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

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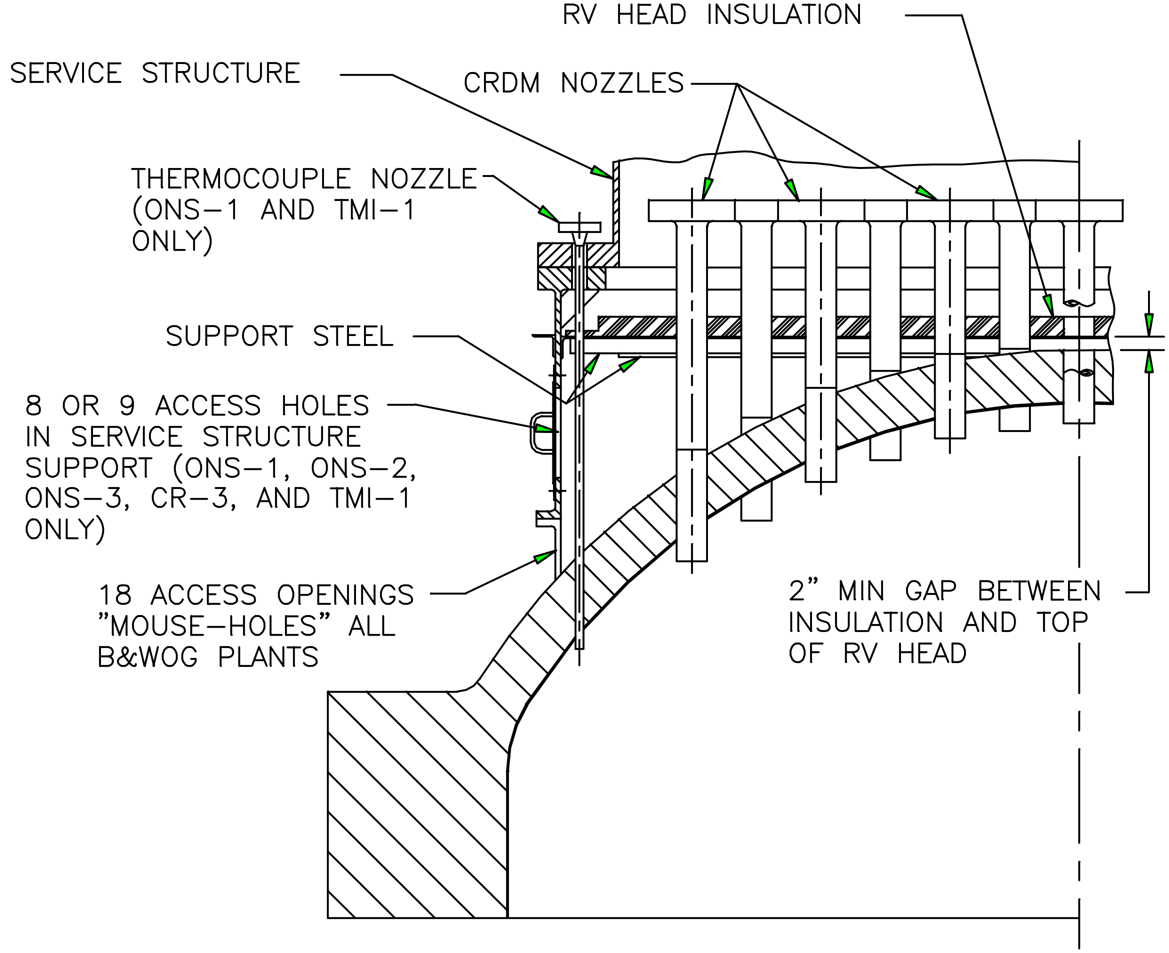
Integrity Assessment for Reactor Vessel Head Penetration Nozzles

