994	CRDM (69)	Utility	2 BUT	2 MPT	69 BET 3 RET	Barry Millsaps (864) 885-3667
Duke Energy Oconee 2	April 1996	CRDM (2)	Utility	0	2 RPT	2 RET	Barry Millsaps (864) 885-3667
Duke Energy Oconee 2	Fall 1999	CRDM (8)	Utility	0	0	8 RET	Barry Millsaps (864) 885-3667
Duke Energy Oconee 1	December 2000	CRDM (17)	Utility	16 RUT	0	17 RET	Barry Millsaps (864) 885-3667
Duke Energy Oconee 3	Spring 2001	CRDM (18)	Utility	18 RUT	0	18 RET	Barry Millsaps (864) 885-3667
Entergy ANO – 1	Spring 2001	CRDM (1)	Utility	1 RUT	0	1 RET	Terry Windham (501) 858-4355
Duke Energy Oconee 2	Spring 2001	CRDM (4)	Utility	4 RUT	0	4 RET	Barry Millsaps (864) 885-3667
Florida Power Crystal River 3	Fall 2001	CRDM (9)	Utility	9 RUT	0	0	Jeff Hecht (352) 795-6486 x3478
Duke Energy Oconee 3	Fall 2001	CRDM (51)	Utility	9 RUT 42 BUT	9 MPT	0	Barry Millsaps (864) 885-3667
Exelon Three Mile Island 1	Fall 2001	CRDM (12)	Utility	12 RUT	9 MPT	0	Brad Oliver (267) 253-5685
FirstEnergy Davis-Besse	Spring 2002	CRDM (69)	FANP	69 BUT 6 RUT	0	0	Rich Chesko (419) 321-7580
Duke Energy Oconee 1	Spring 2002	CRDM (4)	Utility	4 RUT	0	0	Barry Millsaps (864) 885-3667
Duke Energy Oconee 2	Fall 2002	CRDM (69)	Utility	65 BUT 15 RUT	7 MPT	0	Barry Millsaps (864) 885-3667
Entergy ANO – 1	Fall 2002	CRDM (31)	Utility	31 BUT	0	0	David Bauman (479) 858-4461
Total FANP Inspections To Date			**14 BHV by FANP**	**738 BUT 318 RUT**	**247 MPT 2 RPT**	**97 BET 66 RET**	

[1] BUT = Blade UT; RUT = Rotating UT
[2] RPT = Remote PT; MPT = Manual PT
[3] BET = Blade ET; RET = Rotating ET

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US RV Head Repair Experience

NPP	INTERVENTION DATE	TYPE OF REPAIR	VENDOR
DC COOK 2	1994	Local excavation and manual weld of 1 nozzle	W
MILLSTONE 2	1995	Local excavation and manual weld of 1 nozzle	W
OCONEE 1	11/00	Manual excavation & manual weld of 1 nozzle and 8 T/C's	FANP
ANO-1	03/01	Manual excavation & manual weld on 1 nozzle	FANP
OCONEE 3	03/01	Manual excavation & manual weld of 9 nozzles with remote machine weld overlay of 5	FANP
OCONEE 2	05/01	Remote ID TemperBead Process on 4 nozzles	FANP
CRYSTAL RIVER 3	10/01	Remote ID Ambient TemperBead Process on 1 nozzle	FANP
TMI 1	10/01	Remote ID Ambient TemperBead Process on 6 nozzles and manual repair of 8 T/C's	FANP
SURRY 1	11/01	Remote ID Ambient TemperBead Process on 6 nozzles	FANP
NORTH ANNA 2	11/01	Local excavation and machine weld of 3 nozzles	W
OCONEE 3	12/01	Remote ID Ambient TemperBead Process on 7 nozzles	FANP
MILLSTONE 2	3/02	Remote ID Ambient TemperBead Process on 3 nozzles	FANP
OCONEE 1	4/02	Remote ID Ambient TemperBead Process on 2 nozzles	FANP
DAVIS-BESSE	4/02	Remote ID Ambient TemperBead Process on 5 nozzles	FANP
POINT BEACH 1	9/02	Cut 3 Guide Sleeves in support of Inspection efforts	FANP
ST. LUCIE 2	10/02	Cut 2 Guide Sleeves in support of Inspection efforts	FANP
NORTH ANNA 2	10/02	Cut 12 Guide Sleeves in support of Inspection efforts	FANP
OCONEE 2	11/02	Remote ID Ambient TemperBead Process on 15 nozzles	FANP
ANO -1	11/02	Imbedded Flaw Process on 2 nozzles	W
ANO -1	11/02	Remote ID Ambient TemperBead Process on 6 nozzles	FANP
BEAVER VALLEY 1	4/03	Local Excavation and overlay of 4 nozzle lower stubs	W
ST. LUCIE 2	5/03	Remote ID Ambient TemperBead Process on 2 nozzles	FANP

FANP has repaired 84 of the 93 RV head penetrations in the last three years.

Nozzle Inspection Techniques

- *Visual Inspection - With and Without Crawler*
- *Rotating / Blade Ultrasonic Inspection of CRDM Nozzles*
  - *Penetrations with or without Thermal Sleeves/Lead Screws*
  - *Rotating UT - Large Cylindrical Probe Inserted in Nozzle*
  - *Blade UT - Flexible Blade Inserted in the Narrow Gap*
  - *Axial and Circumferential Crack Detection and Sizing*
  - *Enhancements*
    - *Examination of Nozzle and J Weld (Leak Path Verification)*
    - *SumoROCKY Delivery*
- *Surface Inspection of J-groove Weld*
  - *Penetrant Testing - Remote and Manual*
  - *Eddy Current Testing - Remote*

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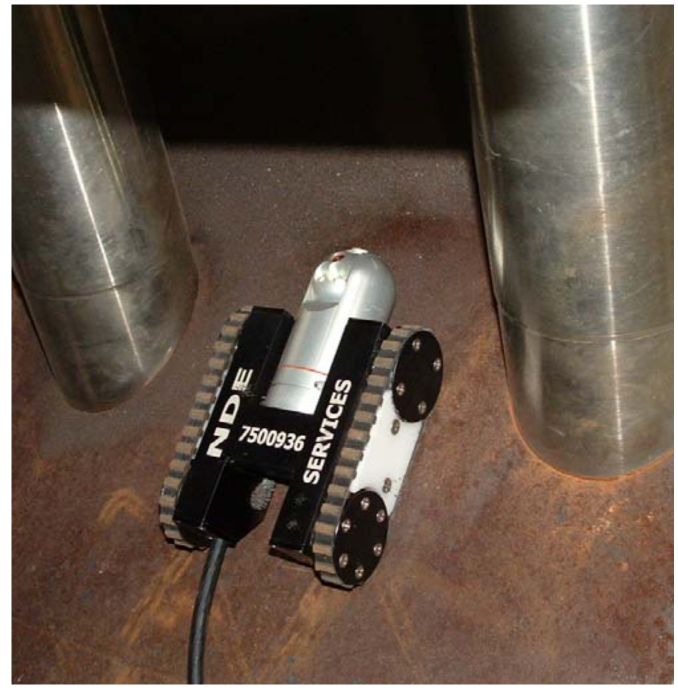
Inspection Techniques - VT

- > Bare Head Visual Inspection
- > Mirror type insulation or removed insulation
  - Remote Crawler
  - Pole
- > Contoured insulation
  - Video probe/snake



Inspection Techniques - ET

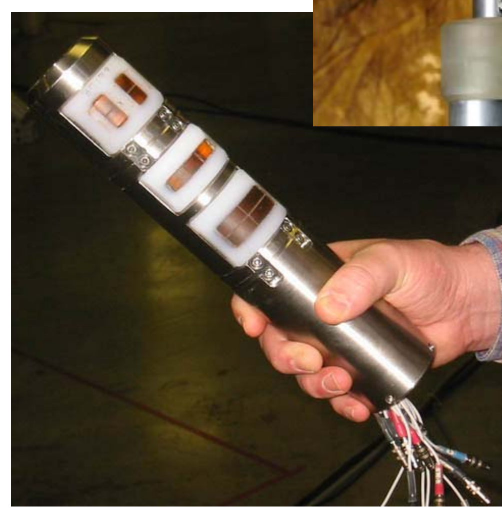
RV Head Remote ET

J-Groove Weld and Nozzle Stub Scanning

Inspection Techniques - UT

> **Ultrasonic Inspection**

- ***Rotating UT***
  - ***Penetrations without Thermal Sleeves/Lead Screws***
  - ***Circumferential and Axial Crack Detection and Sizing***
  - ***Initial Inspection of CRDM Nozzles and Inspection of IDTB Repair***
  - ***Leak Path Detection***
- ***SumoROCKY delivery***



Inspection Techniques - UT

> **Ultrasonic Inspection**
- ***Circumferential Blade UT***
  - ***Penetrations with Thermal Sleeves/Lead Screws***
  - ***Flexible Blade Inserted in the Narrow Gap***
  - ***Detection and Sizing of all Circumferential Cracks and Most Axial Cracks***
  - ***Leak Path Detection***
- ***Range of Axial Blade Probes Available, If Needed***
- ***SumoROCKY Delivery***

UT Blade Probe with SumoROCKY Manipulator

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Leak Path Detection

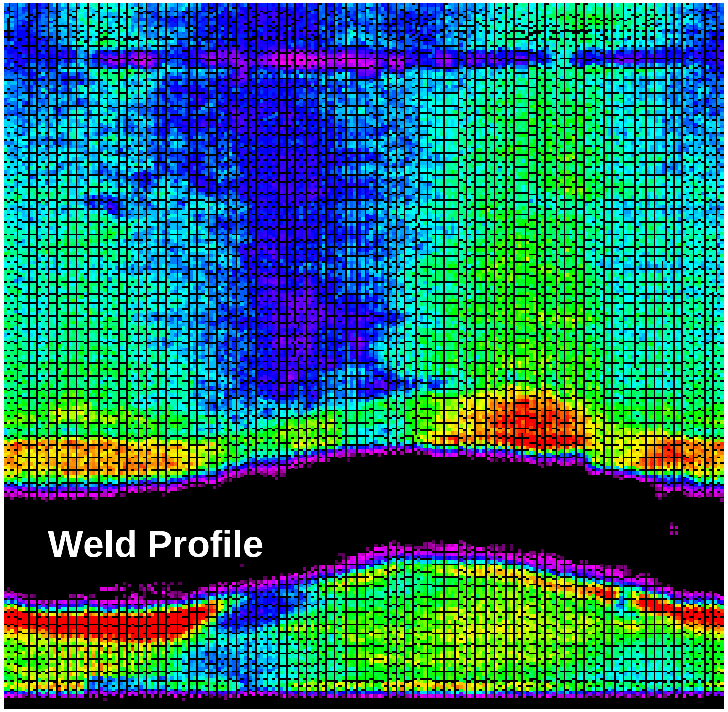
> **What is it?**

- ***UT Image of the Amplitude Profile Resulting From Changes in Reflectivity of the Nozzle Backwall in the Interference Fit Region of the Nozzle***
- ***Sees Changes in the Geometry of the Interference Fit Caused by Erosion/Corrosion of Head Material***
- ***Patterns Form in the C-scan Image Indicative of a Leak Path***

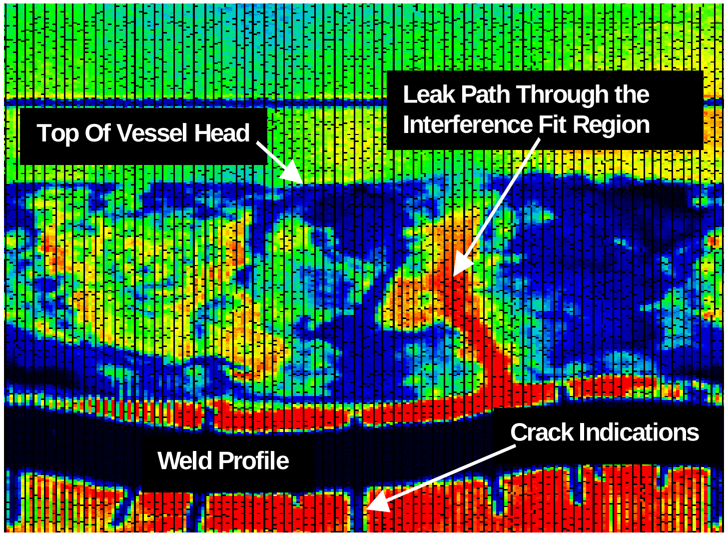
> **How Reliable is it?**

- ***NRC Order (EA-03-009) identified technique as underhead inspection option with UT of the nozzle***
- ***Database includes over 1000 nozzle scans***

Leak Path Detection
Typical Response for Normal Interference Fit



Without Leak



With Leak

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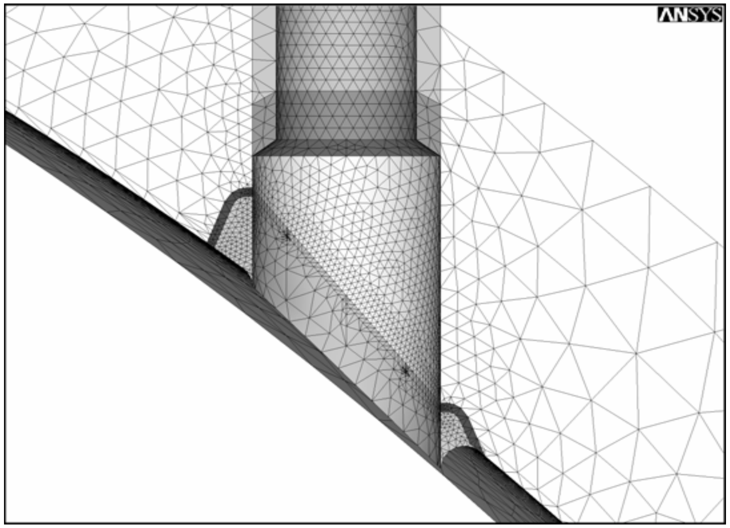
Framatome ANP Repair Approaches

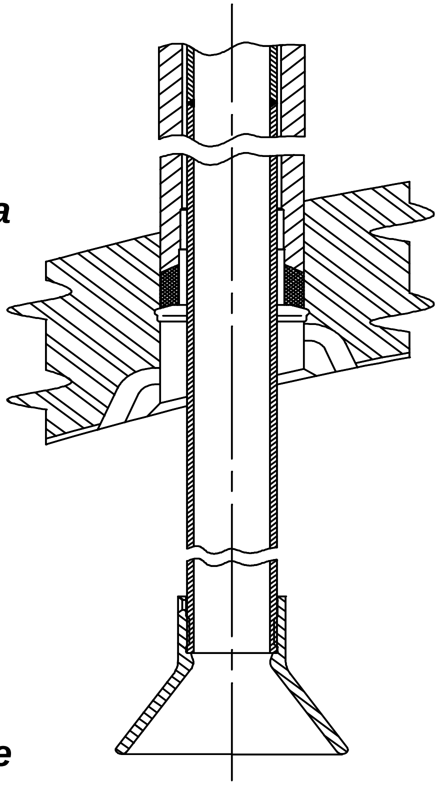
- ***Remote ID Temper Bead (IDTB) Process - Recommended***
  - ***Good contingency approach to be prepared for any failure event***
    - ***Structural Weld Defects***
    - ***Nozzle ID Defects***
    - ***Nozzle OD Defects***
    - ***Multiple Defects in Nozzles With Multiple Failure Modes***
    - ***Maximizes Repair Life Due to Remediation of Weld HAZ***
    - ***Not Flaw Dependent***
    - ***Remote Application***
    - ***Full Nozzle Replacement Possible***



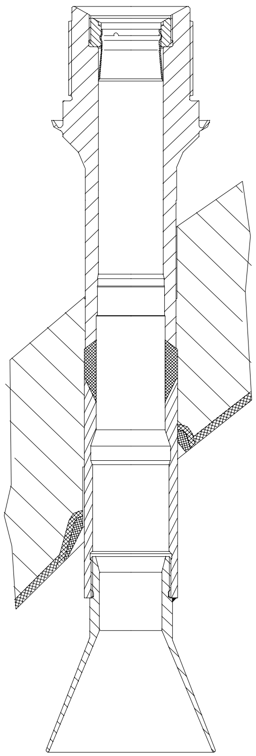
Framatome has repaired 84 RV Head Penetrations in the US over the last 30 months on B&W, W, & CE designed Units.

Remote ID Temperbead CEDM/CRDM Repair Process

- > Remove Guide Sleeve
- > Base Line NDE
- > Roll Nozzle in Repair Region
- > Machine Weld Prep & PT Prep Area
- > Grind Original Structural Weld Chamfer
- > Perform Structural Weld
  - Ambient Temperature Temper Bead
- > Prepare Welded Surface For NDE (Grinding / Boring)
- > Perform Post-Repair UT & PT
- > Remediate Rolled and Repaired Areas With Abrasive Water Jet
- > Install Replacement Guide Sleeve
- > Fully Analyzed to meet ASME Code

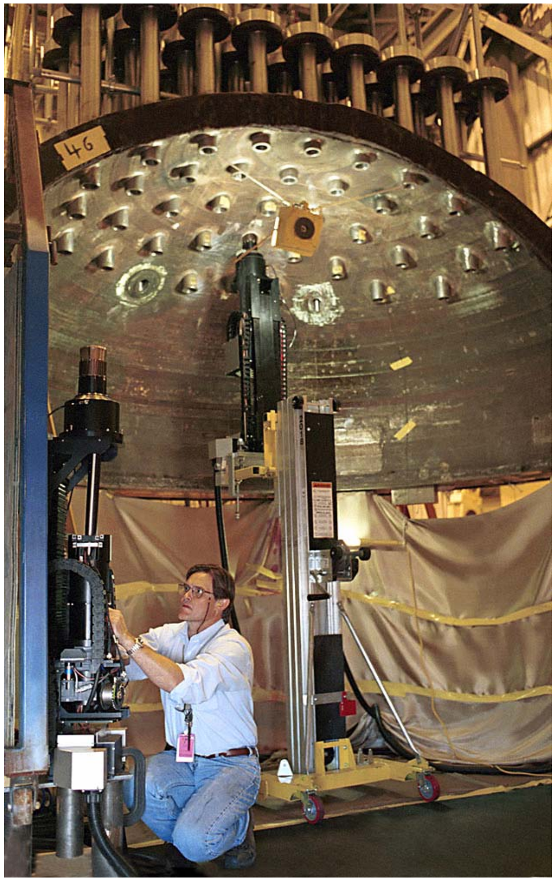


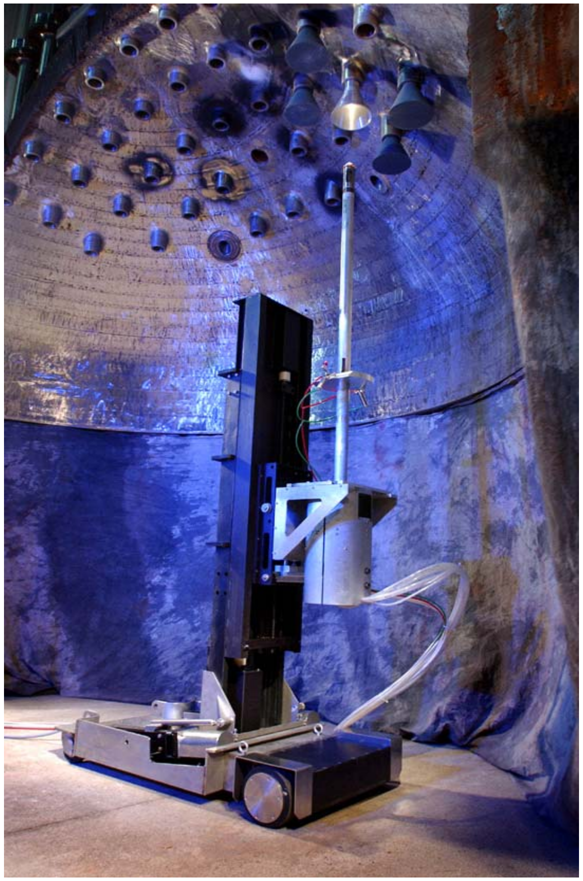
W



CE

Head Mockups





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Summary of U.S. PWR Reactor Vessel Head Nozzle Inspection Results

U.S. Nuclear Regulatory Commission
Argonne National Laboratory

Conference on Vessel Head Penetration Inspection, Cracking, and Repairs

September 29 – October 2, 2003
Marriott Washingtonian Center
Gaithersburg, Maryland

G. White, DEI
N. Nordmann, DEI
L. Mathews, SNOC
C. King, EPRI

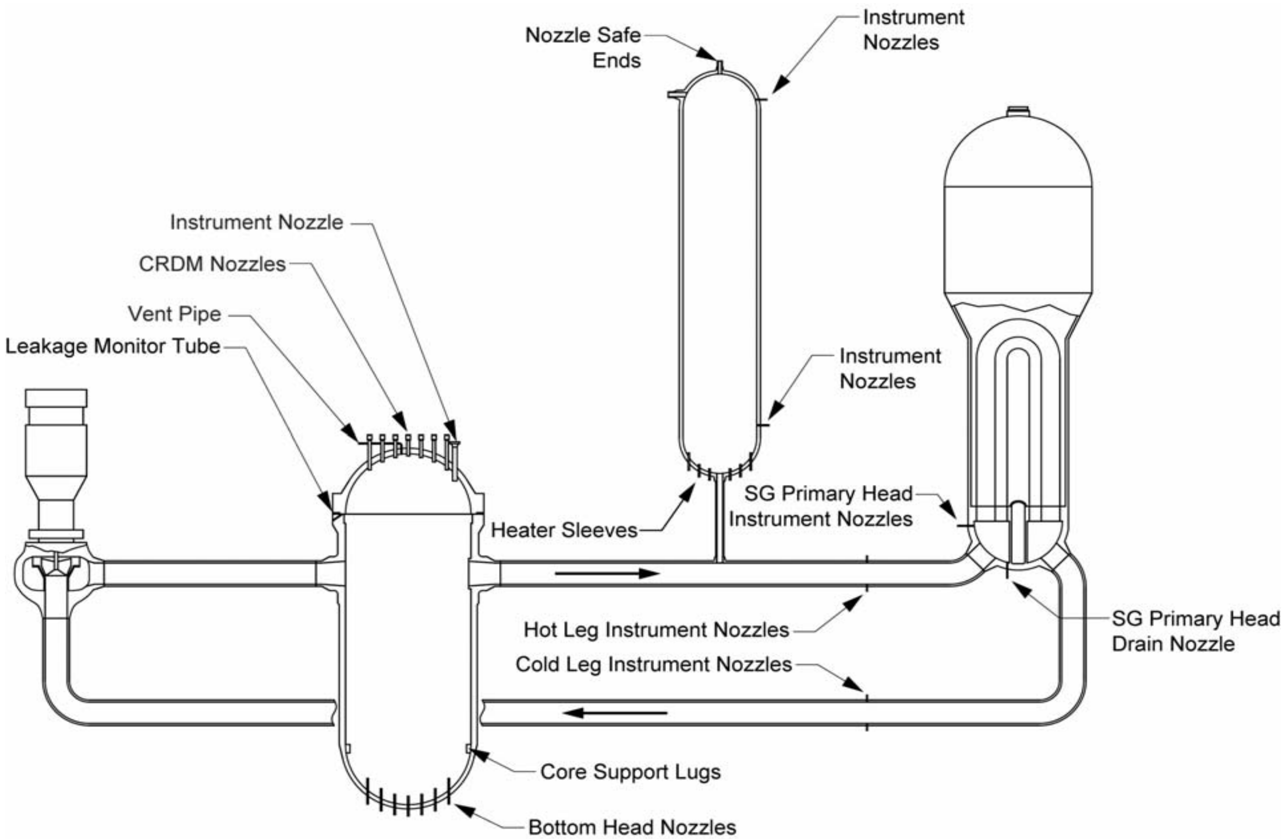
Topics

- Uses of Inspection Summary Statistics
- Introduction
  - Penetration types
  - Materials Reliability Program (MRP) database
  - Inspection techniques
  - Inspections performed to date
- Cracking Detected
  - Leakage and boric acid wastage
  - Circumferential nozzle cracking
  - J-groove attachment weld cracking
- Subpopulation Statistics
  - By EDY group
  - By head fabricator
  - By nozzle material supplier
- Planned Head Replacements and Inspections

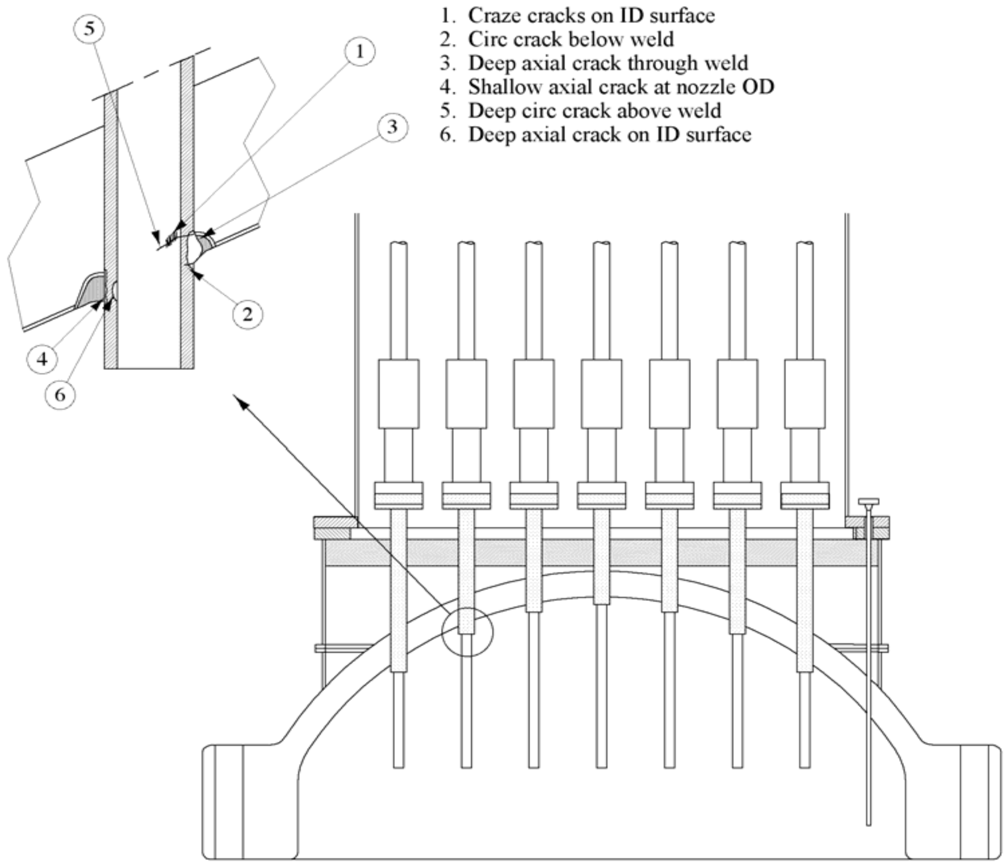
Uses of Inspection Summary Statistics

- Verify use of time at temperature (EDYs) as a susceptibility indicator
- Reveal cracking trends for fabrication and materials groups
- Support safety analysis assessments
  - Weibull statistical modeling of crack initiation or leakage
  - Check of crack growth rates developed using laboratory test data
  - Crack location and orientation assumptions
  - Low alloy steel wastage assessments
- Facilitate periodic evaluations of industry inspection plan
- Support responses to NRC questions

Introduction
Locations of Thick-Section Alloy 600

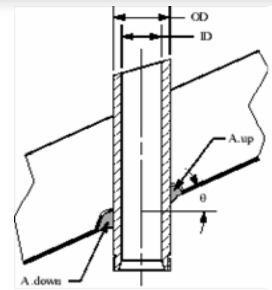


Introduction
Typical PWR RV Head Nozzle PWSCC

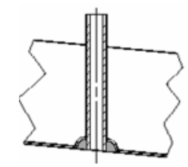


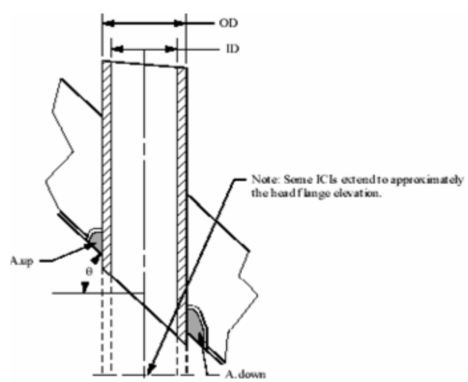
Introduction
Penetration Types

- 69 operating PWR units in the U.S.
- J-groove nozzle designs (all Alloy 600)
  - 3871 CRDM nozzles (55 units)
  - 1090 CEDM nozzles (14 units)
  - 94 in-core instrument (ICI) nozzles (11 units)
  - 59 vent line nozzles (59 units)
  - 16 small-bore thermocouple nozzles (2 units)
  - 8 auxiliary head adapters nozzles (2 units)
  - 2 de-gas line nozzles (2 units)
- Nozzle designs without J-groove welds
  - 3 full penetration weld vent line nozzles (3 units)
  - 6 internals support housing nozzles (2 units)
  - 20 auxiliary head adapters nozzles (5 units)



Basic CRDM/CEDM nozzle design


J-groove vent nozzle design



Typical ICI nozzle design

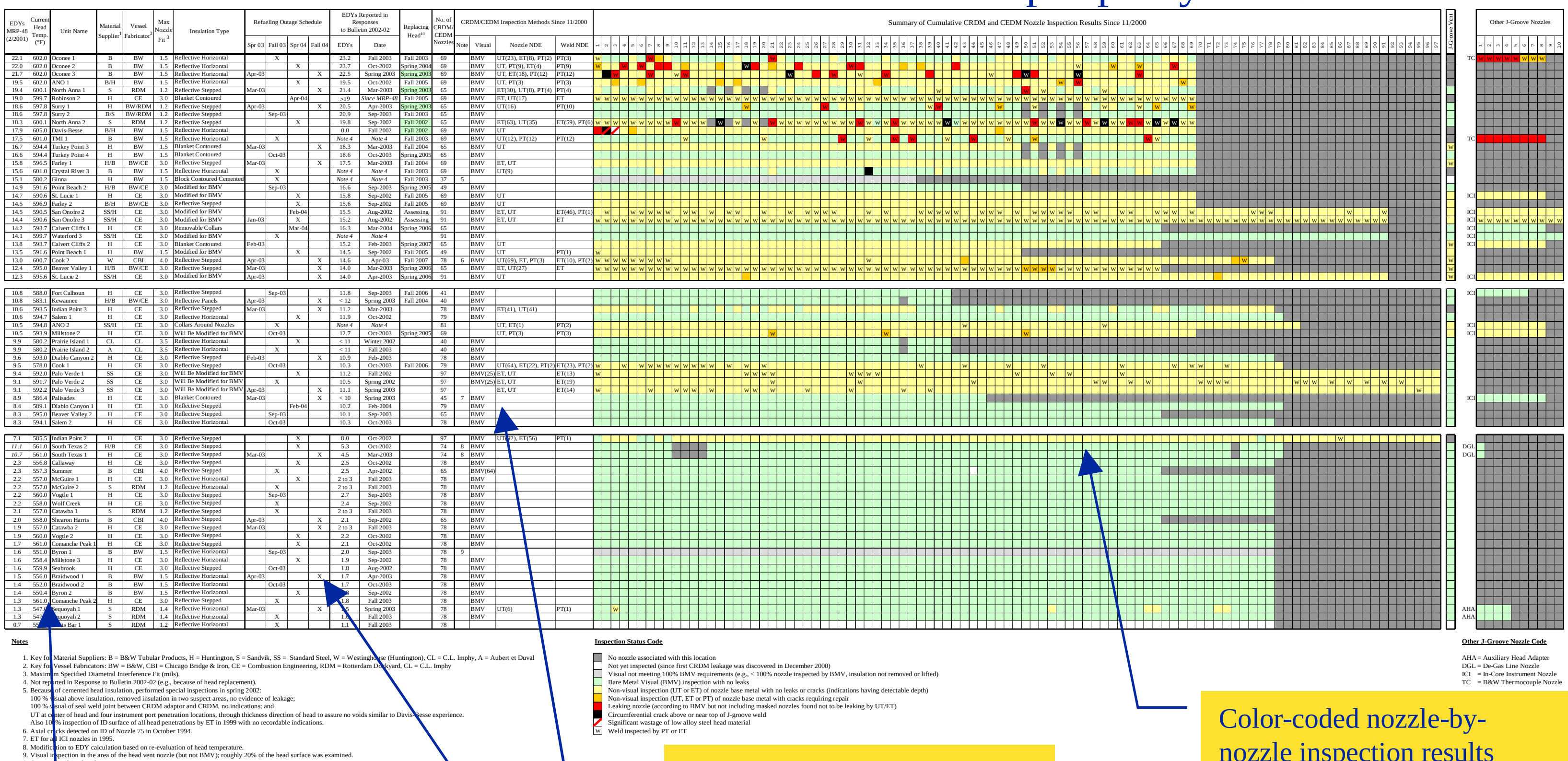
Introduction
MRP Database

- The Materials Reliability Program (MRP) collects inspection results data and updates the summary statistics each outage season
  - Data are collected on the individual flaw level
  - Summary statistics are generated from the detailed level
- The key parameters table graphically shows:
  - The extent to which the fleet has been inspected
  - The extent of detected cracking, leakage, and wastage correlated with effective degradation time (EDYs) and position on the head
  - Key operating and design data
  - Refueling outage schedule and current head replacement plans

Introduction
Key Parameters Table

Toward head periphery

EDYs



MRP-48 EDYs, head temp., unit name, and basic design info

Types of inspections performed

Outage schedule, BL 2002-02 EDYs, and head replacement plans

Color-coded nozzle-by-nozzle inspection results (CRDM/CEDM, vent, other)

Introduction
NRC Chart for Tracking Insp. Results[1]

