Inspection Plan
PWR Reactor Pressure Vessel (RPV) Head Penetrations
Revision 0
May 17, 2002

Purpose

The purpose of the industry inspection plan for RPV head penetrations is to provide further guidance for PWR licensees subsequent to responding to NRC Bulletins 2001-01 and 2002-01. This inspection plan provides the basis for a long-term management program for the RPV Head penetrations and is not intended to supplant previous inspections, evaluations, or site-specific regulatory commitments. The industry inspection plan goal is to preserve the structural integrity thereby ensuring safe operation. Structural integrity is defined as maintaining an acceptably low probability of developing cracking that could lead to nozzle ejection. A robust GL 88-05 program remains the primary defense against boric acid wastage of low-alloy steel. However, the inspection frequencies within this plan have been conservatively established relative to the structural integrity of the RPV Head. The inspection plan is structured to provide a graduated approach to inspections to allow early detection of leakage or through-wall cracking prior to challenging structural integrity or significant wastage. Industry data is used in conjunction with a risk assessment model to demonstrate that the increase in predicted core damage frequency (CDF) resulting from RPV head penetration cracking is within regulatory guidance (RG 1.174).

Scope

The guidance provided in this document is applicable to the pressure boundary of the RPV head penetrations fabricated from Alloy 600 with Alloy 82/182 weld material. This plan does not address inspection requirements for Alloy 690/52/152 materials. For the purpose of this plan, through-wall cracks are defined as cracks that provide a leak path from the primary side environment to the nozzle annulus. Also for the purpose of this plan, it is assumed that a GL 88-05 walk down of the plant is effectively performed each refueling outage.

Risk Informed RPV Head Penetration Inspection Methodology Bases

CRDM/CEDM Nozzle Inspection Bases and Categorization

A risk informed inspection schedule for the CRDM/CEDM nozzles is presented below. Pertinent information and bases for this risk informed schedule is provided in Reference 1.

Probabilistic fracture mechanic (PFM) analyses using the Monte-Carlo simulation algorithm were performed to determine the probability of leakage and failure versus time for a set of input parameters, including head operating temperature, inspection types (visual or NDE) and inspection intervals. Input into this algorithm included experience-based time to leakage correlations that use a Weibull model of plant inspections to date, fracture mechanics analyses of various nozzle configurations containing axial and circumferential cracks and MRP developed statistical crack growth rate data for Alloy 600. The parameters used in the model were benchmarked against the most severe cracking found to date in the industry (Oconee-3) and produced results that are in agreement with experience to date. The moderate susceptibility limit was defined as the number of effective degradation years (EDYs) at which a plant reaches either a probability of one leaking nozzle = 20%, or a probability of net section collapse (NSC i.e. nozzle ejection) = 1×10^{-4} Effective Degradation Years, EDY, is defined as Effective Full Power Years @ 600F. The high susceptibility limit was defined as the EDYs at which a plant reaches a probability of nozzle ejection = 1×10^{-3}, which is consistent with NRC RG 1.174 guidance for change in Core Damage Frequency.

A comparison of the PFM results with those from deterministic analyses indicated that the risk-based limits are conservative.

The inspection schedule then employs plant categories defined by these risk-informed susceptibility limits (Reference 1) and specified as follows:

- Low susceptibility: less than 10 Effective Degradation Years, EDY (defined as 10 Effective Full Power Years @ 600F), without a leak or identified crack
- Moderate susceptibility: greater than or equal to 10 EDY and less than18 EDY without a leak or identified through-wall crack, and
- High susceptibility: greater than or equal to 18 EDY or units that have identified leaks or through-wall cracks.

Explanation of EDY and the method to relate this parameter to Effective Full Power Years at a given head temperature are provided in Reference 3.

CRDM/CEDM J-Groove Weld Inspection Bases

Circumferential cracks in the J-groove weld do not pose a significant risk of nozzle ejection. Cracking that is completely within the weld metal, even if 360^o around the nozzle, will not lead to ejection since the portion of the weld that remains attached to the outside surface of the nozzle will not be able to pass through the tight annular fit.

There would be a risk of ejection for the case of lack-of-fusion between the J-groove weld and outside surface of the nozzle over most of the weld circumference. However, the tolerable extent of lack-of-fusion, which still maintains 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.

Therefore, although the nozzle J-groove weld is anticipated to have a higher crack growth rate than the nozzle base metal, no inspection requirements and flaw evaluation procedures specific to the weld are required in addition to those otherwise specified or referenced in this document.

CRDM/CEDM Head Penetration Inspection and Flaw Acceptance Criteria

A penetration whose visual examination detects relevant conditions (See Reference 2) on the surface of the head at the nozzle-to-head interface shall be unacceptable for continued service until supplemental examinations or any evaluations are complete and identified flaws meet applicable acceptance criteria. Such relevant conditions may be evidence of borated water leakage from PWSCC cracks in the CRDM/CEDM nozzle's pressure boundary or evidence of general corrosion of the head from other primary coolant leakage. Guidance for visual examination of applicable relevant conditions is contained in Reference 2.

