Integrity Assessment for Reactor Vessel Head Penetration Nozzles at B&W-Design Plants

Presented by

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Attachment 5

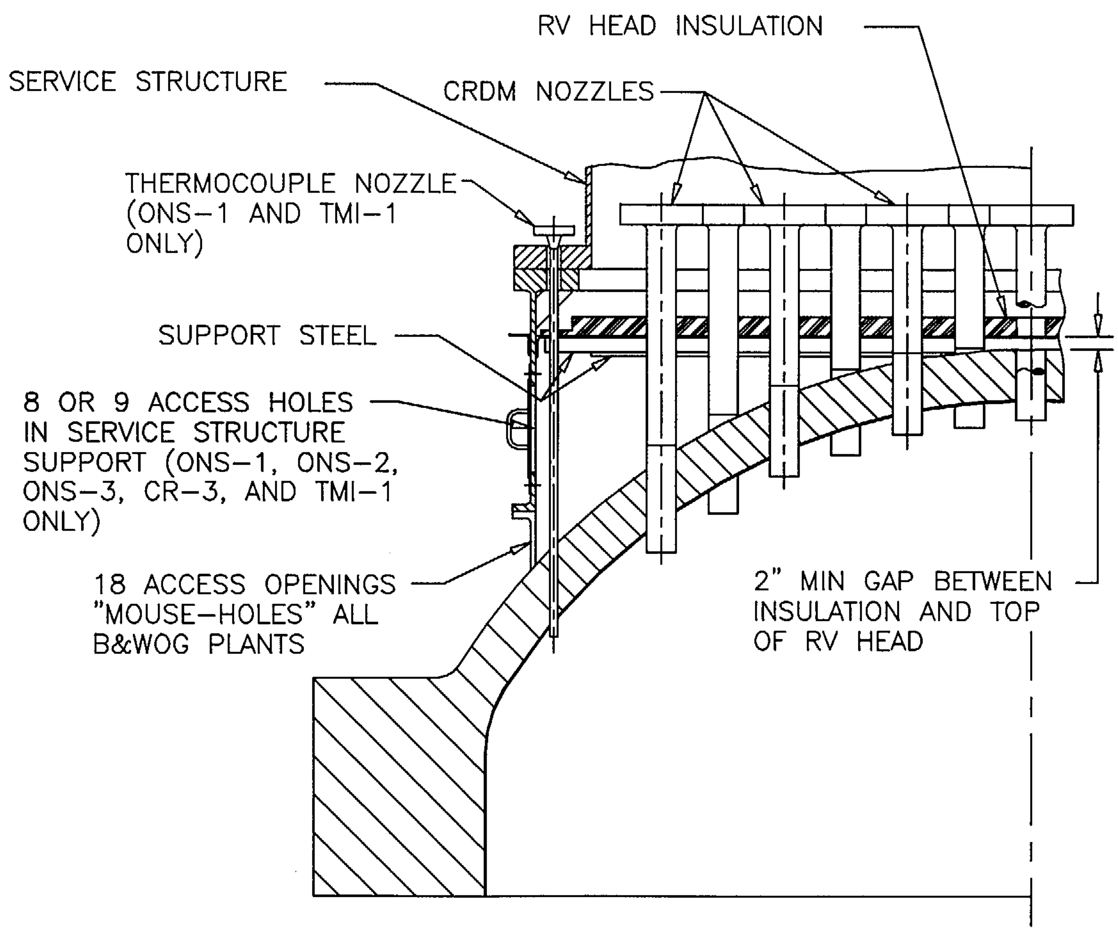
Integrity Assessment for Reactor Vessel Head Penetration Nozzles

- Introduction
- Summary of Recent Cracking Incidents
- Evaluations of Cracking
- Assessment of Operating Plants
- Summary and Conclusions

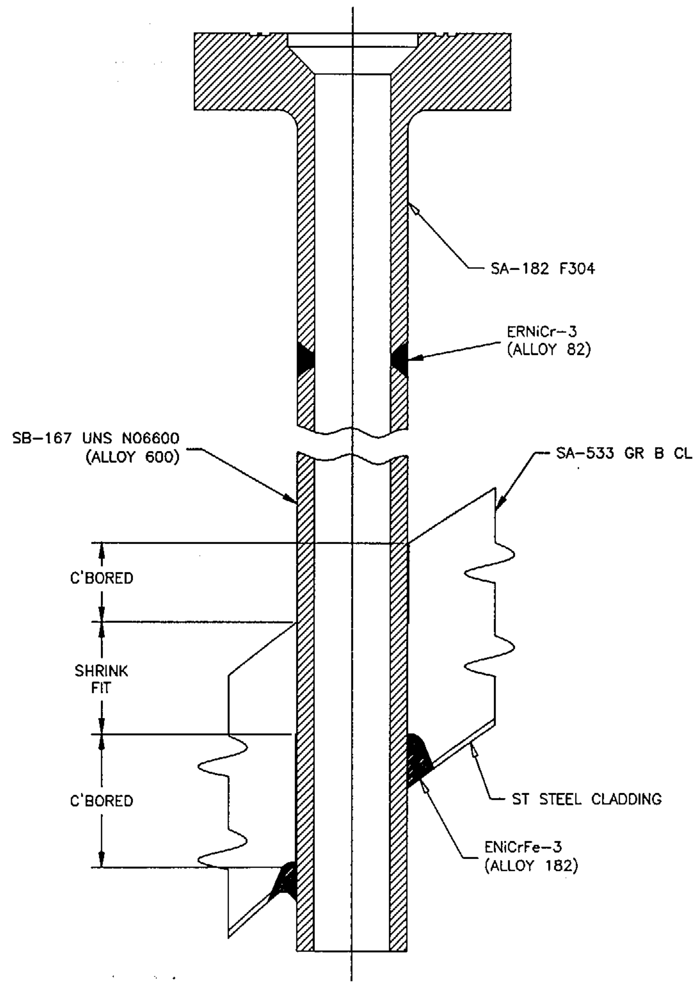
Introduction

- ID-initiated CRDM nozzle cracking first observed at Bugey-3 (1991)
- Recent J-groove weld and OD-initiated cracking observed at B&W-design plants
  - ONS-1 (November 2000)
  - ONS-3 (February 2001)
  - ANO-1 (March 2001)
- This assessment prepared to update existing work to cover these new forms of cracking

Side View Schematic of B&W-Design Reactor Vessel Head, CRDM Nozzles, Thermocouple Nozzles, and Insulation



