Figures

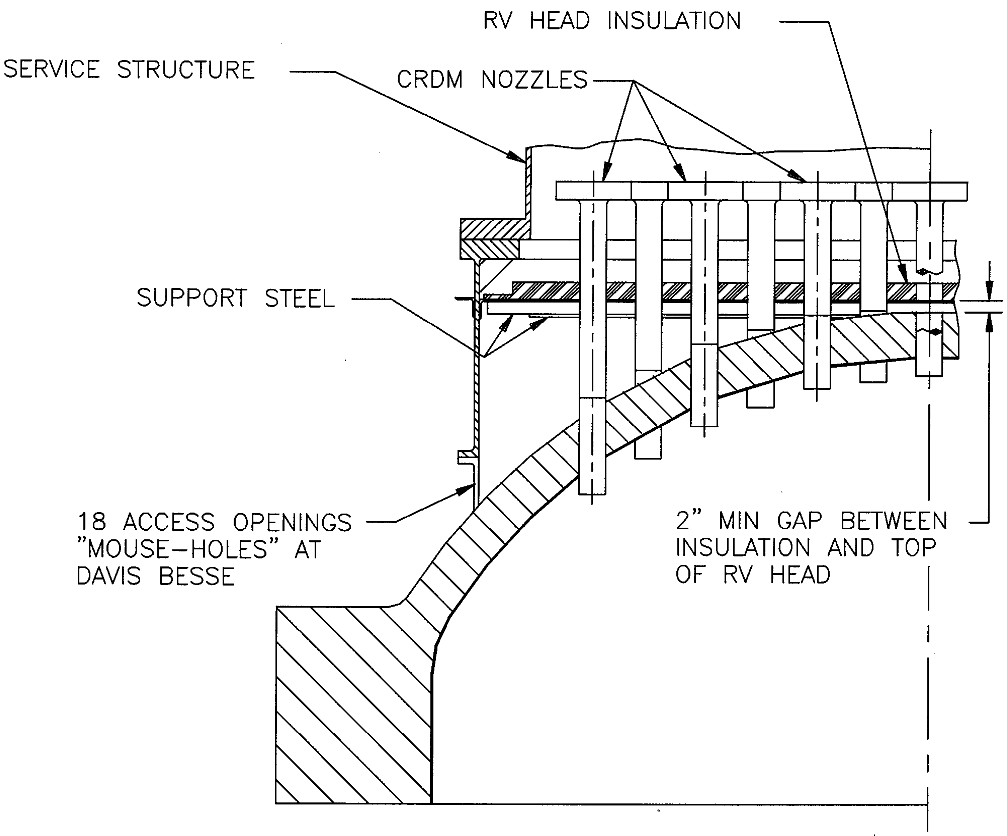


Figure 1. Davis-Besse RPV Top of Head Section View

Source: EPRI/DEI

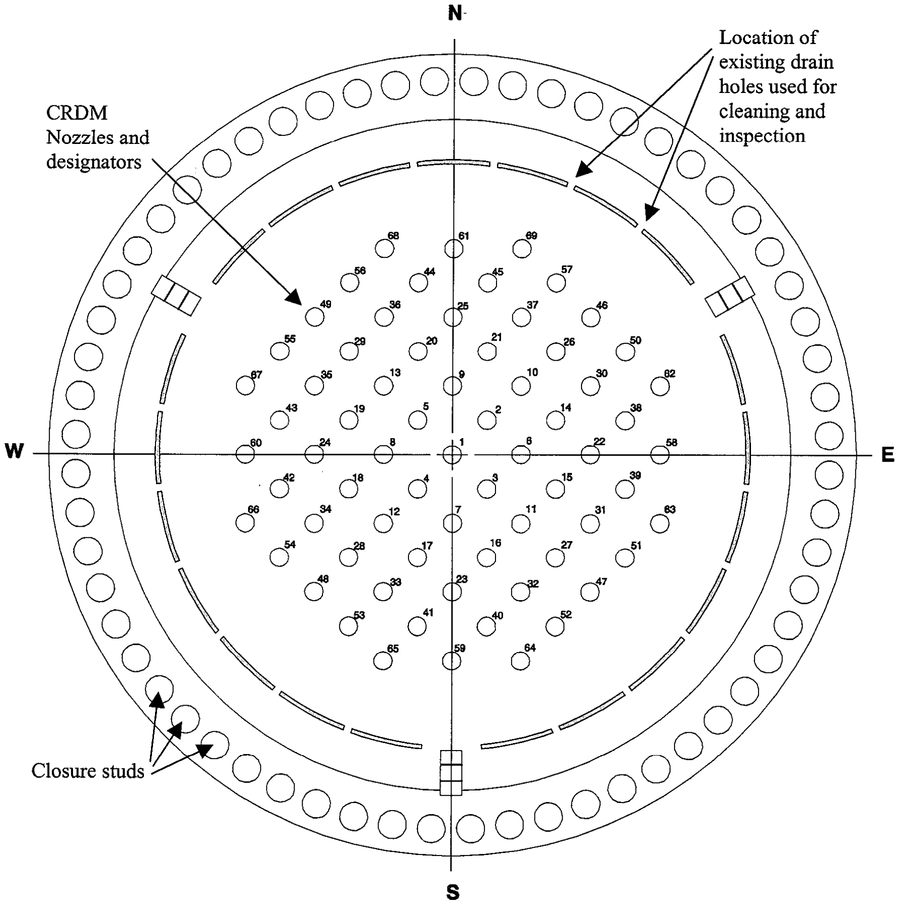


Figure 2. Davis-Besse RPV Top of Head Plan View

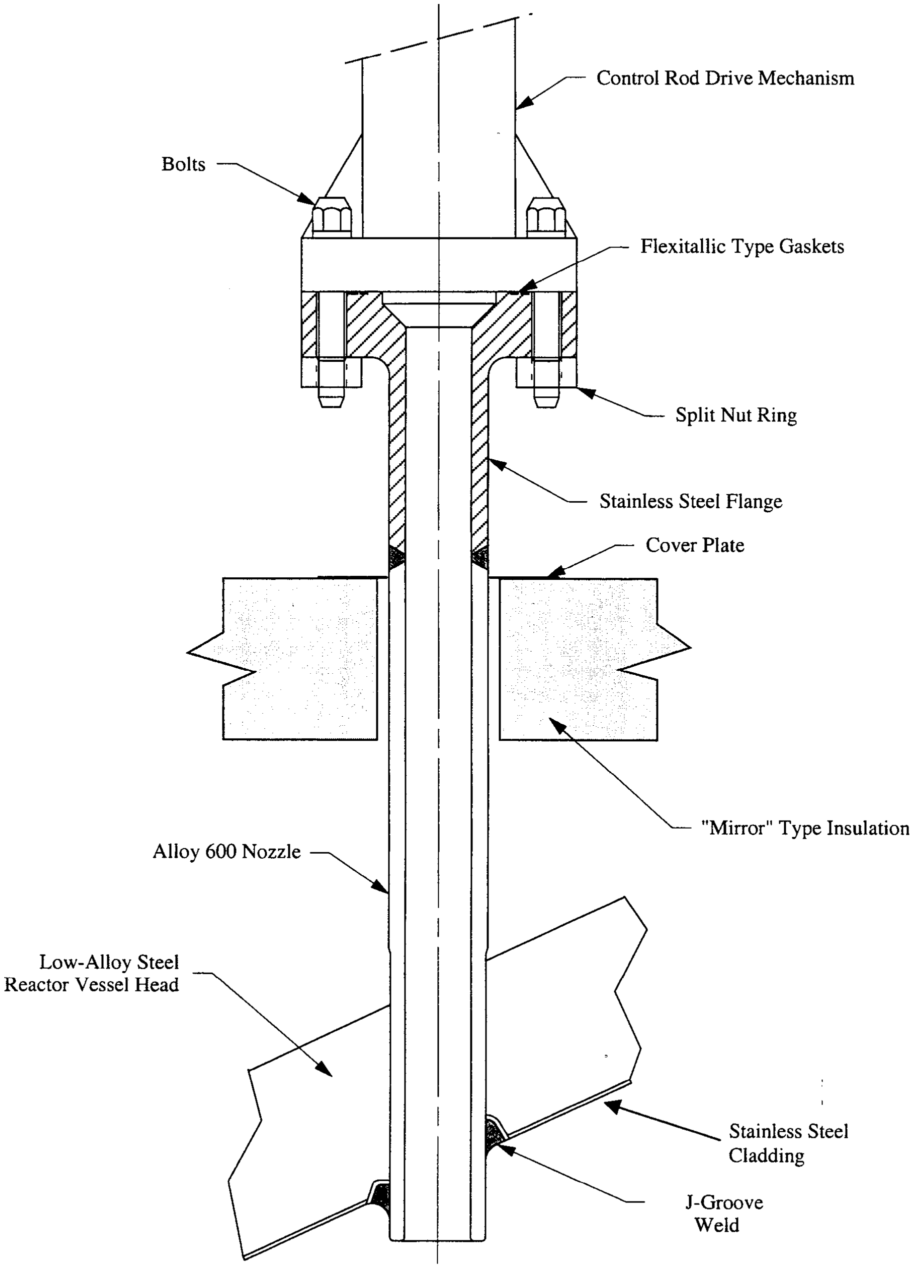


Figure 3. Davis-Besse CRDM Nozzle General Arrangement

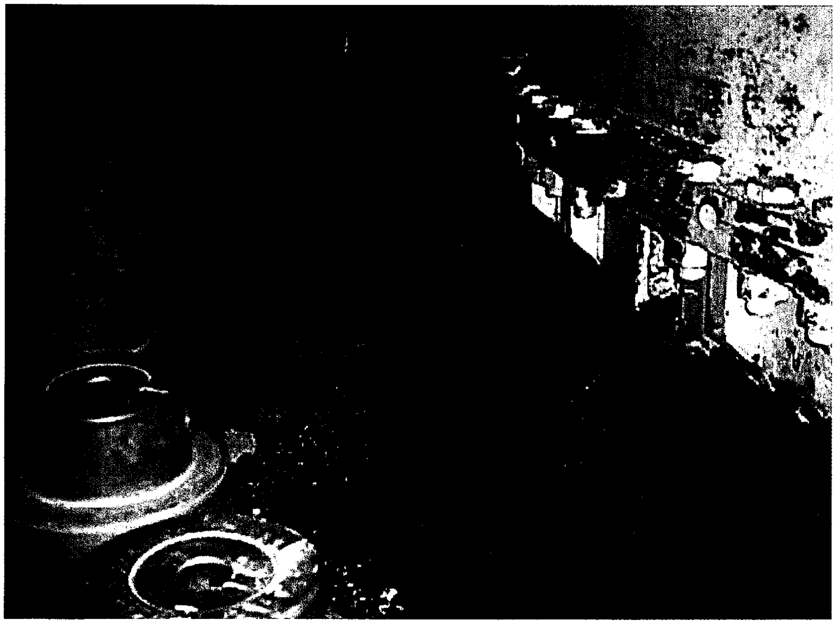
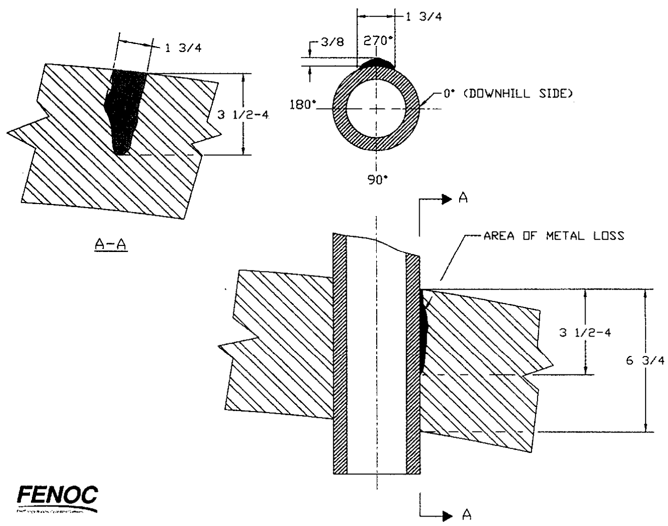


Figure 4. Boric Acid and Iron Oxide on Vessel Flange at 12RFO

Nozzle 2 Corrosion Profile



FENOC

12

Figure 5 Nozzle 2 Corrosion Area Location, Size, and Profile.

