# RPV Head Penetration Inspection Plan

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# Inspection Plan Background

- MRP approved Inspection Plan and technical bases were presented to NRC staff on May 22
  - Technical Bases documents were provided to NRC on July 1, 2002.
- NRC Technical Comments
  - Plan should address inspections for both wastage and nozzle ejection issues
  - Address leakage past possible tight nozzle/head interference fits
  - Address replacement head material of Alloy 690/152/52
- General NRC Feedback
  - Managing problem through leakage identification

# Inspection Plan Background

- Inspection Plan revised to address NRC comments
  - Provided Technical Basis to address cracking and leakage detection from tight nozzles
  - Supplemental examination dealing with head wastage and its relationship to a plant's 88-05 program
  - Alloy 690/152/52 replacement head material
  - Editorial changes

# Plan's Purpose

- Provide guidance and the basis for a graduated degradation management program for RPV head penetrations.
- Require inspections to allow early detection of leakage or cracking prior to challenging structural integrity
  - Structural integrity is defined as maintaining an acceptably low probability of developing cracking that could lead to nozzle ejection or the loss of ASME Code margins due to consequential head wastage.
- Clearly indicate that Alloy 690/152/52 head material will be addressed as part of the plan when appropriate technical information applicable to this material becomes available.
- Note that the plan will be re-evaluated periodically

# Scope

- Applies to the pressure boundary of the RPV head penetrations fabricated from Alloy 600 with Alloy 82/182 weld material.
- Investigate boric acid head deposits for evidence of general head corrosion from primary coolant leakage per the requirements of GL 88-05.
- Supplemental direct or remote visual exam is defined to allow effective identification of boric acid deposits on the head

# Risk Informed Penetration Inspection

- Penetration inspection schedule is based on a risk informed analysis of nozzle cracking within B&W designed and manufactured RPV nozzle material and head geometry
  - These materials/plant type bound the PWR fleet based on experience to date.
- A probabilistic fracture mechanics (PFM) analysis was used to determine probability of penetration leakage and nozzle ejection versus time.
  - This analysis conservatively supports established inspection schedules for the penetrations.

# Risk Based Susceptibility

- Moderate susceptibility boundary:
  - The number of EDYs at which a plant reaches
    - probability of one leaking nozzle = 20% (approximately equal to the probability of net section collapse (NSC i.e. nozzle ejection) = $1 \times 10^{-4}$
- High susceptibility boundary:
  - The number of EDYs at which a plant reaches:
    - probability of nozzle ejection = $1 \times 10^{-3}$ (approximately equal to the probability of one leaking nozzle = 75% )
      - consistent with NRC RG 1.174 guidance for change in Core Damage Frequency.

# Plant Categories

- Low Susceptibility:
  - less than 10 Effective Degradation Years, EDY (defined as Effective Full Power Years @ 600F), without a leak or identified crack
- Moderate Susceptibility:
  - greater than or equal to 10 EDY and less than 18 EDY without a leak or identified through-wall crack
- High Susceptibility:
  - greater than or equal to 18 EDY or units that have identified leaks or through-wall cracks.

# Penetration J-Groove Weld Inspection Bases

- Circumferential cracks in the J-groove weld do not pose a significant risk of nozzle ejection.

- Lack-of-fusion: extent to still maintain structural integrity is similar to the acceptable extent of through-wall circumferential cracking (i.e. >75% of the circumference).
  - There is no precedent for such a large area of lack-of-fusion.
  - Inspections performed to date do not show significant areas of lack-of-fusion

# Inspection Types

- Bare metal visual (BMV) examination
  - Entire intersection between the RPV head and each penetration must be viewed as well as approximately 1 inch of the adjacent bare surface of the upper head
- Supplemental visual (SV) examination
  - a direct or remote visual examination, which may be addressed through a plant's 88-05 program, to identify evidence of significant boric acid accumulation that may be associated with incipient wastage
  - Requirements applicable to
    - RPV heads with accessible upper surface
    - RPV heads with closely conforming rigid insulation
- Non-visual examination, NDE

# NDE Examination

- A surface technique intended to identify cracking emanating from the pressure retaining wetted surface of the J-groove weld and the adjacent inside and outside diameter surface of the penetration.

OR

- A volumetric technique intended to identify cracking propagating through the root of the J-groove weld and/or the penetration base material into the penetration annulus.

OR

- A combination of the above two examinations such that any cracking that could provide a leak path through the pressure boundary is detected

# SV for Boric Acid

- Calculated the volume of boric acid deposits as a function of leak rate for two operating cycles.
  - BMV: capable of detecting avg leak rate $1x10^{-6}$ gpm
  - SV: capable of detecting avg leak rate of 0.0003 gpm
  - GL 88-05 (general visual inspection): capable of detecting a 0.003 gpm
- Significant corrosions over larger areas involves local cooling of the metal surface temperature to ~212°F
  - Need leak rate at approximately 0.1 gpm

# Supplemental Visual Details

- RPV heads with accessible upper surface
  - Area of interest - the exterior bare surface of the RPV upper head
  - Minimum detectable condition - a significant accumulation of boric acid crystals
    - major dimension greater than 4” and
    - with discernable thickness (i.e., not a film or stain)
  - Accessibility - sufficient to observe the minimum detectable condition anywhere within the area of interest

# Supplemental Visual Details (cont.)

- RPV heads with closely conforming rigid insulation, the following alternative requirements may be met
  - Area of interest - entire periphery and outer surface of the installed insulation (including joints between insulation segments, and annular gaps between insulation and head penetrations) and exposed portions of the head and flange
  - Minimum detectable condition - evidence of RCS leakage, bulging insulation, etc.
  - Accessibility - sufficient to observe the minimum detectable condition located anywhere within the area of interest.

