# Materials Reliability Program Inspection Plan for Reactor Vessel Closure Head Penetrations in U.S. PWR Plants (MRP-117)

**1007830**

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# REPORT SUMMARY


Since late 2000, U.S. inspections have shown that although most of the observed nozzle cracking is axial in orientation, several circumferentially oriented cracks have developed above the top of the J-groove weld. Such circumferential cracks could potentially lead to nozzle ejection and a small- or medium-break loss of coolant accident (LOCA) if the circumferential crack were to grow most of the way around the nozzle, typically to a size of at least 330°. A second potential safety concern is boric acid corrosion of the low alloy steel material of the reactor vessel closure head (RVCH). In response to these concerns, the U.S. Nuclear Regulatory Commission (NRC) issued several generic communications, including NRC Order EA-03-009, which specifies interim inspection requirements for all domestic RVCHs and their penetrations. Inspections of penetration nozzles in PWR RVCHs have shown that these alloy 600 components are susceptible to aging degradation due to primary water stress corrosion cracking (PWSCC).

## Objectives
The objective of the industry inspection plan is to preserve 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 or the loss of ASME Code margins due to consequential wastage. The Materials Reliability Program MRP-110 safety assessment report demonstrates, given a program of inspections performed under the requirements of this inspection plan, an extremely low probability of damage to the nuclear fuel core and a low probability of primary coolant leakage associated with the potential for aging degradation of the nickel-alloy components of RVCH penetrations.

## Approach
The dominant potential safety concerns associated with PWSCC of the penetration nozzles or their J-groove attachment welds are nozzle ejection due to large circumferential cracks located in the nozzle above the top of the J-groove weld and structurally significant loss of head shell material due to excessive boric acid wastage resulting from leakage and concentration of the borated reactor coolant. The inspection coverage and frequency requirements of this inspection plan were designed on the basis of the nozzle ejection and head wastage evaluations summarized in the safety assessment report for RVCH penetrations (MRP-110).

## Results
Bare metal visual and nonvisual nondestructive examination (NDE) requirements have been established based on conservative deterministic and probabilistic safety assessments and probability of leakage calculations. A bare metal visual (BMV) examination and three types of nonvisual NDE have been defined. This report summarizes the inspection plan requirements for RVCHs with alloy 600 nozzles. This inspection plan also provides requirements for inspection of replacement heads with penetrations fabricated from alloy 690 material. The requirement is that

a BMV examination be performed every third refueling outage or five calendar years, whichever occurs first. The nonvisual examination requirement is that an initial in-service nonvisual NDE be performed within 10 calendar years following head replacement, with repeat nonvisual NDEs to be performed every 10 calendar years thereafter.

### EPRI Perspective

This report and the associated safety assessment report (MRP-110) completely replace the previous MRP inspection plan, document MRP-75, Revision 1, issued in 2002. The associated safety assessment report (MRP-110) is the top-level safety assessment document for RVCH penetrations. As such, it references other closely related documents, including the nozzle ejection assessments (MRP-105, MRP-104, and MRP-103), crack growth rate evaluations (MRP-21, MRP-55), and inspection guidance and demonstration reports (EPRI 1007842 and MRP-89). Also referenced is MRP-111, which evaluates the expected performance of the replacement head materials—alloy 690 nozzles and alloy 52/152 welds—given currently available data.

This inspection plan document and the referenced reports constitute a technical basis for setting inspection requirements for RVCHs and their penetrations. However, Revision 0 of this document, MRP-117, is not intended for implementation by plants. Rather, it has been issued to support the ASME committees for Section XI of the Boiler and Pressure Vessel Code in their efforts to develop Code Case N-729, "Alternative Examination Requirements for PWR Closure Heads With Nozzles Having Pressure-Retaining Partial-Penetration Welds." This Revision 0 is being submitted to the NRC staff for comment. As such, the guidance provided in this document is not required under the implementation protocol of the Nuclear Energy Institute (NEI) 03-08 at this time.

### Keywords

Primary Water Stress Corrosion Cracking (PWSCC)
Boric Acid Corrosion
Alloy 600
Alloy 82/182
Alloy 690
Alloy 52/152
Control Rod Drive Mechanism (CRDM) Nozzle
Control Element Drive Mechanism (CEDM) Nozzle
J-Groove Weld
Reactor Vessel Closure Head (RVCH) Penetration
Inspection Plan

# ABSTRACT

This report provides inspection rules for reactor vessel closure heads (RVCHs) and their penetrations for U.S. pressurized water reactor (PWR) plants, including requirements for periodic bare metal visual examinations for evidence of primary coolant leakage and periodic nonvisual nondestructive examinations for indications of service-induced cracking. However, Revision 0 of this document is not intended for implementation by plants. Rather it has been issued to support the ASME committees for Section XI of the Boiler and Pressure Vessel Code in their efforts to develop Code Case N-729, "Alternative Examination Requirements for PWR Closure Heads With Nozzles Having Pressure-Retaining Partial-Penetration Welds," and this Revision 0 is being submitted to the NRC staff for comment. As such, the guidance provided in this document is not required under the implementation protocol of NEI 03-08 at this time.

Inspections of penetration nozzles in PWR vessel closure heads have shown that these nickel-chromium-iron Alloy 600 components may be susceptible to active aging degradation due to primary water stress corrosion cracking (PWSCC). The dominant potential safety concerns associated with PWSCC of the penetration nozzles or their J-groove attachment welds are:

1. nozzle ejection due to large circumferential cracks located in the nozzle above the top of the J-groove weld, and
2. structurally significant loss of head shell material due to excessive boric acid wastage resulting from leakage and concentration of the borated reactor coolant.

The safety evaluations summarized in report MRP-110, *Materials Reliability Program Reactor Vessel Closure Head Penetration Safety Assessment for U.S. PWR Plants*, show that protection against nozzle ejection and significant head wastage is maintained given the inspections defined by this inspection plan. Specifically, the MRP-110 safety assessment report demonstrates, given a program of inspections performed under the requirements of Sections 4, 5, and 6 of this document, an extremely low probability of damage to the nuclear fuel core and a low probability of primary coolant leakage associated with the potential for aging degradation of the nickel-alloy components of RVCH penetrations.

This report is organized as follows:

- Section 1 provides a brief background discussion, explains the purpose of the inspection plan, and presents the general approach of the inspection plan.
- Section 2 defines the scope of the inspection plan. The plan covers all RVCH penetrations in U.S. PWR plants that are attached to the inside surface of the head by a J-groove attachment weld, including Alloy 690 nozzles attached with Alloy 52/152 J-groove welds in replacement heads.

- Section 3 briefly discusses the technical bases for the inspection plan and references the top-level safety assessment report (MRP-110), as well as the main lower-level evaluations associated with PWSCC of RVCH penetrations.
- Section 4 cites the acceptance criteria that are applicable to service-induced cracking of RVCH penetrations that is detected by visual examination for evidence of primary coolant leakage or by nonvisual examination techniques, such as ultrasonic or eddy current testing.
- Section 5 defines the minimum examination requirements, including inspection coverage, that apply for bare metal visual examination and three types of nonvisual nondestructive examination.
- Section 6 defines the inspection schedule for both visual and nonvisual examinations under the inspection plan. Flowcharts are provided that summarize the rules for determining the minimum frequency of inspection.
- Section 7 lists the ongoing activities of the MRP in the area of aging degradation of RVCH penetrations that could potentially warrant future revisions to this inspection plan document. If warranted by evaluations of newly available plant inspection or laboratory test data, the requirements of this inspection plan will be revised by the MRP as appropriate.
- Section 8 lists the references cited in this report.
- Appendix A provides the analysis procedures that shall be used to demonstrate the adequacy of the NDE examination zone for a particular RVCH penetration in the event of impediments to satisfaction of the examination zone and coverage requirements of Section 5.2 such as physical obstructions, threads on the nozzle end, or an ultrasonic testing corner shadow zone.
- Appendix B presents the methodology for calculating the effective degradation year (EDY) and reinspection year (RIY) parameters that are used in Section 6 to define the frequency of inspections. Each of these two parameters is a measure of effective time at temperature. Appendix B includes an example EDY/RIY calculation.

# ACKNOWLEDGMENTS

This report is a product of the Alloy 600 Issues Task Group (ITG) of the Materials Reliability Program (MRP). Larry Mathews of Southern Nuclear Operating Company is the chairman of the Alloy 600 ITG, and Craig Harrington of TXU Energy is the chairman of the Reactor Vessel Head Working Group within the Alloy 600 ITG. Christine King is the EPRI project manager for the Alloy 600 ITG. The inspection plan for reactor vessel closure head penetrations represents a consensus of the members of the MRP.

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# 1
# INTRODUCTION

## 1.1 Background

Inspections of penetration nozzles in PWR reactor vessel closure heads (RVCHs) have shown that these Alloy 600 components are susceptible to aging degradation due to primary water stress corrosion cracking (PWSCC). Several PWR plants in the U.S. have experienced cracks in control rod drive mechanism (CRDM) nozzles and J-groove welds, and some of these plants have experienced primary coolant leaks from through-thickness cracks in the nozzles or welds. The stresses that make the nickel-chromium-iron Alloy 600 nozzles and their Alloy 82/182 J-groove attachment welds susceptible to cracking are induced by shrinkage as the J-groove attachment weld joining the penetration nozzle to the inside surface of the RVCH cools during vessel fabrication.

Since late 2000, inspections in the U.S. have shown that although most of the observed nozzle cracking is axial in orientation, several circumferentially oriented cracks have developed above the top of the J-groove weld, including 165° through-wall circumferential cracks in two nozzles at one plant. Such circumferential cracks could potentially lead to nozzle ejection and a small- or medium-break loss of coolant accident (LOCA) if the circumferential crack were to grow most of the way around the nozzle, typically to a size of at least 330°. A second potential safety concern is boric acid corrosion of the low alloy steel material of the RVCH. The large wastage cavity observed at another plant in 2002 resulted from what is believed to be at least six years of leakage and concentration of the borated reactor coolant. As of June 2004, the heads at 11 U.S. units have been replaced due to concerns regarding PWSCC, and at least 22 additional heads have been scheduled for replacement.

In response to these concerns, the U.S. NRC has issued three bulletins and one order:

- NRC Bulletin 2001-01, "Circumferential Cracking of Reactor Pressure Vessel Head Penetration Nozzles" [1]
- NRC Bulletin 2002-01, "Reactor Pressure Vessel Head Degradation and Reactor Coolant Pressure Boundary Integrity" [2]
- NRC Bulletin 2002-02, "Reactor Pressure Vessel Head and Vessel Head Penetration Nozzle Inspection Programs" [3]
- NRC Order EA-03-009, "Order Establishing Interim Inspection Requirements for Reactor Pressure Vessel Heads at Pressurized Water Reactors" [4]

The Order, which was originally issued on February 11, 2003, and revised on February 20, 2004, specifies interim inspection requirements for domestic reactor vessel closure heads and their penetrations.

## 1.2 Purpose of Inspection Plan

The objective of the industry inspection plan is to preserve 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 or the loss of ASME Code margins due to consequential wastage. Specifically, the MRP-110 [5] safety assessment report demonstrates an extremely low probability of damage to the nuclear fuel core and a low probability of primary coolant leakage associated with the potential for aging degradation of the nickel-alloy components of RVCH penetrations. The safety assessment necessarily assumes that an appropriately designed program of inspections is implemented. The industry inspection plan requirements contained in Sections 5 and 6 are designed to fulfill these inherent inspection assumptions of MRP-110 and thereby ensure that the safety assessment conclusions remain valid.

## 1.3 Approach

The dominant potential safety concerns associated with PWSCC of the penetration nozzles or their J-groove attachment welds are nozzle ejection due to large circumferential cracks located in the nozzle above the top of the J-groove weld and structurally significant loss of head shell material due to excessive boric acid wastage resulting from leakage and concentration of the borated reactor coolant. The inspection coverage and frequency requirements of Sections 5 and 6 were designed on the basis of the nozzle ejection and head wastage evaluations summarized in the safety assessment report for RVCH penetrations (MRP-110 [5]). The nonvisual inspections that are required by the inspection plan are intended to detect any service-induced cracking before the cracking could lead to through-wall cracking, leakage, circumferential cracking above the top of the J-groove weld, release of loose parts, or incipient boric acid wastage of the low alloy steel head. The periodic bare metal visual examinations for evidence of primary coolant leakage provide additional assurance against nozzle ejection and significant head wastage in the unlikely case that through-wall cracking were still to occur.

The safety assessment report (MRP-110 [5]) and its referenced lower-level documents demonstrate protection against nozzle ejection and significant head wastage while also demonstrating additional defense in depth through maintenance of a low probability of through-wall cracking and leakage of the primary coolant. MRP-110 is the top-level safety assessment document for RVCH penetrations, and as such it references other closely related documents, including the nozzle ejection assessments (MRP-105 [6], MRP-104 [7], and MRP-103 [8]), related inspection experience summary (MRP-87 [9]), crack growth rate evaluations (MRP-21 [10], MRP-55 [11]), and inspection guidance and demonstration reports (EPRI 1007842 [12] and MRP-89 [13]).

### *1.3.1 Inspection Requirements for Heads With Alloy 600 Nozzles*

The inspection plan requires periodic rigorous bare metal visual examinations for all Alloy 600 RVCH penetrations in order to provide early indication of any primary coolant leakage based on the presence of boric acid deposit accumulations. Such a discovery requires additional NDE to be performed to bound the potential damage. The plan also requires periodic nonvisual examinations—using ultrasonic testing, eddy current testing, or dye penetrant testing—of the nozzle base metal for all Alloy 600 RVCH penetrations attached to the inside head surface with

J-groove attachment welds. More frequent nonvisual NDE inspections are required for plants that do not perform nonvisual examinations of the wetted surface of the J-groove welds for indications of service-induced cracking as part of the NDE inspection. Although weld-initiated cracking has to date been observed to be limited to heads in certain fabrication and operating condition categories and the heads in these categories have largely been replaced, weld inspection data produced under this inspection plan will be monitored.

### *1.3.2 Inspection Requirements for Replacement Heads With Alloy 690 Nozzles*

Section 6 also provides requirements for inspection of replacement heads having penetrations fabricated from Alloy 690 nozzles with Alloy 52/152 J-groove attachment welds. These requirements are based on the results of the study presented in report MRP-111 [14]. This study shows, on the basis of both laboratory test data and plant experience, that Alloy 690 base metal and Alloy 52/152 weld metals are much more resistant to PWSCC initiation than Alloy 600 base metal and Alloy 82/182 weld metals. The MRP-111 evaluation of laboratory and plant experience indicates a material improvement factor of at least 26 for Alloy 690 versus mill-annealed Alloy 600, with larger improvement factors expected with more years of experience accumulated in the laboratory and field.

The visual examination requirement for such replacement heads is that a rigorous bare metal visual examination be performed every third refueling outage or 5 calendar years, whichever occurs first. The nonvisual examination requirement is that an initial in-service nonvisual examination be performed within 10 calendar years following head replacement, with repeat nonvisual examinations to be performed every 10 calendar years thereafter.

## 1.4 Inspection Plan Status and Implementation Protocol

This Revision 0 of this document is not intended for implementation by plants. Rather it has been issued to support the ASME committees for Section XI of the Boiler and Pressure Vessel Code in their efforts to develop Code Case N-729, “Alternative Examination Requirements for PWR Closure Heads With Nozzles Having Pressure-Retaining Partial-Penetration Welds,” and this Revision 0 is being submitted to the NRC staff for comment. As such, the rules for inspection of RVCH penetrations and disposition of any service-induced cracking detected listed in Sections 4, 5, and 6 and Appendices A and B of this document are not required under the implementation protocol of NEI 03-08 at this time.

However, if this document is implemented by the industry under the implementation protocol of NEI 03-08, then it is intended that all these requirements would become mandatory for all PWR plants in the U.S., with the exception of the following two good practice recommendations:

- The recommendation in Section 5.1 that the current industry guidance document regarding the performance of visual examination of the RVCH and its penetrations [12] should be consulted
- The recommendation in Section 6.5.2 that the MRP pre-service inspection guidance for replacement RVCHs [15] be considered

# 2 SCOPE

## 2.1 All Reactor Vessel Closure Heads and All Nozzles With J-groove Attachment Welds

The inspection plan in this document is applicable to all reactor vessel closure heads (RVCHs) in domestic PWR plants. Inspection requirements are provided for heads having nozzles fabricated from Alloy 600 material and attached to the inside head surface with Alloy 82/182 J-groove attachment welds. In addition, separate inspection requirements are provided for replacement heads having nozzles fabricated from Alloy 690 material and attached to the inside head surface with Alloy 52/152 J-groove attachment welds.