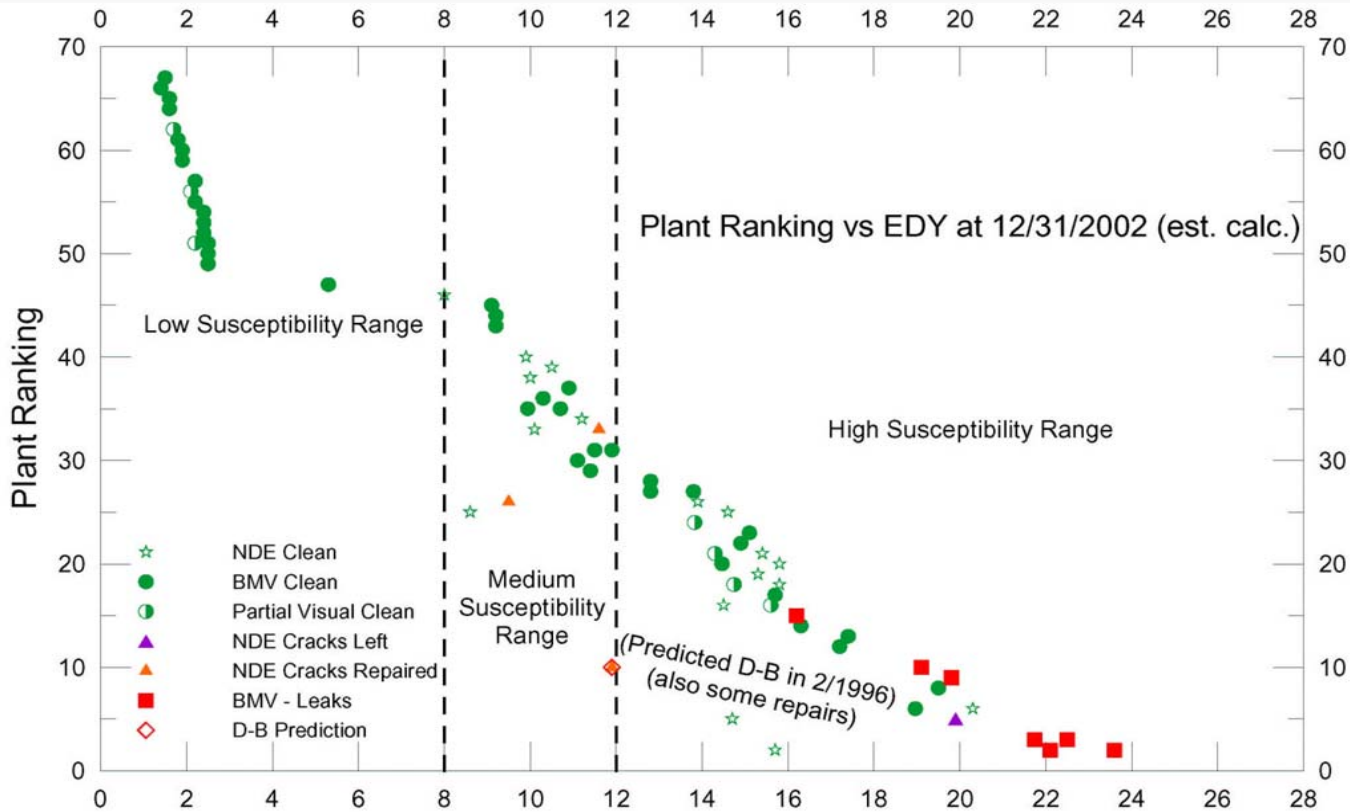


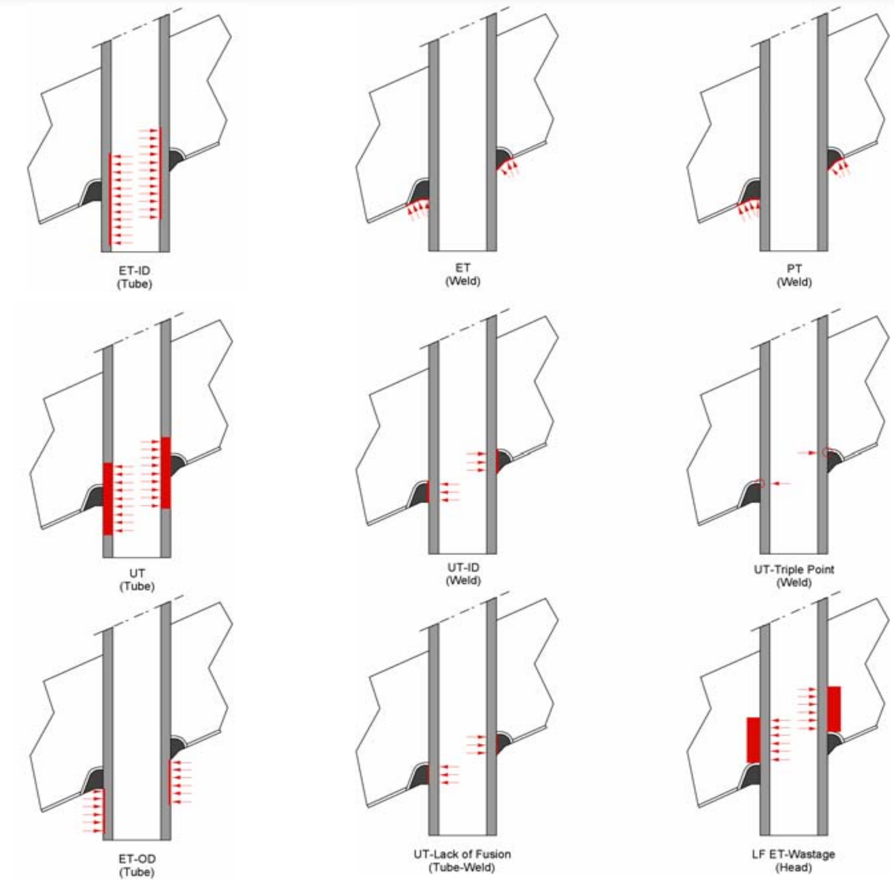
Figure 1. Ranking of domestic plants according to the EDY formula, showing results of inspections, evidence of leakage, and repairs. Many plants are shown with multiple symbols, indicating a "clean" inspection at inspection opportunity, followed by a different finding at a subsequent inspection (e.g., Oconee 2: clean NDE @ EDY=15.7, leaks and circ. flaws @ 22.1)

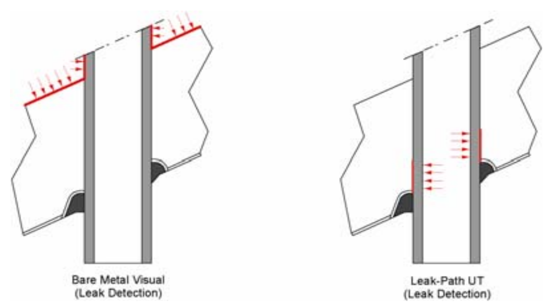
[1]Attachment to Memo, L. Marsh, "Use of the 'EDY' Formula – Susceptibility Model Critique," NRR-2002-018 User Request & LLTF Recommendations Action Plan, July 14, 2003

EPRI

Introduction
Inspection Techniques

- Inspection techniques include visual inspections for leaks and surface and volumetric NDE of the nozzle,
  J-groove attachment weld, and interference fit zone





Introduction
Inspections Performed to Date

- From December 2000 through spring 2003, bare metal visual (BMV) and/or nonvisual NDE examinations have been performed on 96% of CRDM and CEDM nozzles
- From December 2000 through spring 2003, nonvisual NDE examinations have been performed on:
  - 40% of all CRDM and CEDM nozzles (UT and/or ET)
  - 68% of the CRDM/CEDM nozzles in heads having > 12 EDYs
  - 47% of the CRDM/CEDM nozzles in heads having 8-12 EDYs
  - 501 J-groove attachment welds (ET or PT)
- In addition, 5 heads have already been replaced

Cracking Detected
Plants with Detected Cracking

Number	Unit	EDYs thru Feb. 2001 (@ 600°F) (MRP-48)	Current Head Temp. (°F)	NSSS Supplier	Vessel Fabricator (Note 1)	Nozzle Material Supplier (Note 2)	No. of CRDM or CEDM Nozzles on Head	Number Cracked Penetrations Detected (Note 3): Tube and/or Weld Cracked	Tube Cracked	Weld Cracked	Notes
1	ANO 1	19.5	602.0	B&W	BW	B/H	69	8	7	2	
2	Beaver Valley 1	12.4	595.0	W	BW/CE	H/B	65	4	4	0	
3	Cook 2	13.0	600.7	W	CBI	W	78	3	3	0	
4	Crystal River 3	15.6	601.0	B&W	BW	B	69	1	1	1	
5	Davis-Besse	17.9	605.0	B&W	BW	B/H	69	5	5	0	
6	Millstone 2	10.5	593.9	CE	CE	H	69	3	3	0	
7	North Anna 1	19.4	600.1	W	RDM	S	65	6	6	1	
8	North Anna 2	18.3	600.1	W	RDM	S	65	42	8	42	
9	Oconee 1	22.1	602.0	B&W	BW	B	69	3	3	2	4
10	Oconee 2	22.0	602.0	B&W	BW	B	69	19	18	4	
11	Oconee 3	21.7	602.0	B&W	BW	B	69	14	14	2	
12	St. Lucie 2	12.3	595.6	CE	CE	SS/H	91	2	2	0	5
13	Surry 1	18.6	597.8	W	BW/RDM	H	65	6	0	6	
14	TMI 1	17.5	601.0	B&W	BW	B	69	8	7	4	4
							Unique Penetration Totals	124	81	64	

NOTES:

1. Key for Vessel Fabricators: BW = B&W, CBI = Chicago Bridge & Iron, CE = Combustion Engineering, RDM = Rotterdam Dockyard, CL = C.L. Imphy
2. Key for Material Suppliers: B = B&W Tubular Products, H = Huntington, S = Sandvik, SS = Standard Steel, W = Westinghouse, CL = C.L. Imphy, A = Aubert et Duval
3. The totals reflect nozzles that were found to have cracks requiring repairs.
   Other than the 16 small-diameter B&W thermocouple nozzles at two plants, all the cracked nozzles detected are either CRDM or CEDM nozzles.
4. Also all 8 small-diameter B&W thermocouple nozzles were found to be cracked.
5. The CEDM nozzle material at this plant was supplied by Standard Steel, and the ICI nozzle material was supplied by Huntington Alloys.

Cracking Detected
Plants with Detected Cracking (cont'd)

- Cracking has been detected at 14 units:
  - 58 CRDM penetrations at 7 B&W plants having B&WTP material
    - mostly tube cracking but also some weld cracking
  - 54 CRDM penetrations at 3 Westinghouse plants having heads fabricated by Rotterdam Dockyards
    - mostly weld cracking
  - 12 additional CRDM and CEDM penetration tubes
    - 4 nozzles fabricated from a B&WTP heat of material at a Westinghouse plant
    - 3 nozzles fabricated from a heat of material processed by Westinghouse in a Westinghouse plant
    - 3 nozzles fabricated from Huntington Alloys material in a CE plant
    - 2 nozzles fabricated from Standard Steel material in a CE plant
  - 16 of 16 small-diameter thermocouple nozzles at periphery of head in 2 plants

Cracking Detected
Leakage and Boric Acid Wastage

Inspection Number	Unit	NSSS Supplier	Approx. EDYs at Insp.	Insp. Date	No. of CRDM Nozzles on Head	Number Leaking Penetrations (Note 1): Total	Due to Tube	Due to Weld	Repair Technique (Note 2)	Repair Method Would Likely Have Detected Significant Wastage?	Notes
1	ANO 1	B&W	19.6	Mar-2001	69	1	1	0	Embedded flaw	No	3
2			21.1	Oct-2002	69	1	1	0	ID temper-bead	Yes	4
3	Crystal River 3	B&W	16.2	Oct-2001	69	1	1	0	ID temper-bead	Yes	
4	Davis-Besse	B&W	19.2	Apr-2002	69	3	3	0	Replaced head	Yes	5
5	North Anna 1	W	21.4	Mar-2003	65	1	0	1	Replaced head	No	
6	North Anna 2	W	19.0	Nov-2001	65	3	0	3	Weld overlay	No	
7			19.7	Sep-2002	65	6	0	6	Replaced head	See Note 7	6, 7
8	Oconee 1	B&W	21.8	Nov-2000	69	1	0	1	Weld overlay	No	8
9			23.2	Mar-2002	69	1	0	1	ID temper-bead	Yes	
10	Oconee 2	B&W	22.2	Apr-2001	69	4	4	0	ID temper-bead	Yes	
11			23.7	Oct-2002	69	10	7	3	ID temper-bead	Yes	
12	Oconee 3	B&W	21.7	Feb-2001	69	9	9	0	ID temper-bead	Yes	
13			22.5	Nov-2001	69	5	5	0	ID temper-bead	Yes	
14	Surry 1	W	19.1	Oct-2001	65	2	0	2	ID temper-bead	Yes	
15	TMI 1	B&W	18.1	Oct-2001	69	5	1	4	ID temper-bead	Yes	9
					Unique Penetration Totals	51	31	20			

NOTES:

1. No CEDM, ICI, or other types of reactor vessel head nozzles have been found to be leaking (other than the B&W thermocouple nozzles at the two units that have this type of nozzle).
2. The "ID temper-bead" repair method for leaking nozzles involves cutting out the lower section of the nozzle, which makes the surface of the penetration hole in the head shell visible.
3. Although the 2001 repair of this nozzle would not have revealed the presence of low-alloy steel wastage, the subsequent repair in 2002 likely would have.
4. The leaking nozzle that was repaired in March 2001 was found to be leaking again in October 2002.
5. Detailed destructive examinations of the original Davis-Besse head have been performed to characterize the extent of wastage.
6. One of the leaking nozzles that was repaired in late 2001 was found to be leaking again in September 2002.
7. Several leaking nozzles have been extracted from the original North Anna 2 head and are expected to be examined for signs of wastage of the low-alloy steel shell material, among other tests.
8. Also 5 of the 8 small-diameter B&W thermocouple nozzles were found to be leaking.
9. Also all 8 small-diameter B&W thermocouple nozzles were found to be leaking.

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Cracking Detected
Orientation/Location for Tube Cracks

		No. of Indications on the Nozzle ID	No. of Indications on the Nozzle OD	*Total*
No. of Axial Tube Indications		112	224	*336*
No. of Circumferential Tube Indications	**Above Weld**	0	7	*7*
	Weld Elevation	0	12	*12*
	Below Weld	6	10	*16*
	Total	*118*	*253*	*371*

Note: Craze cracking and other shallow indications with no depth detectable by UT are not included.

Cracking Detected
Circumferential Nozzle Cracking

Circumferential Nozzle Cracking Above or Near the Top of the Weld

				Inspection Results							
Unit	NSSS Design	Nozzle ID	Nozzle Angle (°)	Date	Approx. EDYs	OD/ ID	Axial Location	Circ. Angle (°)	UH/DH Side	Depth (in)	TW Depth (%)
Crystal River 3	B&W	32	26.2	Oct-01	16.2	OD	above weld	91	DH	0.29	47%
Davis-Besse	B&W	2	8.0	Mar-02	19.2	OD	above weld	34	DH	0.31	50%
North Anna 2	W	15	19.8	Sep-02	19.7	OD	≥1.12" below root	5	DH	0.23	36%
		41	33.1			OD	≥0.52" below root	46	DH	0.10	16%
		54	38.6			OD	≥0.04" below root	79	UH	0.23	36%
						OD	≥0.28" below root	32	DH	0.16	25%
		59	40.0			OD	≥0.31" below root	76	DH	0.15	24%
						OD	≥0.32" below root	50	UH	0.15	24%
		65	42.6			OD	≥0.32" below root	72	DH	0.15	24%
						OD	≥0.20" below root	30	UH	0.08	12%
		67	42.6			OD	≥0.80" below root	44	DH	0.09	15%
Oconee 2	B&W	18	18.2	Apr-01	22.2	OD	above weld	36	DH	0.07	11%
Oconee 3	B&W	11	16.2	Feb-01	21.7	OD	over weld	153	DH	0.36	57%
						OD	over weld	113	UH	0.25	40%
		23	23.2			OD	above weld	66	DH	0.22	35%
		50	35.1			OD	above weld	165	UH	0.62	pin holes
		56	35.1			OD	above weld	165	UH/DH	0.62	100%
		2	8.0	Nov-01	22.5	OD	above weld	48	DH	0.18	29%
		26	24.7			OD	over weld	44	DH	0.07	11%

Cracking Detected
Summary

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- About 51 CRDM nozzles have been found to be leaking:
  - All in the “> 12 EDY” category
  - 40 of 483 (8.3%) CRDM penetrations in 7 B&W plants
  - 11 CRDM penetrations in 3 heads fabricated by Rotterdam Dockyards, all due to weld cracking
- Little or no wastage has been detected except for the Davis-Besse experience
  - 42 of the leaking CRDM nozzles were repaired in a manner such that if significant boric acid wastage had occurred, it would likely have been detected
- As expected based on the welding residual stress analyses, the nozzle cracking is primarily axial
  - 35 of 371 detected nozzle flaws are circumferential
  - Only 2 circ flaws above or near top of weld are through-wall

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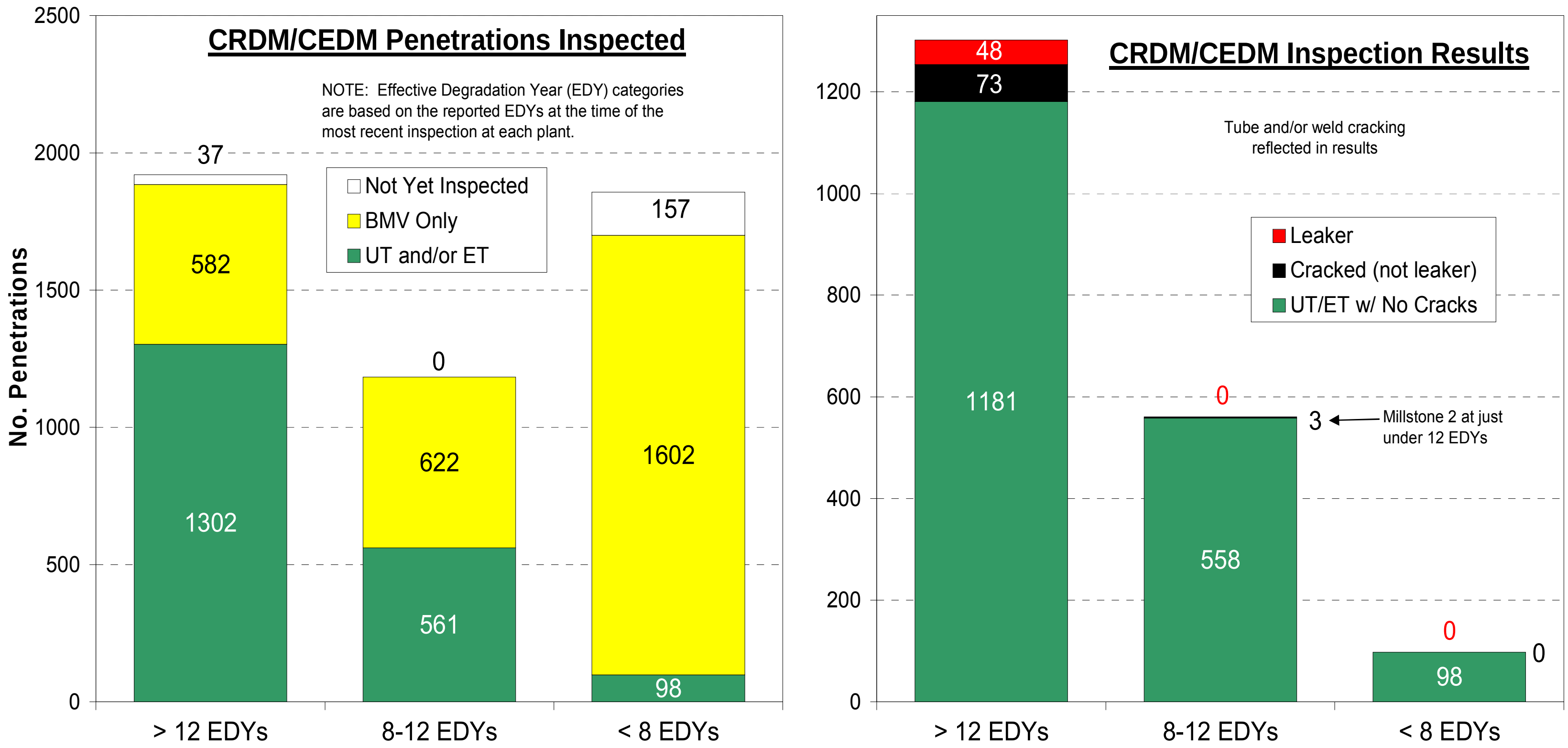
Subpopulation Statistics
Introduction

- The summary statistics on the following slides are for inspections performed over the period from December 2000 through August 2003
  - Following first leak detected late 2000
  - After awareness of nozzle cracking originating on the nozzle OD below the weld and of weld cracking
- The left bar chart on each slide indicates the inspection status totals
  - Some nozzles in the 5 heads already replaced were never inspected by a nonvisual technique
- The right bar chart on each slide indicates the result totals for the nonvisual NDE inspections
  - All nozzles found to be leaking were also inspected using a nonvisual technique

Subpopulation Statistics
By EDY Group



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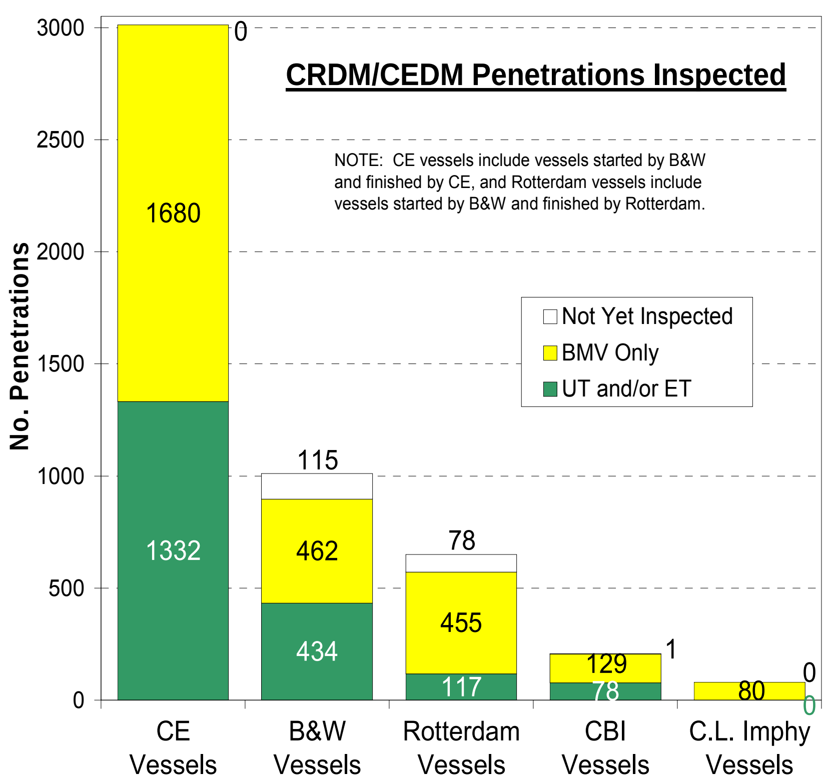
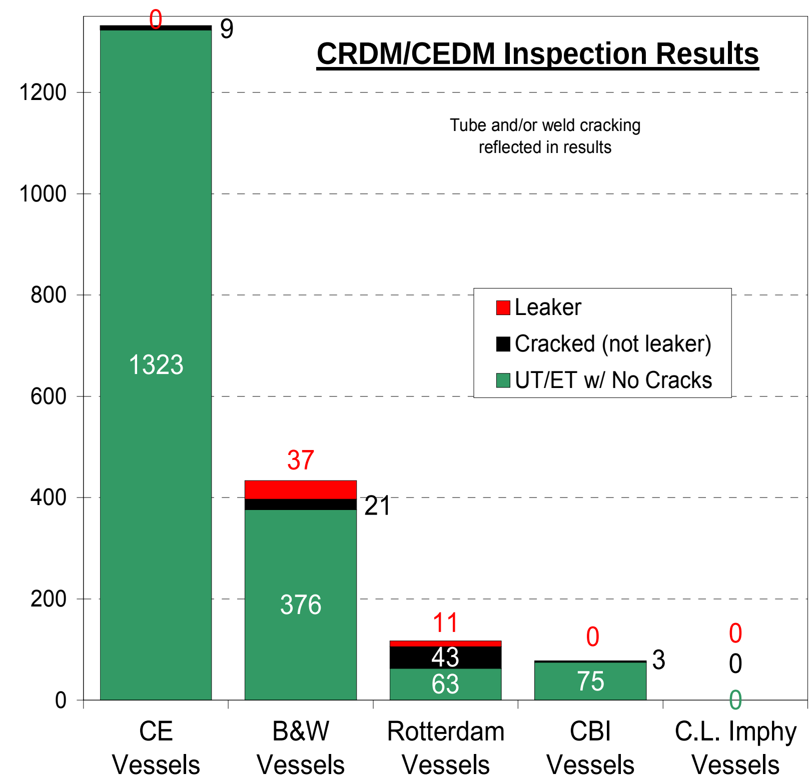
Subpopulation Statistics
By Head Fabricator (All EDY)





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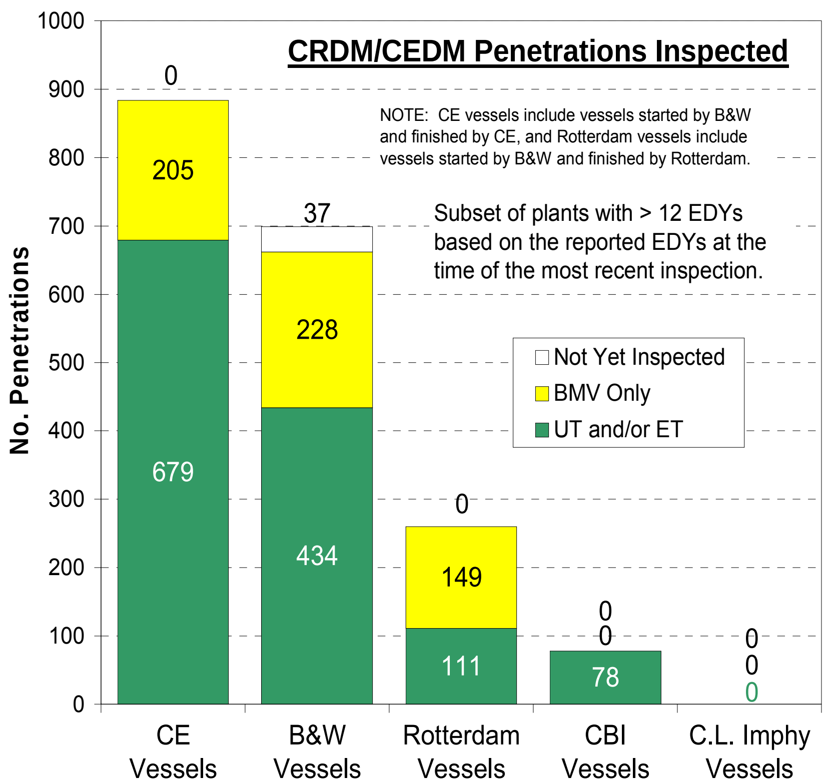
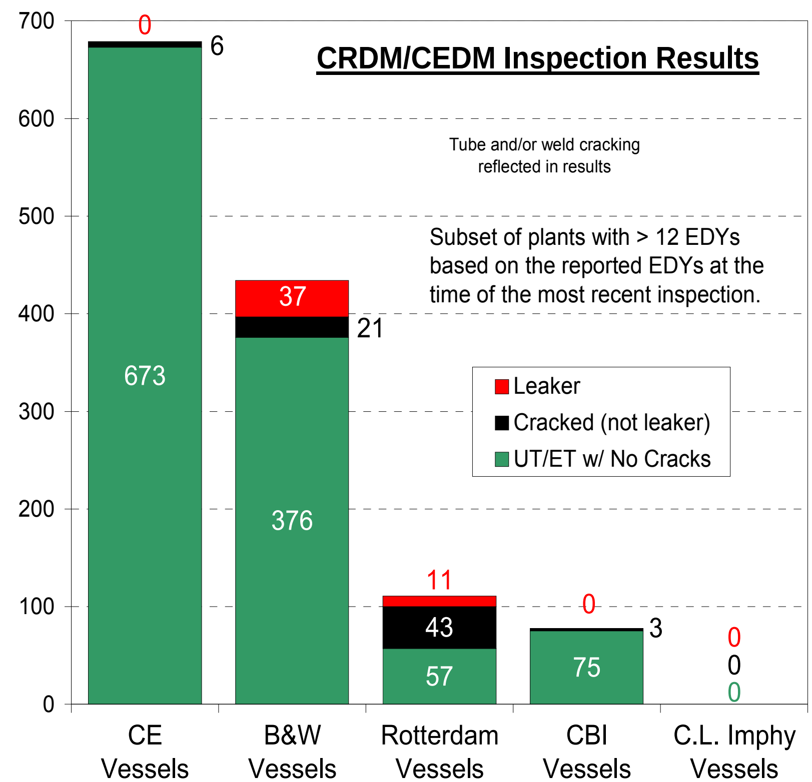
Subpopulation Statistics
By Head Fabricator (>12 EDYs)





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Subpopulation Statistics
By Nozzle Mat'l Supplier (All EDY)

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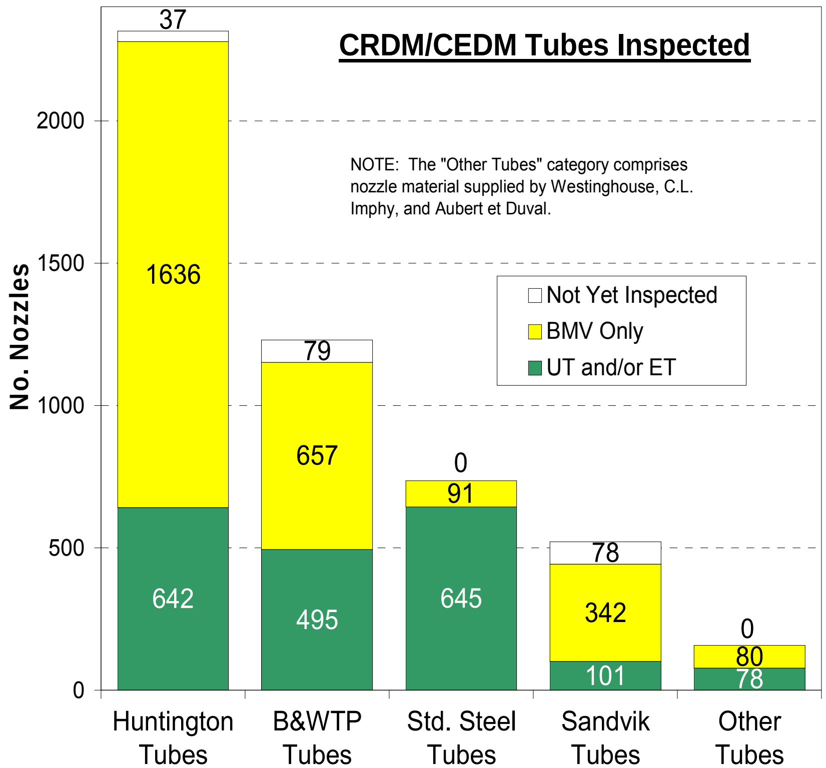
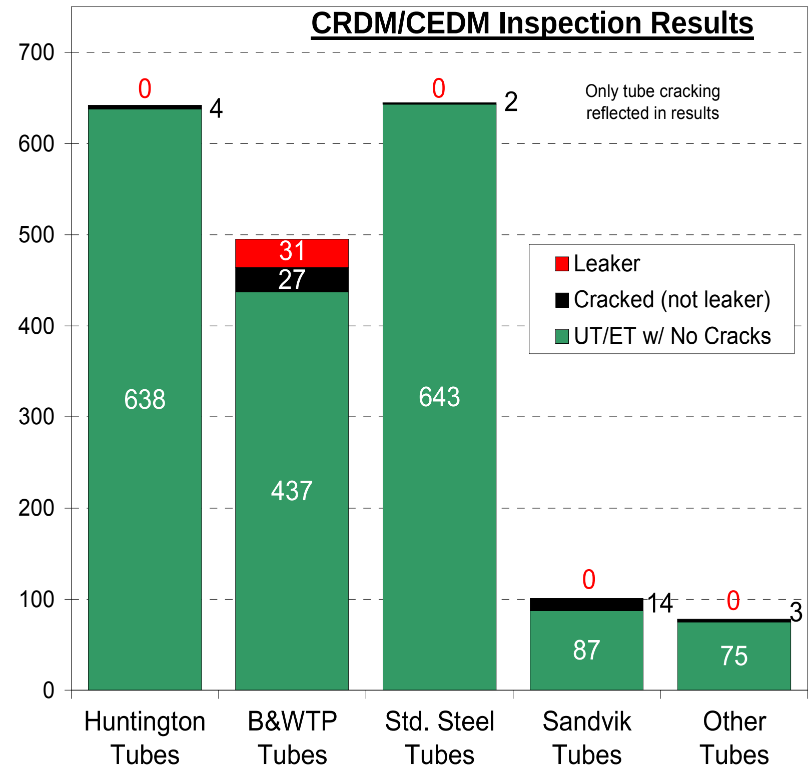
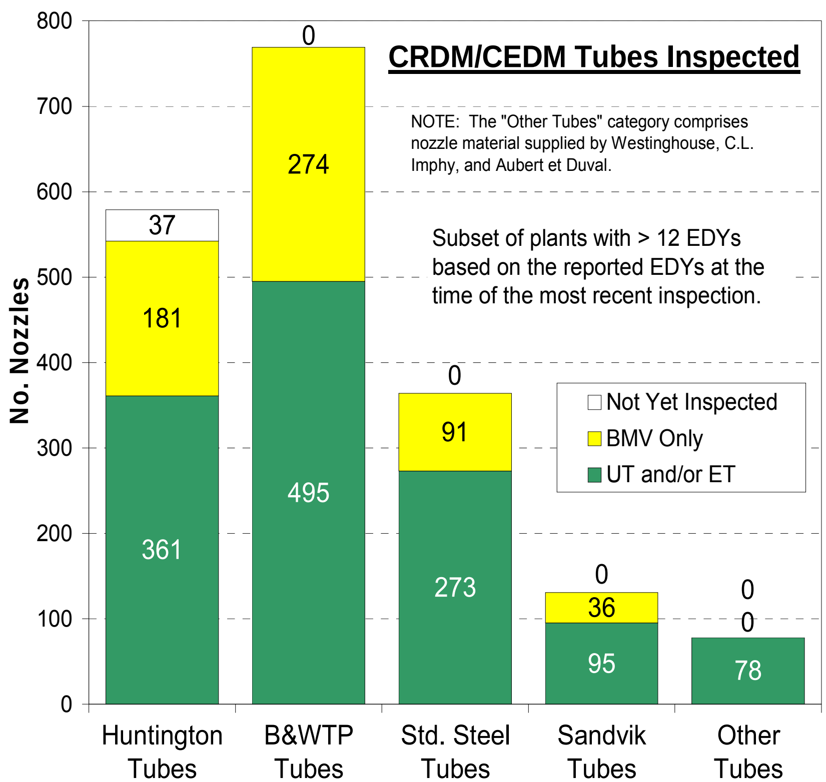
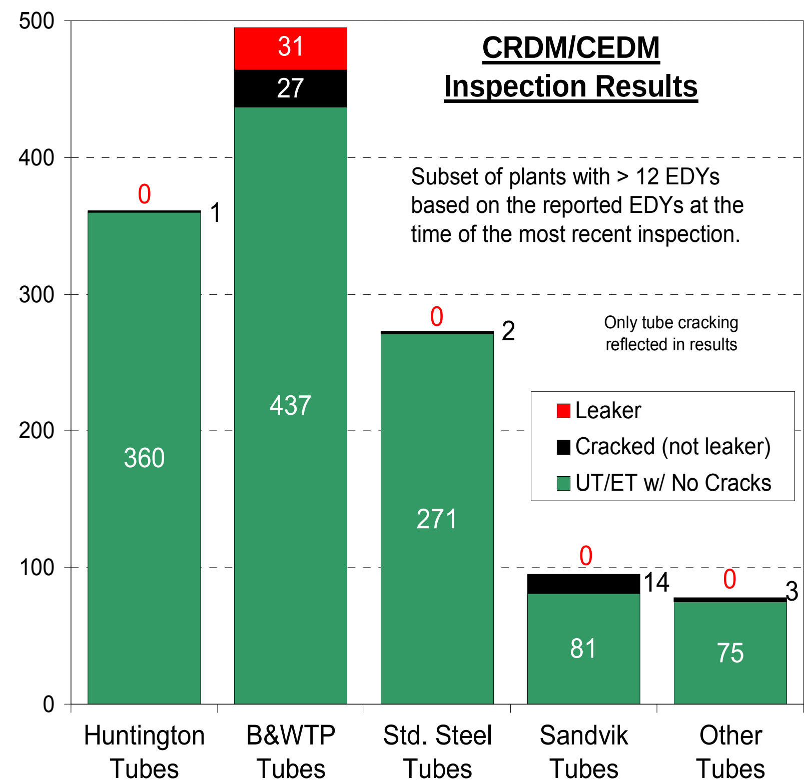




