Inspection Plan
PWR Reactor Pressure Vessel (RPV) Upper Head Penetrations
Revision 0
June 27, 2002

1.0 Purpose

The purpose of the industry inspection plan for RPV upper 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 foundation for a long-term management program for the RPV head penetrations; however, due to the evolving nature of this issue, this plan will be reviewed within three years from issuance. This inspection plan is not intended to supplant previous inspections, evaluations, or site-specific regulatory commitments. The industry inspection plan goal is to preserve structural integrity thereby ensuring safe operation. Structural integrity is defined as maintaining an acceptably low probability of developing primary water stress corrosion cracking (PWSCC) that could lead to nozzle ejection or the loss of ASME Code margins due to consequential wastage. This plan is primarily structured to address PWSCC as the fundamental failure mechanism. However, the inspection plan also applies a graduated approach to inspections to allow early detection of leakage, through-wall cracking, or incipient wastage prior to challenging structural integrity. 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).

2.0 Scope

The guidance provided in this document is applicable to the pressure boundary of the RPV upper head penetrations fabricated from Alloy 600 with Alloy 82/182 weld material. When appropriate technical information is available to define inspection requirements for Alloy 690/52/152 material, this inspection plan will be updated. 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.

3.0 Risk Informed RPV Upper Head Penetration Inspection Methodology Bases

3.1 RPV Upper Head Penetration Inspection Bases and Categorization

The RPV head penetration nozzle inspection schedule presented in Section 6.0 is based on a risk informed analysis of nozzle cracking within B&W designed and manufactured RPV nozzle material and head geometry. Pertinent information and bases for this risk informed schedule are provided in 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.

Probabilistic fracture mechanics (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 non-visual NDE) and inspection intervals. Input into this algorithm included an experience-based time to leakage correlation 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 (B&W Plants) and produced results that are in agreement with experience to date.

The moderate susceptibility limit was defined as the number of effective degradation years (EDY) 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}. EDY is defined as Effective Full Power Years (EFPY) @ 600F (RPV head temperature). Explanation of EDY and the method to relate this parameter to Effective Full Power Years at a given head temperature are provided in References 1 and 3. The high susceptibility limit was defined as the number of EDY 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. This NRC guidance specifies an acceptable change in core damage frequency (1×10^{-6} per plant year) for changes in plant design parameters, technical specifications, etc. Therefore, this inspection plan is designed to keep a change in a plant's core damage frequency associated with RPV head penetration cracking to less than 1×10^{-6} per plant year. Since the probability of core damage given a nozzle ejection has been estimated to be 1×10^{-3}, and the probability of nozzle cracking resulting in nozzle ejection is maintained, by implementation of this inspection plan, to be no greater than 1×10^{-3}, the resulting incremental change in core damage frequency under this plan is expected to be less than 1×10^{-6} (i.e., 1×10^{-3} times 1×10^{-3} equals 1×10^{-6}) per plant year.

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 EDY, 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, and
- High susceptibility: greater than or equal to 18 EDY or units that have identified leaks or through-wall cracks.

3.2 Penetration 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 material 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.

<u>4.0 RPV Head Flaw Acceptance Criteria</u>

Boric acid deposits on the RPV head shall be investigated to determine the source and for evidence suggesting general corrosion of the head from primary coolant leakage per the requirements of GL 88-05 (see Reference 2 guidance). When necessary to allow adequate examination, the boric acid crystals and residue shall be removed and a subsequent visual exam (direct or remote) of the previously obscured surfaces shall be performed to evaluate and determine the condition of the underlying base materials. Based on these visual exams, corrective actions shall be taken in accordance with the site’s corrective action program.

A penetration whose visual examination detects relevant conditions indicative of boric acid deposits emanating from the nozzle-to-head annulus (see Reference 2) shall be unacceptable for continued service until supplemental examinations or evaluations are complete and any identified flaws meet applicable acceptance criteria.