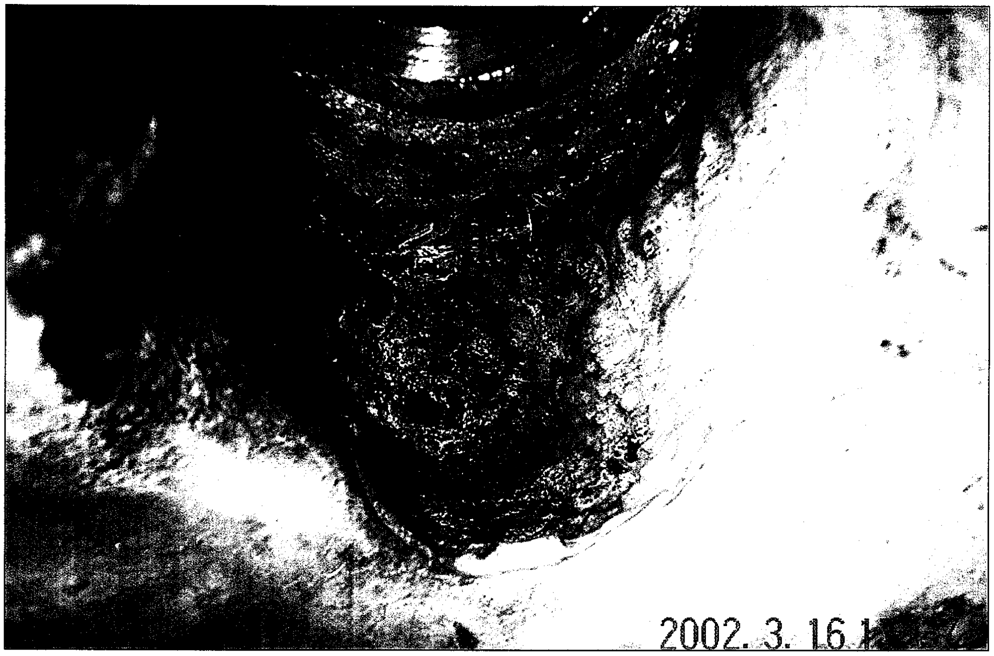


Figure 6. Cavity in Reactor Vessel Head Between Nozzle 3 and 11

Source: EPRI/DEI

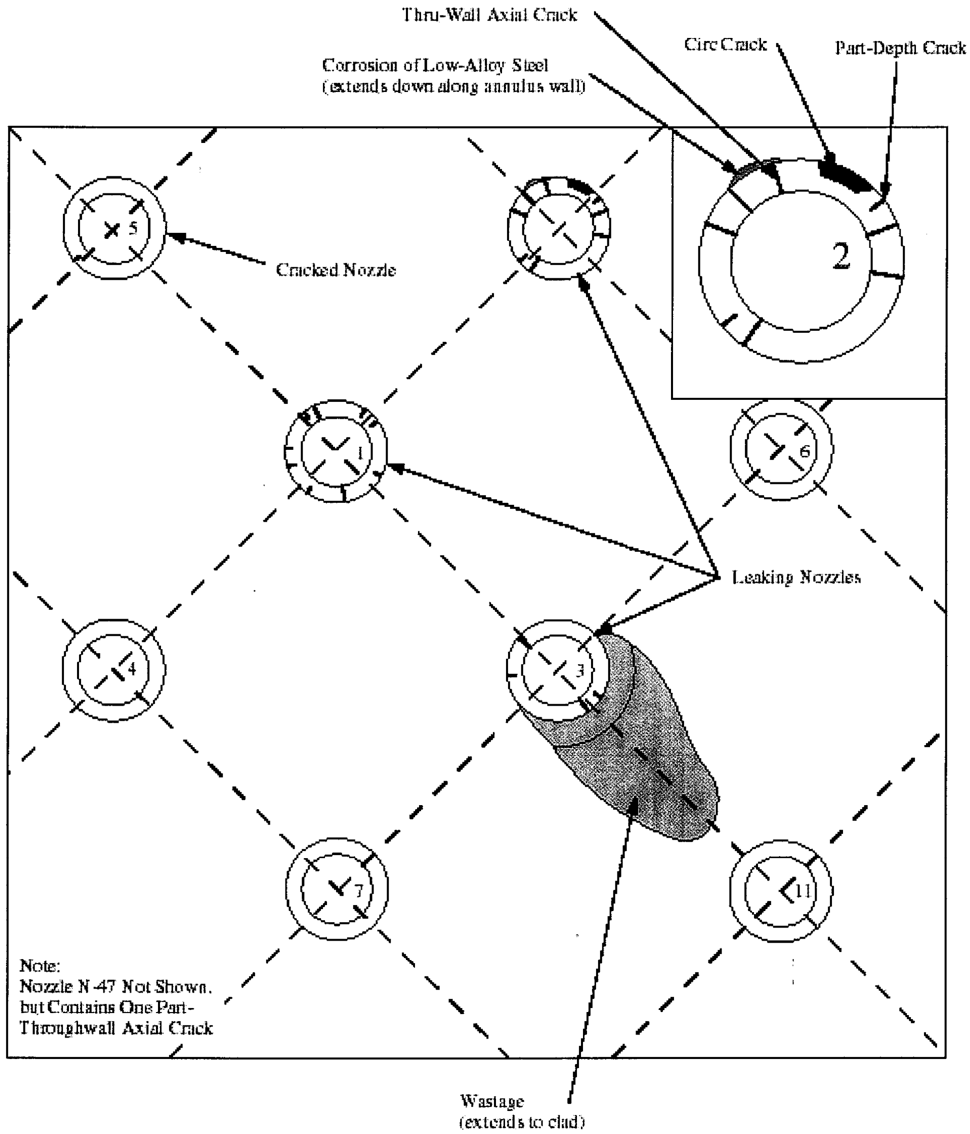


Figure 7. Locations of Cracks and Corrosion on Davis-Besse RPV Head at 13RFO

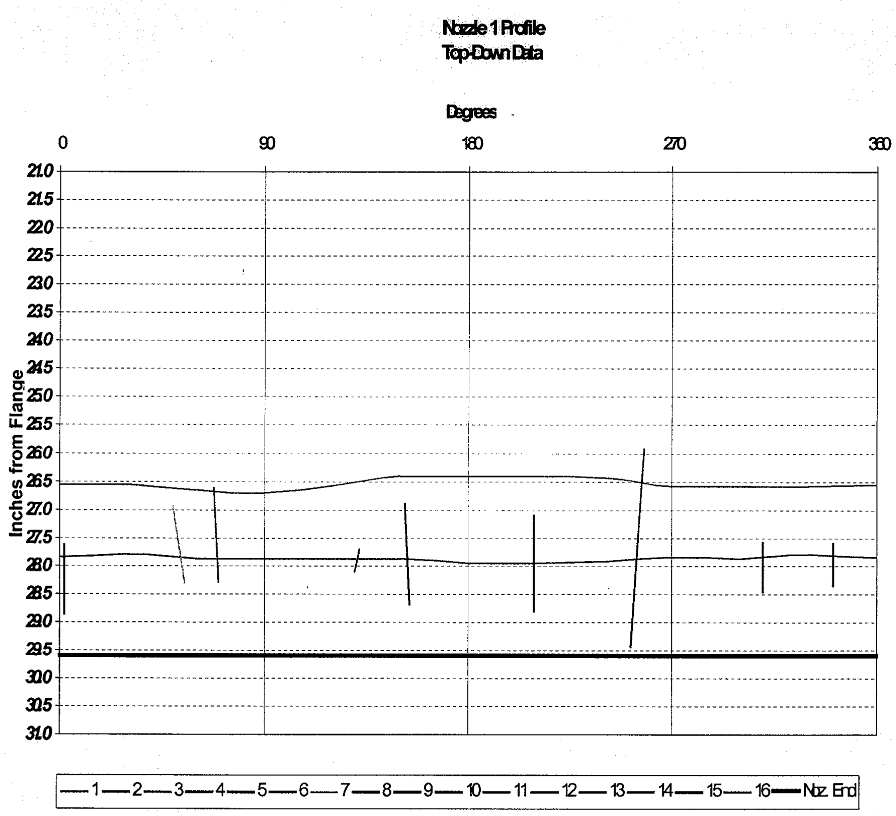


Figure 8. Nozzle 1 Crack Locations and Sizing

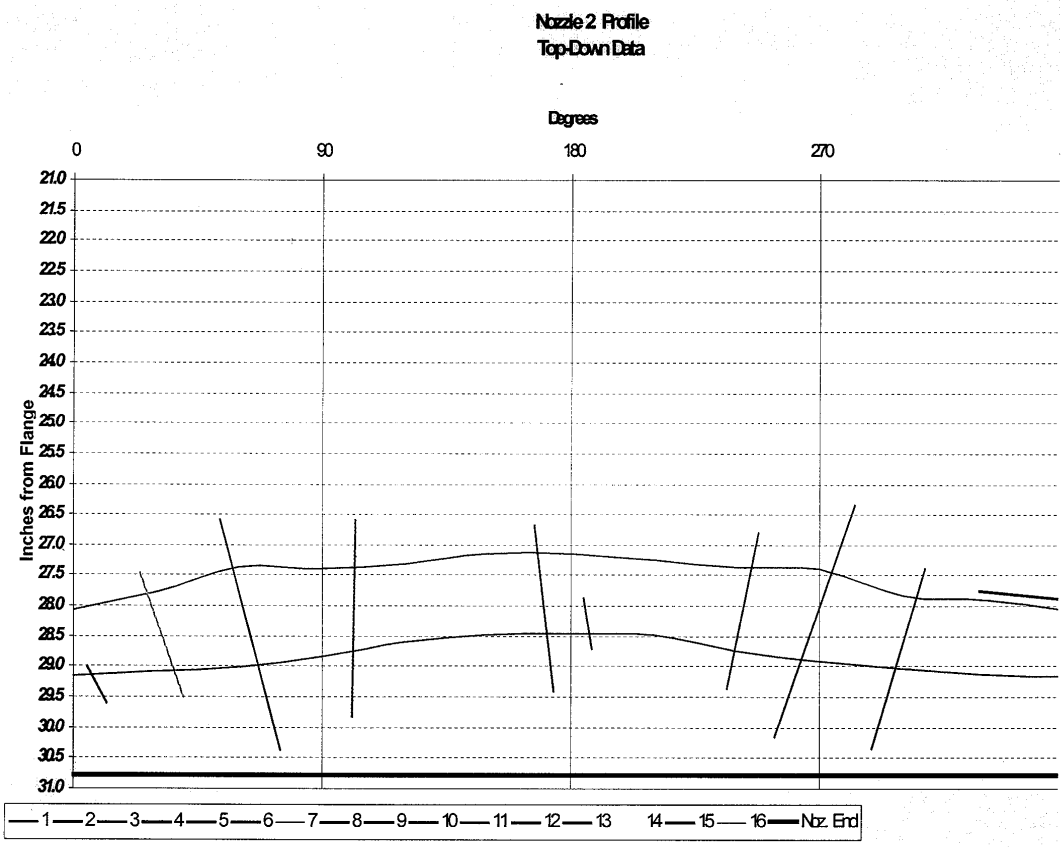


Figure 9. Nozzle 2 Crack Locations and Sizing

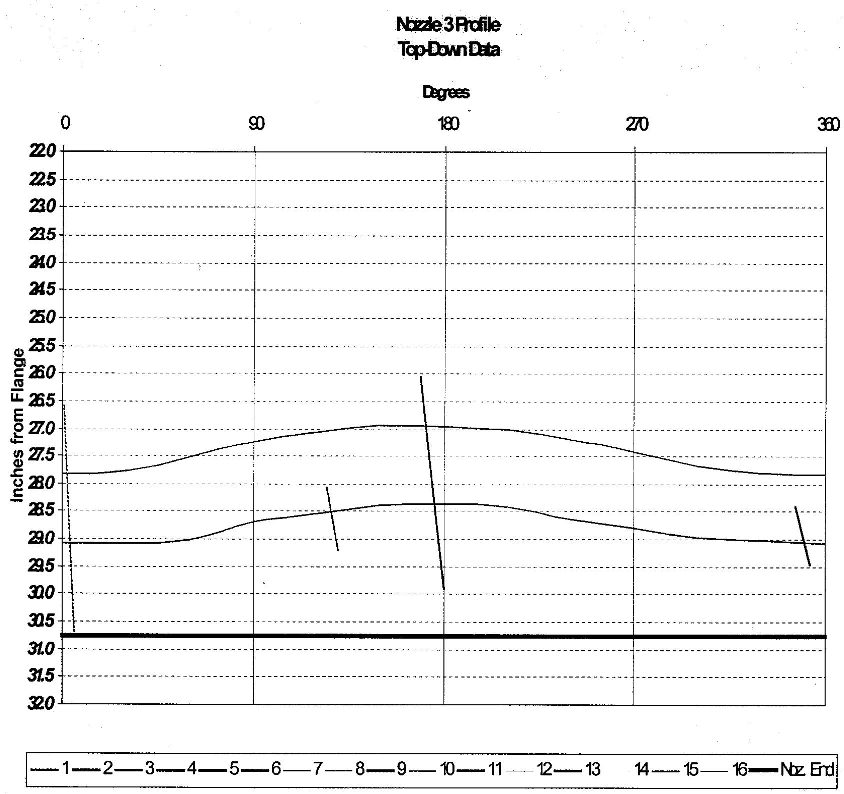


Figure 10. Nozzle 3 Crack Locations and Sizing

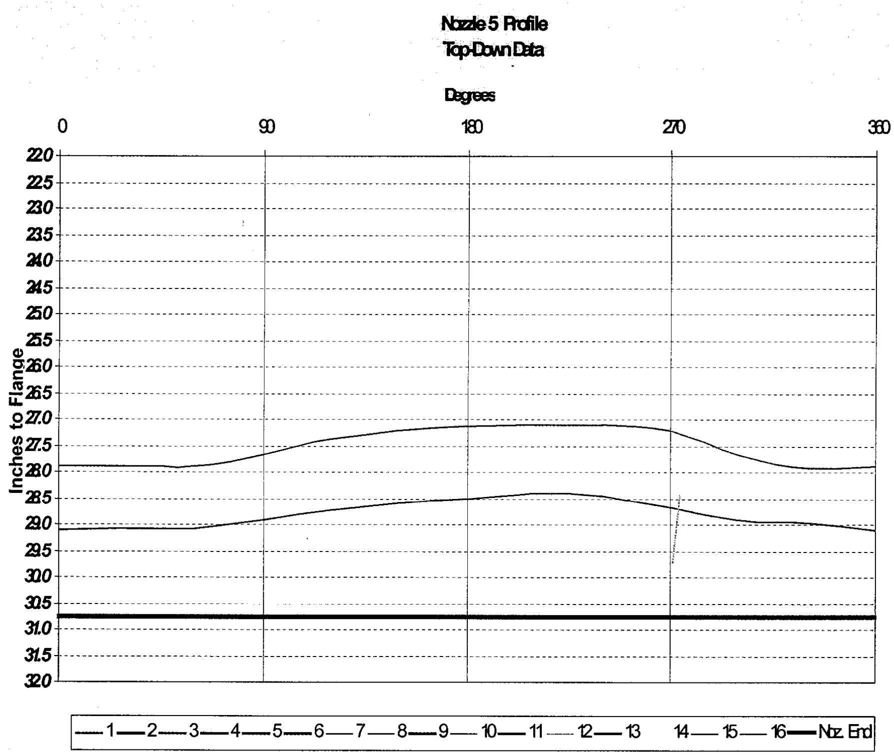


Figure 11. Nozzle 5 Crack Locations and Sizing

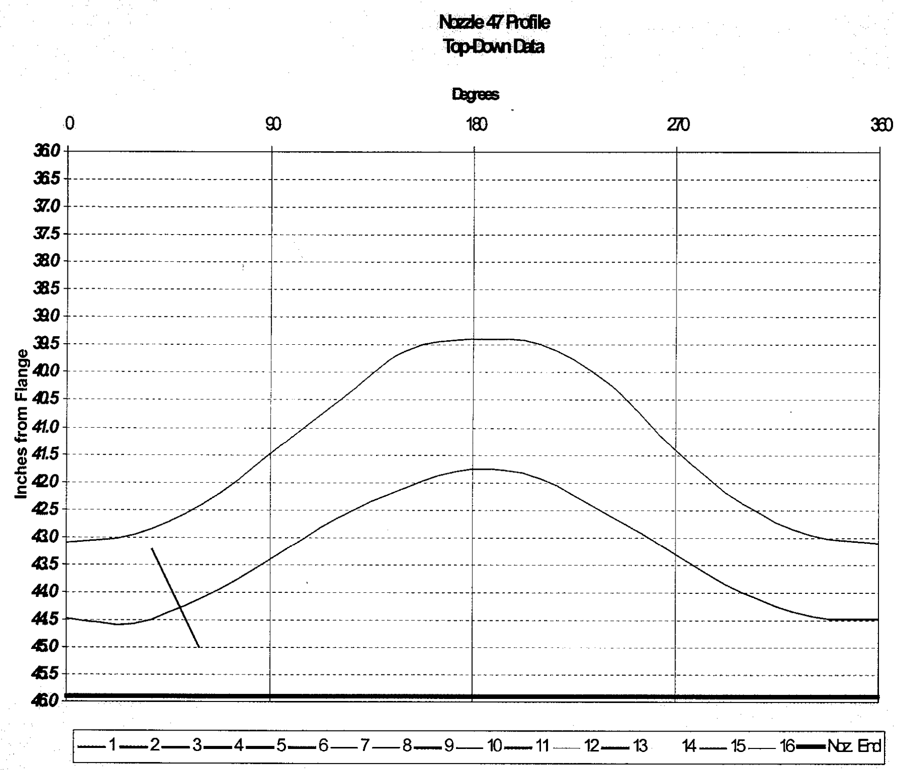


Figure 12. Nozzle 47 Crack Locations and Sizing

Figure 13. Corrosion and Possible Impingement at Nozzle N-3

DAVIS-BESSE RFO-13

180°

Nozzle 3

90° 270° 0°

	A	B	C	D	E	F	G	H	I	J
1	6.5	2.6	3.4	0.344					NR	3.9
2	6.2	6.2	1.2	0.344					NR	NR
3	6.2	6.2	1.4	NR	0.346				1.2	6.2
4	5.9	NR	NR	0.309	0.260	0.365	0.305	0.313	NR	6.0
5	3.6	3.6	0.303	0.255	0.273	0.260	0.302	0.299	5.2	3.8
6	6.6	3.0	0.301	0.240	0.291	0.301	0.303	0.302	0.310	0.315
7	3.6	6.2	0.299	0.300	0.311	0.298	0.304	3.600	3.600	3.6
8	6.4	6.2	0.301	0.300	0.300	0.300	0.300	3.400	3.400	5.8
9	6.8	6.2	0.279	0.280	0.340	0.350	0.360	0.370	0.370	0.303
10	NR	NR	0.279	0.276						0.380
11	NR	NR	0.304							