The inspection plan addresses the potential for aging degradation of the subject RVCH penetrations. The top-level safety assessment report for RVCH penetrations (MRP-110 [5]) describes the basic designs of the various types of nozzles attached to the inside head surface with J-groove attachment welds. Most of these nozzles are control rod drive mechanism (CRDM) nozzles, control element drive mechanism (CEDM) nozzles, in-core instrumentation (ICI) nozzles, and head vent nozzles.[1]

## 2.2 Nozzles Without J-groove Attachment Welds

In addition to the 5,139 RVCH nozzles with J-groove attachment welds in the set of original heads for the 69 currently operating PWR plants, there are 30 nozzles that do not include J-groove attachment welds. These are four "butt weld" design Alloy 600 head vent nozzles (welded to a low alloy steel nozzle inserted in the head with a full penetration weld) at four units, six internals support housing nozzles at two units, and 20 auxiliary head adapter nozzles at five units. At this limited number of plants, the RVCH penetrations that do not include J-groove welds are addressed by the requirements of plant-specific in-service inspection (ISI) programs. Therefore, the inspection requirements of the inspection plan do not include nonvisual NDE inspections of the types of RVCH penetrations that do not include J-groove welds. Because the analyses documented in MRP-110 (e.g., failure mode and effect analysis, stress analyses) do not generally apply to these nozzles, specific nonvisual inspection requirements are not provided herein.

Note that of this group of 30 nozzles in the set of original heads, only the four "butt weld" design head vent nozzles are installed in heads not operating near the reactor cold leg temperature.

[1] Note that not all CRDM and CEDM nozzles are used for control rod (element) drive shafts. Some CRDM nozzles are empty (spares) or are used for part-length shafts, thermocouple instrumentation, or the reactor vessel level instrumentation system, and some CEDM nozzles house heated junction thermocouple instrumentation.

Alloy 600 material operating near the cold leg temperature has a significantly reduced likelihood of cracking compared to nozzles operating near the hot leg temperature because PWSCC is a thermally activated process.

## 2.3 Definition of Through-Wall Cracking

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 interference fit zone, often termed the “annulus,” on the nozzle OD above the top of the J-groove weld.

# 3 INSPECTION METHODOLOGY BASES

The MRP-110 [5] safety assessment report and its referenced lower-level documents [6–14] demonstrate protection against nozzle ejection and significant head wastage, and provide additional defense in depth through maintenance of a low probability of through-wall cracking and leakage of the primary coolant. MRP-110 assumes implementation of an appropriately designed inspection regime to ensure both present and future component condition compliance with the safety assessment bases. The program of inspections defined within Sections 5 and 6 herein were evaluated with the same analytical tools used in the safety assessment to ensure compliance with its inherent inspection assumptions. The nonvisual inspections that are required by the inspection plan are intended to detect any service-induced cracking before the cracking could lead to through-wall cracking, leakage, circumferential cracking above the top of the J-groove weld, release of loose parts, or incipient boric acid wastage of the low alloy steel head. The periodic bare metal visual examinations for evidence of primary coolant leakage provide additional assurance against nozzle ejection and significant head wastage in the unlikely case that through-wall cracking were still to occur.

## 3.1 Protection Against Pressure Boundary Leakage

The failure mode and effect analysis (FMEA) and flaw tolerance calculations presented in MRP-110 [5] show that the dominant potential nuclear safety concerns associated with aging degradation of RVCH penetrations are nozzle ejection and head or cladding rupture due to boric acid wastage. The small leak rates (e.g., on the order of $1\times10^{-6}$ to $1\times10^{-5}$ gpm) typically associated with through-wall cracking in RVCH penetrations do not represent a direct safety concern. However, through-wall cracking is a necessary precursor for boric acid wastage of the low alloy steel material of the RVCH. In addition, experience has shown (supported by stress analyses) that through-wall cracking is a likely precursor of circumferential nozzle cracking that could grow to a size that could cause net section collapse and nozzle ejection.

Therefore, the inspection plan provides additional defense in depth by maintaining a low probability of leakage due to aging degradation of RVCH penetrations. The main MRP nozzle ejection evaluation (MRP-105 [6]) presents probability of leakage calculations that confirm that the inspection plan results in a low probability of leakage. In addition, the probability of leakage calculations, assuming inspections are performed under this MRP inspection plan, show very similar results for representative sample cases compared to a program of inspections performed in accordance with the revised NRC Order [4]. Furthermore, as discussed in detail in Section 4 of MRP-110 [5], the heads that remain in service are mostly in materials and fabrication categories that have experienced relatively low rates of PWSCC, even given adjustment of the results for the effect of head temperature.

## 3.2 Protection Against Circumferential Nozzle Cracking and Nozzle Ejection

MRP-105 [6] is the principal nozzle ejection safety assessment report and covers all the domestic operating units on the basis of four representative sample plants. This report includes both deterministic calculations of circumferential crack growth and a full probabilistic Monte Carlo simulation of the process leading to nozzle ejection that reflects the uncertainties in the various process parameters. MRP-104 [7] presents deterministic nozzle ejection calculations specifically for the 48 currently operating Westinghouse design and 14 currently operating Combustion Engineering design plants, including an assessment of the effect of normal operating pressure and temperature on the initial interference fit between the nozzle and head. MRP-103 [8] is specific to the seven B&W design plants and includes a deterministic calculation and an event-tree probabilistic safety assessment. As discussed in Section 6 of MRP-110 [5], these assessments are similar in form but are based on different input assumptions for a few parameters.

The probabilistic fracture mechanics (PFM) analyses of MRP-105 [6] using the Monte-Carlo simulation algorithm were performed to determine the probability of failure versus time for a set of input parameters, including head operating temperature, inspection types (visual or nonvisual NDE), and inspection intervals. Input into this algorithm included an experience-based time to leakage correlation that uses 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 (MRP-55 [11]). The parameters used in the model were benchmarked against the complete set of reported circumferential cracks located in the nozzle wall above or near the top of the J-groove weld in U.S. plants, and produced results that are in agreement with experience to date.

These nozzle ejection safety assessment reports [6,7,8] demonstrate that there is considerable structural margin against nozzle ejection due to circumferential cracking because of the time required for a circumferential crack to grow to the critical size, typically at least 330°. The nonvisual examination intervals required by Section 6, which are defined on the basis of effective time at temperature (reinspection years—RIYs) accumulated since the time of the previous nonvisual examination and the type of the previous nonvisual examination, support these complementary safety assessments.

In particular, the PFM assessments of MRP-105 [6] demonstrate an acceptably low probability of nozzle ejection given the range of conditional core damage probabilities (CCDPs) that bound the nozzle ejection event (see Section 8 of MRP-110 [5]). Given the inspections required by Section 6, the calculated core damage frequency (nozzle ejection frequency times CCDP) associated with the maximum predicted nozzle ejection frequency (about $7\times10^{-4}$ per plant year [6]) is on the order of $1\times10^{-6}$ per plant year. This result is consistent with the philosophy of NRC Regulatory Guide 1.174, which specifies an acceptable change in core damage frequency of $1\times10^{-6}$ per plant year for permanent changes in plant design parameters, technical specifications, etc. and which also may be applied to evaluation of inspection program changes. Furthermore, as demonstrated in MRP-105 for four representative plant examples, the core damage frequency associated with this industry inspection plan is very similar to the corresponding values calculated assuming inspections performed in accordance with NRC Order EA-03-009 [4]. Finally, note that MRP-105 includes coverage and probability of detection assumptions for both the bare metal visual and the nonvisual NDE inspections consistent with the examination requirements in Section 5.

## 3.3 Protection Against Generation of Loose Parts

A potential safety concern in addition to nozzle ejection and boric acid corrosion is the generation of loose parts due to RVCH nozzle cracking of the lower extension of the nozzle below the J-groove weld. Loose parts may either be captured by a drive rod or released to the flow in the upper plenum of the reactor vessel. Captured loose parts have the potential to prevent control rod motion, while non-captured loose parts have the potential to prevent control rod motion or to damage fuel pins, steam generator tubes, the steam generator tubesheet, or the bottom reactor vessel area. Release of a non-captured loose part would require either a 360° below-weld circumferential crack or multiple below-weld axial and circumferential cracks in a nozzle, depending on whether the penetration contains a drive rod. Because nozzle ejection is always assumed to produce a LOCA with a conditional core damage probability (CCDP) of roughly $1\times10^{-3}$ to $1\times10^{-2}$, nozzle ejection, rather than loose parts generation, is the limiting event for determining an appropriate reinspection interval for nonvisual examinations. The nonvisual examination zone requirements in Section 5, however, include coverage of the high stress zone in the nozzle below the J-groove weld.

## 3.4 Protection Against Significant Boric Acid Wastage of the Low Alloy Steel Head

Section 7 of the top-level safety assessment report (MRP-110 [5]) describes the evaluations that verify that protection against boric acid wastage is provided by the bare metal visual examinations for evidence of leakage required by Sections 5 and 6 of this document. This conclusion is supported by the experience with over 50 leaking CRDM nozzles, including the observation that the large wastage cavity at one plant would have been detected relatively early in the wastage progression had bare metal visual examinations been performed at each refueling outage, and likely even if performed less frequently, with appropriate corrective action. In addition, the wastage modeling presented in MRP-110 supports the adequacy of bare metal visual examination performed according to the sensitivity and coverage requirements of Section 5.1 and at the frequency defined in Section 6. For plants other than those categorized as low susceptibility on the basis of cumulative EDYs, Section 6 requires that bare metal visual examinations be performed during every refueling outage. The bare metal visual examination interval of every third refueling outage or 5 calendar years, whichever occurs first, for heads with low EDY and no previous cracking detected that required repair is appropriate given:

- the very low probability of leakage calculated for such heads [6],
- the greater time required for crack growth to occur to the point that the leak rate increases to a rate that may support rapid boric acid wastage (see Section 7 of MRP-110), and
- the general visual assessment including under the insulation from multiple access points that is required during the other refueling outages to check for gross evidence of the buildup of boron and/or corrosion product deposits.

## 3.5 Penetration J-Groove Weld Inspections

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° 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., greater than 75% of the circumference [5]). There is no precedent for such an extensive area of lack-of-fusion, and inspections performed to date do not show large areas of lack-of-fusion [5].

Furthermore, as discussed in Section 4 of MRP-110 [5], weld-initiated cracking has to date been observed to be limited to heads in certain fabrication and operating condition categories with high EDY values, and the heads in these categories have largely been replaced. However, the nozzle J-groove weld material is anticipated on average to have a higher crack growth rate than the nozzle base metal (MRP-21 [10]). Weld cracking could lead to leakage of primary coolant to the annulus on the nozzle OD, but not directly to nozzle ejection. The resulting damage could be wastage of the low alloy steel head, but the weld crack itself does not present a safety concern. However, cracking that initiates on the wetted surface of a J-groove weld or buttering and is circumferential in orientation may have the potential to grow and produce a circumferential crack in the nozzle wall located just below the top of the J-groove weld. Such a crack could conceivably grow around the nozzle circumference to allow nozzle ejection in the absence of leakage to the annulus.

Given these potential concerns, Section 6 requires more frequent nonvisual NDE inspections for plants that do not perform nonvisual examinations of the wetted surface of the J-groove welds as part of the NDE inspection. The weld inspection data produced under this inspection plan will be monitored.

## 3.6 Guidance for Replacement Heads With Alloy 690 Nozzles

The inspection requirements for replacement heads with Alloy 690 nozzles are based on the results of the study presented in report MRP-111 [14] and summarized in the safety assessment (MRP-110 [5]). This study shows, on the basis of both extensive laboratory test data and plant experience, that Alloy 690 base metal and Alloy 52/152 weld metals are much more resistant to PWSCC initiation than Alloy 600 base metal and Alloy 82/182 weld metals. Alloy 690/52/152 materials have been in service for over 15 calendar years with no reported indications of PWSCC in any components, including Alloy 690 steam generator tubes, Alloy 690 replacement nozzles, and Alloy 52/152 welds. The MRP-111 evaluation of laboratory and plant experience indicates a material improvement factor of at least 26 for Alloy 690 versus mill-annealed Alloy 600, with larger improvement factors expected with more years of experience accumulated in the laboratory and field.[2]

[2] The average material improvement factor of 26 for Alloy 690 versus mill-annealed Alloy 600 calculated in MRP-111 [14] using laboratory test data is conservatively low as no PWSCC was detected in the laboratory PWSCC

This factor of 26 is much greater than the maximum time factor of 6.7 implied by the nonvisual NDE interval of 10 years required in Section 6 for replacement heads with Alloy 690/52/152 materials in comparison to the minimum reinspection interval of 1.5 years for heads with Alloy 600/82/182 materials. Assuming the material improvement factor of 26, the nonvisual NDE interval of 10 years for replacement heads with Alloy 690/52/152 materials is equivalent to a reinspection interval of only 7 months for heads with Alloy 600/82/182 materials. Therefore, the reinspection interval of 10 years for replacement heads with Alloy 690/52/152 materials represents almost a factor of 4 conservatism versus that which is supported by extensive laboratory data and more than 15 years of plant experience.

## 3.7 Bare Metal Visual (BMV) Examination Coverage Requirement

In the case of unobstructed RVCH upper surfaces, the visual examination requirement is for a direct, bare metal visual (BMV) examination of the entire head upper surface, including 100% (360°) of each nozzle-head intersection. However, in the case of installed obstructions on the head upper surface, Section 5.1.1 establishes the following minimum coverage requirements for the BMV examination:

- Coverage of the entire unobstructed portion of each nozzle-head intersection, but no less than 90% coverage of up to five (5) nozzle-head intersections and no less than 100% (360°) coverage of the remaining nozzle-head intersections.
- Coverage of the entire unobstructed RVCH upper surface above the head flange, but no less than 95% of the RVCH surface in the penetration region as defined in Figure 5-1.

These coverage requirements are appropriate to ensure safety and plant defense in depth. The BMV examinations provide two principal elements of protection. First, the BMV examination acts as a backup examination to the required periodic nonvisual NDE inspections in protecting against the possibility of nozzle ejection due to circumferential cracking. The probabilistic fracture mechanics model of MRP-105 [6] for evaluating nozzle ejection considers only a modest benefit of BMV examinations in triggering detection of circumferential nozzle flaws as this model assumes only a 60% probability of detection (POD) for leaking penetrations.[3] Therefore, the BMV coverage requirements are well within the parameters of the main nozzle ejection evaluations.

Second, as discussed in Section 3.4 above, the BMV examination provides protection against significant boric acid wastage of the low alloy steel head material. Plant experience with over 50 leaking CRDM nozzles documented in Section 7 of MRP-110 [5] and wastage modeling documented in Appendix E of MRP-110 show that significant amounts of wastage (i.e., >> 1 $in^3$) will very likely be preceded by relatively large amounts of boric acid deposits (i.e., >> 10 $in^3$) on the head upper surface. Moreover, the maximum uninspected portion of the total set of nozzle-head intersections is only on the order of 1% per the BMV coverage requirements. Given the periodic nonvisual NDE inspections that are also performed, there is an extremely low

initiation tests for Alloys 690, 52, and 152. All the original reactor vessel heads in the U.S. were fabricated using mill-annealed Alloy 600 nozzles.

[3] The MRP-105 probabilistic model uses a greatly reduced BMV leakage POD for nozzles for which leakage was missed by the previous inspection in the Monte Carlo life simulation. The full 60% POD applies only for the first simulated BMV examination after the time that a specific nozzle is simulated to be leaking.

probability that significant wastage could occur given the BMV examination requirements of this document.

These same results from the previous paragraph also provide the technical basis for the visual examination acceptance criteria provided in Section 4.1.2 for "masked" penetrations. These acceptance criteria permit a limit of three (3) penetrations masked by deposits produced by leakage from a source above the head without necessarily triggering appropriate supplemental inspections including surface and/or volumetric examination of the affected penetrations before the head is returned to service. There is no plausible common failure mode that could lead to both a masking leak source from above the reactor vessel head and a through-wall crack on the same penetration tube. Therefore, the unlikely possibility of small amounts of deposits emanating from one or more of three masked penetrations—particularly with no leakage detected from any of the unmasked penetrations[4]—is well within the assumptions of the nozzle ejection [6] and wastage [5] evaluations.