Schematic View of B&W-Design CRDM Nozzle Area



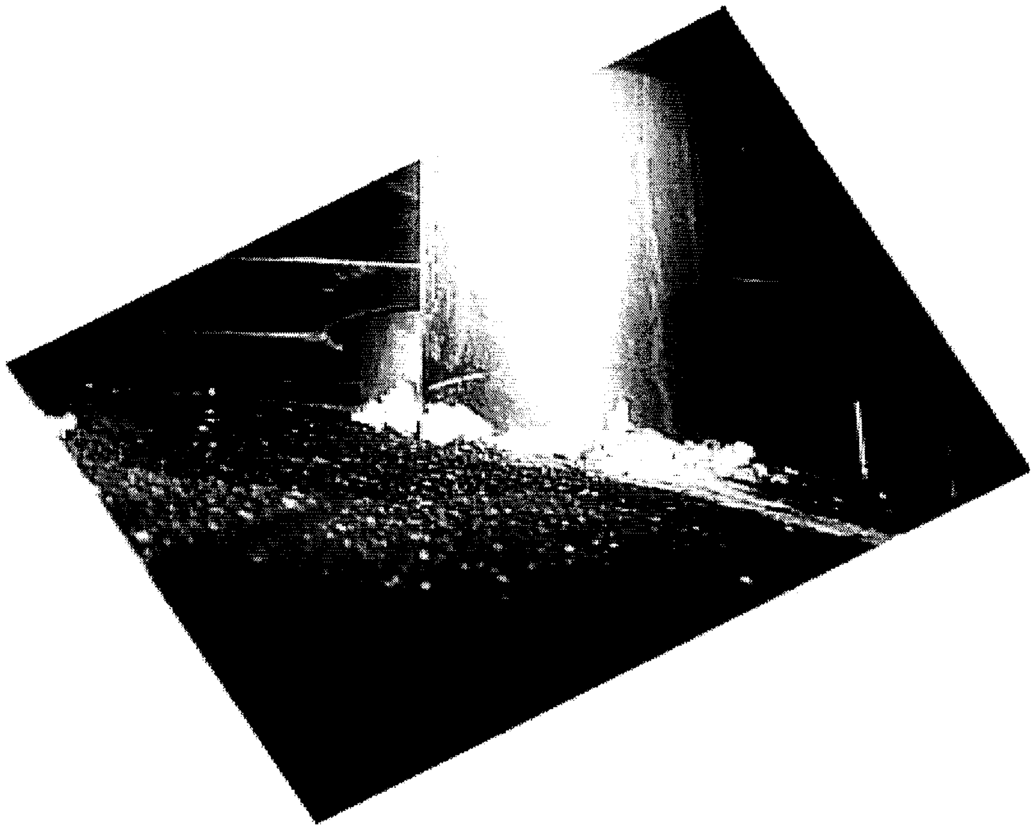
Issue Background

- Bugey-3 cracking characterized as:
  - ID-initiated, through-wall axial flaws
  - Through-wall flaw initiated OD circumferential flaw in RV head penetration crevice
- Lack of fusion detected in attachment welds at Ringhals-2 (1992)
- Industry safety assessments prepared (early 90's) for these types of cracking

Issue Background (Cont.)

- Generic Letter 97-01 issued (1997)
  - Industry responses prepared
  - B&WOG response included an integrated plan
- Materials Reliability Program (MRP) initiated (1999) to address issue on industry-wide basis

ONS-1 RV Head Showing Boric Acid At CRDM Nozzle 21



ONS-1 RV Head Showing Boric Acid At Thermocouple Nozzle

Summary of Recent Cracking Incidents

ONS-1

- All eight thermocouple nozzles contained flaws predominantly axial in orientation
  - Five nozzles identified as leaking
  - ID cracking observed on all eight nozzles
  - Cracking penetrated into all eight nozzle welds
- CRDM nozzle 21 did not contain ID flaws
  - Flaws in weld material, predominantly axial/radial in orientation, identified as leak source
  - Flaw propagated through the weld area along the nozzle OD

Summary of Recent Cracking Incidents (Cont.)

ONS-3

- Nine CRDM nozzles found leaking
  - Numerous axially oriented flaws identified
  - OD-initiated circumferential flaws (relatively deep and below the weld) identified on four nozzles
  - OD-initiated circumferential flaws (above the weld and up to through-wall) identified on two nozzles
  - Some weld cracking also identified

Summary of Recent Cracking Incidents (Cont.)

<u>ANO-1</u>

- CRDM nozzle 56 found leaking
  - No ID axially oriented flaws identified
  - One OD-initiated circumferential flaw that turned axial identified
  - Flaw propagated through the weld area along the nozzle OD

Evaluations of Cracking

CRDM Nozzle ID Surface Evaluations

- Stress analyses show that hoop stresses are controlling
  - Predominant flaws expected to initiate and propagate axially
- Service experience confirms this
- Safety assessment (1993) shows that it would take at least six years for a flaw to grow through-wall and extend to two inches above the weld

Evaluations of Cracking (Cont.)

CRDM Nozzle OD Surface Evaluations

- Stress analyses show that axial stresses are tensile in the crevice between the nozzle and the head
- Stresses support development of OD flaws anywhere along the circumference
- Service experience confirms this
- Recent safety assessment shows:
  - A 180° OD flaw would take over three years to grow through-wall
  - An additional four years to grow another 25% around the nozzle
  - Precludes gross net-section failure using a safety factor of 3 with additional margin

Evaluations of Cracking (Cont.)

CRDM Nozzle OD Surface Evaluations

- Stress analyses show that hoop stresses are controlling below the weld on downhill side, but similar on uphill side
- Stresses support development of axial flaws on downhill side
- However, circumferential flaws could occur on uphill side
- Service experience tends to confirm this, although circumferential flaws have also been observed on downhill side
- Recent safety assessment shows that it would take approximately four years for a flaw to grow through-wall

Evaluations of Cracking (Cont.)

CRDM Nozzle Weld Evaluations

- Stress analyses show that hoop stresses are controlling
  - Predominant flaws expected to initiate and propagate axially through the weld in a radial direction from the nozzle
- Service experience confirms this
- Available crack growth rates indicate that crack growth through the J-groove weld would be rapid

Evaluations of Cracking (Cont.)

<u>Leakage Assessment:</u>

- Leakage assessments performed for axial flaws in 1993
- Additional efforts performed to address recent observations
- Annular gaps develop between the CRDM nozzle and the RV head in the RV head penetration
  - Minimum radial gap is 0.001 inches for both the center nozzle and the outermost nozzle designs

Evaluations of Cracking (Cont.)

<u>Leakage Assessment:</u>

- Axial or circumferential through-wall flaws expected to initially produce very low leakage rates
  - As flaws continue to grow, leakage rates will increase
  - Leakage will be observed on the RV head
- Weld flaws envisioned to break the surface as pinhole type cracks or as tight PWSCC cracks and therefore result in very low leakage rates

Evaluations of Cracking (Cont.)