Nozzle 11

Approximate Location

Figure 14. Nozzle 3 Clad Thickness Measurements

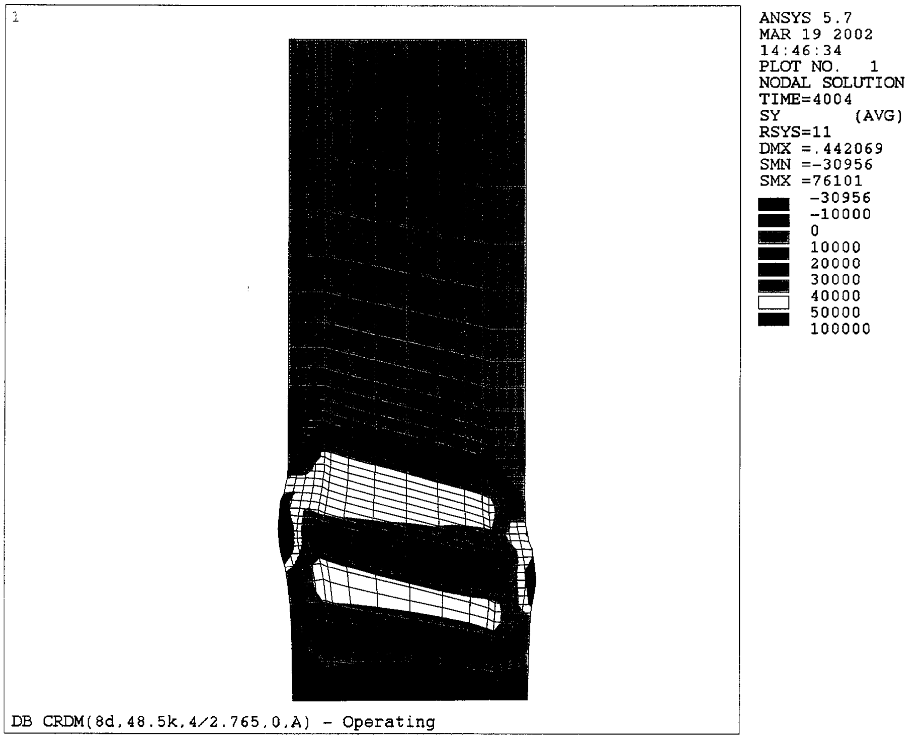


Figure 15. Hoop Stresses and Operating Condition Deflections in CRDM Nozzles 2-5

Source: EPRI/DEI

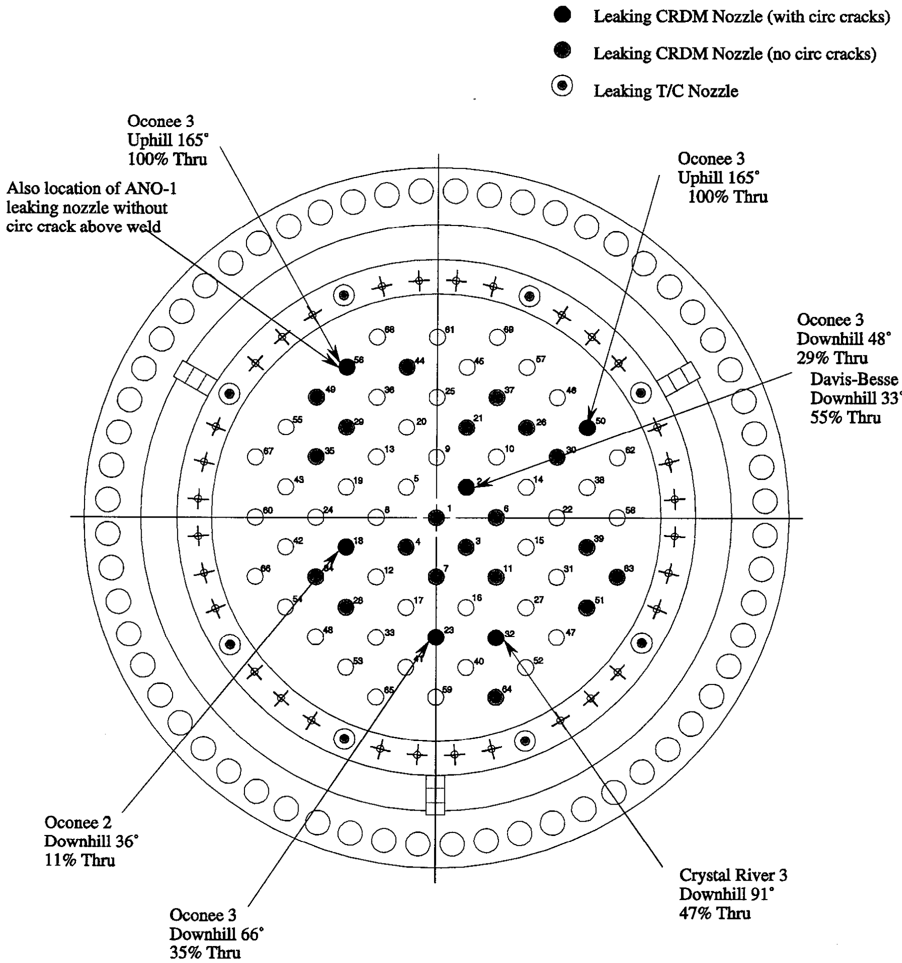


Figure 16. Location of Leaking Nozzles in B&W Design Plants

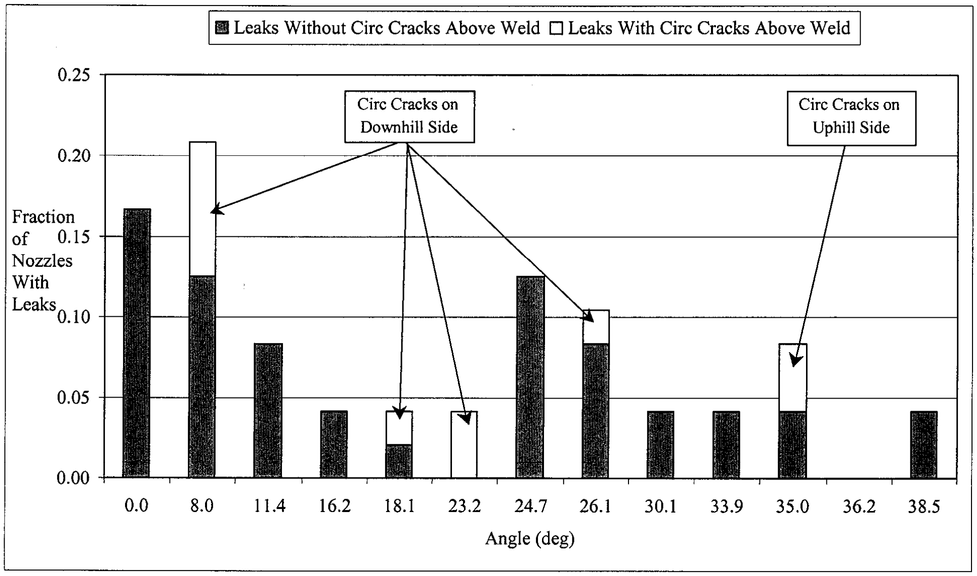


Figure 17. Distribution of Leaking Nozzles in B&W Design Plants

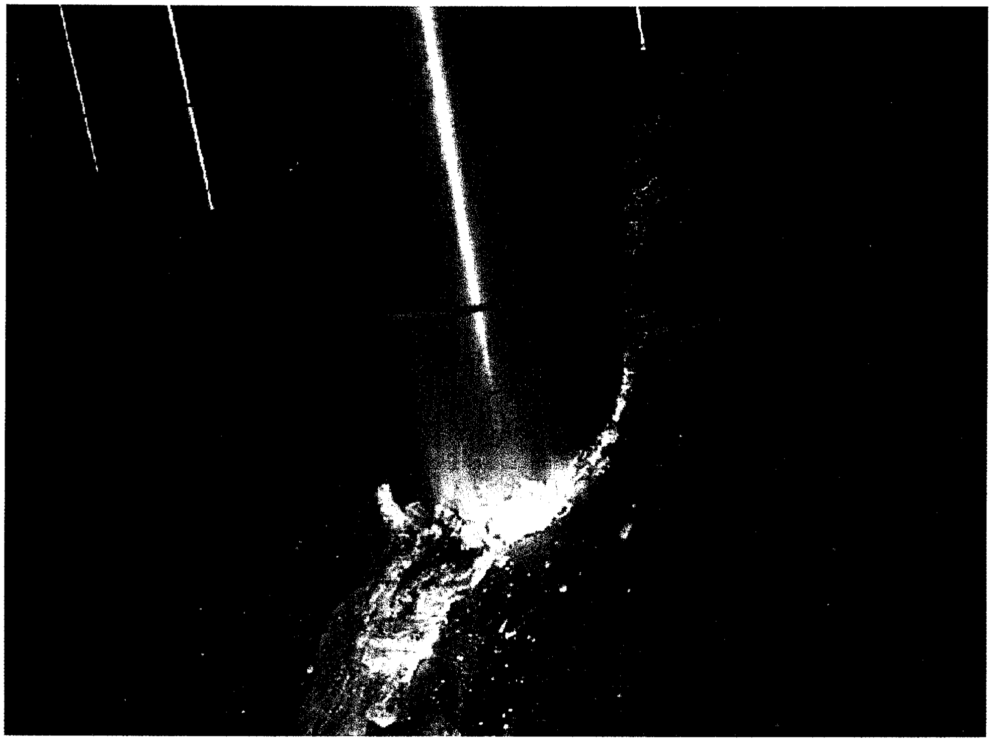


Figure 18. CRDM Nozzle Leakage Observed at Oconee 3

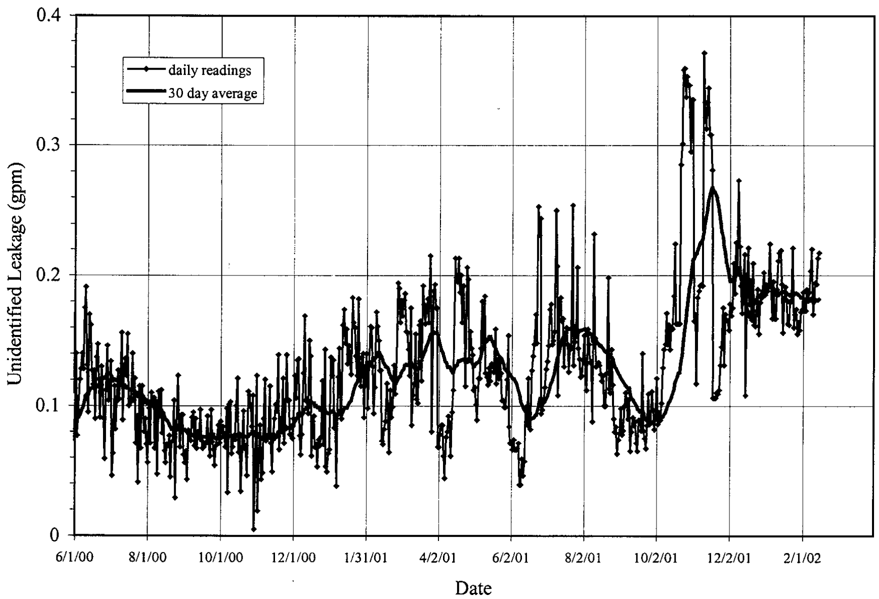


Figure 19. Unidentified Leak Rate at Davis-Besse (Cycle 13)

Source: EPRI/DEI

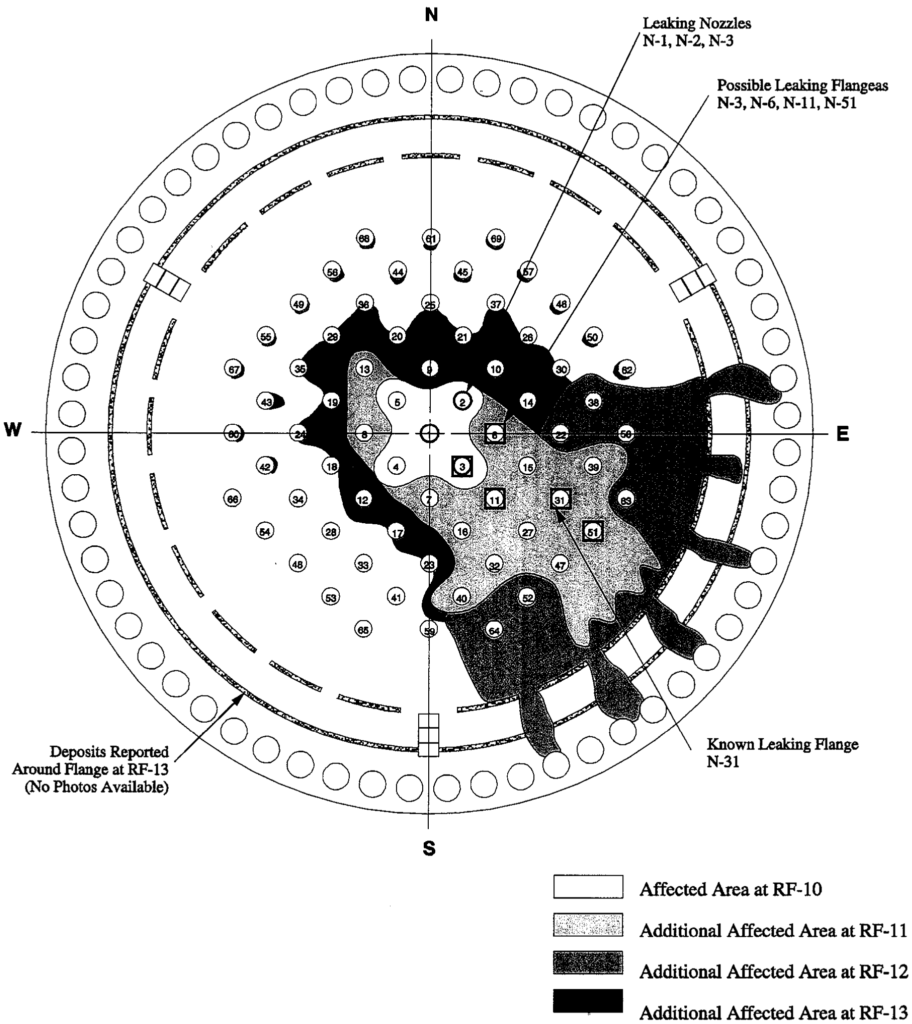


Figure 20. As-Found Locations of Boric Acid Deposits on Davis-Besse Vessel Head (10RFO to 13RFO)

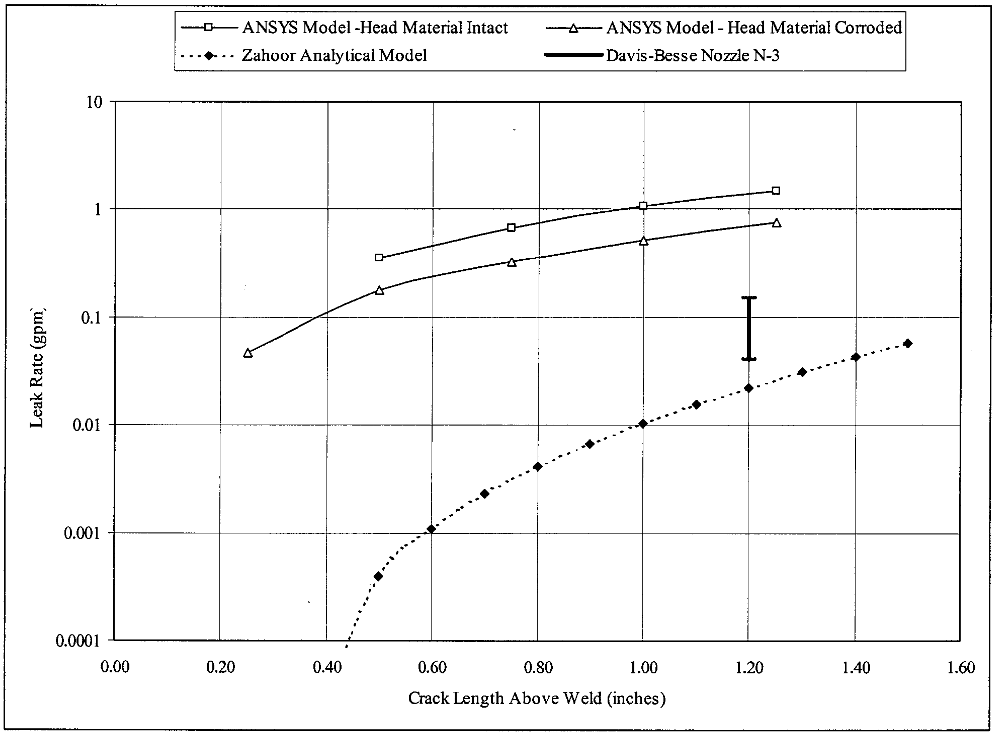
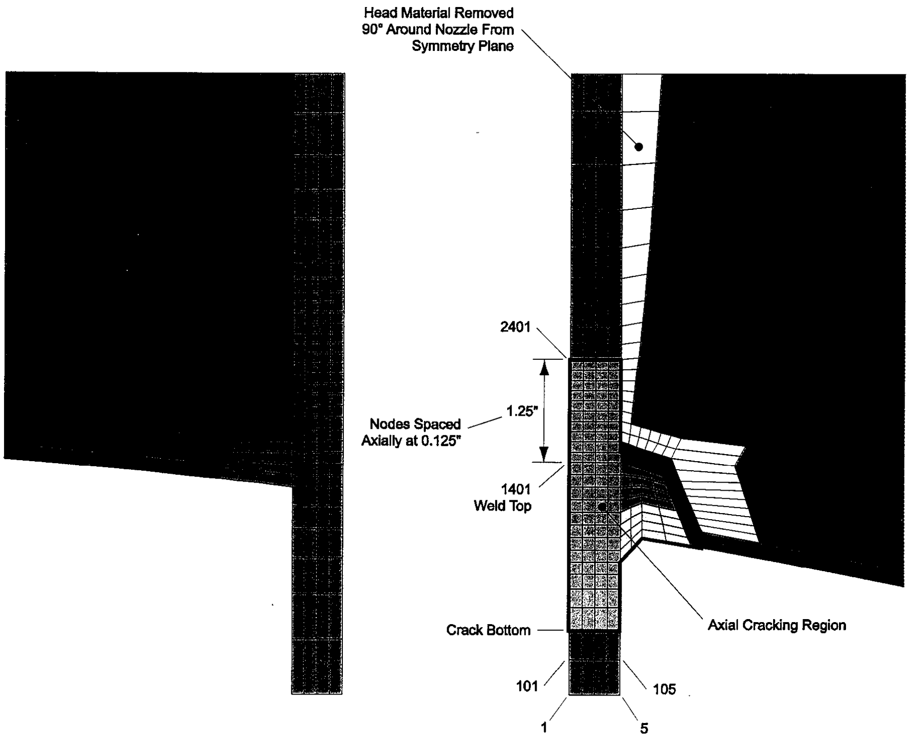