## 3.8 Nonvisual Examination Zone Requirement

The examination zone coverage requirements defined in paragraph 5.2.1 for the nonvisual examination techniques—ultrasonic, eddy current, and dye penetrant testing—are based on stress analysis calculations and inspection experience for RVCH penetrations as documented in MRP-95 [16]. Both the stress results and inspection experience show that PWSCC is highly unlikely to initiate outside the examination zone defined in paragraph 5.2.1. Even if cracking did initiate outside the examination zone, the time to reach crack locations and sizes that represent a significant nozzle ejection or wastage concern is consistent with the nonvisual and visual reinspection intervals and examination zones.

As required in Section 5.2.1, all plants shall verify that their specific RVCH penetration designs are bounded by the MRP-95 [16] determination of the appropriate examination zone for the nozzle base metal. Alternatively, plants shall develop appropriate site-specific examination zone requirements per Appendix A or paragraph 6.8.

[4] Leakage detected from any of the unmasked penetrations would trigger an immediate nonvisual NDE inspection of all the J-groove RVCH penetrations per the requirements of Section 6.7.1.

# 4
# ACCEPTANCE CRITERIA

## 4.1 Acceptance Criteria for Visual Examinations for Evidence of Leakage

### *4.1.1 Determination of Source of Leakage and Corrective Actions*

The source of boron or corrosion product deposits detected on the reactor vessel closure head or related insulation, discovered during inspections required under this inspection plan or otherwise, shall be determined, and the head in the area of the deposits shall be examined for evidence suggesting general corrosion from primary coolant leakage [12]. When necessary to allow adequate visual examination, the boron and/or corrosion product deposits and residue shall be removed and the bare metal visual examination (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 examinations, corrective actions shall be taken in accordance with the site's corrective action program. A penetration for which visual examination detects relevant conditions indicative of boron or corrosion product deposits emanating from the nozzle-to-head annulus [12] shall be unacceptable for continued service until supplemental examinations or evaluations are complete and any identified flaws meet applicable acceptance criteria [17,18]. Such supplemental examinations shall be appropriate to the conditions found to verify the integrity of the affected area and penetrations.

If the source of boron or corrosion product deposits located adjacent to a nozzle-to-head intersection cannot be determined with high confidence (using established methods such as deposit morphology, appearance of streaks on nozzle emanating from above the head, etc.), then the appropriate supplemental examinations, including surface and/or volumetric examination of the affected penetration, shall be performed to verify the integrity of the affected area and penetration before the head is returned to service.

### *4.1.2 Masked Nozzle-to-Head Intersections*

If the source of boron or corrosion product deposits located adjacent to a nozzle-to-head intersection is determined with high confidence to be a mechanical joint, seal weld, or other component located above the head, then the affected penetration is termed "masked" because of the possibility that a small volume of deposits emanating from the nozzle-to-head annulus may be obscured by the larger volume of deposits resulting from the established source of leakage above the head.

If four (4) or more masked penetrations are detected during a refueling outage, then appropriate supplemental examinations, including surface and/or volumetric examination of all the masked penetrations, shall be performed to verify the integrity of the masked penetrations and the regions of the head surrounding the masked penetrations before the head is returned to service. The technical basis for not requiring supplemental examinations for up to three (3) masked penetrations is addressed in Section 3.7. If not already required by Section 6.2 or 6.5.1, a bare metal visual (BMV) examination (defined in Section 5.1) shall be performed during the next refueling outage for all masked penetrations (nozzle-to-head intersection and immediate surrounding head top surface) not examined using supplemental methods including surface and/or volumetric examination.

## 4.2 Acceptance Criteria for Nonvisual Nondestructive Examinations

Flaw acceptance criteria for RVCH penetration nozzles have been developed by the ASME Boiler & Pressure Vessel Code Section XI committees [17,18]. These criteria shall be applied for acceptance of detected flaws in RVCH penetration nozzles. Note that these ASME criteria are essentially identical to previously published NRC guidance [19]. 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
# EXAMINATION REQUIREMENTS

## 5.1 Visual Examinations

The following general prerequisites and performance criteria apply:

- The RVCH penetration area shall 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 shall not be compromised by the presence of existing deposits on the RVCH, or other factors that could interfere with the examination,
- Optical aid(s) (e.g., camera) used shall be able to resolve the 0.158-inch (4-mm) character height under conditions similar to those for the actual inspection (lighting, view angle, etc.) [12], and
- Written procedure(s) shall be developed with appropriate controls over technique and examiner qualification.

The current industry guidance document regarding the performance of visual examination of the RVCH and its penetrations [12] should be consulted. Acceptance criteria for bare metal visual (BMV) examinations are provided in Section 4.1.

### *5.1.1 Bare Metal Visual (BMV) Examination*

The bare metal visual (BMV) examination is a direct visual examination of the bare-metal surface of the entire RVCH upper surface above the head flange, including 100% (360°) of the intersection of each nozzle with the head upper surface.

However, for heads having portions of the upper surface above the head flange or segments of individual nozzle-head intersections obscured by physical obstructions (i.e., insulation, insulation support feet, shroud support ring/lug, etc.), the following specific requirements shall be met to demonstrate compliance:

- Coverage of the entire unobstructed portion of each nozzle-head intersection, but no less than 90% coverage of up to five (5) nozzle-head intersections and no less than 100% (360°) coverage of the remaining nozzle-head intersections.
- Coverage of the entire unobstructed RVCH upper surface above the head flange, but no less than 95% of the RVCH surface in the penetration region as defined in Figure 5-1.

- Allowed obscured areas shall be examined upslope and downslope from the obstructions (whether within the penetration region defined in Figure 5-1 or not) to identify any evidence of boron or corrosion product deposits.
- If any evidence of boron or corrosion product deposits are identified adjacent to, beneath, or downslope from an obstruction, the RVCH upper surface under the obstruction shall be examined in the area of the identified evidence to ensure that the RVCH is not degraded.

The technical basis for these BMV coverage requirements are discussed in Section 3.7. Alternatively, plants may develop appropriate site-specific BMV coverage requirements per paragraph 6.8.

### *5.1.2 As-Left Head Cleanliness Condition*

Upon completion of each BMV examination, the plant shall clean the RVCH upper surface as necessary to ensure that the upper surface is free of debris and deposits, consistent with the following guidance to prevent interference with the subsequent detection of evidence 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 subsequent BMV examinations. The evaluation shall also include an assessment of the potential for the cleanliness exception to contribute to degradation of the low alloy steel material of the RVCH.

## 5.2 Nonvisual NDE Examination

### *5.2.1 Examination Zone Volume for Nozzle Base Metal*

The nozzle base metal examination volume for each RVCH penetration is defined in Figure 5-2:

- For nozzles having an incidence angle, $\theta$, less than or equal to 30° or having a nominal outside diameter greater than or equal to 4.5 inches, the inspection volume A-B-C-D is from 1.5 inches above the highest point of the root of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) to 1.5 inches below the lowest point at the toe of the J-groove weld on a horizontal plane perpendicular to the nozzle axis (or the bottom of the nozzle if less than 1.5 inches).
- For nozzles having an incidence angle, $\theta$, greater than 30° and a nominal outside diameter less than 4.5 inches, the inspection volume A-B-C-D is from 1.0 inch above the highest point of the root of the J-groove weld (on a horizontal plane perpendicular to the nozzle axis) to 1.0 inch below the lowest point at the toe of the J-groove weld on a horizontal plane perpendicular to the nozzle axis (or the bottom of the nozzle if less than 1.0 inch).

All plants shall verify that their specific RVCH penetration designs are bounded by the MRP-95 [16] determination of the above examination zone. Alternatively, plants shall develop appropriate site-specific examination zone requirements per Appendix A or paragraph 6.8.

### *5.2.2 Inspection Methods*

Three types of nonvisual NDE examination are defined below. The reinspection interval determined under Section 6 is in part a function of the NDE type previously met. The ultrasonic testing and eddy current testing inspections shall be performed using demonstrated inspection processes.

#### 5.2.2.1 Nonvisual NDE Type 3

The Type 3 nonvisual examination shall include an examination in accordance with either (i), (ii), or (iii) below for each of the RVCH penetrations attached to the inside head surface with a J-groove weld:

(i) Ultrasonic testing of the RVCH penetration nozzle volume (i.e., nozzle base material) for the examination zone A-B-C-D defined in paragraph 5.2.1, or

(ii) Eddy current testing or dye penetrant testing of the wetted surface of the J-groove weld (filler metal and buttering) and the wetted surface of the RVCH penetration nozzle base material for the examination zone defined in paragraph 5.2.1 (surfaces A-D and F-E-C in Figure 5-2),[5] or

(iii) A combination of (i) and (ii) applied to portions of the base metal volume A-B-C-D and the wetted surfaces A-D and F-E-C, defined in Figure 5-2. Substitution of a portion of a volumetric examination on a nozzle with a surface examination may be performed with the following requirements:

1. On nozzle material below the toe of the J-groove weld (E in Figure 5-2), both the outside diameter (E-C) and inside diameter (E'-D) surfaces of the nozzle shall be examined.
2. On nozzle material above the toe of the J-groove weld (E in Figure 5-2), surface examination of the inside diameter surface (A-E') of the nozzle is permitted provided a surface examination of the J-groove weld (F-E) is also performed.

#### 5.2.2.2 Nonvisual NDE Type 2

The Type 2 nonvisual NDE shall satisfy all the requirements of the Type 3 nonvisual NDE. In addition, the Type 2 nonvisual NDE shall satisfy the following two requirements:

[5] For the wetted surface NDE option, it is not required to inspect the bottom (end) surface of the nozzle, even if the distance from the lowest point at the toe of the J-groove weld to the end of the nozzle is less than the "*a*" dimension shown in Figure 5-2. Based on the evaluations documented in MRP-110 [5], it is extremely unlikely that any potential cracks in the bottom (end) surface of the nozzle that do not contact the nozzle ID nor the nozzle OD below the J-groove weld toe could lead to structurally significant cracking or wastage before the time of the next required nonvisual NDE inspection. It is also unlikely that such potential cracks in the bottom surface could lead to any leakage before the time of the next required nonvisual NDE inspection.

- Ultrasonic testing per paragraph 5.2.2.1(i) of at least 95% of the RVCH penetrations attached to the inside head surface with J-groove welds
- Eddy current testing or dye penetrant testing of the wetted surface of the J-groove welds (surface F-E in Figure 5-2) for at least 50% of the RVCH penetrations attached to the inside head surface with J-groove welds

#### 5.2.2.3 Nonvisual NDE Type 1

The Type 1 nonvisual NDE shall satisfy all the requirements of the Type 3 nonvisual NDE. In addition, the Type 1 nonvisual NDE shall satisfy the following two requirements:

- Ultrasonic testing per paragraph 5.2.2.1(i) of at least 95% of the RVCH penetrations attached to the inside head surface with J-groove welds
- Eddy current testing or dye penetrant testing of the wetted surface of the J-groove welds (surface F-E in Figure 5-2) for 100% of the RVCH penetrations attached to the inside head surface with J-groove welds

### *5.2.3 Inspection Coverage Requirements*

#### 5.2.3.1 Nozzle Base Metal Coverage

The following nozzle base metal coverage requirements apply to the Type 1, 2, and 3 NDE inspections:

(i) For the volumetric examination option in paragraph 5.2.2.1(i), at least 90% of the volume of nozzle base metal within the examination zone A-B-C-D defined in Figure 5-2 shall be covered for each penetration. In addition, at least 95% of the total nozzle base metal volume within the examination zone A-B-C-D for all RVCH nozzles attached to the head inside surface with J-groove welds shall be covered.

(ii) For the surface examination option in paragraph 5.2.2.1(ii), at least 90% of the total wetted surface area within the examination zone (A-D plus F-E-C) defined in Figure 5-2 shall be covered for each penetration. In addition, at least 95% of the total wetted surface area within the examination zone (A-D plus F-E-C) for all RVCH nozzles attached to the head inside surface with J-groove welds shall be covered.

(iii) For the combination examination option in paragraph 5.2.2.1(iii), the combination of ultrasonic, eddy current, and dye penetrant testing shall result in equivalent coverage no less than the minimum coverage of volumes and surfaces required under the volumetric (i) or surface (ii) examination options above.

#### 5.2.3.2 Weld Wetted Surface Coverage

The following weld wetted surface coverage requirements apply only to the Type 1 and 2 NDE inspections:

For an inspection to meet the requirements of a Type 1 or 2 nonvisual NDE, 90% of the weld wetted surface (surface F-E in Figure 5-2) shall be covered by the surface examinations for each individual penetration that is counted toward the 50% (Type 2) or 100% (Type 1) number of penetrations requirement. In addition, at least 95% of the total wetted surface area for the set of penetrations included in the 50% (Type 2) or 100% (Type 1) penetration count shall be covered.

### *5.2.4 Exceptions to NDE Examination Zone and Coverage Requirements*

Appendix A provides the analysis procedures that shall be used to demonstrate the adequacy of the NDE examination zone for a particular RVCH penetration in the event of impediments to satisfaction of the above examination zone and coverage requirements such as physical obstructions, threads on the nozzle end, or an ultrasonic testing corner shadow zone. Alternatively, plants may develop appropriate site-specific NDE coverage requirements per paragraph 6.8.

