CERTIFICATE

This is to certify that the attached proceedings before the United States Nuclear Regulatory Commission in the matter of:

Name of Proceeding: Advisory Committee on Reactor Safeguards Materials and Metallurgy & Plant Operations Joint Subcommittee Meeting

Docket Number: n/a

Location: Rockville, MD

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission taken by me and, thereafter reduced to typewriting by me or under the direction of the court reporting company, and that the transcript is a true and accurate record of the foregoing proceedings.

Matt Needham

Matt Needham
Official Reporter
Neal R. Gross & Co., Inc.

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
MATERIALS & METALLURGY AND PLANT OPERATIONS SUBCOMMITTEES
VHP CRACKING AND RPV HEAD DEGRADATION
ROOM T-2B3, 11545 ROCKVILLE PIKE, ROCKVILLE, MARYLAND

April 22, 2003

- PROPOSED AGENDA -

	SUBJECT	PRESENTER	TIME
I.	Introductory Remarks Subcommittee Chairmen	F.P. Ford, ACRS J.D. Sieber, ACRS	8:30 - 8:35 a.m.
II.	Overview of NRC Activities	Richard Barrett, NRR	8:35 - 8:50 a.m.
III.	Industry Positions on RPV Head and VHP Nozzle Inspections	Christine King, MRP Larry Mathews, MRP Craig Harrington, MRP Tom Alley, MRP	8:50 - 10:15 a.m.
		*****BREAK*****	10:15 - 10:30 a.m.
IV.	Industry Positions on RPV Head and VHP Nozzle Inspections (Continued)	Christine King, MRP Larry Mathews, MRP Craig Harrington, MRP Tom Alley, MRP	10:30 - 12:00 noon
		*****LUNCH*****	12:00 - 1:00 p.m.
V.	Industry Positions on RPV Head and VHP Nozzle Inspections (Continued)	Christine King, MRP Larry Mathews, MRP Craig Harrington, MRP Tom Alley, MRP	1:00 - 2:30 p.m.
		*****BREAK*****	2:30 - 2:45 p.m.
VI.	NRC Sponsored Research	William Cullen, RES	2:45 - 4:45 p.m.
VII.	General Discussion and Adjournment		4:45 - 5:30 p.m.

Note: Presentation time should not exceed 50% of the total time allocated for a specific item. Number of copies of presentation materials to be provided to the ACRS - 40.

ACRS CONTACT: Maggalean W. Weston, mww@nrc.gov or (301) 415-3151.

Reactor Vessel Head Inspection Results

Advisory Committee on Reactor Safeguards
Materials & Metallurgy and
Plant Operations Subcommittees

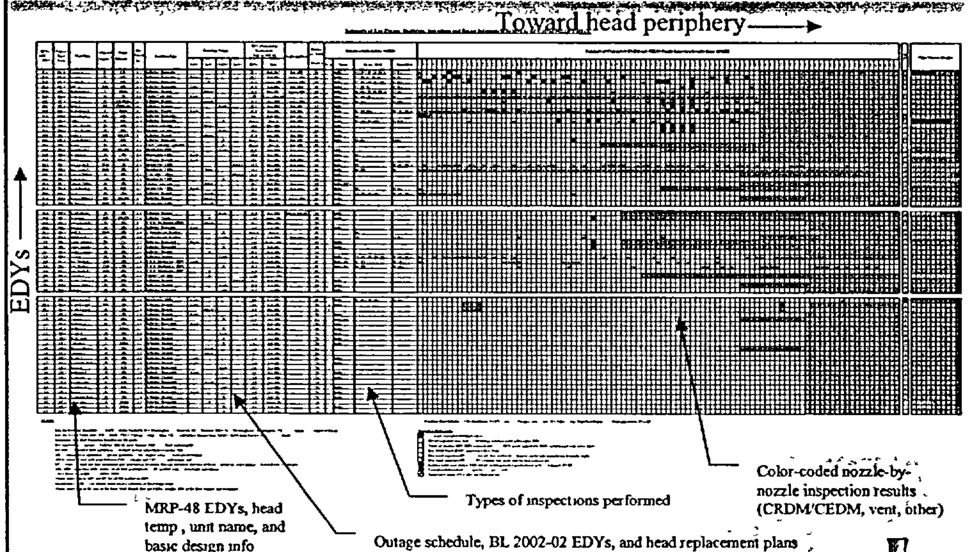
Vessel Head Penetration Cracking and
RPV Head Degradation

April 21, 2003
Room T-2B3
11545 Rockville Pike
Rockville, Maryland

Larry Mathews, SNOC
MRP Alloy 600/82/182
Issue Task Group Chairman

- Overview Table of Inspection Results by Plant
- Subpopulation Summary Statistics
  - By EDY Group
  - By Head Fabricator and Tubing Supplier
  - Detected Circumferential Cracks
- Inspection Plans for Spring 2003 Outages

Overview Table of Inspection Results



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- The overview 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
- The overview table complements more detailed outage-specific and defect-specific inspection results tables that are used to generate statistical (i.e., Weibull) fits
- The MRP plans to release a revision to the table at the end of each outage season

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Cracking

No	Unit	NSSS Supplier	Approx. EDYs at Inspection	Date	Number of Nozzles on Head: CRDM	CEDM	ICI	Total	Nozzles Inspected by Non-Visual: Total	Total %	No. Leaking Nozzles/ Welds: Leaking	% of Total Inspected	No. Cracked Nozzles/ Welds: Cracked	% of Total Inspected	No. Nozzles with Base Metal Cracks	No. Nozzles with Weld Metal Cracks	No. Nozzles with Axial Cracks	No. Nozzles with Circ Cracks
1	ANO 1	B&W	19.6	Mar 2001	69			69	1	1.4%	1	100.0%	1	100.0%	1	0	1	1
2	ANO 1	B&W	21.1	Oct 2002	69			69	69	100.0%	1	1.4%	8	11.6%	8	8	8	0
3	Cook 2	W	13.9	Jan 2002	78			78	78	100.0%	0	0.0%	2	2.6%	2	0	2	0
4	Crystal River 3	B&W	16.2	Oct-2001	69			69	9	13.0%	1	11.1%	1	11.1%	1	1	1	1
5	Davis-Besse	B&W	19.2	Apr 2002	69			69	69	100.0%	3	4.3%	5	7.2%	5	0	5	1
6	Millstone 2	CE	11.2	Feb-2002		69	8	77	77	100.0%	0	0.0%	3	3.9%	3	1	3	2
7	North Anna 1	W	20.0	Oct 2001	65			65	30	46.2%	0	0.0%	6	20.0%	6	0	6	0
8	North Anna 2	W	19.0	Nov 2001	65			65	3	4.6%	3	100.0%	3	100.0%	3	3	3	0
9	North Anna 2	W	19.7	Sep 2002	65			65	65	100.0%	6	9.2%	42	64.6%	7	42	1	6
10	Oconee 1	B&W	21.8	Nov-2000	69			69	18	26.1%	1	5.6%	1	5.6%	1	1	1	0
11	Oconee 1	B&W	23.2	Mar 2002	69			69	5	7.2%	1	20.0%	3	60.0%	3	1	3	0
12	Oconee 2	B&W	22.2	Apr 2001	69			69	4	5.8%	4	100.0%	4	100.0%	4	4	4	1
13	Oconee 2	B&W	23.7	Oct-2002	69			69	69	100.0%	7	10.1%	15	21.7%	15	5	10	0
14	Oconee 3	B&W	21.7	Feb 2001	69			69	18	26.1%	9	50.0%	10	55.6%	10	0	10	5
15	Oconee 3	B&W	22.5	Nov-2001	69			69	52	75.4%	5	9.6%	7	13.5%	7	2	7	2
16	Surry 1	W	19.1	Oct 2001	65			65	16	24.6%	2	12.5%	6	37.5%	0	6	0	0
17	TMI 1	B&W	18.1	Oct-2001	69			69	12	17.4%	5	41.7%	7	58.3%	7	4	7	0
Totals for Inspections Since First U.S. Leakage (11/2000)					3871	1090	94	5055	1462	28.9%	47	3.2%	120	8.2%	82	75	71	19

NOTE The table does not reflect the small-diameter thermocouple nozzles found to be cracked and leaking at Oconee 1 and TMI 1 (These are the only two plants that have this type of nozzle)

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EDY at Next RFO	No. Units	BMV: No. Units 100% Inspected	BMV: No. Nozzles Inspected	Nozzle Tube ET/UT: No. Units 100% Inspected	Nozzle Tube ET/UT: No. Nozzles Inspected	Weld ET/PT: No. Units 100% Inspected	Weld ET/PT: No. Welds Inspected
>12 EDY	30	27 (90%)	1898 (92%)	13 (43%)	1016 (49%)	3 (10%)	338 (16%)
8–12 EDY	15	8 (53%)	510 (49%)	4 (27%)	354 (34%)	0 (0%)	61 (6%)
< 8 EDY	24	17 (71%)	1327 (71%)	0 (0%)	92 (5%)	0 (0%)	1 (0%)
Totals	69	52 (75%)	3735 (75%)	17 (25%)	1462 (29%)	3 (4%)	400 (8%)

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[illegible] Inspection Results
By EDY Group

EDY at Next RFO	No Nozzles	Leaking Nozzles: Nozzles Leaking (Inspected)	Leaking Nozzles: % Leaking	Nozzle Tubes Cracked: Nozzles Cracked (Inspected)	Nozzle Tubes Cracked: % Cracked	Welds Cracked: Welds Cracked (Inspected)	Welds Cracked: % Cracked
>12 EDY	2069	47 (1898)	2 5%	82 (1016)	8.1%	75 (338)	22.2%
8–12 EDY	1035	0 (510)	0 0%	0 (354)	0.0%	0 (61)	0.0%
< 8 EDY	1857	0 (1327)	0 0%	0 (92)	0 0%	0 (1)	0.0%
Totals	4961	47 (3735)	1 3%	82 (1462)	5 6%	75 (400)	18 8%

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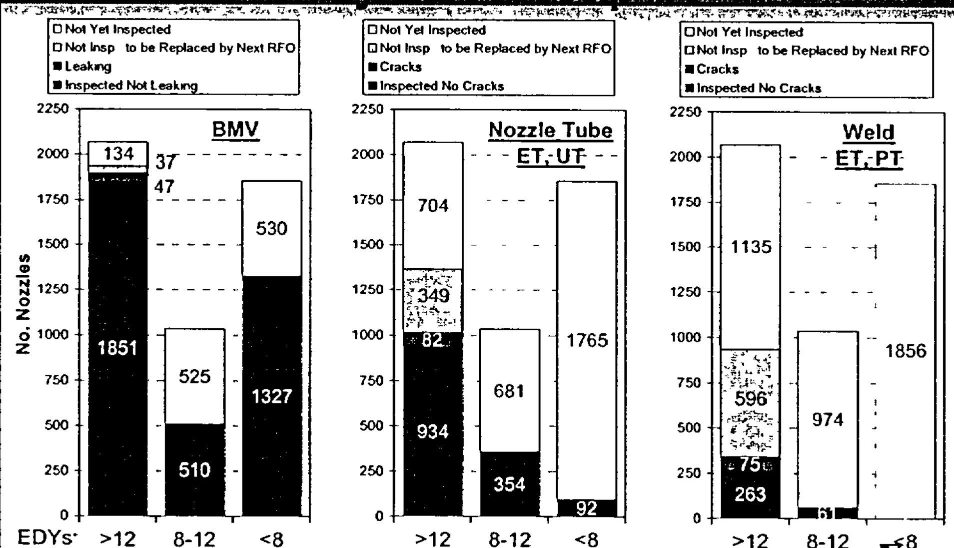

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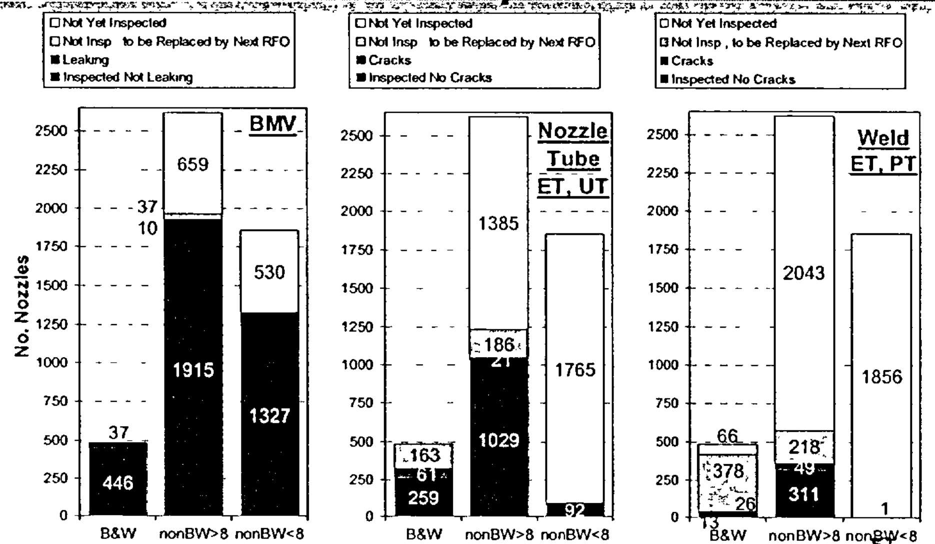
B&W Units Separated Out

NSSS Supplier / EDY at Next RFO	No. Units	BMV: No. Units 100% Inspected	BMV: No Nozzles Inspected	Nozzle Tube ET/UT: No. Units 100% Inspected	Nozzle Tube ET/UT: No. Nozzles Inspected	Weld ET/PT: No. Units 100% Inspected	Weld ET/PT: No. Welds Inspected
B&W NSSS	7	7 (100%)	483 (100%)	4 (57%)	320 (66%)	0 (0%)	39 (8%)
non-B&W > 8 EDY	38	28 (74%)	1925 (73%)	13 (34%)	1050 (40%)	3 (8%)	360 (14%)
non-B&W < 8 EDY	24	17 (71%)	1327 (71%)	0 (0%)	92 (5%)	0 (0%)	1 (0%)
Totals	69	52 (75%)	3735 (75%)	17 (25%)	1462 (29%)	3 (4%)	400 (8%)

B&W Units Separated Out

NSSS Supplier / EDY at Next RFO	No. Nozzles	Leaking Nozzles: Nozzles Leaking (Inspected)	Leaking Nozzles: % Leaking	Nozzle Tubes Cracked: Nozzles Cracked (Inspected)	Nozzle Tubes Cracked: % Cracked	Welds Cracked: Welds Cracked (Inspected)	Welds Cracked: % Cracked
B&W NSSS	483	37 (483)	7.7%	61 (320)	19.1%	26 (39)	66.7%
non-B&W > 8 EDY	2621	10 (1925)	0.5%	21 (1050)	2.0%	49 (360)	13.6%
non-B&W < 8 EDY	1857	0 (1327)	0 0%	0 (92)	0.0%	0 (1)	0.0%
Totals	4961	47 (3735)	1.3%	82 (1462)	5.6%	75 (400)	18 8%

CRDM/CEDM Nozzle Inspection Results
B&W Units Separated Out



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- The total RVH nozzle population includes 3871 CRDM nozzles, 1090 CEDM nozzles, and 94 ICI nozzles at 69 units
- Bare-metal visual (BMV) and/or non-visual NDE inspections have now been performed on about 81% of the RVH nozzles
  - About 47 nozzles have been found to be leaking
- Almost 8% of the nozzles in B&W plants have leaked, but leakage in non-B&W plants is limited to North Anna 2 and Surry 1 leakage, which is primarily due to weld cracking
- Non-visual examinations have been performed on:
  - About half of the ">12 EDY" nozzles and a third of the "8-12 EDY" nozzles
  - About two-thirds of the nozzles in B&W plants and 25% of the nozzles in non-B&W plants

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Summary of Inspection Results Statistics (cont'd)

- About 19% of the inspected B&W plant nozzles show base metal cracking
- Base metal cracking in non-B&W plants is limited to Millstone 2 (3 nozzles) and Cook 2 (1 nozzle), although North Anna 1 and 2 may have experienced some base-metal initiated cracking (Sandvik material)
- About 8% of the J-groove welds have been examined by ET or PT
- Weld experience ranges from no indications in a relatively high EDY plant (Robinson) to relatively extensive weld cracking in another high EDY plant (North Anna 2)
- To date, weld cracking has been limited to vessels fabricated by Rotterdam Dockyards and B&W-designed units

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Inspection Plans for Spring 2003 (prior to NRC Order EA-03-009)