Figure 21. Nozzle Crack Leakage Rate Calculation Results



Downhill Plane Nodes are 0's Series
Uphill Plane Nodes are 80,000's Series

Tube Node Series: 1's at Nozzle ID, 5's at Nozzle OD
Shell Node Series: 5's at Shell ID (merged w/tube OD) in weld region
6's at Shell ID above weld region
15's at edge of shell section

Node Numbers Increase by 100 up the length of the tube and shell
Node Numbers Increase by 1 along the tube and shell radius

Figure 22. Finite Element Model Boundary Conditions to Simulate Axial Crack

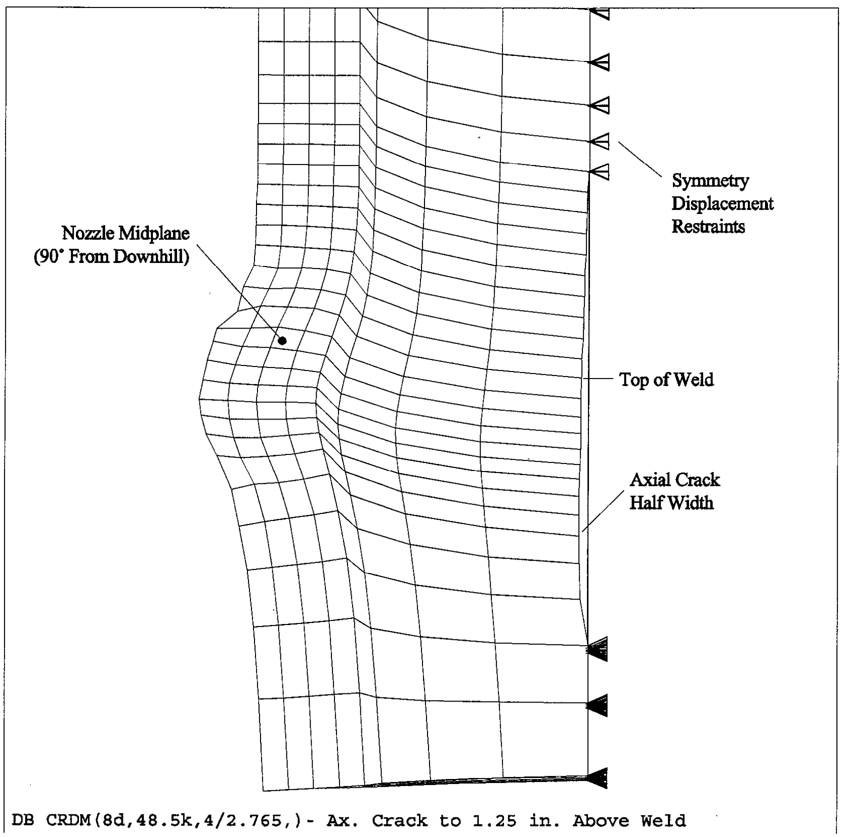


Figure 23. Crack Opening Displacement with the Crack Surface Nodes Released

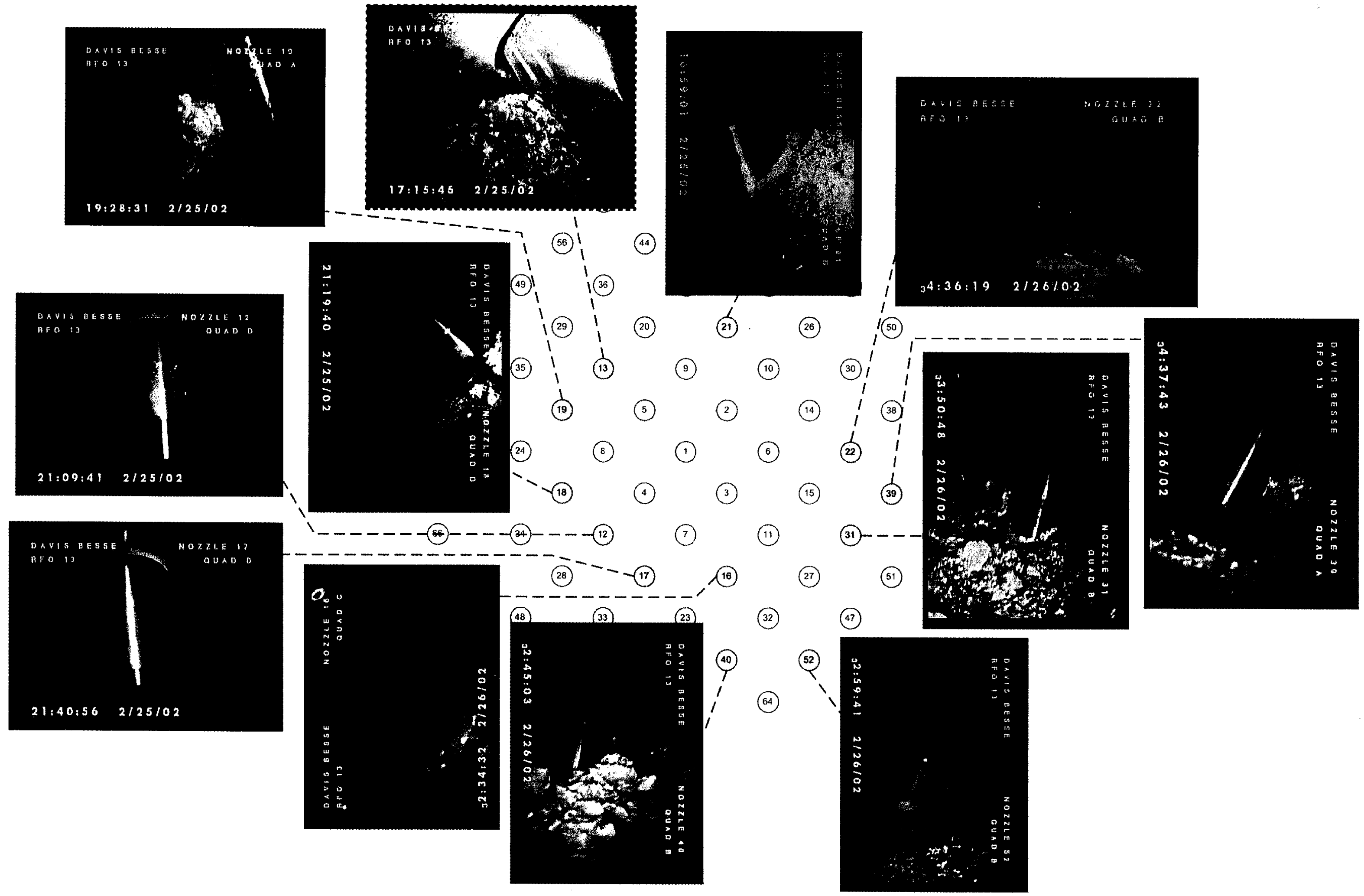


Figure 24. Boric Acid Deposits on Top of Head at Start of 13 RFO

Source: EPRI/DEI

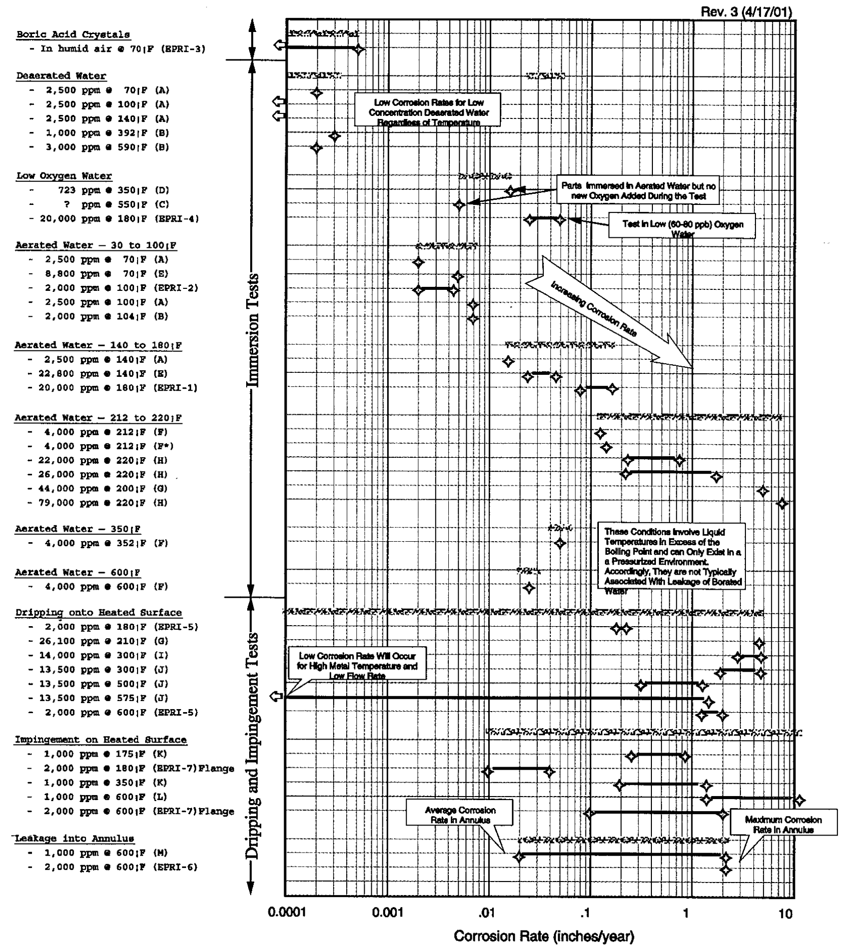
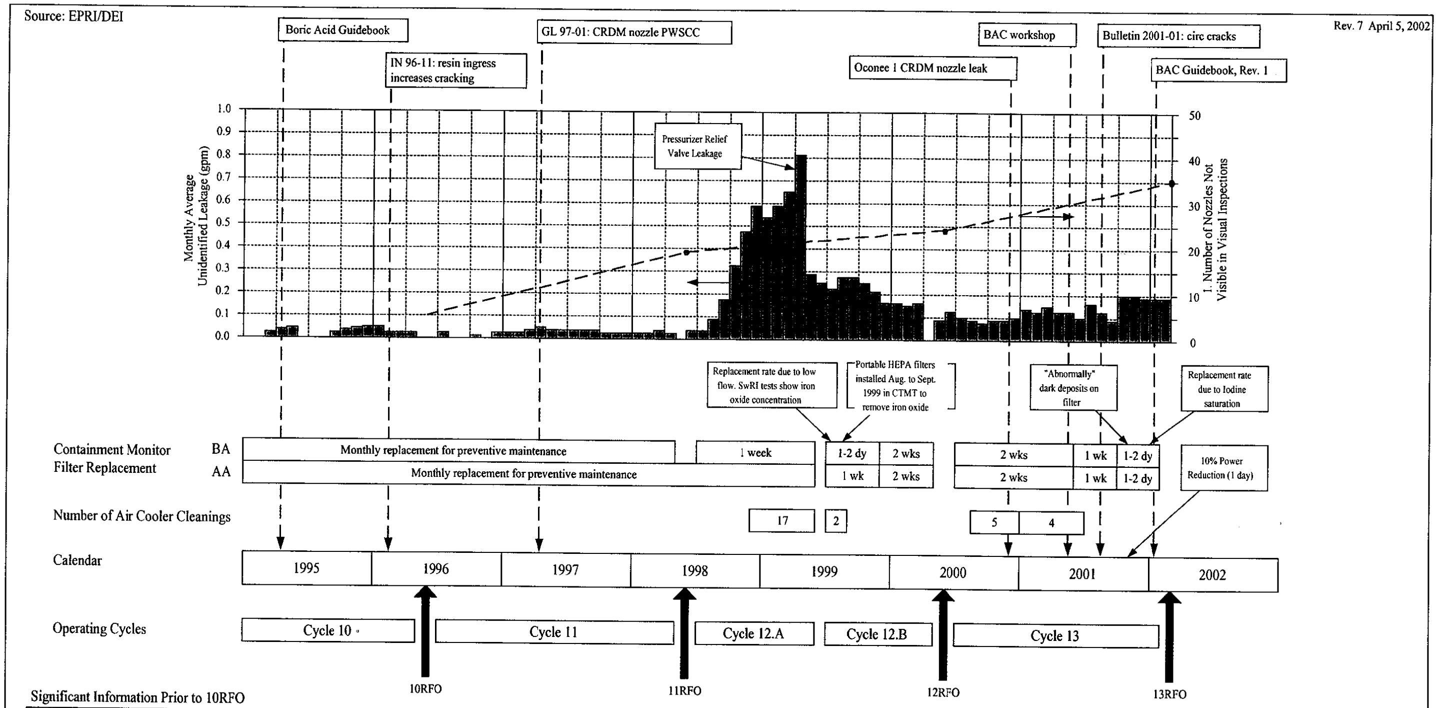


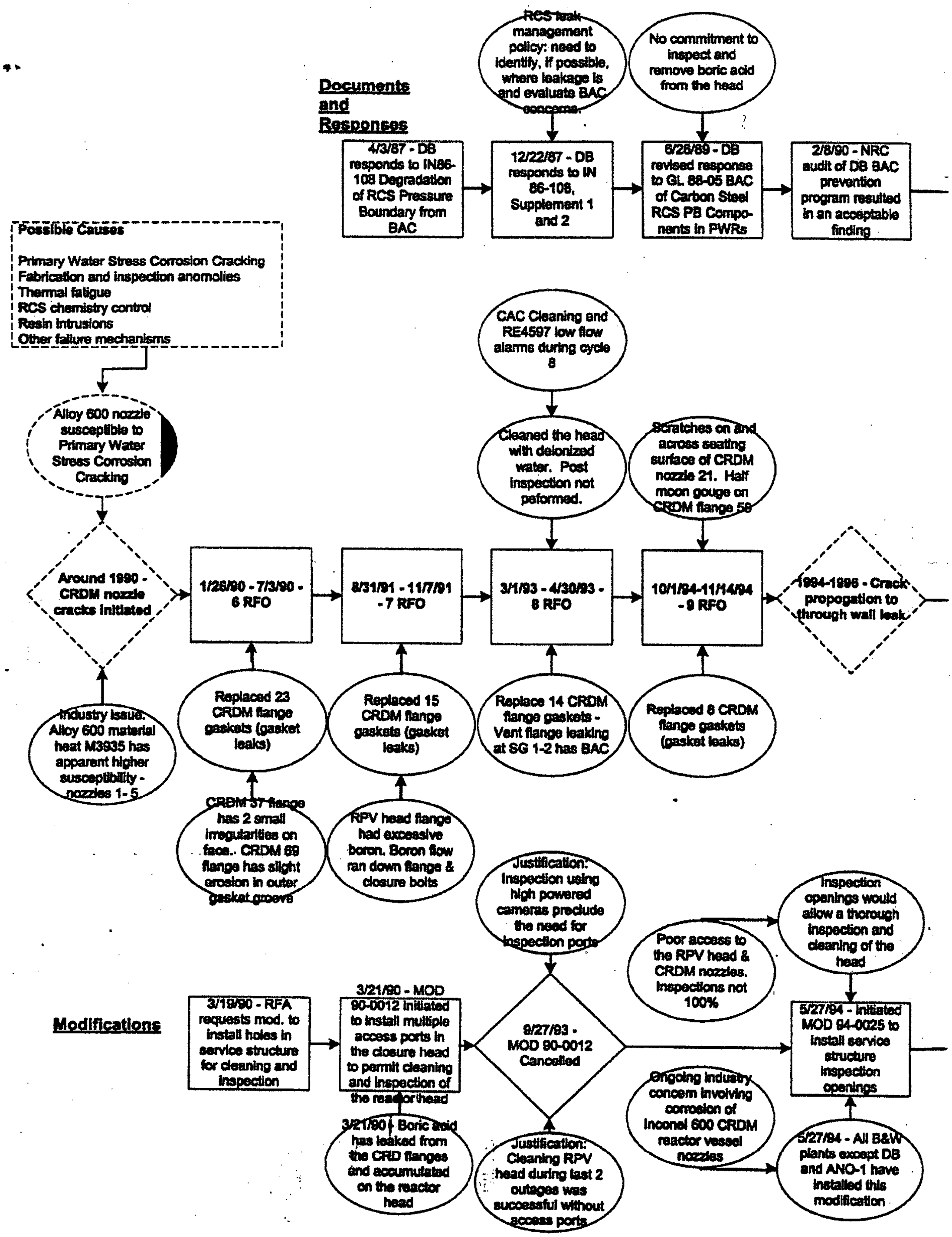
Figure 25. Corrosion Rate for EPRI Experiments (Proprietary)