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

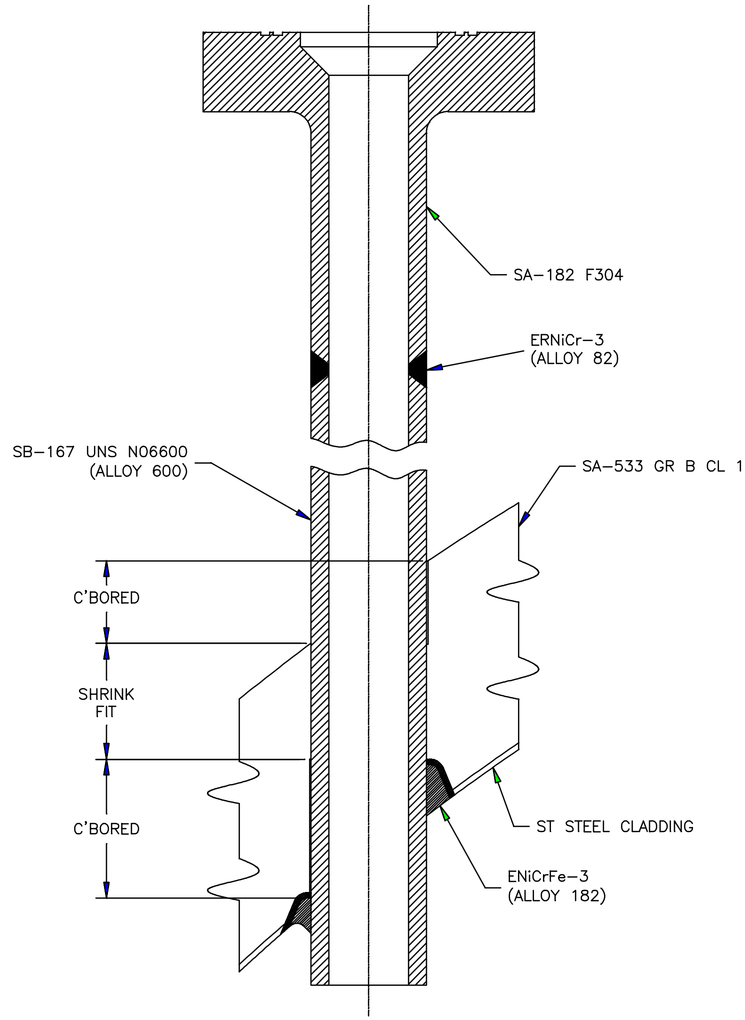
Introduction

- 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.)

ANO-1

- 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^{o} 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.)

Leakage Assessment:

- 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.)