EPRI

Subpopulation Statistics
By Nozzle Mat'l Supplier (>12 EDYs)





Subpopulation Statistics
Summary

- The 51 leaking CRDM penetrations and all but 12 of the 124 cracked penetrations detected are from the 15 highest ranked units on the basis of time at temperature
- Incidence of cracking in heads fabricated by CE is relatively low:
  - 9 of 1332 (0.7%) penetrations in CE-fabricated heads inspected nonvisually have shown cracking
  - 58 of 434 (13%) penetrations in B&W-fabricated heads inspected nonvisually have shown cracking
  - 54 of 117 (46%) penetrations in Rotterdam-fabricated heads inspected nonvisually have shown cracking
  - Comparisons for EDY groups show that these differences reflect more than just EDY differences

Subpopulation Statistics
Summary (cont'd)

- Incidence of cracking in nozzle tubes fabricated from material supplied by Huntington Alloys or Standard Steel is relatively low
  - 6 of 1287 (0.5%) nozzles in this category inspected nonvisually have shown cracking
  - 58 of 495 (12%) nozzles fabricated from B&W Tubular Products material inspected nonvisually have shown cracking
  - Comparisons for EDY groups show that these differences reflect more than just EDY differences
- Detected weld cracking has been limited to vessels fabricated by Rotterdam Dockyards and B&W-designed units

Planned Replacements & Inspections
Announced Head Replacements

Announced Head Replacement Plans as of September 2003

Status	Year	Season	No.	Unit Name
Already replaced	2002	Fall	1	Davis-Besse
			2	North Anna 2
	2003	Spring	3	North Anna 1
			4	Oconee 3
			5	Surry 1
Replacing next refueling outage		Fall	6	Crystal River 3
			7	Ginna
			8	Oconee 1
			9	Surry 2
			10	TMI 1
	2004	Spring	11	Oconee 2
		Fall	12	Farley 1
			13	Kewaunee
			14	Turkey Point 3
Replacing after next refueling outage	2005	Spring	15	Millstone 2
			16	Point Beach 2
			17	Turkey Point 4
		Fall	18	ANO 1
			19	Farley 2
			20	Point Beach 1
			21	Robinson 2
			22	St. Lucie 1
	2006	Spring	23	Beaver Valley 1
			24	Calvert Cliffs 1
			25	St. Lucie 2
		Fall	26	Cook 1
			27	Fort Calhoun
	2007	Spring	28	Calvert Cliffs 2
		Fall	29	Cook 2

Planned Replacements & Inspections *Summary*

- 27 units have refueling outages this fall:
  - 5 will replace their heads with new heads having Alloy 690 material
  - About 6 plants in the “8-12 EDY” and “> 12 EDY” categories are expected to perform nonvisual inspections of all nozzles
- After fall 2003, it is expected that:
  - BMV and/or nonvisual NDE examinations will have been performed on all RV head nozzles
  - 28 of the 29 plants in the NRC’s high susceptibility category (> 12 EDYs or detected cracking) will have completed baseline nonvisual examinations or head replacement
  - 6 of the 16 plants in the NRC’s moderate susceptibility category (8-12 EDYs) will have completed baseline nonvisual examinations
- After fall 2005, all 46 plants with > 8 EDYs are expected to have completed baseline nonvisual examinations or head replacement

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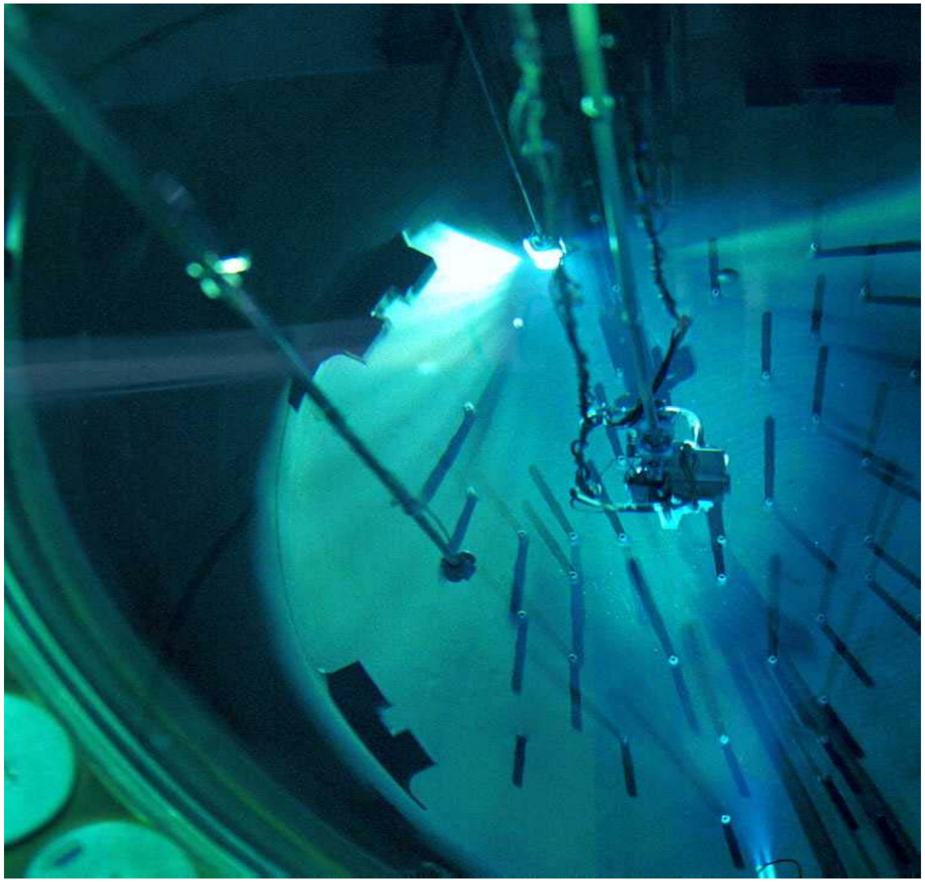
Conclusions

- Time at temperature is an important susceptibility factor
- The head fabricator and nozzle material supplier are also significant factors
  - Relatively little nozzle cracking has been detected in heads fabricated by CE using nozzle material supplied by Huntington Alloys or Standard Steel
  - No weld cracking has been detected in heads fabricated by CE
  - The reasons for these effects are not clear but likely are associated with material and fabrication processing parameters such as:
    - Annealing temperature, cooling rate, and effect on microstructure
    - Straightening practices during nozzle fabrication
    - Machining practices, surface cold work, and fabrication-related defects
    - Welding procedure details

Inspection Technology for BMI Penetrations

M. S. Lashley, South Texas Project, R. F. Cole, and S. W. Glass, Framatome ANP Inc.



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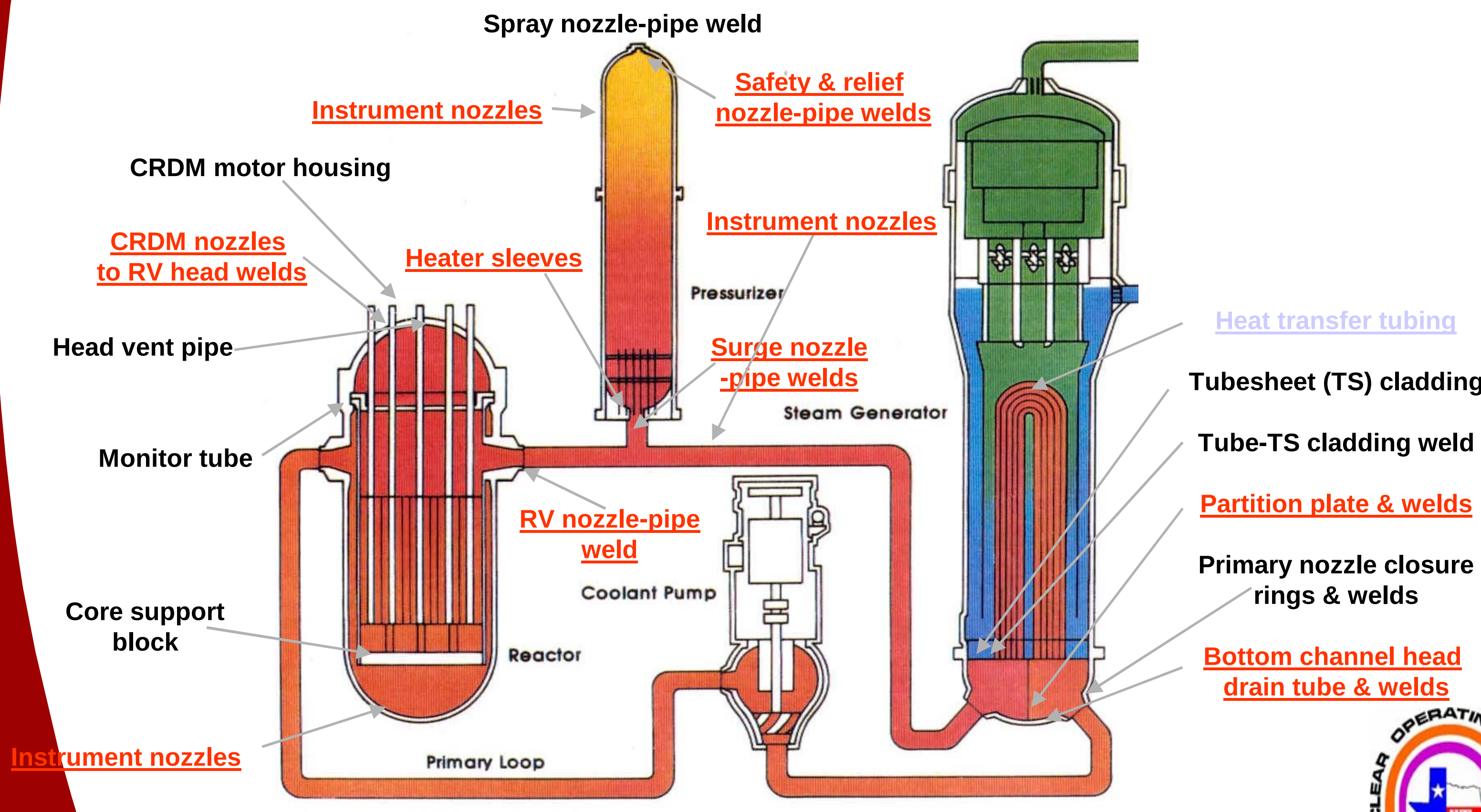
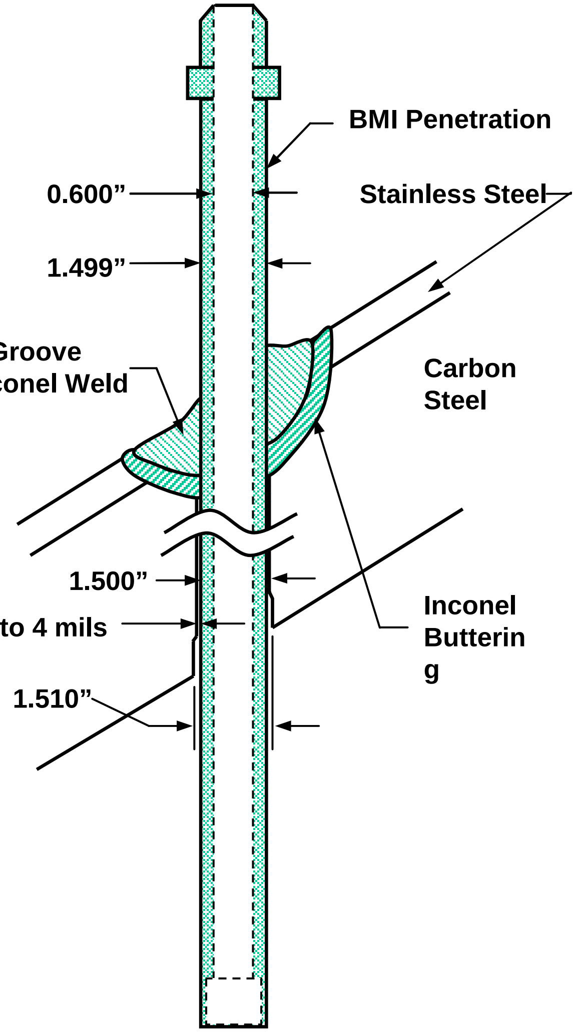
Typical Alloy 600 locations



* Represents locations that have experienced cracking and or leakage at other PWRs are highlighted in red.

BMI Guide Tube Penetration



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In France, EDF commissioned development of BMI ultrasonic inspection methods and has performed more than 500 examinations since 1992. Framatome has participated in all of these examinations. The 4 columns represent the type of UT examinations performed. Until the South Texas project, no confirmed leaking tubes had been detected.

Plant - Unit	TOFD C	TOFD L	OL 0° base	OL 0° Comp.
TRICASTIN 1	**49**	**22**		
BUGEY 3	**50**	**50**		
FESSENHEIM 2	**50**	**50**		**11**
BUGEY 2	**50**	**50**		**16**
NOGENT 1	**58**	**58**		**26**
BLAYAIS 3	**50**	**50**		**22**
BUGEY 3	**50**	**50**	**50**	
TRICASTIN 2	**50**	**50**	**50**	
GRAVELINES 4	**50**	**50**	**50**	
PALUEL 1	**58**	**58**	**?**	**?**
FLAMANVILLE 1	**58**	**58**		**13**
GRAVELINES 1	**50**	**50**		**3**
SOUTH TEXAS 1	**58**	**58**	**58**	
Total	681	654	208	91

Comprehensive Examination Performed Using Industry Experts

- UT from penetration tube ID
- Enhanced visual exam of J-groove weld surface
- Volumetrically interrogate vessel base metal for wastage
- ET from penetration tube ID
- ET of J-groove weld surface
- Profilometry
- Borescope examinations
- Helium tests
- Metallurgical analyses of removed nozzle remnants
- Boat sample analyses

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Unit 1 Reactor Vessel Bottom Head

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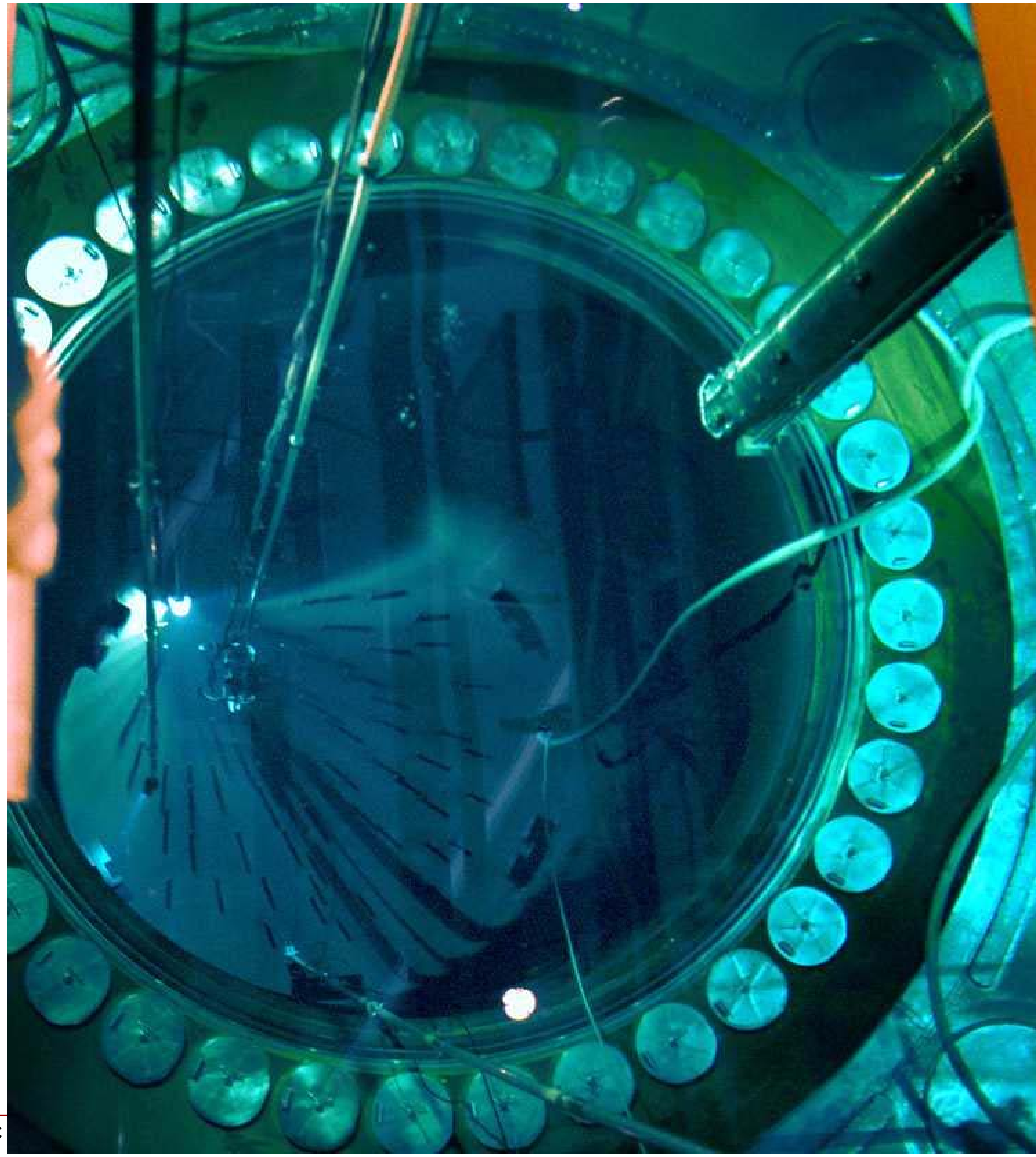

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Penetration Overview

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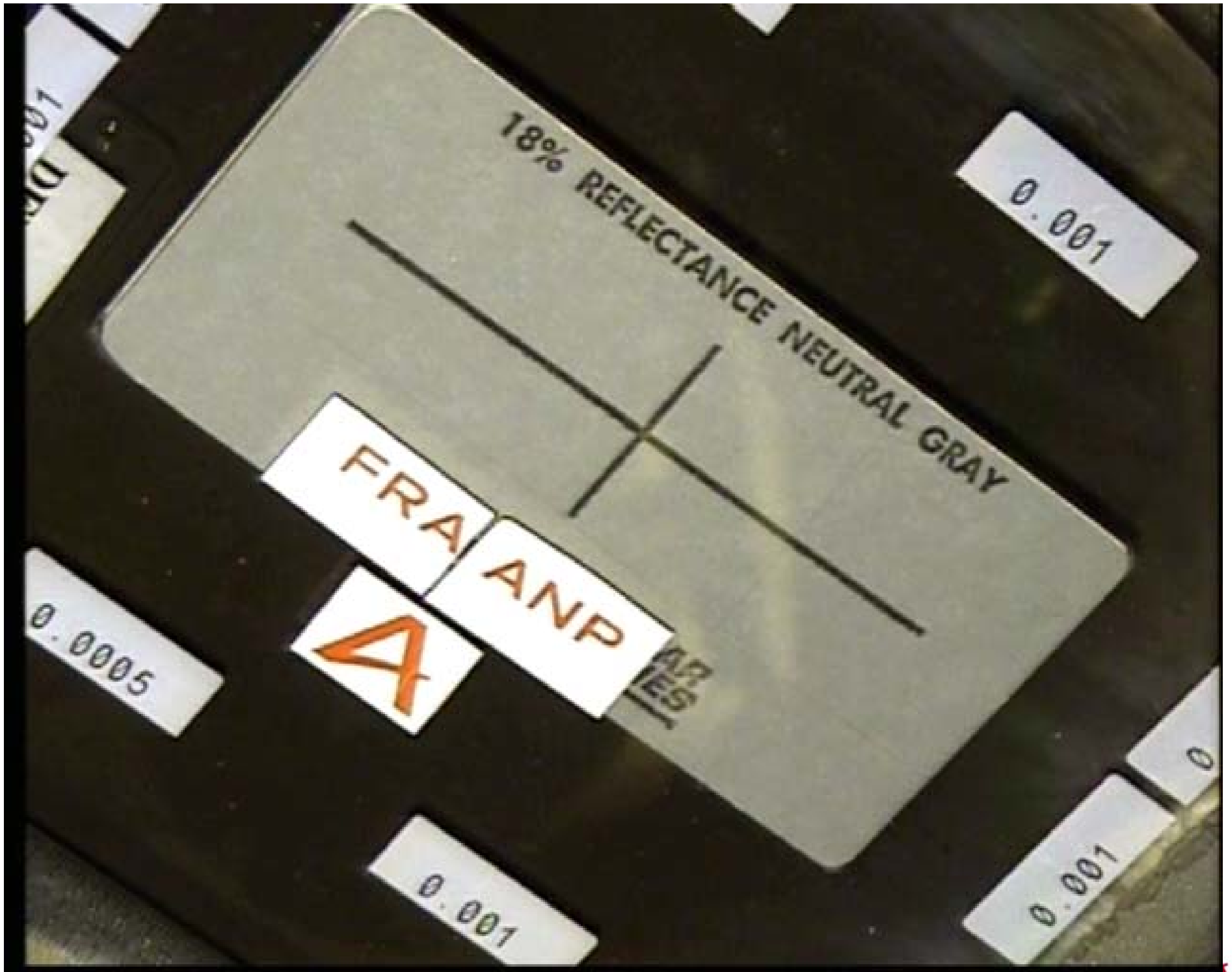
Enhanced Visual



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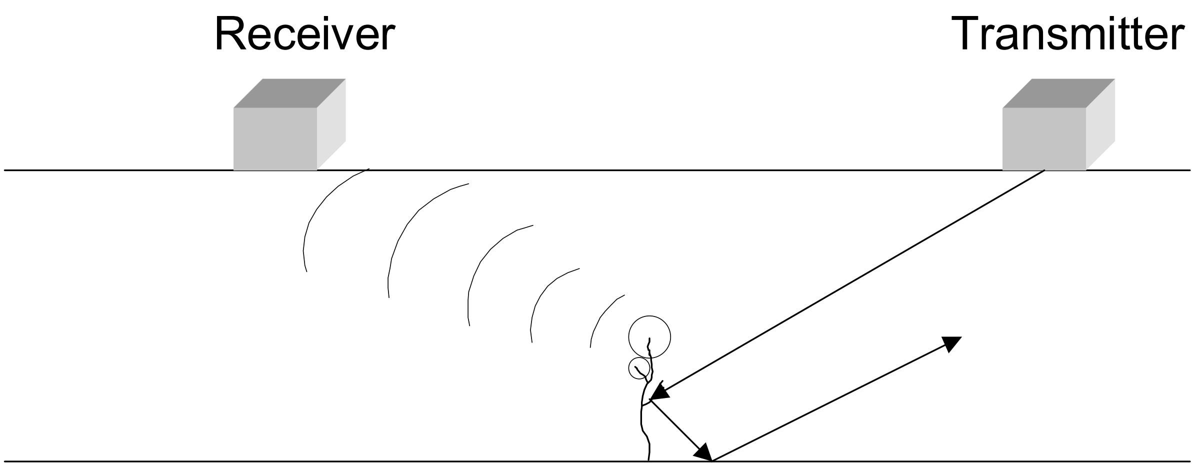
The South Texas project BMI inspection was performed with THE French tool. Subsequently, the US division has developed a second tool that incorporates improvements dictated by experience with the French tool.

French UT Probe Delivery Tool

US UT Probe Delivery Tool

STP NUCLEAR OPERATING COMPANY

Time of Flight Diffracted (TOFD)



Low-amplitude, secondary wave generated by excitation of flaw

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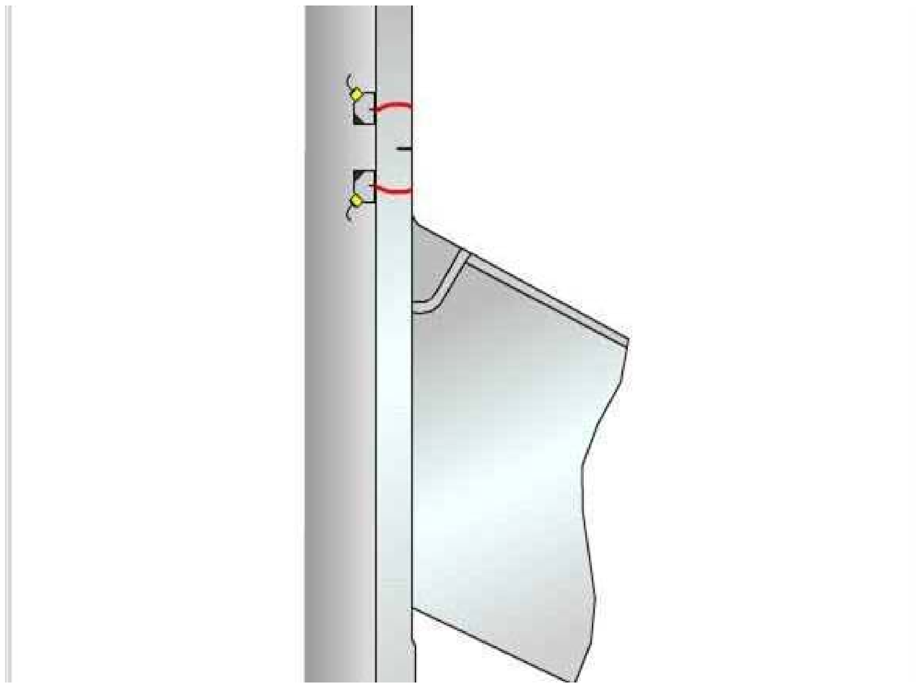
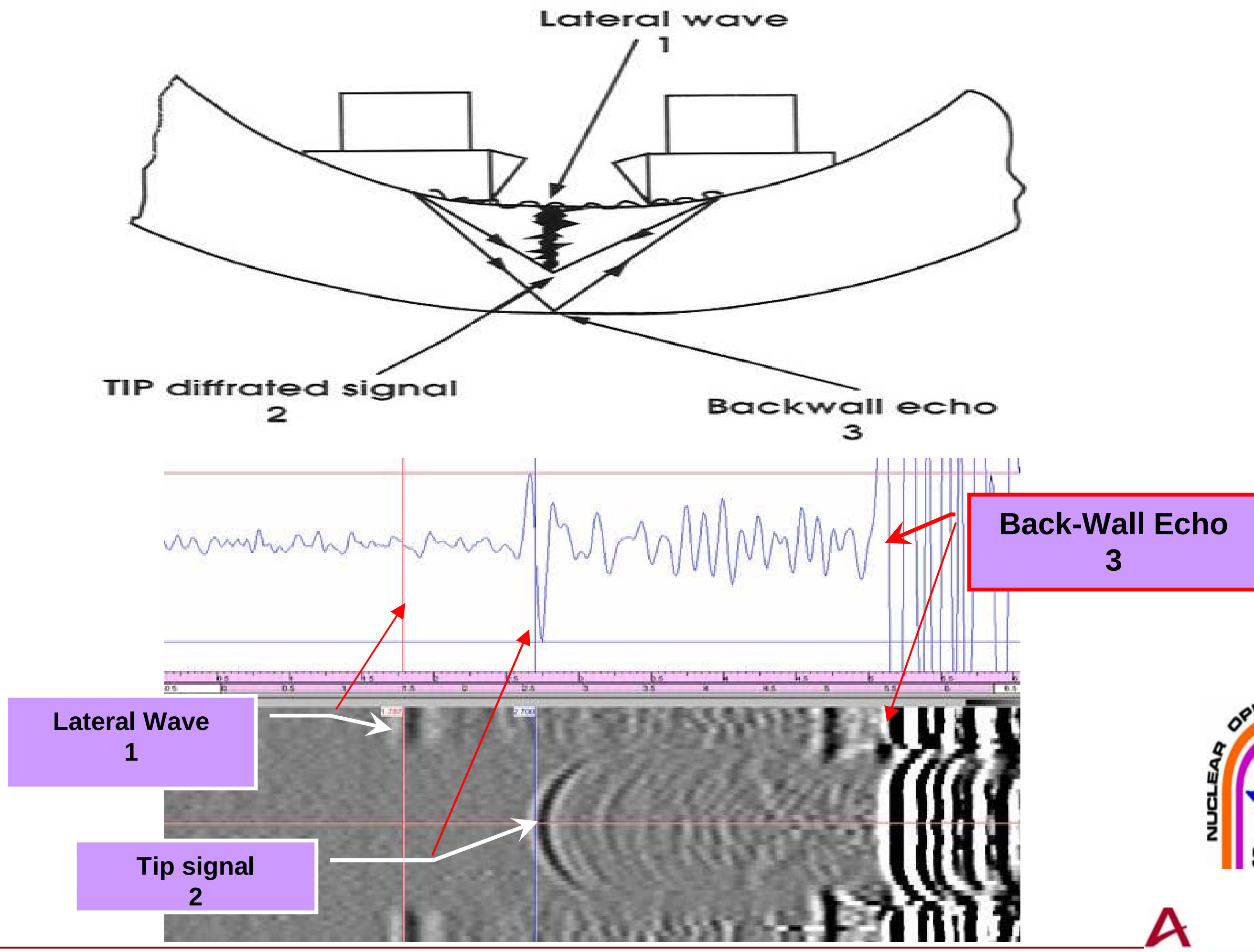
TOFD Animation



Double click in box to start animation when in "slide-show-presentation mode", accept warning, then enlarge by dragging corner to display full screen

TOFDT (Time Of Flight Diffraction Technique)



Demonstration Protocol

- Scope
  - Detection and sizing of axial and circumferential flaws in the tube
    - » Isolated flaws
    - » Axial and circumferential flaws in conjunction
    - » ID and OD flaws
  - Discrimination of flaws from sources of false calls
  - Flaw locations relative to component geometry

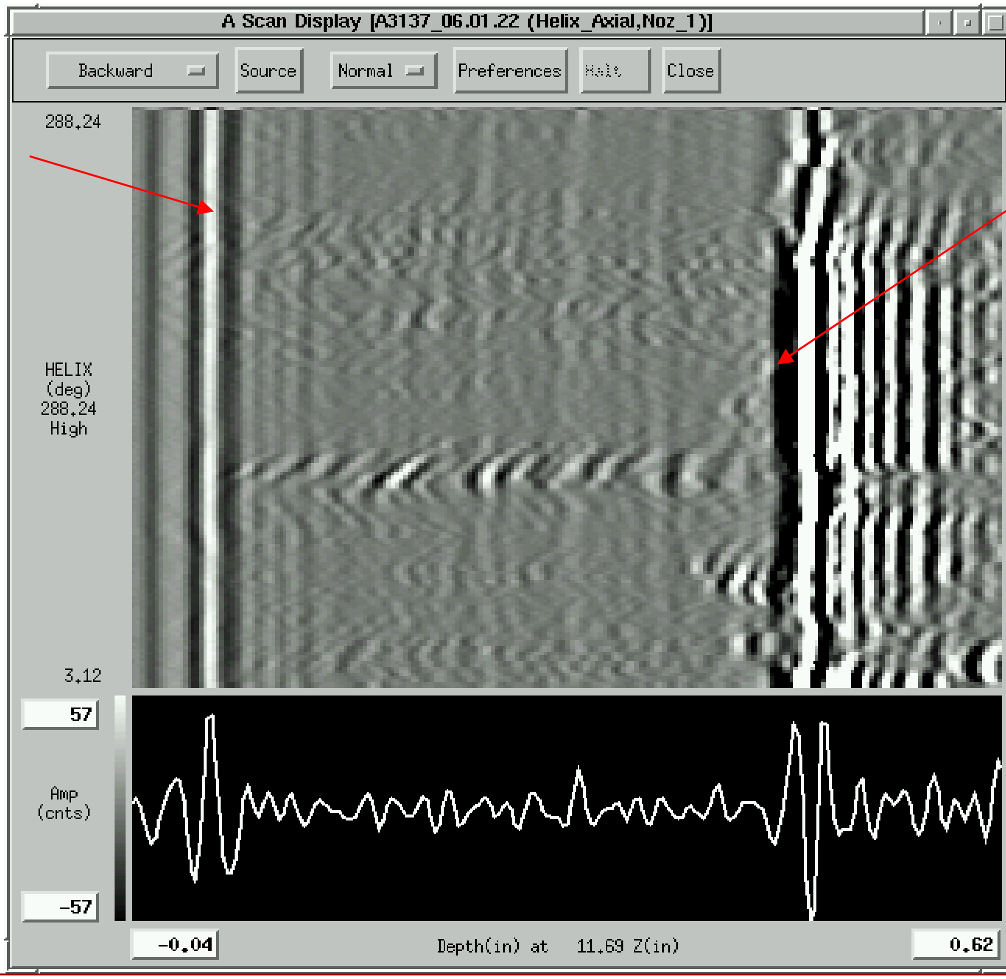
Demonstration Protocol (cont'd)