Wastage Assessment:

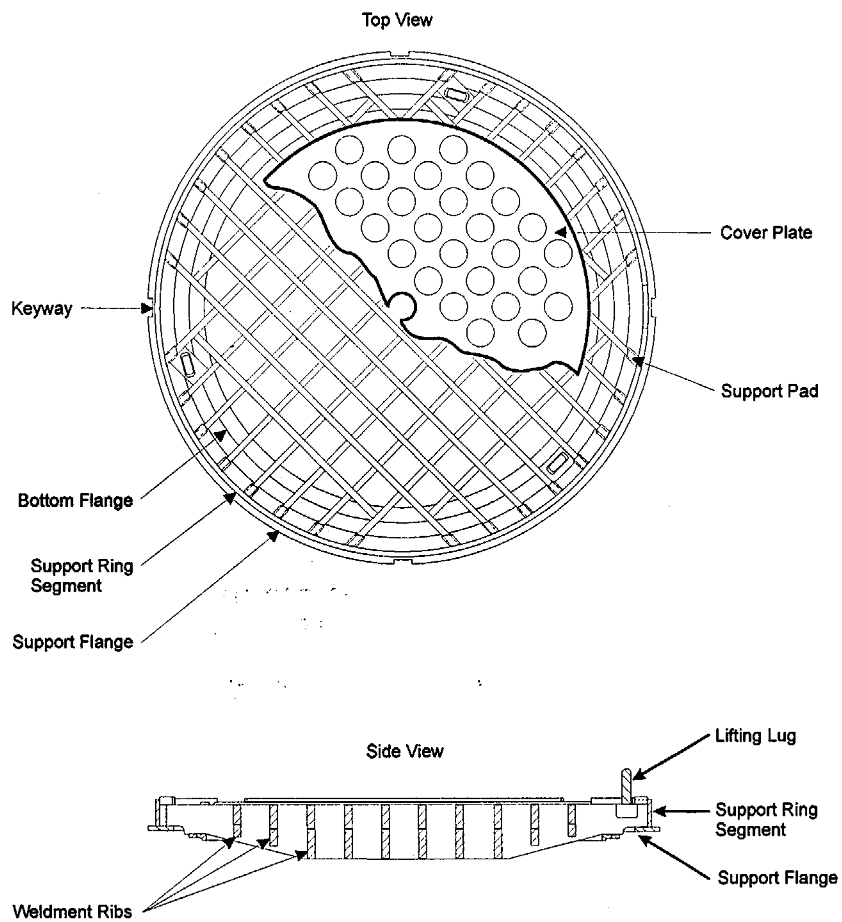
- Cracks resulting in significant leakage could cause corrosion of the RV head
- Wastage assessment performed in previous safety assessment (1993)
- Cracks resulting in significant leakage could cause corrosion wastage of RV head
  - Safe operation of RV head, from ASME Code evaluation standpoint, for at least six years

Evaluations of Cracking (Cont.)

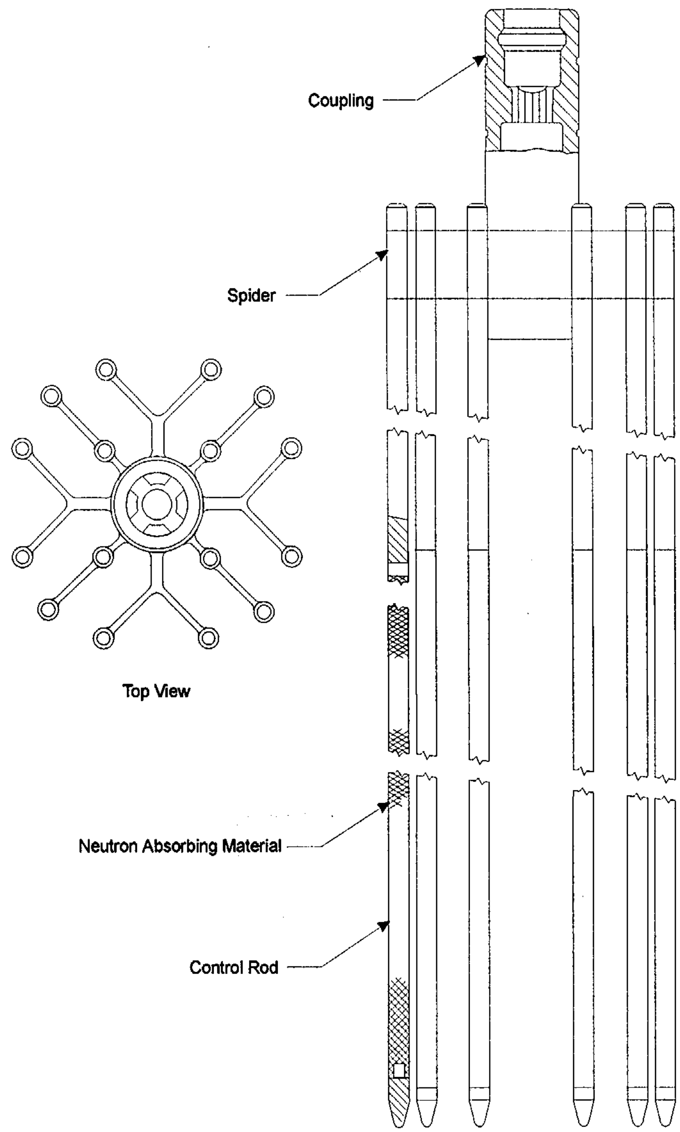
Loose Part Assessment:

- Circumferential cracking of CRDM nozzle below the weld could link with two or more axial cracks and form a loose part.
- A loose part could potentially be transported to three places:
  - Onto the plenum cover plate
  - Through the RCS piping and into the steam generator
  - Into the column weldments

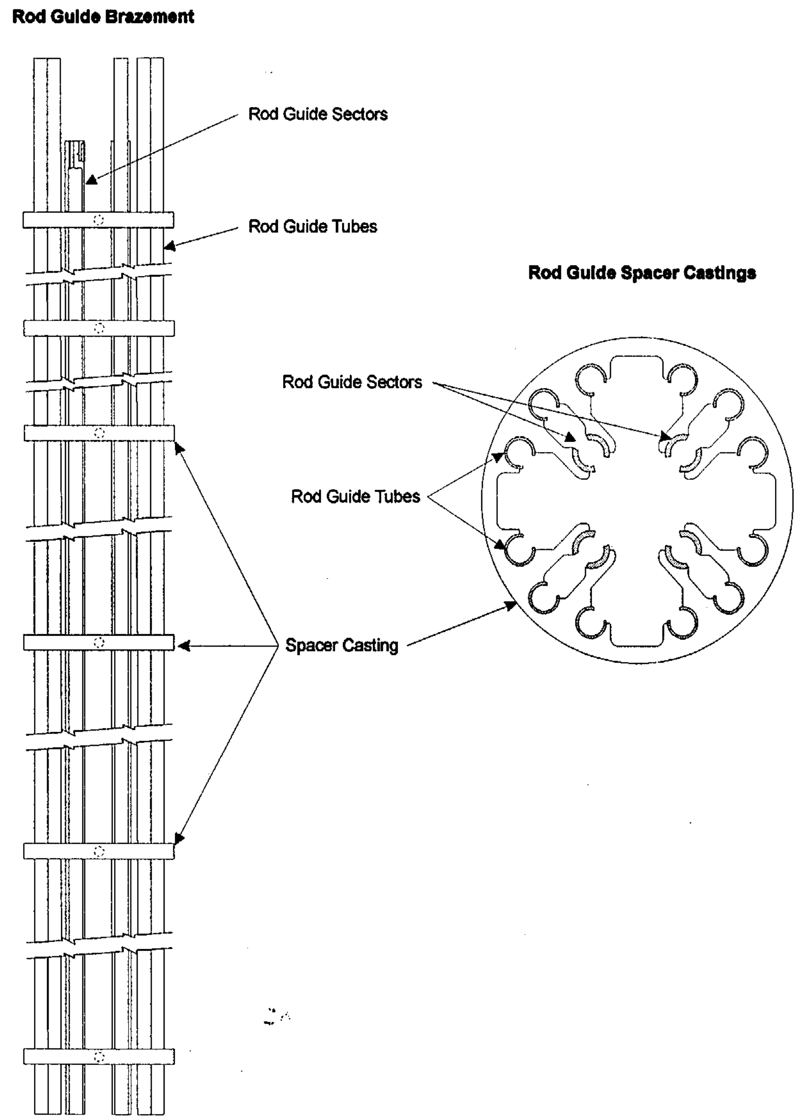
Plenum Cover Assembly.