Leaks or through wall cracks should be further evaluated per the guidance provided below under Section 6.4, "*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 originally 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.

5.0 Examination Requirements (Critical Attributes)

5.1 Visual Examinations - the following general prerequisites and performance criteria apply:

- the RPV head penetration area must be accessible consistent with the tools and techniques to be employed and the applicable inspection requirements identified below,
- visual access to the area of interest should not be compromised by the presence of existing deposits on the RPV head, or other factors that could interfere with the examination, and
- written procedure(s) should be developed with appropriate controls over technique and examiner qualification.

5.1.1 Bare Metal Visual (BMV) Examination – a detailed visual examination meeting the following additional requirements:

- Optical aid(s) (for example, camera) used should be able to resolve the 0.044-inch (1.118-mm) character height at a distance of no more than 1 foot (0.305 m) (see Reference 2), and
- The entire intersection between the RPV head and each penetration can be readily viewed as well as approximately one inch of the adjacent bare surface of the upper head.

5.1.2 Supplemental Visual (SV) Examination – a direct or remote visual examination, which may be addressed through a plant's 88-05 program, with the following additional attributes intended to identify evidence of significant boric acid accumulation that may be associated with incipient wastage:

- RV 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 with:
        - major dimension greater than 4" (i.e., large enough to not be hidden behind a penetration tube), and
        - with thickness such that the condition of the underlying metal cannot be readily determined (i.e., not a film or stain),
    - Accessibility – sufficient to observe the minimum detectable condition located anywhere within the area of interest (viewing the entire circumference of each RPV head penetration is not required).

- RV heads with closely conforming rigid insulation - the following alternative requirements may be met:
    - Area of interest - entire periphery and outer surface of the permanently installed insulation (including joints between insulation segments, and annular gaps between the insulation and RPV head penetrations) and exposed portions of RPV head and flange
    - Minimum detectable condition - any evidence of RCS leakage such as flow emanating from beneath the insulation, bulging insulation, or boric acid accumulation emerging upward through the joints and gaps between adjoining insulation panels from the RV head surface,
    - Accessibility – sufficient to observe the minimum detectable condition located anywhere within the area of interest.

5.2 Non-Visual Examination (NDE)

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

6.0 Plant-specific RPV Head Penetration Inspection Schedule

This inspection plan will be implemented at the next refueling outage following completion of the plant's head penetration inspections in response 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 if they meet the critical inspection attributes required of this plan. The subsequent re-inspection frequency will be based on the completion date of that previous inspection. Inspection methods may be chosen on a per-penetration basis (e.g., non visual examination may used for some penetrations, while visual is used for others). Figures 1 and 2 are flowcharts 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 re-inspection frequency is dictated by the new category and the method of the previous exam. If the previous inspection is within the frequency of the new category, no new inspection is required upon entering the new category.

The BMV and NDE examination frequencies have been conservatively established based on the risk informed analyses of nozzle cracking (Reference 1), primarily to protect against circumferential cracking and potential nozzle ejection. The SV examination frequency is conservatively established to enhance detection of incipient wastage from all sources on and around the RPV head and to ensure the subsequent BMV is not obscured by boric acid accumulation. The SV frequency may be revised at a future date with an appropriate technical basis. The BMV and NDE examination frequencies have been conservatively established based on the risk informed analyses of nozzle cracking (Reference 1), primarily to protect against circumferential cracking and potential nozzle ejection. The SV examination frequency is conservatively established to enhance detection of incipient wastage from all sources on and around the RPV head and to ensure the subsequent BMV is not obscured by boric acid accumulation. The SV frequency may be revised at a future date with an appropriate technical basis. The present SV frequency assumes that each plant's GL 88-05 program implemented at each RFO includes a 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).

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

6.1.1 Perform either 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.

6.1.2 In addition, perform Supplemental Visual examinations every 2nd refueling outage during those outages when the 6.1.1 examinations are not required. The initial inspection following a 100% non-visual examination of all RPV head penetrations and associated J-groove welds may be performed during the 3rd refueling outage following the 100% non-visual examination.