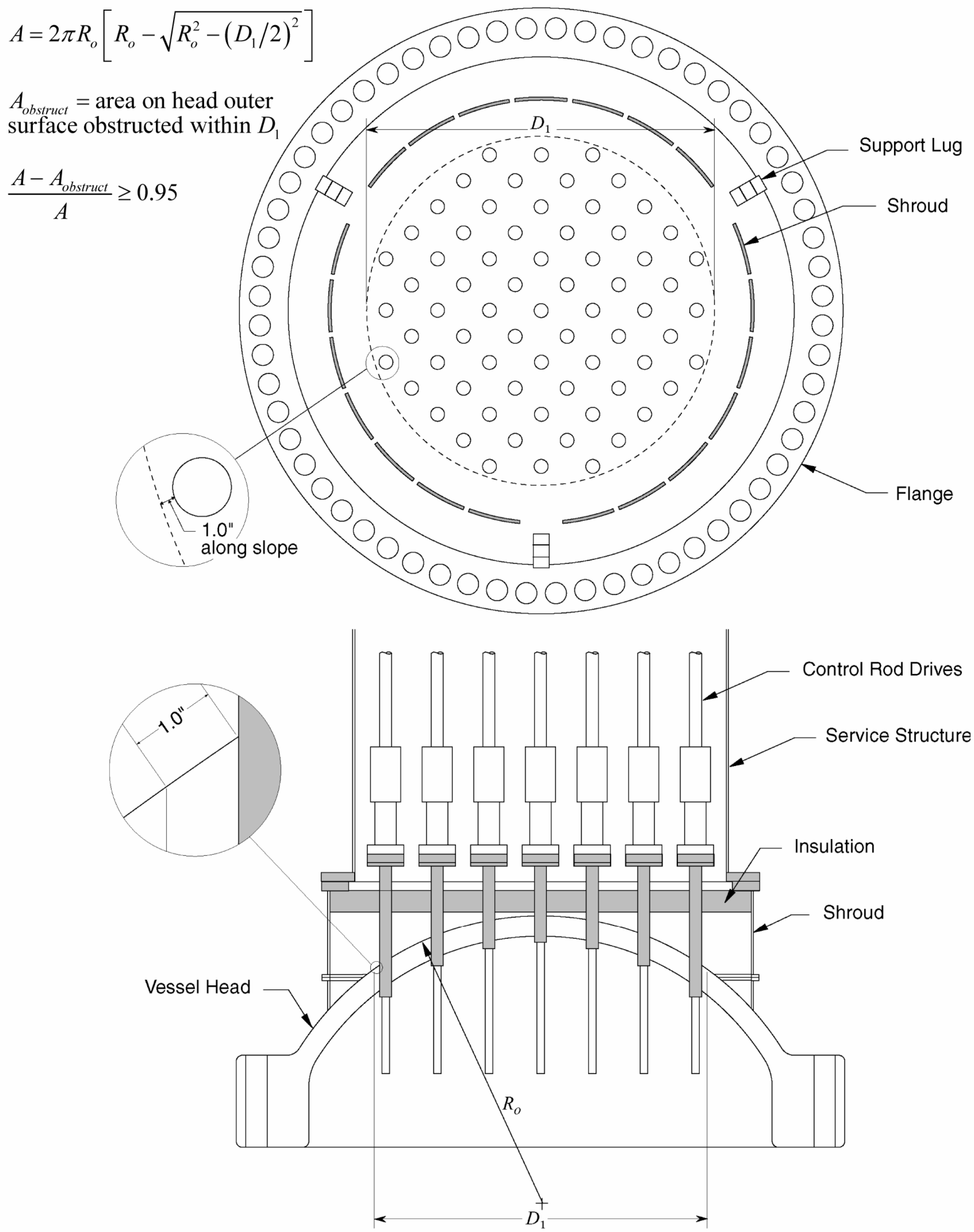
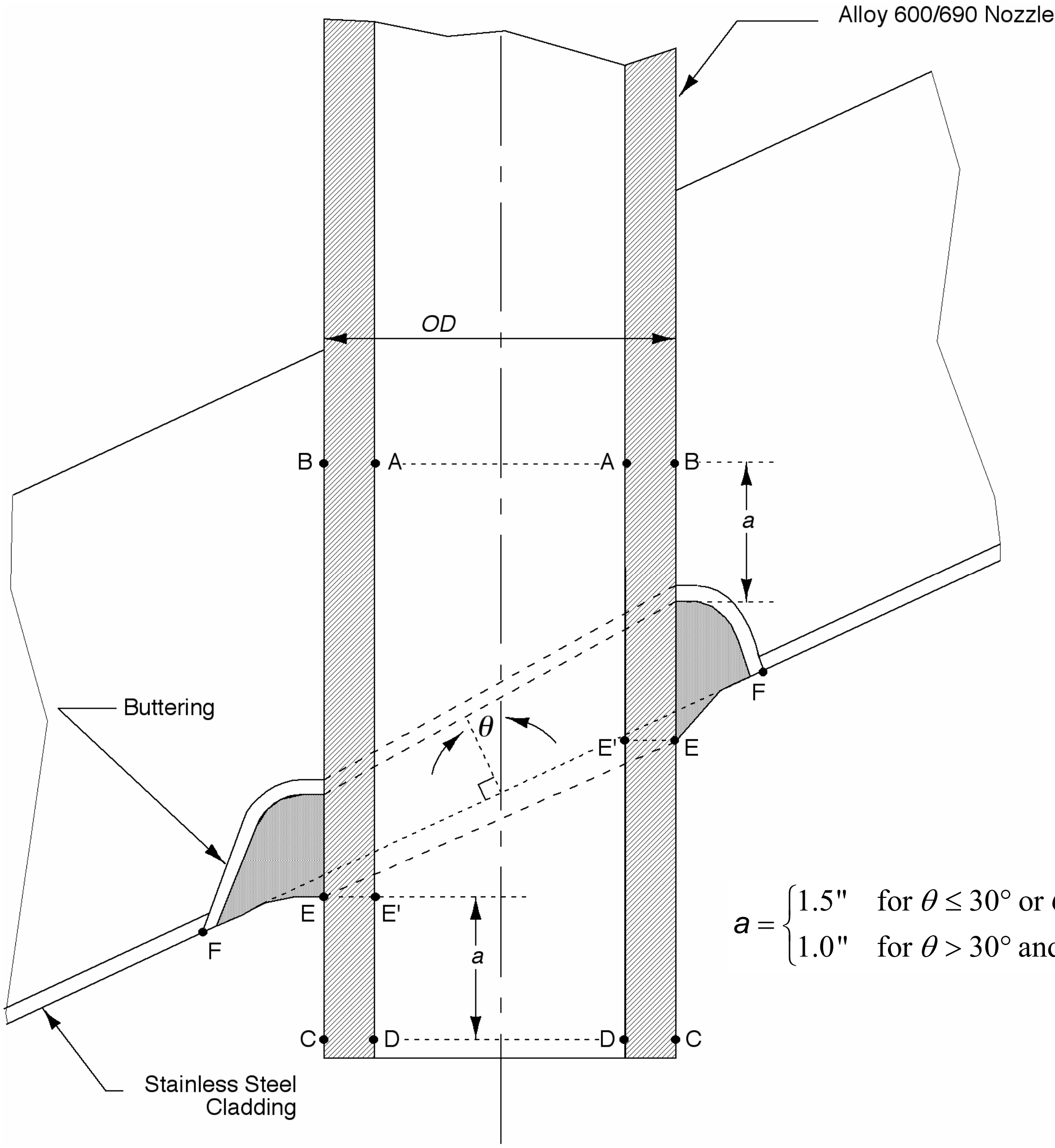



**Figure 5-1**
**Bare Metal Visual Examination Zone for RVCHs With Surface Obscured by Physical Obstructions**




$$a = \begin{cases} 1.5" & \text{for } \theta \leq 30° \text{ or } OD \geq 4.5" \\ 1.0" & \text{for } \theta > 30° \text{ and } OD < 4.5" \end{cases}$$

| | | |
|---|---|---|
| **A-B-C-D** | **=** | **Volumetric examination zone for the tube (base metal)** |
| **A-D** | **=** | **Surface examination zone for the tube ID** |
| **F-E-C** | **=** | **Surface examination zone for the J-groove weld (filler metal and buttering) and tube OD below the weld** |
| **F-E** | **=** | **Surface examination zone for the J-groove weld (filler metal and buttering)** |

**Figure 5-2**
**NDE Inspection Zone**

# 6
# PLANT-SPECIFIC INSPECTION SCHEDULE

Separate requirements are presented below for reactor vessel closure heads (RVCHs) with Alloy 600 nozzles and Alloy 82/182 J-groove welds and for replacement RVCHs with Alloy 690 nozzles and Alloy 52/152 J-groove welds. None of the examinations specified under Section 6 are required for RVCHs during the outage that the head is being replaced. The calendar time intervals cited in Section 6, with the exception of the 10-year interval required for nonvisual examination of replacement heads with Alloy 690 nozzles (paragraphs 6.5.3 and 6.5.4), are actual time intervals and shall not be interpreted as allowing an extension for scheduling purposes.

## 6.1 Time-at-Temperature Calculations

Because the rate of PWSCC degradation is dependent on temperature, the timing of BMV and nonvisual NDE inspections required under this inspection plan for heads with Alloy 600 nozzles is based on calculation of two parameters that are measures of operating time normalized to a reference RVCH temperature through an Arrhenius relationship. As such, these parameters depend only on the thermal activation energy and the plant-specific operating time and head temperature. As described below, the effective degradation year (EDY) and reinspection year (RIY) parameters, calculated with differing activation energies, are applied in the inspection requirements of the inspection plan. Operating time is measured in terms of effective full power years (EFPY) of operation.

Note that because of thermal-hydraulic differences between reactor designs, some plants operate with a head temperature close to or somewhat below the hot leg temperature, while other plants are designed to direct a small amount of internals bypass flow to the upper head plenum region and thus operate with a head temperature closer to the cold leg temperature.

### *6.1.1 Cumulative EDYs Based on Thermal Activation Energy for Crack Initiation*

The number of effective degradation years (EDYs) accumulated since initial head operation based on the thermal activation energy for crack initiation is an accepted measure of the potential for RVCH penetration cracking to occur. Therefore, this parameter is used to establish the timing of the baseline nonvisual examination (Section 6.3) and the reinspection interval for BMV examinations (Section 6.2). Appendix B explains how the EDY parameter is calculated and demonstrates the procedure for an example case, including the use of the thermal activation energy appropriate for crack initiation of 50 kcal/mole [20]. The EDY calculation shall include all operating time projected until the time of the upcoming refueling outage.

### *6.1.2 Interval of RIYs Based on Thermal Activation Energy for Crack Growth*

The thermal activation energy for crack growth differs from that for crack initiation and is an appropriate parameter for setting the timing of repeat nonvisual NDE inspections that are intended to prevent pressure boundary leakage from occurring. Conservatively one may assume that a nonvisual NDE inspection leaves behind a crack of a size just below the detectability limit for the type of NDE performed. The time for this hypothetical flaw to grow until pressure boundary leakage is produced would be governed by a crack growth mechanism, and PWSCC research has shown growth to be less temperature-sensitive than crack initiation. Therefore, the reinspection interval for nonvisual NDEs for heads with Alloy 600 nozzles (Section 6.4) is based on the reinspection year (RIY) parameter, which is defined using the thermal activation energy appropriate for crack growth of 31 kcal/mole [10,11]. Appendix B explains how the RIY parameter is calculated and demonstrates the procedure for an example case.

The lower choice for the activation energy in the RIY parameter compared to that for the EDY parameter also conservatively reduces the benefit for the relatively low head temperature at some plants in the determination of the nonvisual NDE reinspection interval. Therefore, when a consistent, unified time-temperature model is applied to the determination of reinspection timing requirements across the fleet, the plants with lower head temperatures will reinspect more frequently using the RIY parameter than using the EDY parameter. As shown in Figure 6-1, the RIY parameter decreases at a significantly smaller rate compared to the EDY parameter as the assumed head temperature is reduced from the reference temperature of 600°F, which is close to the maximum reported actual head temperature of 605°F. Therefore, the RIY parameter is conservatively applied to the timing of the repeat nonvisual NDE inspections, which are intended to prevent pressure boundary leakage.

## 6.2 Visual Examination Requirements for Heads With Alloy 600 Nozzles

As described below and illustrated in Figure 6-2, the visual examination requirements for heads with Alloy 600 nozzles depend on the plant's calculated value for EDY.

### *6.2.1 Plants With EDY ≥ 8 or Previous Service-Induced Cracking Requiring Repair*

Plants having heads with a calculated value of EDY ≥ 8 or with previously detected service-induced cracking that required repair shall perform a BMV examination during every refueling outage.

### *6.2.2 Plants With EDY < 8 and No Previous Service-Induced Cracking Requiring Repair[6]*

Plants with a calculated value of EDY < 8 and with no previously detected service-induced cracking that required repair shall perform the BMV examination every third refueling outage or

[6] Note that in practice the only original heads with EDY < 8 are those reported to operate at temperatures close to the reactor cold-leg temperature. In addition, all plants having original heads with EDY < 8 (in 2004) have already performed an initial BMV examination.

5 calendar years, whichever occurs first. In addition, during the refueling outages that a BMV examination is not performed, a general visual assessment including under the insulation from multiple access points shall be performed to check for gross evidence of the buildup of boron and/or corrosion product deposits.

If service-induced cracking that required repair per the current flaw evaluation guidance [17,18] has been detected during any previous outage in any of the J-groove RVCH nozzles or J-groove weld material, then the BMV examination shall be performed every refueling outage.

## 6.3 Baseline Nonvisual Examination Requirements for Heads With Alloy 600 Nozzles

As described below and illustrated in Figure 6-3, baseline nonvisual NDEs are required for all the J-groove penetrations in original Alloy 600 RVCHs according to essentially the same schedule currently required by NRC Order EA-03-009 [4] for initial nonvisual NDEs.

### *6.3.1 Plants With EDY > 12 or Previous Service-Induced Cracking Requiring Repair*

Plants with a calculated value of EDY > 12 or with previously detected service-induced cracking in any of the J-groove RVCH nozzles or J-groove weld material that required repair per the current flaw evaluation guidance [17,18] shall perform a baseline Type 1, 2, or 3 nonvisual NDE inspection during the first refueling outage upon entering this category (or during the first refueling outage following the implementation date of this plan if the head was in this category on the implementation date of this plan), unless a baseline Type 1, 2, or 3 nonvisual NDE has already been performed.

### *6.3.2 Plants With 8 ≤ EDY ≤ 12 and No Previous Service-Induced Cracking Requiring Repair*

Plants with a calculated value of 8 ≤ EDY ≤ 12 and with no previously detected service-induced cracking in any of the J-groove RVCH nozzles or J-groove weld material that required repair per the current flaw evaluation guidance [17,18] shall perform a baseline Type 1, 2, or 3 nonvisual NDE inspection no later than the time of the second refueling outage after entering the category (or no later than the time of the second refueling outage after February 11, 2003, if the head was in this category on February 11, 2003), unless a baseline Type 1, 2, or 3 nonvisual NDE has already been performed.

### *6.3.3 Plants With EDY < 8 and No Previous Service-Induced Cracking Requiring Repair*

Plants with a calculated value of EDY < 8 and with no previously detected service-induced cracking in any of the J-groove RVCH nozzles or J-groove weld material that required repair per the current flaw evaluation guidance [17,18] shall perform a baseline Type 1, 2, or 3 nonvisual NDE inspection no later than February 10, 2008.

## 6.4 Repeat Nonvisual Examination Requirements for Heads With Alloy 600 Nozzles

All plants with RVCHs having Alloy 600 nozzles shall perform periodic nonvisual examinations. An additional nonvisual inspection interval limitation applies to plants that have previously detected service-induced cracking in any of the J-groove RVCH nozzles or J-groove weld material that required repair per the current flaw evaluation guidance [17,18].

### *6.4.1 Options for Satisfying Inspection Interval Requirement*

As described below and illustrated in Figure 6-3, repeat nonvisual NDEs are required according to the number of RIYs accumulated since the previous inspection and according to the type of nonvisual NDE previously performed. For information, Table 6-1 shows the maximum number of operating cycles that are permitted between nonvisual NDEs as a function of operating head temperature, cycle length, and capacity factor. This inspection interval requirement shall be satisfied in one of three ways as described below.

The requirements of paragraph 6.4.1 may be applied on a nozzle-by-nozzle basis (i.e., partial inspections during more than one outage) provided that overall the inspection coverage meets the requirements of Section 5.

#### 6.4.1.1 Type 3 Nonvisual NDE

The nonvisual inspection interval requirement is satisfied if a Type 1, 2, or 3 nonvisual NDE is performed before RIY > 2.25 and before more than 8 calendar years since the time that a previous Type 3 nonvisual NDE was performed. If the head temperature, cycle length, and capacity factor are such that RIY > 2.25 are accumulated in one operating cycle, then the next nonvisual NDE shall be performed at the time of the next refueling outage.

#### 6.4.1.2 Type 2 Nonvisual NDE

The nonvisual NDE inspection interval requirement is satisfied for plants that have an appropriate risk analysis showing a conditional core damage probability (CCDP) that bounds an RVCH nozzle ejection event and which is no greater than $5\times10^{-3}$ if a Type 1, 2, or 3 nonvisual NDE is performed before RIY > 3.00 and before more than 10 calendar years since the time that a previous Type 2 nonvisual NDE was performed.

Otherwise, the nonvisual inspection interval requirement is satisfied if a Type 1, 2, or 3 nonvisual NDE is performed before RIY > 2.25 and before more than 8 calendar years since the time that a previous Type 2 nonvisual NDE was performed. In this case, if the head temperature, cycle length, and capacity factor are such that RIY > 2.25 are accumulated in one operating cycle, then the next nonvisual NDE shall be performed at the time of the next refueling outage.

The CCDP for the RVCH nozzle ejection event is typically bounded by the CCDP for non-isolable small- and medium-break LOCAs in the RCS piping, which are standard analyzed accident events. Note that for some plants a standard analyzed LOCA designated for a small-small piping break may also be relevant. See Section 8 of the safety assessment for RVCH penetrations (MRP-110 [5]) for a discussion of the CCDP in the context of the RVCH nozzle ejection event.

#### 6.4.1.3 Type 1 Nonvisual NDE

The nonvisual inspection interval requirement is satisfied if a Type 1, 2, or 3 nonvisual NDE is performed before RIY > 3.00 and before more than 10 calendar years since the time that a previous Type 1 nonvisual NDE was performed.

### *6.4.2 Heads With Previous Service-Induced Cracking Requiring Repair*

In addition to satisfying the inspection interval requirements of Section 6.4.1, plants having heads for which service-induced cracking has been detected during any previous outage in any of the J-groove RVCH nozzles or J-groove weld material and required repair per the current flaw evaluation guidance [17,18] shall perform a Type 1, 2, or 3 nonvisual NDE within two operating cycles of the most recent inspection meeting the requirements of a Type 1, 2, or 3 nonvisual NDE.