Control Rod Spider Assembly.



Control Rod Guide Brazement Assembly



Evaluations of Cracking (Cont.)

Loose Part Assessment:

- Deposited onto the plenum cover plate
  - No impact on safety or plant operation
- Transported through the RCS piping and into the steam generator
  - No safety concern
  - Potential equipment damage (S/G tube ends)
- Transported into the column weldments
  - Potential safety concern
  - Could preclude complete control rod insertion

Evaluations of Cracking (Cont.)

Loose Part Assessment:

- ONS-3 experience indicates that circumferential and axial cracking below the weld is accompanied by through-wall axial cracking above the weld
- Extensive examinations performed worldwide indicate that predominant cracking orientation is axial
- High probability that detectable leakage would precede development of a loose part

Evaluations of Cracking (Cont.)

Safety Analysis Review:

- Existing plant LOCA and Non-LOCA analyses reviewed
- LOCA analyses postulate break sizes from 0.01 ft^2 to 14.2 ft^2 in area in any RCS pipe
  - CRDM nozzle catastrophic failure bounded by these analyses
  - Favorable from core cooling standpoint (i.e., no ECCS fluid is bypassed out of the break)

Evaluations of Cracking (Cont.)

Safety Analysis Review:

- Non-LOCA analyses evaluate consequences of a control rod ejection accident (CREA)
- Included in individual plant FSAR
- Typical analysis methodology uses core average power response
  - Calculation results sensitive to the total amount of reactivity inserted, not the number of control rods ejected
  - Existing analysis remain bounding for any number of ejected control rods, provided total reactivity inserted into core remains less than values analyzed and reported in FSAR

Assessment of Operating Plants

- Axial and circumferential CRDM nozzle cracking cannot be ruled out
- Cracking of J-groove attachment weld material cannot be ruled out
- Loose parts are not expected
  - Leakage will be observed well before loose part develops

Assessment of Operating Plants (Cont.)

- Leakage has been very small, so RV head wastage is not expected
  - Visual exam through access holes in service structure provides for early detection of leakage
- Additional safety margins still exist for continued operation (e.g., ductile material)

Assessment of Operating Plants (Cont.)

Corrective Actions:

- Short-term
  - GL 88-05 visual inspections of RV head
  - Repair as needed
- Long-term
  - ONS: Replacement of RV head with nozzles fabricated from Alloy 690
  - Remaining B&W-design plants: RV head replacement under consideration

Summary and Conclusions

- CRDM nozzle cracking can occur
  - Cracks are predominantly axial in orientation
  - Circumferential cracking can occur (below and above J-groove weld)
- J-groove weld cracking can occur
  - Cracks are predominantly axial/radial in orientation
- Cracks result in detectable leakage well before catastrophic nozzle failure

Summary and Conclusions (Cont.)

- Leakage is detected during GL 88-05 visual examinations of RV head area
  - Leakage is detected before significant damage to the RV head can occur
  - Leakage will be identified well before ASME Code margins are exceeded

Summary and Conclusions (Cont.)

- One of two of the most susceptible B&W-design plants (ONS-2) inspected all 69 nozzles in 1994 and continued with two follow-up inspections
- Recent observations at ONS-1, ONS-3, and ANO-1 add credence to safety assessments performed

Summary and Conclusions (Cont.)

- Utilities with a B&W-design :
  - Comply with 10CFR50.55a
  - Continue to meet intent of GDC-14, GDC-30, and GDC-31
- Inspections, other than visual examinations in accordance with GL 88-05, are not necessary from a safety perspective

Oconee Unit 1 & Unit 3
Reactor Vessel Head Leakage

Cracking of RV Head Penetrations
Due to Primary Water Stress
Corrosion Cracking (PWSCC)

M.R.Robinson, Duke Power Company
April 12, 2001

Discussion Outline

- Oconee Unit 1 and 3 Background
- Investigations Performed
  - Non-Destructive Examinations
  - Metallurgical Examinations
  - Analytical Evaluations
- Summary of Indications and Characterizations
- Repair Plans
- Nuclear Safety Significance

Background

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- Visual inspection of Unit 1 RV head identified small amounts of boron accumulation at the base of CRDM nozzle 21 and several T/C nozzles.

- Visual inspection of Unit 3 reactor vessel head identified small amounts of boron accumulation at the base of several CRDM nozzles. The suspect nozzles were #'s 3, 7, 11, 23, 28, 34, 50, 56, 63.

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Background Information

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- T/C nozzles installed in Unit 1(only) for instrumentation purposes, but were never put into service.
- Located outboard of the CRDMs and fabricated from 0.75" Schedule 160 Alloy 600 pipe
- Material Specification is SB-167 and procured from Huntington Alloys as cold drawn, ground, and annealed pipe
- Procured to 1965 ASME B&PV Code

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Background Information

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- CRDM (69) nozzles are constructed of Alloy 600 and procured in accordance with requirements of SB-167, Section II to 1965 Edition including addenda through Summer 1967 of ASME B&PV Code.
- CRDM nozzle material was hot rolled and annealed by B&W Tubular Products Division.
- Four heats of material used in ONS -1 (M1723,C2649,M1228, M2559); Unit 3 has 2 heats of material (M3935,C2649)
- CRDM nozzles were shrink fit into reactor vessel head penetration and welded with a J-groove weld with Alloy 600 filler

Background Information

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- Modifications to cut access ports (9 each - 12 in diameter) into the Oconee service structure were completed during outages in Spring 1994, Spring 1993, and Fall 1994 for Units 1, 2, and 3 respectively.
- Modifications to service structure allowed access to domed portion of head for bare metal inspections and wash down of the head to remove old boron deposits.