# GL 88-05 Implementation

- At each RFO, general inspection of easily observed portions of the RPV head
  - This inspection shall contain the necessary attributes to ensure effective identification of evidence associated with significant primary coolant leakage (e.g., a large swath of rust and/or boric acid stain or film).

# Penetration and Head Wastage Inspection Schedule – Low Susceptibility

***For low susceptibility plants (< 10 EDY):***

- Perform a Bare Metal Visual (BMV) examination of 100% of the RPV head penetrations once per 10 EFPY;
- Or, perform NDE (i.e., non-visual examination) of 100% of the RPV head penetrations and associated J-groove welds once per 10 EFPY
- Perform supplemental visual exam every 2nd RFO during those outages where a BMV or non-visual examination are not required. Initial inspection following 100% non-visual examination is at the 3rd RFO after the examination.

# Penetration and Head Wastage Inspection Schedule– Moderate Susceptibility

***For moderate susceptibility plants*** (10 EDY≤X< 18 EDY)**:**

- Perform a BMV examination of 100% of the RPV head penetrations at the 1st RFO upon entering this category (or not more than 2 EDY since the most recent exam) and once every 2 EDY, not to exceed 5 EFPY.
- Or, perform NDE (i.e., non-visual examination) of 100% of the RPV head penetrations and associated J-groove welds at the 1st RFO upon entering this category and once every 4 EDY, not to exceed 10 EFPY.
- Perform supplemental visual exam every 2nd RFO during those outages where a BMV or non-visual examination is not performed. Initial inspection following 100% non-visual examination is at the 3rd RFO after the examination.

# Penetration and Head Wastage Inspection Schedule– High Susceptibility

***For high susceptibility plants*** (≥18 EDY)***:***

- Perform a BMV examination of 100% of the RPV head penetrations at every RFO upon entering this category.
  - perform NDE (i.e., non-visual examination) of 100% of the RPV head penetrations and associated J-groove welds, or portions thereof that can be examined without undertaking physical modifications for accessibility, within 4 EDY upon entering this category or issuance of this Plan, whichever is later.

- Or perform NDE of 100 % of the RPV head penetrations and associated J-groove welds at the 1st RFO upon entering this category and once every 4 EDY, not to exceed 6 EFPYs.

# Inspection Schedule – High Susceptibility (cont.)

***For high susceptibility plants*** (≥18 EDY)***:***

- Perform supplemental visual exam every 2nd RFO during those outages where a non-visual examination are not required. Initial inspection following 100% non-visual examination is at the 3rd RFO after this examination.

# Inspection Plan

- **Plants with leak(s) or through wall cracks identified:**
  - Discovery Inspection
    - Perform a non-visual examination of the RPV head penetrations and associated J-groove welds to characterize the crack or leak identified.
    - Indications are evaluated or repaired in accordance with flaw evaluation guidelines.
  - Note, nozzles with through-wall indications shall be evaluated for cavities and corrosion of the reactor vessel head adjacent to the penetration and repairs made as necessary.

# Plants with Leak(s) or Through Wall Cracks

## Expansion Inspection

- To be implemented no later than next RFO following the discovery of a leak or through-wall crack
  - Perform NDE ( i.e., non-visual examination) of 100% of the RPV head penetrations and associated J-groove welds.
    - Indications are evaluated or repaired in accordance with flaw evaluation guidelines (see Reference 4).
  - Or, perform an evaluation to justify continued visual examination until the component is removed from service.

# Plants with Part- Through Wall Cracks Identified

- Discovery Inspection
  - Indications are evaluated or repaired in accordance with flaw evaluation guidelines.
- Indications Left in Service
  - Re-inspection is performed in accordance with flaw evaluation guidelines and crack growth
  - Re-inspection of an embedded flaw is performed at
    - the next scheduled RFO and once every ISI period thereafter
    - in accordance with the flaw evaluation guidelines

# As-Left RPV Head Cleanliness Condition

- Upon completion of each visual examination (BMV or SV), the RPV head surface should be clean of debris and deposits consistent with the following guidance to prevent interference with subsequent detection of leakage:
  - Isolated, loosely adherent, boric acid crystal “crumbs” may remain once documented,
  - Thin, surface-conforming boric acid films with thickness such that the condition of the underlying metal can be readily determined (I.e., a film or stain) may remain once documented, and
  - Other cleanliness exceptions may be allowed to remain if fully documented as to composition and extent and provided that a written evaluation concludes that the condition is acceptable and will not interfere with any necessary subsequent BMV or SV.

# Conclusions

- Provides a graduated degradation management program for RPV head penetrations.
- Requires inspections to allow early detection of leakage or cracking prior to challenging structural integrity

- Technical Basis Documents
  - Technical Basis for RPV Upper Head Penetration Inspection Plan, by Peter C. Riccardella, June 2002.
  - Probability of Detecting Leaks in RPV Upper Head Nozzles by Visual Inspections, by Steve Hunt, June 2002.
  - Supplemental Visual Inspection Interval to Ensure Low Risk of Rapid Boric Acid Corrosion, July 17, 2002. DRAFT – to be provided in August