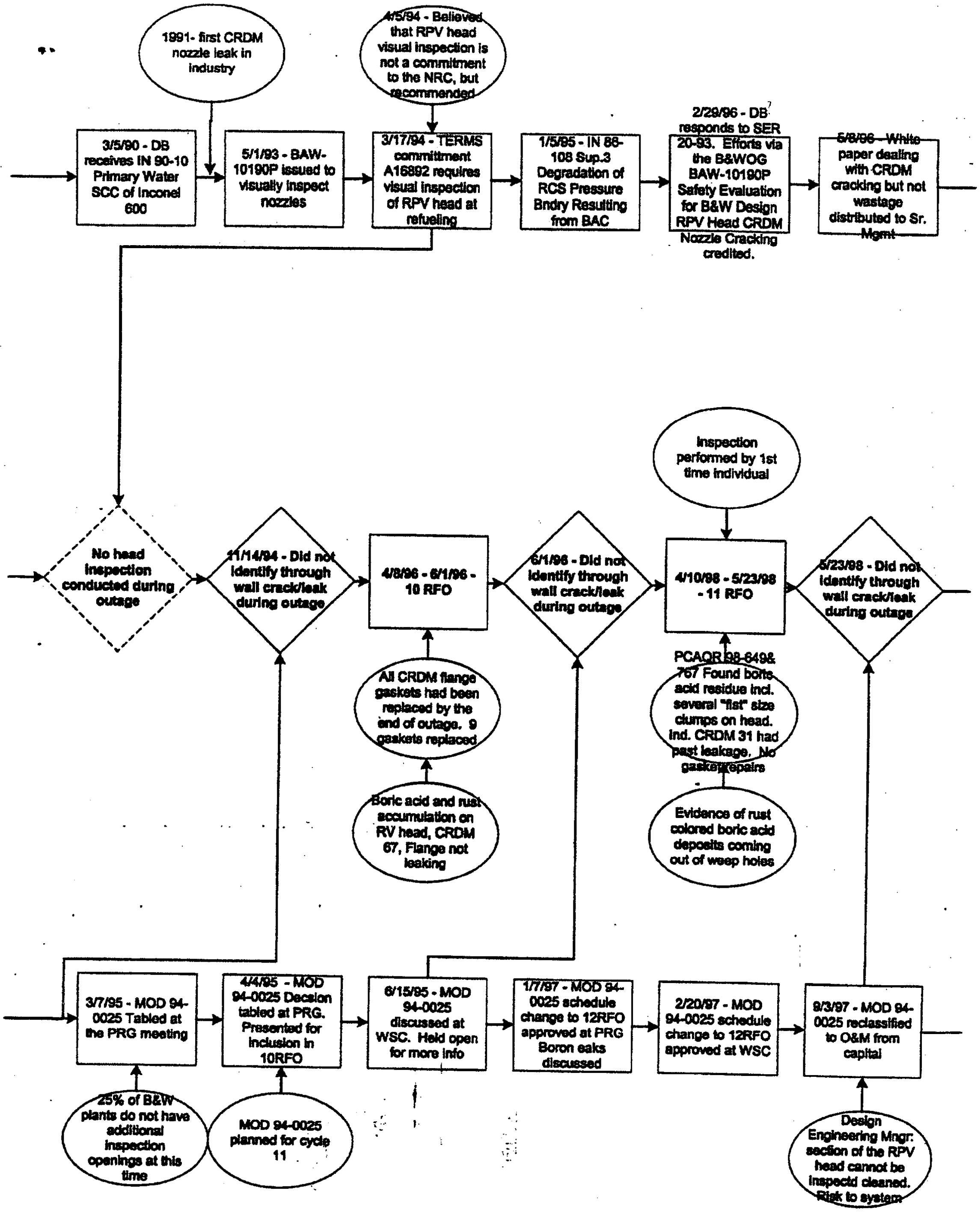
Significant Information Prior to 10RFO					
1) Nozzle 66 gasket replaced at 7RFO and 8 RFO	1) One flange with indications of minor leakage	1) Nozzle 31 gasket leaks but not changed 2) BA is powder and white	1) Replaced gaskets on flanges 3, 5, 6, 11, 31 2) "Red" deposits under nozzle 3 flange 3) Bottom of nozzle 3 flange not inspected due to hard BA	1) No leakage from flange gaskets 2) "Red" deposits under nozzle 3 flange 3) Difficult to get camera in place due to hard, brown, boric acid	CRDM Flange Conditions
1) Head flange clean in 1994	1) BA flowing towards mouseholes in S-E quadrant	First indication of red colored boric acid deposits from mouseholes in quadrant of S-E quadrant	Significant flow of red colored boric acid deposits from mouseholes, piling to 6" deep behind studs in S-E quadrant	1) Significant flow of boric acid deposits from mouseholes in S-E quadrant 2) BA deposits extend around entire flange 1" deep max	RPV Flange Conditions
1) BA deposits dripping through insulation at 8RFO 2) Head "cleaned" at 8RFO 3) Head not inspected during 9RFO	1) Visual inspection 65/69 nozzles 2) Minor BA deposits around outer nozzles of RV Head 3) BA deposits at center of head	1) Vsual inspect 50/69 nozzles 2) Loose BA piling up behind outer nozzles 3) BA brittle, breaks easily	1) Visual inspect 45/69 nozzles 2) BA definitely red and hard to break up (needed crowbar) "lava-like"	1) Visual inspect 34?/69 nozzles N-1: leak [Nozzles 5 & 47 cracked] N-2: leak, circ & minor wastage N-3: leak & major wastage	RPV Head Conditions

Figure 26. Timeline of Key Events Related to Reactor Vessel Head Boric Acid Corrosion

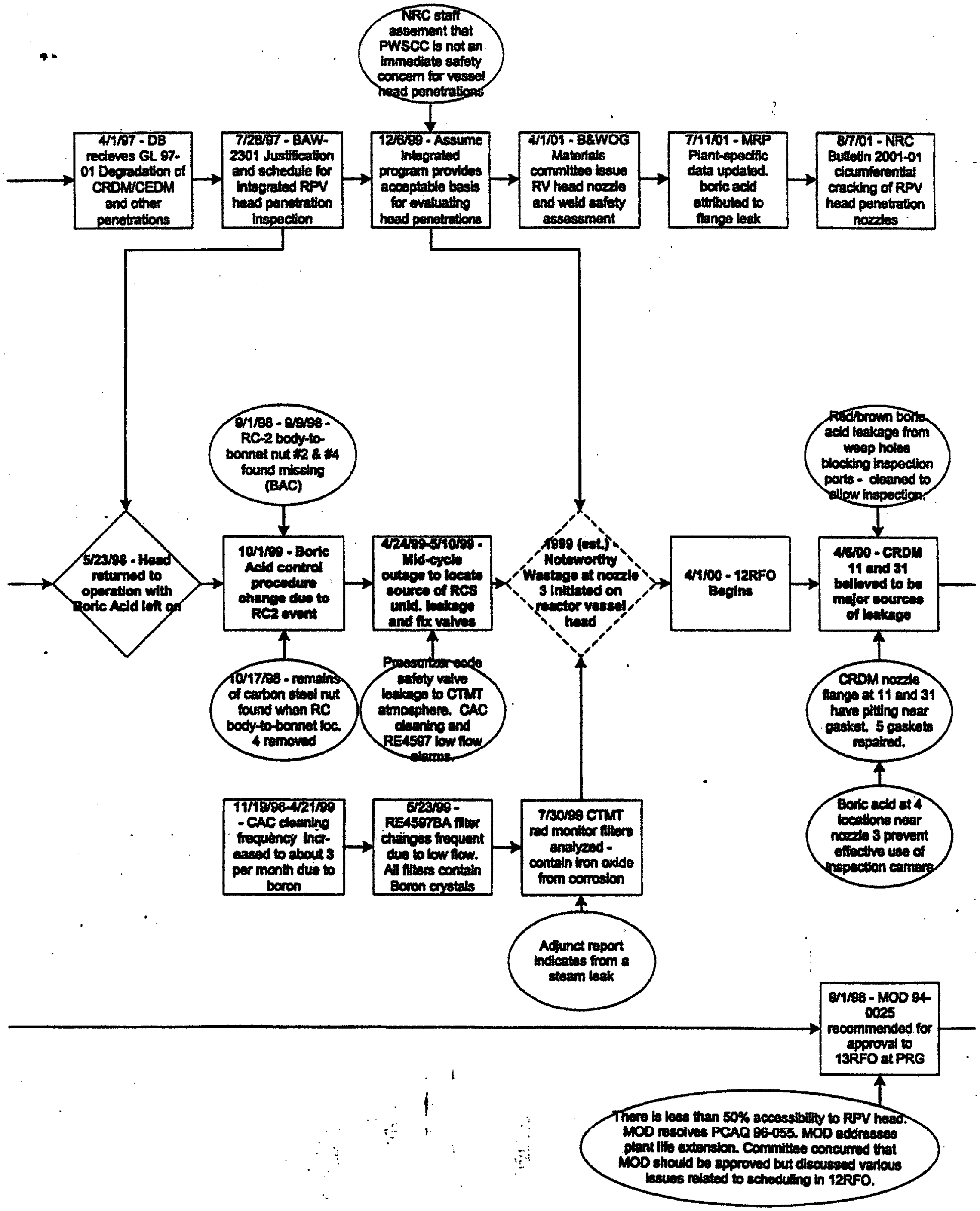
Figure 27. Events and Causal Factors Chart on Following 5 pages:

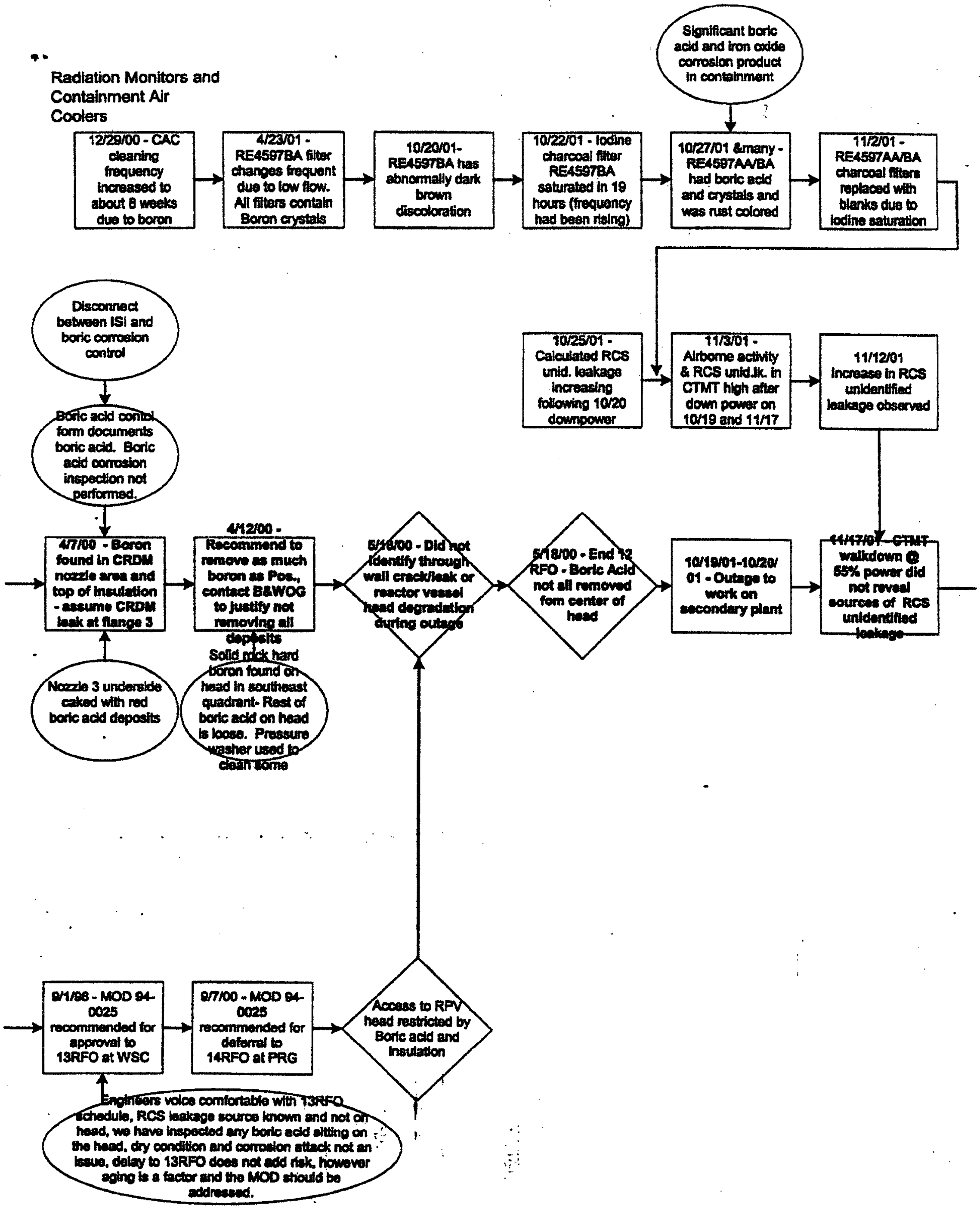


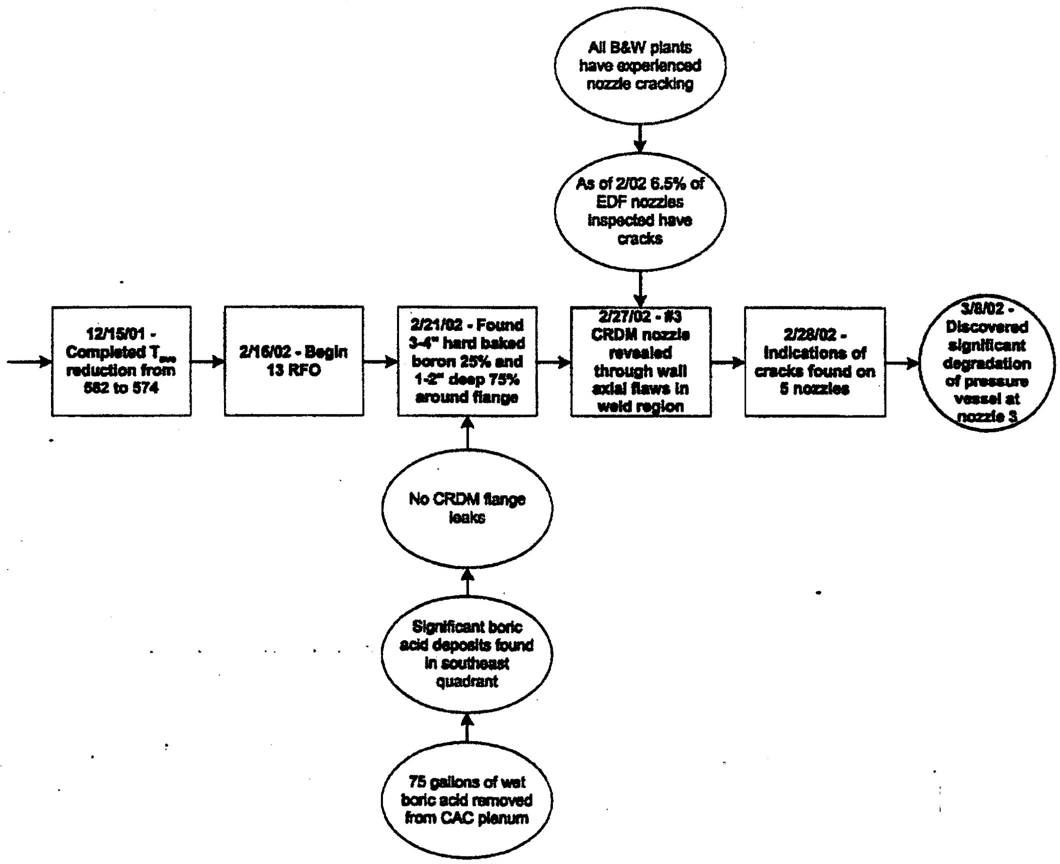
Documents and Responses
RCS leak management policy: need to identify, if possible, where leakage is and evaluate BAC concerns.
No commitment to inspect and remove boric acid from the head
4/3/87 - DB responds to IN86-108 Degradation of RCS Pressure Boundary from BAC
12/22/87 - DB responds to IN 86-108, Supplement 1 and 2
6/28/89 - DB revised response to GL 88-05 BAC of Carbon Steel RCS PB Components in PWRs
2/8/90 - NRC audit of DB BAC prevention program resulted in an acceptable finding
Possible Causes
Primary Water Stress Corrosion Cracking
Fabrication and inspection anomolies
Thermal fatigue
RCS chemistry control
Resin intrusions
Other failure mechanisms
Alloy 600 nozzle susceptible to Primary Water Stress Corrosion Cracking
CAC Cleaning and RE4597 low flow alarms during cycle 8
Cleaned the head with deionized water. Post inspection not peformed.
Scratches on and across seating surface of CRDM nozzle 21. Half moon gouge on CRDM flange 58
Around 1990 - CRDM nozzle cracks initiated
1/26/90 - 7/3/90 - 6 RFO
8/31/91 - 11/7/91 - 7 RFO
3/1/93 - 4/30/93 - 8 RFO
10/1/94-11/14/94 - 9 RFO
1994-1996 - Crack propogation to through wall leak
Industry issue. Alloy 600 material heat M3935 has apparent higher susceptibility - nozzles 1- 5
Replaced 23 CRDM flange gaskets (gasket leaks)
Replaced 15 CRDM flange gaskets (gasket leaks)
Replace 14 CRDM flange gaskets - Vent flange leaking at SG 1-2 has BAC
Replaced 8 CRDM flange gaskets (gasket leaks)
CRDM 37 flange has 2 small irregularities on face. CRDM 69 flange has slight erosion in outer gasket groove
RPV head flange had excessive boron. Boron flow ran down flange & closure bolts
Justification: Inspection using high powered cameras preclude the need for inspection ports
Poor access to the RPV head & CRDM nozzles. Inspections not 100%
Inspection openings would allow a thorough inspection and cleaning of the head
Modifications
3/19/90 - RFA requests mod. to install holes in service structure for cleaning and inspection
3/21/90 - MOD 90-0012 initiated to install multiple access ports in the closure head to permit cleaning and inspection of the reactor head
9/27/93 - MOD 90-0012 Cancelled
5/27/94 - Initiated MOD 94-0025 to install service structure inspection openings
3/21/90 - Boric acid has leaked from the CRD flanges and accumulated on the reactor head
Justification: Cleaning RPV head during last 2 outages was successful without access ports
Ongoing industry concern involving corrosion of Inconel 600 CRDM reactor vessel nozzles
5/27/94 - All B&W plants except DB and ANO-1 have installed this modification



1991- first CRDM nozzle leak in industry
4/5/94 - Believed that RPV head visual inspection is not a commitment to the NRC, but recommended
3/5/90 - DB receives IN 90-10 Primary Water SCC of Inconel 600
5/1/93 - BAW-10190P issued to visually inspect nozzles
3/17/94 - TERMS committment A16892 requires visual inspection of RPV head at refueling
1/5/95 - IN 86-108 Sup.3 Degradation of RCS Pressure Bndry Resulting from BAC
2/29/96 - DB responds to SER 20-93. Efforts via the B&WOG BAW-10190P Safety Evaluation for B&W Design RPV Head CRDM Nozzle Cracking credited.
5/8/96 - White paper dealing with CRDM cracking but not wastage distributed to Sr. Mgmt
Inspection performed by 1st time individual
No head inspection conducted during outage
11/14/94 - Did not identify through wall crack/leak during outage
4/8/96 - 6/1/96 - 10 RFO
6/1/96 - Did not identify through wall crack/leak during outage
4/10/98 - 5/23/98 - 11 RFO
5/23/98 - Did not identify through wall crack/leak during outage
All CRDM flange gaskets had been replaced by the end of outage. 9 gaskets replaced
PCAQR 98-649& 767 Found boric acid residue incl. several "fist" size clumps on head. Ind. CRDM 31 had past leakage. No gasket repairs
Boric acid and rust accumulation on RV head, CRDM 67, Flange not leaking
Evidence of rust colored boric acid deposits coming out of weep holes
3/7/95 - MOD 94-0025 Tabled at the PRG meeting
4/4/95 - MOD 94-0025 Decision tabled at PRG. Presented for inclusion in 10RFO
6/15/95 - MOD 94-0025 discussed at WSC. Held open for more info
1/7/97 - MOD 94-0025 schedule change to 12RFO approved at PRG Boron eaks discussed
2/20/97 - MOD 94-0025 schedule change to 12RFO approved at WSC
9/3/97 - MOD 94-0025 reclassified to O&M from capital
25% of B&W plants do not have additional inspection openings at this time
MOD 94-0025 planned for cycle 11
Design Engineering Mngr: section of the RPV head cannot be inspectd cleaned. Risk to system


NRC staff assement that PWSCC is not an immediate safety concern for vessel head penetrations
4/1/97 - DB recieves GL 97-01 Degradation of CRDM/CEDM and other penetrations
7/28/97 - BAW-2301 Justification and schedule for integrated RPV head penetration inspection
12/6/99 - Assume integrated program provides acceptable basis for evaluating head penetrations
4/1/01 - B&WOG Materials committee issue RV head nozzle and weld safety assessment
7/11/01 - MRP Plant-specific data updated. boric acid attributed to flange leak
8/7/01 - NRC Bulletin 2001-01 cicumferential cracking of RPV head penetration nozzles
9/1/98 - 9/9/98 - RC-2 body-to-bonnet nut #2 & #4 found missing (BAC)
Red/brown boric acid leakage from weep holes blocking inspection ports - cleaned to allow inspection.
5/23/98 - Head returned to operation with Boric Acid left on
10/1/99 - Boric Acid control procedure change due to RC2 event
4/24/99-5/10/99 - Mid-cycle outage to locate source of RCS unid. leakage and fix valves
1999 (est.) Noteworthy Wastage at nozzle 3 initiated on reactor vessel head
4/1/00 - 12RFO Begins
4/6/00 - CRDM 11 and 31 believed to be major sources of leakage
10/17/98 - remains of carbon steel nut found when RC body-to-bonnet loc. 4 removed
Pressurizer code safety valve leakage to CTMT atmosphere. CAC cleaning and RE4597 low flow alarms.
CRDM nozzle flange at 11 and 31 have pitting near gasket. 5 gaskets repaired.
11/19/98-4/21/99 - CAC cleaning frequency increased to about 3 per month due to boron
5/23/99 - RE4597BA filter changes frequent due to low flow. All filters contain Boron crystals
7/30/99 CTMT rad monitor filters analyzed - contain iron oxide from corrosion
Boric acid at 4 locations near nozzle 3 prevent effective use of inspection camera
Adjunct report indicates from a steam leak
9/1/98 - MOD 94-0025 recommended for approval to 13RFO at PRG
There is less than 50% accessibility to RPV head. MOD resolves PCAQ 96-055. MOD addresses plant life extension. Committee concurred that MOD should be approved but discussed various issues related to scheduling in 12RFO.


Radiation Monitors and Containment Air Coolers
12/29/00 - CAC cleaning frequency increased to about 8 weeks due to boron
4/23/01 - RE4597BA filter changes frequent due to low flow. All filters contain Boron crystals
10/20/01- RE4597BA has abnormally dark brown discoloration
10/22/01 - Iodine charcoal filter RE4597BA saturated in 19 hours (frequency had been rising)
Significant boric acid and iron oxide corrosion product in containment
10/27/01 &many - RE4597AA/BA had boric acid and crystals and was rust colored
11/2/01 - RE4597AA/BA charcoal filters replaced with blanks due to iodine saturation
Disconnect between ISI and boric corrosion control
10/25/01 - Calculated RCS unid. leakage increasing following 10/20 downpower
11/3/01 - Airborne activity & RCS unid.lk. in CTMT high after down power on 10/19 and 11/17
11/12/01 Increase in RCS unidentified leakage observed
Boric acid control form documents boric acid. Boric acid corrosion inspection not performed.
4/7/00 - Boron found in CRDM nozzle area and top of insulation - assume CRDM leak at flange 3
4/12/00 - Recommend to remove as much boron as Pos., contact B&WOG to justify not removing all deposits
5/16/00 - Did not identify through wall crack/leak or reactor vessel head degradation during outage
5/18/00 - End 12 RFO - Boric Acid not all removed fom center of head
10/19/01-10/20/01 - Outage to work on secondary plant
11/17/01 - CTMT walkdown @ 55% power did not reveal sources of RCS unidentified leakage
Nozzle 3 underside caked with red boric acid deposits
Solid rock hard boron found on head in southeast quadrant- Rest of boric acid on head is loose. Pressure washer used to clean some
9/1/98 - MOD 94-0025 recommended for approval to 13RFO at WSC
9/7/00 - MOD 94-0025 recommended for deferral to 14RFO at PRG
Access to RPV head restricted by Boric acid and insulation
Engineers voice comfortable with 13RFO schedule, RCS leakage source known and not on head, we have inspected any boric acid sitting on the head, dry condition and corrosion attack not an issue, delay to 13RFO does not add risk, however aging is a factor and the MOD should be addressed.


All B&W plants have experienced nozzle cracking
As of 2/02 6.5% of EDF nozzles inspected have cracks
12/15/01 - Completed T_{ave} reduction from 582 to 574
2/16/02 - Begin 13 RFO
2/21/02 - Found 3-4" hard baked boron 25% and 1-2" deep 75% around flange
2/27/02 - #3 CRDM nozzle revealed through wall axial flaws in weld region
2/28/02 - Indications of cracks found on 5 nozzles
3/8/02 - Discovered significant degradation of pressure vessel at nozzle 3
No CRDM flange leaks
Significant boric acid deposits found in southeast quadrant
75 gallons of wet boric acid removed from CAC plenum

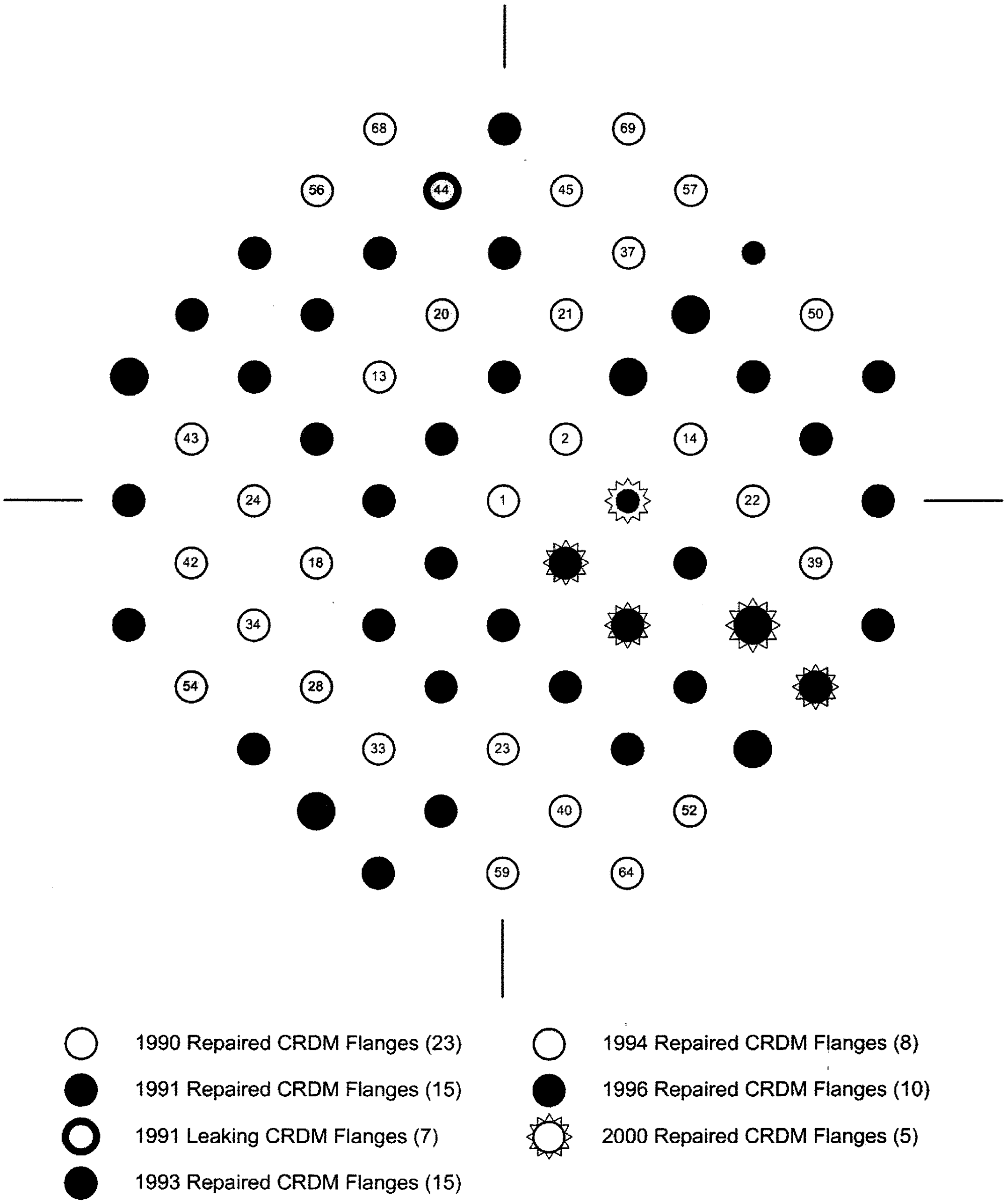


Figure 28. Leaking Flanges Found and Repaired During Each Outage

Figure 29. Flange Leakage with Stalactite Formation from Insulation and Stalagmite Formation on top of Reactor Vessel Head (8RFO)