CRDM Nozzle Penetration Machining & Buttering Process

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- Penetration buttered with Alloy 182 weld metal using SMAW
- Rough machine CRDM penetration in closure head
- Layout J groove weld preps at each penetration
- Form J groove weld preps (air arc)
- Grind J groove for MT and welding
- Inspect, MT, and repair, if necessary
- Inspect, and MT repairs, if necessary
- Butter J groove per Welding Data Sheet
- Inspect, grind, and PT J groove butter
- Repair, if necessary
- Inspect and PT repair, if necessary
- Final stress relieve closure head at 1100F to 1150F for 8 hours minimum
- Final machine clad J grooves
- Grind, inspect, and PT J grooves
- Final machine CRDM penetrations, including counterbore
- Inspect and MT penetrations

CRDM Nozzle to Reactor Vessel Closure Head Assembly Process

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- Machine OD of nozzle to corresponding closure head penetration diameter
  - Maintain diametrical interference
  - Cool nozzle to -140F
- Install CRDM nozzle into corresponding closure head penetration
- Allow nozzle to warm to 70F minimum
- Inspect nozzles and tack weld per Welding Data Sheet
  - SB-167 to Alloy 182 buttering using E-NiCrFe-3 filler
- Inspect tack welds
- Build up CRDM nozzle to head weld per Welding Data Sheet
- Grind, PT and inspect each 9/32" of weld as it is built up
- Repair weld as it is built up, if necessary
- Grind and PT repairs, if necessary
- Put down grind bead, TIG
- Grind radius, PT, and repair
- Final inspection

CRDM Nozzle Layout

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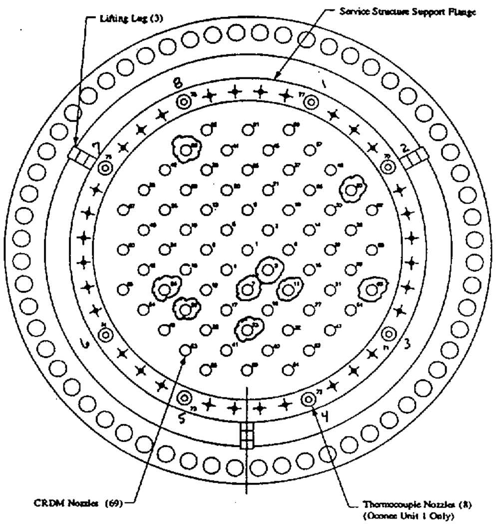

Schematic View of B&W-Design CRDM Nozzle Area

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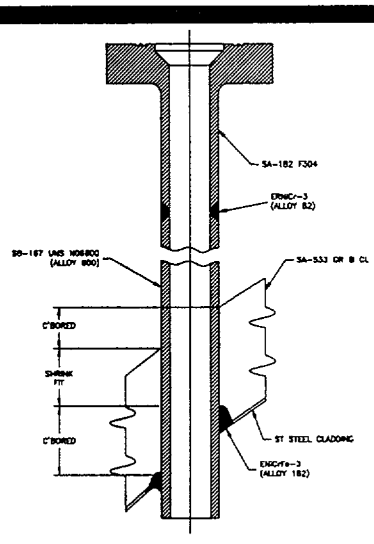

CRDM Nozzle #56

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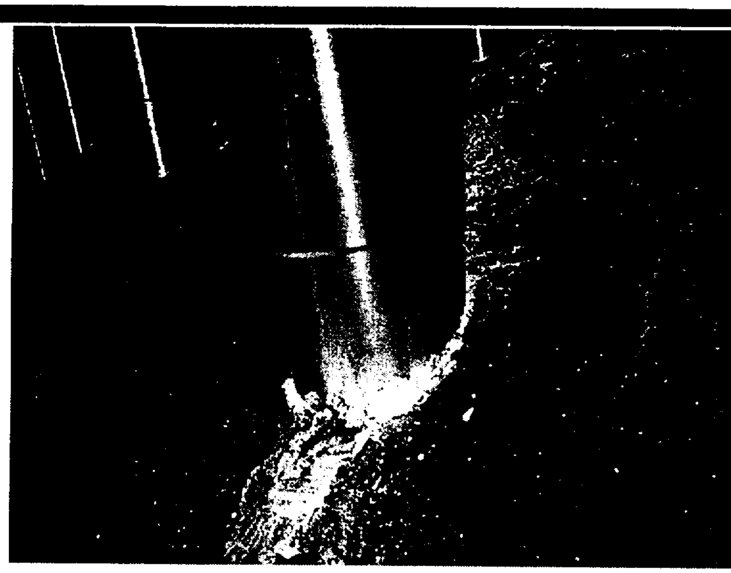

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CRDM Nozzle #50

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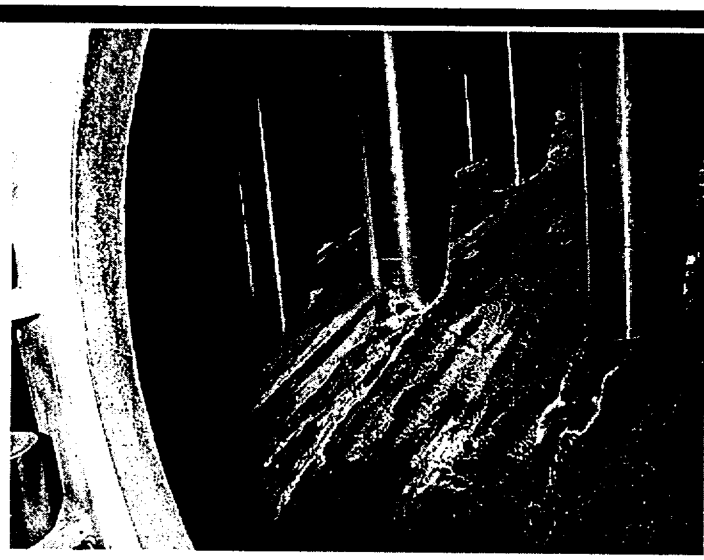

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CRDM Nozzle #11

Investigations Performed

- Non-Destructive Examinations
- Metallurgical Examinations
- Analytical Evaluations

Non-Destructive Examinations

- Pre-Repair Inspections Performed
  - Visual inspections of all 69 CRDM nozzles
  - Dye Penetrant (PT)
  - Eddy Current Testing (ECT)
  - Ultrasonic Examination-Axial
  - Ultrasonic Examination-Circumferential

Visual Inspections

- Bare head inspections are performed through the modified openings in the head service structure
- Visual inspections are performed as part of each refueling outage for our response to GL 88-05 and 97-01
  - The same experienced system engineer performs these inspections
- Heads essentially clear of old boron deposits
- Amount of leakage from each leaking nozzle has been very small, which suggests, low leak rates
- No evidence of boric acid corrosion on top of head

Inspections

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- Dye Penetrant (PT) Inspection
  - Surface examination that looks at the weld surface area and the top 1 inch of the nozzle that projects down into the plenum of the head
  - Performed on suspected leaking CRDM nozzles
- Eddy Current (ECT) Inspection
  - Surface examination (plus 2 to 3 mm into the material) from the nozzle ID
  - Performed on suspected leaking nozzles
  - Checks a band 6 inches above the weld down to free end of nozzle
  - Later performed on additional nozzles, to address extent of condition
    - 8 Unit 1 CRDM nozzles
    - 69 Unit 2 CRDM nozzles (1994 inspection)
    - 8 Unit 2 CRDM nozzles (1999 inspection)
    - 18 Unit 3 CRDM nozzles

Inspections

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- Ultrasonic Examinations (UT) Axial
  - Volumetric examination to locate and depth size axial indications on both the nozzle inside diameter and the nozzle outside diameter
  - Performed on the suspected leaking nozzles and on additional nozzles to address extent of condition
    - 18 nozzles on Unit 3 inspected
    - 2 nozzles on Unit 2 (1996 inspection)
- Ultrasonic Examinations (UT) Circumferential
  - Volumetric examination to detect the presence of circumferential cracking or indications and lack of bond
  - Performed on the suspected leaking nozzles and on additional nozzles to address extent of condition
    - 18 nozzles on Unit 1 (lack of bond)
    - 18 nozzles on Unit 3 (circumferential)