- Process - follows MRP process for VHP demos
  - Phase 1 (open/non-blind)
    - » Allow refinement of procedures under realistic, controlled conditions
    - » Allow analysis of results to determine and improve capabilities of individual techniques within the procedure
      - Detection, sizing, location
  - Phase 2 (monitored/blind)
    - » Demonstrates capability
      - Detection, sizing, location

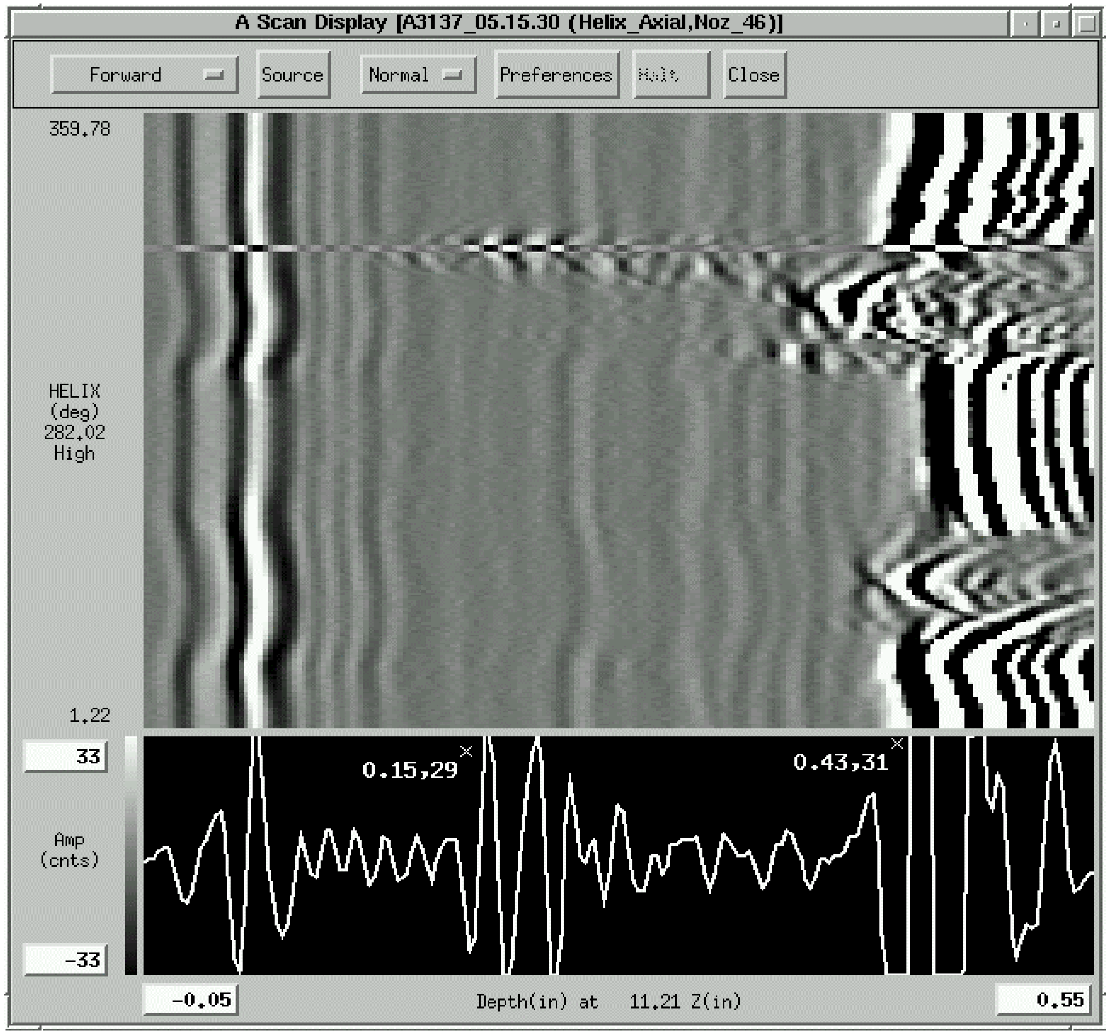
Penetration #1 Axial Probe

Tube ID

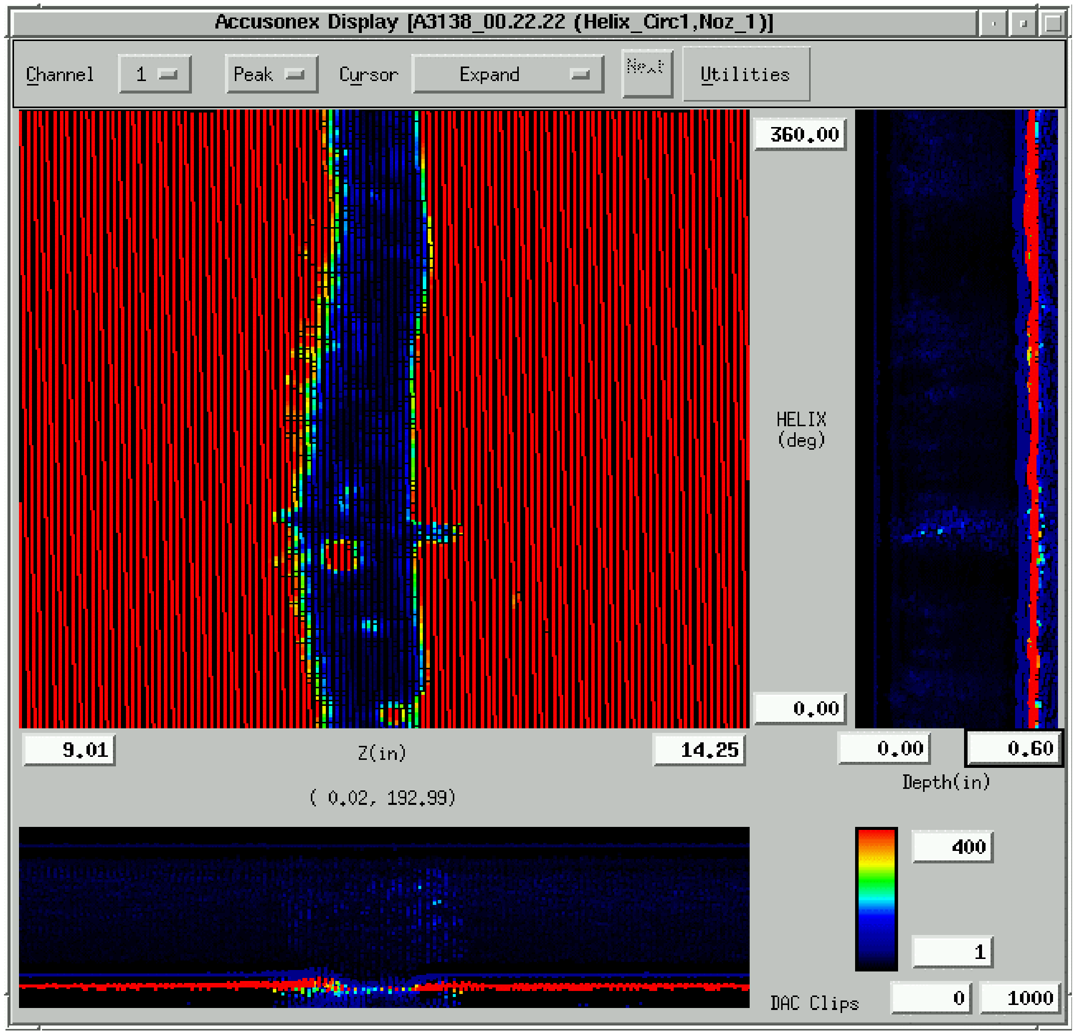
Tube OD



Penetration #46 Axial Scan



Penetration #1 Weld Profile



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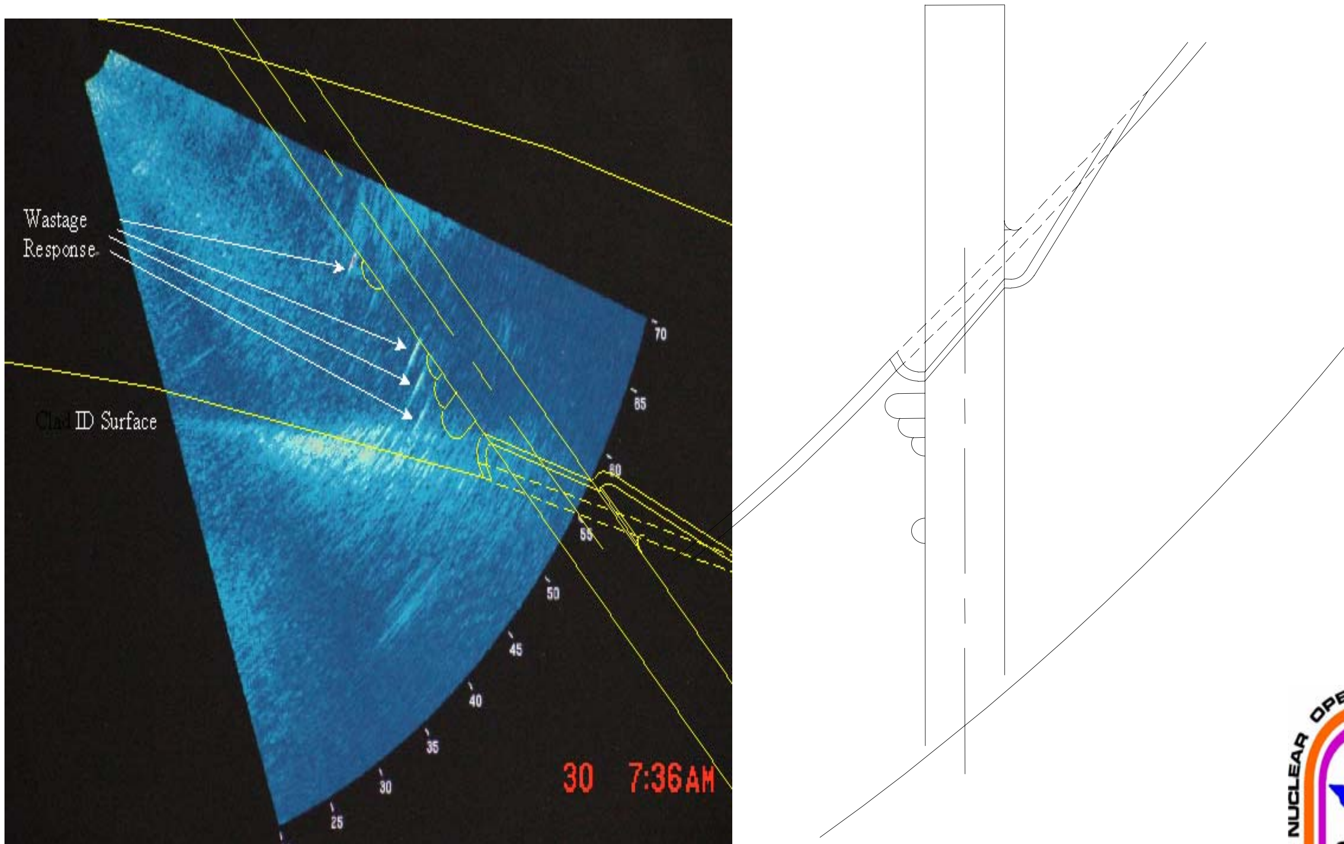
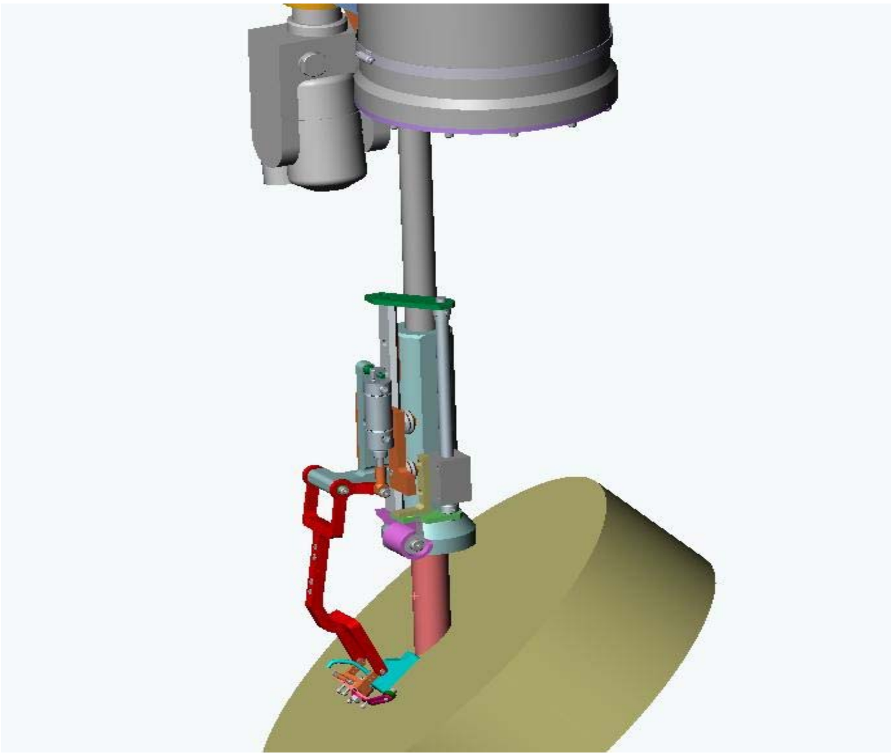
Phased Array UT to Identify Wastage



Eddy Current J-Groove Probe

Incore J-Groove Eddy Current



Examination Matrix

Techniques	Benefits
UT - circ	Most beneficial tool to detect and size flaws of different depths, lengths, and orientation.
UT - axial	Very beneficial to detect and size flaws
UT - 0	Good tool to discriminate between weld defects and cracks
EVT-1	Beneficial to detect surface indications with 0.0005 inch opening
UT - PA	Very beneficial to interogate complex geometry of the annulus
ET - J groove	Beneficial to detect and length size surface breaking flaws, can be limited due to surface contour and fillet region
ET - bobbin	Benficial to detect and length size surface breaking flaws
ET - profilometry	Technique limited to detecting tube deformation
VT - borescope	Minimum benefit
He leak test	Good test to confirm location

Framatome Continuing Development for BMI Nozzle NDE

- Improved UT probes for
  - combined circ and ax inspection
  - multiple probe designs developed, optimized, and tested for various tube IDs and wall thickness
  - improved fabrication techniques for lower cost and higher reliability
- Lessons learned improvements in EC tool and probe.
- Improved bare-metal examination tools & methods - particularly for difficult-to-remove insulation.
- Additional tools fabricated to be better prepared for emergent examinations should they be required.
- Planning begun for integrated 10-year ISI and BMI examination.

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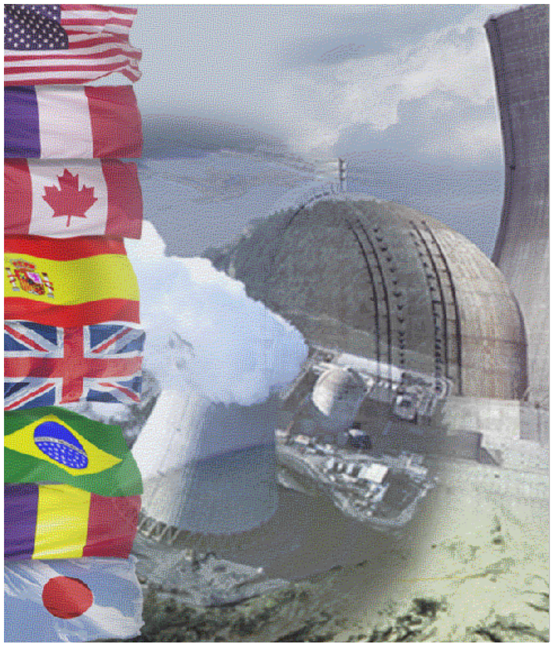
Summary of NDE

- Technology exists
- Limited quantity of tools
- TOFD is a highly capable technique
- Advancements have been made to interrogate the J groove surface and the annular region
- Framatome Development continues to assure tools are ready to meet additional BMI inspection challenges should the need arise



EPRI MRP Alloy 600 RPV Head Penetration Inspection Demonstration Program

Tom Alley, Duke Energy

E. Kim Kietzman

Frank Ammirato

EPRI

Conference on Vessel Head Penetration Inspection, Cracking, and Repairs

September 29-October 1, 2003

Gaithersburg, MD

CRDM Head Penetration NDE Background

- Original (97-01) demonstrations addressed cracks initiating on the inside surface of the penetration only
- Discovery of tube OD and weld cracking and BMI leakage identified the need to modify & extend the NDE demonstration program
  - Inspection technology required rapid development, deployment and field adaptation of existing inspection equipment
- First phase of MRP demonstrations was available to support fall 2001 inspections
  - Detection of “safety-significant” flaws in the tube
  - Qualify delivery devices
- Second phase performed to support fall 2002
  - J-groove weld flaws
  - More base metal flaws to evaluate depth sizing
  - Increase number of mockups available for training/practice
  - Extended into 2003
- BMI nozzle NDE demonstration program initiated

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MRP Visual Examination Guidance

- EPRI MRP Inspection Committee Task
  - Develop visual inspection training package for fall 2001
    - Published as TR report
  - Updated TR was published for spring and Fall 2002 inspections
  - Will be updated to incorporate results/lessons learned from Fall 2003 BMI visual inspections, false call data

MRP Approach to NDE Demonstrations

- Head Penetration WG defines NDE objectives using analytical evaluations and service experience:
  - Identify relevant flaw mechanisms
  - Define inspection locations & volumes (e.g., OD, ID)
  - Define ranges of flaws to address (depth, length, orientation)
- Inspection WG develops demonstration program
  - Approach
  - Mockup design & procurement
    - Specifications for flaws in mockups
    - Realism of mockups (geometry, distortion, clearance, access, scratches, magnetic deposits, etc.)
  - Demonstration protocol & schedules (blind/non-blind, scope, result reporting process)
  - Publish results
  - Interpret results

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MRP Approach to Demonstrations, cont.

- All VHP NDE demonstrations since 1994 have had common characteristics:
  - Blind
    - Supported by non-blind preparation phases
  - Procedure only,
    - no personnel qualifications
  - Capability measurements only
    - no acceptance (pass-fail) criteria

MRP Approach to Demonstrations, cont.

- Demonstration protocol
  - Vendor collects data on mockups & reports findings to NDE Center
  - NDE Center evaluates measured -vs.- true values
    - Detection (# detected/total flaws)
    - Location with respect to pressure boundary
    - Sizing
    - False call performance
    - Coverage
  - NDE Center documents procedure essential variables
  - Decision logic must be captured in the procedure and used during the demonstration
  - Results are published &n communicated to utilities who are required to protect vendor proprietary information

MRP Demonstrations – Results

- Complex examination volume
- Vendor procedures include many technique options and probe combinations, examples:
  - Rotating probes
  - Blade probes
    - Probes are designed to accomplish specific objectives:
      - Specific volumes
      - Flaw orientations
      - Detection technique, e.g.., corner trap or tip diffraction
      - Sizing technique
- MRP Demonstrations document performance of individual probes/scans
  - More than one probe may be required to examine the specified inspection volume to detect/size specified flaw locations and orientations

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MRP Activities - Volumetric Examination Demonstration Program

- Fall 2001 demonstrations
  - Focus - Detection of "Safety-Significant" flaws in the tube base metal
  - Three vendors participated
    - Wesdyne
      - Blade-probe and Open-tube UT and ET
    - Framatome
      - Blade-probe and Open-tube UT and ET
    - Tecnatom
      - Blade-probe and Open-tube UT and ET

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2001 Demonstration Description

- Mock-ups
  - Field-removed- Oconee CRDM Penetration Samples
    - Demonstrate flaw detection
    - Good range of flaw sizes and orientation
      - OD Circumferential (up to 45 degrees off-axis),
      - OD Axial
      - ID Axial
  - Full-scale mock-up
    - Demonstrates effects of weld & capability to address geometry
    - Important examination considerations
      - Flaw location relative to weld
      - Flaw clusters
      - Triple-point indications

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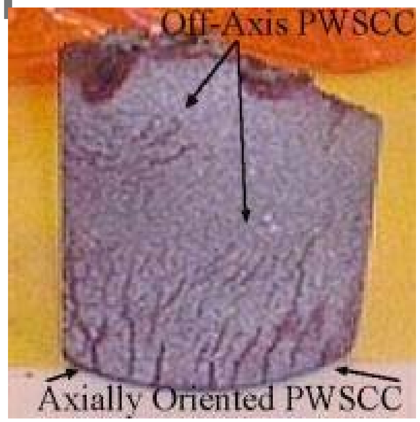
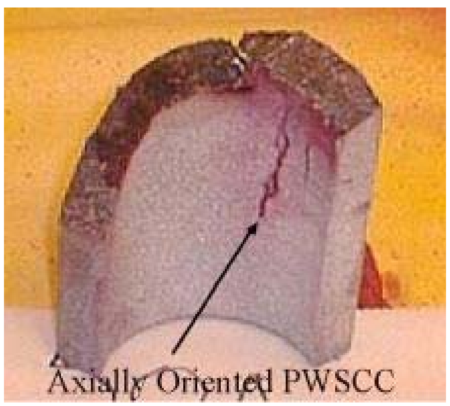
Oconee Specimens

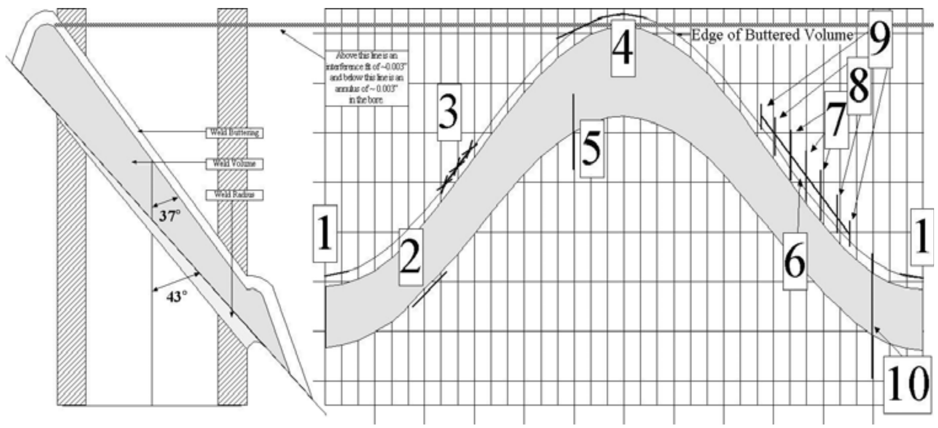


- Specimen #56
  - OD-initiated PWSCC
    - Range of sizes & locations
  - Off-axis flaws (~45 degrees) are representative of circumferential flaw in outermost penetration



- Specimen #50
  - ID-initiated PWSCC

2001 Full-Scale Mock-up



♦#1 & 4 – Circ. above weld. Corner trap one direction only. Min. skew angle. This circ position exhibits maximum distortion during fabrication, affecting UT contact.

♦#2 – Circ. Below weld. No corner trap when UT oriented down. Near max skew angle.

♦#3 – Circ. flaw at max skew. Cross-hatch simulates PWSCC affecting corner-trap

♦#5 & 10– Axial flaw. Corner-trap lost over weld. Maximum distortion.

♦#6,7, 8, 9 – Circ. & axial combination.

2001 Demonstration Results

- Results distributed periodically by MRP
- Results summarize the capability of numerous probe types
  - Blade probes of various types, focal depths, frequencies, probe sizes & scanning directions
  - Rotating probes
  - Probes are designed to accomplish specific objectives:
    - Specific volumes, e.g, tube ID, OD or mid wall
    - Flaw orientations (Axial/Circumferential)
    - Detection technique, e.g., corner trap or tip diffraction
- In most cases, multiple demonstrations were supported
    - changing inspection requirements
    - equipment modifications and updates

Example Results

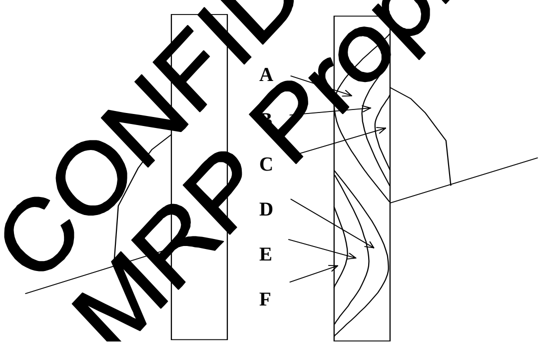
Example Detailed Summary Table

Summary of Detection Techniques	A OD to ID	B OD to mid-wall	C Shallow OD-initiated	D ID to OD	E ID to mid-wall	F Shallow ID-initiated	Weld Mapping	♦ Procedure # & Date	Demonstration Date
	e CRDM Demonstrations conducted for 97-01 (ID flaws).								
BP TOFD for Axial flaws (7 mhz)					D, S	D, S	M	EN [illegible].4.1 GEN 3 ***(1)***	02/1994
BP TOFD for Circ Flaws (7 mhz)					D, S	D, S	[illegible]	[illegible]N 2.4.1 GEN 3 ***(1)***	02/1994
BP ID ET					D, S	D, S	N/A	***(1)***	02/1994
RP TOFD for Axial Flaws (7 mhz)					D, S	D, S	M	EN 2.4.1 GEN [illegible] ***(1)***	02/1994
RP ID ET					D, S	D, S	N/A	***(1)***	02/1994
RP TOFD for Axial (7 mhz)					D, S	D, S	M	[illegible]AM[illegible]-062 ***(2)***	12/1996
RP ID ET					D, S	D, S	N/A	STD-[illegible]MD-061 ***(2)***	12/1996
BP TOFD for Axial flaws 10 mhz PCS 10 w/RD-Tech System					D, S	D, S	[illegible]	[illegible]B 447, Rev. 3 05/08/2000 ***(3)***	05/2000
BP TOFD for Axial flaws 6 mhz PCS 18 w/RD-Tech System					D, S	D, S	[illegible]	PB 447, Rev. 3 05/08/2000 ***(3)***	05/2000
BP TOFD for Circ flaws 10 mhz PCS 10 w/RD-Tech System					D, S	D, S	N/A	PB 447, Rev. 3 05/08/2000 ***(3)***	05/2000
BP TOFD for Circ flaws 6 mhz PCS 18 w/RD-Tech System					D, S	D, [illegible]	M	PB 447, Rev. 3 05/08/2000 ***(3)***	05/2000
BP ID ET					[illegible] S	D, S	N/A	***(3)***	05/2000
	WesDyne CRDM [illegible]emonstrations conducted for MRP (OD flaws).								
BP TOFD for Axial flaws 6 mhz PCS 18 & PCS 24 w/RD-Tech System	***(4)***	***(4)***	***(4)***	***(4, 5)***	***(4, 5)***	***(4, 5)***	M	ISI-UT-002, Rev.0, 09/2001 ***(6)***	09/2001
BP TOFD for Circ flaws 6 mhz PCS 18 & PCS 24 w/RD-Tech System	***(4)***	***(4)***	***(4)***	***(4, 5)***	***(4, 5)***	***(4, 5)***	M	ISI-UT-002, Rev.0, 09/2001 ***(6)***	09/2001
BP PE for Circ flaws w/RD-Tech System	***(4, [illegible]***	***(4, 7)***	[illegible]	N/A	N/A	N/A	N/A	ISI-UT-002, Rev.0, 09/2001 ***(6)***	09/2001
BP TOFD for [illegible]xial flaws 6 mhz PCS 18 w/Intraspect S[illegible]stem	***(4, 5)***	***[illegible], 5)***	OR	***(4, 5)***	***(4, 5)***	***(4, 5)***	M	ISI-UT-002, Rev.0, 09/2001 ***(6)***	01/2002
BP TOFD for [illegible]ial Fl[illegible]ws 6 mhz PCS 24 w/Intraspect System	OR	[illegible]	D	***(4, 5)***	***(4, 5)***	***(4, 5)***	M	ISI-UT-002, Rev.0, 09/2001 ***(6)***	01/2002
BP TOFD for Circ flaws 6 mhz PCS 18 w/Intraspect System	***(4, 5)***	***(4, 5)***	OR	***(4, 5)***	***(4, 5)***	***(4, 5)***	M	ISI-UT-002, Rev.0, 09/2001 ***(6)***	01/2002
BP TOFD for Circ Flaws 6 mhz PCS 24 w/Intraspect System	[illegible]R	D	D	***(4, 5)***	***(4, 5)***	***(4, 5)***	M	ISI-UT-002, Rev.0, 09/2001 ***(6)***	01/2002
RP TOFD (only 5 mhz PCS 24 demonstrated) w/Intraspect System	OR	D	D	***(4, 5)***	***(4, 5)***	***(4, 5)***	M	WDI-UT-008, Rev.0 01/2002 ***(6)***	01/2002

Notes for Table:

BP: Blade Probe UT/ET.
TOFD: Time-of-Flight-Diffraction UT
PE: Pulse-Echo UT
D: Detected flaw successfully in Oconee specimens or EPRI 97-01 mock-ups. The 97-01 flaws were demonstrated to have similar ET and UT characteristics to PWSCC.
S: Sized flaw successfully in EPRI 97-01 mock-ups. The 97-01 flaws were demonstrated to have similar ET and UT characteristics to PWSCC. Sizing of OD initiated flaws not currently addressed by the MRP demonstration.
M: Weld mapping demonstrated with 97-01 mockups.
RP: Rotating Probe UT/ET.
OR: Outside depth range of probe desig[illegible].

(1)



Demonstrations for 2002

- Demonstration Scope
  - Flaw characterization capabilities
    - Depth sizing
    - Length sizing
    - Location with respect to weld
  - Increased population of flaws
  - Attachment weld flaws
    - Identification of flaws reaching triple-point
      - Creating leak path
  - Effect of Cluster flaws
    - Masking flaws in remaining tube volume

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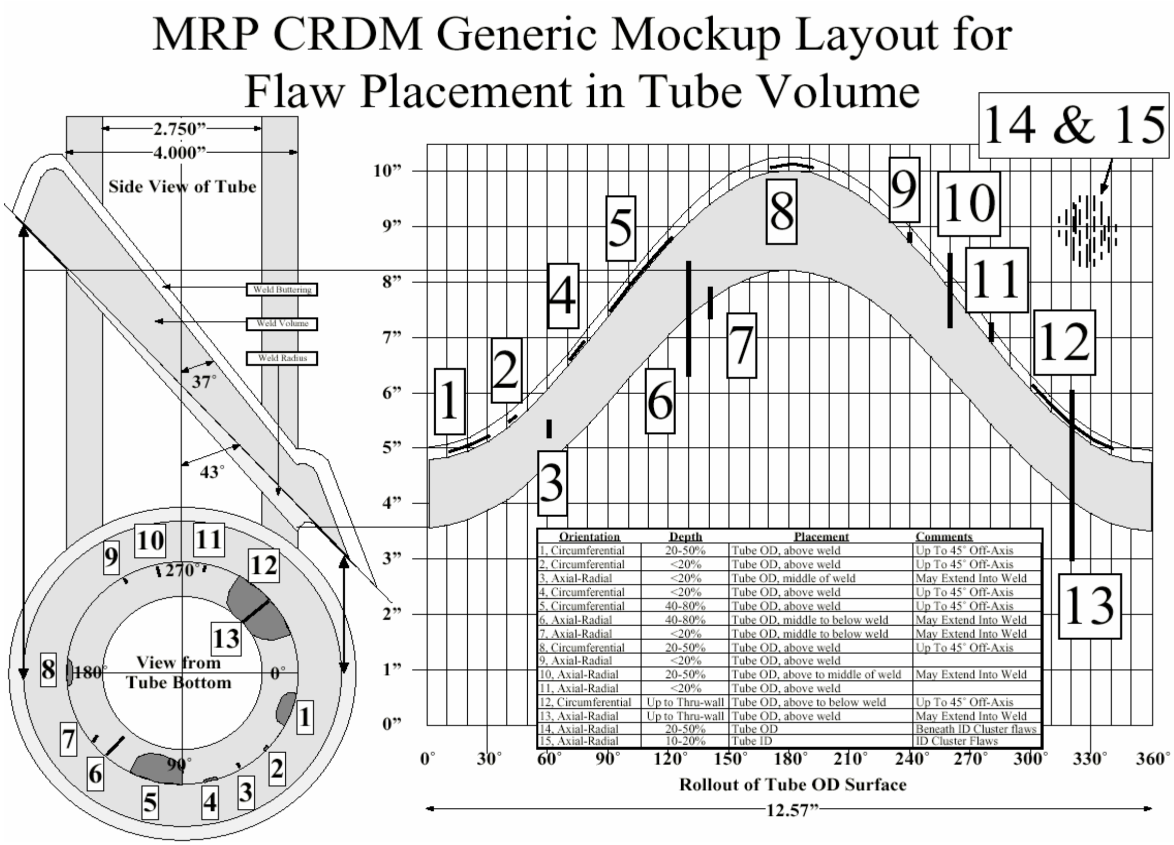
2002 CRDM VHP Mockups

- Flaw types determined by MRP Inspection/Assessment Committees
  - Axial, circ, & off-axis tube flaws
    - Library of flaws spanning full range of depth/length
  - Cluster flaws in tube
    - Library of flaws spanning full range of depth/length
  - Axial & circ. attachment weld flaws
    - Library of flaws spanning full range of depth/length
    - Located at weld/head & weld/tube interface
      - Most challenging geometry
    - Flaws approaching & thru triple-point
      - Allowing leak point to annulus

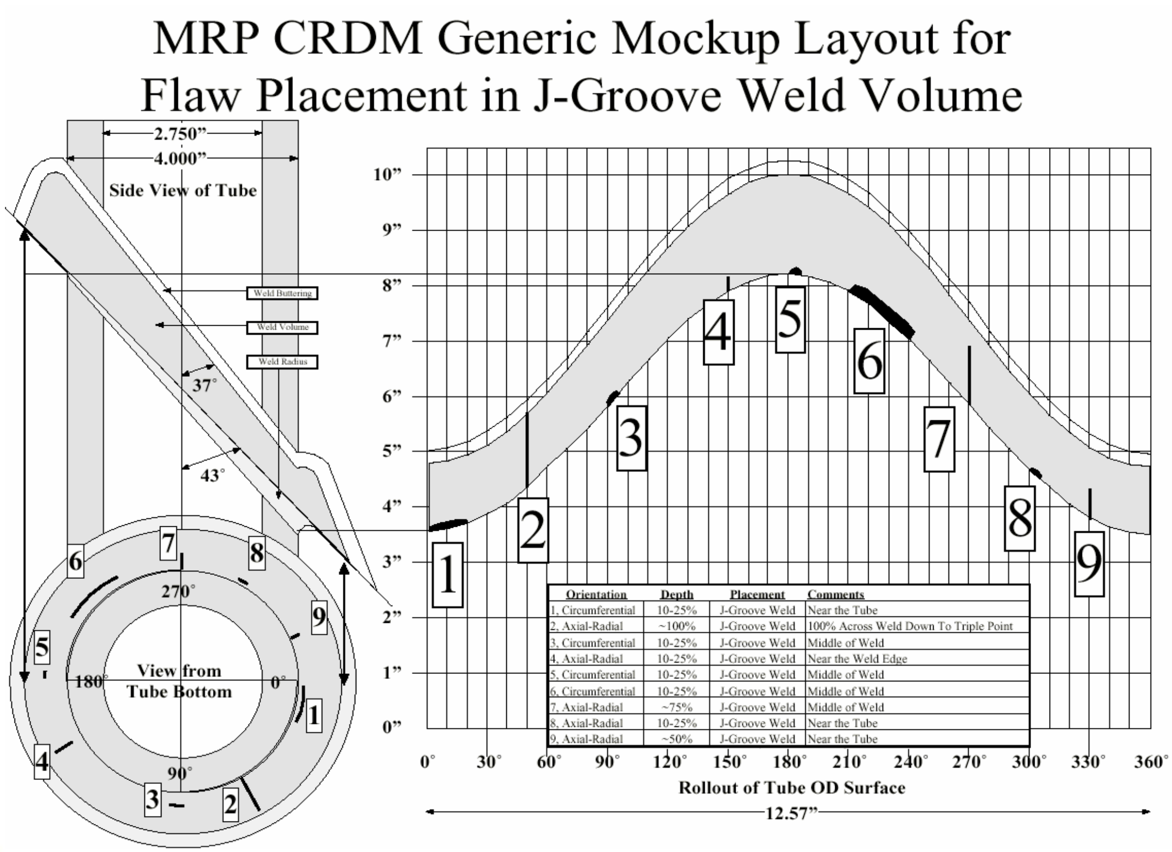
2002 Mock-up – Tube Flaws- Schematic



Orientation	Depth	Placement	Comments
1, Circumferential	20-50%	Tube OD, above weld	Up To 45° Off-Axis
2, Circumferential	<20%	Tube OD, above weld	Up To 45° Off-Axis
3, Axial-Radial	<20%	Tube OD, middle of weld	May Extend Into Weld
4, Circumferential	<20%	Tube OD, above weld	Up To 45° Off-Axis
5, Circumferential	40-80%	Tube OD, above weld	Up To 45° Off-Axis
6, Axial-Radial	40-80%	Tube OD, middle to below weld	May Extend Into Weld
7, Axial-Radial	<20%	Tube OD, middle to below weld	May Extend Into Weld
8, Circumferential	20-50%	Tube OD, above weld	Up To 45° Off-Axis
9, Axial-Radial	<20%	Tube OD, above weld	
10, Axial-Radial	20-50%	Tube OD, above to middle of weld	May Extend Into Weld
11, Axial-Radial	<20%	Tube OD, above weld	
12, Circumferential	Up to Thru-wall	Tube OD, above to below weld	Up To 45° Off-Axis
13, Axial-Radial	Up to Thru-wall	Tube OD, above weld	May Extend Into Weld
14, Axial-Radial	20-50%	Tube OD	Beneath ID Cluster flaws
15, Axial-Radial	10-20%	Tube ID	ID Cluster Flaws

NOTE: Flaw locations and sizes are shown only to describe typical types of flaws to be included in blind mockups. Actual flaw sizes and locations are confidential. Drawing is not to scale.

