CASE N-729-1

Approval Date: March 28, 2006

The ASME Boiler and Pressure Vessel Standards Committee took action to eliminate Code Case expiration dates effective March 11, 2005. This means that all Code Cases listed in this Supplement and beyond will remain available for use until annulled by the ASME Boiler and Pressure Vessel Standards Committee.

Case N-729-1
Alternative Examination Requirements for PWR Reactor Vessel Upper Heads With Nozzles Having Pressure-Retaining Partial-Penetration Welds
Section XI, Division 1

Inquiry: What alternative examination requirements to those of Table IWB-2500-1, Examination Category B-P (1980 Edition through the 2004 Edition) and Examination Category B-E (1980 Edition through the 1992 Edition), IWB-2200, IWB-2400, and IWB-3000, may be used for PWR reactor vessel upper heads with nozzles having pressure-retaining partial-penetration welds?

Reply: It is the opinion of the Committee that the following alternatives to the requirements of Table IWB-2500-1, Examination Category B-P (1980 Edition through the 2004 Edition) and Examination Category B-E (1980 Edition through the 1992 Edition), IWB-2200, IWB-2400, and IWB-3000, may be used for PWR reactor vessel upper heads with nozzles having pressure-retaining partial-penetration welds.

-1000 SCOPE AND RESPONSIBILITY

-1100 SCOPE

This Case provides alternative requirements for examination of PWR reactor vessel upper heads with nozzles having pressure-retaining partial-penetration welds.

-1200 COMPONENTS SUBJECT TO EXAMINATION

-1210 EXAMINATION REQUIREMENTS

The examination requirements shall apply to the following:

(a) Heads having nozzles fabricated from UNS N06600 material with UNS N06082 or UNS W86182 partial-penetration welds.

(b) Heads having nozzles fabricated from Primary Water Stress Corrosion Cracking (PWSCC) resistant materials, such as UNS N06690 base metal with UNS N06052 or UNS W86152 partial-penetration welds.

-2000 EXAMINATION AND INSPECTION

-2200 PRESERVICE EXAMINATION

-2210 BASELINE EXAMINATION

The examinations listed in Table 1 shall be performed completely, once, as a baseline examination. These examinations shall include all nozzles. Examinations performed prior to implementation of this Case that meet the requirements of Table 1 may be credited.

-2220 PRESERVICE EXAMINATION AFTER REPAIR/REPLACEMENT ACTIVITIES

Prior to return to service, the applicable volumetric and surface examinations listed in Table 1 shall be performed on items affected by the repair/replacement activity.

-2400 INSPECTION SCHEDULE

-2410 INSPECTION PROGRAM

Inservice examination methods and frequency, as required by Table 1, shall be determined using the following parameters to characterize the susceptibility to crack initiation and the potential for crack propagation:

(a) Susceptibility to crack initiation is represented by the EDY parameter, calculated as follows:

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

(b) Potential for crack propagation is represented by the RIY parameter, calculated as follows:

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

where

EDY = total effective degradation years, normalized to a reference temperature of 1059.67R (588.71K)

$\Delta EFPY_j$ = effective full power years accumulated during time period j

Q_g = activation energy for crack growth = 31 kcal/mol (130 kJ/mol)

Q_i = activation energy for crack initiation = 50 kcal/mol (209 kJ/mol)

R = universal gas constant = 1.103×10^{-3} kcal/mol-R (8.314 J/mol K)

RIY = reinspection years, normalized to a reference temperature of 1059.67R (588.71K)

$T_{head\,j}$ = 100% power head temperature during time period j

T_{ref} = reference temperature = 1059.67R (588.71K)

n = number of time periods with distinct 100% power head temperature[1] since initial head operation

$n1$ = number of the first time period with distinct 100% power head temperature[1] since time of most recent volumetric or surface NDE

$n2$ = number of the most recent time period with distinct 100% power head temperature[1]

-2420 SUCCESSIVE EXAMINATIONS

(a) If a component is accepted by evaluation for continued service in accordance with -3132.3, the areas containing the flaws shall be reexamined prior to the end of the evaluation period used in the flaw evaluation. If the provisions of Table 1 do not require reexamination of the areas containing the flaws at least once per inspection period, a reexamination shall be performed during the next three inspection periods listed in the schedule of the inspection program of IWA-2400.

(b) If the reexaminations required by -2420(a) reveal that the flaws remain essentially unchanged for three successive examinations, the component examination schedule may revert to the schedule of examinations identified in Table 1.

-2430 ADDITIONAL EXAMINATIONS

If an examination performed in accordance with Table 1 or -2420 reveals a leak or a flaw not acceptable for continued service in accordance with the provisions of -3132.3, a Level 3 examination in accordance with Table 1 [Note (6)] shall be performed on all items of that Item Number prior to return to service. Additionally, a visual examination in accordance with Table 1 [Note (1)] (VE throughout this Case), if not already completed during the current outage, shall be performed prior to return to service.

-2500 EXAMINATION REQUIREMENTS

Components shall be examined as specified in Table 1. Volumetric and surface examinations shall be qualified in accordance with the low rigor requirements of Article 14 of Section V. If obstructions or limitations prevent examination of the volume or surface required by Fig. 2 for one or more nozzles, the analysis procedure of Appendix I shall be used to demonstrate the adequacy of the examination volume or surface for each such nozzle. If Appendix I is used, the evaluation shall be submitted to the regulatory authority having jurisdiction at the plant site.