Leaks or through wall cracks should be further evaluated per the guidance provided below under "*Plants with leak(s) or through wall cracks identified*". Acceptance criteria proposed by the NRC for the flaws were specified in Reference 4. The MRP and ASME Section XI Code are working to develop final criteria, and until those criteria are issued, those of Reference 4 may be used. Additionally, the penetration containing relevant conditions shall be acceptable for continued service if the relevant conditions are corrected by a repair/replacement activity or by other corrective measures necessary to meet the acceptance criteria.

Plant-specific CRDM/CEDM Head Penetration Inspection Schedule

This inspection plan will be implemented at the next refueling outage following the plant's responses to NRC Bulletin 2001-01 or 2002-01. At the plant's option, the inspections in response to NRC Bulletin 2001-01 or 2002-01 may be substituted for the first inspection required by this plan. The subsequent re-inspection frequency will be based on the completion date of that previous inspection. Figure 1 is a flowchart of the inspection plan provided in the text below. The plant categories have been initially defined as noted above (and in Reference 1) based on preliminary bounding risk assessment activities. When a plant moves from one category to another (e.g. by gaining more EDY), the next inspection is dictated by the new category. The following head 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 (Reference 1). The cracking susceptibility of this material is used to bound the materials contained in the PWR fleet based on experience to date and therefore this inspection plan is considered to be conservative and applicable to all other domestic PWR plants.

For low susceptibility plants (< 10 Effective Degradation Years, EDY):

- Perform a Bare Metal Visual (BMV) examination of 100% of the CRDM/CEDM penetrations once per 10 years, beginning no later than the third ISI interval.
- Or, perform NDE (i.e., non-visual examination) of 100 % of the CRDM/CEDM penetrations and associated J-groove welds once per 10 years, beginning no later than the third ISI interval.

Note: if leakage, or through wall cracking is identified, the plant is reclassified as "high susceptibility". If only part through-wall cracks are identified, the plant is reclassified as "moderate susceptibility". The NDE examination of the J-groove weld should, as a minimum, identify if any cracking exists by either inspecting the wetted surface or inspecting the root of the J-groove weld.

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

- Perform a BMV examination of 100% of the CRDM/CEDM penetrations at the 1st RFO upon entering this category and once every 2 EDY not to exceed 5 EFPYs.
- Or, perform NDE (i.e., non-visual examination) of 100 % of the CRDM/CEDM penetrations and associated J-groove welds at the 1st RFO upon entering this category and once every 4 EDY not to exceed 10 EFPYs.

Note: if leakage, or through wall cracking is identified, the plant is reclassified as "high susceptibility". If part through-wall cracks are identified, the classification of the plant does not change. The NDE examination of the J-groove weld should, as a minimum, identify if any cracking exists by either inspecting the wetted surface or inspecting the root of the J-groove weld.

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

- Perform a BMV examination of 100% of the CRDM/CEDM penetrations at every RFO upon entering this category, and perform NDE (i.e., non-visual examination) of 100% of the CRDM/CEDM penetrations and associated J-groove welds or portions thereof that can be examined without incurring undue hardship within 4 EDY upon entering this category or issuance of this Plan, whichever is later.

Note: the population of examinations is based on providing additional defense-in-depth.

- Or, perform NDE (i.e., non-visual examination) of 100 % of the CRDM/CEDM penetrations and associated J-groove welds at the 1st RFO upon entering this category and once every 4 EDY not to exceed 6 EFPYs.

Note: the NDE examination of the J-groove weld should, as a minimum, identify if any cracking exists by either inspecting the wetted surface or inspecting the root of the J-groove weld.

The following information is provided as guidance for use when leakage and/or cracks are identified.

Plants with leak(s) or through wall cracks identified:

- **Discovery Inspection**
  - Perform a non-visual examination of the CRDM/CEDM penetrations and associated J-groove welds to characterize the crack or leak identified.
  - Indications are evaluated or repaired in accordance with approved 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. Any identified corrosion shall be evaluated and repaired as necessary.

- **Expansion of Inspection**
  Implement the following expansion guidance either during the Discovery Inspection or no later than the next RFO following discovery of a leak or through-wall crack in any CRDM/CEDM penetration or associated J-groove weld. Either:
  - Perform NDE (i.e., non-visual examination) of 100% of the CRDM/CEDM penetrations and associated J-groove welds.
    - Indications are evaluated or repaired in accordance with approved flaw evaluation guidelines (Reference 4).

- Or, perform an evaluation to justify continued visual examination until the RVH component is removed from service.
- Or, perform NDE at a frequency to be determined such that the 3x safety margin of a hypothetical circumferential crack growing above the weld is not exceeded prior to the next inspection.

Indications Left in Service

- Re-inspection of the indication is performed in accordance with the flaw evaluation guidelines (Reference 4) and projected crack growth.
- Re-inspection of an embedded flaw is performed at 1) the next scheduled refueling outage and once every ISI period thereafter, or 2) in accordance with a site-specific evaluation.