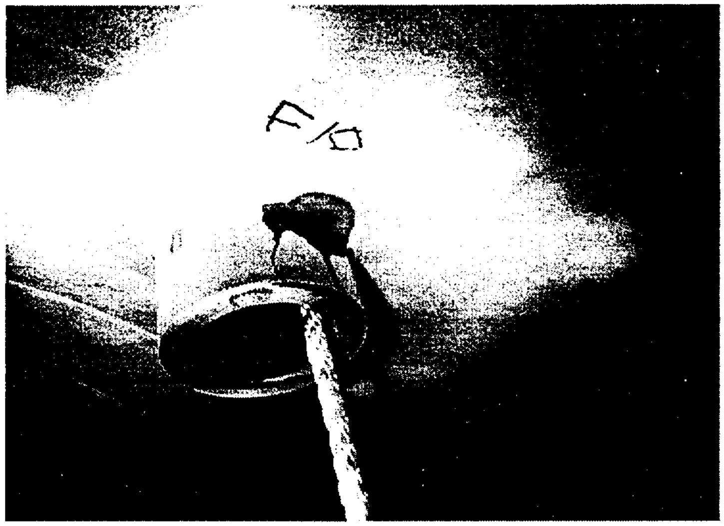
Inspections: Eddy Current Testing

- ID ECT inspection using motorized rotating pancake coil probe with 3 coil configurations.
  - Design includes differential pancake coil w/ 45 degree offset operated in differential and absolute modes, a mid-frequency plus coil configuration, and a circumferential oriented coil.
  - Data acquired in a helical scan using FTI top down manipulator as shown during EPRI spring '96 demonstration.
  - All probes were run at frequencies of 600, 280 and 100 kHz.

Inspections: Ultrasonic Inspections

- The ID UT inspection was performed using a CRDM nozzle transducer package that contains three transducer configurations.
  - The package includes a forward and backward scatter time of flight configuration for flaw characterization and a 0 degree longitudinal wave configuration for weld profiling.
  - Data was acquired in a circumferential scan path using the Framatome top down manipulator.
  - CRDM transducer package was demonstrated during an EPRI 1993 performance demonstration.

CRDM Nozzle #11



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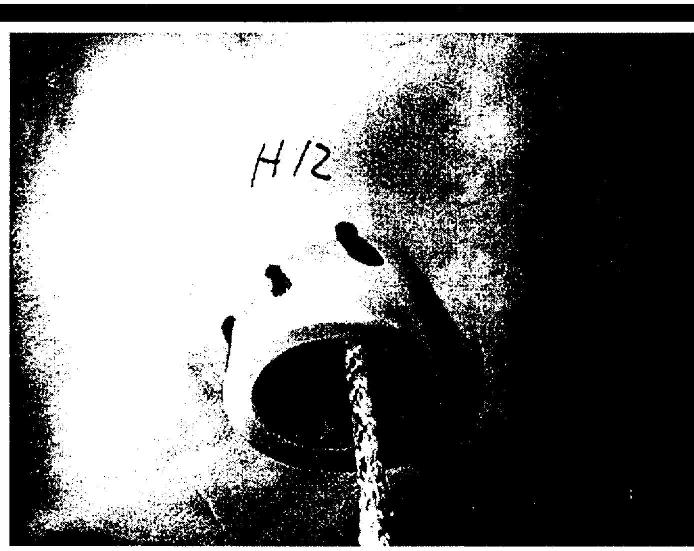
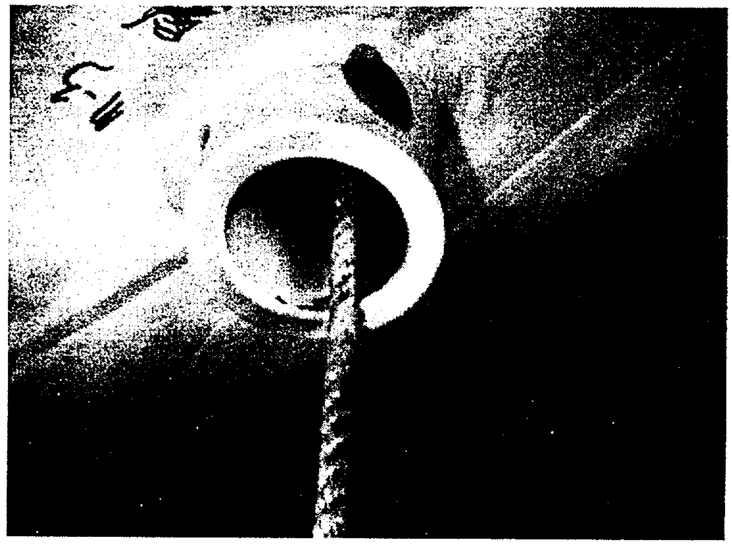
CRDM Nozzle #23



CRDM Nozzle #56



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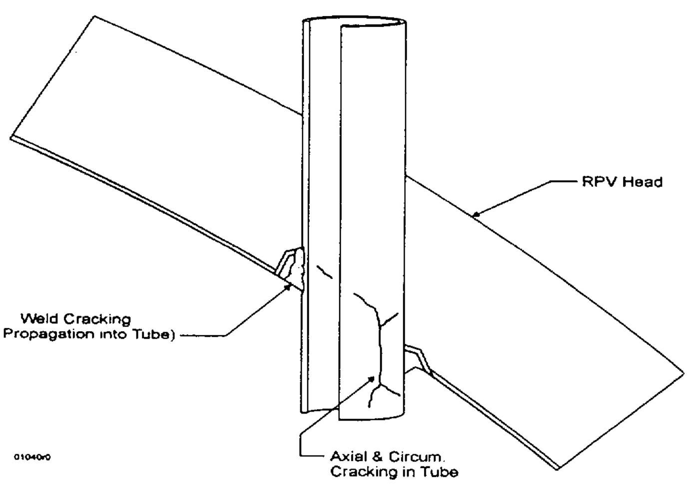
CRDM Nozzle Cracks at ONS 1 & 3



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UNIT 1 - SUMMARY OF NOZZLE INDICATIONS & CHARACTERIZATION

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Nozzle	
#21	▪ Crack originated in 182 weld filler material and later moved into wall of CRD nozzle ▪ Crack was radial and axial ▪ No circumferential crack
T/C 1-8	▪ Numerous axial cracks both above and below weld ▪ Weld profile significantly larger than specified by design
21,42, 49,55, 56,61, 67,68	▪ ECT inspection for extent of condition ▪ Nozzles 61,67,68 craze cracks above and below weld ▪ Flaw length about 78mm and about 3mm deep ▪ Other nozzles clear of indications