2002 Mock-up – Weld flaws-Schematic



Orientation	Depth	Placement	Comments
1, Circumferential	10-25%	J-Groove Weld	Near the Tube
2, Axial-Radial	~100%	J-Groove Weld	100% Across Weld Down To Triple Point
3, Circumferential	10-25%	J-Groove Weld	Middle of Weld
4, Axial-Radial	10-25%	J-Groove Weld	Near the Weld Edge
5, Circumferential	10-25%	J-Groove Weld	Middle of Weld
6, Circumferential	10-25%	J-Groove Weld	Middle of Weld
7, Axial-Radial	~75%	J-Groove Weld	Middle of Weld
8, Axial-Radial	10-25%	J-Groove Weld	Near the Tube
9, Axial-Radial	~50%	J-Groove Weld	Near the Tube

NOTE: Flaw locations and sizes are shown only to describe typical types of flaws to be included in blind mockups. Actual flaw sizes and locations are confidential. Drawing is not to scale.

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2002 Mock-up Selection Considerations

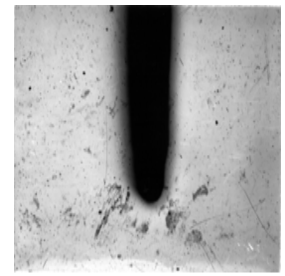
- Mock-up flaws must be representative and appropriate for the NDE Method(s) to be demonstrated
  - Need to provide representative responses for:
    - UT
      - Specular reflection, Tip-diffracted response, Corner-trap response
    - ET
      - Realistic electromagnetic properties, crack width
- Goal is realistic reproduction of Key detection or sizing variables
  - Any differences are monitored and considered during the demonstration
- Challenge: Numerous NDE methods are being applied & numerous flaw types/exam volumes to be considered

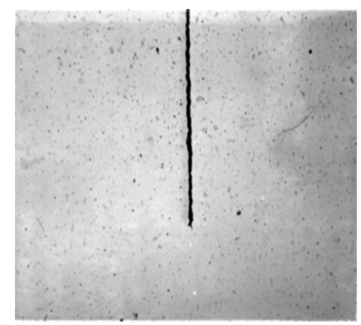
2002 Mock-up Flaws Selected

- CIP
  - Appropriate for ET
    - Tight, no unrealistic electromagnetic features
  - Appropriate for UT,
    - Comparable tip response
      - Most important - primary method of detection
    - Best control of flaw dimension
    - Realistic irregularity of flaw face in 600 tube
    - Branching simulated by using multiple flaws
- Accelerated Corrosion Cracks
  - Combined with CIP, will provide range of crack widths
  - No unrealistic electromagnetic features

Manufactured Flaws - CIP

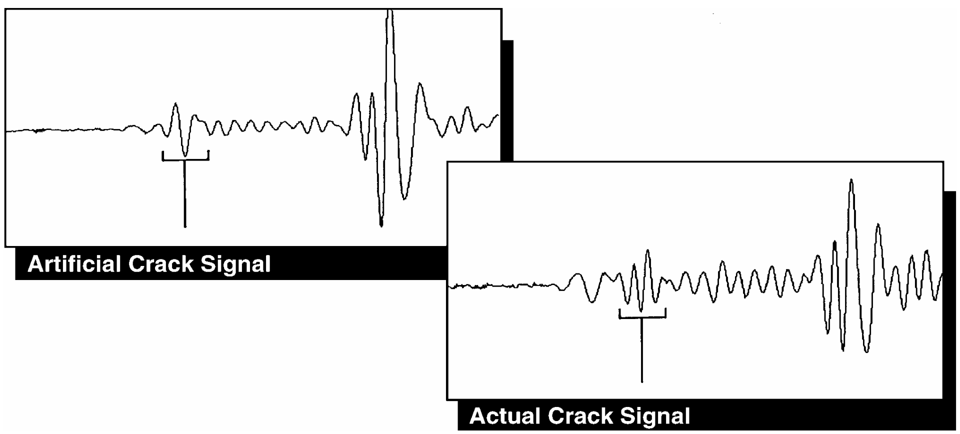
- CIP processed EDM notches, used in previous 97-01 demonstrations
  - Cold isostatic processing (CIP) "squeezes" notch
    - Sharpens tip
    - Reduce width to crack-like dimension
    - Induce crack-like faceting
  - Reduced temperature (< HIP) will not totally close flaw or alter electromagnetic properties that affect ET responses
  - Very good control of:
    - Flaw length, depth & position.
    - Width (affects UT & ET responses)
    - Photos show notch before and after CIP processing





Manufactured Flaws – CIP cont..

- Demonstrated that UT and ET responses & dynamic characteristics were equivalent to flaws removed from Bugey VHP penetration



- Subsequent field data has confirmed equivalence

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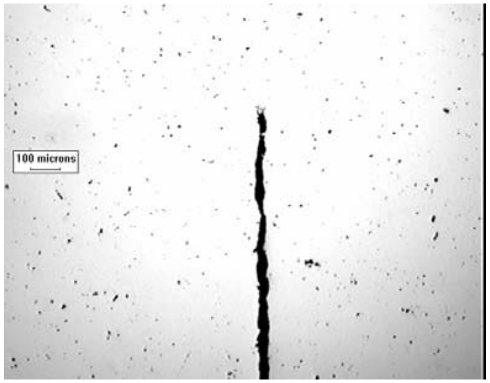
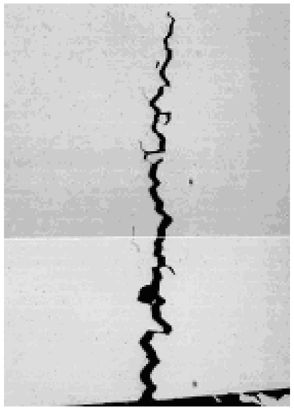
CIP Flaw Mock-ups – Technical Basis

- Photos show field-removed flaw (top) & CIP flaw
- Tip of CIP flaw has similar crack tip size
- Ultrasonic tip response equivalent to findings from several plants





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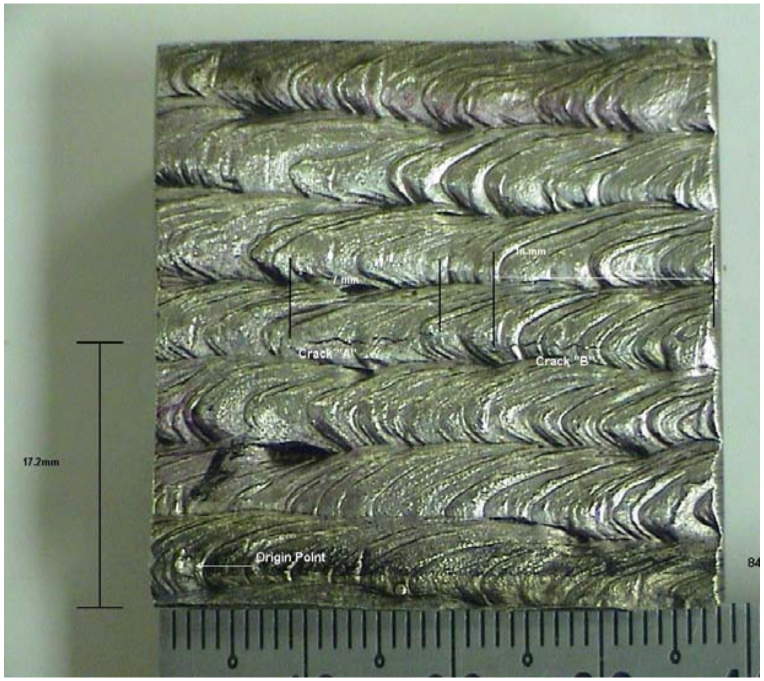
Stress Corrosion Weld Crack Specimens

- Laboratory-grown SCC
  - Three-point bend stress applied
  - Corrosive fluid applied to selected area only
- As-welded and ground surfaces
- Flaws vary in:
  - Length, width, orientation with respect to weld direction



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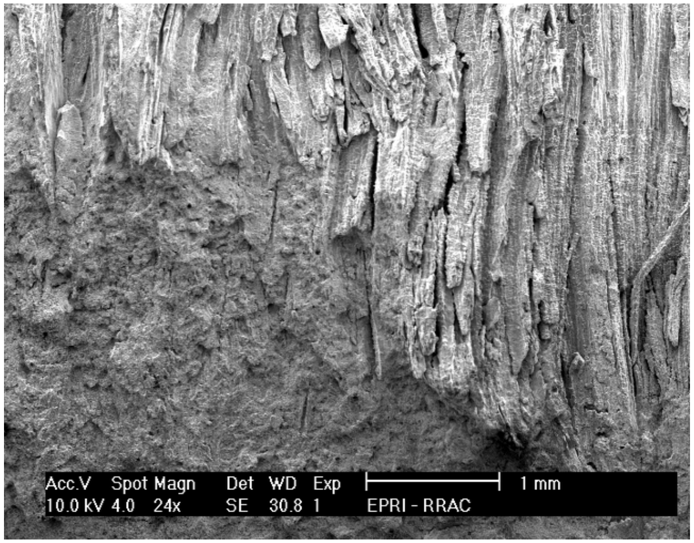
Stress Corrosion Weld Cracks

- SCC crack face showing interdendritic nature
- SCC crack grown, then specimen was broken apart
  - Upper right shows crack following weld dendrites
  - Lower left is ductile tear from break



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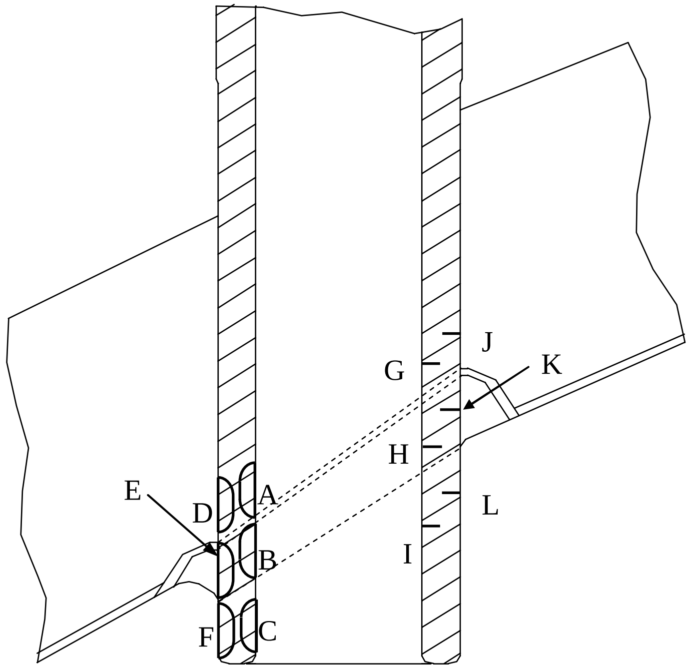
2002 Demonstrations

- Full-scale Tube Flaw Mock-up “J”
  – CIP manufactured flaws in tube volume
- Full-scale Weld Flaw Mock-up “K”
  – CIP manufactured flaws in volume of attachment weld
  – CIP flaws open to “wetted-surface”
- Full-scale Mock-up with SCC flaw Inserts “L”
  – Flaws open to “wetted-surface”

2002 Demo Tube Flaw mock-up "J"

- Full-scale mock-up with CIP flaws in tube



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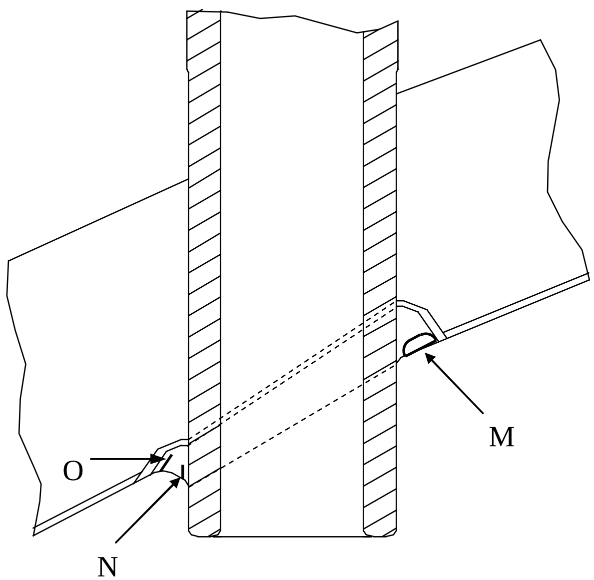
2002 Demo Weld Flaw Mock-up "K"

- CIP flaws for UT from inside surface of tube

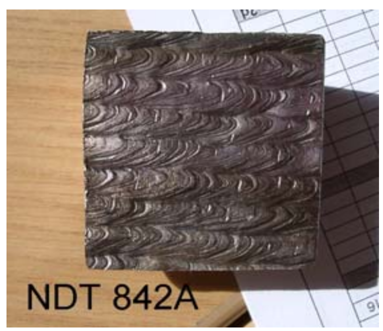


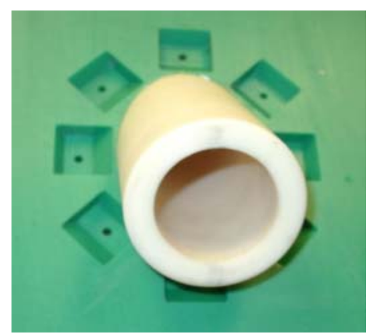
EPRI

2002 Demo Weld Flaw Mock-up "L"

- Contains SCC flaw coupons for demo of ET on wetted surface

- Coupons contain cracks of varying
  - width
  - length
  - Orientation





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New Mock-ups

- Bottom Mounted Instrumentation nozzles
  - Incorporates South Texas Plant experience
  - Designed using same philosophy, methods, and criteria used for upper head penetration mockups
  - Representative of Westinghouse 2-, 3-,and 4-loop units and B&W designs
  - Currently under construction
- New upper head mockups under construction
  - Enables release of original mockups for training & practice

NDE Center Funded Activities to Supplement MRP Inspection WG Tasks

- Flaw manufacturing technology for Alloy 600/182
- ET technology for inspection of attachment weld
- Industry liaison
  - Direct Utility & Owners groups Support
    - Inspection equipment or approaches
  - ASME task group support
  - Butt weld/dissimilar metal weld inspection technology & qualification

Summary

- MRP has organized a comprehensive approach to address recent industry events
- Considerable progress has been made in a short amount of time
- Demonstrations underway
  - Extensive demonstration activity completed for upper head penetrations
  - BMI program initiated

Action Items

- TR Report Production (Formal Status)
  - Report should field deployable techniques only
  - After possibly:
    - Tecnatom Demo
    - Fram ET Demo
  - Cut-off date for report content (Feb 28)
  - Report produced
    - May-June
- Visual Inspection Guideline

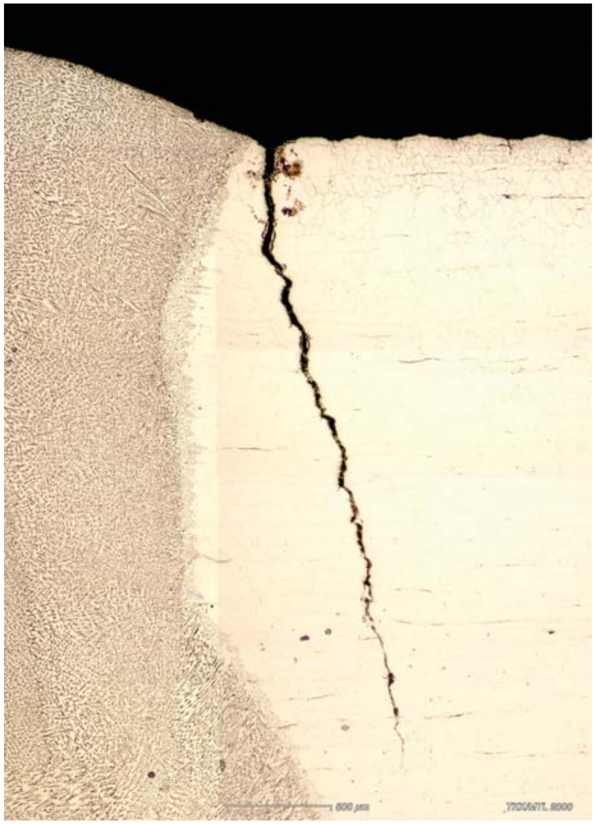
Production of realistic flaw in Alloy 600 for qualification purposes

Mika Kemppainen, Iikka Virkkunen, Jorma Pitkänen,
Kari Hukkanen and Hannu Hänninen
Trueflaw Ltd., Espoo, Finland
VTT Industrial Systems, Espoo, Finland
Teollisuuden Voima Oy, Olkiluoto, Finland
Helsinki University of Technology, Espoo, Finland

True damage mechanism for artificial flaws

- In-situ crack production
  - Real fatigue cracks
  - No additional welds
  - No microstructural alterations
- Controlled loading
  - Single and separate cracks
  - No specimen size limitations

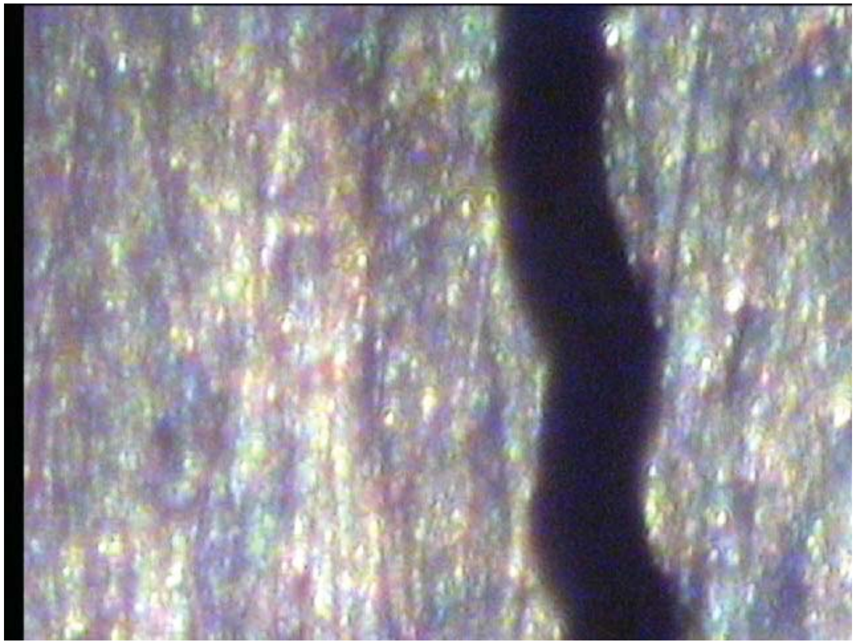
Controlled loading - controlled cracks



- Thermal fatigue offers:
  - Local loading
    - In situ production to full-size components
  - Highly controllable crack growth
    - Orientation
    - Size

Controlled loading - controlled cracks

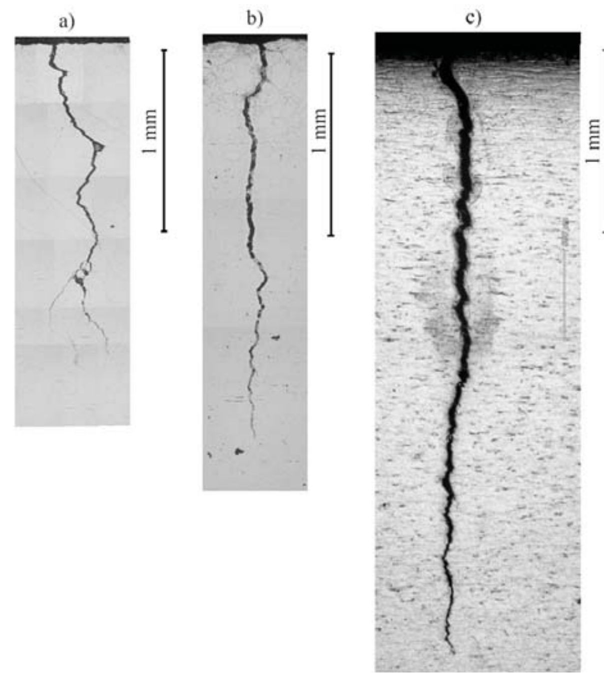
- Thermal fatigue loading
  - Crack closes during heating
  - Crack opens during cooling



How does a True Flaw look like?

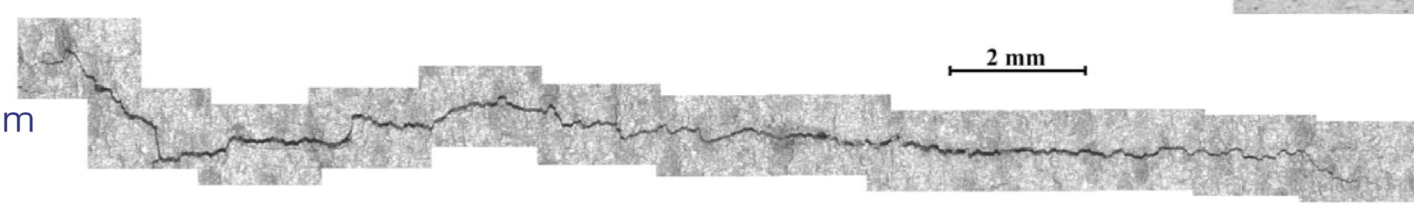
Austenitic stainless steel

- Rough and tight crack in cross-section
- Tortuous surface propagation



L= 8 mm

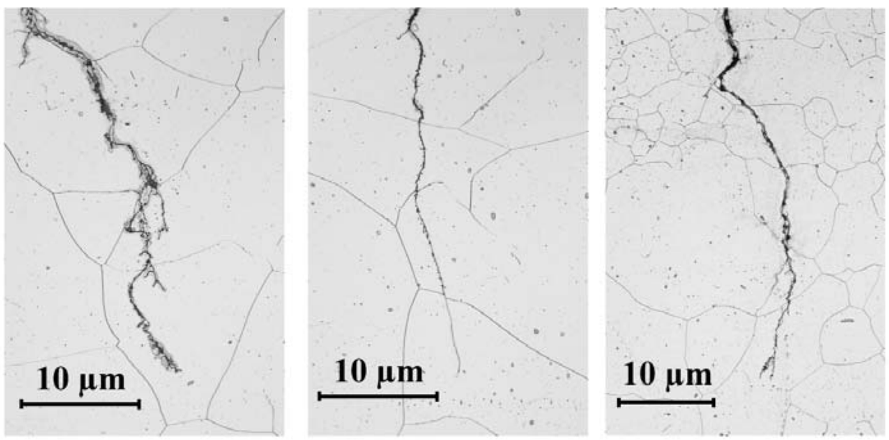
L= 20 mm

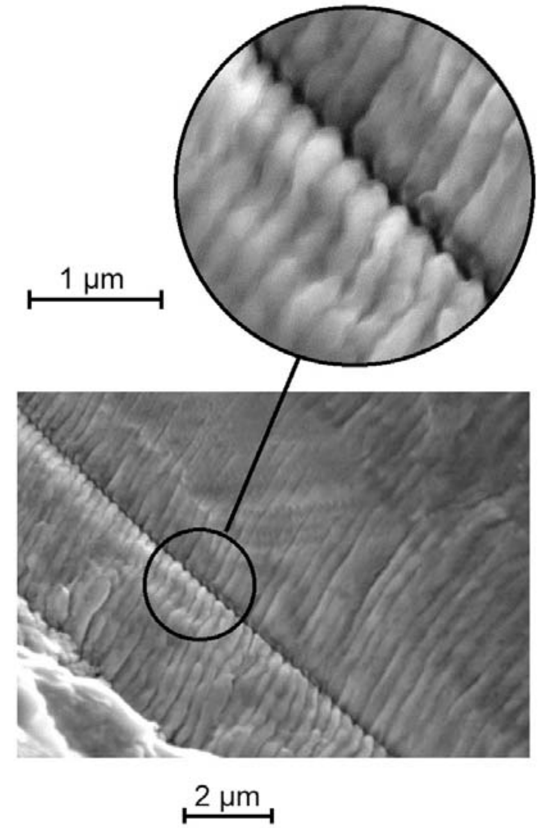


How does a True Flaw look like?

Austenitic stainless steel

- Tight crack tip
- Striations visible on the fracture surface
  - due to cyclic loading





True Flaw for Inconel 600

Core Spray Nozzle

- BWR type NPP
- Inconel 600 Safe-End
- Ready-made specimen for NDT qualification containing different flaws

True Flaw manufacturing

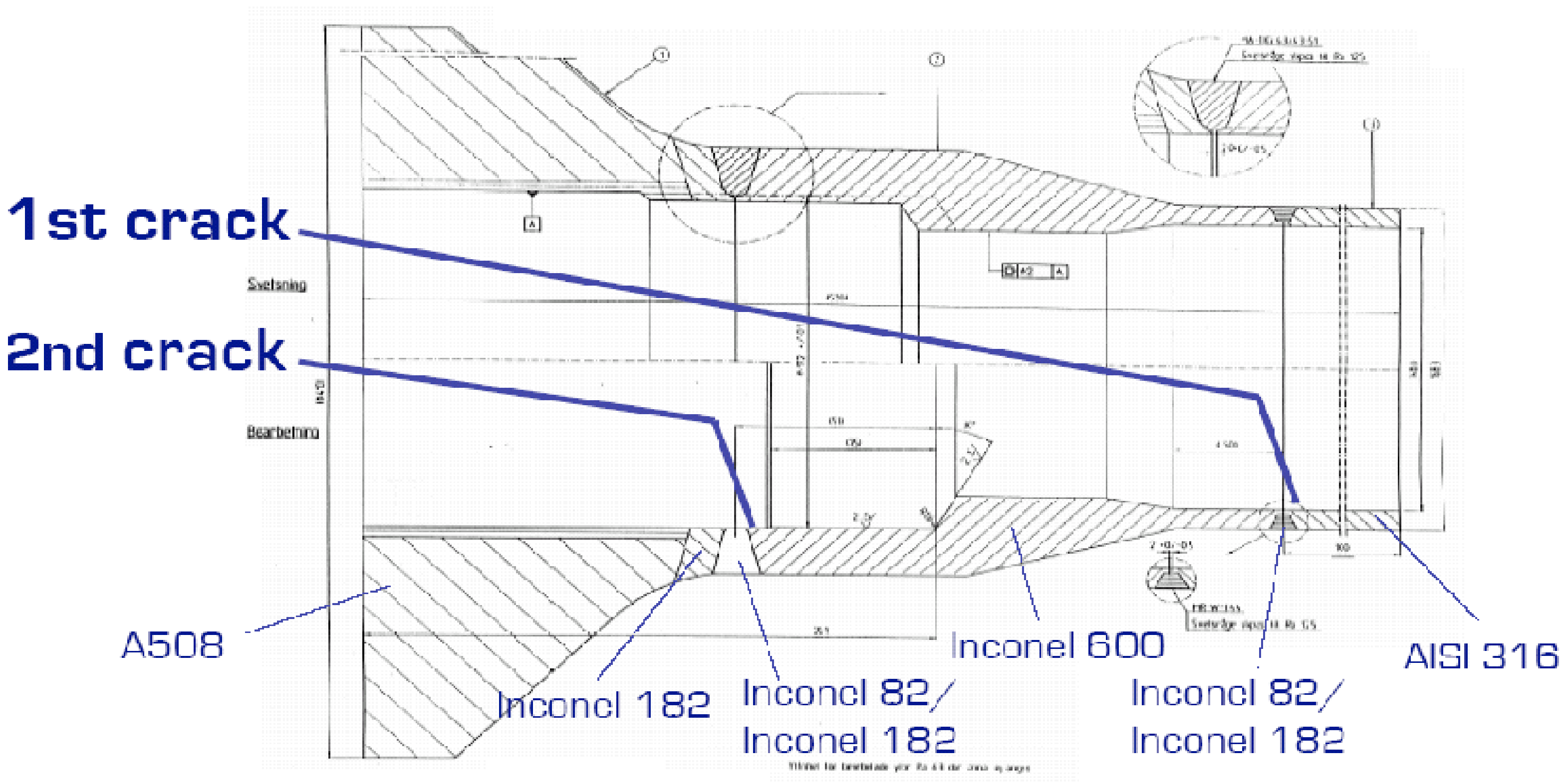
- To finished surfaces
- Without welding or machining
- Existing, previously made flaws do not affect flaw production

True Flaw for Inconel 600

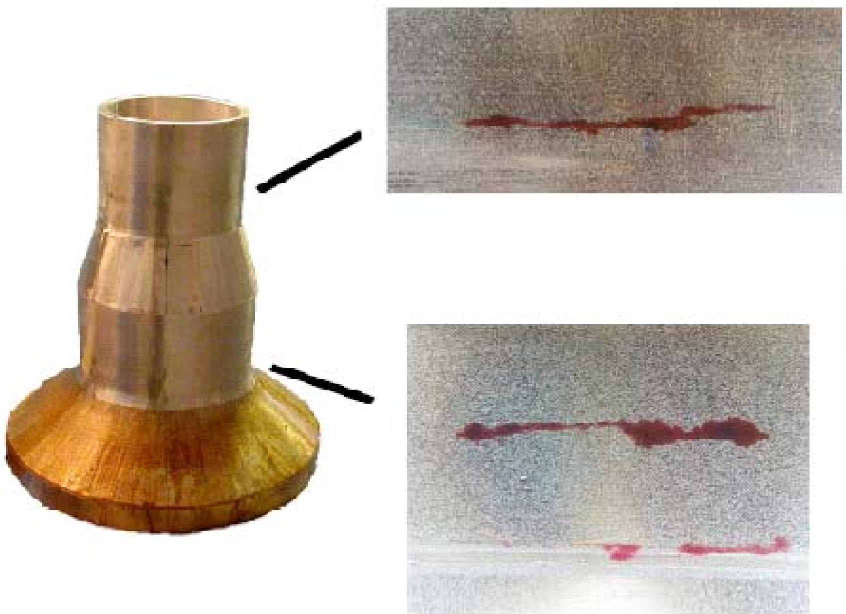
True crack production

- 2 cracks in the HAZ of welds
- At the inner surface of the nozzle
- 1st crack in AISI 316 vs. Inconel 600 weld
  - In AISI 316
- 2nd crack in Inconel 600 vs. A508 buttering weld
  - In Inconel 600

Locations of Manufactured Flaws



True Flaw in Inconel 600 Safe-End



Crack in AISI 316

- In HAZ of the joint weld
- 15,5 mm x 5 mm
- Size controlled by the process and confirmed by UT