EDYs at Spring RFO (Note 1)	Unit Name	NSSS Vendor	Material Supplier (Note 2)	Vessel Fabricator (Note 3)	Previous Inspections (Since 11/2000)			Plans for Spring 2003 RFO (Note 4)			Current Head Replacement Plans
					Visual for Leakage	A600 Nozzle Tubes	A182 Weld Metal	Visual for Leakage	A600 Nozzle Tubes	A182 Weld Metal	
22.5	Oconee 3	BW	B	BW	BMV	UT ET(18),PT(12)	PT(12)	Head Replacement with A690			Spring 2003
21 4	North Anna 1	W	S	RDM	BMV	ET(30) UT(8),PT(4)	PT (4)	Head Replacement with A690			Spring 2003
20 5	Surry 1	W	H	BW RDM	BMV	UT(16)	PT(10)	Head Replacement with A690			Spring 2003
18 3	Turkey Point 3	W	H	BW	BMV	-		BMV	UT	-	Assessing
17 5	Farley 1	W	H B	BW CE	BMV	-	-	BMV	ET UT	-	Fall 2004
15 2*	San Onofre 3	CE	SS/H	CE	BMV(34)	-	-	BMV	UT	ET	Assessing
15 2	Calvert Cliffs 2	CE	H	CE	BMV(8 ICI)		-	BMV	UT		Assessing
14 6	Cook 2	W	W	CBI	BMV	ET UT	ET(10)	BMV	-		-
14 0	St Lucie 2	CE	SS H	CE	BMV		-	BMV	UT		Assessing
14 0	Beaver Valley 1	W	H B	BW CE	BMV	-	-	BMV	ET UT	ET	Spring 2006
< 12	Kewaunee	W	H B	BW CE	BMV	-	-	BMV	-		-
11 2	Indian Point 3	W	H	CE	-	-	-	BMV	ET UT	-	-
11 0	Palo Verde 3	CE	SS H	CE			-	BMV(24)	UT		-
10 9	Diablo Canyon 2	W	H	CE	-	-	-	BMV	-		-
< 10	Palisades	CE	H	CE	-		-	BMV	-		-
4 5	South Texas 1	W	H	CE		-	-	BMV		-	-
2 to 3	Catawba 2	W	H	CE			-	BMV	-		-
2 1*	Shearon Harris	W	B	CBI	-			BMV			-
1 7	Braidwood 1	W	B	BW		-	-	BMV	-	-	-
1 5	Sequoyah 1	W	S	RDM				BMV	-		-

NOTES

1 EDYs as reported by each plant in their responses to Bulletin 2002-02 The asterisks indicate EDYs at time of the Bulletin 2002-02 response rather than the projected EDYs at the spring 2003 refueling outage (8 2002 for San Onofre 3 and 9 2002 for Shearon Harris)

2 Key for Material Suppliers B = B&W Tubular Products H = Huntington S = Sandvik SS = Standard Steel, W = Westinghouse (Huntington) CL = C L Imphy A = Aubert et Duval

3 Key for Vessel Fabricators BW = B&W CBI = Chicago Bridge & Iron, CE = Combustion Engineering RDM = Rotterdam Dockyard. CL = C L Imphy

4 The spring 2003 inspections for San Onofre 3 have already been completed with no indications of cracking or leakage The spring 2003 inspections for Diablo Canyon 2 have already been completed with no indications of leakage

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Inspection Plans for Spring 2003

- 20 units have refueling outages this spring:
  - Oconee 3, North Anna 1, and Surry 1 will replace their heads with new heads having Alloy 690 material
  - All 17 other units will perform 100% BMV and/or non-visual inspections
  - All the plants having greater than 12 EDYs will have performed a non-visual baseline examination by the end of the spring outage season
- The spring 2003 outage season mainly concludes the initial set of inspections following Bulletin 2001-01. After this spring:
  - All but two units (< 2 EDYs) will have completed 100% BMV and/or non-visual inspections (97% of the total nozzle population)
  - 20 of the 28 units with > 12 EDYs (as of February 2001) will have completed baseline non-visual examinations or head replacement

Inspection Plans for Spring 2003 (cont'd)

- After fall 2003, it is expected that:
  - All 69 units will have completed 100% BMV and/or non-visuals (or head replacement)
  - 27 of the 28 units with > 12 EDYs (as of February 2001) will have completed baseline non-visual examinations or head replacement (28th unit plans such an inspection at its next RFO in spring 2004)
- Upon the conclusion of the spring outage season, the MRP will again look for correlations between cracking and factors such as EDYs, tubing material supplier, and vessel head fabricator

Process for Revising the MRP Inspection Plan

Advisory Committee on Reactor Safeguards
Materials & Metallurgy and
Plant Operations Subcommittees

Vessel Head Penetration Cracking and
RPV Head Degradation

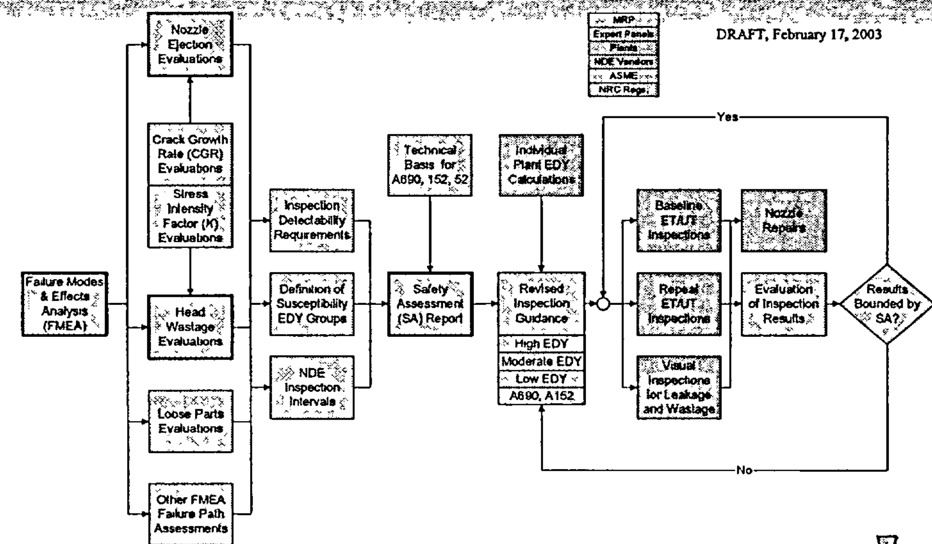
April 21, 2003
Room T-2B3
11545 Rockville Pike
Rockville, Maryland

David A. Steininger
EPRI, MRP and SGMP
Craig Harrington, TXU
MRP Alloy 600/82/182 ITG
RV Head Working Group Chairman

Topics

- Overall Safety Assessment Process
- Transition to Combination Baseline Inspections with Inspection Intervals Chosen to Ensure Safety
- Failure Modes and Effects Analysis
- Main Evaluations
  - Nozzle Ejection
  - Head Wastage
- Supporting Evaluations
  - Crack Growth Rates
  - Stress Intensity Factors
  - Proposed Additional Boric Acid Corrosion Testing
- Schedule for Issuing Revised Inspection Plan and Safety Assessment Report

Overall Process Flowchart



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Safety Assessment Process: Key Points

- The MRP approach is transitioning to ensuring safety through "combination" baseline inspections at all plants with:
  - The timing for the baseline inspection and the re-inspection interval based on the technical evaluations and
  - More frequent bare metal visual (BMV) inspections providing backup to the program of periodic combination inspections
- The revised MRP inspection plan will be formed on the basis of a comprehensive safety assessment (SA) report
- The SA report:
  - Begins with a failure modes and effects analysis (FMEA) to anticipate the possibility of failure modes that have not been observed in the field and
  - Includes the analysis tools previously developed and described in MRP-75

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Safety Assessment Process: Key Points (cont'd)

- The results of the FMEA are used to establish the required technical evaluations and ultimately the inspection detectability requirements
- Existing calculations show that non-visual inspections do not have to be performed every refueling outage to ensure safety
  - Extremely low probability of nozzle ejection and significant wastage
  - Extremely small consequential increase in core damage frequency, consistent with NRC Reg. Guide 1.174

Combination Baseline Inspections

- Subsequent to the release of the MRP-75 inspection plan and technical bases and in light of the most recent inspections results, the MRP has released a letter to the industry recommending a transition to combination baseline inspections
- Three types of combinations inspections:
  - (UT/BMV) UT of the base metal from the tube ID and bare-metal visual (BMV)
  - (UT/ET) UT of the base metal from the tube ID and ET/PT of the weld surface
  - (ET/ET) ET of the base metal ID and OD and ET/PT of the weld surface
- The timing of the baseline inspection and the inspection interval will be based on the technical evaluations to ensure safety

Combination Baseline Inspections (cont'd)

- Time at temperature (EDYs) will continue to form the basis for the susceptibility groups
- It is expected that high susceptibility plants will perform the combination baseline inspection by the next refueling outage
- It is expected that moderate susceptibility plants will perform the baseline inspection by approximately 2005 at the latest
- It is expected that low susceptibility plants will perform the baseline inspection by approximately 2007 at the latest

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Failure Modes and Effects Analysis: Introduction

- FMEA is a technique of TQM (Total Quality Management) to ensure product reliability
- Typically, a table of the following characteristics of the possible failure modes is prepared:
  - Cause
  - Effect (consequence)
  - Detectability
  - Frequency of Occurrence
- Relationships among the failure modes are illustrated using a block diagram
- FMEA is a tool that helps anticipate new failure modes

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Failure Modes and Effects Analysis: Application to RVH Nozzles

- For RVH penetrations, there are three principal failure modes:
  - Nozzle Ejection Due to Net Section Collapse
  - Cladding Blowout Due to Wastage
  - RCS Damage Due to Loose Parts Generation
- There are several levels in the failure process for these modes:
  - PWSCC initiation (nozzle ID, nozzle OD below weld, weld surface)
  - PWSCC growth (axial and circ in nozzle, axial-radial and circ-axial in weld; weld to nozzle and nozzle to weld; turn from axial to circ)
  - Leakage to annulus (new crack initiation and low-alloy steel wastage)
  - Growth to allowable size / wastage until code allowable stresses are reached
  - Growth to net section collapse or loose parts release / wastage to cladding blowout
  - Small/medium LOCA and possible consequential damage / loose parts damage
  - Effect on core damage frequency (CDF)

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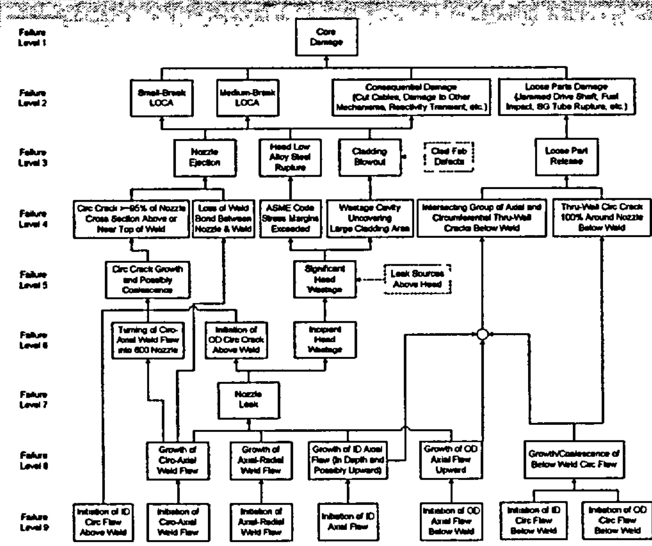
Failure Modes and Effects Analysis: Simplified Block Diagram

PRELIMINARY



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Failure Modes and Effects Analysis: Classification of Failure Conditions

- Each failure condition will be classified as:
  - Not credible,
  - Not actionable, or
  - Actionable
- A classification as "not credible" will require a strong technical argument and thorough documentation with a high threshold
- A classification as "not actionable" requires that adequate protection be provided at a higher level in the failure process
- Conditions classified as "actionable" will be inputs to the probabilistic and deterministic evaluations and will ultimately shape the detectability requirements specified in the inspection plan

Failure Modes and Effects Analysis: Additional Higher Order Factors

- Additional factors being considered in the FMEA include:
  - Environmental fatigue
  - Fabrication practices such as nozzle straightening or nickel plating
  - Surface and imbedded flaws produced during fabrications such as welding lack of fusion and hot cracking
  - The condition of the inside surface cladding
  - Primary water chemistry factors such as resin intrusions
  - Leaks from sources above the head
  - Plant-specific differences in the air flow across the head top surface

Failure Modes and Effects Analysis: Frequency of Occurrence

- Weibull reference curves based on the latest inspection results
  - Plant experience may support different curves for different nozzle material suppliers and different weld fabricators
- Crack growth rates based on MRP-55 and stress intensity factor calculations
- Existing small- and medium-break LOCA analyses
- Consequential damage assessments
- Loose parts damage assessments

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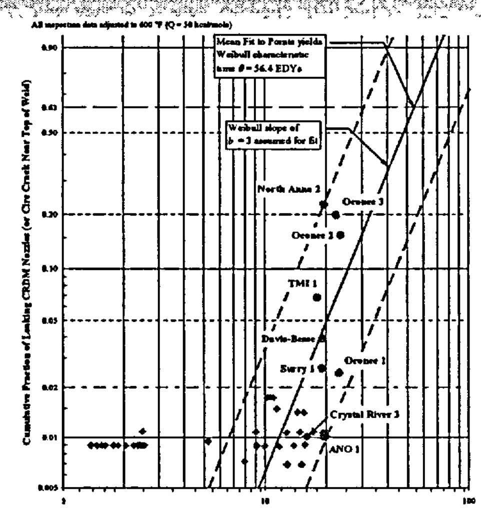
Failure Modes and Effects Analysis: Example Weibull Plot

- Plot covers all plants
- Leakage (or circ crack near weld root) due to base metal and weld metal initiated cracking combined on this plot
- Diamonds conservatively represent 42 plants that did not detect any leakage during BMV inspections



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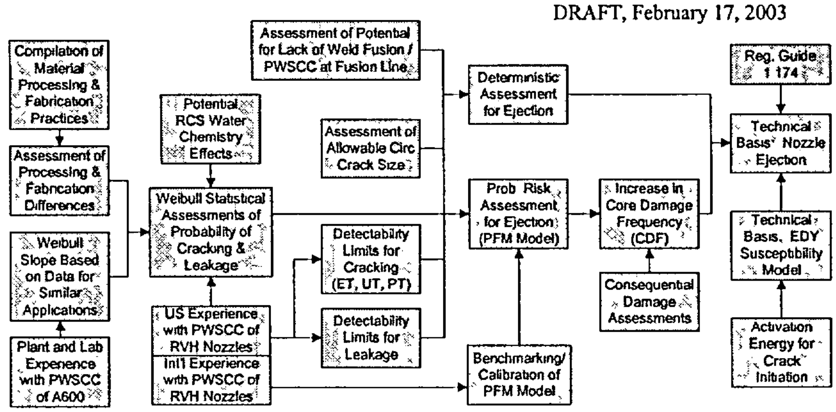
Main Evaluations: Nozzle Ejection

DRAFT, February 17, 2003



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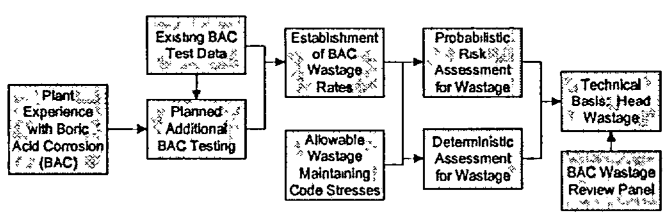
Main Evaluations: Head Wastage

DRAFT, February 17, 2003



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Supporting Evaluations: Crack Growth Rates

- The MRP report addressing the crack growth rates (CGRs) of Alloy 600 base metal (MRP-55) was formally submitted to the NRC in September 2002
- The EPRI-MRP expert panel on CGRs has completed preliminary assessments of Alloy 182 and 82 weld metal
- A report addressing the weld metal will be produced after additional data is produced, collected, and evaluated
- The expert panel will meet in late March in Washington, DC around the NRC conference to discuss the weld metal evaluations

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Supporting Evaluations: Stress Intensity Factors

- Stress intensity factor calculations have been completed for several CRDM nozzle geometries
- Comparison to date with the results produced by the NRC contractor have shown good agreement
- Additional work will be used to bound the magnitude of the stress intensity factors as a function of nozzle and weld geometry and material properties (e.g., nominal nozzle tube yield strength)
- The stress intensity factors are a secondary influence behind the crack growth rates on the probability of nozzle ejection

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Supporting Evaluations: Boric Acid Corrosion (BAC) Testing

- The MRP has completed scoping work to define the types of testing that are appropriate to produce key BAC data that are not available
  - Analysis work to understand the thermal-hydraulic and chemical environments along the leak path
  - Analysis work to define the key parameters that drive the corrosion and erosion processes in the nozzle crevice
  - A probabilistic wastage model to assess the risk of producing a wastage cavity large enough to result in shell stresses exceeding the ASME code allowables (Appendices C, D, and E of MRP-75, Rev. 1)
  - An expert panel to review the probabilistic wastage model
- The MRP is in the process of requesting proposals for performing the needed testing including mock-up testing
  - BAC testing work is expected to be awarded in May 2003