## 6.5 Requirements for Replacement Heads With Alloy 690 Nozzles

The following requirements apply to replacement heads having Alloy 690 nozzles with Alloy 52/152 J-groove attachment welds.

### *6.5.1 Visual Examination Requirements*

An initial BMV examination shall be performed before or during the third refueling outage after installation of the replacement head, or within 5 calendar years of replacement, whichever occurs first. Repeat BMV examinations shall be performed at least every third refueling outage or every 5 calendar years, whichever occurs first, as illustrated in Figure 6-4.

### *6.5.2 Recommendation for Pre-Service Inspection*

It is recommended that prior to installation of the replacement head the RVCH penetrations in the replacement head be characterized using NDE techniques. Such information may be valuable for interpretation of data collected during in-service examinations. The MRP has released recommended guidance for such pre-service inspections [15].

### *6.5.3 Initial In-Service Nonvisual Examination Requirement*

As illustrated in Figure 6-5, all plants having replacement heads with Alloy 690 nozzles attached with Alloy 52/152 J-groove welds shall perform an initial in-service Type 1, 2, or 3 nonvisual NDE within 10 calendar years following head replacement. (This 10 calendar year period may be extended by as much as 1 year to enable the inspection to coincide with a plant outage.)

However, for this inspection to satisfy the initial in-service nonvisual examination requirement, it shall be performed no earlier than 6 calendar years after head replacement.

### *6.5.4 Repeat Nonvisual Examination Requirement*

As illustrated in Figure 6-5, all plants having replacement heads with Alloy 690 nozzles attached with Alloy 52/152 J-groove welds shall perform a repeat nonvisual NDE (Type 1, 2, or 3) 10 calendar years following the most recent nonvisual NDE. This 10 calendar year period may be reduced or extended by as much as 1 year to enable the inspection to coincide with a plant outage.

## 6.6 Visual Inspections to Identify Leakage from Above the Head

For all plants, during each refueling outage, visual inspections shall be performed to identify potential boric acid leaks from pressure-retaining components above the RVCH. Any leakage detected shall be evaluated in accordance with the requirements of Section 4.1.

## 6.7 Plants that Have Identified Service-Induced Cracking

Plants that have identified service-induced cracking of J-groove RVCH penetrations through nonvisual examinations or through examinations triggered by the detection of boron or corrosion product deposits (Section 4.1) shall satisfy the requirements listed below in addition to the general nonvisual NDE interval requirement in paragraph 6.4.2.

### *6.7.1 Discovery Outage Requirements*

The following are requirements for any outage that service-induced cracking is detected in any of the J-groove RVCH nozzles or J-groove weld material:

- A nonvisual examination of the affected RVCH nozzles(s) and associated J-groove welds shall be performed as necessary to characterize the crack(s) identified. The nonvisual examination of the affected penetration(s) shall meet the minimum requirements defined under Section 5.2.
- 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.
- Indications shall be evaluated or repaired in accordance with Section 4.2.
- For repaired RVCH nozzles that establish a new pressure boundary, ultrasonic testing shall be performed for the new weld and at least one (1) inch above the new weld in the nozzle base material. For RVCH penetration nozzles or J-groove welds repaired using a weld overlay, the overlay shall be examined by a surface examination technique.
- If any of the service-induced cracking detected during the discovery outage required repair, a BMV examination and a Type 1, 2, or 3 nonvisual NDE for all RVCH nozzles shall be performed, unless already performed during the discovery outage.

### *6.7.2 Specific Inspection Requirements for Subsequent Refueling Outages*

The following are requirements specific to penetrations for which service-induced cracking has been detected and applicable to subsequent refueling outages:

- Reinspection of indications left in service shall be performed in accordance with Reference [17] or [18], or the current flaw evaluation guidance, including projected crack growth.
- Reinspection of an embedded flaw is performed:
  - At each of the next two scheduled refueling outages, or
  - In accordance with a site-specific evaluation.

## 6.8 Plant-Specific Alternatives

Based on appropriate plant-specific evaluations, alternative inspection requirements may be implemented. Alternative requirements may be implemented addressing inspection method, frequency, or coverage (i.e., specific nozzles or portions of nozzles or welds). Alternatives shall be evaluated based on the objectives and criteria discussed in Sections 1, 2, and 3 of this document and discussed with the NRC.

## 6.9 Reporting Requirements

For each inspection performed in accordance with this inspection plan, a summary report of the inspection results shall be submitted to the NRC Public Document Room within 90 days after returning the plant to operation. This report shall include the cumulative number of EDY at the time of the inspections calculated as described in Appendix B. In addition, if any of the analysis procedures described in Appendix A were used to demonstrate the acceptability of exceptions to the examination zone and coverage requirements of Section 5.2, then the report shall include a summary of such analysis methods and the analysis results.

**Table 6-1**
**Inspection Intervals for Nonvisual Examinations for Heads With Alloy 600 Nozzles (For Information Only)**

| Head temp. (°F) | Inspection interval = Before either 2.25 RIY or 8 calendar years is exceeded | | | | | | | | | Inspection interval = Before either 3.00 RIY or 10 calendar years is exceeded | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | EFPY interval | Maximum number of fuel cycles between inspections for 18- or 24-month cycle length and capacity factor *CF* | | | | | | | | EFPY interval | Maximum number of fuel cycles between inspections for 18- or 24-month cycle length and capacity factor *CF* | | | | | | | |
| | | 18-month cycle | | | | 24-month cycle | | | | | 18-month cycle | | | | 24-month cycle | | | |
| | | *CF* = 0.900 | *CF* = 0.925 | *CF* = 0.950 | *CF* = 0.980 | *CF* = 0.900 | *CF* = 0.925 | *CF* = 0.950 | *CF* = 0.980 | | *CF* = 0.900 | *CF* = 0.925 | *CF* = 0.950 | *CF* = 0.980 | *CF* = 0.900 | *CF* = 0.925 | *CF* = 0.950 | *CF* = 0.980 |
| 605 | 1.986 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2.649 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 604 | 2.036 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2.715 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 603 | 2.088 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2.784 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| 602 | 2.140 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2.854 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 |
| 601 | 2.194 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2.926 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 |
| 600 | 2.250 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3.000 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| 599 | 2.307 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3.076 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| 598 | 2.366 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3.154 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| 597 | 2.426 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3.235 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| 596 | 2.488 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3.317 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| 595 | 2.551 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3.402 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| 594 | 2.617 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3.489 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| 593 | 2.684 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3.579 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| 592 | 2.753 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3.671 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 |
| 591 | 2.824 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 3.765 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 |
| 590 | 2.897 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 3.862 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| 589 | 2.972 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 3.962 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 588 | 3.049 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 4.065 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 587 | 3.128 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 4.170 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| 586 | 3.209 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 4.279 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 |
| 585 | 3.293 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 4.390 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 |
| 584 | 3.379 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 4.505 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| 583 | 3.467 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 4.623 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| 582 | 3.558 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 4.744 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| 581 | 3.652 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 4.869 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| 580 | 3.748 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 4.997 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| 578 | 3.948 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 5.264 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| 576 | 4.160 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 5.547 | 4 | 3 | 3 | 3 | 3 | 2 | 2 | 2 |
| 574 | 4.384 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 5.846 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 2 |
| 572 | 4.622 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 6.162 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 |
| 570 | 4.873 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 6.497 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 |
| 568 | 5.139 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 6.852 | 5 | 4 | 4 | 4 | 3 | 3 | 3 | 3 |
| 566 | 5.420 | 4 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 7.227 | 5 | 5 | 5 | 4 | 4 | 3 | 3 | 3 |
| 564 | 5.718 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 2 | 7.624 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 3 |
| 562 | 6.034 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 8.045 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 |
| 560 | 6.369 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 8.491 | 6 | 6 | 5 | 5 | 4 | 4 | 4 | 4 |
| 558 | 6.723 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 8.964 | 6 | 6 | 6 | 6 | 4 | 4 | 4 | 4 |
| 556 | 7.099 | 5 | 5 | 4 | 4 | 3 | 3 | 3 | 3 | 9.465 | 6 | 6 | 6 | 6 | 5 | 5 | 4 | 4 |
| 554 | 7.497 | 5 | 5 | 5 | 5 | 4 | 4 | 3 | 3 | 9.996 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 |
| 552 | 7.919 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 10.559 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 |
| 550 | 8.368 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 11.157 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 |
| 547 | 9.091 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 12.122 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 |

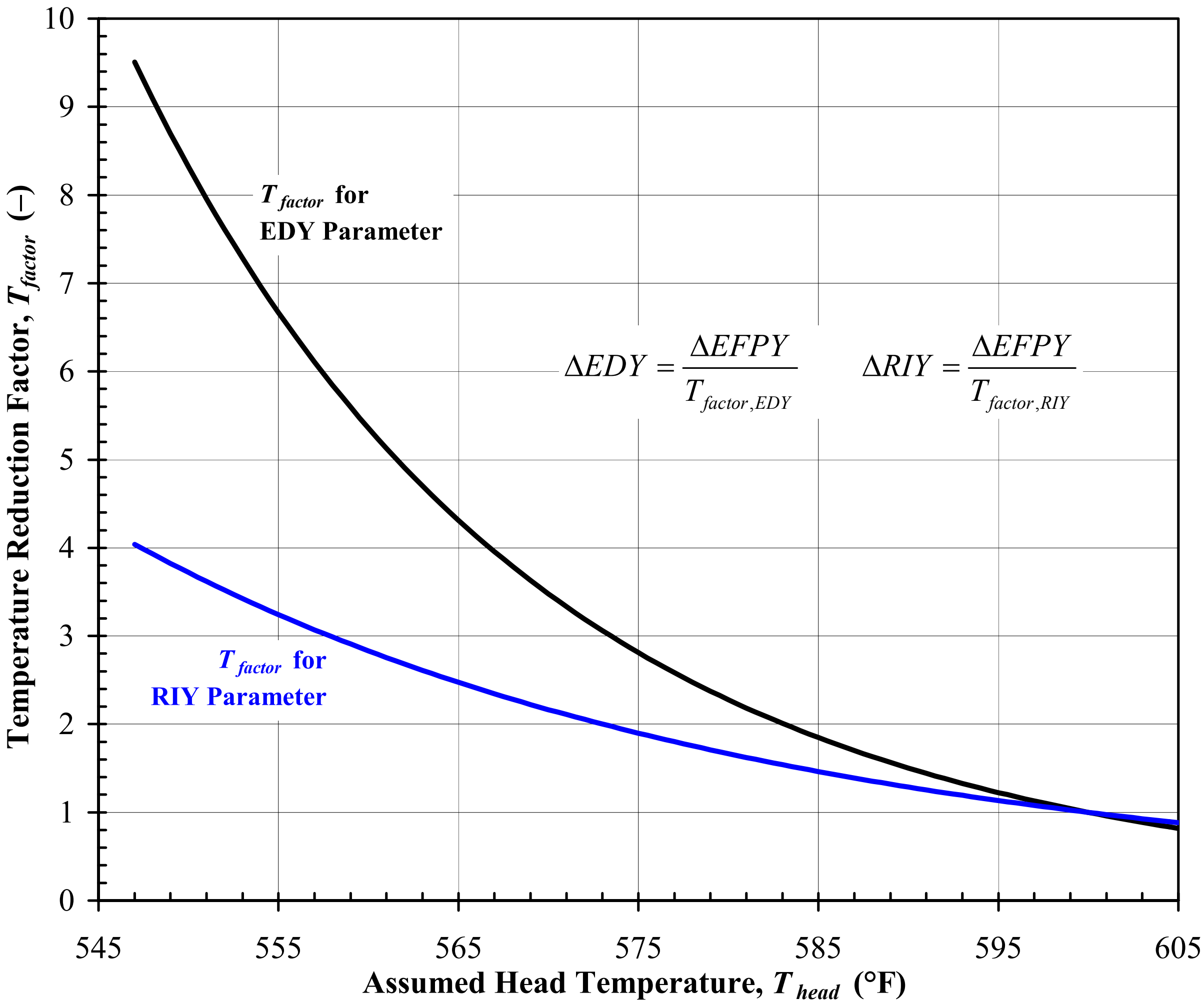



**Figure 6-1**
**Dependence of the EDY and RIY Parameters on Assumed Head Temperature Illustrating the Reduced Sensitivity of the RIY Parameter to Cooler Head Temperatures**

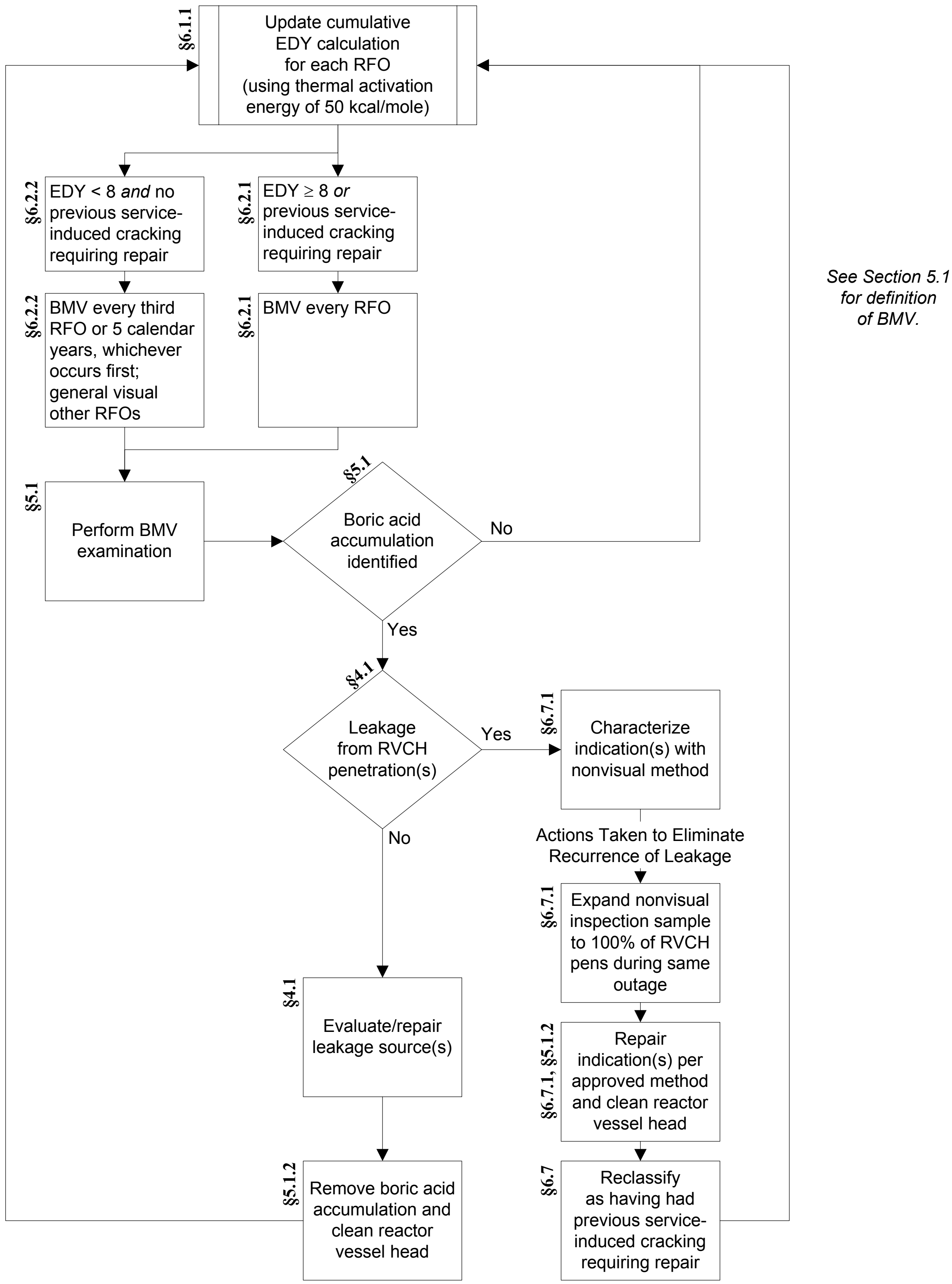
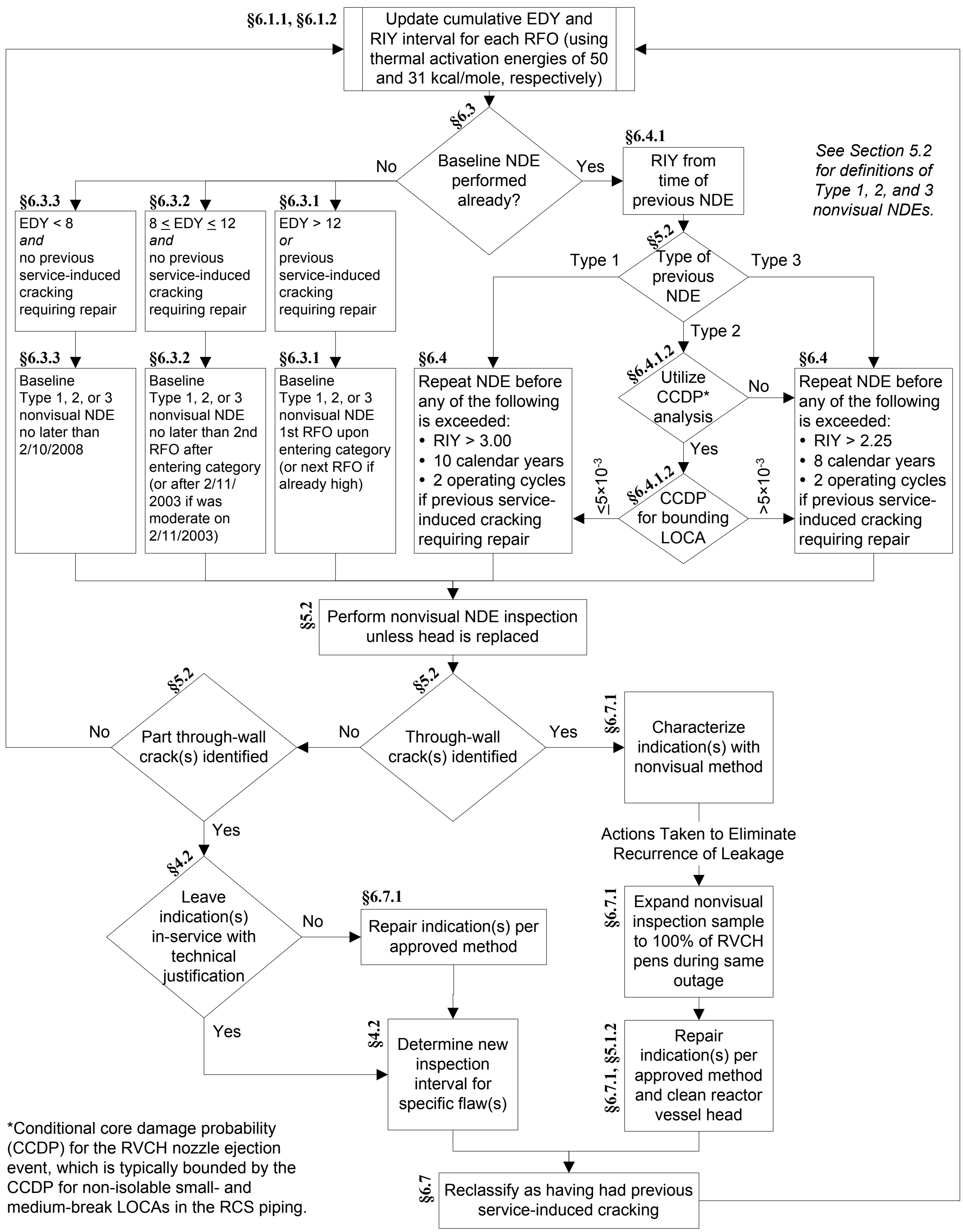