-3000 ACCEPTANCE STANDARDS

-3100 EVALUATION OF EXAMINATION RESULTS

-3130 INSERVICE VOLUMETRIC AND SURFACE EXAMINATIONS

-3131 General

(a) The volumetric and surface examinations required by -2500 and performed in accordance with IWA-2200 shall be evaluated by comparing the examination results with the acceptance standards in -3132.1, except where -3131(b) is applicable.

(b) When flaws are detected by a required volumetric or surface examination, the component is acceptable for continued service provided the requirements of IWB-3112(b) are met.

(c) Volumetric and surface examination results shall be compared with recorded results of the preservice examination and prior inservice examinations. Acceptance of components for continued service shall be in accordance with -3132.

[1] Head temperature at 100% power may have been changed during the life of the plant due to design changes, power uprates, etc., and the summation is over the number of distinct periods, either since initial head operation for EDY or since the last volumetric or surface NDE for RIY.

-3132 Acceptance

-3132.1 Acceptance by Volumetric or Surface Examination

(a) A component whose volumetric or surface examination confirms the absence of flaws shall be acceptable for continued service.

(b) A component whose surface examination detects linear indications of any size, or rounded indications if other relevant conditions indicate nozzle leakage exists on the partial-penetration weld shall be corrected in accordance with the provisions of -3132.2.

E *(c)* A component with planar flaws in the nozzle base metal shall be corrected in accordance with the provisions of -3132.2 or -3132.3. Linear indications detected by surface examination of the nozzle base material shall be considered planar. Prior to evaluation, the depth of linear indications shall be further characterized by volumetric examination. If volumetric examination cannot be performed, the linear indication shall be assumed to be planar and through-wall.

-3132.2 Acceptance by Repair/Replacement Activity. A component whose volumetric or surface examination reveals a leak or flaw not acceptable for continued service in accordance with the provisions of -3132.3 is unacceptable for continued service until the additional exams of -2430 are satisfied and the component is corrected by a repair/replacement activity to the extent necessary to meet the acceptance standards of -3000.

-3132.3 Acceptance by Analytical Evaluation. A component whose volumetric examination detects planar flaws or whose surface examination detects linear indications which are assumed to be planar, is acceptable for continued service without repair/replacement activity if an analytical evaluation meets the requirements of IWB-3660 of the 2004 Edition. The area containing the flaw shall be reexamined in accordance with -2420(a) and (b).

-3140 INSERVICE VISUAL EXAMINATIONS (VE)

-3141 General

(a) The VE required by -2500 and performed in accordance with IWA-2200 and the additional requirements of this Case shall be evaluated by comparing the examination results with the acceptance standards specified in -3142.1.

(b) Acceptance of components for continued service shall be in accordance with -3142.

(c) Relevant conditions for the purposes of the VE shall include areas of corrosion, boric acid deposits, discoloration, and other evidence of nozzle leakage.

-3142 Acceptance

-3142.1 Acceptance by VE

(a) A component whose VE confirms the absence of relevant conditions shall be acceptable for continued service.

(b) A component whose VE detects a relevant condition shall be unacceptable for continued service until the requirements of -3142.1(b)(1), (b)(2), and (c) below are met. E

(1) Components with relevant conditions require further evaluation. This evaluation shall include determination of the source of the leakage and correction of the source of leakage in accordance with -3142.3.

(2) All relevant conditions shall be evaluated to determine the extent, if any, of degradation. The boric acid crystals and residue shall be removed to the extent necessary to allow adequate examinations and evaluation of degradation, and a subsequent VE of the previously obscured surfaces shall be performed, prior to return to service, and again in the subsequent refueling outage. Any degradation detected shall be evaluated to determine if any corrosion has impacted the structural integrity of the component. Corrosion that has reduced component wall thickness below design limits shall be resolved through repair/replacement activity in accordance with IWA-4000.

(c) A nozzle whose VE indicates relevant conditions indicative of possible nozzle leakage shall be unacceptable for continued service unless it meets the requirements of -3142.2 or -3142.3.

-3142.2 Acceptance by Supplemental Examination. A nozzle with relevant conditions indicative of possible nozzle leakage shall be acceptable for continued service if the results of supplemental examinations [-3200(b)] meet the requirements of -3130.

-3142.3 Acceptance by Corrective Measures or Repair/Replacement Activity

(a) A component with relevant conditions not indicative of possible nozzle leakage is acceptable for continued service if the source of the relevant condition is corrected by a repair/replacement activity or by corrective measures necessary to preclude degradation.

(b) A component with relevant conditions indicative of possible nozzle leakage shall be acceptable for continued service if a repair/replacement activity corrects the defect in accordance with IWA-4000.

-3200 SUPPLEMENTAL EXAMINATIONS

(a) Volumetric or surface examinations that detect flaws which require evaluation in accordance with -3130 may be supplemented by other techniques to characterize the flaw (i.e., size, shape, and orientation).

(b) The supplemental examination performed to satisfy -3142.2 shall include volumetric examination of the nozzle tube and surface examination of the partial-penetration weld, or surface examination of the nozzle tube inside surface, the partial penetration weld, and nozzle tube outside surface below the weld, in acccordance with Fig. 2, or the alternative examination area or volume shall be analyzed to be acceptable in accordance with Appendix I. The supplemental examinations shall be used to determine the extent of the unacceptable conditions and the need for corrective measures, analytical evaluation, or repair/replacement activity.