Deliverables and Schedule

- A comprehensive safety assessment (SA) report will form the basis for a revised MRP inspection plan
- As appropriate, the SA report will reference other reports (e.g., the MRP report on crack growth rates of Alloy 600—MRP-55)
- Some calculations remain to be revised and extended, but much of the material to be incorporated into the SA report has already been completed in support of MRP-75
- Data developed subsequent to the initial release of the SA report will be evaluated for consistency with the SA evaluations once such data become available
- The MRP expects to be prepared to discuss the contents of the SA and the revised inspection plan summer 2003
- In the meantime, technical discussions with the NRC staff will continue

North Anna Unit 2 Reactor Vessel Head

Advisory Committee on Reactor Safeguards
Materials & Metallurgy and
Plant Operations Subcommittees

Craig Harrington TXU
Chair RPV Head Working Group
April 21, 2003

Present Situation

- Inspection findings drive industry response in a reactive mode
- Regulator imposes more requirements for inspection
- Inspections find unexplained and unexpected cracking at some plants
- The root cause is not known
- The inspections will ensure safety, but this is not an effective, efficient or economical strategy for the industry

Enabling Actions to Achieve MRP Goals

- Comprehensive metallurgical examination of a failed component
- Determine root cause and generic implications
- Establish correlation between NDE indications and as found defects

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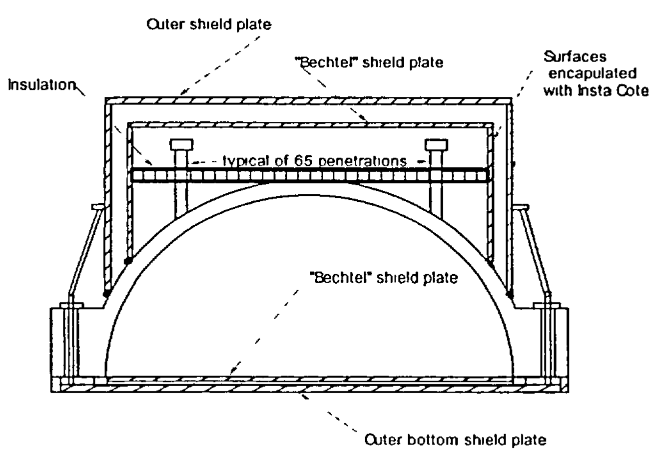
Figure 2
Conceptual Shipping Arrangement
Information Only not Official



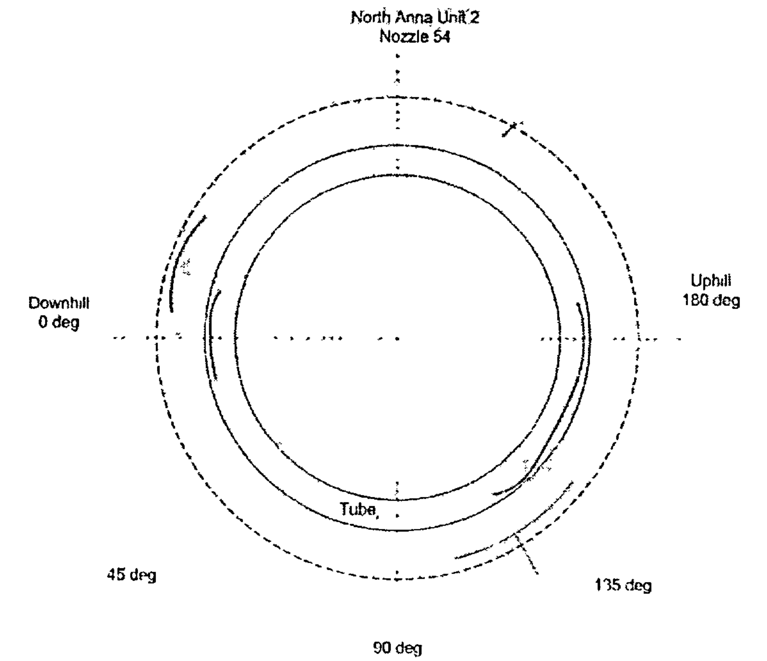
Objectives for Destructive Examination

- 1. Understand the formation of the circumferential flaws in the outer diameter of the nozzle base material and map its position relative to flaws in the J-groove weld.
- 2. Determine the most probable cause(s) of initiation and propagation of the weld flaws.
- 3. Characterize the final nozzle-annulus operating environment prior to shutdown and identify the associated corrosion mechanisms by analysis of annular deposits and local base material surface characteristics.

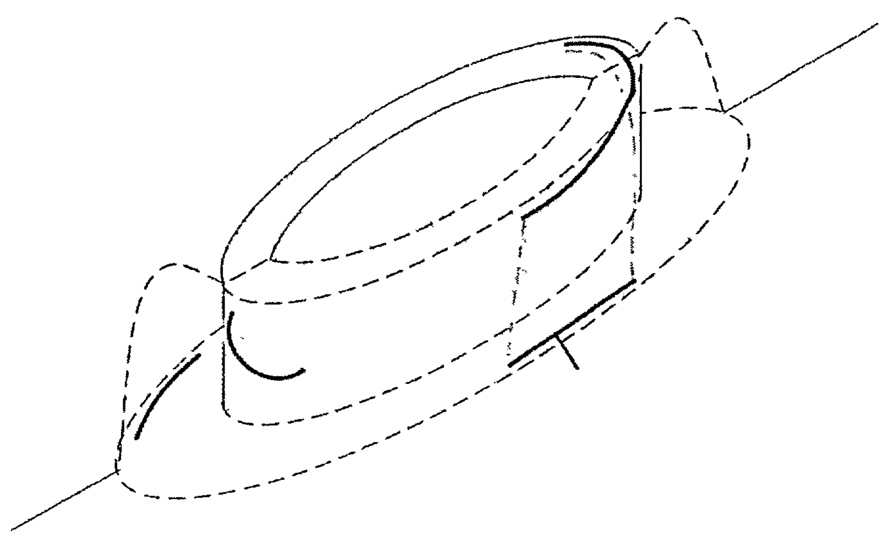
Objectives for Destructive Examination

1. 4. Examine the previously repaired nozzle (#51) that exhibited visual evidence of renewed leakage to determine both the mode(s) of degradation that resulted in leakage and the leak path through the pressure boundary.

- 5. Facilitate development of a better understanding of the actual capability of current inspection techniques and technologies to detect OD circumferential cracks in the base material and axial/circumferential cracks in the weld material by conducting vendor non-destructive examinations prior to nozzle destructive examinations.
- 6. Finally, acquire samples of base material and weld metal for future PWSCC testing of Alloy 600/182 thick-walled material.



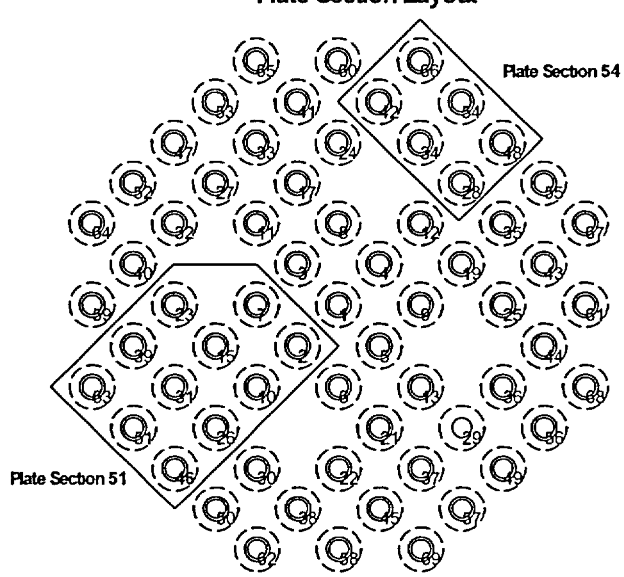
Nozzle 54 – View 2



Penetration	NDE results	Addresses Objective #(s)	Additional Information
54	Visual. Not leaking UT ID and OD Indication in Nozzle Weld ET circ and axial	1, 2, 5	OD Circ #1. Length 42 deg Depth 0 16" OD Circ #2: Length 80 deg Depth 0.23" Weld Circ #1 Length 1 5" Weld Circ #2 Length 1 22" Weld Axial Length 0.32"
59	Visual Masked UT OD circs in Nozzle Weld ET Circs	1 2, 5	OD Circ #1 Length 76 deg Depth 0 15" OD Circ #2: Length 50 deg Depth 0.32" Weld Circ #1 Length 3 05" Weld Circ #2 Length 5 31"
31	Visual Leaking UT. No detectable indications Weld: ET axials	2, 3, 5	Weld Axial #1 Length 0 08" Weld Axial #2 Length 0 16" Weld Axial #3 Length 0.20" Weld Axial #4 Length 0.20" Weld Axial #5 Length 0.24"
51 Weld repaired in 2001	Visual Leaking UT Weld Interface Indication (Evidence of leak path) Weld PT linear	2, 3, 4 5	
63 Weld repaired in 2001	Visual Masked UT ID Indication in Nozzle Probable Leak Path Weld PT linear	2 4 5	
10	Visual Leaking UT Weld Interface Indication Lack of Fusion Weld None	NDE	
Need to determine the CRDM nozzle numbers	Sample RPV nozzle material from several different heats of material Sample should capture the full circumference and be about 6 inches long	6	Heats to consider 710147, 755536, 710208, 772024 or 568011

Figure 1

Plate Section Layout



Current Actions

- Proposals due 2/24
- Finalize a sectioning plan that focuses on priority of examination of particular nozzles
- Determine if any additional NDE testing is necessary
- Determine the cost of the project by competitive bid
- Coordinate sample removal process
- Select Laboratory for DE testing

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Status of Reactor Vessel Head Penetration Inspection Activities

Tom Alley, Duke Energy
Chair, Alloy 600 Inspection WG

ACRS Materials & Metallurgy and Plant Operations Subcommittees
February 18-19?, 2003

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Presentation Outline

- CRDM Issue Background
- Top-of-head Visual Exam Guidance
- MRP Approach to NDE Demonstration
- 2001 Demonstration Process & Results
- 2002 Demonstration Process & Results
- Future Demonstration Activities
- Other Future Inspection Committee Activities
  - Database??
- Summary

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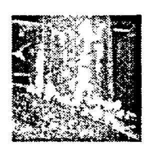
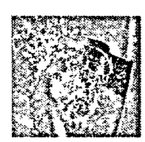
CRDM Head Penetration NDE Background

- Original (97-01) demonstrations addressed cracks initiating on the inside surface of the penetration only
- Discovery of tube OD and weld cracking identified the need to modify the NDE demonstration program
  - Inspection technology required rapid development, deployment and field adaptation of existing inspection equipment
- Visual evidence of leakage vastly different from originally postulated
- First phase of MRP demonstrations was available to support fall 2001 inspections
  - Detection of "safety-significant" flaws in the tube
- Second phase performed to support fall 2002 inspections
  - J-groove weld flaws
  - More base metal flaws to evaluate depth sizing

MRP Activities – Visual Examination Guidance

- EPRI MRP Inspection Committee Task
  - Develop visual inspection training package for fall 2001
    - Capture lessons learned related to conducting inspections and visual evidence
  - Updated TR was published for spring and Fall 2002 inspections





MRP Approach to Demonstrations

- RPV Head Working Group 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 Working Group 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)
- Tiger Team formed to design mock-ups
  - RPV Head Working Group
  - Inspection Working Group
    - Design criteria for mock-ups

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MRP Demonstration Process

- All CRDM Head Penetration NDE demonstrations had the following characteristics:
  - Blind
    - supported by non-blind preparation phases
  - Procedure demonstration
    - No acceptance criteria
    - Demonstration best available techniques
      - *ASME code will probably develop technique/personnel qualifications*
  - Measurements of flaw detection capability and limits
    - No acceptance (pass-fail) criteria

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MRP Demonstration Process

- Demonstration protocol
  - Vendor collects data on mockups & reports findings
    - evaluates measured vs. true values
    - Detection (# detected/total flaws)
    - Location with respect to pressure boundary
    - Sizing results documented
    - False call performance
  - NDE Center documents procedure essential variables
    - Allows verification that the techniques used are the same techniques that were demonstrated
  - Analysis process used in the demonstration and must be captured in the procedure
  - Results are provided to utilities

MRP Demonstration Process - Overview

- **Complicated examination volume**
- **Vendor UT inspection procedures include <u>many</u> technique options and probe combinations, examples:**
  - Open-tube probes
  - Blade probes
    - Probes are designed to accomplish specific objectives:
      - *Specific volumes*
      - *Flaw orientations, e g , circumferential or axial flaws*
      - *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

2001 Demo Description

- Focus - Detection of "Safety-Significant" flaws in the tube base metal
- Mock-ups
  - Oconee CRDM Penetration Tubes
    - 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 (Designed and deployed in 3 months)
    - Demonstrates effects of weld & capability to address geometry
      - *Deliver the tooling (i e. maintain contact)*
      - *Query the appropriate inspection volume*
    - Important examination considerations
      - *Flaw location relative to weld*
      - *Flaw clusters*
      - *Triple-point indications*
    - Using EDM notches
    - Initial demo was blind; upon completion all data was shared with the inspection vendor to improve their techniques and train personnel.

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2001 Demo Mock-ups - 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

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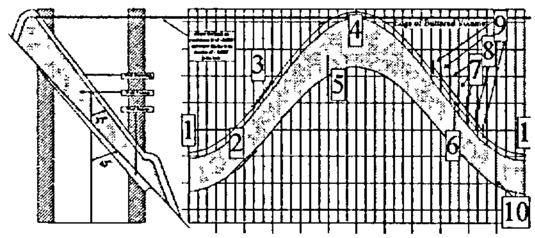
2001 Demo Mock-ups – Full Scale



- #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 Demo - Participating Vendors

- 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

2001 Demo Results

- Distributed periodically by MRP
- Results summarize the capability of numerous probe types
  - Vendors detected the crack tips in the Oconee tube ends after enhancing their procedures.
  - Vendors detected the flaws placed in the full scale mockup
- In most cases, multiple demonstrations were supported
  - As a result of
    - changing inspection requirements
    - equipment modifications and updates

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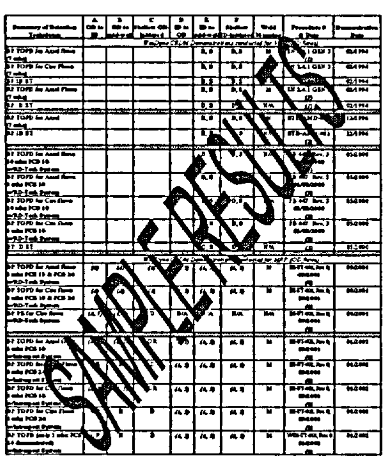
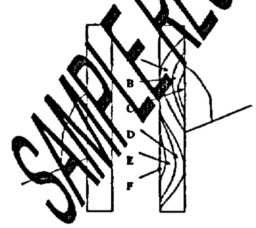
Vendor A 2001 UT Demo Results



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 [illegible]. The 97-01 flaws were demonstrated to have similar ET and UT characteristics [illegible] PWSCC
S: Sized flaw successfully in EPRI 97-01 mock-ups. The 97-01 [illegible] were demonstrated to have similar ET and UT characteristics to PWSCC [illegible] 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 design.