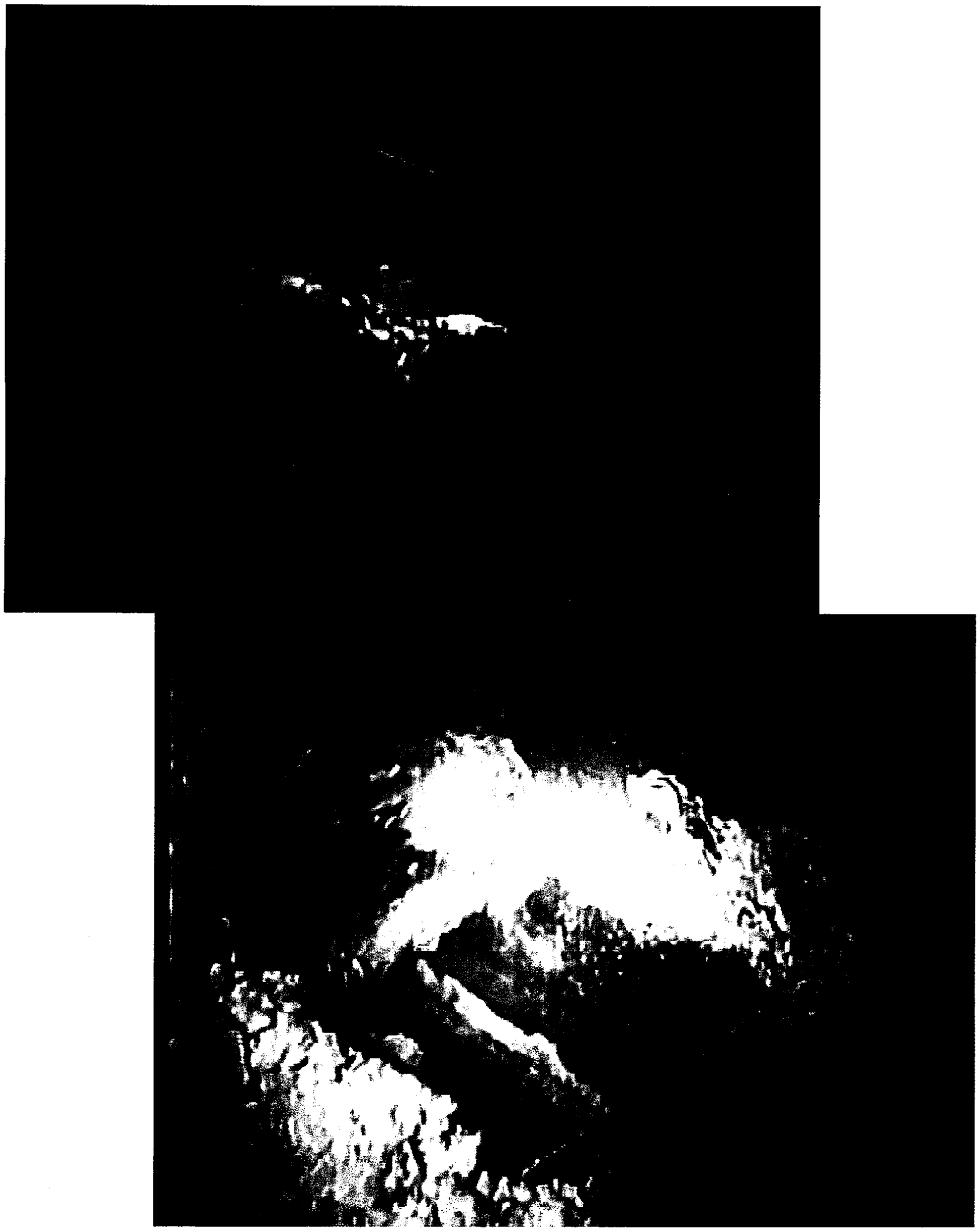


Figure 30. Flange Leakage Crusted On Side of Nozzles and Stalactites from Gaps in Insulation (8RFO)

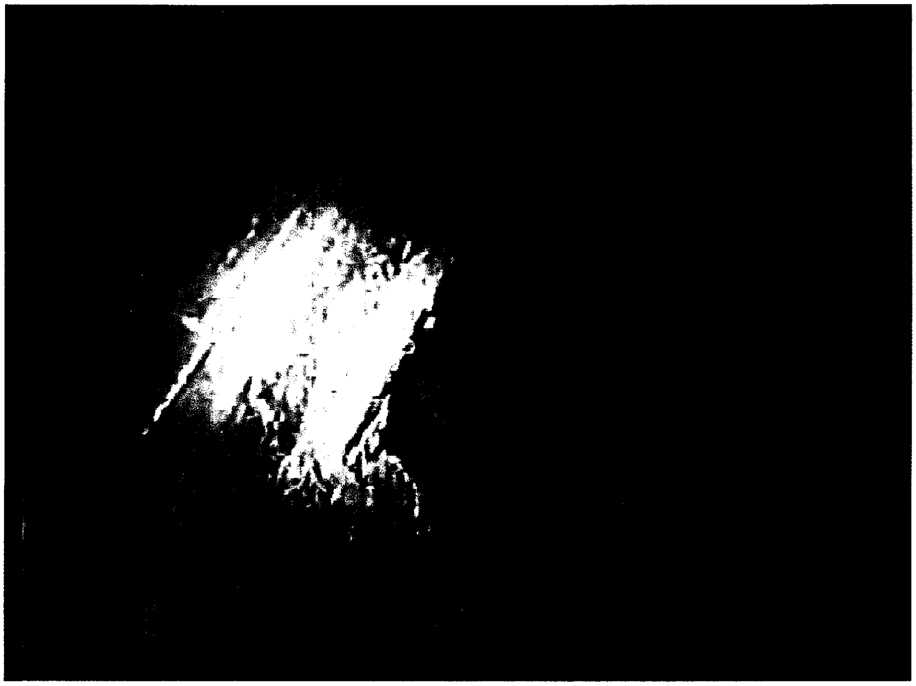


Figure 31. Reddish Brown Boron Deposits Crusted on Side of Nozzle (8RFO)

Figure 32. Boron Deposits – Source Unclear (8RFO)

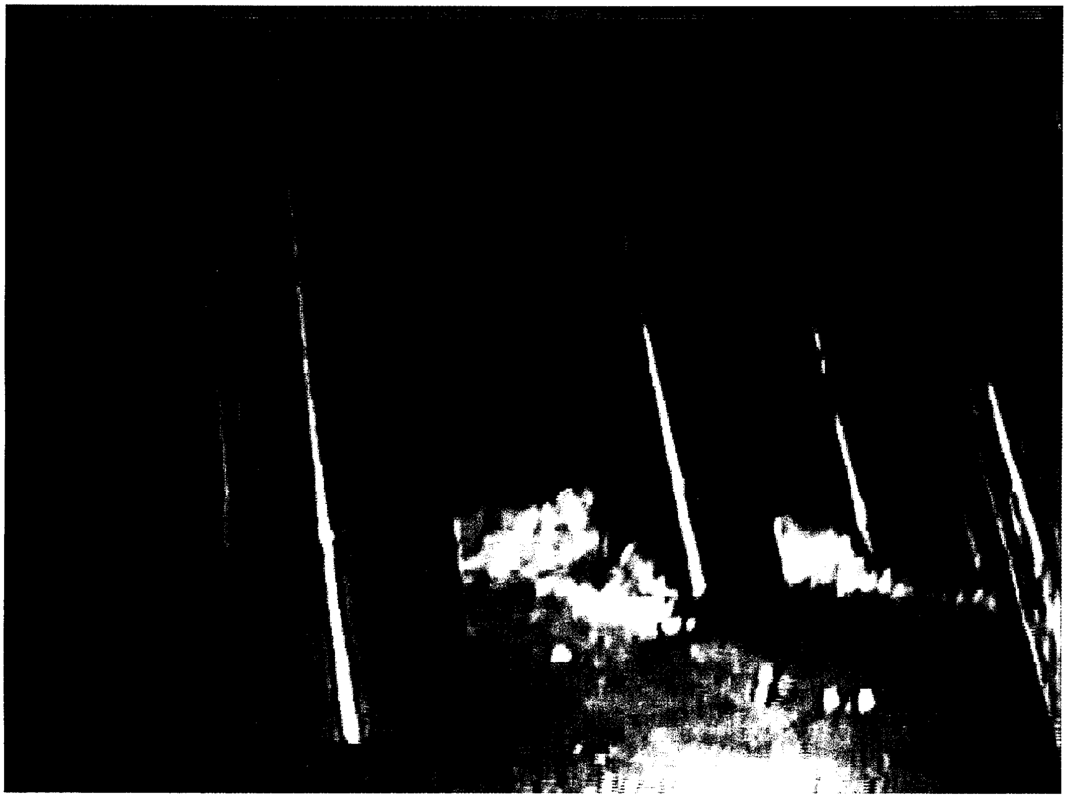


Figure 33. North Side of Reactor Vessel Head (10RFO)

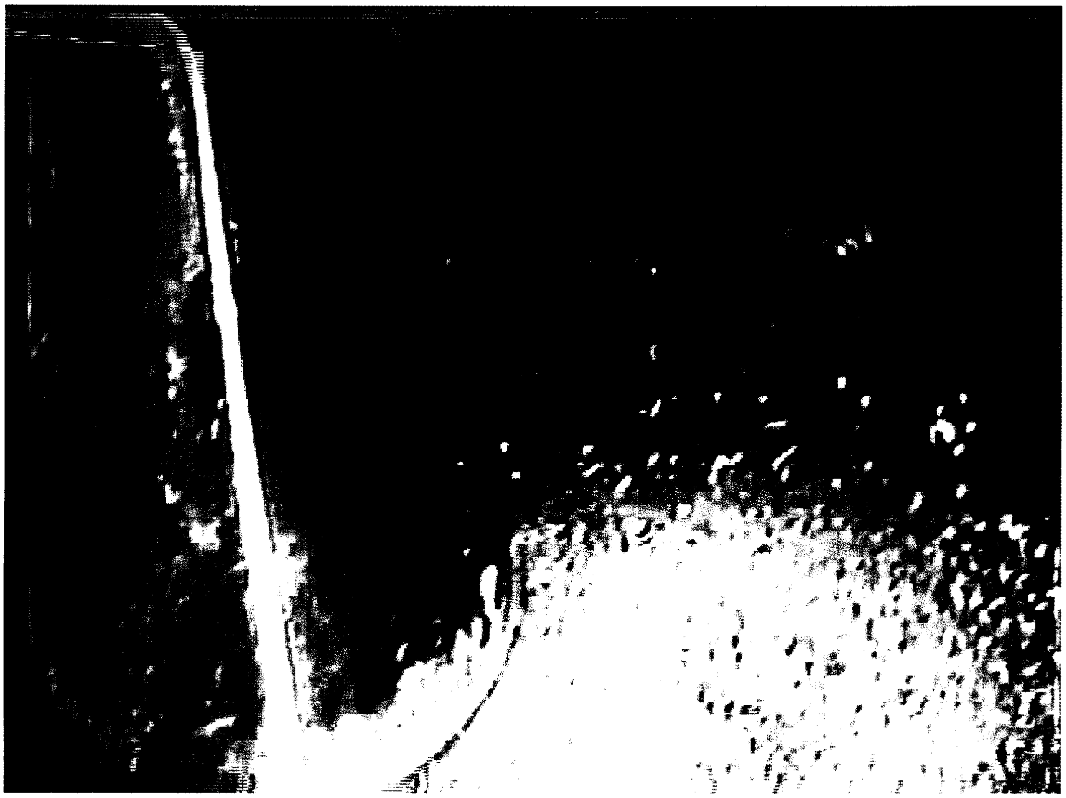


Figure 34. Boron Deposits Near Top of Reactor Vessel Head (10RFO)

Figure 35: Typical Deposits for Periphery (10RFO)

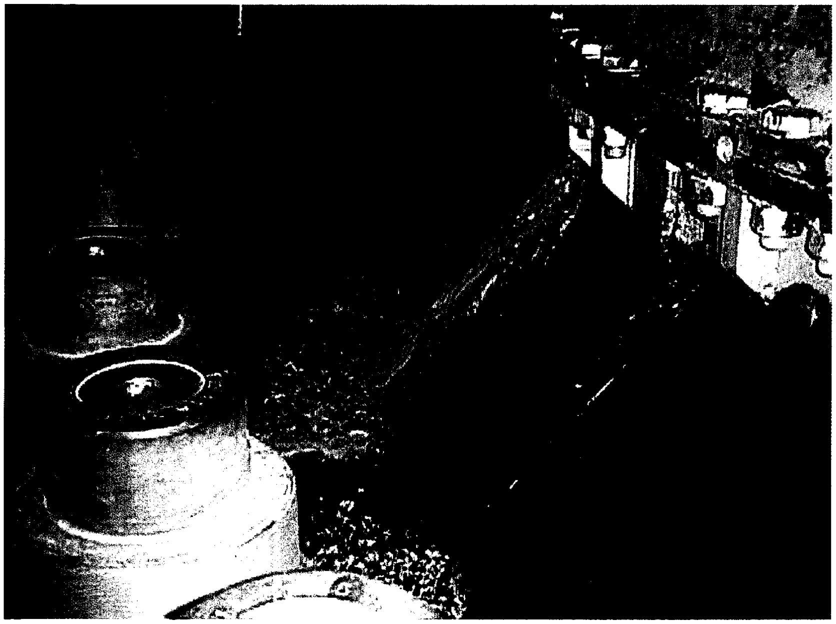


Figure 36. Red Rusty Boric Acid Deposits on Vessel Flange at 12RFO

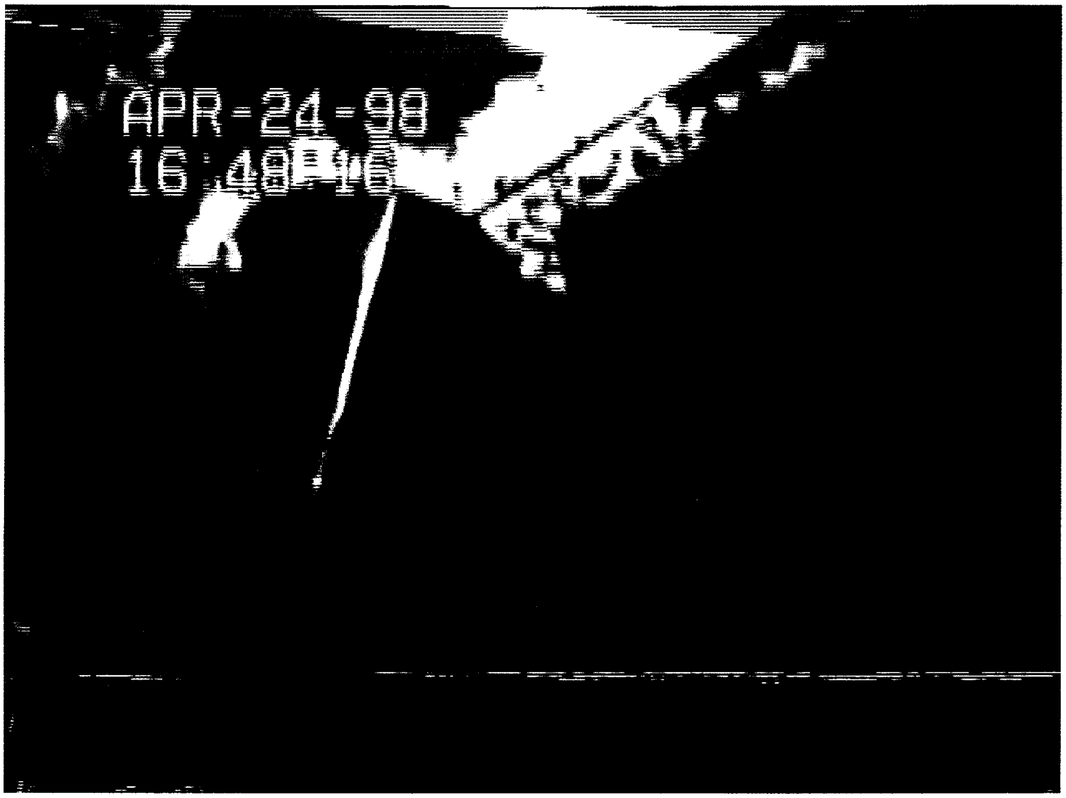


Figure 37. Boron Piled Under the Insulation (11RFO)

I HAVE NO PICTURES FROM 2000 OUTAGE.