<u>Wastage Assessment:</u>

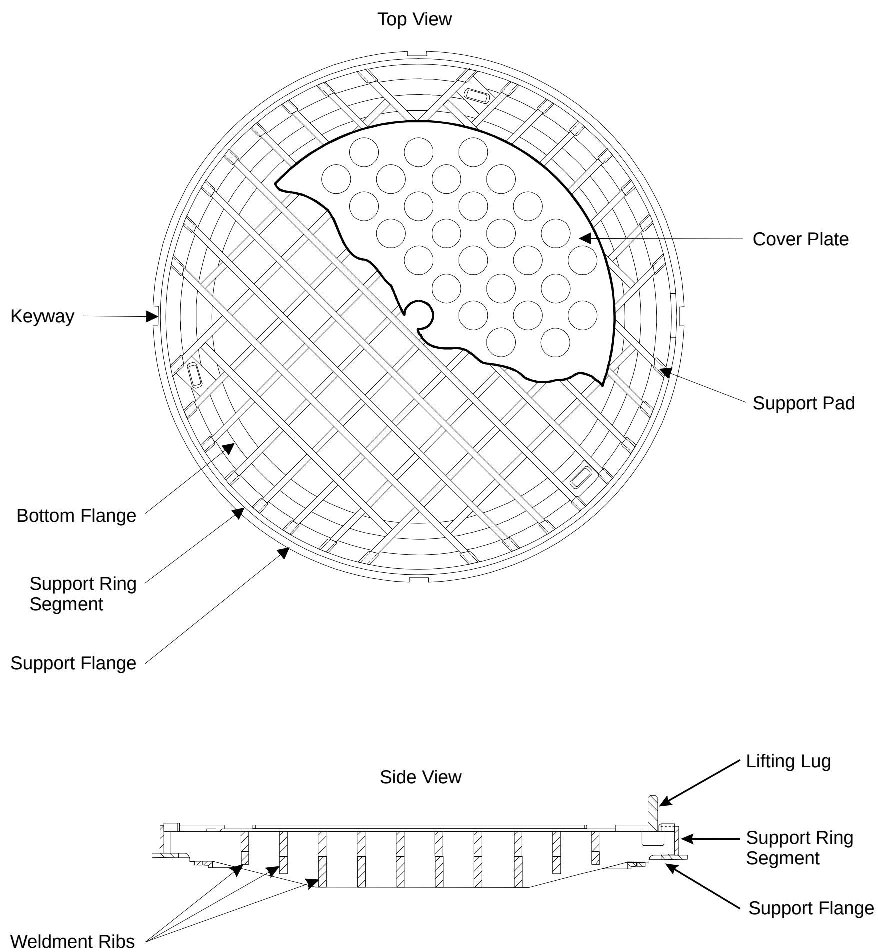
- Cracks resulting in significant leakage could cause corrosion of the RV head
- Wastage assessment performed in previous safety assessment (1993)
- Cracks resulting in significant leakage could cause corrosion wastage of RV head
  - Safe operation of RV head, from ASME Code evaluation standpoint, for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

Evaluations of Cracking (Cont.)

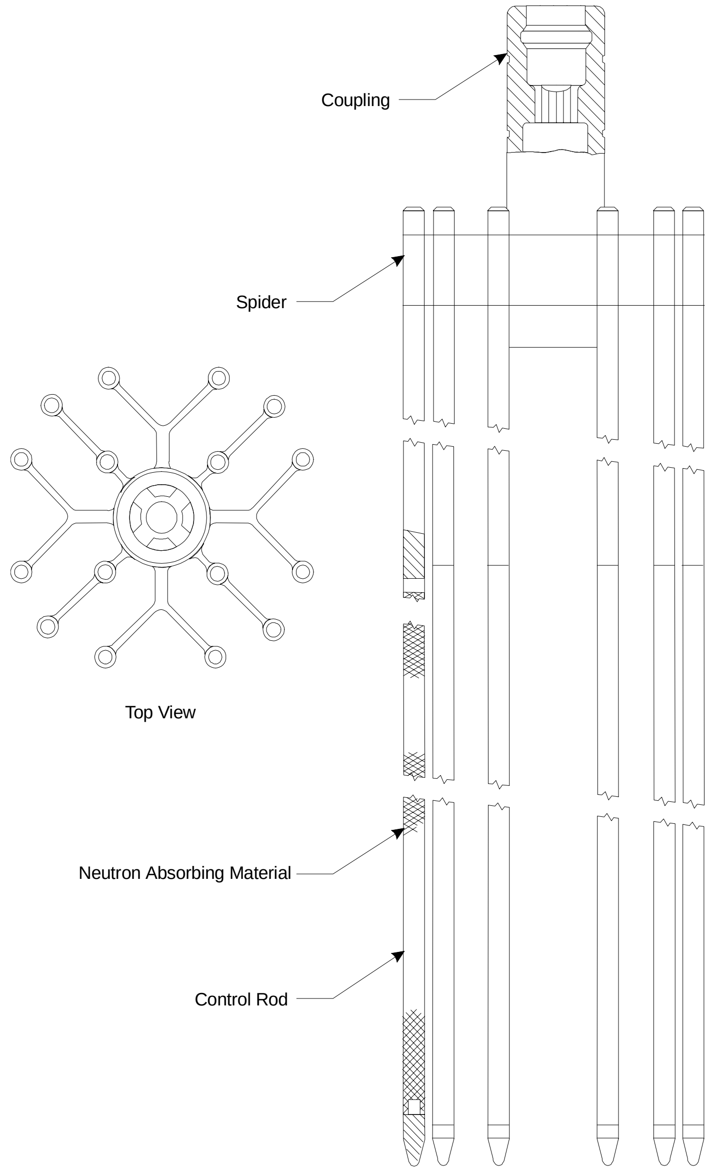
Loose Part Assessment:

- 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

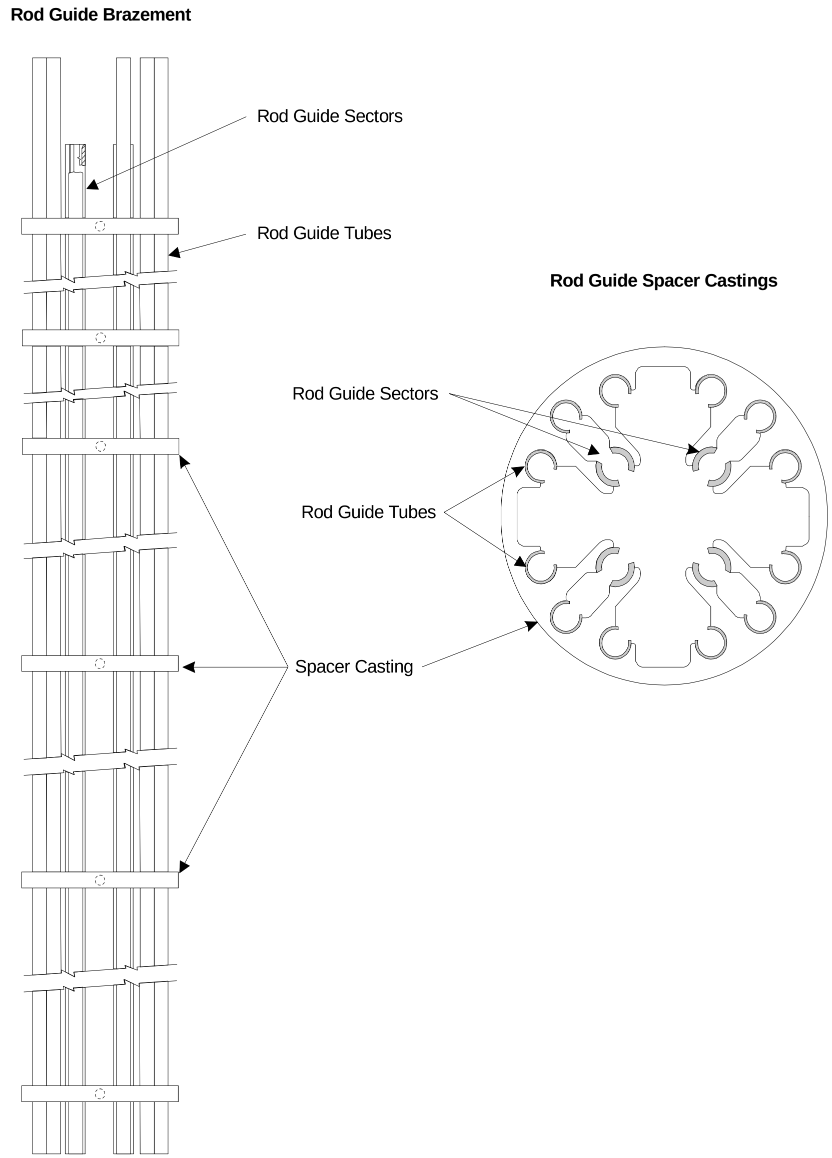
Plenum Cover Assembly.



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.)

<u>Safety Analysis Review:</u>

- 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