(1) Westinghouse Procedure (USA)
(2) ABB/CE Procedure (USA)
(3) Westinghouse TRC Procedure (Sweden)
(4) In the current MRP scope, but it was [illegible]
(5) Technically justified, based on the 97-[illegible] results
(6) WesDyne Procedure (Includes former Westinghouse-USA, ABB/CE-USA, and Westinghouse TRC-Sweden)
(7) Technically justified, based on [illegible] flaw



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Demonstrations for 2002 & Future

- Demonstration Scope
  - Replaced EDM notches
    - More realistic using CIP processing
  - 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
  - Effect of Cluster flaws
    - Masking flaws in remaining tube volume

2002 Mockups – Tiger Team Goals

- **Blind Mock-up**
- **Demonstrate sizing capabilities**
- **Full Scale Mock-up**
- **Establish Inspection Thresholds**
- **No POD**
- **Practice Blocks and Blind Blocks**
- **Include Effects of Crazed Cracking**

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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

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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

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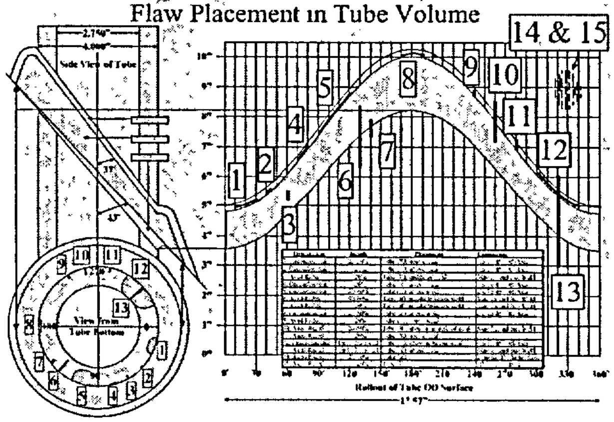
2002 Mockups

- Flaw types as determined by Tiger Team Committee
  - Axial, circ, & off-axis tube flaws
    - ~20 flaws, up to 100% deep, 0.1 to 3.0" in length
  - Cluster flaws in tube
    - ~25 flaws up to 20% deep, 0.1 to .25" in length
  - Axial & circ attachment weld flaws
    - ~15 flaws, up to 100% deep, 0.1 to 1.0" in length
    - Located at weld/head & weld/tube interface
      - *Most challenging geometry*
    - Flaws approaching & thru triple-point
      - *Allowing leak point to annulus*

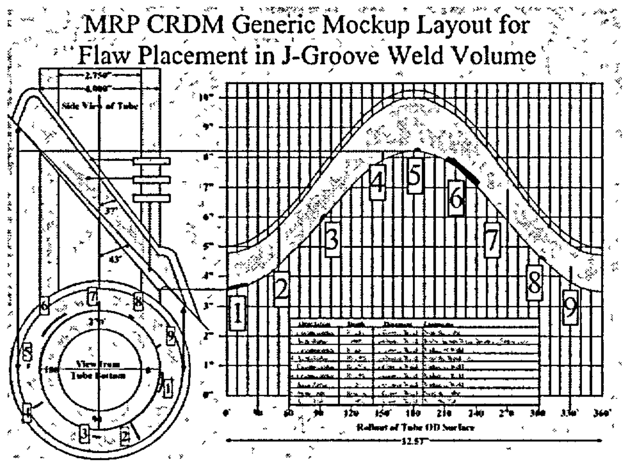
2002 Mock-up – Tube Flaws

MRP CRDM Generic Mockup Layout for Flaw Placement in Tube Volume



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



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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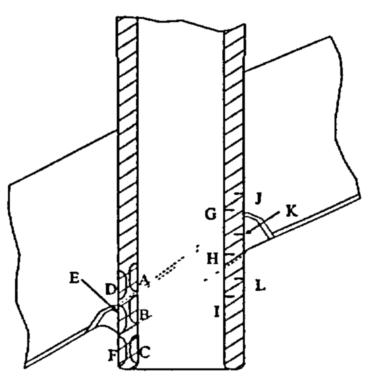
2002 Demo Tube Flaw mock-up "J"

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



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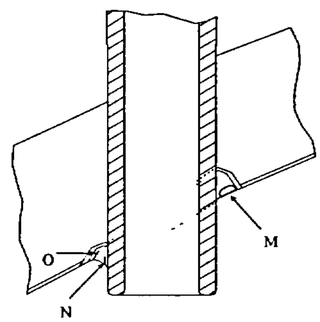
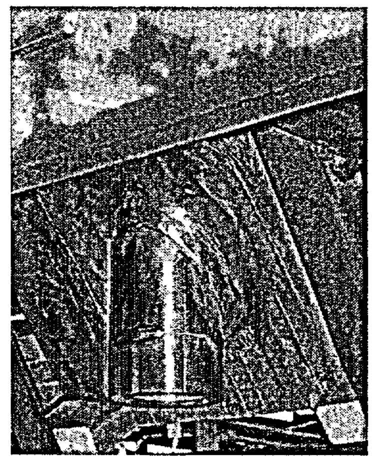
2002 Demo Weld Flaw Mock-up "K"

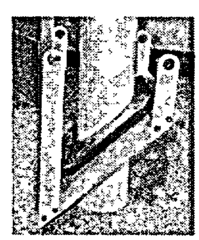
- **CIP flaws for**
  - UT from inside surface of tube
  - And ET from the wetted surface

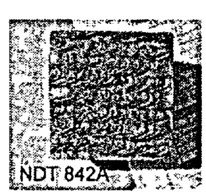


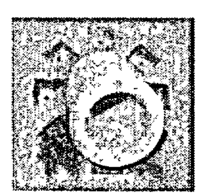


2002 Demo Weld Flaw Mock-up "L"

- **SCC flaw coupons for demo of ET on wetted surface**
- **Coupons contain cracks of varying**
  - width
  - length
  - Orientation

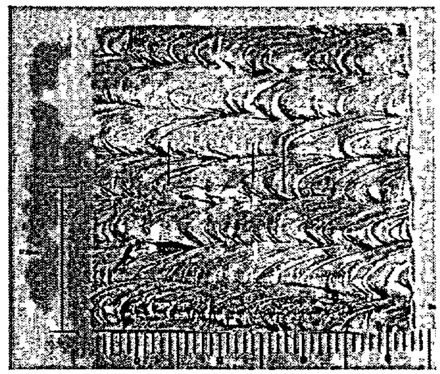






2002 Demo – Mock-up "L" Crack Specimens

- Laboratory-grown SCC
- As-welded and ground surfaces
- Flaws vary in:
  - Length, width, orientation with respect to weld direction



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2002 Demonstrations – Vendor A

- Blade-Probe UT of penetration tube
  - Flaws ranging ~ 15 to 100% TWE detected when flaws are oriented perpendicular to beam direction
  - Flaws ranging ~15 to 100% TWE detected when flaws are oriented parallel to beam direction
- Open-tube "Rotating" probe of penetration tube
  - Flaws ranging ~ 13 to 100% TWE detected when oriented perpendicular
  - Flaws ranging ~15 to 100% TWE detected when flaws are oriented parallel to beam direction

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2002 Demonstrations – Vendor B

- Blade-Probe UT of penetration tube
  - Flaws ranging ~ 15 to 100% TWE detected when when flaws are oriented perpendicular to beam direction
  - Flaws ranging ~15 to 100% TWE detected when flaws are oriented parallel to beam direction
- Open-tube "Rotating" probe of penetration tube
  - Tube flaws ranging ~ 10 to 100% TWE detected when flaws are oriented perpendicular to beam direction
  - Flaws ranging ~15 to 100% TWE detected when flaws are oriented parallel to beam direction
- Open-tube "Rotating" probe of tube/weld interface
  - Tube/weld interface flaw detected when flaw length extended to triple-point
  - Weld metal flaws that did not extend to the triple point were not detected.

2002 Demonstrations - Vendor C

- Results are in course of preparation
- Preliminary assessment shows that UT detection results are consistent with other vendors
- Demonstration of ET inspection of the wetted surface of the attachment weld is still in process

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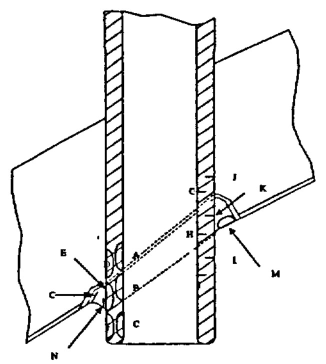
Flaw Designations Nomenclature

Flaw Designation	Flaw Description	Contained in Mockups
A	ID Axial Above the Weld	Yes
B	ID Axial Over the Weld	Yes
C	ID Axial Below the Weld	Yes
D	OD Axial Above the Weld	Yes
E	OD Axial Over the Weld	Yes
F	OD Axial Below the Weld	Yes
G	ID Circumferential Above the Weld	N/A (Note 1)
H	ID Circumferential Over the Weld	N/A (Note 1)
I	ID Circumferential Below the Weld	Yes
J	OD Circumferential Above the Weld	Yes
K	OD Circumferential Over the Weld	Yes
L	OD Circumferential Below the Weld	Yes
M	Axial/Radial @ Wetted Surface of the J-Groove Weld	Yes
N	Circumferential/Axial (reference to tube) on Wetted Surface near interface of tube to J-Groove Weld	Yes
O	Circumferential/Axial (referenced to tube) on Wetted Surface near Head (clad) to J-Groove Weld	Yes
Notes:	(1) Presence of back-wall does not influence detection and analysis of ID surface initiated flaws to the degree that it affects OD surface initiated flaws	



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Vendor A UT Detection Results

	Vendor A – UT Blade & Open Tube Probe Detection Results See Flaw Table 4 and drawing for description of flaw types "A" through "O"					
Field Used UT Techniques	A, B, & C ID Axial Flaws	G, H, & I ID Circumferential Flaws	D, E, & F OD Axial Flaws	J, K, & L OD Circumferential Flaws	M, N, & O Weld Flaws	Cluster Flaws OD Flaws under shallow (<3 mm deep) ID Cluster Flaws
"Axial Blade" (TOFD UT COAF) (Note 1) 3 degree scan increment	5%-86% TWE detected (Note 4) Orientation of flaws < 12 % TWE was inconsistent (Note 5)	11%-49% TWE detected Orientation of flaws < 12 % TWE was inconsistent	28%-100% TWE detected 4 flaws < 24% TWE missed. 1 D type flaw 1-E type flaw, 2-EF type flaws	15%-100% TWE detected 1 K-type false call @ 7% TWE (Note 6)	(Note 7)	100% detection of ID & OD
"Circ Blade" (TOFD UT AOCF) (Note 2) 3 degree scan increment	11%-86% TWE detected 1 B type flaw < 5% TWE missed Orientation of flaws < 12 % TWE was inconsistent (Note 5)	11%-49% TWE detected Orientation of flaws < 12 % TWE was inconsistent	15%-100% TWE detected 4 flaws < 13% TWE missed 2-D type flaws, 1-E type flaw, 1-EF type flaw	15%-100% TWE detected 1 K-type false call @ 15% TWE (Note 6)	(Note 7)	100% detection of ID & OD
"Open-Tube" (Note 3) 5 degree scan increment	5%-86% TWE detected (Note 5)	11%-49% TWE detected	13%-100% TWE detected 3 flaws < 12% TWE missed 1-D type flaw, 1 E type flaw 1-EF type flaw	15%-100% TWE detected 1 K-type false call @ 15% TWE (Note 6)	(Note 7)	100% detection of ID & OD
"Open-Tube" (Note 3) 3 degree scan increment	5%-86% TWE detected (Note 5)	11%-49% TWE detected	13%-100% TWE detected 3 flaws < 12% TWE missed 1-D type flaw, 1-E type flaw 1 EF type flaw	15% 100% TWE detected 1 K-type false call @ 15% TWE (Note 6)	(Note 7)	100% detection of ID & OD
Notes:	(1) TOFD UT COAF (Circumferentially Oriented for Axial Flaws) used for detection and sizing of flaws. (2) TOFD UT AOCF (Axially Oriented for Circumferential Flaws) used for detection and sizing of flaws. (3) TOFD UT COAF/AOCF, Pulse/Echo, and 0 degree used for detection and sizing of flaws. (4) Through-wall-extent (TWE) of flaw depth in the tube thickness. (5) Inadequate resolution to separate closely associated (approx. 3 mm spacing) flaws. (6) Appears to be a welding defect at the tube-to-weld-interface. (7) Equipment and procedure were not optimized to resolve indications extending beyond the tube-to-weld interface in the weld volume					

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2002 Demonstrations ET of Attachment Weld

- **Detection is sensitive to weld surface conditions**
  - Ground Surface Condition
    - Detected 0.16" long, 0.00031" wide
  - Un-ground (as-welded) Surface Condition
    - Detected 0.55" long, 0 00197" wide
    - Missed; 1.42" long, 0.00591" wide
  - Continue to pursue additional/alternate techniques to improve the detection capabilities

Future Demos

- **Tecnatom**
  - ET of Attachment Weld
    - Scheduled for May 2003
- **Framatome**
  - ET of Attachment weld
    - Scheduled for February 2003
  - "Other" surface method for wetted surface of attachment weld
    - Scheduled for 1st quarter of 2003

Future Demos (cont'd)

- WesDyne
  - UT of tube/weld interface
  - ET of attachment weld
  - Thermal imaging
- B&W Canada
  - UT of tube/weld interface
    - 1st quarter of 2003
  - ET of attachment weld
    - 1st quarter of 2003

Future Activities

- **New mock-ups under construction**
  - Existing mock-ups will be made available to vendors for personnel training and technique refinement
- **Replacement head inspection**
  - Equivalence studies
  - Mock-up drawings
- **North Anna Head**
  - Coordinate & Support Data collection by other Vendors
  - Support sectioning and required NDE

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Summary

- MRP has organized a comprehensive approach to address recent industry events
- Considerable progress has been made in a short amount of time
- Demonstrations continuing
- Emphasis on examination of attachment weld and increased inspection efficiency

RES/DET/MEB Programs and Activities to Address:
1. CRDM Cracking Issues
2. Davis-Besse Cavity Exams & Safety Assessment

ACRS Materials and Metallurgy, and Plant Operations Subcommittees

Meeting on
Vessel Head Penetration Cracking and RPV Head Degradation
April 22, 2003

William H. Cullen, Jr.
301-415-6754
whc@nrc.gov

RES/DET/MEB Programs and Activities to Address: CRDM Cracking Issues

A. NRC-Funded SCC Program & Products
   1. On-going EAC Program
   2. Testing of Davis-Besse Materials
   3. LLTF Rec. to Review Worldwide Experience with Alloy 600 CRDMs, Boric Acid Corrosion

B. Additional Programs with Expected, Relevant Products
   1. Japanese Coordinated Program
   2. ICG-EAC Round Robin
   3. Other Programs

C. Heat-by-Heat Analysis of Domestic Plant CRDMs

D. Stress Analysis of CRDM Penetrations

E. NRC-Industry Collaboration on CRDM Cracking Issues

F. Davis-Besse Cavity Exam Update – What it Means To NRC/RES

G. LLTF Recommendations - Barrier Integrity Action Plan - Tomorrow

RES/DET/MEB Programs and Activities to Address: Davis Besse Root Cause & Safety Assessment

A. Corrosion of RPV Boundary Materials in Boric Acid Solutions
   1. Features of Program at Argonne Nat. Lab
   2. LLTF Recommendation to Review Worldwide Experience

B. Structural Integrity Assessment
   1. Approach of Program at ORNL

C. D-B Cavity Sample Plan, and Head Disposition
   1. Documented Findings to Date
   2. Description of Last Phase of the Program
   3. Salvaging of Components from Discarded Head
   4. Additional Tasks for Future Programs

NRC's SCC Programs & Products

A. On-going EAC Program at Argonne Nat. Lab.

1. SCC Testing of Alloys 600, 182, 690 and 152 in BWR and PWR water
   a. Also evaluating strength, metallography for insight into mechanisms
2. Been testing since 1997, NUREG/CR-6717
   a. Letter report on SCC in 182 due 10/04, NUREG due 12/05

B. Testing of Davis-Besse Materials (part of BAC program at ANL)

1. Alloy 600 from Nozzle #3 (M3935), and Alloy 182 from #11 J-weld

C. LLTF Rec. to Review Int'l Experience with Alloy 600 CRDMs

1. Critique of susceptibility model [EDY = EFPY * (temp. factor)] – Done 2/28/03
2. Report on worldwide Alloy 600 cracking experience (Dec. '03)
3. Report on worldwide boric acid corrosion experience (Oct. '04)

Additional Programs

Products (CGR Data, Mechanistics) Will Contribute to Existing Databases

1. Japanese Coordinated Program
   a. Electric Joint Research Project
      - SCC and SSRT on Alloys MA600, Alloy 132, 82, TT690, Alloys 152 & 52
   b. National Nickel-Based Alloy Material Project
      - SCC on Alloys MA600, Alloy 132, 82, TT690, Alloys 152 & 52
2. ICG-EAC Round Robin
   a. Purpose: resolve factors that cause differences in stress corrosion crack growth rate response, esp. in Alloy 182 weld
   b. Status: Specimens distributed, some tests completed, reports next month
   c. Expectations:
      - Phase 1 – Collect info – Completed
      - Phase 2 – Test 30% CW A600 in '03, Compare results, Improve methods
      - Phase 3 – Test Alloy 182
3. Other Programs
   a. Tests underway in France, Spain and Sweden
4. Dialogue to Obtain Mockups from Replacement Head Fabrication

Plant-specific (heat-specific) cross-correlations starting from Davis-Besse

Heat Identification	Other Plants With Heads Containing Same Heat of Material
M3935 (3 of 5 cracked)	Oconee 3 (replace in '03), Ark. Nuclear One 1 (replace in '05)
C2649-1	Oconee 1 (replace in '03), Oconee 2 (replace in '04) Oconee 3, ANO 1
M4437	Not found in any other plant's CRDMs

So, specifics about nozzle heats from D-B are not applicable in the long-term for other licensees. However . . . .