-9000 GLOSSARY

bounding loss of coolant accident conditional core damage probability (CCDP): the plant-specific conditional core damage probability for the loss of coolant accident (e.g., medium, small, or small-small break) that bounds the consequences of the head nozzle-ejection event.

effective degradation years (EDY): the lifetime accumulated effective time at temperature, normalized to 1059.67R (588.71K), with an activation energy characteristic of initiation of Primary Water Stress Corrosion Cracking in UNS N06600, 50 kcal/mol (209 kJ/mol).

reinspection years (RIY): the accumulated effective time at temperature between examinations normalized to 1059.67R (588.71K), with an activation energy characteristic of growth of Primary Water Stress Corrosion Cracking in UNS N06600, 31 kcal/mol (130 kJ/mol).

TABLE 1
EXAMINATION CATEGORIES

CLASS 1 PWR REACTOR VESSEL UPPER HEAD

Item No.	Parts Examined	Examination Requirements/ Fig. No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination	Deferral of Examination to End of Interval
B4.10	Head with UNS N06600 nozzles and UNS N06082 or UNS W86182 partial penetration welds	Fig. 1	Visual, VE (1), (2)	-3110	Each refueling outage (3), (4)	Not permissible
B4.20	UNS N06600 nozzles and UNS N06082 or UNS W86182 partial-penetration welds in head	Fig. 2 (5)	Volumetric (6) Surface (6)	-3130 -3140	All nozzles, every 8 calendar years or before RIY = 2.25, whichever is less (7), (8), (9), (10)	Not permissible
B4.30	Head with nozzles and partial-penetration welds of PWSCC-resistant materials	Fig. 1	Visual, VE (1), (2)	-3110	Every third refueling outage or 5 calendar years, whichever is less (3)	Not permissible
B4.40	Nozzles and partial-penetration welds of PWSCC-resistant materials in head	Fig. 2 (5)	Volumetric (6) Surface (6)	-3130 -3140	All nozzles, not to exceed one inspection interval (nominally 10 calendar years) (8), (10)	Not permissible

NOTES:

(1) The VE shall consist of the following:
- (a) A direct examination of the bare-metal surface of the entire outer surface of the head, including essentially 100% of the intersection of each nozzle with the head. If welded or bolted obstructions are present (i.e., mirror insulation, insulation support feet, shroud support ring/lug), the examination shall include ≥95% of the area in the region of the nozzles as defined in Fig. 1 and the head surface uphill and downhill of any such obstructions. The examination may be performed with insulation in place using remote equipment that provides resolution of the component metal surface equivalent to a bare-metal direct examination.
- (b) The examination may be performed with the system depressurized.
- (c) The examination shall be performed with an illumination level and a sufficient distance to allow resolution of lower case characters not greater than 0.105 in. (2.7 mm) in height.

(2) Personnel performing the VE shall be qualified as a VT-2 visual examiner and shall have completed at least four (4) hr of additional training in detection of borated water leakage from UNS N06600, UNS N06082 or UNS W86182 components and the resulting boric acid corrosion of adjacent ferritic steel components.

(3) Examination may be performed with the system depressurized.

(4) If EDY < 8 and no flaws unacceptable for continued service under -3130 or -3140 have been detected, the reexamination frequency may be extended to every third refueling outage or 5 calendar years, whichever is less, provided an IWA-2212 VT-2 visual examination of the head is performed under the insulation through multiple access points in outages that the VE is not completed. This IWA-2212 VT-2 visual examination may be performed with the reactor vessel depressurized.

(5) If the examination area or volume requirements of Fig. 2 cannot be met, the alternative requirements of Appendix I shall be used and the evaluation shall be submitted to the regulatory authority having jurisdiction at the plant site.

TABLE 1 EXAMINATION CATEGORIES (CONT'D)

NOTES:

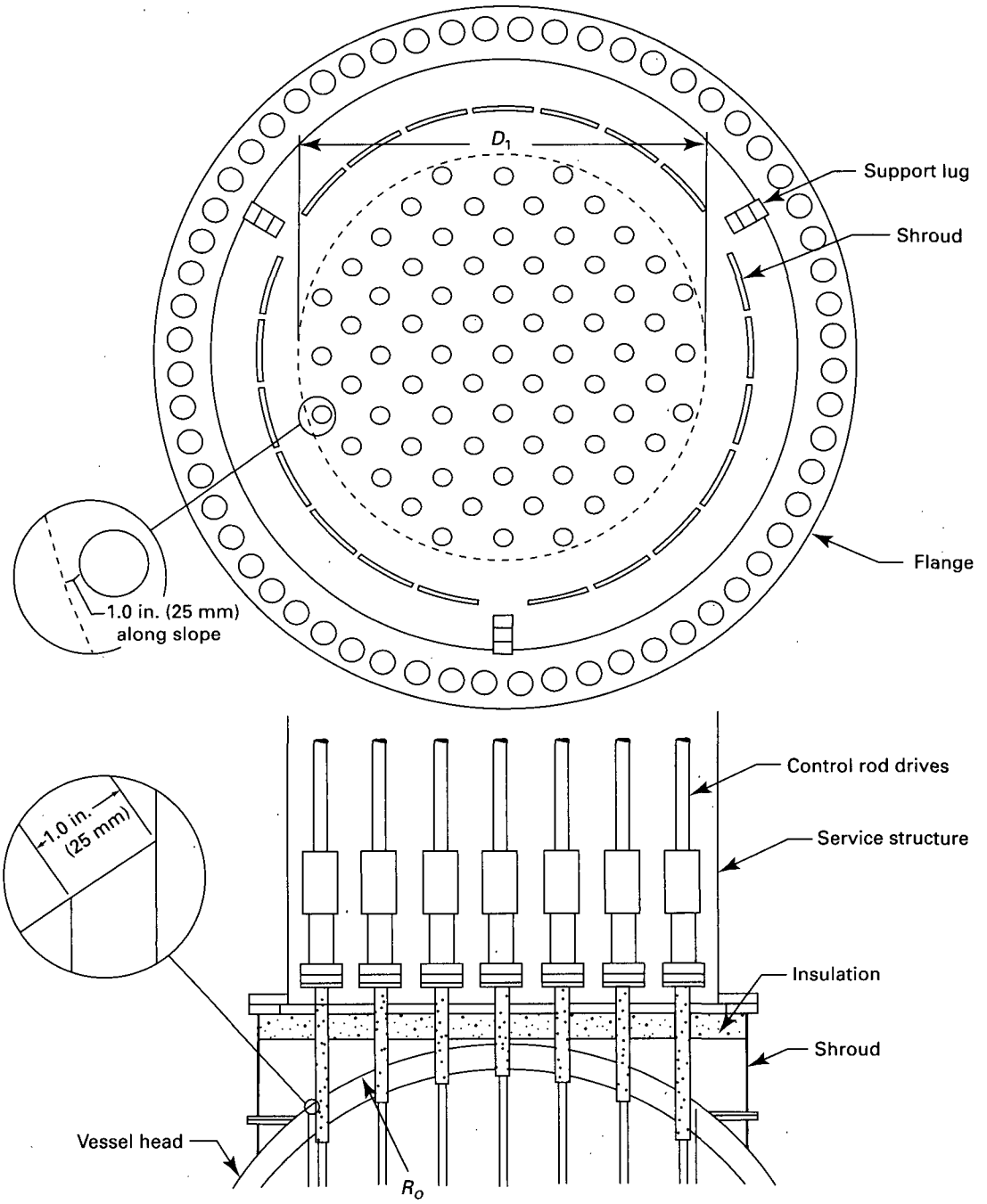
(6) Three levels of volumetric and surface examination are allowed (for Item B4.20, see [Note (9)] for effect of each level on reexamination frequency):
  (a) Level 1: The volumetric examination requirements of Level 3 examination and surface examination of all J-groove nozzle welds.
  (b) Level 2: The volumetric examination requirements of Level 3 examination and surface examination of ≥ 50% of the J-groove nozzle welds.
  (c) Level 3: Volumetric examination ≥ 95% of the required examination volume of the nozzle tubes in the aggregate, or surface examination of ≥ 95% of the required examination area of the nozzle tubes and the J-groove nozzle welds, in the aggregate, or a combination of the two. If a surface examination is being substituted for a volumetric examination on a portion of a nozzle, that surface examination shall be of the inside surface of the volume not examined volumetrically, in combination with either the outside surface of the unexamined volume if the unexamined volume is below the toe of the weld [E on Fig. 2] or the surface of the J-groove nozzle weld if the unexamined volume is above the toe of the weld.

(7) If not previously performed, baseline volumetric and surface examinations shall be performed.
  (a) for plants with EDY > 12, at the next refueling outage,
  (b) for plants with EDY ≥ 8 and EDY ≤ 12, no later than the second refueling outage, or,
  (c) for plants with EDY < 8, no later than February 10, 2008.

(8) If flaws have previously been detected that were unacceptable for continued service in accordance with -3132.3 or that were corrected by a repair/replacement activity of -3132.2 or -3142.3(b), the reexamination frequency is the more frequent of the normal reexamination frequency (before RIY = 2.25) or every second refueling outage, and [Note (9)] does not apply. Additionally, repaired areas shall be examined during the next refueling outage following the repair.

(9) Reexamination may be extended to RIY = 3, not to exceed nominal 10 calendar years, if either of the following apply:
  (a) previous examination was Level 1, or
  (b) previous examination was Level 2 and plant-specific bounding LOCA CCDP ≤ 5×10^{-3}

(10) Includes essentially 100% of surface or volume.