6.1.3 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".

6.1.4 For plants whose inspection periods are controlled either by EDY or EFPY, the inspection periods may be increased by a maximum of 0.5 EFPY for scheduling purposes.

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

6.2.1 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. Alternatively, 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.

6.2.2 In addition, perform Supplemental Visual examinations every 2nd refueling outage during those outages when the 6.2.1 examinations are not required. The initial inspection following a 100% non-visual examination of all RPV head penetrations and associated J-groove welds may be performed during the 3rd refueling outage following the 100% non-visual examination.

6.2.3 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.

6.2.4 For plants whose inspection periods are controlled either by EDY or EFPY, the inspection periods may be increased by a maximum of 0.5 EFPY for scheduling purposes.

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

6.3.1 Perform a BMV examination of 100% of the RPV head penetrations at every RFO upon entering this category. Alternatively, 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 6 EFPY.

6.3.2 In addition, perform Supplemental Visual examinations every 2nd refueling outage during those outages when the 6.3.1 examinations are not required. The initial inspection following a 100% non-visual examination of all RPV head penetrations and associated J-groove welds may be performed during the 3rd refueling outage following the 100% non-visual examination.

6.3.3 For plants performing visual examinations to meet the requirements of 6.3.1, 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. This additional NDE requirement is based on providing defense-in-depth.

6.3.4 For plants whose inspection periods are controlled either by EDY or EFPY, the inspection periods may be increased by a maximum of 0.5 EFPY for scheduling purposes.

6.4 Plants With Leak(s) Or Through Wall Cracks Identified:

6.4.1 Discovery Inspection

- Perform a non-visual examination of the leaking RPV head penetration(s) 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.

6.4.2 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 RPV head penetration or associated J-groove weld. Either:

- 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 approved flaw evaluation guidelines.
- Or, perform a plant-specific technical evaluation to justify continued visual examination until the component is removed from service.

6.5 Plants With Part-Through Wall Cracks Identified:

6.5.1 Discovery Inspection

- Indications are evaluated or repaired in accordance with approved flaw evaluation guidelines.

6.5.2 Indications Left in Service

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

7.0 As-Left RPV Head Cleanliness Condition

Upon completion of each visual examination (BMV or SV), the RPV head upper surface should be clean of debris and deposits consistent with the following guidance to prevent interference with the 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,
- 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 visual examination (BMV or SV).

8.0 References

1. Technical Basis for RPV Upper Head Penetration Inspection Plan, by Peter C. Riccardella and Nathaniel G. Cofie, Prepared for EPRI's MRP PWR Alloy 600 Assessment Committee, June 2002.

2. EPRI Technical Report, Visual Examination for Leakage of PWR Reactor Head Penetrations on Top of the RPV Head: Revision 1, Report 1006899, 4/04/02.