Crack in Alloy 600

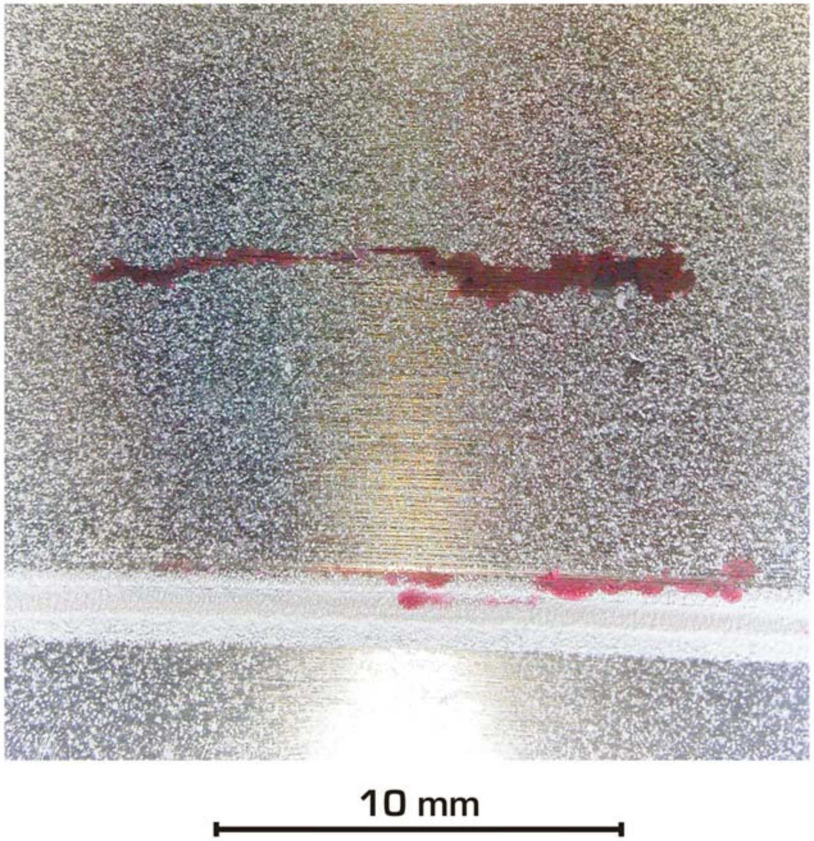
- HAZ of the buttering weld
- 14,2 mm x 5 mm
- Size controlled by the process and confirmed by UT

True Flaw in Inconel 600 Safe-End

Dye penetrant test

- Crack in the of Inconel 600

=> 14,2 mm x 5 mm



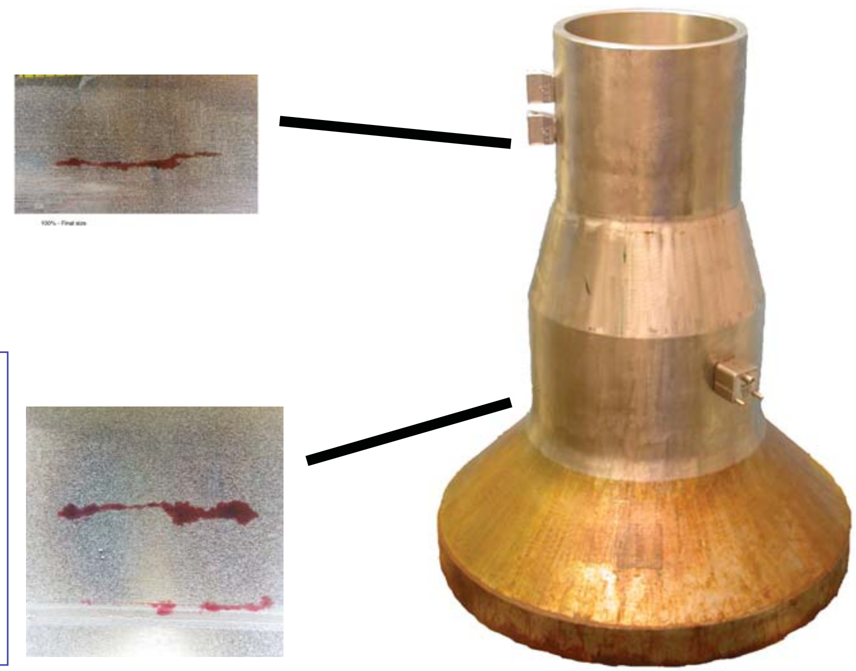
Arrangements for in-situ UT measurements

Two UT probes

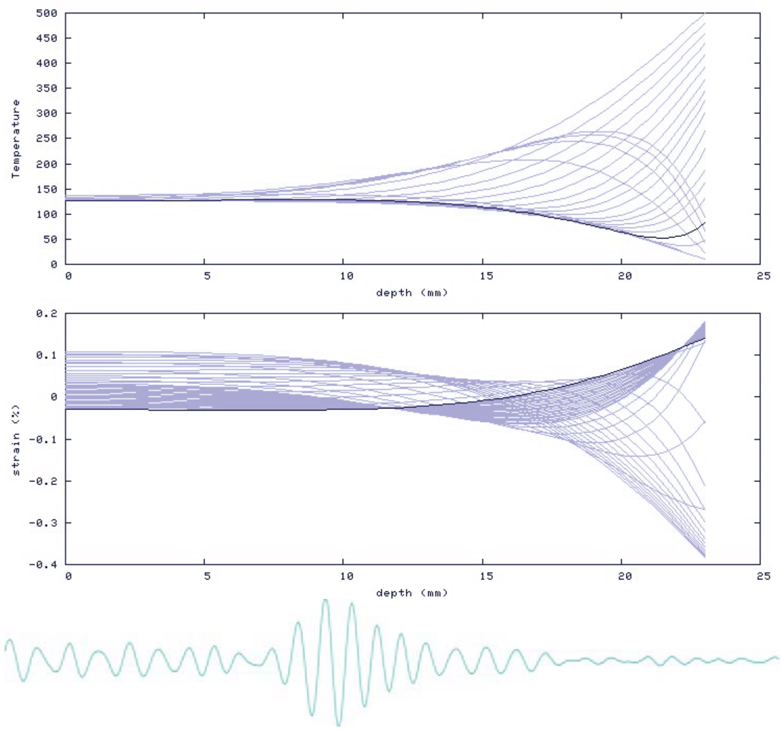
- Transverse wave
- 55° and 70°

One UT probe

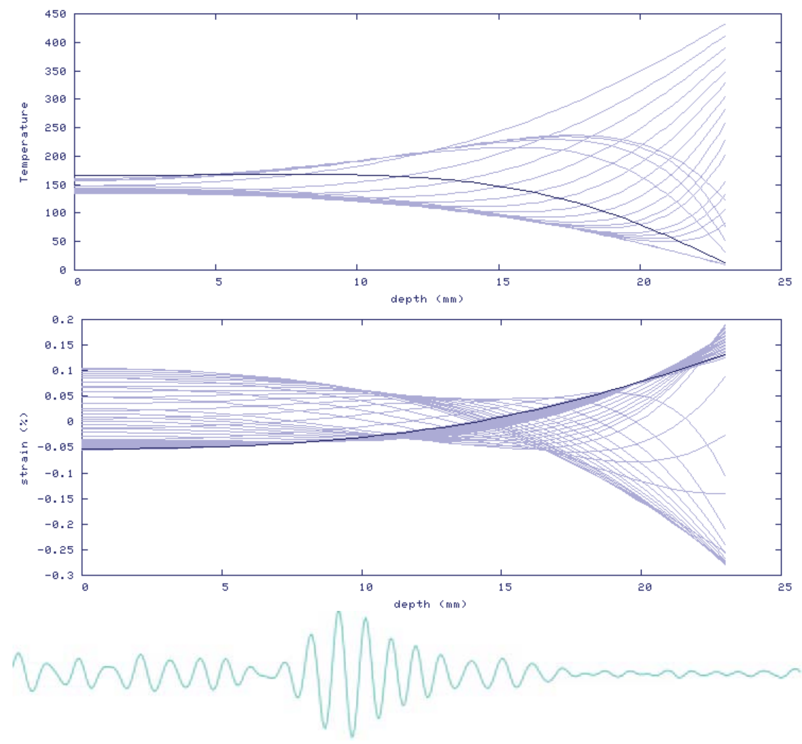
- Transverse wave
- 41°
- 1.5 MHz



Applied loads - results



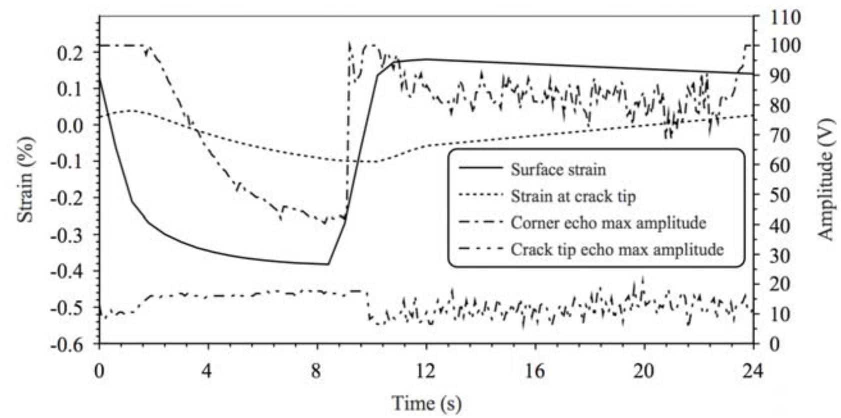
B1

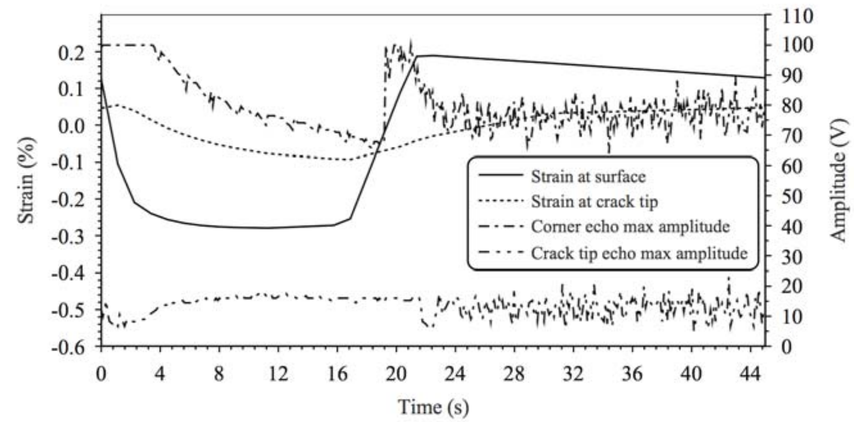


B2

Loading alters amplitude

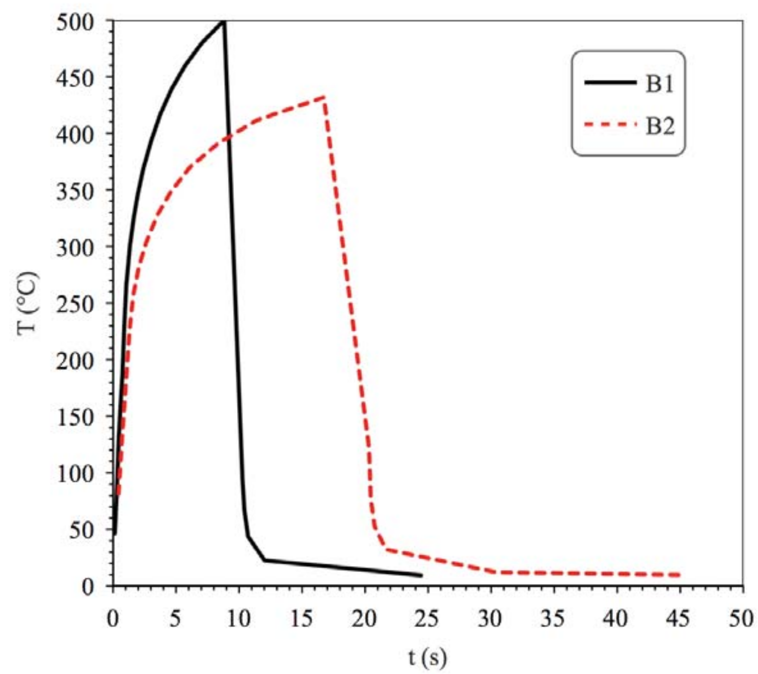
- Compression during heating decreases corner echo amplitude
- Tip echo amplitude increases during heating





Applied loads - analysis

- The applied loads were analyzed by FEM
  - 1-dimensional model
  - linear-elastic material
  - loaded by measured surface temperatures



Conclusions - True Flaw Production

Crack production is possible to

- Different materials including Alloy 600
- Ready-made components without welding or machining
- Offers for NDT qualification
  – Crack production method to new and old components and mock-ups
  – Use of realistic cracks

A BNFL Group Company

CONFERENCE ON VESSEL HEAD PENETRATION
INSPECTION, CRACKING AND REPAIRS
Gaithersburg, MD – Sept. 29-Oct. 2, 2003

Generic Guidance for an Effective Boric Acid Inspection Program for Pressurized Water Reactors WCAP-15988-NP

GUTTI RAO
Westinghouse Electric Company
SATYAN SHARMA
American Electric Power Company
DENNIS WEAKLAND
FirstEnergy Nuclear Operating Company

BNFL

Purpose

- To Provide A Generic Guidance to PWR Licensees to Aid in Developing Plant Specific Boric Acid Corrosion Control Programs (BACCP)

Objectives

- To Ensure that the implemented Plant Specific BACC Programs provide a reasonable assurance of compliance with the Regulatory Requirements specified in GL88-05, BL2001-01 and BL2002-02.

- To implement uniform BACC Programs/ Procedures throughout the industry.

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Objectives

- To take advantage of the available tools, methods and procedures to detect, assess and remediate the BAC Issues and eliminate their recurrence.

- To ensure that the Plant BACC Programs incorporate and keep up with the industry experience.

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Background and Basis (Drivers)

- Numerous leaks reported in the RCS and Borated Systems since Late ‘70’s
- GL88-05 in 1988 requiring Licensees to address small RCS Leaks
- CRDM Alloy 600, Alloy 82/182 Cracking experience of the past decade
- NRC IEB 2001-01, 2002-02 and Davis-Besse Incident
- Wide variations in the GL88-05 Plant Procedures and 60-Day Responses

WOG MSC Task Team

- WOG MSC Task Team Chartered to Develop 'Generic Guidance' (WCAP-15988-NP)
  - Ten Member Task Team representing PWR Owners Groups, INPO, NEI and EPRI
  - Issued Final Report WCAP-15988-NP in March, 2003
  - WCAP-15988, Rev. 1 is being developed to include Industry experience since March, 2003

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WCAP-15988-NP

Table of Contents

WCAP-15988-NP

Table of Contents (continued)

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WCAP-15988-NP

Table of Contents (continued)

Scope

- Sample Reviews of GL88-05 Procedures and 60-Day Responses
- Prioritization of Listing of Alloy 600/82/182 Locations (based on wastage/safety significance)
- Identification of Primary and Auxiliary System Potential Leak Locations and Related Wastage Potential
- Review of Industry Documented Leaks

Scope (cont'd.)

- Identification of Specific Improvements/ Enhancements to 88-05 Inspection Procedures
- Incorporation of Industry Experience (CRDM leaks and head wastage)
- Responsive to INPO Review Guidelines and Expectations
- On-Line Monitoring and Early Warning Indicators
- Lessons Learned from Davis-Besse Incident

Attributes Considered

- Attention to Procedures for Identification of Small RCS Leaks Below Tech Spec Limits
- Responsive to 88-01, 2001-01, BL2002-02 and BL2003-02 Requirements
- Incorporate EPRI Corrosion Handbook Procedures
- Lessons Learned from Davis-Besse
- Attention to Industry Documented Leaks
- Cycle Specific Inspection Reports
- Database for Trend Tracking
- Administrative Control and Program Ownership
- Attention to Early Warning Leak Detection Systems and Indicators
- Include All Pressure Boundary Alloy 600 and Alloy 82/182 Locations
- Primary and Auxiliary Systems Leak Susceptible Locations
- Leak Proximity to Carbon/Low Alloy Steel Components
- State-of-the-Art Detection Systems
- Personnel Qualification and Training Guidelines

Attributes Considered (cont'd)

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- Coordination and Responsibility Flow Chart
- Coordinate Information from Parallel Programs
- Cycle Specific Reports and Trend Tracking
- Audits and Self-Assessments
- Other (cracking) susceptible Locations (IGSCC & IGSCC), including Plant Specific Material & Design and Component Considerations
- Continuous Improvement Program (self-assessments, audits, benchmarking, etc.)
- Data Collection and Recording Methods
- Criteria for the Removal of Insulation
- Inspection of Inaccessible Locations
- Methods of Gathering Information Prior to Removing Evidence (buildup)
- Corrective Actions to Prevent Recurrence of BAC
- Responsive to INPO Review Guidelines and Expectations

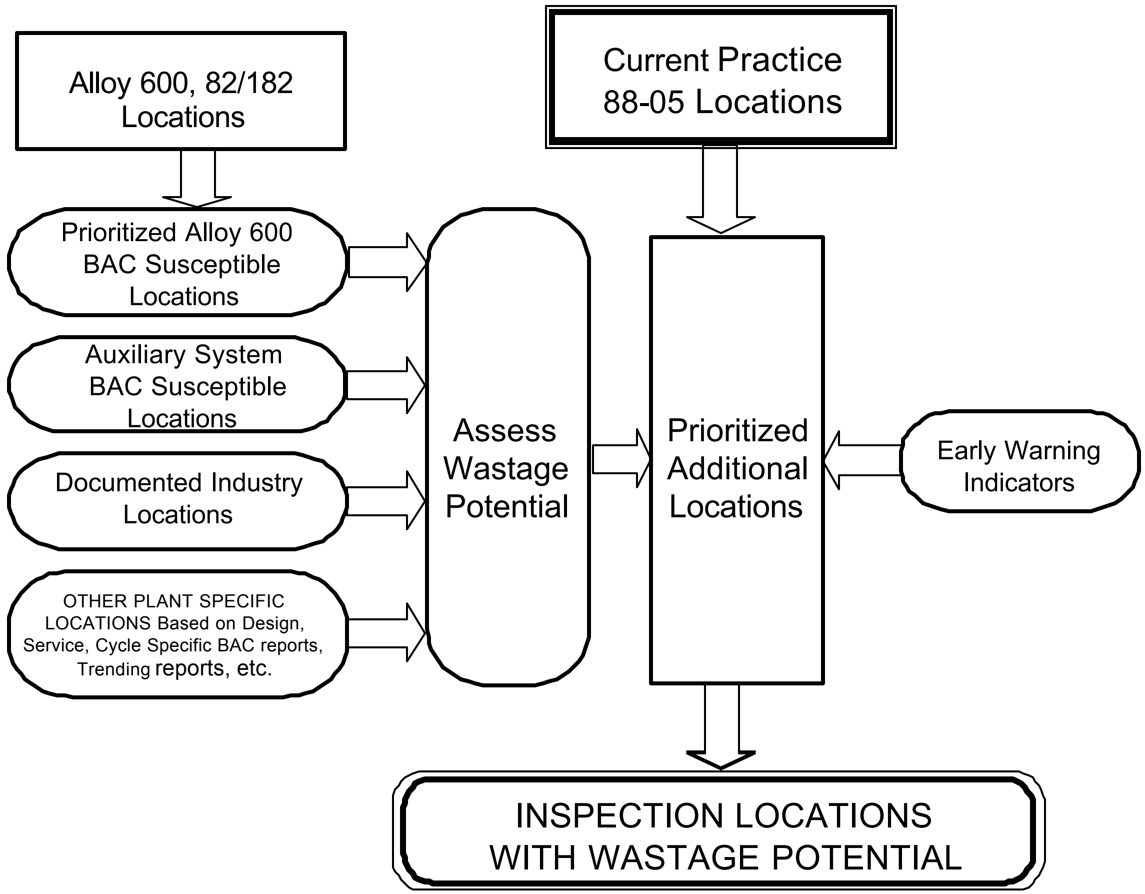
Inspection Locations

- Industry Documented Leaks
- 88-05 Locations
- Alloy 600/82/182 Locations
- Plant Specific Locations Based on Component Design, Material and/or Service History
- Other Locations Potentially Susceptible to IGSCC, TGSCC (based on field modifications and service history)
- Potential Leak Locations in the RCS and Auxiliary Systems Having Proximity to Carbon/Low Alloy Steel Components

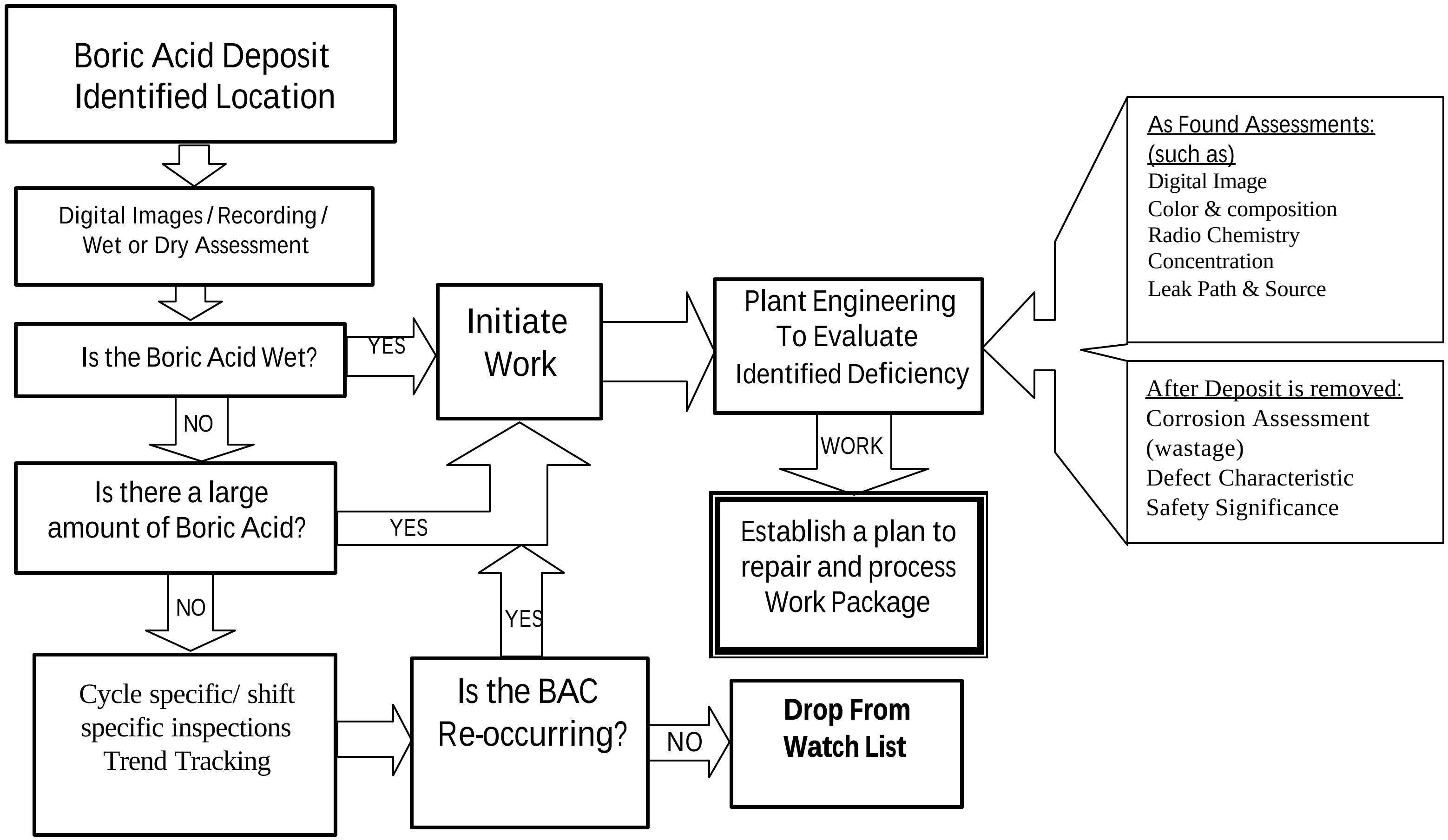
Examples of Systems Containing Boric Acid

- Reactor Coolant System
- Chemical and Volume Control System
- Safety Injection System
- Residual Heat Removal/Shutdown Cooling System
- Reactor Plant Sampling System
- Spent Fuel Pool Cooling and Purification System
- Containment Depressurization System
- Containment Spray System
- Reactor Plant Vent and Drain System
- Liquid Waste Disposal System
- Gaseous Waste Disposal System

Identification of Inspection Locations with Wastage Significance



Criteria for Boric Acid Deposit Assessment



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Alloy 600 and Alloy 82/182 Locations in the Primary Pressure Boundary Components of Westinghouse PWR Units

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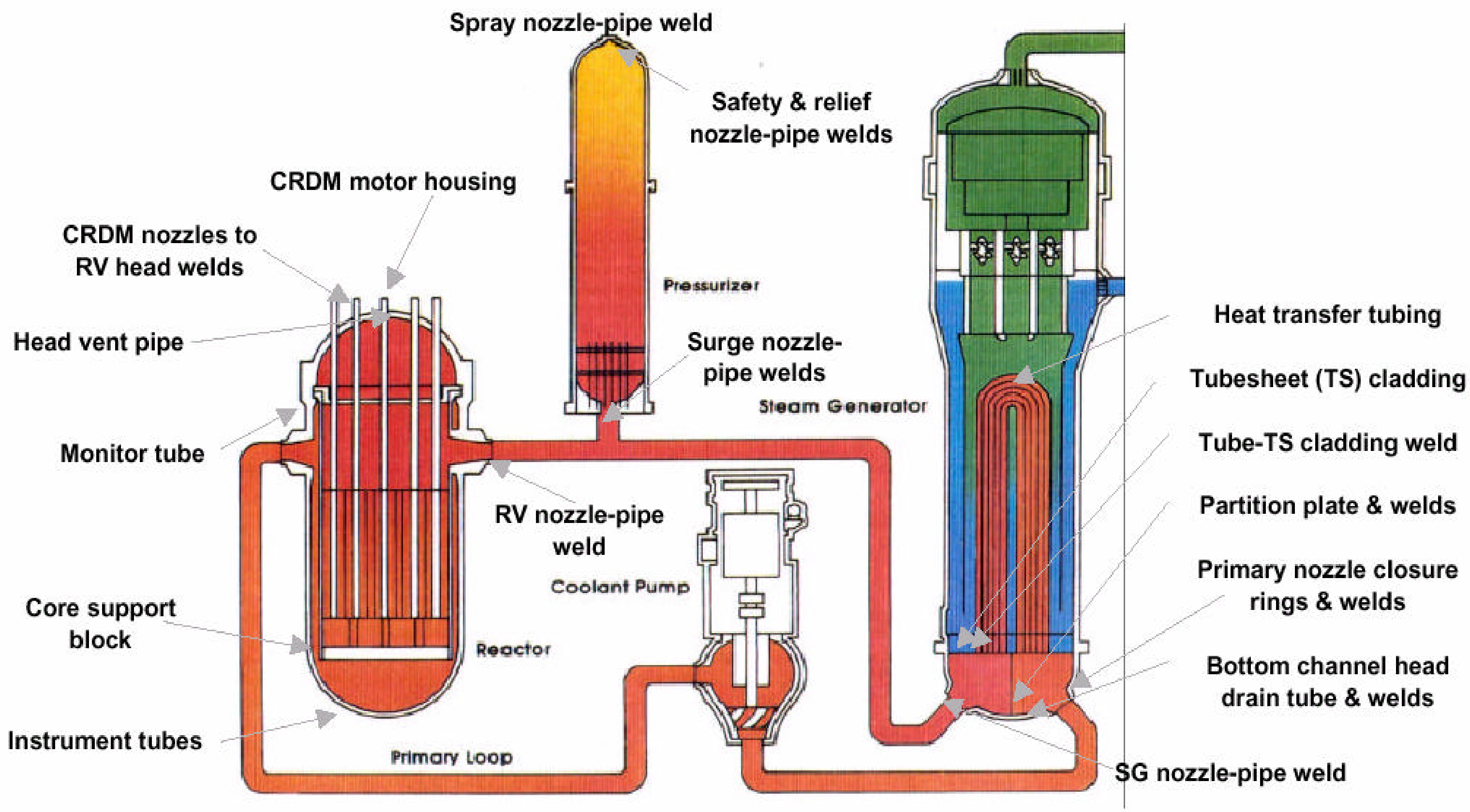

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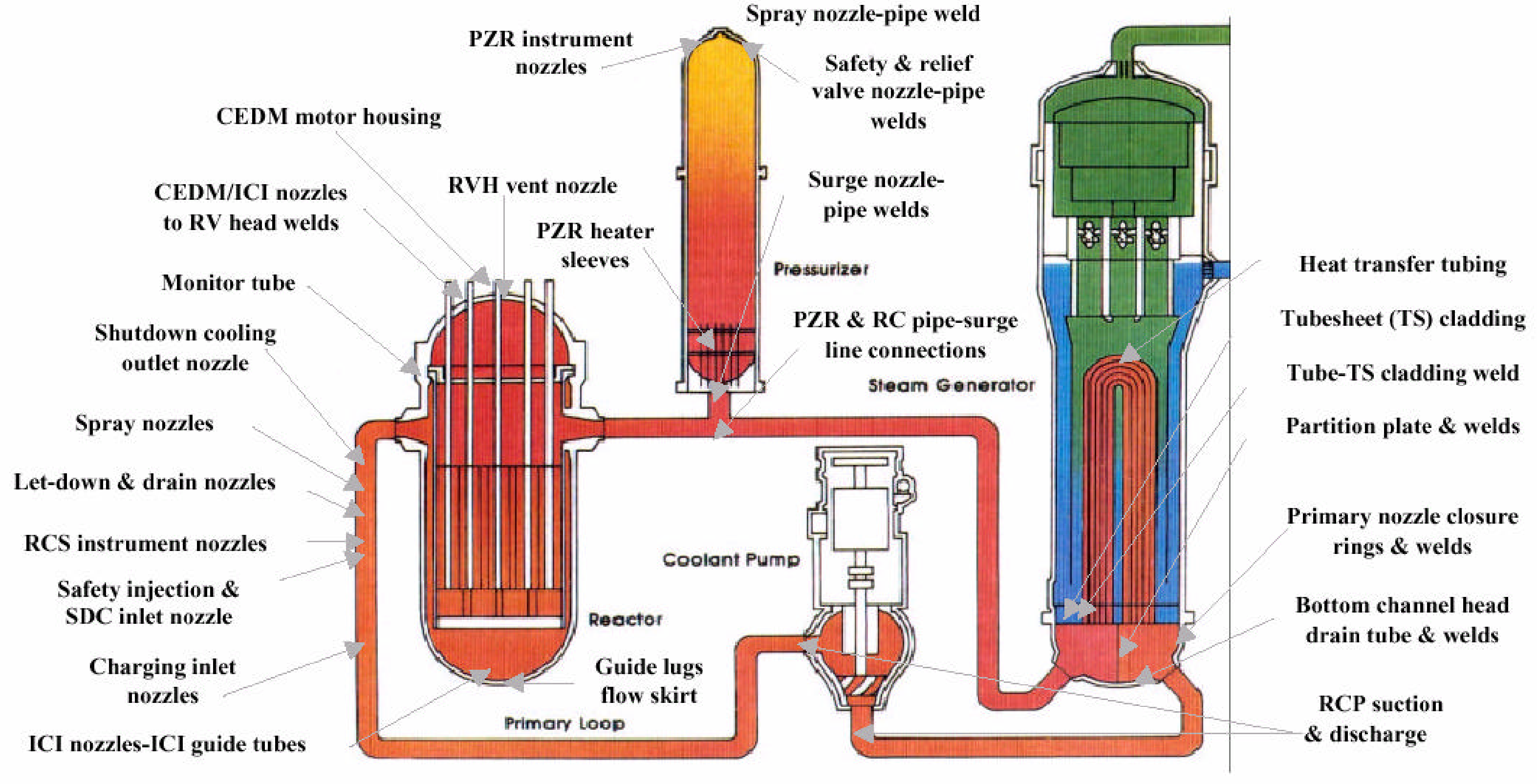
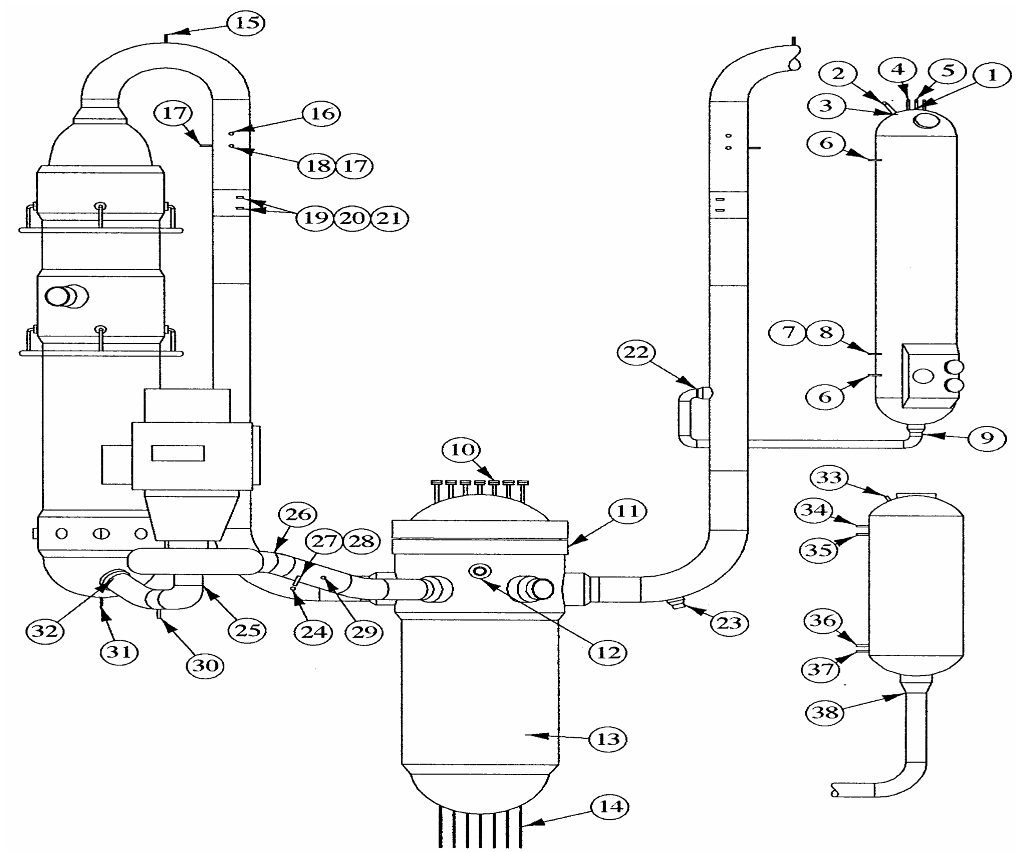
Alloy 600 and Alloy 82/182 Locations in the Primary Pressure Boundary Components of CE PWR Units



BNFL

General Locations of Alloy 600 Type Materials in the B&W (177-FA Design) Reactor Coolant System (Prepared by DEI)



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PROPOSED REVISIONS TO WCAP-15988

WCAP-15988 Will be updated to include:

- INPO findings from recent audits
- Update rankings for systems and components
- Impact of NRC order
- Definition of clean head
- Inspection procedures for BMI

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PROPOSED REVISIONS TO WCAP-15988 (cont'd.)