Iron rich deposits on

Figure 38. Boric Acid Deposits with Heavy Iron Concentration on Underside of Nozzle 3 (13RFO)

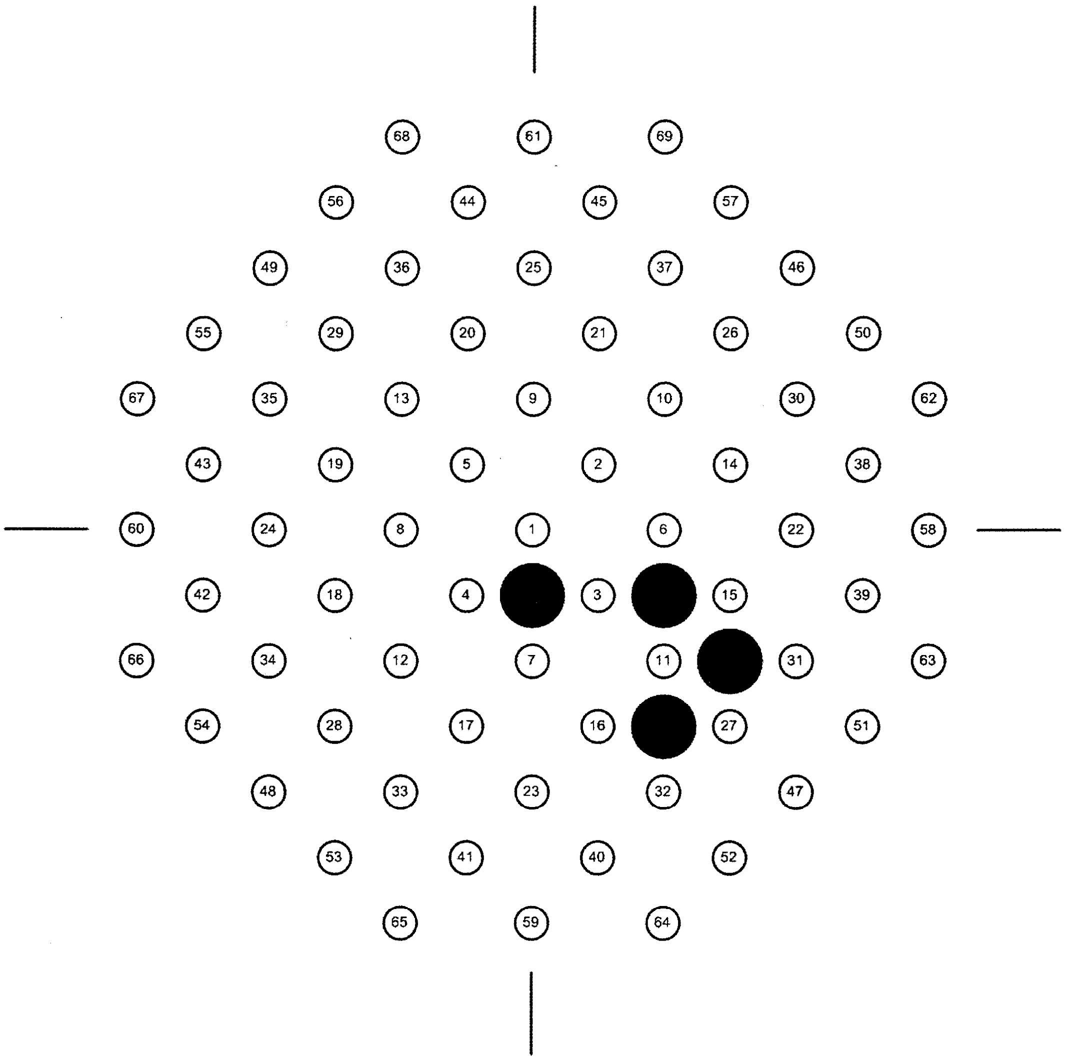
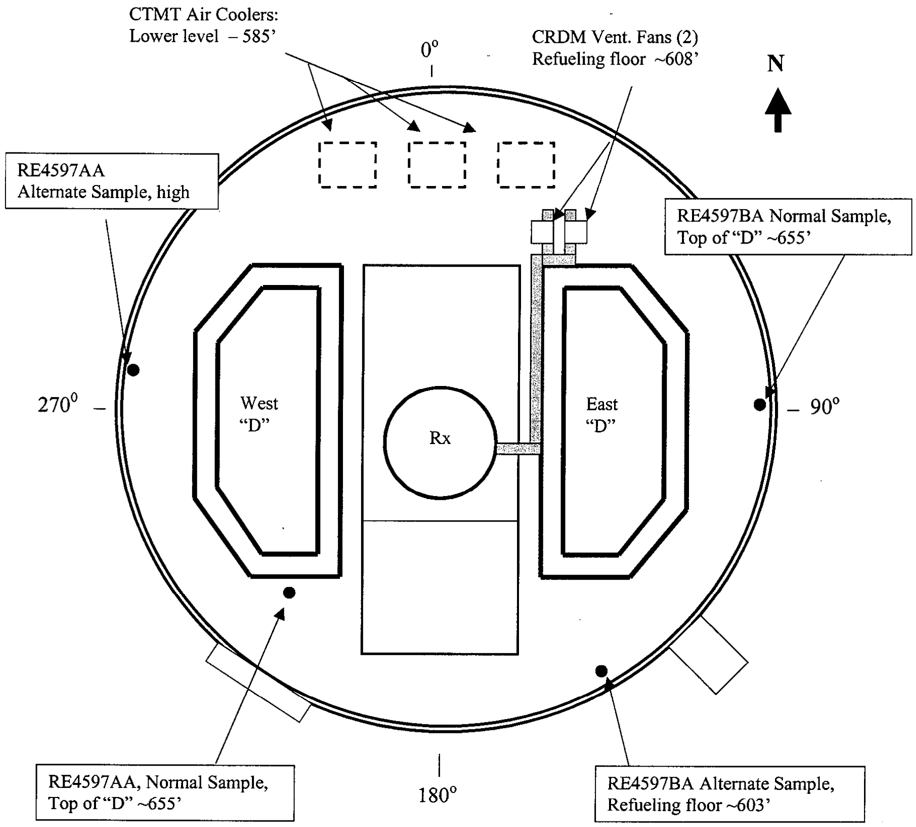


Figure 39. 2000 Interferences with CRDM Flange Inspection



(not to scale)

Figure 40. RE4597 Sample Location

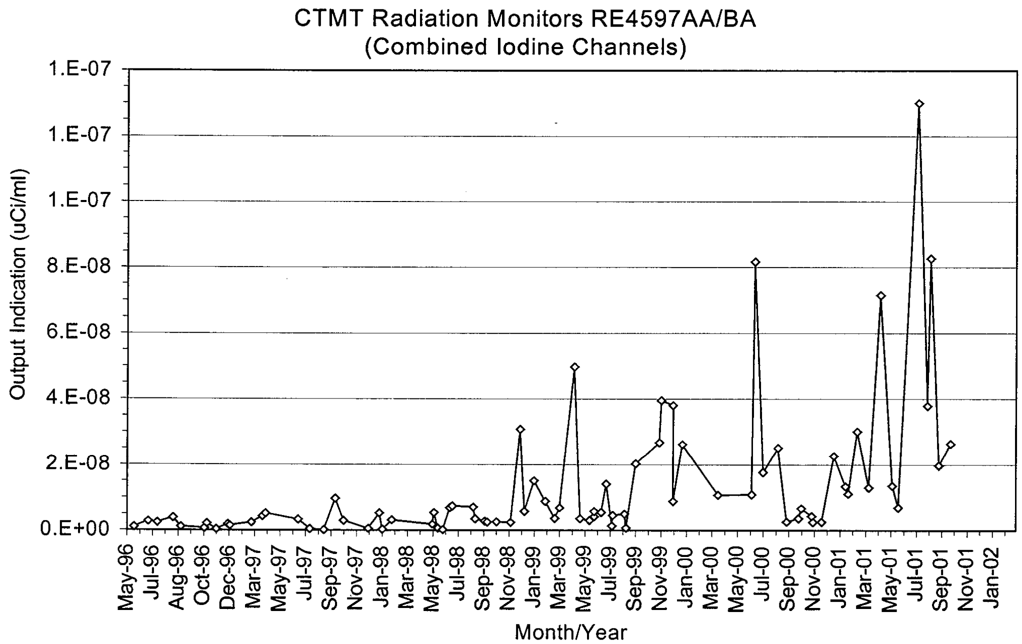


Figure 41. CTMT Radiation Monitors RE4597AA/BA
(Combined Iodine Channels)

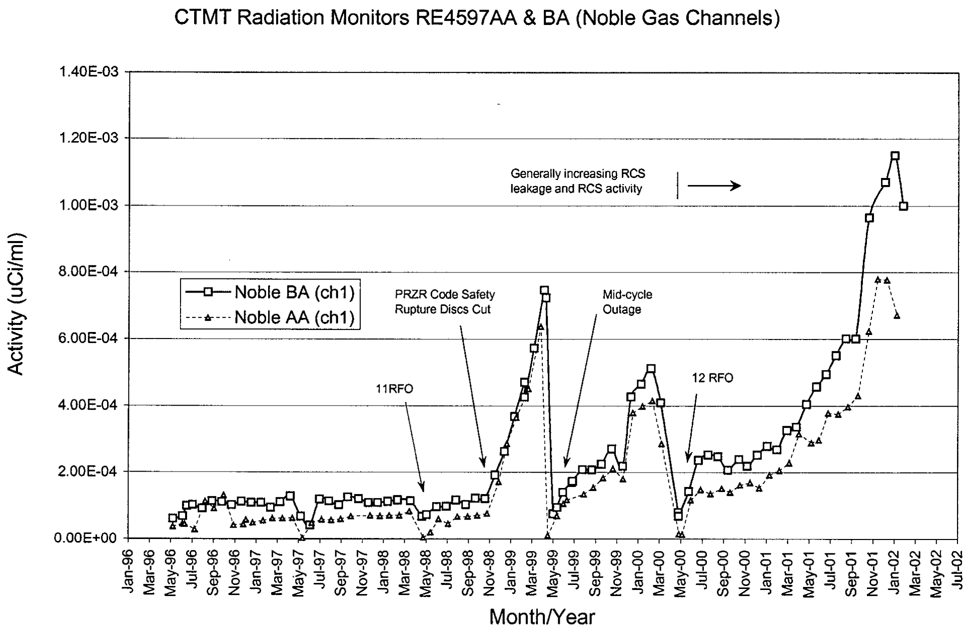


Figure 42. CTMT Radiation Monitors RE4597AA & BA
(Both Noble Gas Channels)

Source: EPRI/DEI

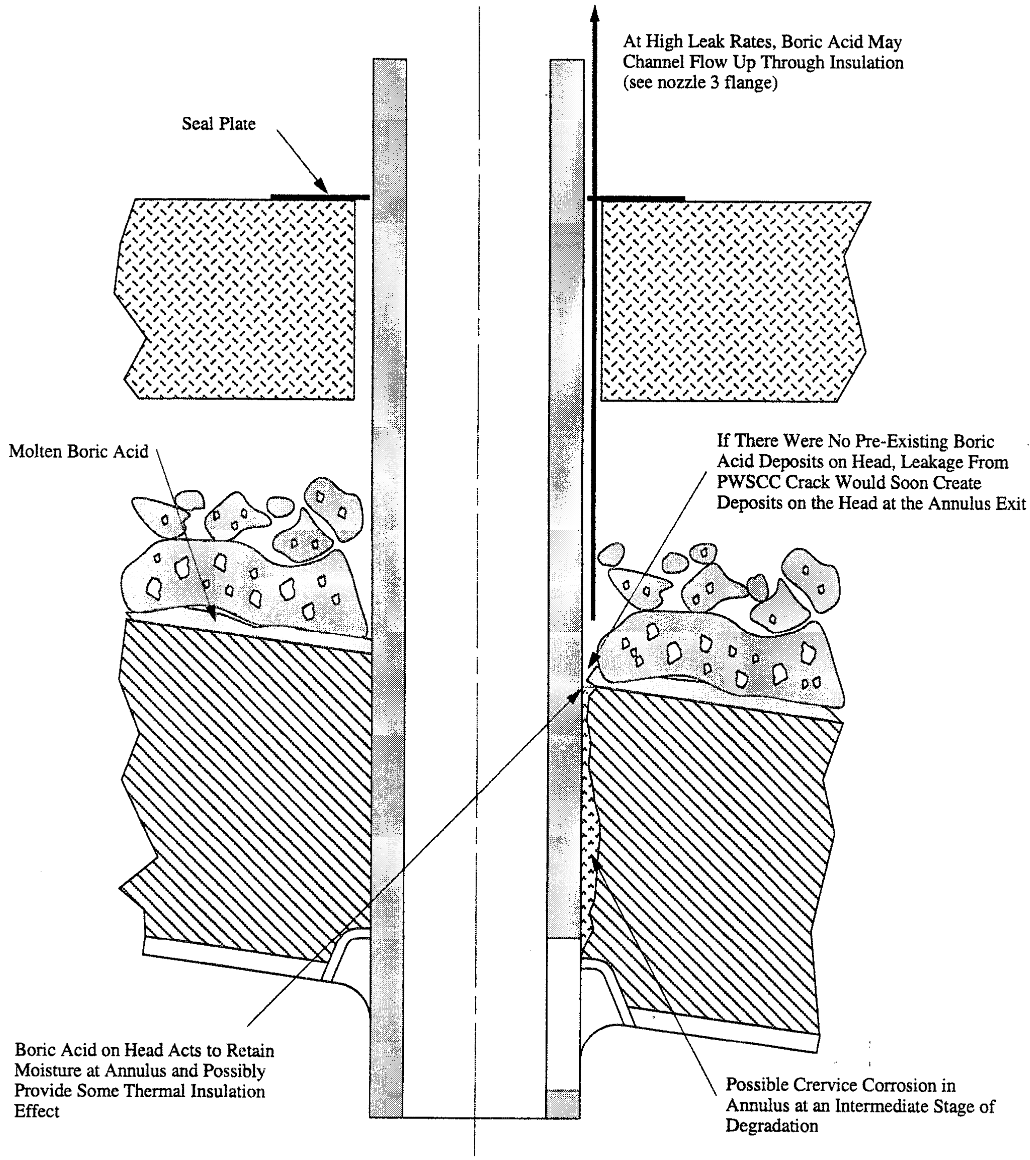


Figure 43. Potential Effects of Boric Acid Deposits on Vessel Top Head Surface.

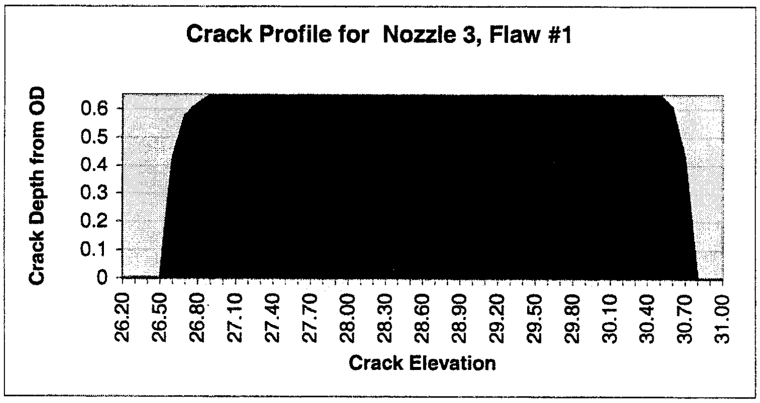


Figure 44. Crack Profile for Nozzle 3, Flaw #1

Attachment 1. Potential Evidentiary Request List

1. Metallurgical Samples From Nozzle 3
It is desirable to obtain the remaining section of Nozzle 3 from the elevation of the cut to the bimetallic weld to the CRDM nozzle flange. Note: *The specimen should not be cleaned prior to input from the Root Cause Team.* This specimen may be used for the following examinations and tests:

    a. Examination of external surface of nozzle looking for evidence of flow up through the annulus. Include high quality photographs

    b. Metallurgical examinations including chemistry, microstructure, etc.

    c. Hardness traverse through the wall thickness (similar to Oconee 3)

    d. Tensile properties at three locations through thickness (similar to Oconee 3)

    e. Others as identified

2. Non-destructive Inspections of Top Head Surface at Nozzle 3 Location
It is desirable to perform several non-destructive inspections of the top head surface:

    a. Priority 1: High quality photographs of the corroded areas adjacent to Nozzle 3. The purpose of the photographs is to show:

        - General extent of corrosion
        - Evidence of flow across clad and base metal surface
        - Evidence of possible impingement of steam jet on surfaces

    b. Priority 2: Casting impression of cavity. The purpose of the impression would be to further aid in identifying the boric acid corrosion mechanisms such as

        - Volume loss
        - Location of volume loss relative to leak
        - Undercutting of low-alloy steel at cladding interface (potential)

3. Specimens From Remaining Material at Nozzle 3 Location
It is desirable to remove specimens of the unsupported J-groove weld and adjacent areas of the unsupported clad. The priorities for these examinations are as follows:

    a. Priority 1: The section of the J-groove containing the downhill (≈0°) crack should be removed. This specimen would be used to:

        - Determine the crack geometry (single crack, branches, etc.)
        - Determine the crack width
        - Assess flow induced erosion on the crack faces
        - Assess the potential for the crack to have started at the J-groove weld surface
        - Assess the potential for weld defects
        - Assess the clad thickness and integrity