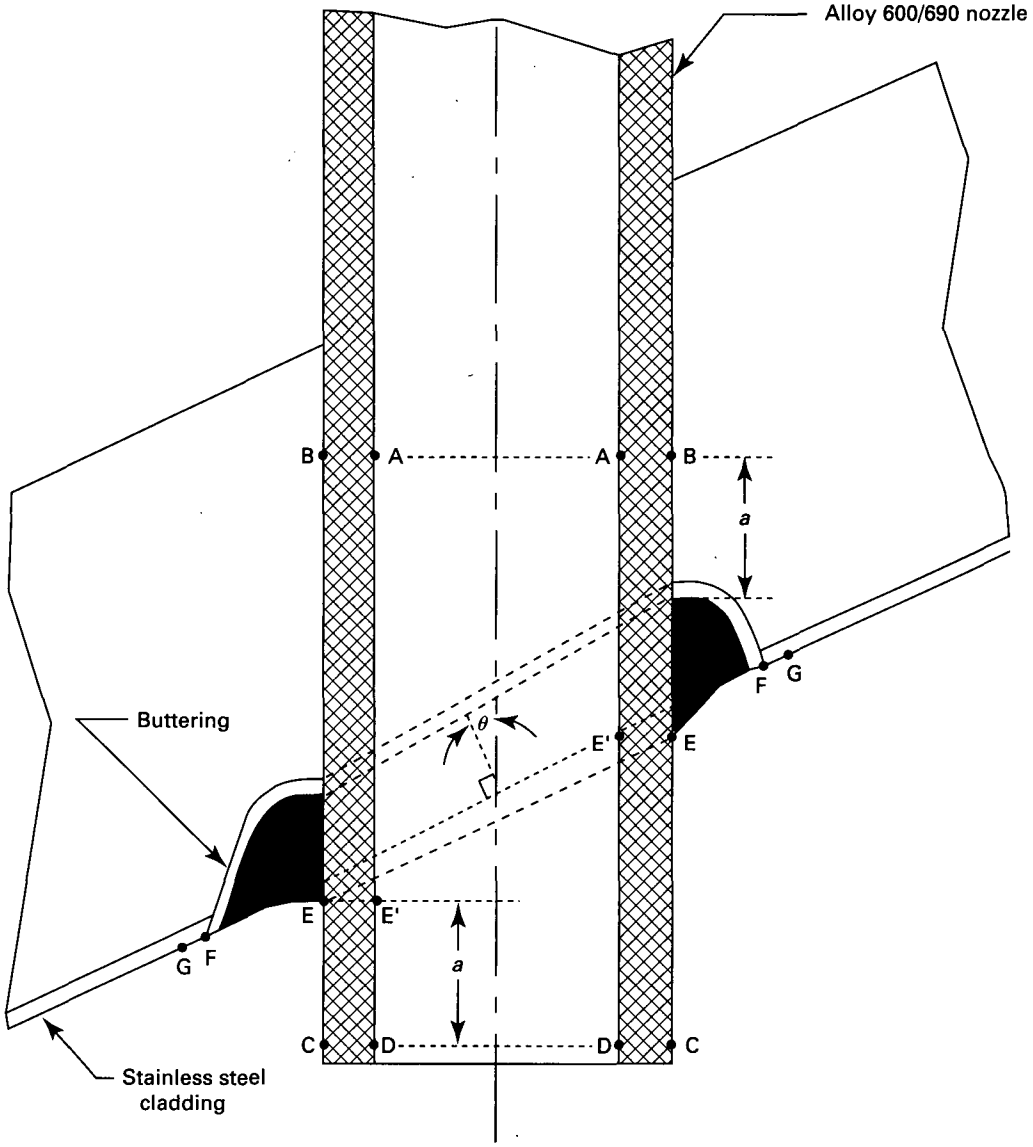


$$A = 2\pi R_o \left[R_o - \sqrt{R_o^2 - (D_1/2)^2} \right]$$

$A_{obstruct}$ = area on head outer surface obstructed within D_1

$$\frac{A - A_{obstruct}}{A} \geq 0.95$$

FIG. 1 PWR REACTOR VESSEL UPPER HEAD EXTENT OF VISUAL EXAMINATION E



a = 1.5 in. (38 mm) for Incidence Angle, θ, ≤ 30 deg and for all nozzles ≥ 4.5 in. (115 mm) OD or 1 in. (25 mm) for Incidence Angle, θ, > 30 deg; or to the end of the tube, whichever is less
A-B-C-D = Extent of volumetric examination for the tube (base metal)
A-D = Extent of surface examination for the tube inside surface
G-F = ¼ in. (6 mm) from the theoretical point "F" in accordance with the design drawings, including tolerances, unless the point "F" can be physically determined.
G-F-E-C = Extent of surface examination for the J-groove weld (filler metal and buttering) and tube outside surface below the weld
G-F-E = Extent of surface examination zone for the J-groove weld (filler metal and buttering)

FIG. 2 EXAMINATION VOLUME FOR NOZZLE BASE METAL AND EXAMINATION AREA FOR WELD AND NOZZLE BASE METAL

MANDATORY APPENDIX I
ANALYSIS PROCEDURE FOR ALTERNATIVE EXAMINATION AREA OR VOLUME DEFINITION

I-1000 SCOPE

This Appendix provides an analysis procedure that shall be used to define an alternative examination area or volume (zone) to that defined in Fig. 2 if impediments (such as physical obstructions, threads on the nozzle end, or an ultrasonic examination corner shadow zone) prevent examination of the complete zone. In such cases, analyses shall be performed to demonstrate that there is an extremely low probability of PWSCC existing wholly in the unexamined zones, and that the potential undetected PWSCC will not lead to a safety concern or an unacceptable probability of leakage in the time interval until the next examination.

For alternative examination zones that eliminate portions of Fig. 2 examination zone above the J-groove weld (Fig. I-1), the analyses shall be performed using at least two of the three techniques below to demonstrate that the applicable criteria are satisfied. For alternative examination zones that eliminate portions of Fig. 2 examination zone below the J-groove weld (Fig. I-2), the analyses shall be performed using at least the stress analysis method (I-2000) or the deterministic fracture mechanics analysis method (I-3000) to demonstrate that the applicable criteria are satisfied.

All other examination requirements of Table 1 shall be met.