WCAP-15988 Will be updated to include:

- Analytical procedures for thorough investigation of BA deposit prior to cleanup
- Industry experience since March, 2003
- Consistency with ASME Section XI Code requirements currently being developed by BAC Task Group

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Risk-Informed Evaluation of PWR Reactor Vessel Head Penetration Inspection Intervals

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Dominion Engineering, Inc.
11730 Plaza America Dr.
Reston, VA 20190

Vessel Head Penetration Inspection,
Cracking and Repair Conference

September 29 – October 2, 2003
Gaithersburg, MD

By:
Glenn White, Dominion Engineering, Inc.
Steve Hunt, Dominion Engineering, Inc.
Nicolas Nordmann, Dominion Engineering, Inc.

Overview

- Purpose of Evaluation
- Evaluation Elements
- Flaw Tolerance Evaluation
- Nozzle Ejection Assessments
  - Deterministic Evaluations
  - Probabilistic Evaluation
- Boric Acid Wastage Assessments
  - Deterministic Evaluations
  - Probabilistic Evaluation
- Conclusions

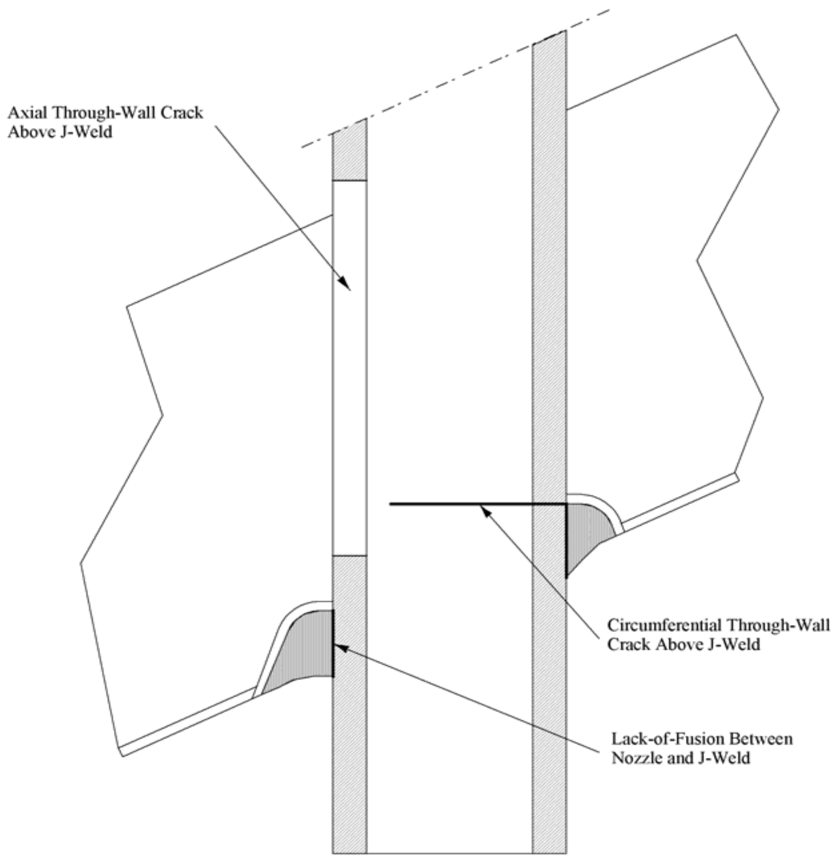
Purpose of Evaluation

- The purpose of the type of evaluation presented is to provide a rational basis for setting the re-inspection interval for nonvisual examination of reactor vessel (RV) closure head penetrations in PWRs
- Deterministic assessments show that nozzle ejection and significant head wastage are unlikely to occur given the indicated re-inspection interval
- Probabilistic assessments show that the requisite levels of nuclear safety are maintained given that the calculated increase in core damage frequency (CDF) due to the potential nozzle ejection and head wastage failure modes is within acceptable limits, i.e., 1×10^{-6} per year

Evaluation Elements

- Flaw and wastage tolerance calculations
- Review of subject plant design, materials, fabrication, and time at temperature
- Evaluation of visual and nonvisual inspection results at the subject plant
- Evaluation of expected inspection detectability limits and probability of detection (POD) curves
- Evaluation of industry inspection results including results for most similar material and fabrication groups
- Nozzle ejection and wastage evaluations
- Risk, consequential damage, and loose parts assessments

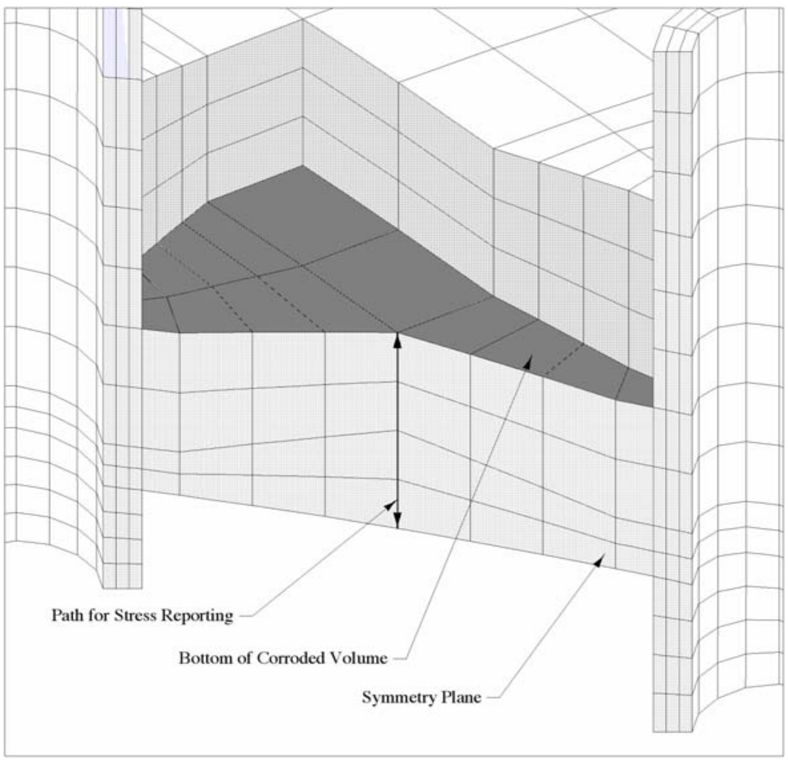
Flaw Tolerance Evaluation
Tolerance to Cracking



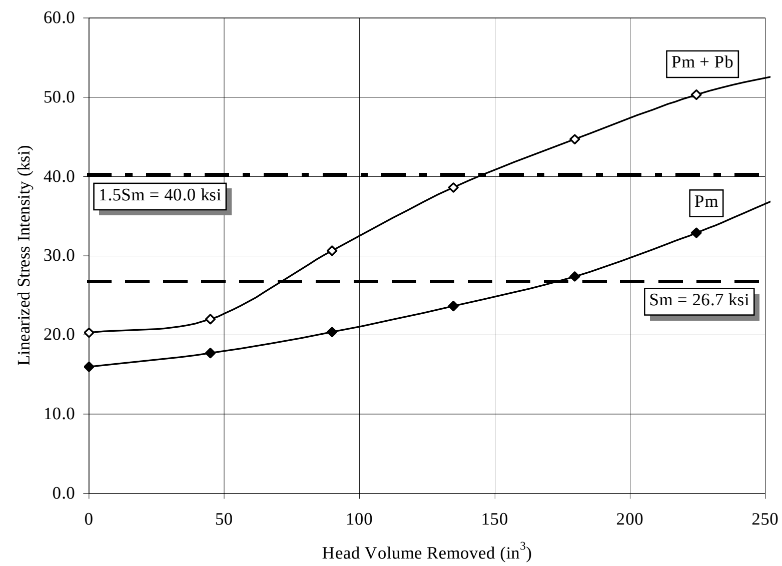
Typical Results for CRDM Nozzle

	2500 psi	6750 psi
Axial through-wall flaw in nozzle above J-weld	14.3 inches	5.3 inches
Circ. through-wall flaw above J-weld	330°	284°
Lack of fusion between nozzle and weld	327°	271°

Flaw Tolerance Evaluation
Tolerance to Boric Acid Wastage



Finite Element Model of Representative Head



Primary Membrane and Membrane Plus Bending Stress as Function of Wastage Volume

Flaw Tolerance Evaluation
Summary

- RV closure head nozzles are generally quite flaw tolerant
- The critical circumferential nozzle flaw size for nozzle ejection for CRDM nozzles is approximately 330°
- The critical flaw size for a "lack-of-fusion" type defect at the tube-to-weld interface is of similar magnitude
- Axial flaws leading to rupture of the CRDM nozzle are too long to be credible given the size of the high stress region
- The allowable wastage volume that maintains ASME Code allowable stresses in the head shell is about 150 in^3 for a representative head design

Deterministic Nozzle Ejection Assessments

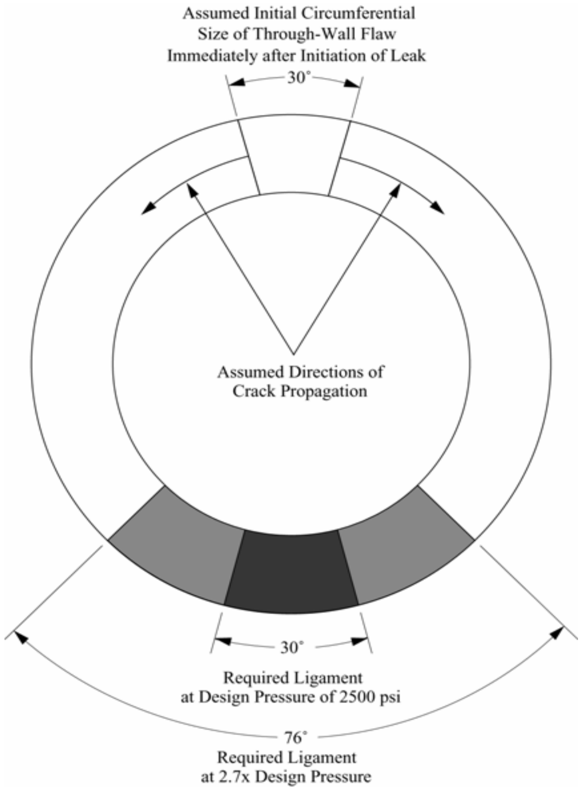
1. Nozzle ejection due to the "lack-of-fusion" type flaw at the tube-to-weld interface is much less credible than nozzle ejection due to a large circumferential nozzle flaw

2. Conservatively assume a 30° through-wall circumferential nozzle flaw above the top of the weld upon restart from the initial nonvisual inspection

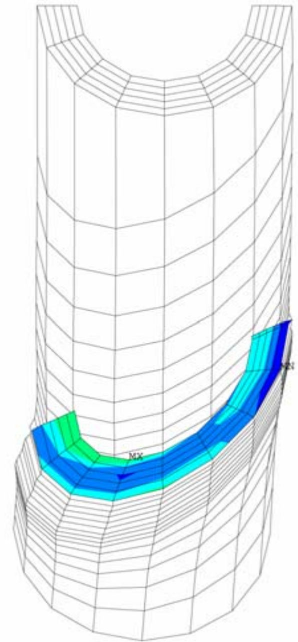
3. Calculate a stress intensity factor (SIF) as a function of circumferential crack size

4. Calculate the time to grow to the critical flaw size using the SIF curve and the deterministic MRP-55 crack growth rate (CGR) for Alloy 600 cracks in contact with the nozzle annulus environment with a safety factor on the pressure loading

Deterministic Nozzle Ejection Assessments
Calculation of Crack Growth Around Nozzle Circumference

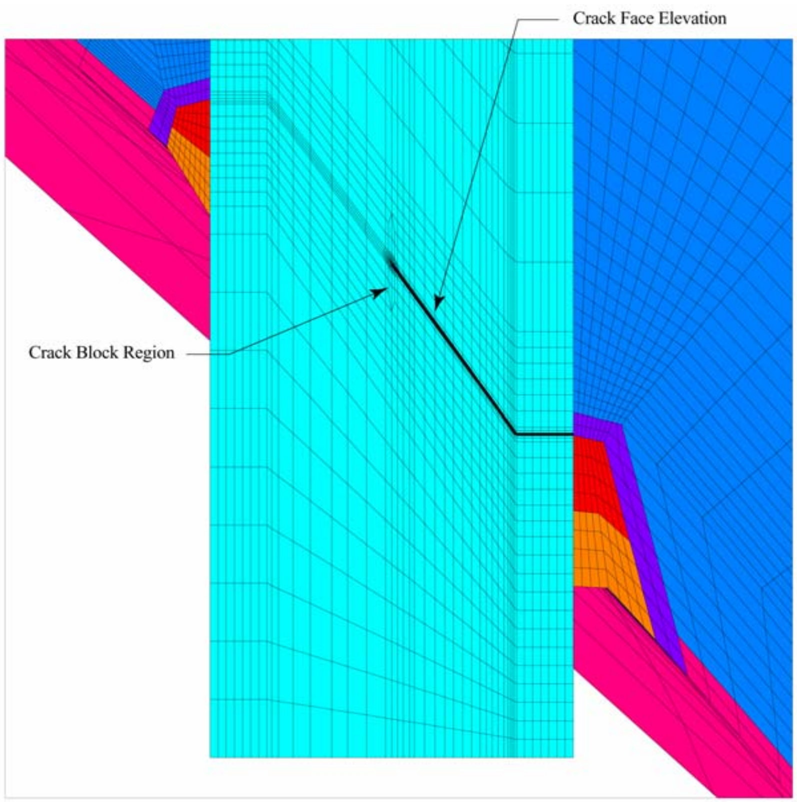


Typical Critical Flaw Size of 330°

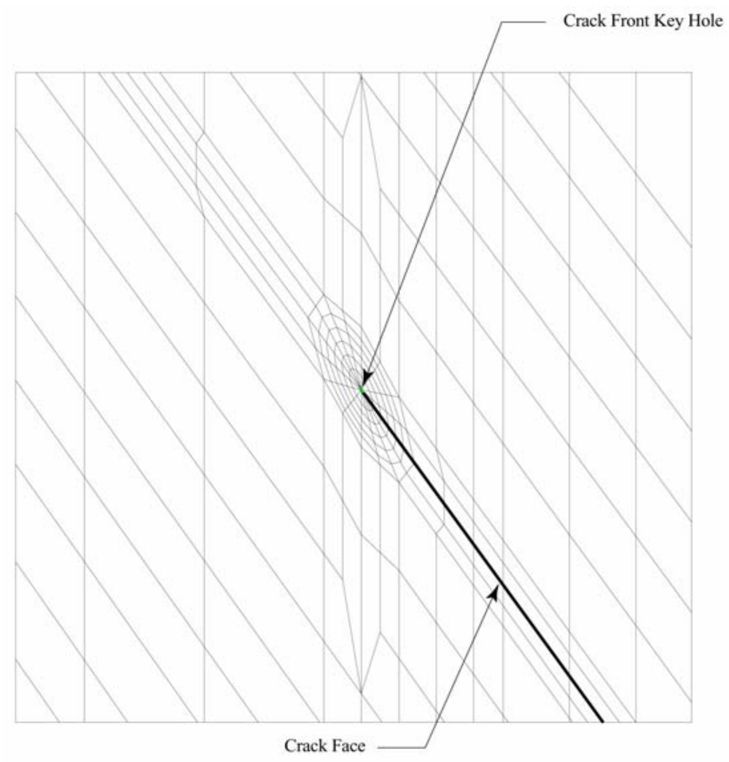


Example of Operating Stress Perpendicular to Circ Crack Plane

Stress Intensity Factor Calculation
Example Fracture Mechanics Analysis for Nozzle Circ Cracks



180° Downhill-Centered Crack



Crack Mesh Detail

Deterministic Nozzle Ejection Assessments
Example Results

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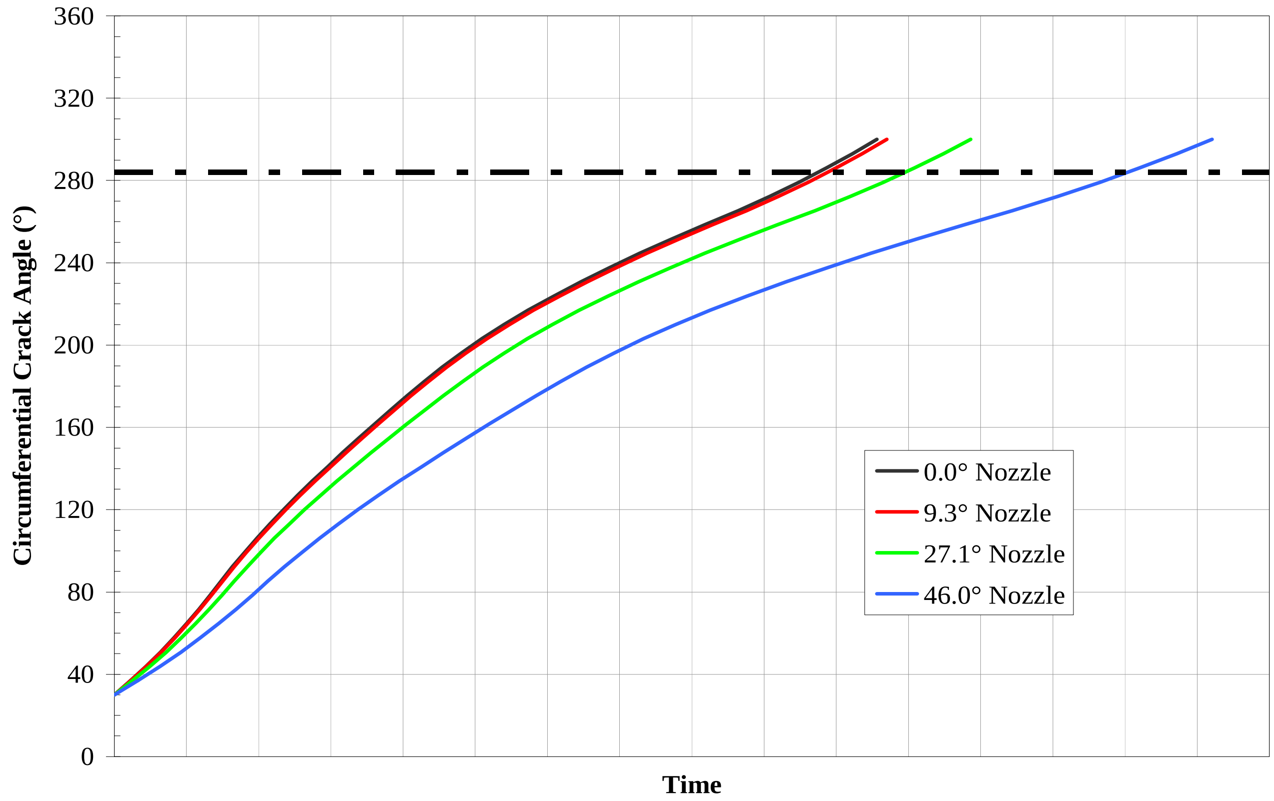
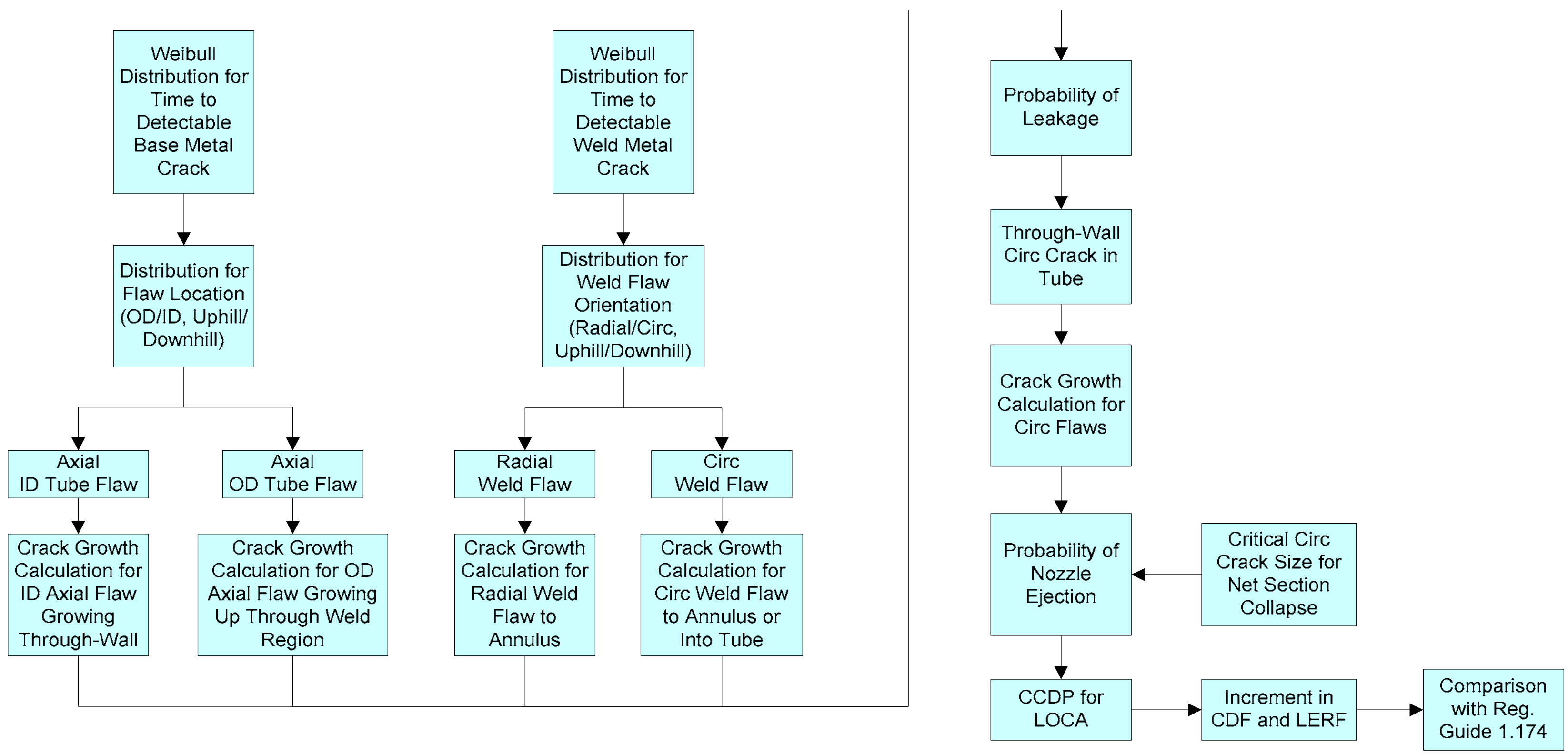


Probabilistic Nozzle Ejection Assessments

Simplified Simulation Model Flowchart



Probabilistic Nozzle Ejection Assessments
Modeled Flaw Geometries

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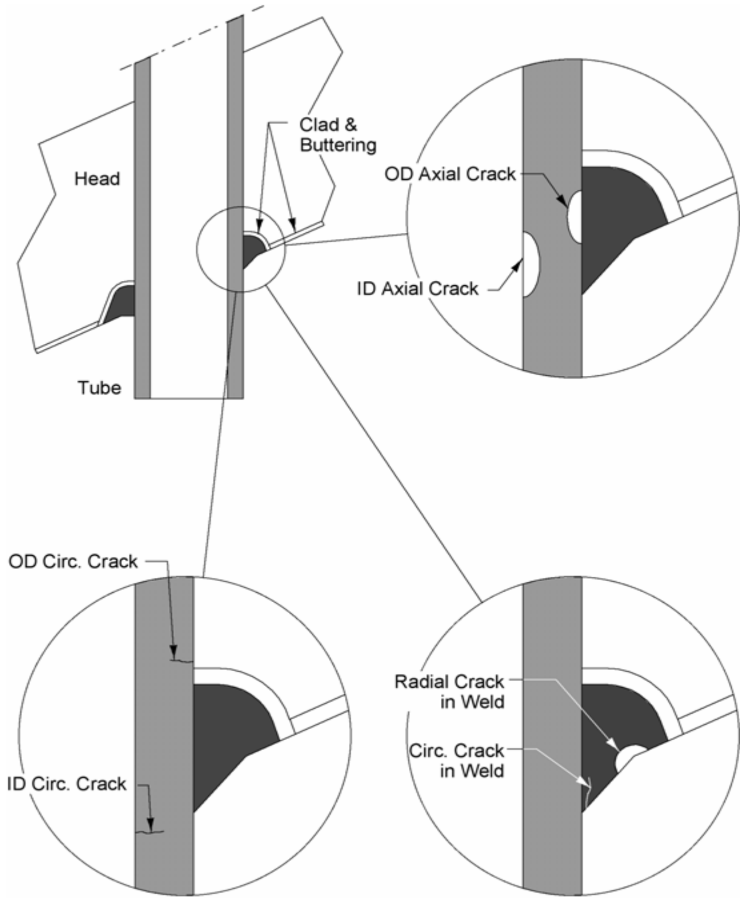
- Cracking from the wetted surface to the nozzle annulus above the weld precedes circ cracking above weld
- Axial base metal cracking on nozzle ID and nozzle OD below the weld explicitly modeled
- Weld cracking to the nozzle annulus explicitly modeled



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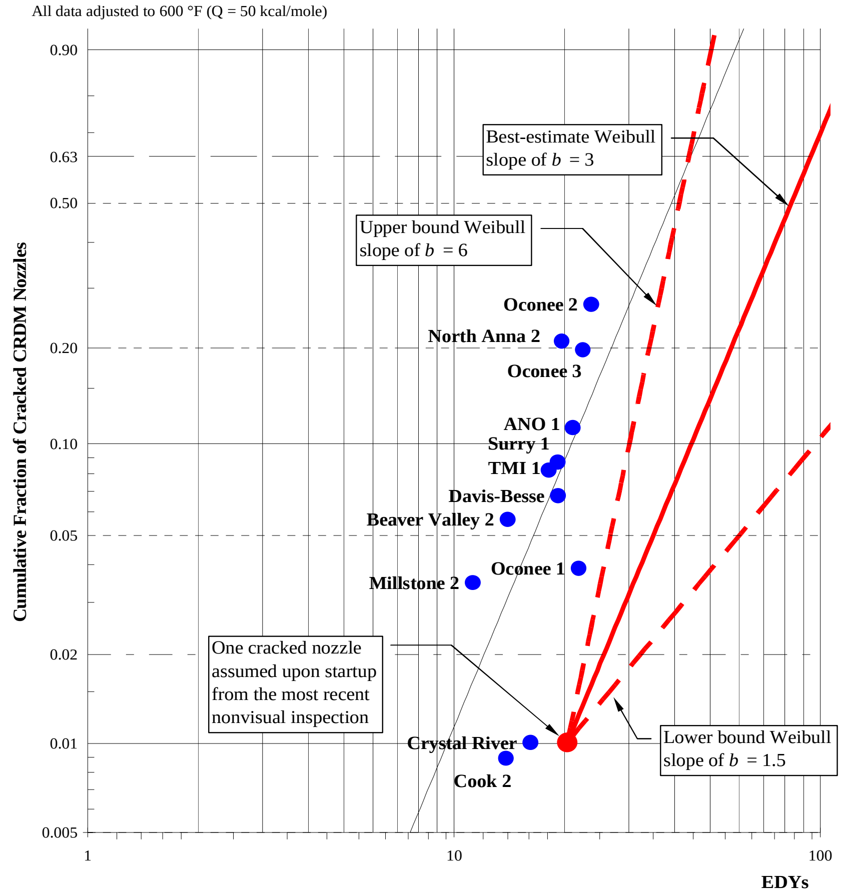
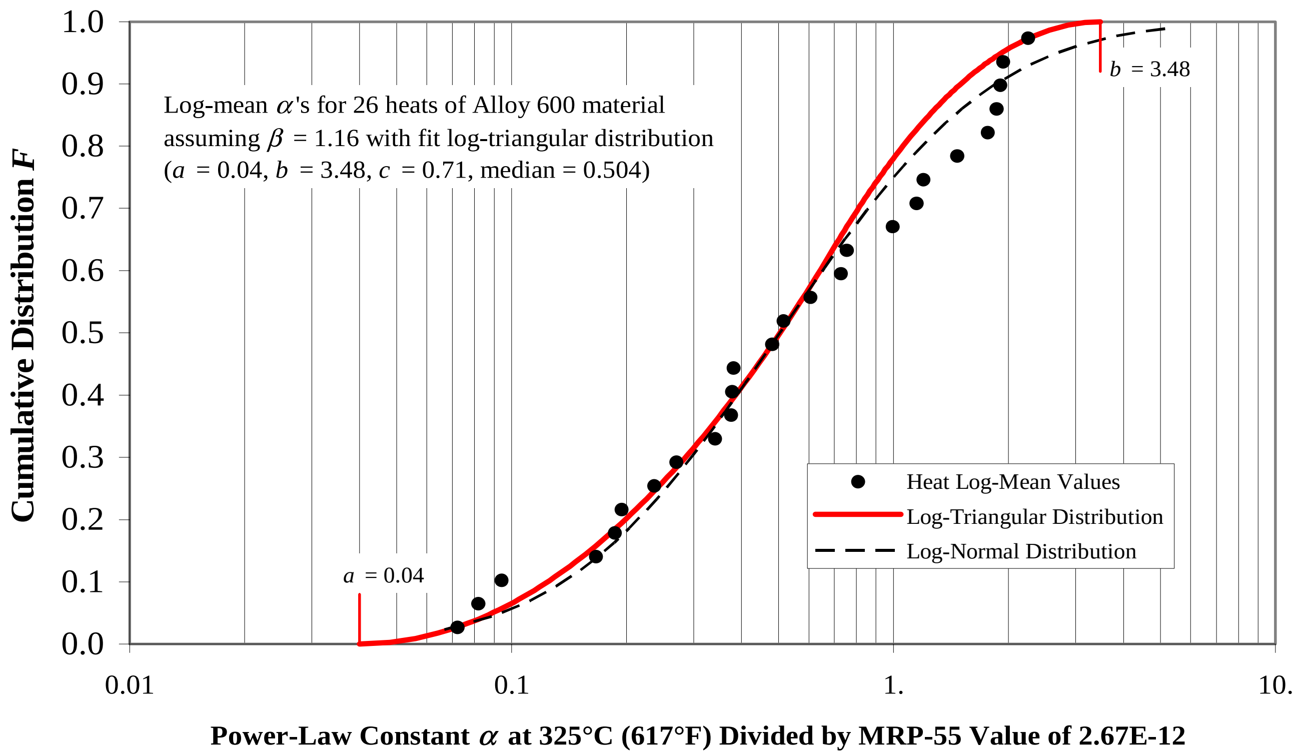
Probabilistic Nozzle Ejection Assessments
Weibull Statistical Modeling of Crack Initiation

- For plants that have performed a nonvisual inspection of all nozzles with no reportable PWSCC indications, it may be assumed that one nozzle immediately is cracked upon restart
- The rate of crack initiation in additional nozzles may be calculated assuming a range of Weibull slopes based on plant and laboratory test data



Deterministic Nozzle Ejection Assessments

Crack Growth Rate for Alloy 600 Based on Lab Data (MRP-55)



Probabilistic Nozzle Ejection Assessments
Assessment of Results

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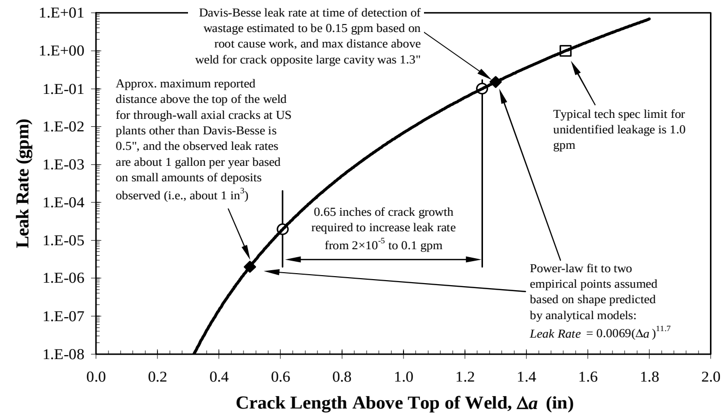
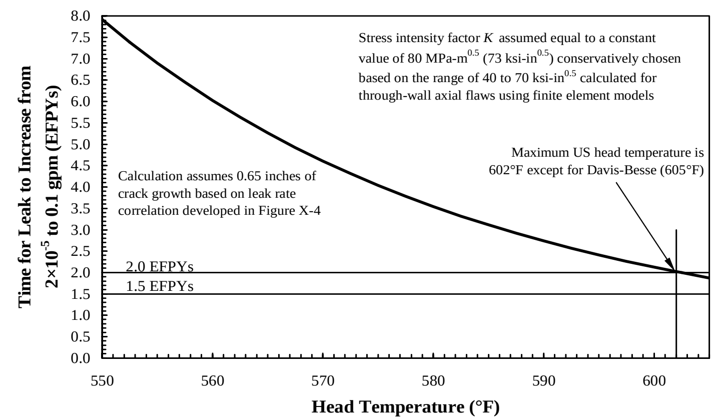
- The increase in CDF is calculated by multiplying the frequency of nozzle ejection times the conditional core damage probability (CCDP) for the appropriately sized loss of coolant accident (LOCA)
- The base case result is compared to the 1.0×10^{-6} per year criterion from Reg. Guide 1.174
- Sensitivity cases are also run to show that the results are not too dependent on the input assumptions and parameter distributions
  - POD curves
  - Crack geometry and location
  - Weibull crack initiation reference
  - Crack growth rate assumptions including weld CGR
  - Credit for bare metal visual (BMV) inspections to detect leak path flaws