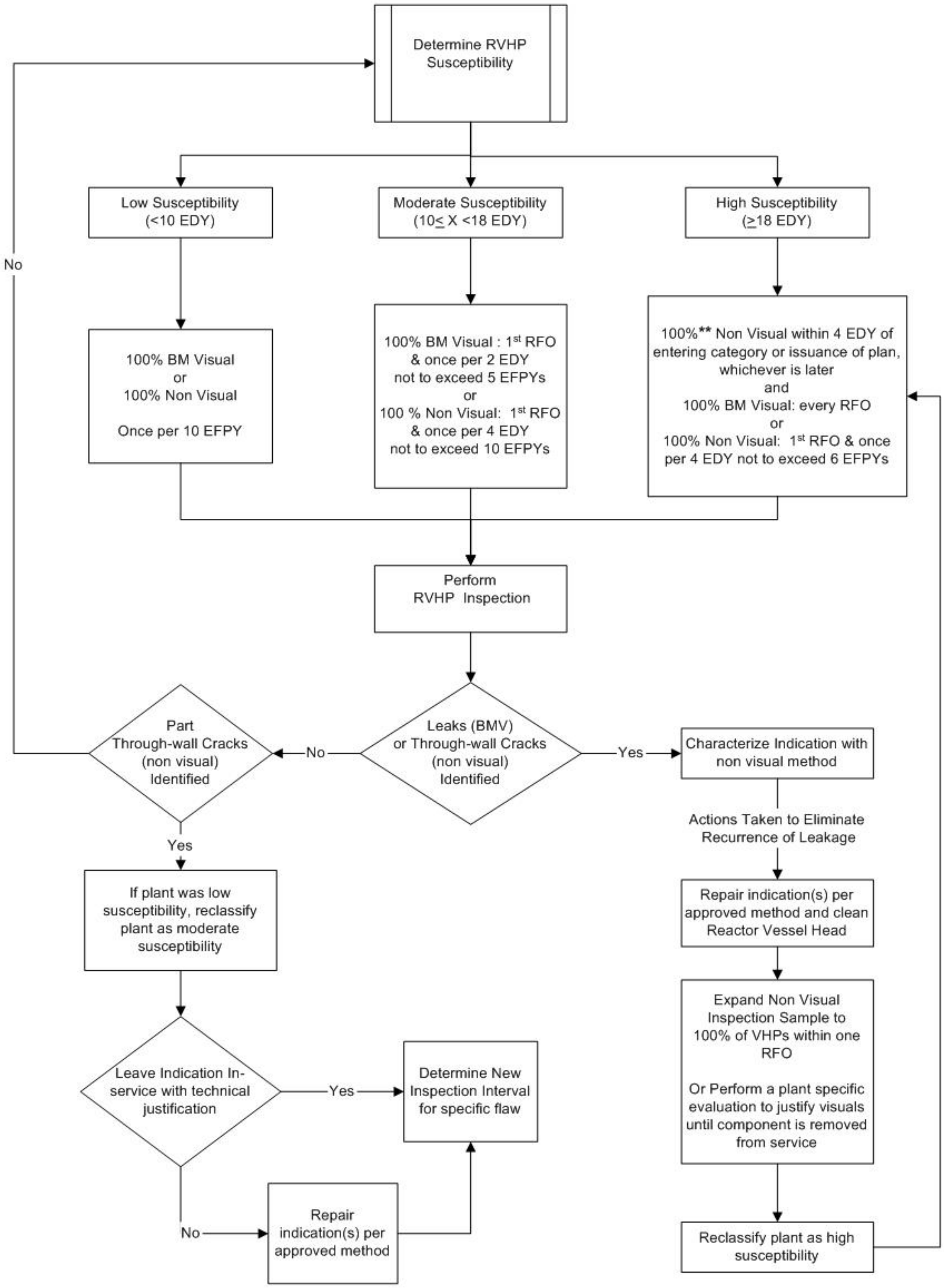
3. EPRI Interim Report, PWR Materials Reliability Project Interim Alloy 600 Safety Assessments for US PWR Plants (MPR-44), Part 2: Reactor Vessel Top Head Penetrations, TP-1001491, Part 2, May 2001.

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

5. Probability of Detecting Leaks in RPV Upper Head Nozzles by Visual Inspections, by Steve Hunt and Mark Fleming, Prepared for EPRI's MRP PWR Alloy 600 Assessment Committee, June 2002.