References

1. Technical Basis for CRDM/CEDM Top Head Penetration Inspection Plan, by Peter C. Riccardella and Nathaniel G. Cofie, Prepared for EPRI's MRP Alloy 600 Assessment Committee, DRAFT, May 2002.

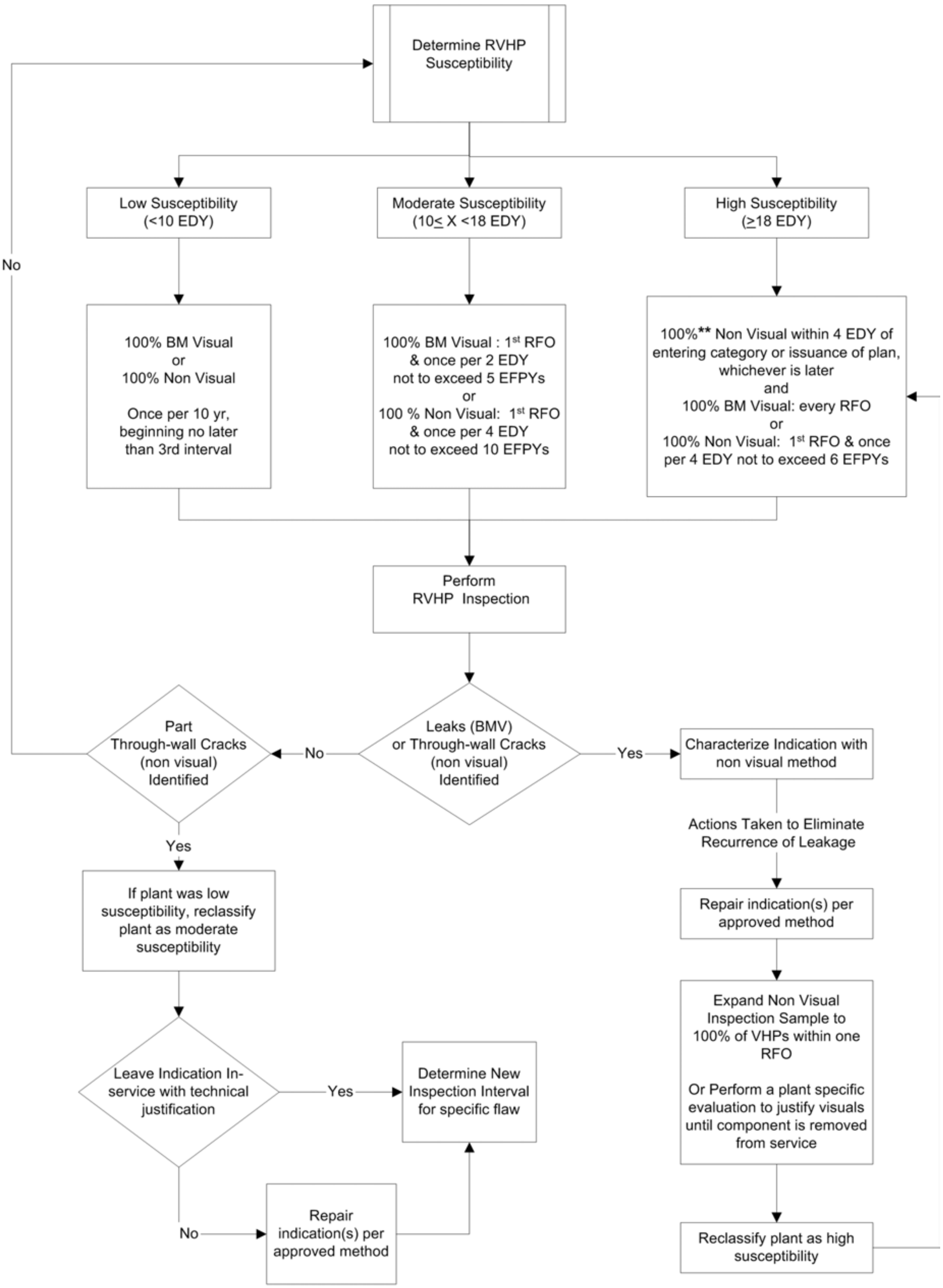
2. EPRI Technical Report, Visual Examination for Leakage of PWR Reactor Head Penetrations on Top of the RPV Head: Revision 1, Report 1006899, 4/04/01.

3. EPRI Interim Report, PWR Materials Reliability Project Interim Alloy 600 Safety Assessments for US PWR Plants (MPR-44), Part 2: Reactor Vessel Top Head Penetrations, TP-1001491, Part 2, May 2001.

4. Letter, Jack Strosnider, NRC, to Alex Marion, NEI, Subject: Flaw Evaluation Criteria, November 21, 2001.

Figure 1

PWR RPV Head Penetrations Inspection Flowchart



** 100% of the CRDM/CEDM penetrations and associated J-groove welds or portions thereof that can be examined without incurring undue hardship