Deterministic Boric Acid Wastage Assessments

- The methodology presented in Appendices C, D, and E of MRP-75 may be used to evaluate the potential for wastage
- The MRP is revising the MRP-75 wastage assessment on the basis of bare metal visual (BMV) inspections being performed each refueling outage
- The methodology is based on the time for the leak rate to increase to the point that cooling is sufficient to support a concentrated boric acid environment

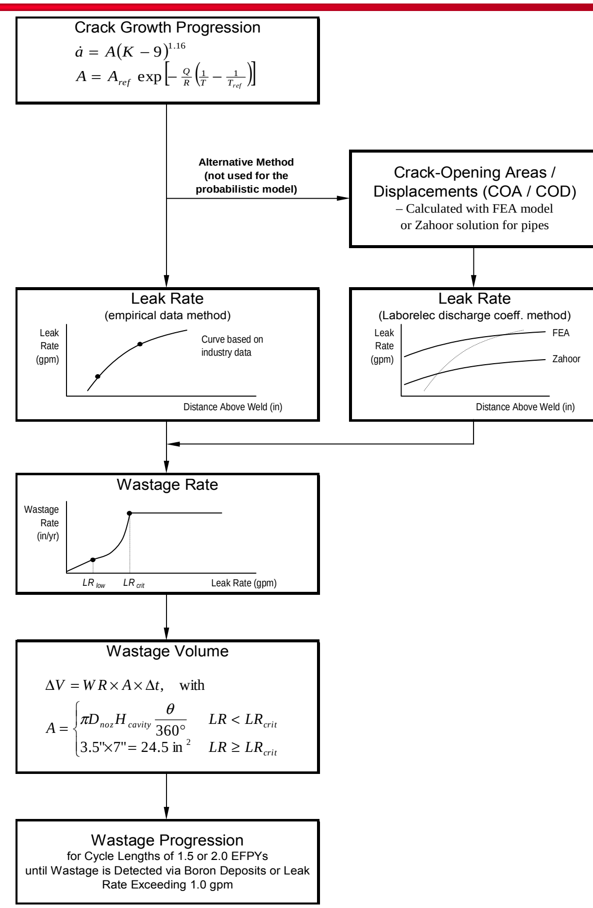




Probabilistic Boric Acid Wastage Assessments

MRP Wastage Model (MRP-75)

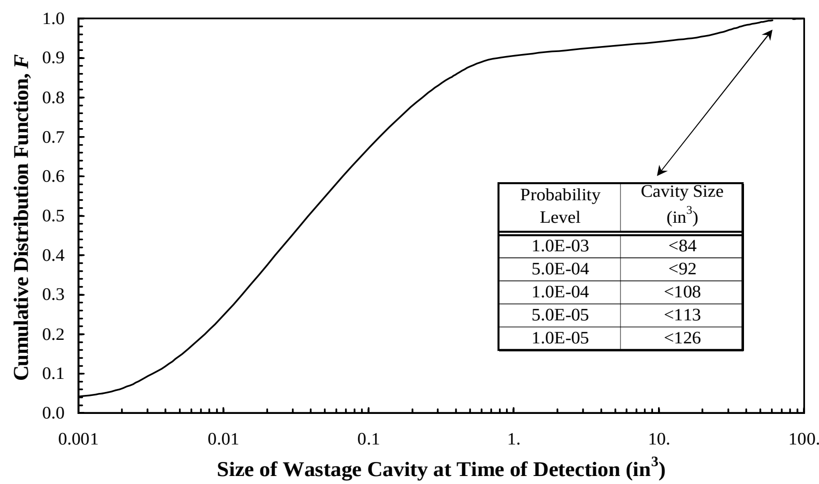
- The probabilistic wastage assessment of MRP-75 considers relatively wide tolerance bands for the key model parameters:
  - Point within operating cycle that wastage begins
  - Stress intensity factor driving crack growth
  - Crack growth rate distribution
  - Leak rate as a function of axial crack length
  - Wastage rate as a function of leak rate
  - Sensitivity of BMV inspection



Probabilistic Boric Acid Wastage Assessments
Typical Results

- Typical results shows that the probability of a leaking nozzle producing wastage greater than the typical 150 in^3 allowable volume is less than 1×10^{-4}

- The impact on the CDF may be estimated by multiplying the result of the probabilistic assessment by the probability of leakage from the nozzle ejection assessment and by the CCDP for the appropriately sized LOCA



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Conclusions

- After consideration of additional factors such as the potential effects of loose parts, consequential damage, and the effect on the large early release frequency (LERF), the methodology forms a rational basis for setting the re-inspection interval
- Because RV head nozzles are quite flaw tolerant, typical results show that re-inspection every second or third operating cycle maintains the requisite level of nuclear safety

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Reactor Vessel Head Penetration Inspection Technology Past, Present and Future

J. P. Lareau

D. C. Adamonis

Westinghouse Electric Company

BNFL

Westinghouse

RPVH Inspection Technology

- Initial Concern was ID Flaws in Nozzle
  - –Eddy Current Testing for Detection
  - –Ultrasonic Testing for Sizing
- Gapscanner sword probes used exclusively
- NDE Qualifications performed to Bulletin 97-01
- DERI Robotic Delivery System

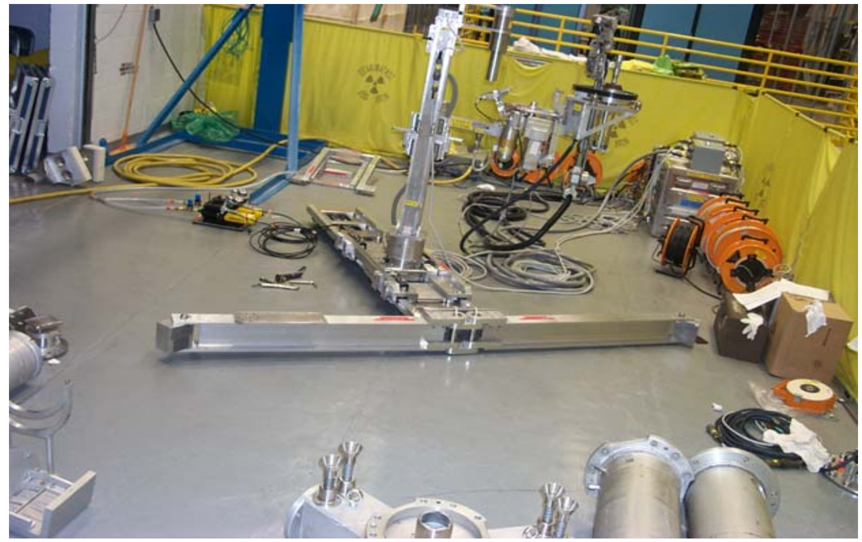
RPVH Inspection Technology

- NRC Bulletins 02-02 and 03-02
  - Emphasis changes to Nozzle OD and Weld
  - Ultrasonic volumetric exam or wetted surface exams required
- Additional Inspection Equipment Required
  - Open Housing Scanner (ET and UT)
  - Weld and Nozzle OD Scanner (ET)

RPVH Inspection Technology

- Inspection Approach from ID
  - –TOFD UT for OD Flaws and Sizing
  - –Eddy Current Testing for ID Flaws
  - –0 Degree UT for Leak Path
- Inspection Approach from OD
  - –Eddy Current Testing for Detection and/or confirmation of ID Results
  - –Weld surface and Nozzle OD Coverage

Under the Reactor Vessel Head Inspection and Repair Equipment Delivery System



- End-effectors for under-head penetration inspection and repair are delivered by the “DERI” manipulator system
  - 5 systems available in the Westinghouse system
  - Over 140 RV Head inspections performed with the DERI/eddy current gap scanner
  - Change out of end effectors is performed remotely

Open Housing Scanner Offers Eddy Current and TOF Inspection Capability

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probe insertion

Gapscanners for Sleeved Penetrations

- Blade probes are delivered into the annulus between the the ID surface of the penetration and OD surface of the thermal sleeve, on the order of 0.125 inches
- The Gapscanner end effectors can be used with a variety of eddy current and ultrasonic blade probes for inspection and characterization
  - Eddy current probes
  - TOFD ultrasonic probes
  - Combination TOFD/ECT probes
  - Pulse-echo ultrasonic probes

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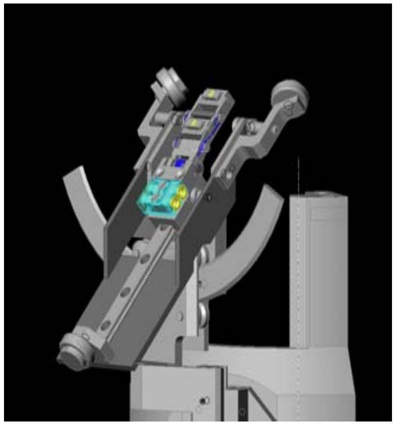
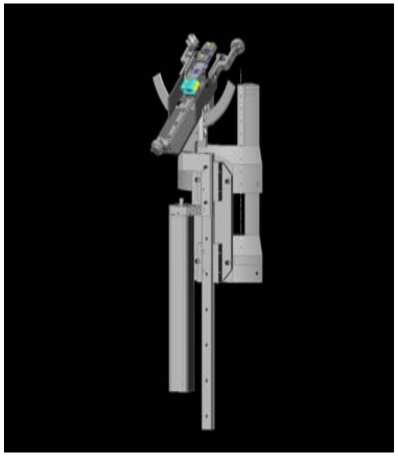
J-Weld and Penetration Tube OD EC Inspection

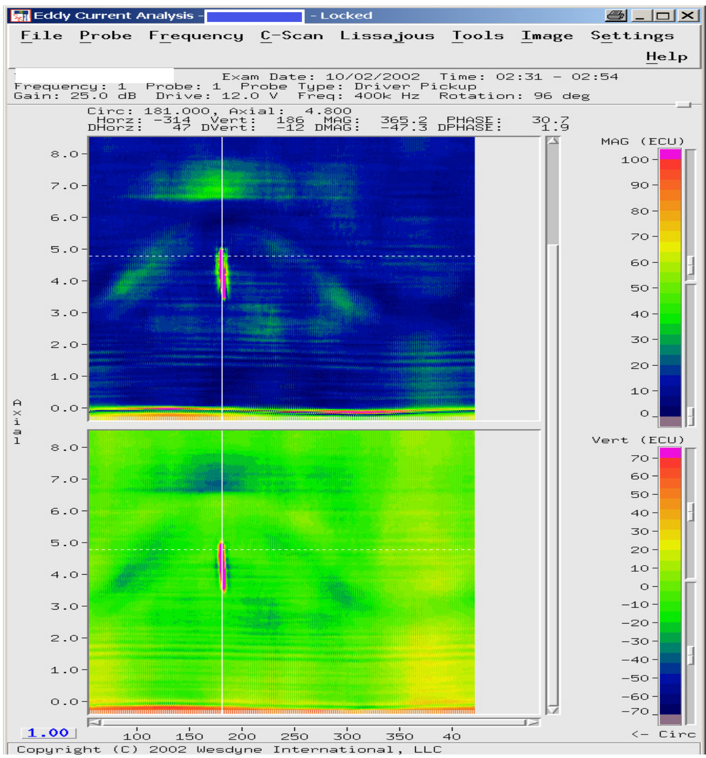


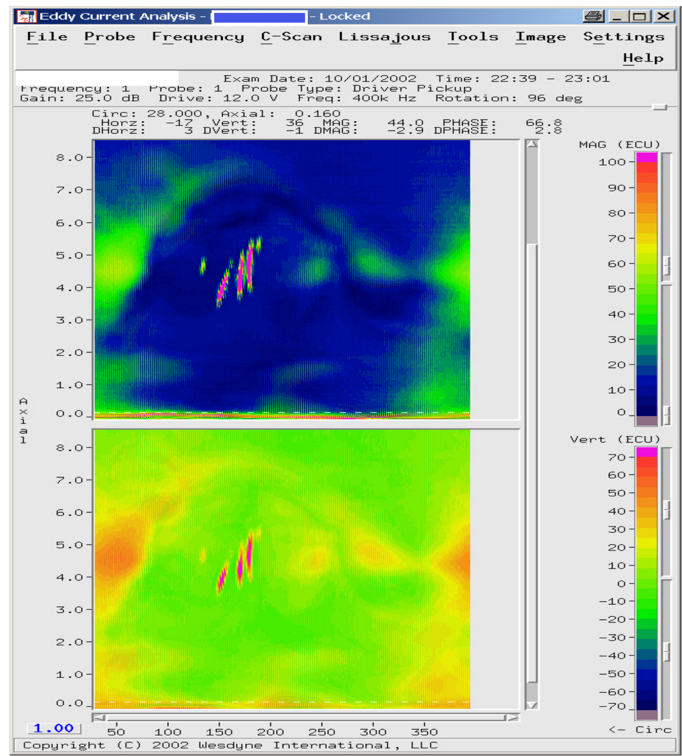


- "Grooveman" is used to perform eddy current inspections of the J-weld and penetration tube OD surface

- "Grooveman" has been used at North Anna Units 1 and 2, DC Cook Units 1 and 2, SONGS 2, H.B. Robinson Unit 2 and Palo Verde Units 1 and 2

Penetration Tube ID Eddy Current Results





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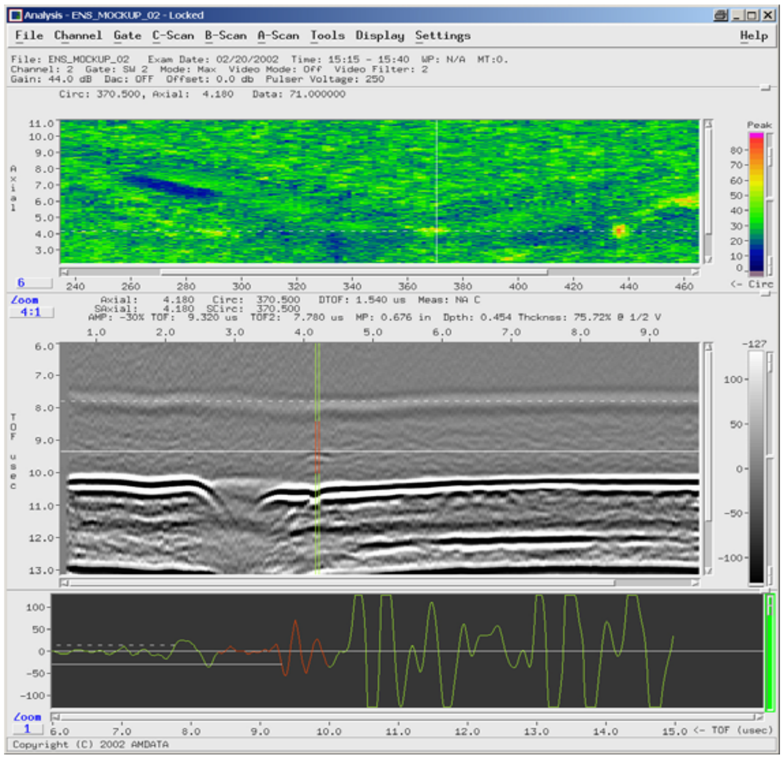
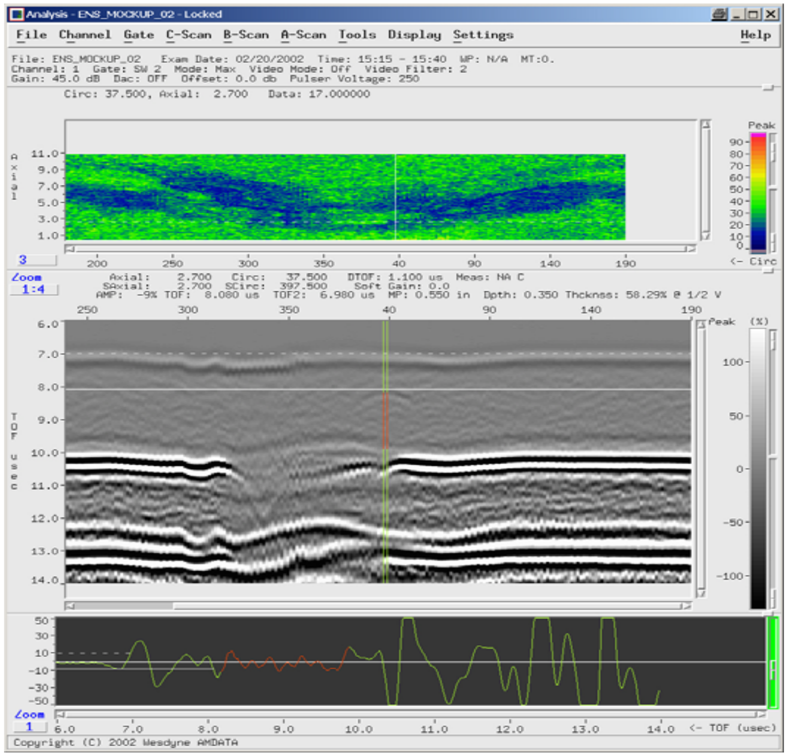
PCS24 TOFD UT Results





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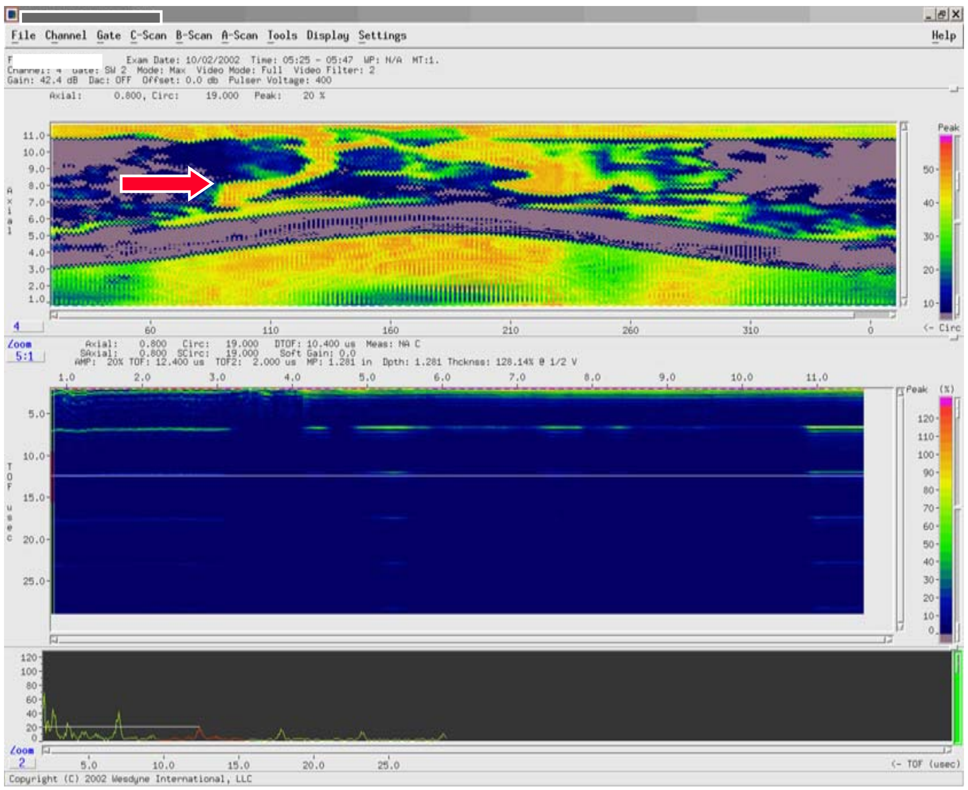
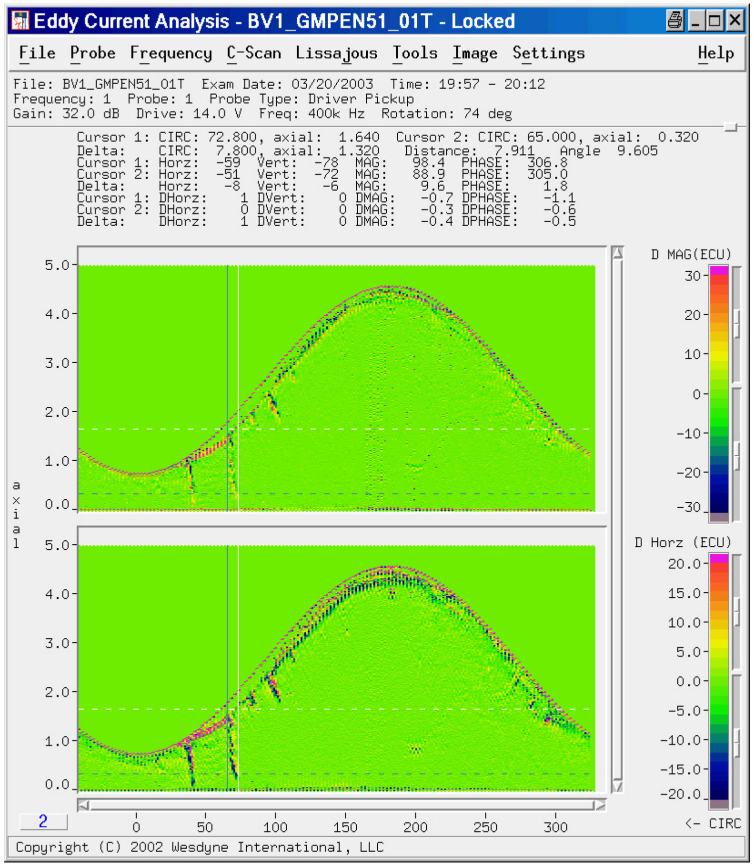
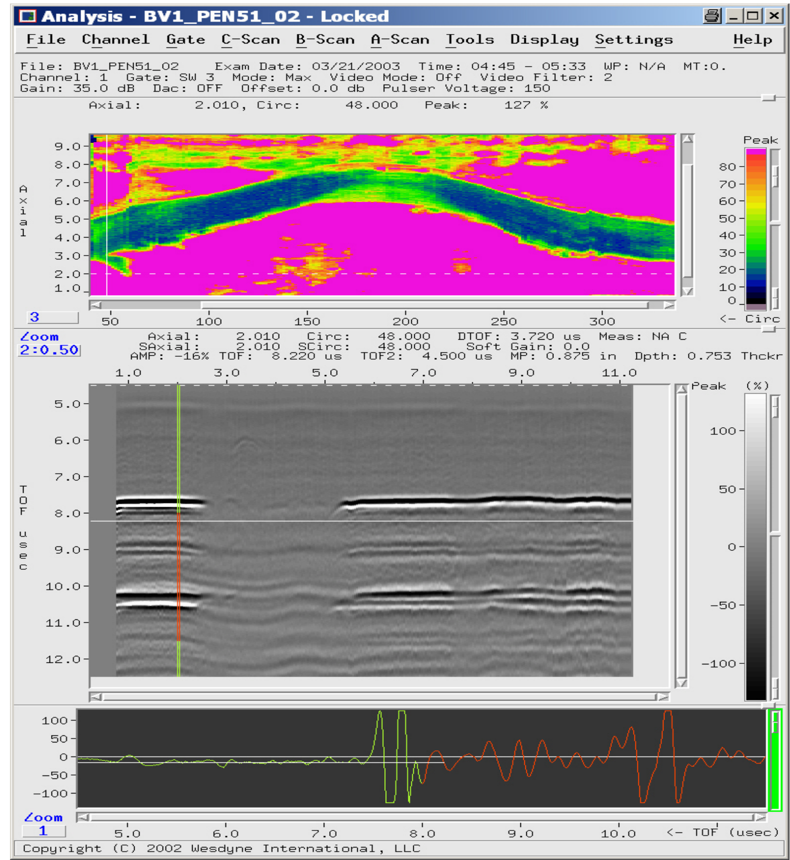
Leak Path Identification



- Not applicable to BMI inspections
- Possible leak path identified with straight beam, high frequency ultrasonics
- Leak path leads to loss of shrink fit integrity and a resulting increase in reflectivity
- Diagnostic tool rather than a primary inspection method

Penetration Tube OD ECT and ID TOFD Results





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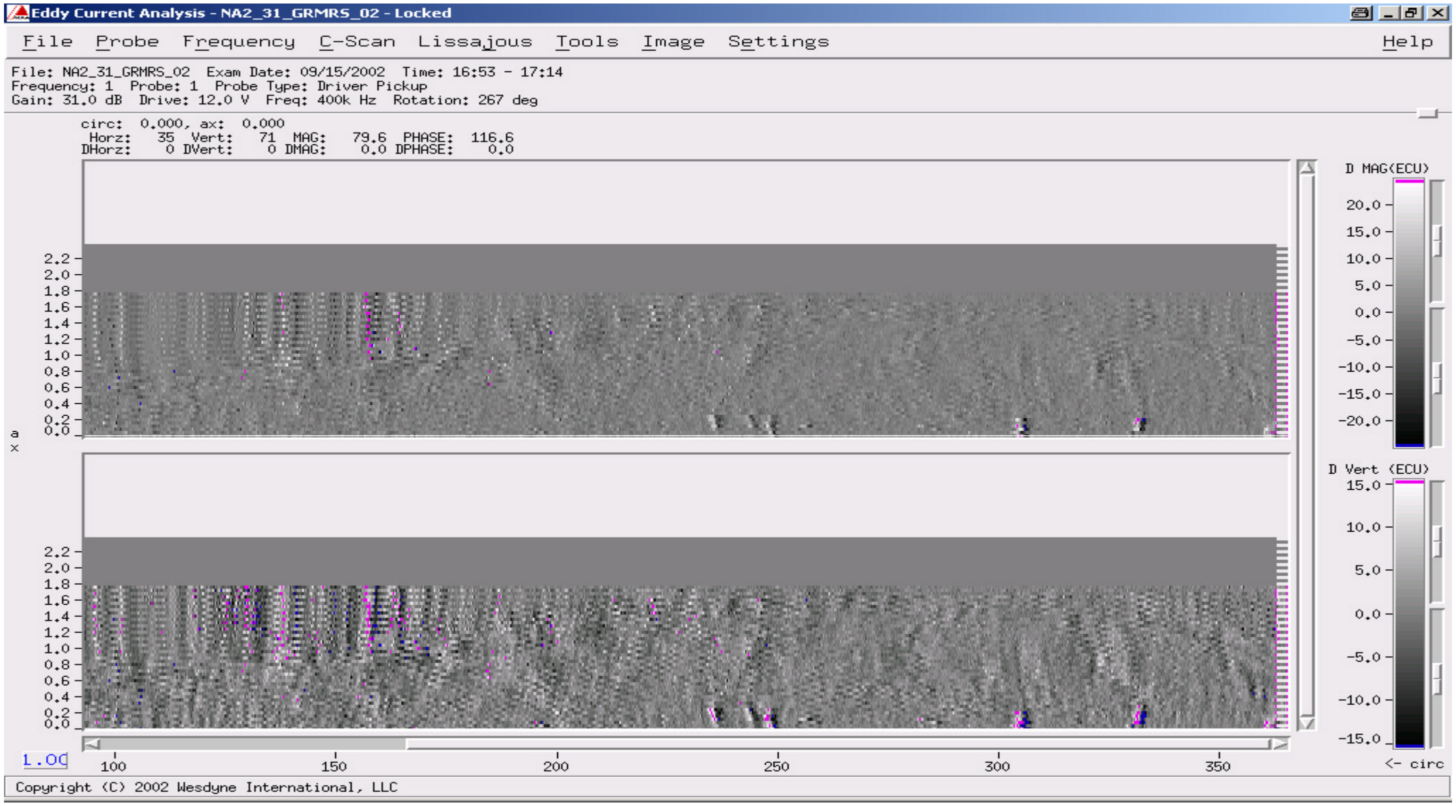
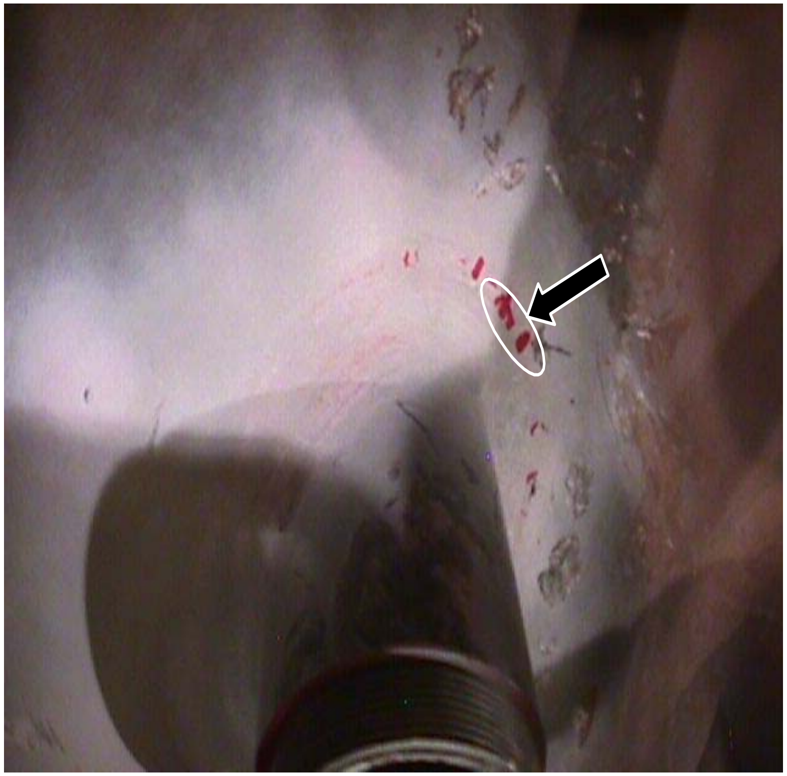
J-Groove Weld ECT Results



Reactor Vessel Head PT Results



RPVH Inspection Technology

- Next Generation Equipment
  - SUPREEM Based Robotics
  - Triple Sword Probe
    - TOFD
    - ET
    - 0 Degree
    - BMI Probes

Rapid Repositioning Accomplished with ROSA

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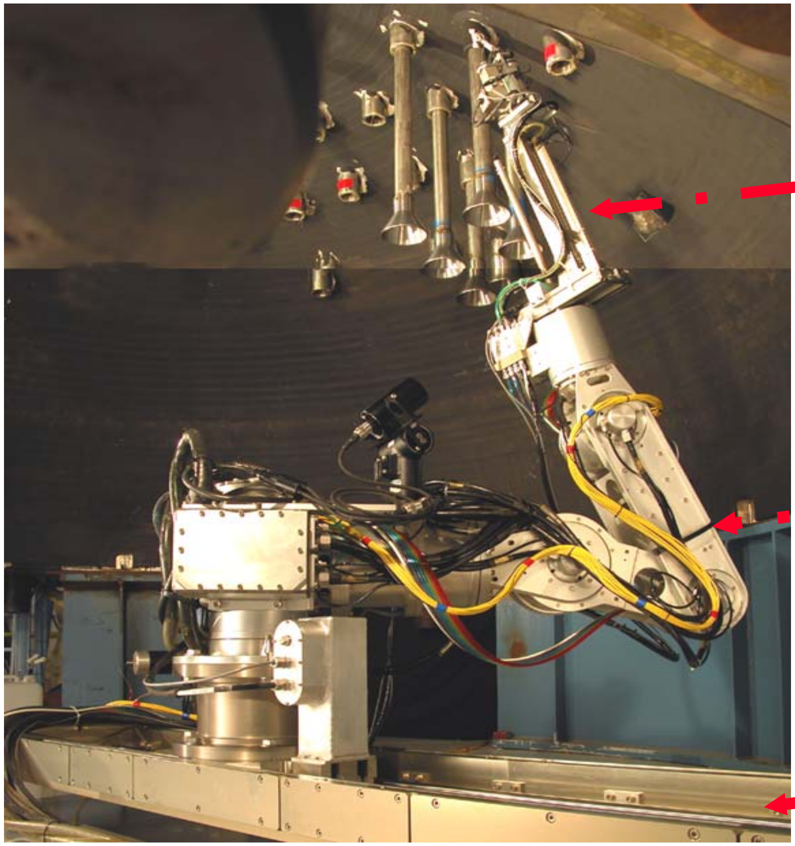
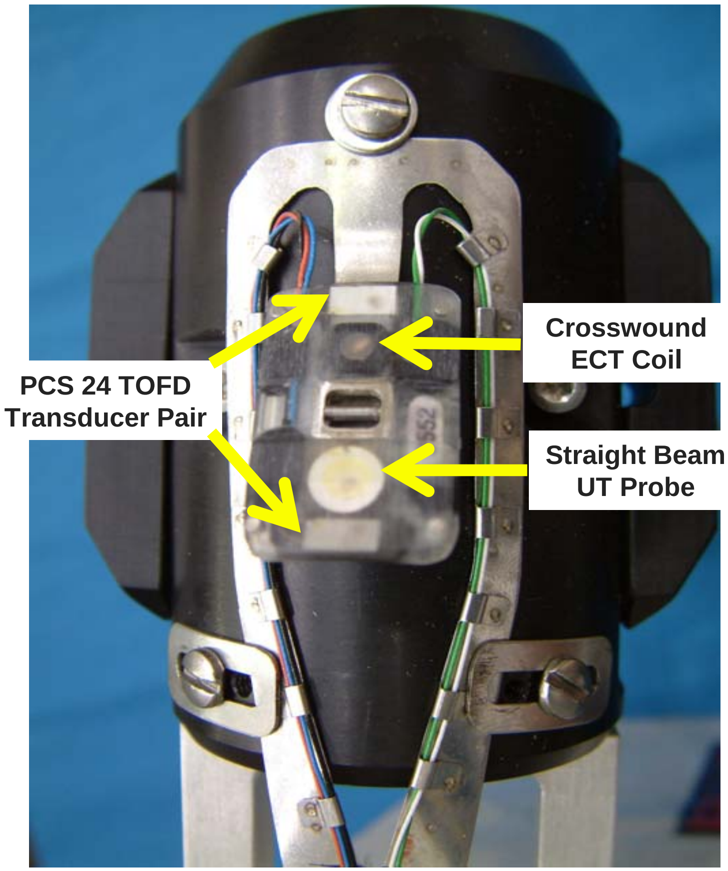


End Effector

Six Degrees of Freedom Robotic Arm

Positioning Track

Westinghouse Triple Combo Blade Probe



- Three examinations performed simultaneously:
  - PCS 24 TOFD ultrasonic examination of penetration tube
  - Eddy current examination of penetration tube ID surface
  - Straight beam ultrasonic examination for leak path identification

Bottom Mounted Instrumentation Inspection

The scanning manipulator is positioned on the nozzle with a ridgid pole system.

Bottom nozzle inspection manipulator

The manipulator positioned on a nozzle.

ET / UT probe for defect detection (left)
UT pulse echo probe for socket weld inspection
UT TOFD probe for defect sizing (right)

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