Plant-specific (heat-specific) cross-correlations starting from North Anna 2

Heat Identification	Other Plants With Heads Containing Same Heat of Material
755534, 755535, 755536, 755537, 755538, 570892, 568011, 710209	North Anna 1, Sequoyah 1
710147	North Anna 1, Sequoyah 2
71207, 71208, 710210	North Anna 1, Sequoyah 1, Sequoyah 2
71206	North Anna 1, Surry 2, Sequoyah 1, Sequoyah 2
772024	Watts Bar-1, Watts Bar-2, Catawba-1, McGuire-2

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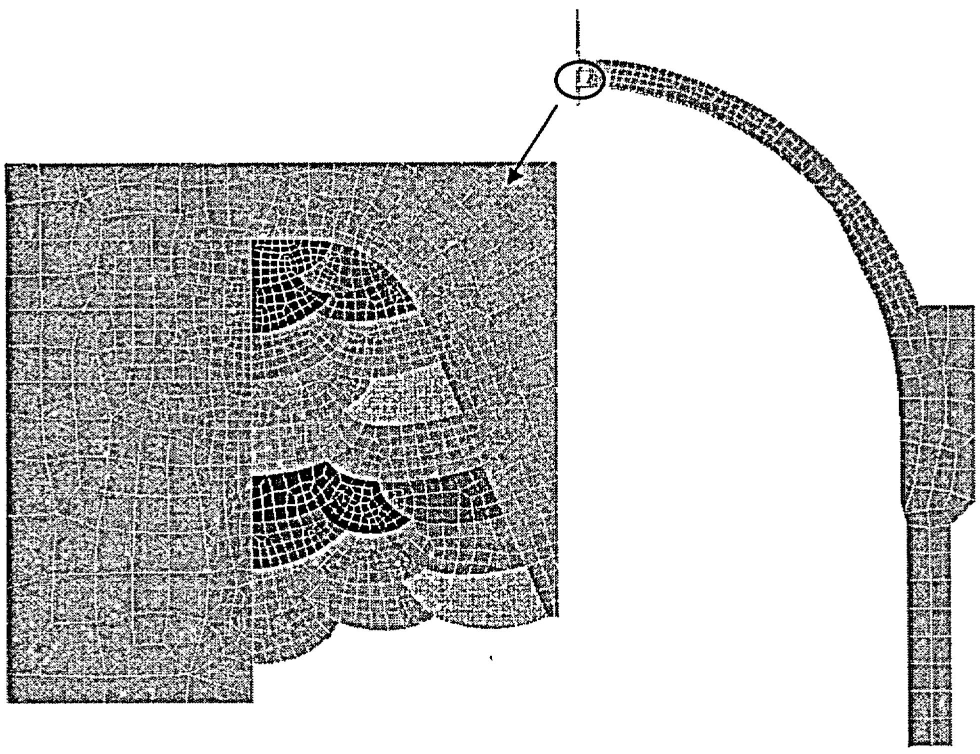
March '03 Conference on CRDM and related Issues

(Including safe ends, ICI penetrations, coolant loop repairs, etc.)

Postponed

- Five main session topics
  - Structural Analysis and Fracture Mechanics Issues (4 papers)
  - Inspection technologies, disposition & sizing of flaws, new developments (9 papers)
  - Crack growth rates for relevant nickel-base alloys & welds (8 papers)
  - Mitigation & Foreign Experience (9 papers)
  - Continued Plant Operation (8 papers)
- March 24 - 26 At Gaithersburg-Marriott
- Expected 140 or more attendees (11 countries) & participants
- Proceedings issued as CD and NUREG/CP
- To Be Rescheduled When Travel Restrictions Are Lifted

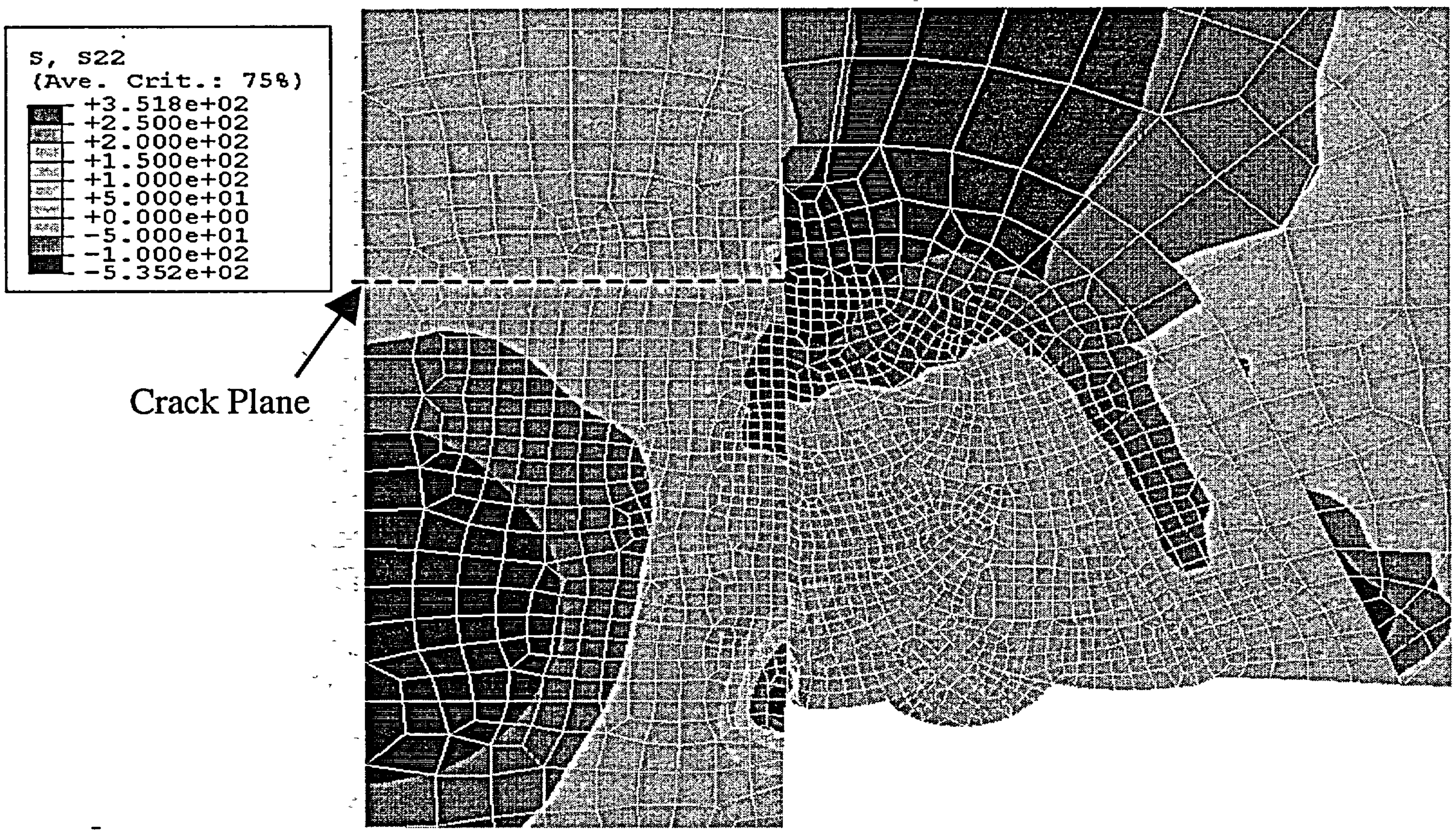
Stress Analysis of CRDM Penetrations



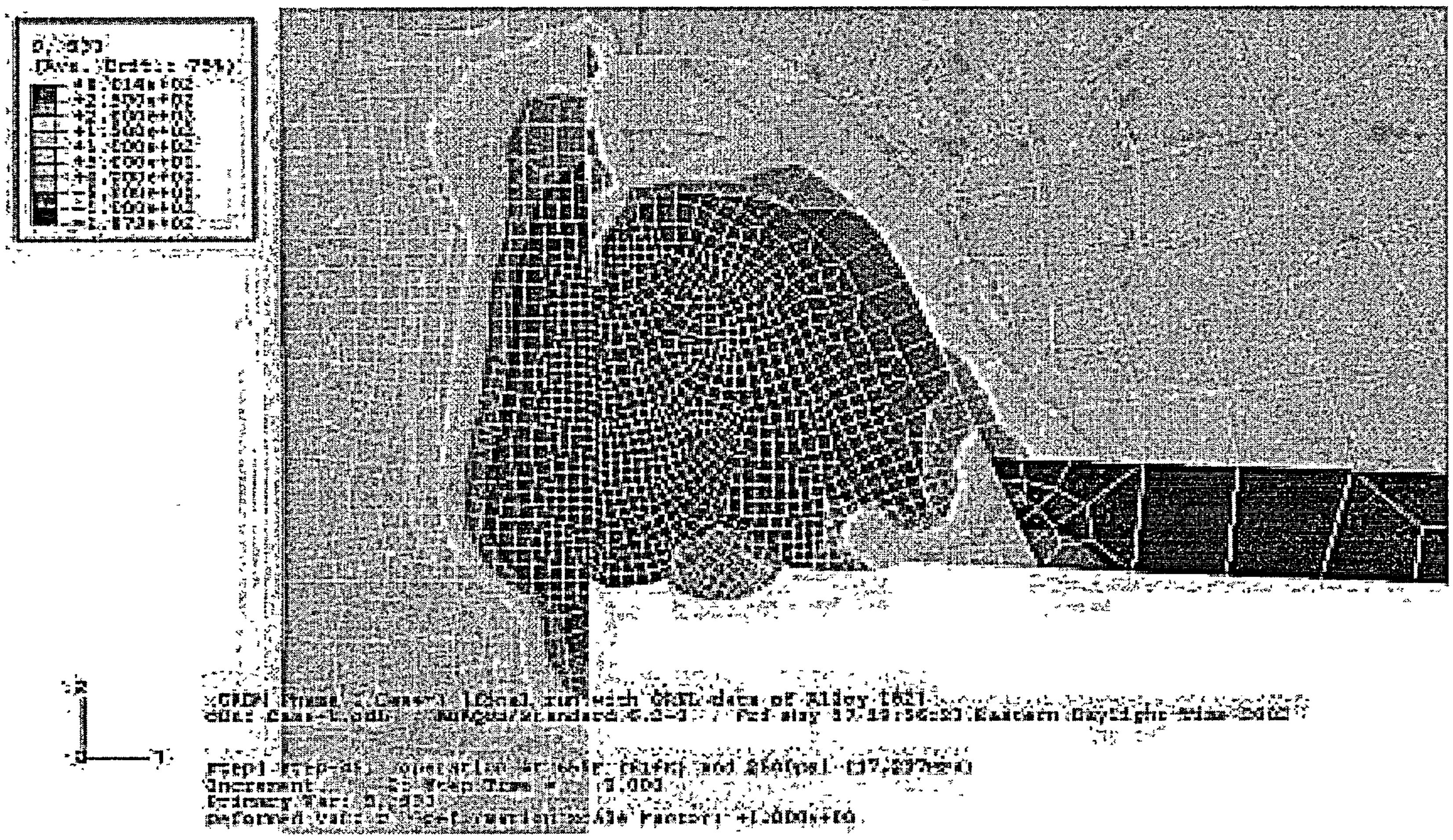
Pass-by-pass simulation of the weld, followed by calculation of the stress, proceed to the next pass, etc.

Calculate axial, radial & tangential, resolve to principal stress.

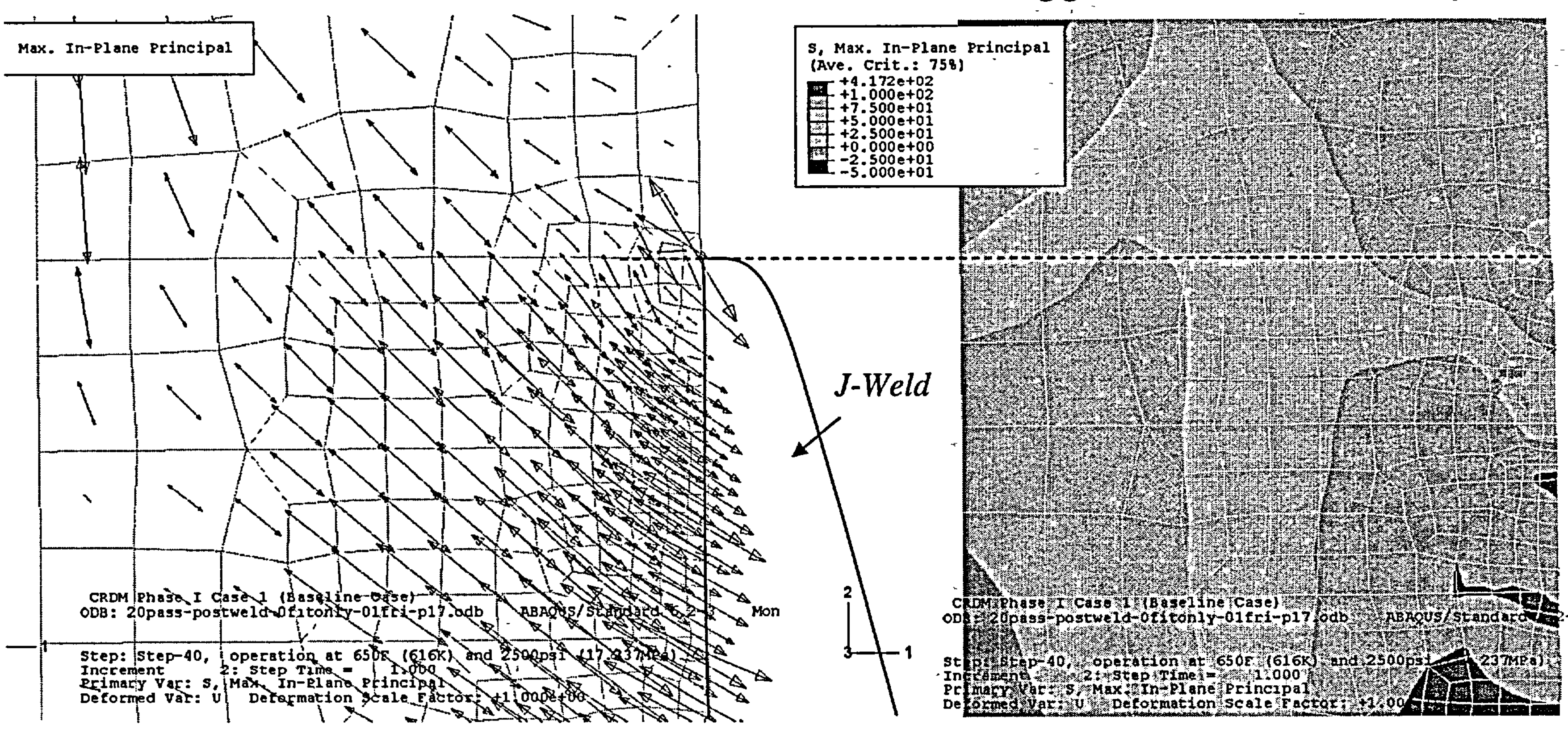
Axial Stresses at NOP/NOT



Hoop stresses at NOP/NOT



Resolution of stresses suggests inclined crack plane



NRC-Industry Collaboration on CRDM Cracking Issues

Task Number	Task
1	Alloy 600/82/182 – (a) crack growth testing Alloy 600 and (b) Alloy 82/182
2	Alloy 690/52/152 – (a) crack growth testing Alloy 690, and (b) Alloy 52/152
3	Boric Acid Corrosion Testing – (a) Expert Panel to review the boric acid corrosion model in MRP-75, (b) Examine Nozzle #2 from Davis-Besse, (c) BAC program at ANL
4	(a) RPV Head Penetration PFM, PRA & Nozzle stress analysis by FEA, (b) Residual stresses in A600 CRDM tubing
5	Failure Analysis of North Anna RPV head – determine impact of findings on susceptibility models, visual inspection validity, and inspection and repair methods (Industry effort underway, '04 funding proposed for NRC collaborative research)
6	Nozzle 46 Davis-Besse RPV head – determine meaning of NDE signals (shadow, or "anomalous indication") and implication for future inspections
7	Mitigation Testing – determine viability and utility of mitigation options, both for Alloy 600 base material (penetrations, etc.) and Alloy 82/182 weld material (J-grooves, butt welds, etc.) (fully an industry effort at present)