**Figure 6-2**
**Visual Inspection Flowchart for Heads With Alloy 600 Nozzles**




*Conditional core damage probability (CCDP) for the RVCH nozzle ejection event, which is typically bounded by the CCDP for non-isolable small- and medium-break LOCAs in the RCS piping.

**Figure 6-3**
**Nonvisual NDE Examination Flowchart for Heads With Alloy 600 Nozzles**

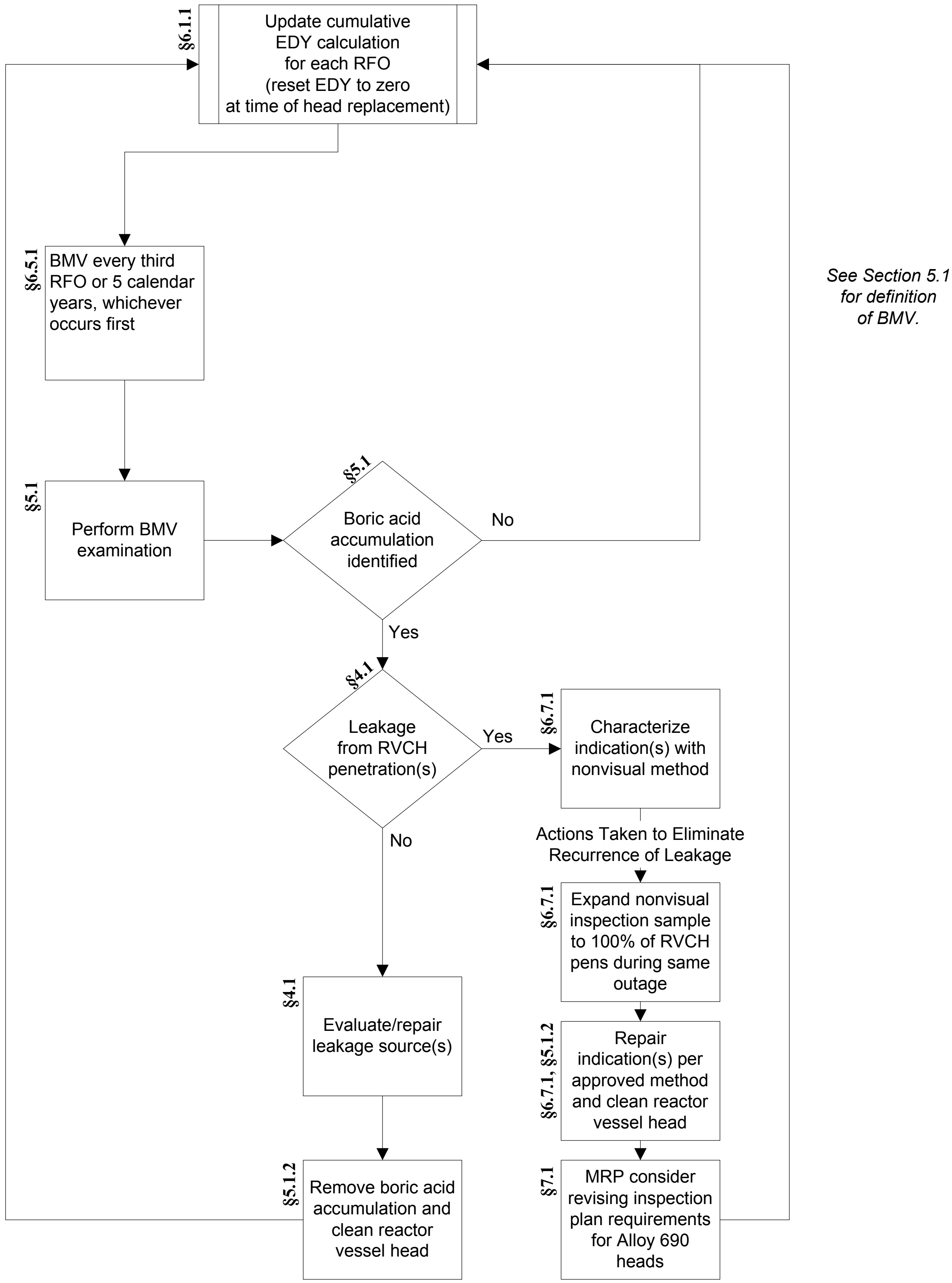



**Figure 6-4**
**Visual Inspection Flowchart for Heads With Alloy 690 Nozzles**

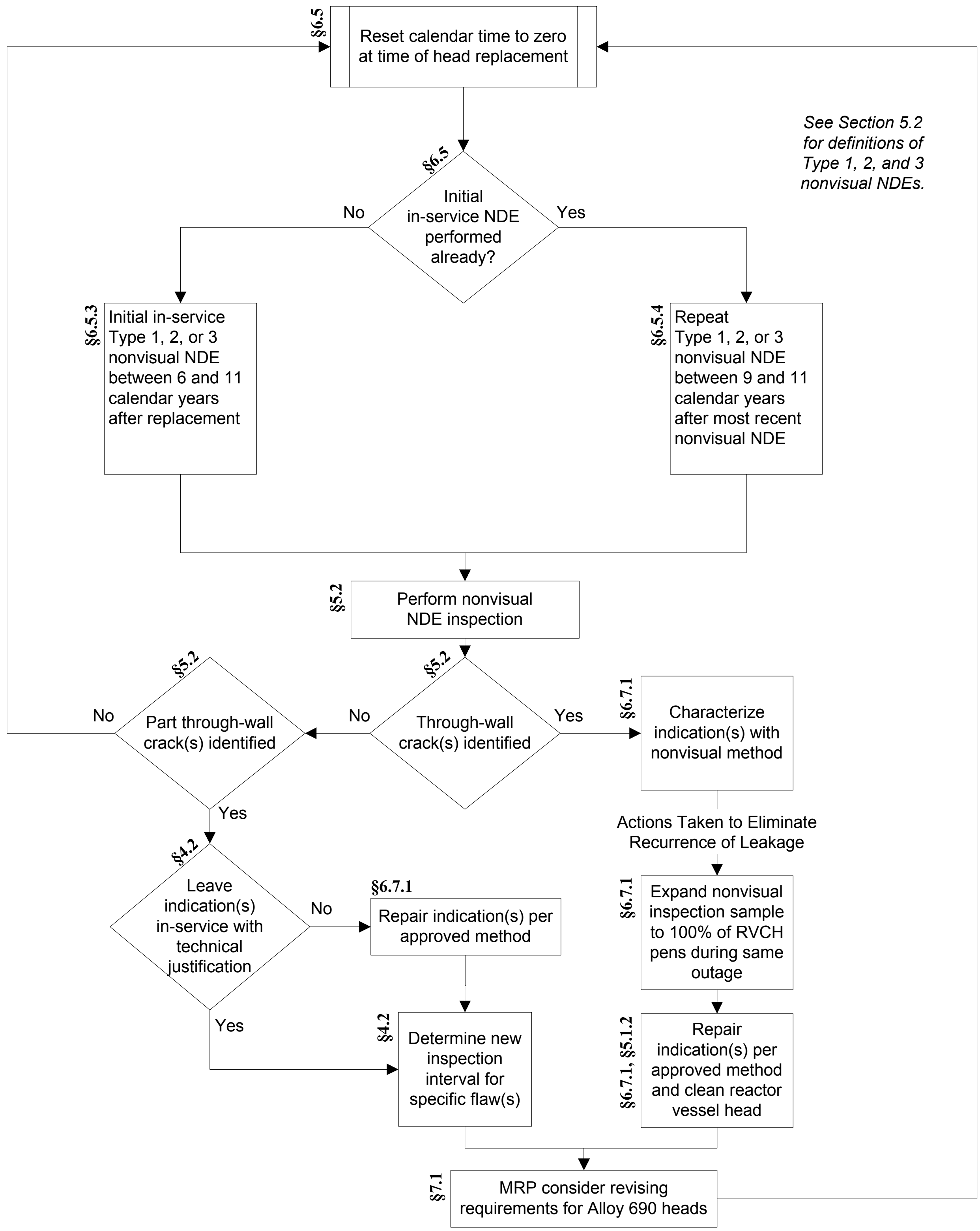



**Figure 6-5**
**Nonvisual NDE Examination Flowchart for Heads With Alloy 690 Nozzles**

# 7 ONGOING MRP ACTIVITIES

This section lists the ongoing activities of the MRP in the area of aging degradation of RVCH penetrations that could potentially warrant future revisions to this inspection plan document.

## 7.1 Ongoing Evaluation of Relevant Plant Inspection Data

The MRP will continue evaluating reactor vessel closure head and RVCH penetration inspection results as such inspections are performed on both heads having Alloy 600 nozzles attached with Alloy 82/182 J-groove welds and heads having Alloy 690 nozzles attached with Alloy 52/152 J-groove welds. If warranted, this inspection plan document will be revised on the basis of such new information.

## 7.2 Ongoing Evaluation of Laboratory Data on Alloy 690 Materials

A strong body of laboratory and plant data shows that the Alloy 690 family of materials is greatly more resistant to PWSCC than the Alloy 600 family of materials. However, the MRP will continue evaluating newly available laboratory data on the resistance to PWSCC of Alloy 690 wrought material and Alloy 52/152 weld material. If warranted, this inspection plan document will be revised on the basis of such new information.

## 7.3 Examination of CRDM Penetrations from Retired North Anna 2 Head

A joint MRP / NRC Research program is in progress to examine CRDM nozzles removed from the retired North Anna 2 head. Multiple penetrations have been removed, decontaminated, and then inspected by several vendors using NDE techniques. At least one penetration is expected to be destructively examined during 2004-2005, with the following principal goals:

- Comparison of NDE and destructive examination results
- Understanding of PWSCC morphology and chemical characteristics
- Characterization of weld condition and fabrication defects
- Determination of extent and characteristics of any wastage

The results of this program will be evaluated by the MRP as they become available, and this inspection plan will be revised if warranted by such evaluations.

## 7.4 MRP Boric Acid Corrosion Laboratory Test Program

The MRP is currently sponsoring an extensive experimental program to verify and refine the wastage modeling assumptions of MRP-110 [5]. The experimental work is expected to include full-scale mockups of leaking CRDM nozzles with a range of leak rates and other conditions. The first results from the mockup testing are expected in 2005. If warranted, the results of this test program, and that of research sponsored by the NRC [21], will be used to revise this inspection plan.

## 7.5 Benefits of Zinc Addition

The EPRI *PWR Primary Water Chemistry Guidelines* [22] suggest that zinc addition be considered as a mitigative measure for PWSCC of pressure boundary components fabricated from Alloy 600 wrought materials or Alloy 82/182 weld materials.

Laboratory tests indicate that additions of zinc to the primary coolant reduce rates of PWSCC initiation and possibly also reduce PWSCC crack growth rates [22,23,24]. With regard to PWSCC initiation, investigators have reported factors of improvement (in terms of the time to initiate cracking) ranging from about 2 (for addition of 20 ppb zinc) to greater than 10 (for 120 ppb zinc). Existing test data for the effect of zinc on the crack growth rate are mixed, with some tests showing a significant reduction in crack growth rate and others no reduction.

There is one domestic PWR station for which zinc addition is being applied and PWSCC degradation (in Alloy 600 steam generator tubes) is sufficiently active that preliminary conclusions regarding the effectiveness in mitigating PWSCC can be made. The results for the two units at this station are encouraging as the rate of new PWSCC indications is decreasing with each refueling outage.

Although early laboratory work [25,26] showed some benefits of zinc addition with regard to reducing intergranular SCC of stainless steels in BWR plants, credit is not being taken for this currently. The present widespread usage of zinc in BWRs is related predominantly to radiation field reduction.

The MRP will continue to evaluate laboratory and plant data regarding the effectiveness of zinc addition as they become available. If warranted, the inspection requirements of this inspection plan may be modified to reflect the benefits of zinc addition.

# 8
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6. *Materials Reliability Program: Probabilistic Fracture Mechanics Analysis of PWR Reactor Pressure Vessel Top Head Nozzle Cracking (MRP-105)*, EPRI, Palo Alto, CA: 2004. 1007834.
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16. *Materials Reliability Program: Generic Evaluation of Examination Coverage Requirements for Reactor Pressure Vessel Head Penetration Nozzles, Revision 1 (MRP-95R1)*, EPRI, Palo Alto, CA: 2004. 1011225.

17. Case N-694, "Evaluation Procedure and Acceptance Criteria for PWR Reactor Vessel Upper Head Penetration Nozzles, Section XI, Division 1," *Cases of ASME Boiler and Pressure Vessel Code*, Approved June 17, 2003.

18. Paragraph IWB-3660, "Evaluation Procedure and Acceptance Criteria for PWR Reactor Vessel Upper Head Penetration Nozzles," *ASME Boiler & Pressure Vessel Code, Section XI*, July 2004 edition.