UNIT 3 - SUMMARY OF NOZZLE INDICATIONS & CHARACTERIZATION

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Nozzle	
# 11	▪ 7 Axial and 3 Circumferential Cracks ▪ 3 Axial thru wall, 2 > 75% thru wall, 2 about 50% thru wall ▪ 3 thru wall are 3" long, 2 > 75% are 3" long, 2 about 50% < 1" long ▪ All circ below weld, 1 is 10%, 1 is 57%, 1 is 70% thru wall ▪ Deep circ crack is about 5.3" long, mid circ crack is 3.9" long ▪ Areas of craze cracking above and below weld at high side
#23	▪ 6 Axial and 2 Circumferential Cracks ▪ 2 Axial thru wall, 4 are 30% to 67% thru wall ▪ 2 thru wall are .6" and 3.8" long, 4 are 0.5" to 1.1" long, both circ below weld, 1 is 77% thru wall, other is 67% thru wall ▪ Circ cracks are about 2" long ▪ Areas of crazed cracking above weld at high side

UNIT 3 - SUMMARY OF NOZZLE INDICATIONS & CHARACTERIZATION

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Nozzle	
#28	▪ 5 Axial and 1 shallow Circumferential Crack below weld ▪ All 5 axial thru wall, All between 1.2" and 2" long ▪ Areas of crazed cracking above weld at high side
#34	▪ 1 Axial and no circumferential cracks ▪ Axial is 35% thru wall and 2" long ▪ Areas of crazed cracking above and below weld at high side
#50	▪ 3 Axial and 2 Circumferential Cracks ▪ 2 Axial thru wall, 1 94% thru wall ▪ Thru wall are between 1.2" and 3" long ▪ Circ below weld was thru wall and 2.4" long ▪ Circ crack is above weld and about 2.4" long

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UNIT 3 - SUMMARY OF NOZZLE INDICATIONS & CHARACTERIZATION

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Nozzle	
#56	▪ 3 Axial and 1 Circumferential Cracks ▪ 1 axial thru wall, One 38% thru wall, One 11% thru wall ▪ Thru wall is 1.7" long, mid depth .75" long, shallow is 1.6" long ▪ Circ crack above weld near high side and about 2.4" long
#3	▪ 7 Axial and no circumferential cracks ▪ No Axial thru wall, all between 33% and 65% thru wall ▪ All between .3" and 1" long ▪ Areas of crazed cracking below weld at high side
#7	▪ 1 Axial and no Circumferential Cracks ▪ Axial is 87% thru wall, 2.3" long ▪ Areas of crazed cracking below weld at high side

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UNIT 3 - SUMMARY OF NOZZLE INDICATIONS & CHARACTERIZATION

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Nozzle	
#63	▪ 6 Axial and no Circumferential Cracks ▪ 3 axial thru wall, 2 are 80% thru wall, One 49% thru wall ▪ Thru wall between 1.7" and 3.3" long, others between .9" and 3.1" long
4,8,10, 14,19, 22,47, 64,65	▪ Cluster indications on all listed nozzles ▪ Maximum depth measured 1.75 mm ▪ Examined for extent of condition

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Unit 3: Summary Nozzle Indications and Characterization

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- Total of 48 indications in the nine leaking CRDMs
  - 39 are axial and located beneath the weld at the uphill and downhill
  - 16 indications thru wall (39%), all are axial, and occur on 6 of 9 nozzles
- Confirmed two (2) above the weld circumferential cracks
  - Nozzle 56 crack was thru wall
  - Nozzle 50 except for pin hole indications on ID was not thru wall
  - Inspection and metallurgical results indicate the circumferential cracks were O.D. initiated.
- Unit 3 CRDMs extent of condition inspections (9 additional nozzles):
  - Cluster indications above and/or below the J groove weld.

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Circumferential Cracks Above Weld

- Discovered during post weld repair NDE of Nozzles 50 & 56
- Circumferential cracks followed the weld profile contour and were O.D. initiated.
- Both ECT and UT inspections identified indications in these areas but were dispositioned as crazed cracks with unusual characteristics
- The original NDE characterization for nozzles 50 and 56 subsequently changed.
- This change in interpretation of the NDE signals is related to the flaw orientation with respect to the sound beam of the UT search units.
- Actions taken as a result of this discovery were:
  - All Unit 1 and 3 ECT and UT data has been re-reviewed applying the LLs
  - EPRI NDEC is leading an independent review of ONS 1 & 3 data to confirm results and findings

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Metallurgical Examinations

- T/C nozzle specimen (2) from Unit 1
- CRDM #21 182 weld filler material boat sample from Unit 1
- CRDM nozzle end pieces (7) from Unit 3
- CRDM nozzle 56 circumferential crack boat sample, Unit 3

Unit 1: Summary Results of Metallurgical Examinations

T/C Nozzles:

- Cracks are intergranular and branched
- Cracks are axial and radial in orientation
- Material appears to be typical of mill annealed Alloy 600 with some evidence of cold working on both the OD and ID surfaces
- Microstructure mixed with both intra and intergranular carbides
- Microstructure characterized by small clusters of small grain with some large grains; Grain size ASTM 7-8
- No indication of aggressive chemical species on the crack face
- The cracks are stress corrosion with primary water as the corrodent

Unit 1: Summary Results of Metallurgical Examinations

CRDM Nozzle 21:

- Crack in weld was completely interdendritic
- PWSCC was the primary mechanism for crack propagation in the CRDM weld and housing
- No conclusive evidence of manufacturing defects in the original weld
- Crack in weld was connected to a branched intergranular crack in the nozzle wall
- Qualitative comparison of boat sample to a 182 weld pad confirmed alloy type material, as expected

Unit 3: Summary Results of Metallurgical Examinations

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CRDM Housing Material Specimen:

- Microstructure of all nozzle materials very similar and typical for mill annealed Alloy 600. Grain size is ASTM 4.
- Grain boundaries contain a semi-continuous carbide decoration
- No ghost grain boundaries or segregated carbide clusters
- All cracks in the samples were intergranular with slight branching
- Micro-hardness survey across the thickness shows a range from about Rb 80 at the ID to Rb 95 at the OD
- Several nozzles exhibited cracks originating at free end of nozzle
- All cracks are stress corrosion cracks with PWSCC as the primary mechanism for crack propagation

Unit 3: Summary Results of Metallurgical Examinations

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CRDM 56 Boat Sample (Circ Crack):

- Boat sample in the area of circ crack that was found above the weld after the weld repairs were completed
- Boat sample contained a face of the circ crack along with 3 small axial cracks that intersect the circ crack
- Section through the axial crack confirms crack is totally intergranular with small intergranular branches
- Scanning electron microscopy of the circ crack face revealed only intergranular morphology.
- There are no tears or other indications of the origin of the circ crack
- Circ crack is indicative of PWSCC

Correlation of Observed Crack Locations with FE Stress Analysis

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- Cracks are:
  - predominately axial and located on the uphill and downhill sides of the nozzle
  - most initiate on the OD of the nozzle
  - circumferential cracks found below and above the weld, at the weld toe on the uphill and downhill sides of the nozzle
- Stress analysis preliminary results:
  - Hoop stresses exceed axial stresses at most locations which suggests axial cracking would be expected. This is consistent with observed field conditions

Correlation of Observed Crack Locations with FE Stress Analysis

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Stress analysis preliminary results:

- Hoop stresses are greatest at both uphill and downhill sides of nozzle. Reasonably good agreement with axial crack locations from field observations.
- Axial stresses tend to be higher on the uphill side of the nozzle relative to downhill side of nozzle. Field observed locations of the circumferential crack locations, under the weld on downhill side does not align with this analysis prediction.
- Microhardness measurements suggest the material yield strength is significantly higher on outside of nozzle than on the inside. The high outside yield strength may explain the preferred OD cracking

Root Cause

Root Cause determination for Unit 1 & 3 RPV closure head penetration leakage is PWSCC.