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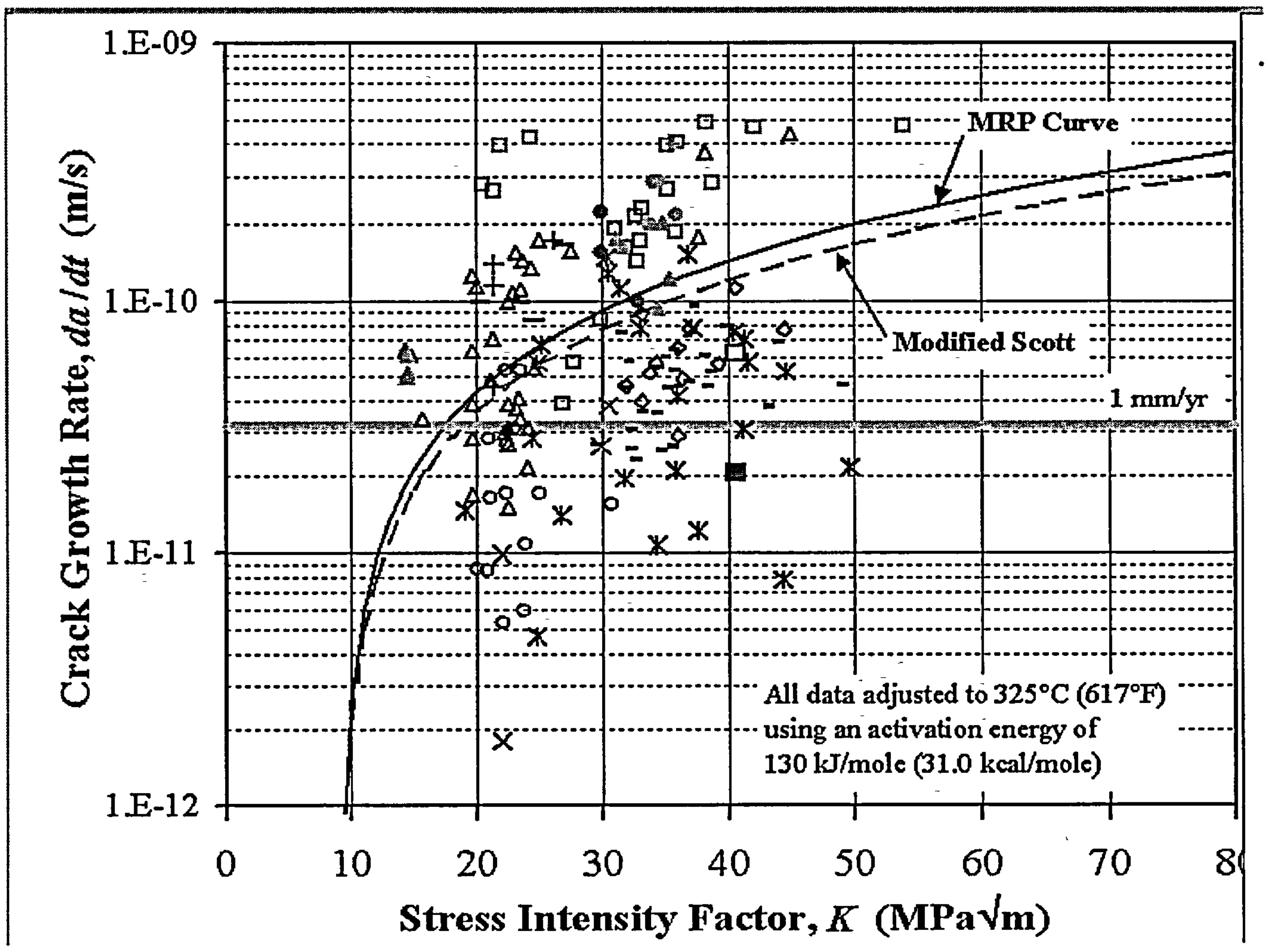
Stress-corrosion crack growth rate data from MRP-55; validated by ITG on CGRs in Alloy 600.

Much more data to be added in next couple of years, mostly through international programs.

ITG now working on Alloy182 compilation – meeting next week.



NRC Research Programs Related to CRDM & Alloy 600

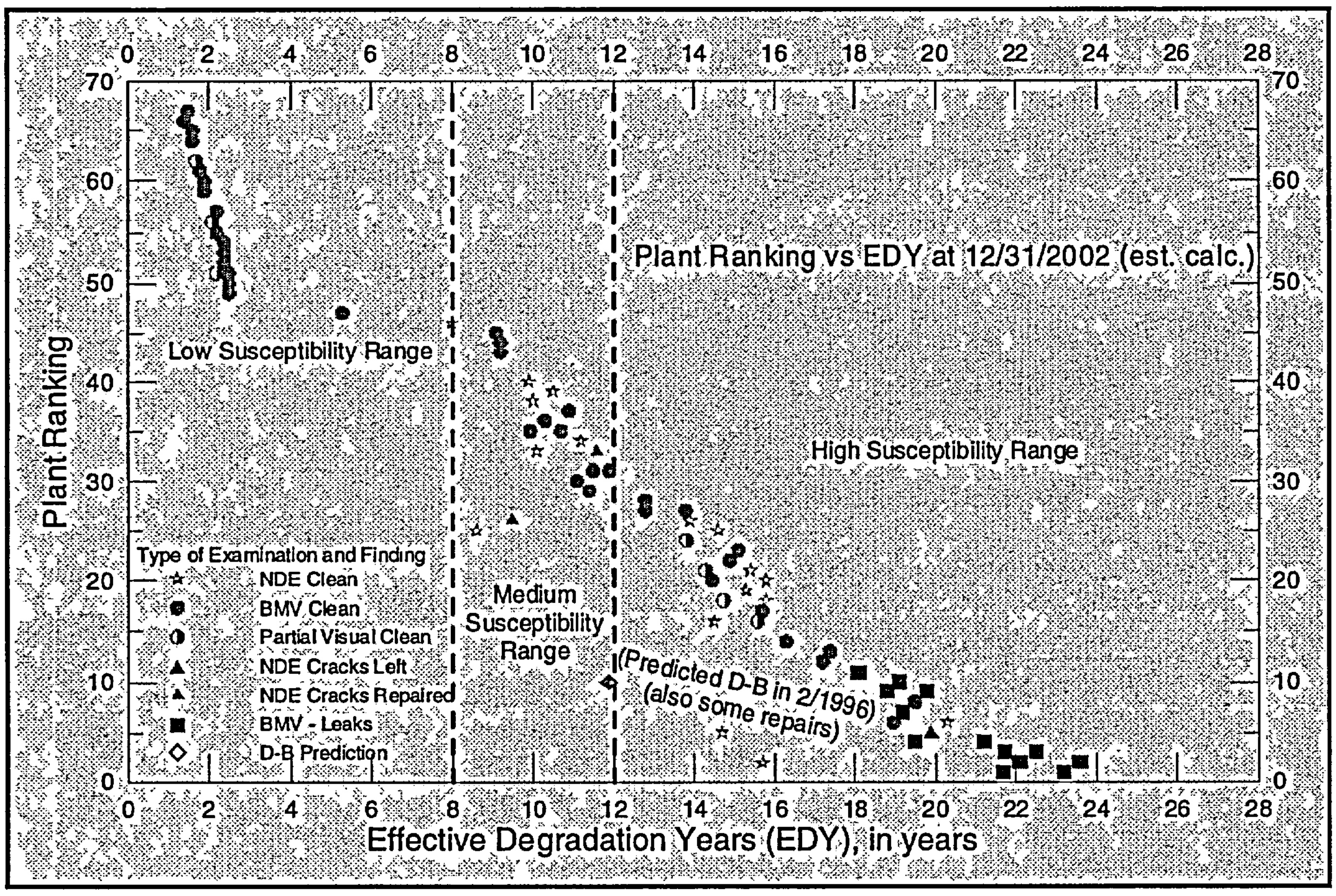
The longer term response

- Continued development of CRDM & closure weld inspection techniques
- Modeling of Residual Stresses (tube fabrication & closure weld induced)
- Improved Probabilistic Model for t_f from Leakage of Circ. Cracks
- Summary Report on Leakage from CRDMs
- Continue Testing SCC Rates of A600, A690 & Welds
  - Supplemented D-B materials (A600, A182) into on-going program

All feed into improved risk analysis models

- Development of an International Cooperative Group on PWSCC of Nickel-base Alloys, Including Inspection and Repair Techniques
- Workshop on March 24-26 to Discuss Issues of PWSCC in Nickel-Base Alloys

Plant Ranking vs. EDY



Current model depends only on time at temperature.

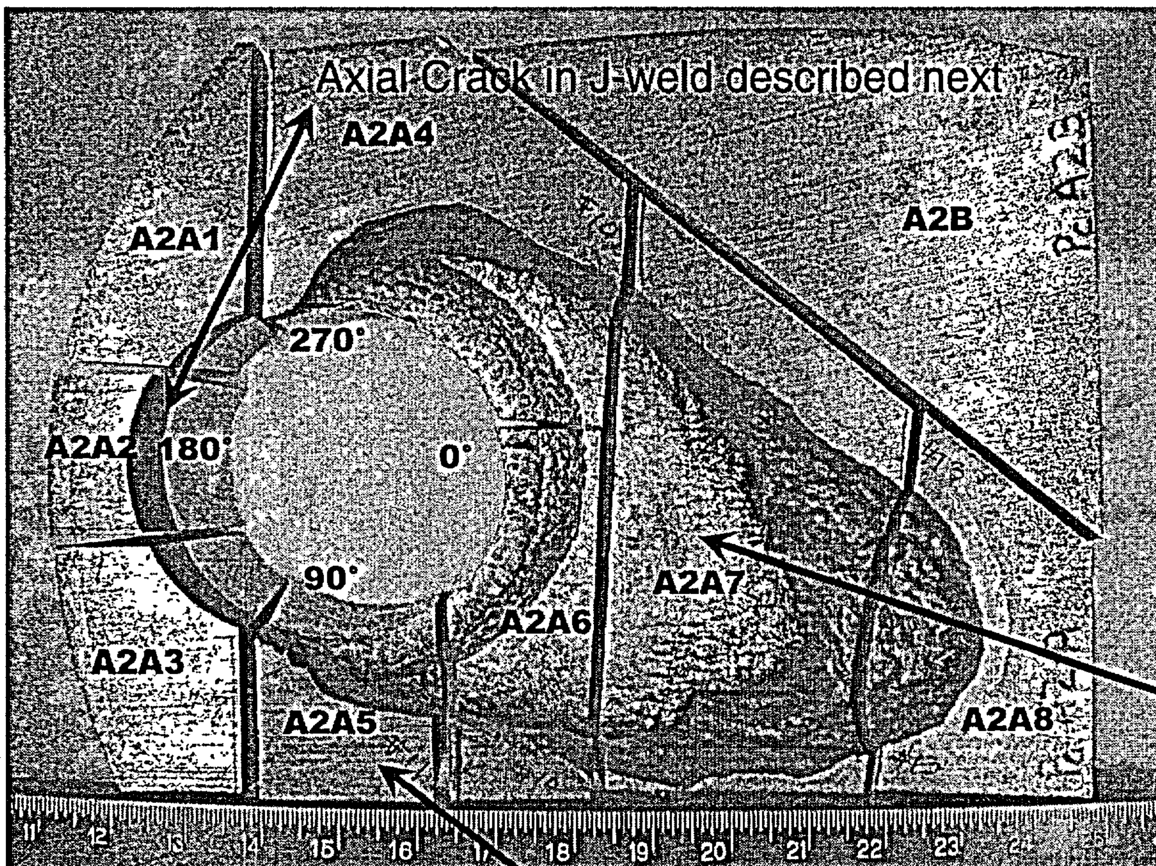
Other factors might be quantified well enough to warrant consideration:

- *Yield strength*
- *GB carbides*
- *Measured da/dt*

Completion of Cavity and Exposed Clad Exams

- Completion due early May, 2003 – docketed shortly after
  - Axial & circumferential cracks in J-weld sectioned, opened
    - Long axial cracks, very short circumferential cracks – both IGSCC
  - Cracks in clad were measured, opened, characterized, deposits analyzed
    - Depth is ~1 – 1.5 mm; all terminate with ~5.0 mm clad remaining
    - Possibly due to stress effect, less possibly a temperature effect
      - Temp gradient in clad was 315°C (RCS side) - ~100°C – cavity side
      - All growth by IGSCC in conc. boric acid solution, no ductile tearing
      - Elicitation of the growth rate would shed light on cavity evolution
  - Walls of the cavity examined for corrosion morphology effects

Exam of exposed clad & J-weld – sectioning scheme



Cracks in clad described later

Piece A2A5 shown on subsequent slide

Photo shows major cuts made in preparation for cavity exam. Most sections were further reduced for metallographic and fractographic exams. Largest cracks were near ~10° (major leak) and 180° (non-leaking).

Examination of cavity characteristics near J-weld

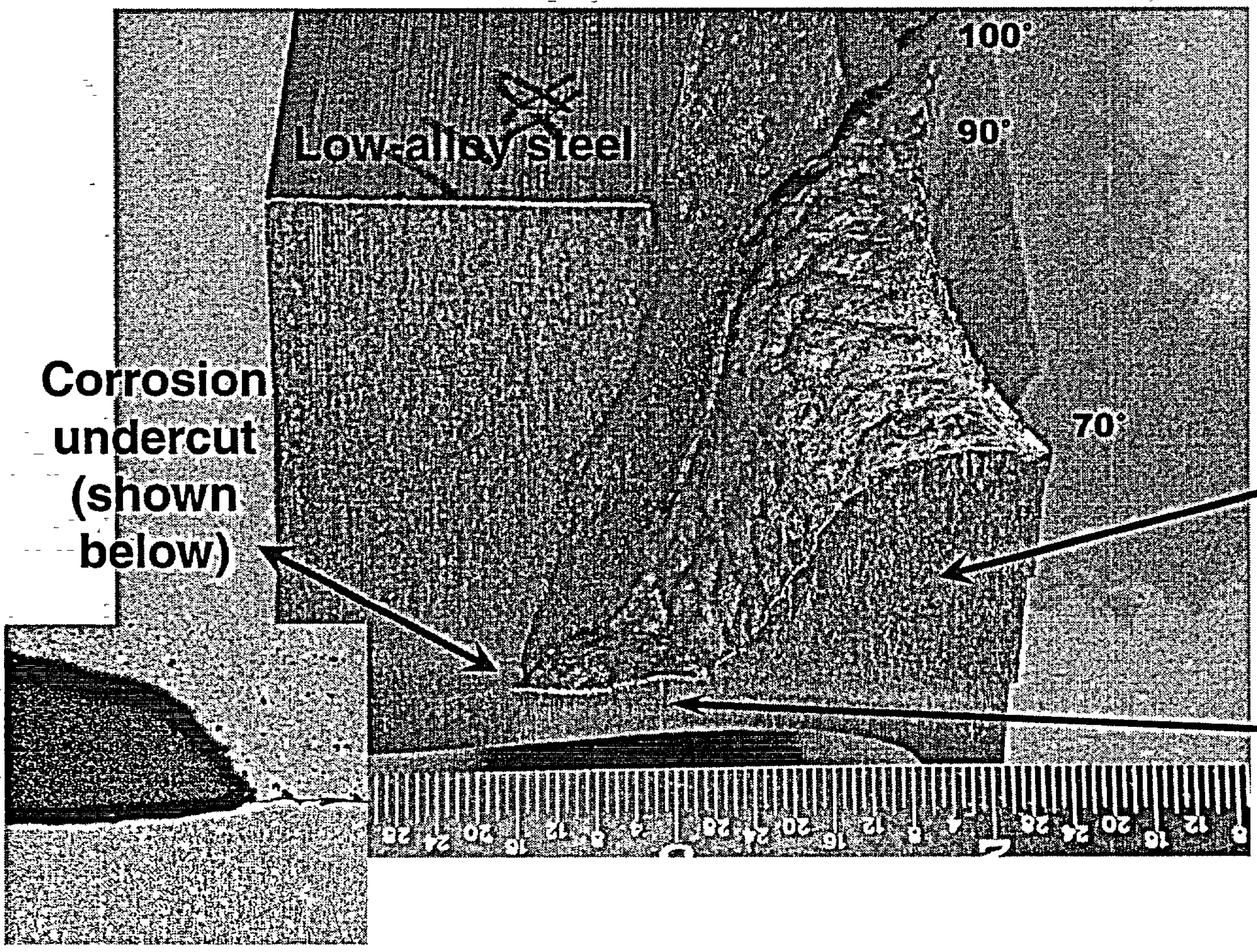
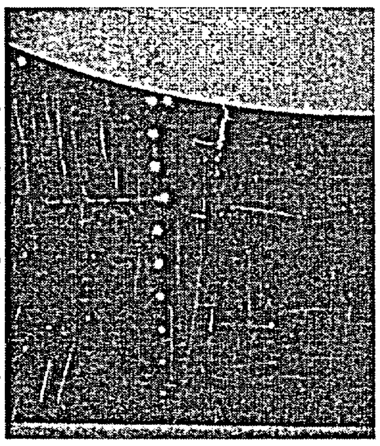
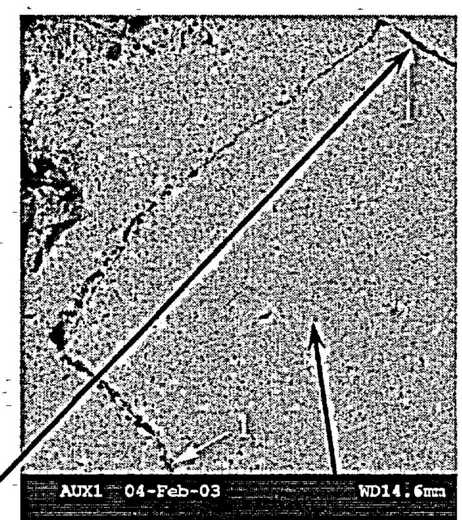


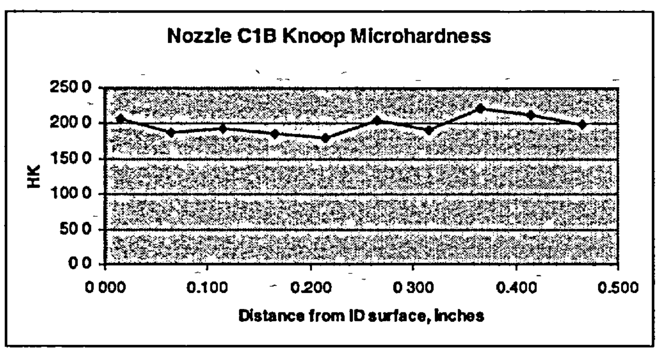
Photo shows exposed J-weld/LAS fusion surface, exposed clad, and corroded LAS near Nozzle #3.