E I-2000 STRESS ANALYSIS

This analysis shall be used to determine a reduced examination zone. Plant-specific analysis shall demonstrate that the hoop and axial stresses on the nozzle inside and outside surfaces remain below 20 ksi (140 MPa) (tensile) over the entire region outside the alternative examination zone but within the examination zone defined in Fig. 2. The analysis shall be performed using either design or as-built weld dimensions for the specific nozzles for which a portion of Fig. 2 examination zone is being eliminated, or for nozzles shown to bound the stresses in those specific nozzles.

I-3000 DETERMINISTIC FRACTURE MECHANICS ANALYSES

The analyses described in I-3100 or I-3200 shall be used to determine a reduced examination zone.

I-3100 ZONES ABOVE THE J-GROOVE WELD

For alternative examination zones above the J-groove weld, the analysis shall demonstrate that a potential circumferential crack in the unexamined zone will not grow to a size that exceeds the acceptance criteria for austenitic piping in IWB-3640 prior to the next scheduled examination.

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

(a) The assumed initial flaw size shall be a through-wall, circumferentially-oriented crack equal to 30 deg of the nozzle circumference, at the outermost edge of the alternative examination zone (Fig. I-1).

(b) Alternatively, the flaw shall 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 alternative examinaton zone.

(c) The flaw shall be assumed to be at either the uphill or the downhill location of the nozzle, whichever results in the higher applied stress intensity factor (Fig. I-1).

(d) The average of inside and outside surface axial stress shall be applied along the entire length of the assumed through-wall crack.

(e) The stress intensity factor for a circumferential, through-wall crack in a cylinder shall be used.

(f) Crack growth rate determination shall be in accordance with Appendix O of Section XI, in the 2004 Edition.

I-3200 ZONES BELOW THE J-GROOVE WELD

For alternative examination zones below the J-groove weld, the analysis shall demonstrate that a potential axial

crack in the unexamined zone will not grow to the toe of the J-groove weld prior to the next scheduled examination.

(a) Method 1. Using 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 prior to the next scheduled examination.

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

(1) 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 alternative examination zone and the lower extremity to be located where either the inside or the outside surface hoop stress becomes compressive (Fig. I-2).

(2) If the hoop stress remains tensile for the entire portion of the nozzle below the weld, an axial through-wall crack shall be postulated from the bottom edge of the alternative examination zone to the bottom of the nozzle (Fig. I-3).

(3) The average of inside and outside surface hoop stresses shall be applied along the entire length of the assumed through-wall crack.

(4) The postulated axial flaw shall be located in the unexamined zone at the azimuthal location that results in the shortest time to reexamination.

(5) The stress intensity factor for an axial through-wall crack in a cylinder shall be used.

(6) Crack growth rate determination shall be in accordance with Appendix O of Section XI, in the 2004 Edition.

(b) Method 2. If acceptability cannot be demonstrated using Method 1, the following shall be performed.

(1) Review the available UT examination data and demonstrate that the as-built J-groove weld depth is larger than the as-designed weld depth.

(2) Determine the hoop stress distribution in the portion of the nozzle below the weld by performing a stress analysis based on the as-built J-groove weld configuration.

(3) Perform the crack growth calculation of Method 1, using the hoop stress distribution for the as-built configuration.

I-4000 PROBABILISTIC FRACTURE MECHANICS ANALYSIS

These provisions shall not be applied to heads having prior PWSCC in nozzles or J-groove welds that required repair/replacement activity. Calculate the percentage of the total required examination zone defined in Fig. 2, for all nozzles in the head, that will be eliminated. Demonstrate, using a probabilistic fracture mechanics method, that the total eliminated examination zone in all nozzles does not lead to unacceptable probabilities of leakage and nozzle ejection prior to the next required examination. A probability of leakage no greater than 5% per vessel per year and a probability of core damage associated with the potential for nozzle ejection no greater than 1×10^{-6} per vessel per year are acceptable.