Figure 1

PWR RPV Head Penetrations Inspection Flowchart

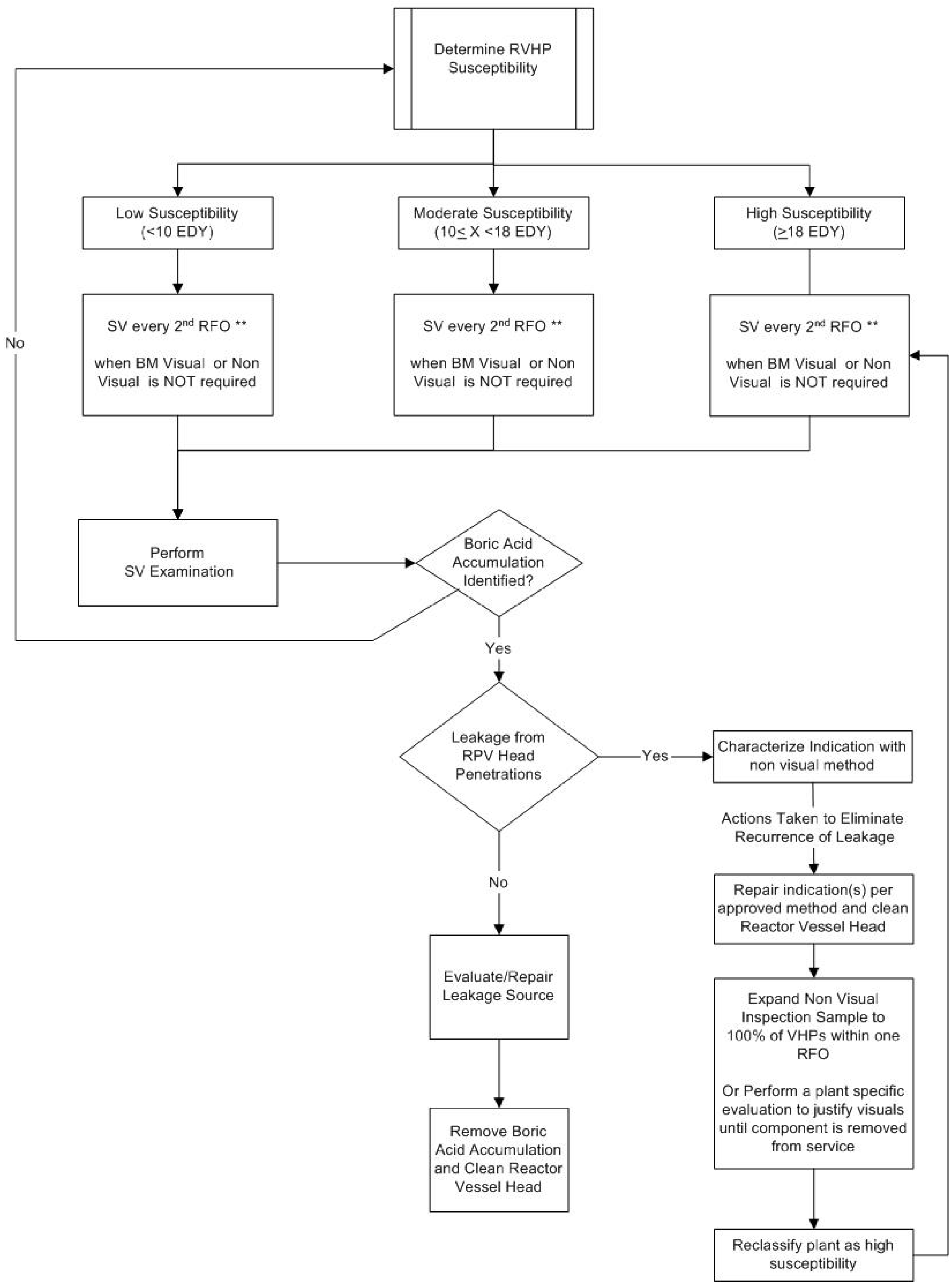


** 100% of the RPV Head penetrations and associated J-groove welds or portions thereof that can be examined without undertaking physical modifications for accessibilty.

Note: This flowchart addresses the RPV Head penetration inspection schedule, not the supplemental visual examinations (See Figure 2).

Figure 2

Supplemental Visual Inspection Flowchart



** The initial inspection following a 100% non-visual examination of all RPV head penetrations and associated J-groove welds may be performed during the 3rd refueling outage following the 100% non-visual examination.