19. Letter from R. Barrett (NRC) to A. Marion (NEI) dated April 11, 2003, "Flaw Evaluation Guidelines." This document included two enclosures: Enclosure 1: *Flaw Evaluation Guidelines and Acceptance Criteria for PWR Reactor Vessel Upper Head Penetration Nozzles*, and Enclosure 2: *Appendix A: Evaluation of Flaws in PWR Reactor Vessel Upper Head Penetration Nozzles*.

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# A
# ANALYSIS PROCEDURE FOR EXCEPTION TO NDE EXAMINATION ZONE REQUIREMENTS

The analysis procedure in this appendix shall be used to demonstrate the adequacy of the NDE examination zone for a particular RVCH penetration in the event of impediments to satisfaction of the examination zone and coverage requirements of Section 5.2 such as physical obstructions, threads on the nozzle end, or an ultrasonic testing corner shadow zone. Analyses shall be performed for nozzles for which the inspection coverage requirements of Section 5.2 are not met, to demonstrate a low probability of PWSCC existing in the uninspected regions, and that potential PWSCC in the uninspected regions will not lead to a safety concern or an unacceptable probability of leakage in the time interval until the next inspection.

For uninspected regions above the J-groove weld, the analyses shall be performed using at least two of the three techniques outlined below (A.1, A.2, and A.3) to demonstrate that the applicable criteria are satisfied. For uninspected regions below the J-groove weld, the analyses shall be performed using at least the stress analysis method (A.1) or the deterministic fracture mechanics analysis method (A.2) to demonstrate that the applicable criteria are satisfied.

## A.1 Stress Analysis

This analysis shall be used to determine an appropriate reduced examination zone relative to the examination zone defined in Section 5.2.1; the inspection coverage requirements of paragraph 5.2.3.1 apply to the reduced examination zone volume.

Demonstrate by plant-specific analysis that the hoop and axial stresses on the nozzle inside and outside surfaces remain below 20 ksi (tensile) over the entire extent of the uninspected region that is outside the reduced examination zone but within the examination zone defined in Section 5.2.1. The analysis may be performed using either design or as-built weld dimensions, and shall be performed either on the actual nozzle(s) for which a portion of the required examination zones is not inspected, or on nozzle(s) which can be shown to bound the stresses in the actual nozzle(s).

## A.2 Deterministic Fracture Mechanics Analyses

This analysis shall be used to determine an appropriate reduced examination zone relative to the examination zone defined in Section 5.2.1; the inspection coverage requirements of paragraph 5.2.3.1 apply to the reduced examination zone volume.

### A.2.1 Uninspected Regions Above the J-Groove Weld

For portions of the examination zone defined in Section 5.2.1 above the J-groove weld which are not inspected, it shall be shown that a potential circumferential crack existing in the uninspected region will not grow to a size that would violate ASME Section XI [27] safety margins for austenitic piping during plant operation until the next scheduled inspection.

The crack growth calculation shall be performed based on the following:

- The assumed initial flaw size shall be a through-wall, circumferentially oriented crack equal to 30º of the nozzle circumference, at the outermost edge of the region which is inspected (Figure A-1).
- Alternatively, the flaw may be assumed to exist in a plane closer to the J-groove weld (i.e. within the inspected region), if such location can be shown to conservatively bound flaws at the outermost edge of the region that is inspected.
- The flaw shall be assumed to be at either the uphill or the downhill location of the nozzle, whichever is governing in terms of applied stress intensity factor (Figure A-1).
- The average of inside and outside surface axial stress shall be applied along the entire through-wall crack length as the crack propagates.
- The stress intensity factor for a circumferential, through-wall crack in a cylinder or equivalent shall be used.
- The recommended Alloy 600 crack growth rate curve in MRP-55 [11] shall be used.

### A.2.2 Uninspected Regions Below the J-Groove Weld

For portions of the examination zone defined in Section 5.2.1 below the J-groove weld which are not inspected, it shall be shown that a potential axial crack existing in the uninspected region will not grow to the toe of the J-groove weld during plant operation until the next scheduled inspection.

*Method 1*: Using the stress analysis results for the as-designed J-groove weld configuration, demonstrate that the upper extremity of an axial through-wall crack would not propagate to the toe of the J-groove weld during plant operation until the next scheduled inspection.

The crack growth calculation shall be performed based on the following:

- The initial axial through-wall crack size shall be determined by assuming its upper extremity to be initially located at the bottom edge of the inspected region and the lower extremity to be located where either the inside or the outside surface hoop stress becomes compressive (Figure A-2).
- In the event that the length of the penetration nozzle extending beyond the J-groove weld is such that the hoop stress remains tensile for the entire portion of the penetration nozzle below the weld, an axial through-wall crack shall be postulated from the bottom edge of the reduced examination zone to the bottom of the nozzle (Figure A-3).

- The average of inside and outside surface hoop stress shall be applied along the entire through-wall crack length as the crack propagates.
- The postulated axial flaw shall be located at the governing azimuthal location considering the entire circumferential length of the uninspected region.
- The stress intensity factor for an axial through-wall crack in a cylinder or equivalent shall be used.
- The recommended Alloy 600 crack growth rate curve in MRP-55 [11] shall be used.

*Method 2*: If acceptability cannot be demonstrated using Method 1, the following may be performed:

- Review the available UT inspection data and demonstrate that the as-built J-groove weld depth is larger than the as-designed weld depth.
- Determine the hoop stress distribution below the weld by performing a stress analysis based on the as-built J-groove weld configuration.
- Perform the crack growth calculation similar to Method 1 above using the hoop stress distribution for the as-built configuration.

## A.3 Probabilistic Fracture Mechanics Analysis

For heads for which no service-induced cracking that required repair has been detected, compute the percentage of total required inspection volume (per Section 5.2.1) that is not inspected for all nozzles in the head, and demonstrate, using methods such as those documented in MRP-105 [6], that the total missed examination zone coverage for the entire head does not lead to unacceptable probabilities of leakage or nozzle ejection, before the next required inspection. In accordance with the discussions in Sections 3.1 and 3.2, a low probability of leakage (e.g., 5% per vessel per year, or less) and an extremely low probability of core damage associated with the potential for nozzle ejection (i.e., on the order of $1\times10^{-6}$ per vessel per year, or less) shall be demonstrated.

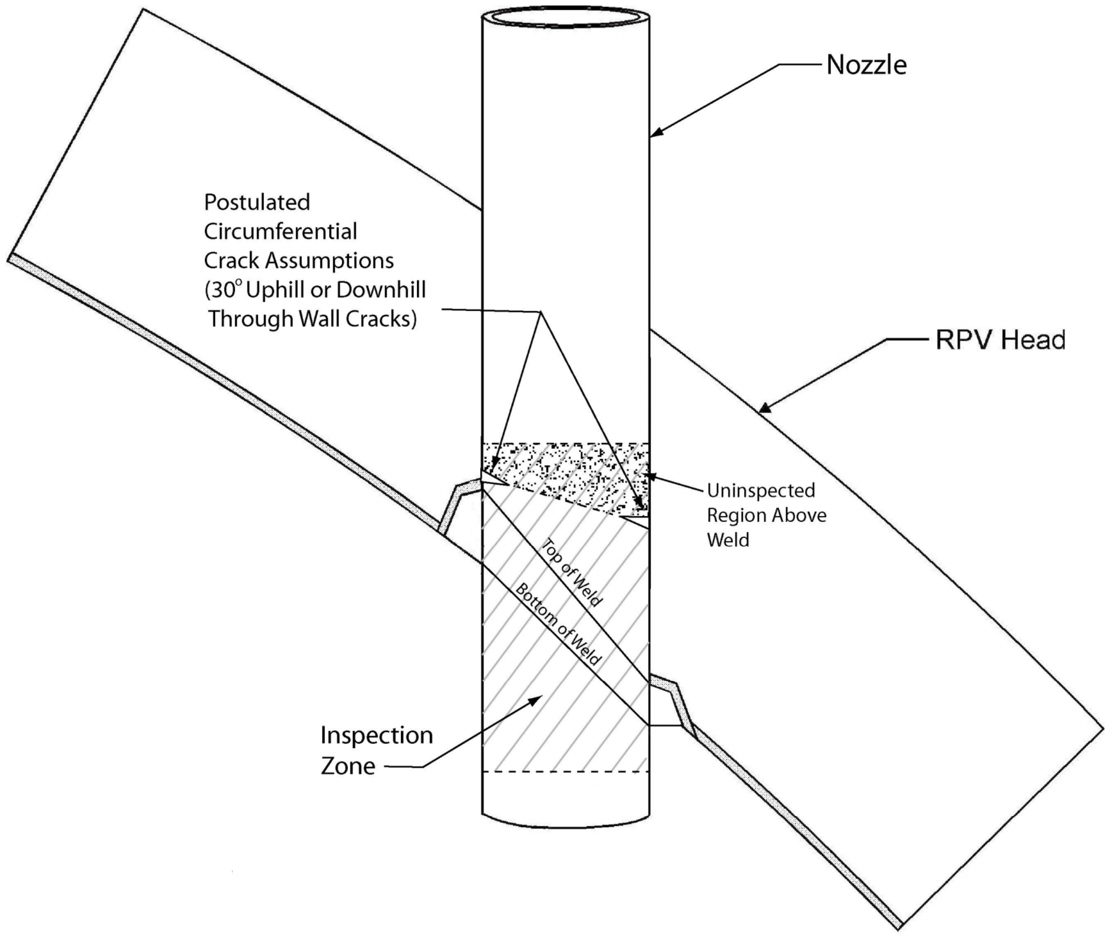


**Figure A-1**
**Circumferential Flaw Assumption for Uninspected Region above J-Groove Weld**

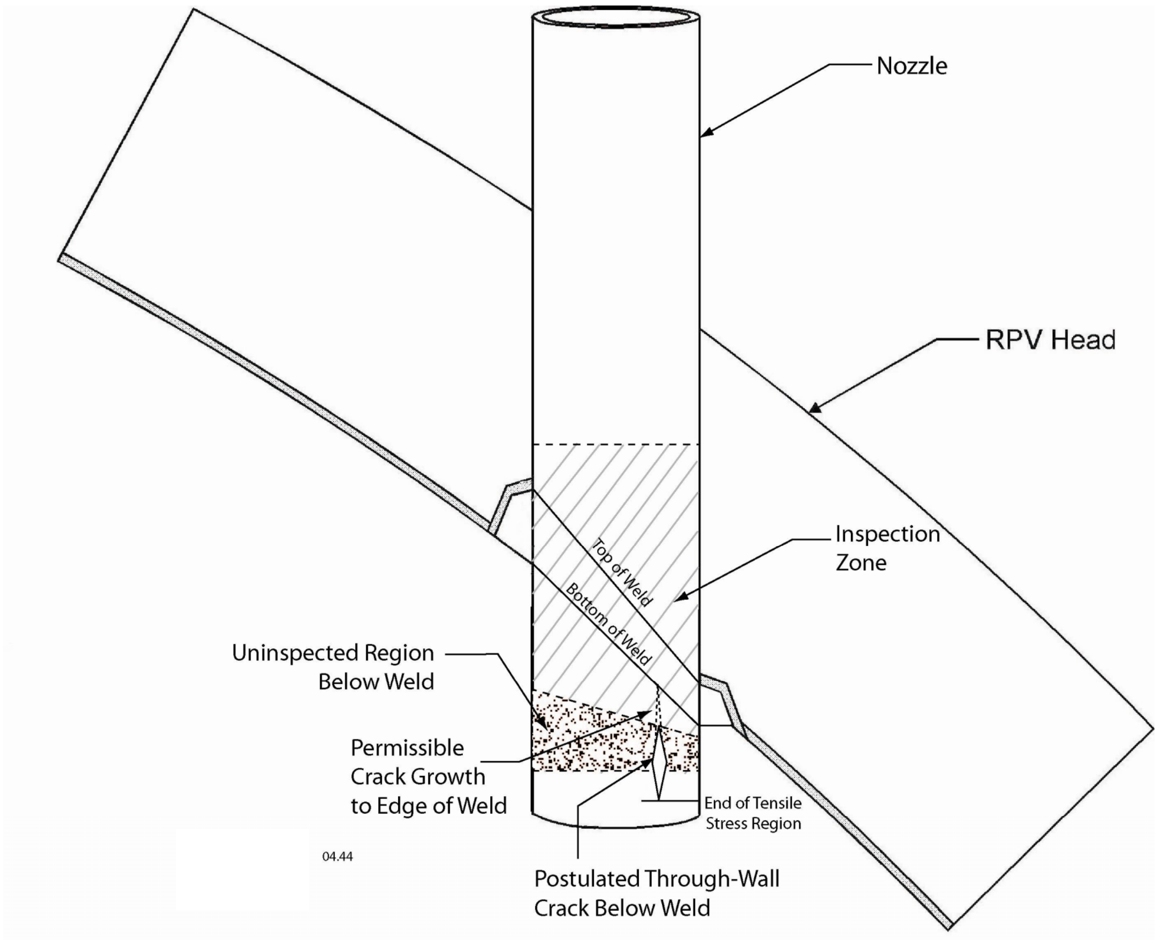


**Figure A-2**
**Axial Flaw Assumption for Uninspected Region below J-Groove Weld**

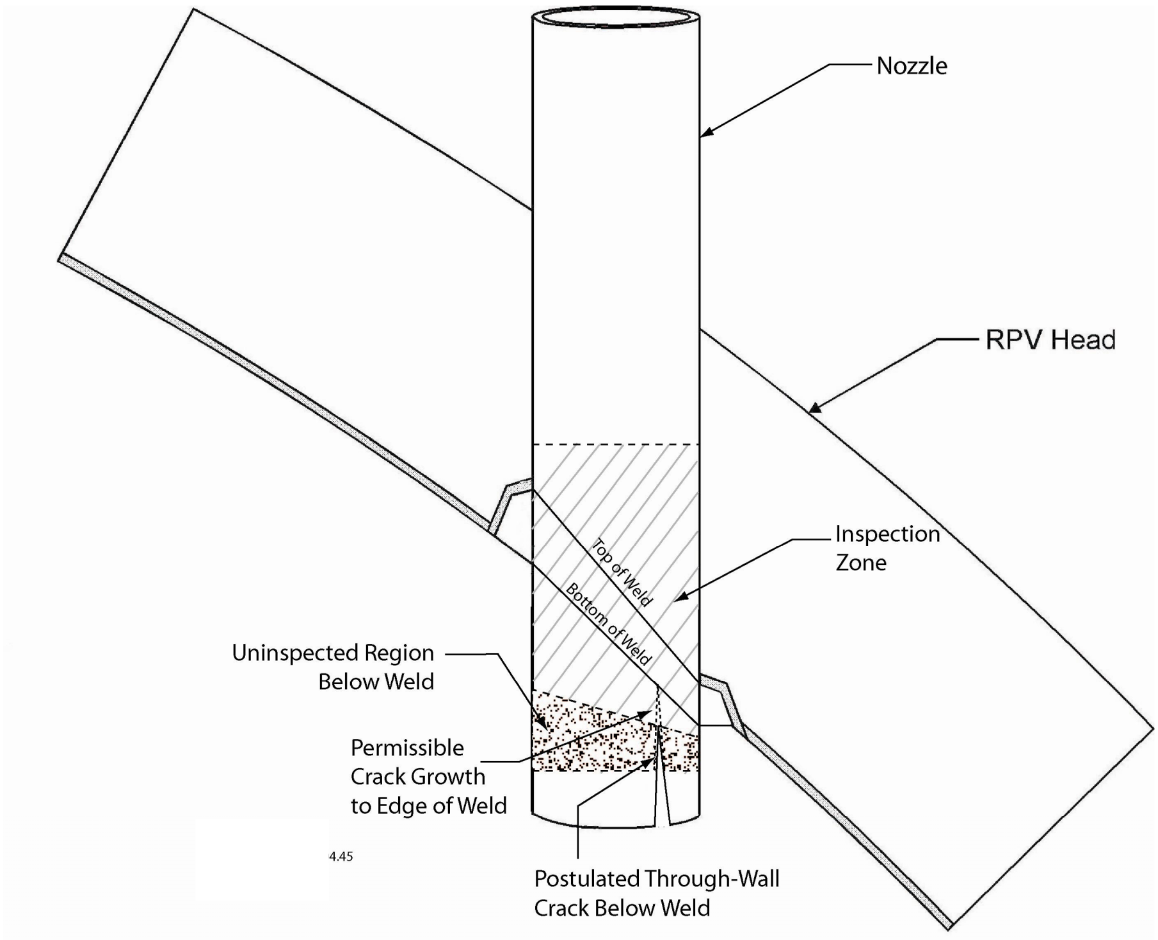


**Figure A-3**
**Axial Flaw Assumption for Uninspected Region below J-Groove Weld (Tensile Stress to Bottom of Nozzle)**

# B
# CALCULATION OF EFFECTIVE TIME AT TEMPERATURE

Because the rate of PWSCC degradation is dependent on temperature, the timing of BMV and nonvisual NDE inspections required under Section 6 for heads with Alloy 600 nozzles is based on calculation of two parameters that are measures of operating time normalized to a reference RVCH temperature through an Arrhenius relationship. As such, these parameters depend only on the thermal activation energy and the plant-specific operating time and head temperature. Other factors such as stress, microstructure, surface cold work, and head fabrication practices are not addressed by the simple calculations described here.