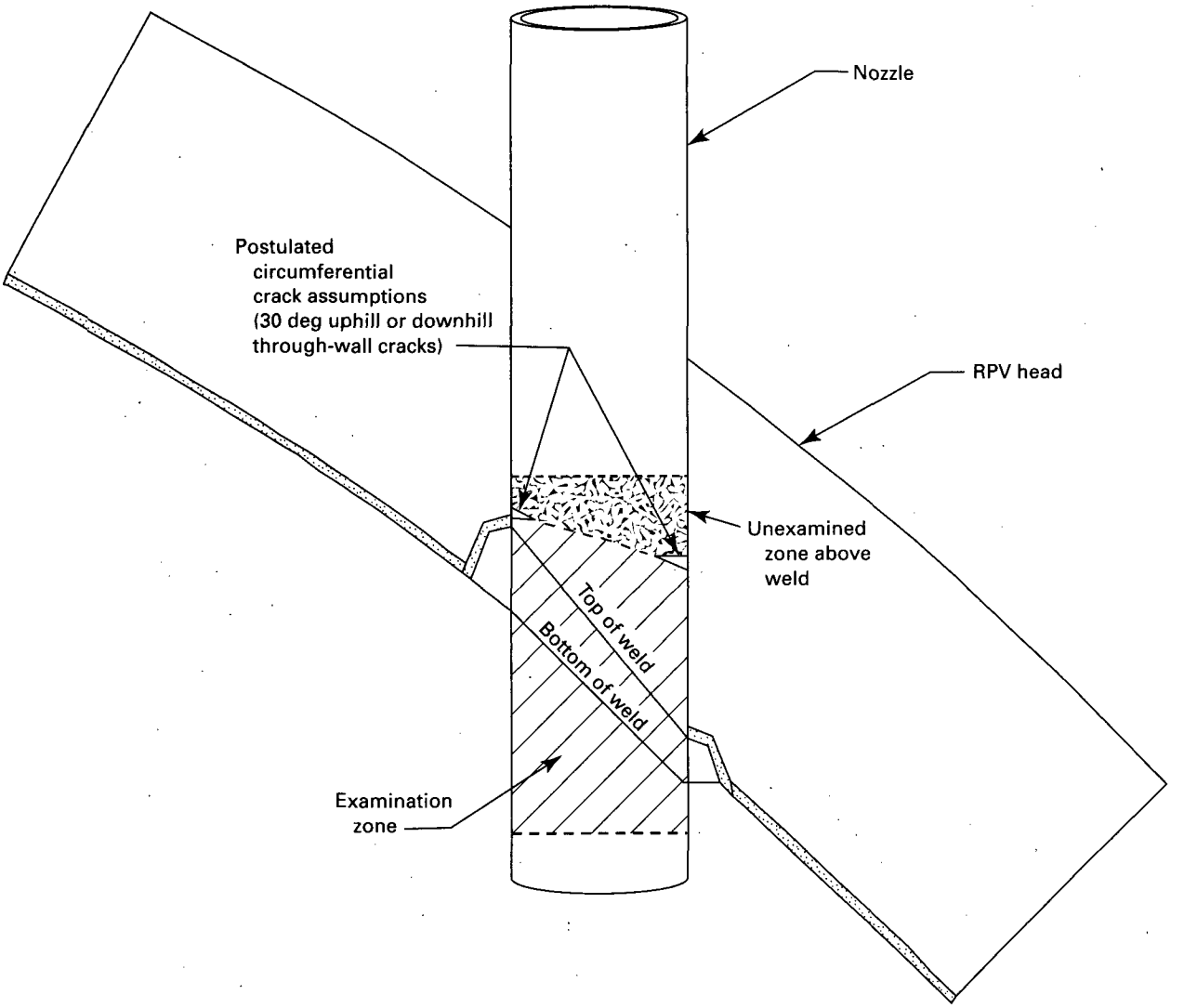


FIG. I-1 CIRCUMFERENTIAL FLAW ASSUMPTION FOR ELIMINATION OF PORTIONS OF THE REQUIRED EXAMINATION ZONE ABOVE J-GROOVE WELD