This determination is based on:

- metallographic examinations
- correlation of crack location and orientation with results of FEA
- evaluation & disposition of other potential failure modes

Current Repair Plans

- Repairs being performed in accordance with 1992 Section XI of ASME Code
- Removing all flaws entirely from both weld material and nozzle base material
- Use temper bead weld repair process to replace the weld
  - Code requirement since excavation entered the "buttering".
  - Involves heating the RV head to 500 degrees F.
- Automated weld process to apply protective layer over J groove weld

CRDM Nozzle #3

Duke Energy

CRDM Nozzle #7

Duke Energy

CRDM Nozzle #11

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CRDM Nozzle #50

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Radiation Dose and Worker Safety

- Projected dose for the Unit 3 RV head repair is approximately 280 Rem.
- Unit 1 dose for CRDM and T/C repairs was 67 Rem.
- Specialized shielding booths have been designed and used to limit dose to personnel performing PTs, grinding and welding under the head.
- Aggressive decontamination (high pressure spray) performed on the underside of the head to lower dose.
- Workers are wearing bubble hoods and layers of anti-contamination and protective clothing.
- Air arc gouging tool is being used to reduce the amount of time spent under the RV head excavating weld material.

Future Plans

- Continue working with NEI, EPRI, industry groups on inspection and repair techniques.
- Continue head inspection program, maintaining the RV head clean to enhance inspection capability.
- An automated ID Temper Bead Repair method which moves the pressure boundary higher in the RV head above the original J-groove weld is being developed for future repairs.
- Long term solution for Oconee is to replace the RV heads on all three units.

Nuclear Safety Significance

- We understand why we're having these leaks -- PWSCC with susceptible material.

- Significant amount of work performed by EPRI, industry and NRC to gain an understanding of this phenomen and the experiences at ONS will advance level of knowledge.

Nuclear Safety Significance

- The BWOG/EPRI MRP is completing a nuclear safety assessment, focusing on PWSCC in CRDM weld materials, loose parts, and circ cracks above weld as a result of the Oconee experience.

- Worldwide operating experience has identified 45 plants with PWSCC issues over the last 15 years.
  - All instances involve minor leakage, not component failure
  - Actual Oconee experience supports conclusion that these components will leak before failure.

Nuclear Safety Significance

Duke Energy

- Accident associated with complete failure of nozzle or weld is rod ejection accident.
  - Safety analysis for this accident is included in the Oconee UFSAR.
  - Procedures and training are in place to respond to this type of accident.
- Structural failure requires a circumferential crack, either:
  - through the nozzle wall above the weld, initiating from the inside or outside diameter of the nozzle

    or

  - through the weld, initiating from the surface and growing both axially and circumferentially up the nozzle-weld interface.

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Nuclear Safety Significance

Duke Energy

- Circ Flaw through Nozzle
  - Must leak before circumferential cracking can begin on nozzle O.D.
  - Once initiated, it would conservatively take more than 6 years to grow through wall.
  - Prior to Oconee Unit 3, operating experience identified only one example of circ cracking above the weld and the leak was found prior to significant cracking.
- Flaw though Weld
  - Would leak prior to crack growing completely through and around weld
  - Hoop stresses would cause axial crack propagation in preference to circumferential cracking
  - Axial crack would leak in as little as 7 years

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Duke Energy

Nuclear Safety Significance

Conclusions:

- CRDM nozzles leak well before reaching the point of complete nozzle failure.
- Axial cracking is the predominant cracking orientation.
- The amount of leakage is small and plant inspections are successful in identifying nozzles that do leak even a small amount.

NRC/MRP/NEI Meeting
on
CRDM Cracking

April 12, 2001

Attachment 3

Agenda

- Oconee Experience
- B&W Plant Design Safety Assessment
- Industry Experience - Under-Insulation Head Inspections
- Generic Safety Assessment Status
- Inspection Planning
- NDE Issues
- Plants with Near-Term Outages
- Future Plans

Industry Experience - Under Insulation Head Visual Inspections

- Plants Inspected (preliminary as of 4/11/01)
  - Oconee 1 - all penetrations each cycle
  - Oconee 2 - all penetrations each cycle
  - Oconee 3 - all penetrations each cycle
  - ANO 1 - all penetrations each cycle
  - Davis Besse - all penetrations each cycle
  - Crystal River 3 - all penetrations each cycle
  - TMI 1 - all penetrations each cycle
  - McGuire 1 - '01 - 11 penetrations
  - North Anna 1 and 2 - all penetrations each cycle
  - SONGS 2 - 10/00 - 24 (30%) CEDM and all 10 ICI penetrations
  - SONGS 3 - 1/01 - 24 (30%) CEDM and all 10 ICI penetrations
  - Farley 1 and 2 - '95 (partial)
  - Cook 1 - '94
- Survey in progress

RPV Head Penetration Generic Safety Assessment

- Circumferential flaw safety assessments submitted in '94
  - Must have primary water in annulus to get circumferential cracking above the weld
  - Only small fraction of cross section required to maintain integrity
- Structural integrity and Code margins have been maintained
- Preliminary safety assessment to be submitted with hot leg cracking assessment
- Effects of recent findings will be incorporated into a final safety assessment after more comprehensive evaluation

Inspection Planning

- Plants already ranked (base metal) in response to GL 97-01
- Under Head Inspections performed and planned based on industry histogram
- Issues raised by recent inspections:
  - Highly ranked sister plants
  - Circumferential flaws
  - Weld/OD cracking
  - Severity of cracking
- Impact on Industry Inspection Program being evaluated
  - Type of inspection
  - Which plants
  - Timing

NDE Issues

- Demonstration program for Inspectors initiated in '93-94
- Focused on ID surface connected base metal flaws (axial and circumferential)
- Lessons learned from recent events:
  - Interpretation of circumferential indications
  - OD and weld inspection techniques are being evaluated
    - Tooling enhancements may be required
  - Visual inspection tooling (remote, etc.)

Plants with Near-Term Outages

- Spring '01
  - Significant number of visual inspections have been performed
    - No structural limits compromised
  - Additional visual inspections are already planned, where practical
  - Visual bare metal inspection very difficult for many units
  - Unplanned outage activities are expensive
    - Time, dose, and cost
  - Continue with MRP guidance for Spring outages
- Fall '01
  - Inspection recommendations will be reissued for fall outages, addressing:
    - availability of improved inspection and repair tooling
    - improvements to existing inspection techniques
    - inspection demonstrations

Future Plans

- Submittal of Preliminary Safety Assessment - About 4/27
- Compile Inspection Experience - About 4/20
- Revision of inspection recommendations for Fall outages - About 6/30
- Final Safety Assessment - About 6/30
- Long Term Inspection and Evaluation Guidelines being developed
- Continued communication and meeting as needed