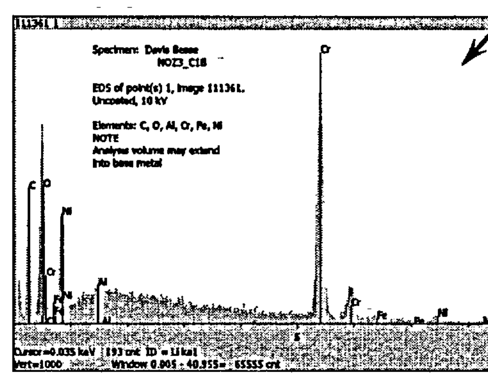
Longest crack in Nozzle #3 (on uphill side)



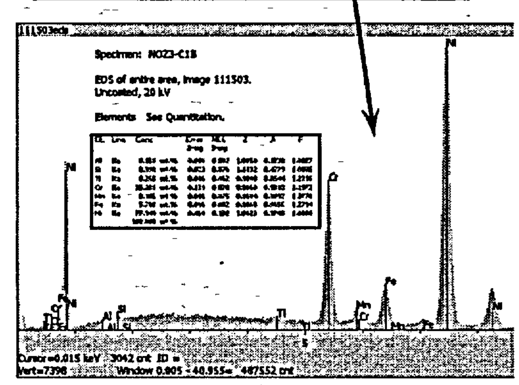
Axial crack in Nozzle #3. Crack was about 1.2 in. above J-weld, but little leakage occurred into the annulus. Hardness is uniform throughout nozzle. Grain bdy. carbide coverage is also good. Alloy is generally OK.







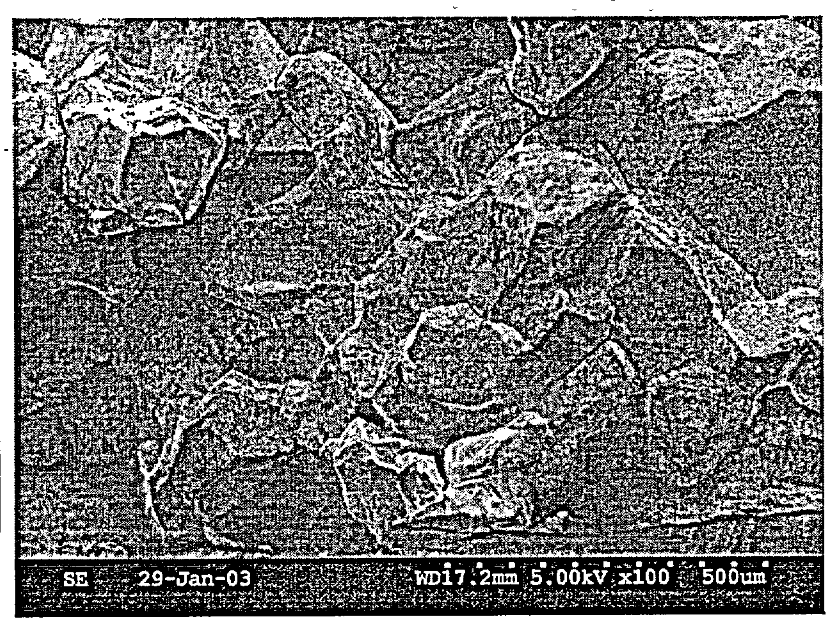
Grain boundary analysis shows high Cr, low-(Fe, Ni)



Matrix analysis shows Ni, Cr, Fe ≈ Alloy 600 composition.

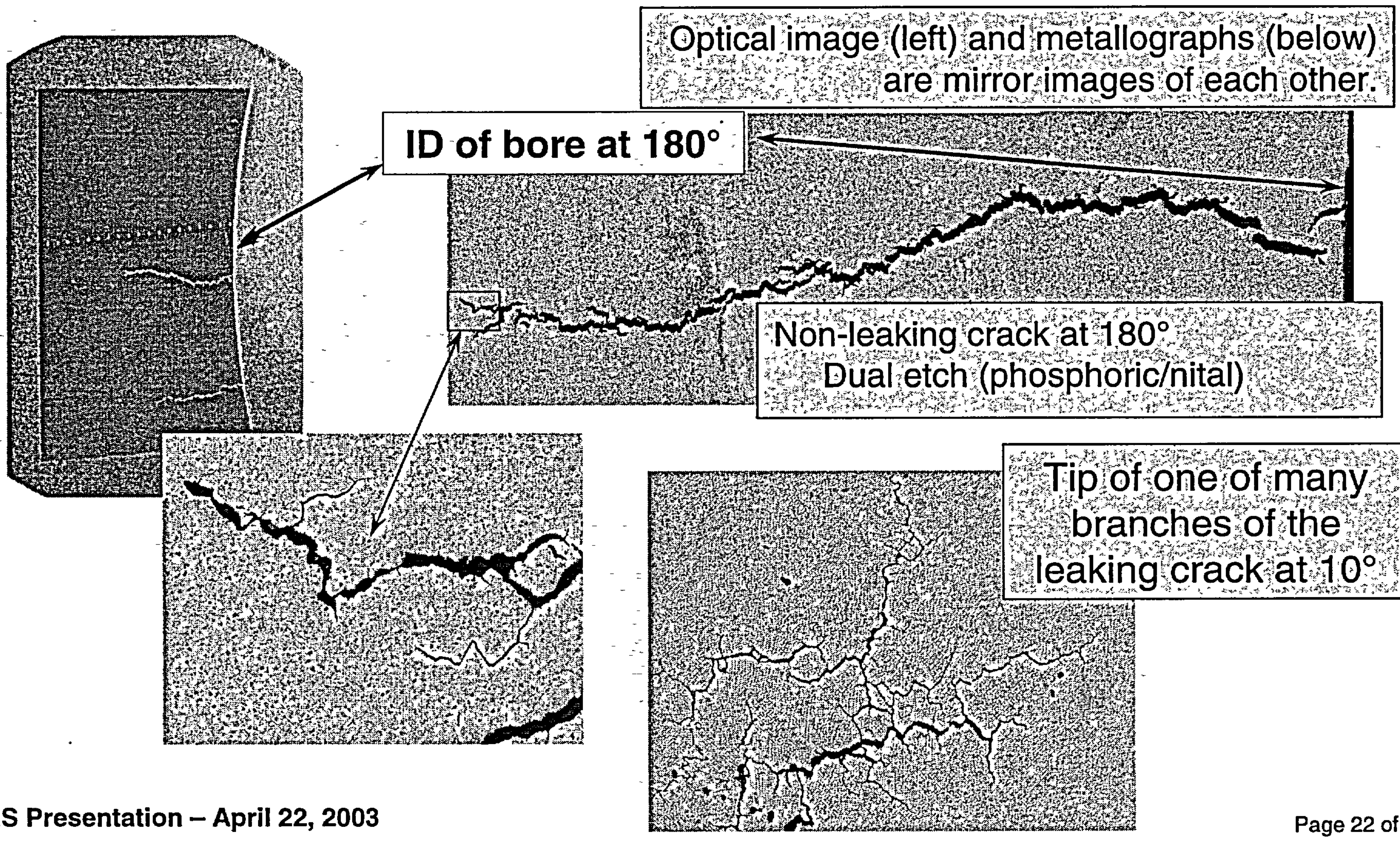
IGSCC in CRDM Nozzle #3

Left: IGSCC crack in Alloy 600 of Nozzle #3, 170° location, near upper end, dual, phosphoric/nital etch.

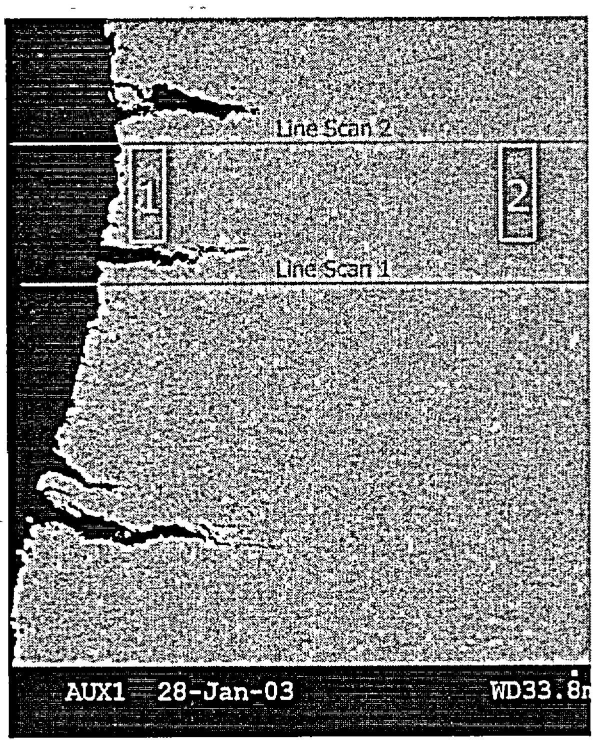


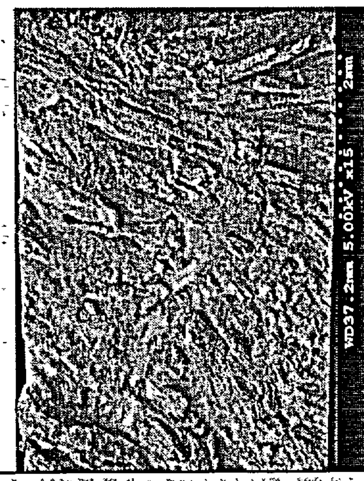
Right: IGSCC surface from Alloy 600 of Nozzle #3. Surface was 100% IGSCC, with substantial amounts of oxygen and carbon in analysis.

Character of IGSCC cracks in J-weld of Nozzle #3



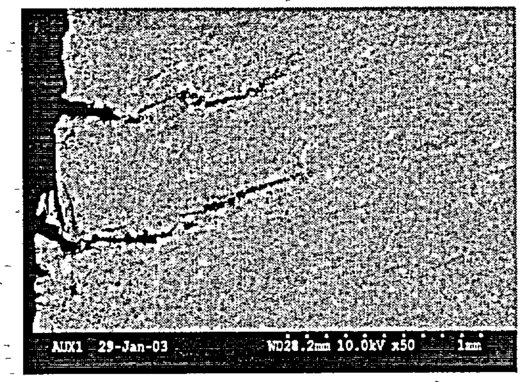
Opened crack in cladding shows interdendritic growth morphology – all IGSCC, no tearing, even near the bulge.

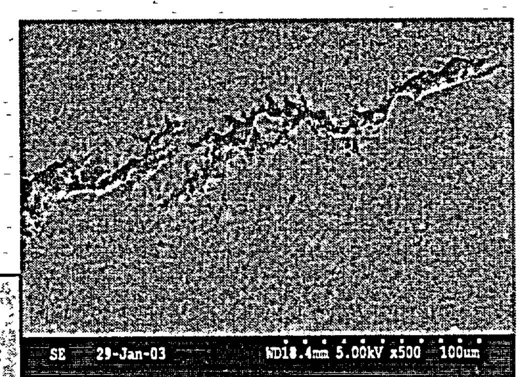




SEM (top) shows interdendritic crack path

SEM (right) shows preferential dissolution of ferrite creates crack path





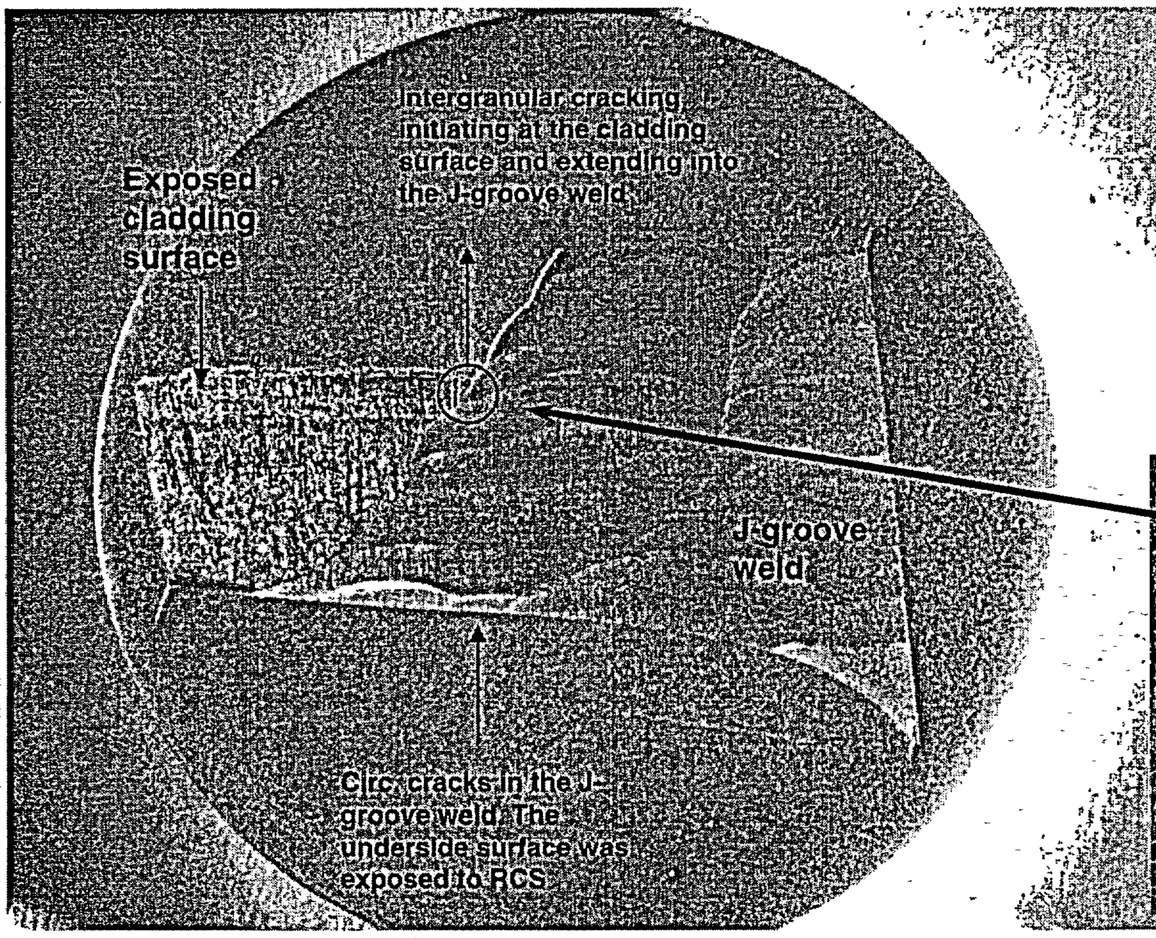
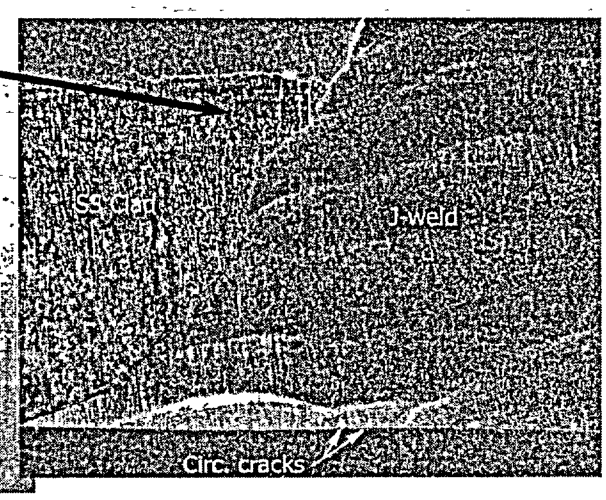
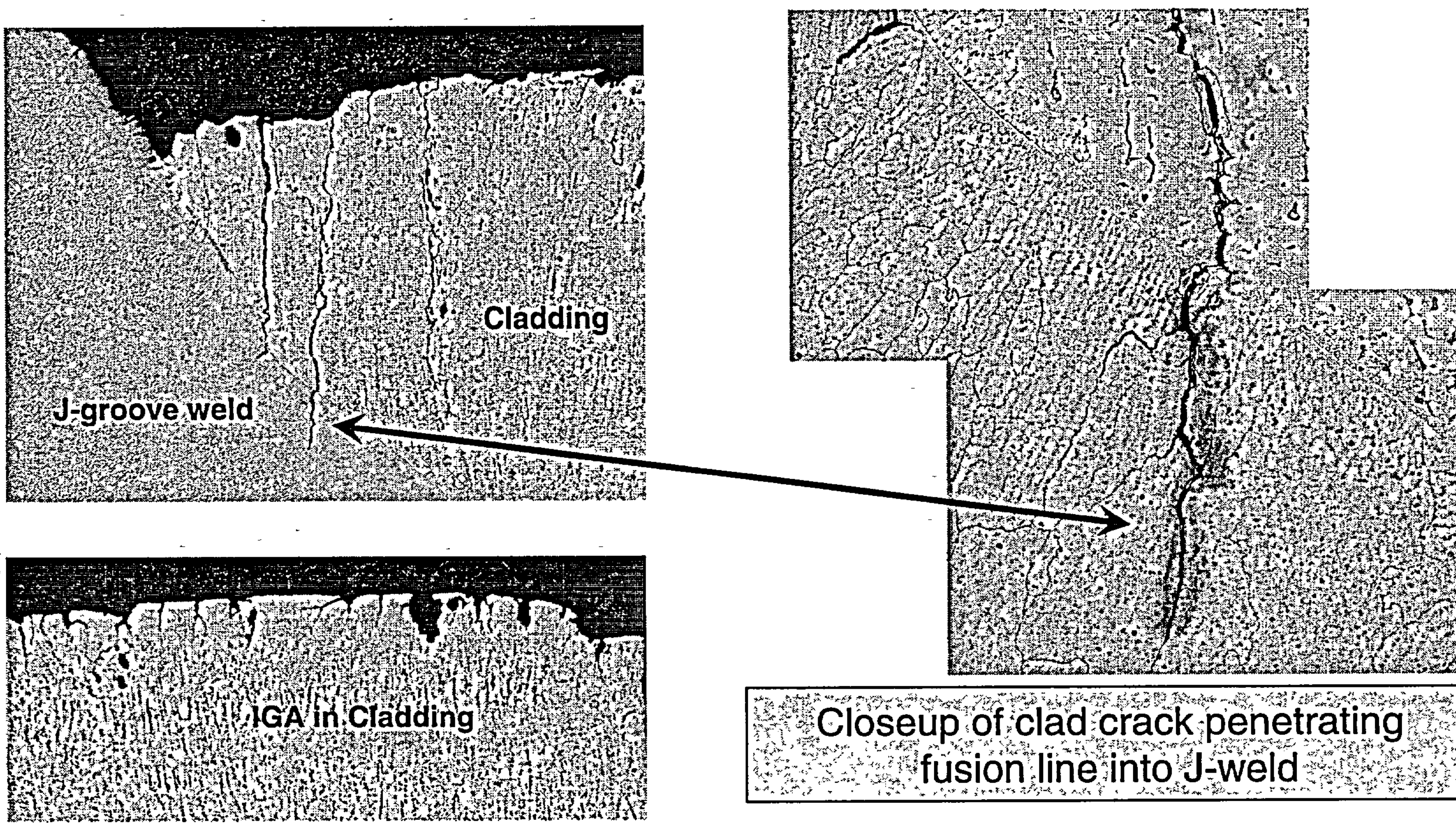