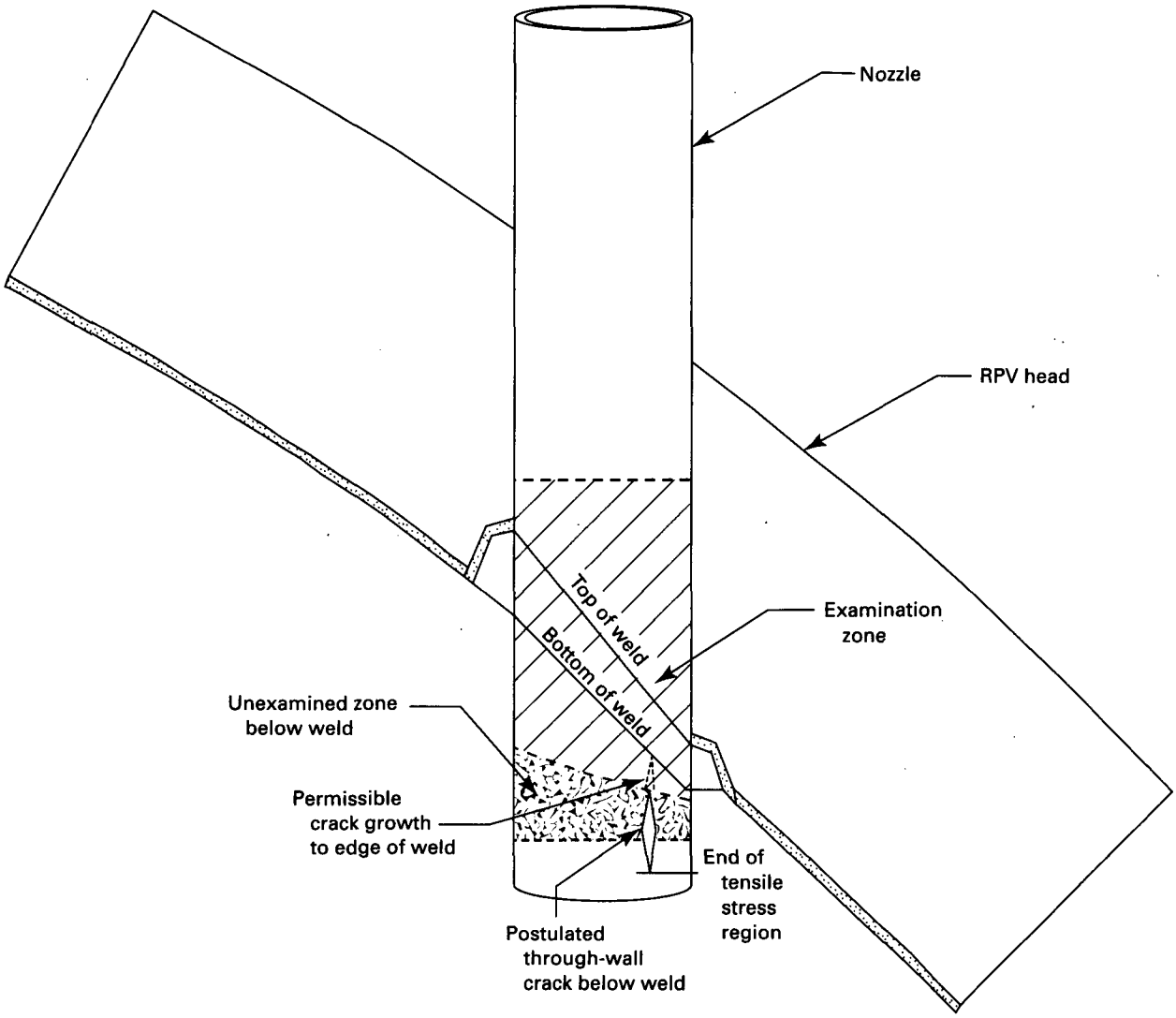


FIG. I-2 AXIAL FLAW ASSUMPTION FOR ELIMINATION OF PORTIONS OF THE REQUIRED EXAMINATION ZONE BELOW J-GROOVE WELD

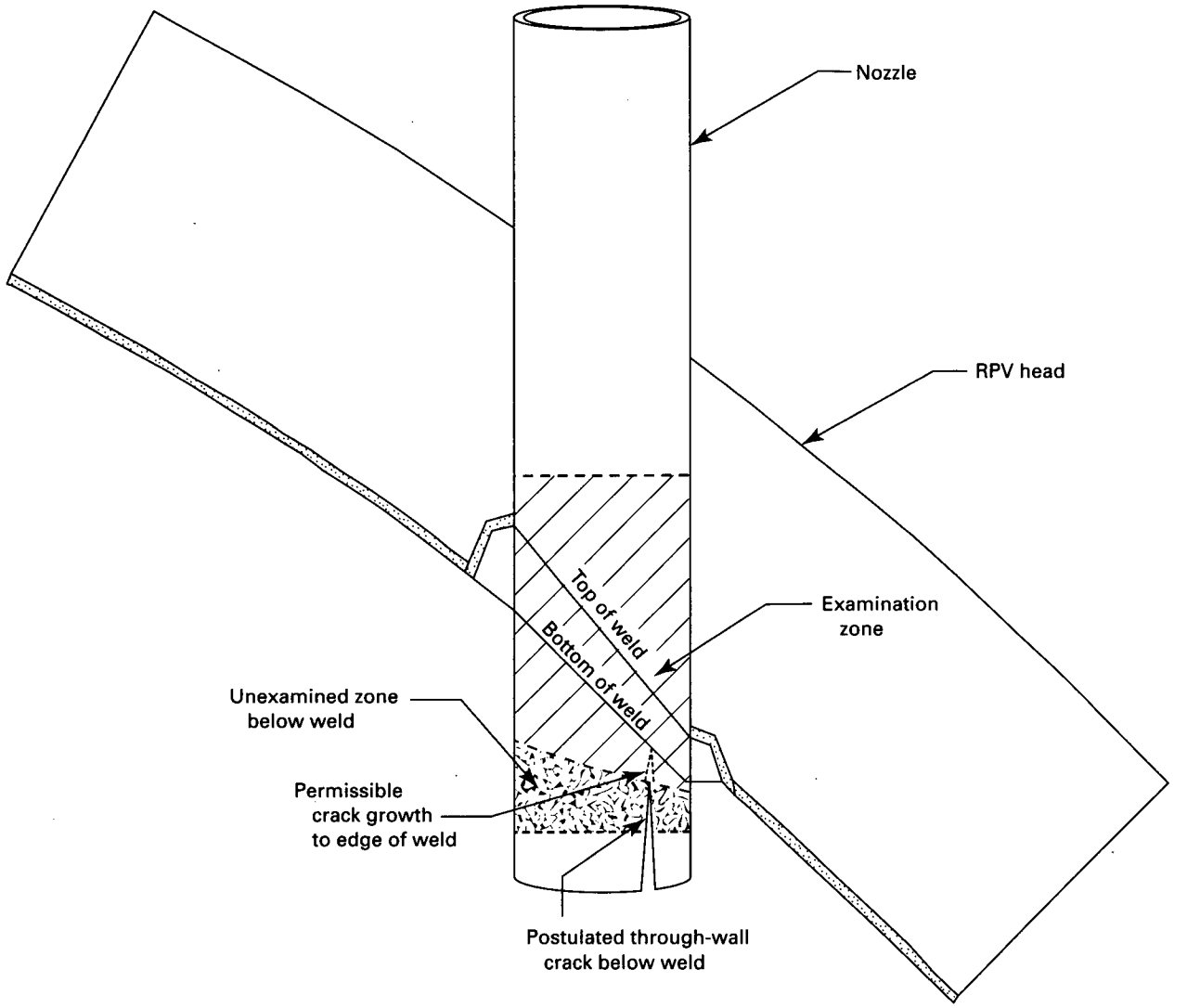


FIG. I-3 AXIAL FLAW ASSUMPTION FOR ELIMINATION OF PORTIONS OF THE REQUIRED EXAMINATION ZONE BELOW J-GROOVE WELD (TENSILE STRESS TO BOTTOM OF NOZZLE)