The effective degradation year (EDY) and reinspection year (RIY) parameters, calculated with differing activation energies, are applied in the inspection requirements of Section 6. This appendix defines these two time-at-temperature parameters and concludes with an example case.

## B.1 Simplified Time-Temperature Model

Since PWSCC of Alloy 600 nozzle material and Alloy 82/182 weld metal is sensitive to temperature, the EDY and RIY calculations adjust the operating time for a particular plant using its head temperature history and the appropriate thermal activation energy. These parameters are based on the number of effective full power years (EFPYs) of operation normalized to a common reference head temperature of 600°F.

The number of EDYs accumulated since initial head operation based on the thermal activation energy for crack initiation of 50 kcal/mole [20] is an accepted measure of the potential for RVCH penetration cracking to occur. Therefore, this parameter is used to establish the timing of the baseline nonvisual examination (Section 6.3) and the reinspection interval for BMV examinations (Section 6.2).

The number of RIYs accumulated between refueling outages based on the thermal activation energy for crack growth of 31 kcal/mole [10,11] is an appropriate parameter for setting the timing of repeat nonvisual NDE inspections that are intended to prevent pressure boundary leakage from occurring. Therefore, the reinspection interval for nonvisual NDEs for heads with Alloy 600 nozzles (Section 6.4) is based on the RIY parameter. As discussed in Section 6.1, the lower choice for the activation energy in the RIY parameter compared to that for the EDY parameter conservatively results in less credit being taken in the determination of the nonvisual NDE reinspection interval for the relatively low head temperature at some plants.

## B.2 Effective Full Power Years

The first step in the EDY and RIY calculations is to assign a parameter representing operating time. The effective full power years (EFPYs) is selected as the measure of operating time because it reflects the effect of lower head temperatures during startups, shutdowns, and periods of reduced power operation. Typically, the EFPYs are based on reactor thermal power and, in practice, are calculated from fuel burnup values.

## B.3 Head Temperature History

The second step in the EDY and RIY calculations is to identify the current reactor closure head temperature at 100% thermal power and any periods of past operation at significantly different temperatures. The three original PWR owners groups previously tabulated head temperatures at each plant as part of the industry response to NRC Generic Letter (GL) 97-01 [28]. Provided that adjustments are made for significant subsequent changes in reactor vessel outlet and inlet temperatures or bypass flow to the upper reactor vessel plenum, the head temperatures tabulated in response to GL 97-01 are appropriate for input to the EDY and RIY calculations.

The EDY parameter calculated on the basis of the head temperatures tabulated in response to GL 97-01 has been shown to be a good predictor of the potential for PWSCC in RVCH penetrations (see Section 4 of MRP-110 [5]). For example, through the spring 2004 outage season, all 69 U.S. plants have performed at least one bare metal visual examination or one nonvisual NDE inspection of all nozzles (or replaced the head), and about 55 CRDM nozzles in the U.S. have been found to be leaking. All of these leaks occurred in the set of 15 units with EDY greater than about 16 at the time of the inspection. No leaks were detected from the 54 units with EDY less than 16. The nonvisual NDE inspection results also show a clear relationship of the EDY parameter with the likelihood of cracking.

Note that because of thermal-hydraulic differences between reactor designs, some plants operate with a head temperature close to or somewhat below the hot leg temperature, while other plants are designed to direct a small amount of internals bypass flow to the upper head plenum region and thus operate with a head temperature closer to the cold leg temperature.

## B.4 Equations

Equations are presented below for the EDY and RIY parameters used in the definition of the inspection plan in Section 6. Upon head replacement, each of these two parameters shall be reset to zero for the calculations used to determine the timing of the inspections applicable to the replacement head.

### B.4.1 Cumulative EDYs Based on Thermal Activation Energy for Crack Initiation

The final step in the EDY calculation is to calculate the operating time normalized to a reference temperature of 600°F. The standard Arrhenius activation energy dependence on temperature is applied to each time period with a distinct head temperature, with the thermal activation energy for crack initiation applied:

$$EDY = \sum_{j=1}^{n} \left\{ \Delta EFPY_j \exp\left[ -\frac{Q_i}{R} \left( \frac{1}{T_{head,j}} - \frac{1}{T_{ref}} \right) \right] \right\}$$ **Equation B-1**

where:

| | | |
|---|---|---|
| $EDY$ | = | total effective degradation years, normalized to a reference temperature of 600°F |
| $\Delta EFPY_j$ | = | effective full power years accumulated during time period $j$ |
| $Q_i$ | = | activation energy for crack initiation (50 kcal/mole) |
| $R$ | = | universal gas constant ($1.103 \times 10^{-3}$ kcal/mol-°R) |
| $T_{head,j}$ | = | 100% power head temperature during time period $j$ (°R = °F + 459.67) |
| $T_{ref}$ | = | reference temperature (600°F = 1059.67°R) |
| $n$ | = | number of time periods with distinct 100% power head temperatures since initial head operation |

This calculation shall be performed with best-estimate values for each input parameter, including extrapolations for the operating time (EFPYs) and head temperature until the time of the next nonvisual NDE inspection.

To calculate the EDY interval for a period of operation with constant nominal 100% power head temperature, the following simplified equation may be used:

$$\Delta EDY = \Delta EFPY \exp\left[ -\frac{Q_i}{R} \left( \frac{1}{T_{head}} - \frac{1}{T_{ref}} \right) \right]$$ **Equation B-2**

### B.4.2 Interval of RIYs Based on Thermal Activation Energy for Crack Growth

To calculate the RIY interval since the time of the previous nonvisual NDE, the following equation similar to Equation B.1 shall be used, with the thermal activation energy for crack growth applied:

$$RIY = \sum_{j=n1}^{n2} \left\{ \Delta EFPY_j \exp\left[ -\frac{Q_g}{R} \left( \frac{1}{T_{head,j}} - \frac{1}{T_{ref}} \right) \right] \right\}$$ **Equation B-3**

where:

| | | |
|---|---|---|
| $RIY$ | = | reinspection years, normalized to a reference temperature of 600°F |
| $\Delta EFPY_j$ | = | effective full power years accumulated during time period $j$ |
| $Q_g$ | = | activation energy for crack growth (31 kcal/mole) |

| | | |
|---|---|---|
| $R$ | = | universal gas constant ($1.103\times10^{-3}$ kcal/mol-°R) |
| $T_{head,j}$ | = | 100% power head temperature during time period $j$ (°R = °F + 459.67) |
| $T_{ref}$ | = | reference temperature (600°F = 1059.67°R) |
| $n1$ | = | number corresponding to first time period with distinct 100% power head temperature since time of most recent nonvisual NDE |
| $n2$ | = | number corresponding to most recent time period with distinct 100% power head temperature |

This calculation shall be performed with best-estimate values for each input parameter, including extrapolations for the operating time (EFPYs) and head temperature until the time of the next nonvisual NDE inspection.

To calculate the RIY interval for a period of operation with constant nominal 100% power head temperature, the following simplified equation may be used:

$$RIY = \Delta EFPY \exp\left[-\frac{Q_g}{R}\left(\frac{1}{T_{head}}-\frac{1}{T_{ref}}\right)\right] \qquad \textbf{Equation B-4}$$

## B.5 Example Calculation

This example calculation will demonstrate the procedure for determining EDY and RIY given changes in 100% power operating head temperature. As shown in Figure B-1, the example plant head is currently operating at a temperature of 596°F. The original nozzle operating temperature was 598°F. At the end of cycle 2 (EOC2) the temperature was reduced to 592°F, at the end of cycle 6 (EOC6) the temperature was increased to 594°F, and at the end of cycle 8 (EOC8) the temperature was increased to 596°F.

### *B.5.1 Cumulative EDYs Based on Thermal Activation Energy for Crack Initiation*

Table B-1 provides the data used to compute the temperature factors and EDYs for these temperature changes. The following equations show how these numbers were calculated:

$$f_{cycles\ 3\text{-}6} = \exp\left[-\frac{50\ \frac{\text{kcal}}{\text{mol}}}{1.103\times10^{-3}\ \frac{\text{kcal}}{\text{mol}\cdot{}^\circ\text{R}}}\left(\frac{1}{(592+459.67)^\circ\text{R}}-\frac{1}{(600+459.67)^\circ\text{R}}\right)\right]=0.7222$$

and

$$EDY = EFPY_{@598^\circ F} f_{@598^\circ F} + EFPY_{@592^\circ F} f_{@592^\circ F} + EFPY_{@594^\circ F} f_{@594^\circ F} + EFPY_{@596^\circ F} f_{@596^\circ F}$$
$$= (2.52)(0.9223)+(4.90)(0.7222)+(2.74)(0.7838)+(1.30)(0.8504) = 9.12 \text{ EDYs}$$

As shown in Table B-1, the total EDY for the example plant is 9.12 compared to 11.46 EFPYs without temperature adjustments. This lower number is due to operating temperatures lower than 600°F.

### *B.5.2 Interval of RIYs Based on Thermal Activation Energy for Crack Growth*

The right portion of Table B-1 illustrates how the RIY calculation is used to set the timing of repeat nonvisual NDEs. The process is shown below for setting the next nonvisual examination after the NDE performed during EOC 6. During cycles 7 and 8 the head temperature is 594°F, and during cycle 9 the head temperature is 596°F, so the following temperature factors may be calculated:

$$f_{cycles\,7\text{-}8} = \exp\left[ -\frac{31\ \frac{\text{kcal}}{\text{mol}}}{1.103\times10^{-3}\ \frac{\text{kcal}}{\text{mol}\cdot°\text{R}}} \left( \frac{1}{(594+459.67)°\text{R}} - \frac{1}{(600+459.67)°\text{R}} \right) \right] = 0.8598$$

$$f_{cycle\,9} = \exp\left[ -\frac{31\ \frac{\text{kcal}}{\text{mol}}}{1.103\times10^{-3}\ \frac{\text{kcal}}{\text{mol}\cdot°\text{R}}} \left( \frac{1}{(596+459.67)°\text{R}} - \frac{1}{(600+459.67)°\text{R}} \right) \right] = 0.9044$$

Then the RIY interval through the end of cycles 7, 8, and 9 may be calculated as follows:

$$RIY_{EOC\,7} = \Delta EFPY_{cycle\,7} f_{cycle\,7\text{-}8} = (1.38)(0.8598) = 1.19$$

$$RIY_{EOC\,8} = \left(\Delta EFPY_{cycle\,7} + \Delta EFPY_{cycle\,8}\right) f_{cycle\,7\text{-}8} = (1.38+1.36)(0.8598) = 2.36$$

$$RIY_{EOC\,9} = \left(\Delta EFPY_{cycle\,7} + \Delta EFPY_{cycle\,8}\right) f_{cycle\,7\text{-}8} + \Delta EFPY_{cycle\,9} f_{cycle\,9} = 2.36 + (1.30)(0.9044) = 3.53$$

Assuming that a Type 1 nonvisual NDE was performed during the EOC 6 refueling outage, then the next nonvisual NDE would have to be performed during the EOC 8 refueling outage in order to satisfy the requirement for RIY to be no greater than 3.00.

**Table B-1**
**Example EDY and RIY Calculation**

| | | Uncorrected | | Cumulative EDY (Note 1) | | | RIY Interval (Note 2) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cycle no. | Head temp. (°F) | EFPYs during cycle | Total EFPYs at EOC | Temp. factor vs. 600°F | EDYs during cycle | Total EDYs at EOC | Temp. factor vs. 600°F | RIYs during cycle | RIYs since last NDE | NDE for RIY < 3.00 |
| 1 | 598 | 1.22 | 1.22 | 0.9223 | 1.13 | 1.13 | 0.9511 | 1.16 | 1.16 | - |
| 2 | 598 | 1.30 | 2.52 | 0.9223 | 1.20 | 2.32 | 0.9511 | 1.24 | 2.40 | NDE |
| 3 | 592 | 1.19 | 3.71 | 0.7222 | 0.86 | 3.18 | 0.8173 | 0.97 | 0.97 | - |
| 4 | 592 | 1.13 | 4.84 | 0.7222 | 0.82 | 4.00 | 0.8173 | 0.92 | 1.90 | NDE |
| 5 | 592 | 1.36 | 6.20 | 0.7222 | 0.98 | 4.98 | 0.8173 | 1.11 | 1.11 | - |
| 6 | 592 | 1.22 | 7.42 | 0.7222 | 0.88 | 5.86 | 0.8173 | 1.00 | 2.11 | NDE |
| 7 | 594 | 1.38 | 8.80 | 0.7838 | 1.08 | 6.94 | 0.8598 | 1.19 | 1.19 | - |
| 8 | 594 | 1.36 | 10.16 | 0.7838 | 1.07 | 8.01 | 0.8598 | 1.17 | 2.36 | NDE |
| 9 | 596 | 1.30 | 11.46 | 0.8504 | 1.11 | **9.12** | 0.9044 | 1.18 | 1.18 | - |

Notes:

(1) The thermal activation energy for EDY is 50 kcal/mole.

(2) The thermal activation energy for RIY is 31 kcal/mole.

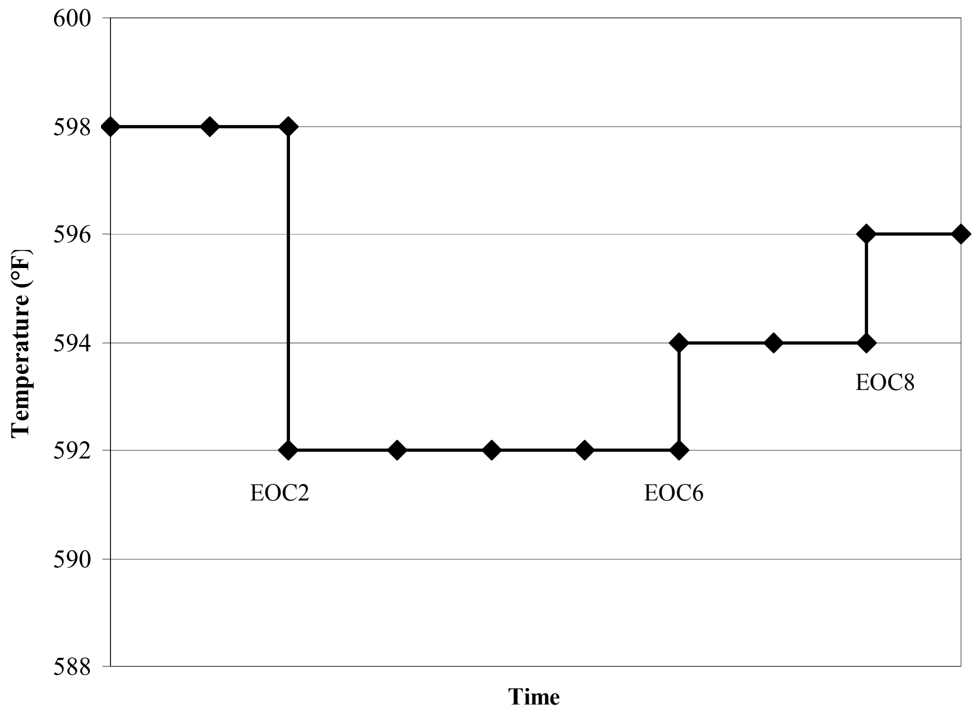


**Figure B-1**
**Example Head Operating Temperature History**