Photo-cross-sections of J-weld and exposed cladding, showing location of cracks in each.



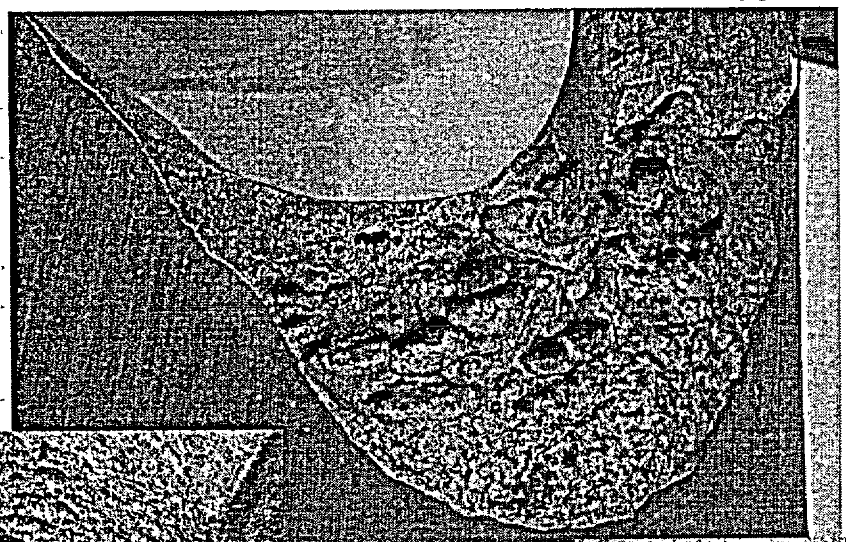
Cracks in the exposed clad, attacked by concentrated, boric acid solutions



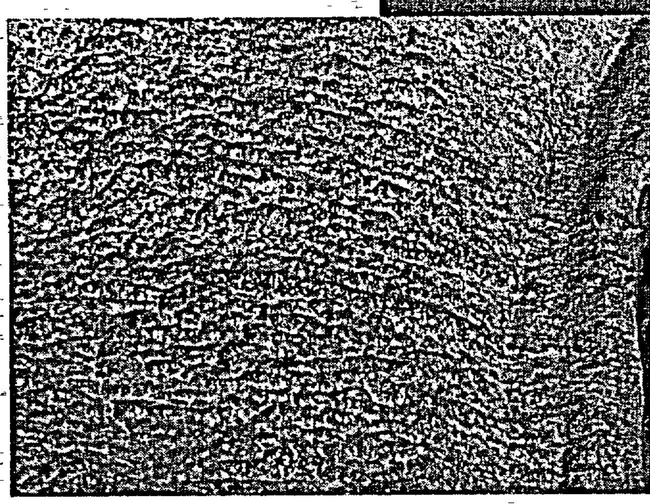
Closeup of clad crack penetrating fusion line into J-weld

Photographs of D-B Cavity Walls

Looking up near nose of the cavity

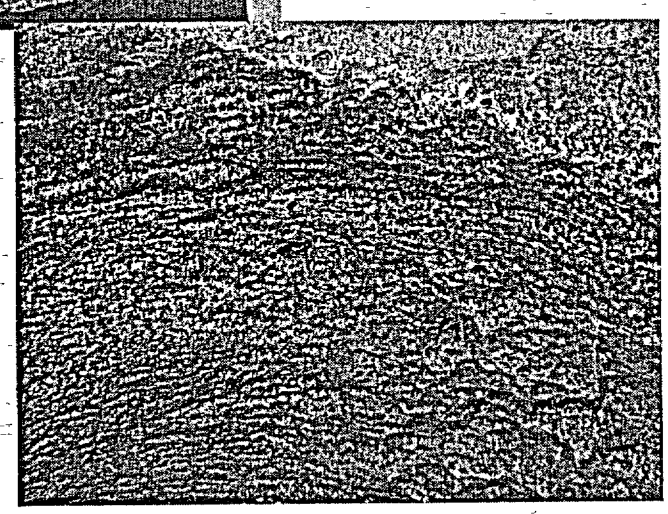


These investigations will help us to understand the corrosion timeline and process

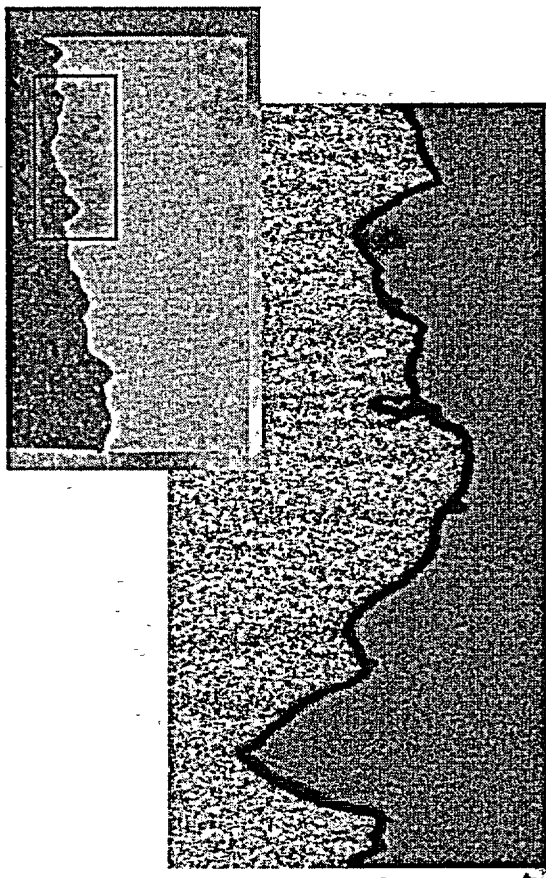


Near 90°

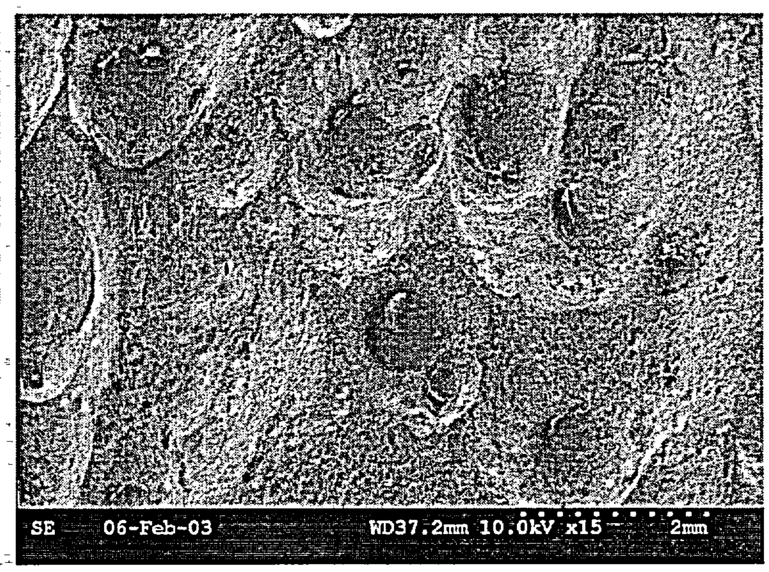
Near 270°



Characterization of the Walls of the Cavity



This section taken from high in the cavity (near 90°, ~2" from top)



Metallographs (stack of three at left at increasing magnification), and SEM show that cavity walls are characterized in places by ~1 mm. diam. pits, associated with banded microstructure.

Davis-Besse Root Cause and Safety Assesssment

1. Features of Boric Acid Corrosion Program at Argonne Nat. Lab
   A. Crack Growth Rates of Alloys 600 & 182 from Davis-Besse Head
   B. Computational Model, Based on Probabilistic Assessment of:
      i. Statistics of Crack Initiation
      ii. Probability of Detection & Accuracy of Sizing
      iii. Crack Growth Rate Variations
      iv. Stress Intensity Factor Gradients (Residual Stress, Interferences)
      v. Critical Crack Sizes, Including Factor of Safety
   C. Electrochemical Potential and Polarization Measurements of Low-Alloy Steel, Alloys 600 & 182 in Concentrated Boric Acid Solutions
      i. Measure E_{cp} for range of solution compositions, temperatures
      ii. Include molten boric acid species at temp. & pressure

2. Next two slides describe MEB Program on Structural Integrity at ORNL

Structural Integrity Assessment

Approach

- Created detailed finite element model of the DB head, wastage cavity, and remaining unbacked cladding.
- Developed two failure models to bound expected behavior:
  1. Plastic instability model calibrated by PVRC-sponsored unflawed rupture disk results.
  2. Ductile tearing initiation model using 3-wire, 308SS quasistatic fracture toughness properties.
- Predicted best-estimate failure probability vs pressure as a function of crack depth.
- Conducted Monte Carlo analysis to determine failure probabilities with respect to the best estimate.

Variable Modeling Categories

- **Probabilistic:** Crack depth, material toughness, rupture disk failure pressure.
- **Conservative Deterministic:** J-groove weld reinforcement; cladding thickness.
- **Best-Estimate Deterministic:** Cladding cavity area; low alloy steel, Alloy 600, and 308 SS constitutive behavior; vessel head geometry; operating temperature and pressure.

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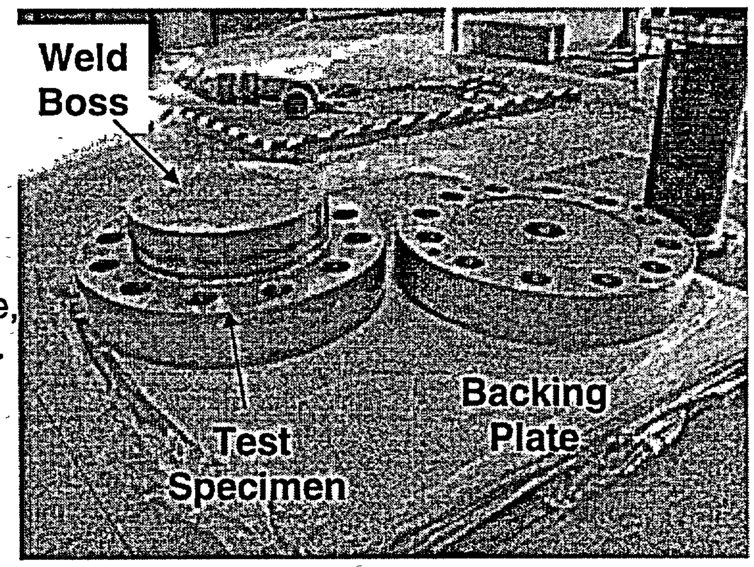
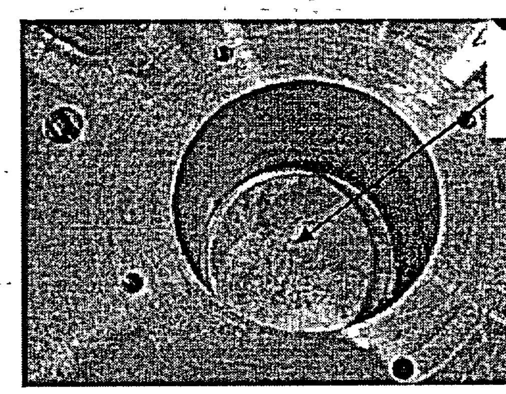
Ongoing Work for ASP Analysis (by 10/03)

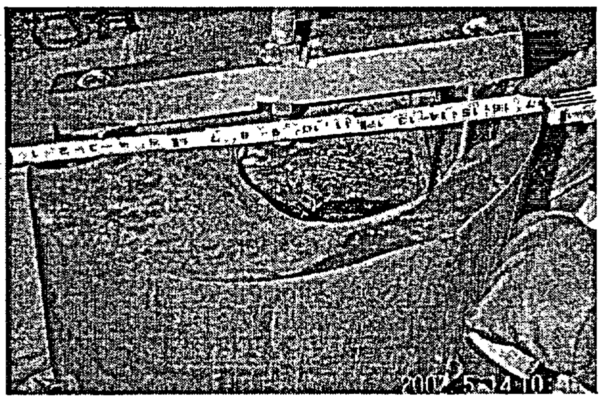
- **Analytical Program**
  - Develop tearing instability model to analyze intermediate-depth flaws.
  - Extend model to predict failure probabilities for the year preceding cavity discovery.
    - Monte Carlo Analysis
    - Probabilistic Variables: Pressure, cavity size, flaw size, wastage rate, material toughness, and burst pressure.
  - More rigorous quantification of geometric, material, and failure model uncertainties.



- **Experimental Program**
  - Conduct material property testing of surrogate cladding material (PVRUF).
  - Perform burst tests on simple, circular or elliptical cavity geometries.
    - Unflawed specimens
    - Flawed specimens
  - Assess accuracy of analytical failure models.



Harvesting of Head for Additional Research



- Nozzle #3 and surrounding low-alloy steel at BWXT-Lynchburg
  - Optical & SEM Micrography of Cavity Surface
  - Cladding Properties, Microstructure, etc.
- Nozzles #2 and #46 - removal in early 2003
  - #2 sent to Argonne for failure analysis
  - #46 sent to PNNL for research on "anomalous" UT indications
  - Additional nozzles for crack growth rate testing
- Crack Growth Rate Testing of Alloy 600 (Nozzle #3) and Alloy 182 (J-weld, from Nozzle #11) soon underway
- North Anna Unit 2 Head Being Harvested by Industry
  - Expect NRC/Industry Coordination of NA2 Research