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MRP **Materials Reliability Program** MRP 2014-010

(via e-mail)

April 10, 2014

Document Control Desk
U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Proposed Edits to WCAP 17096-NP, Revision 2

This letter provides proposed revised text to the draft WCAP 17096-NP, Revision 2 "Reactor Internals Acceptance Criteria Methodology and Data Requirements" as discussed with NRC staff reviewers in 2013. The suggested changes were made based on the NRC RAIs, draft Safety Evaluation, and lessons learned from recent plant specific work performed by Westinghouse. The updated text has been reviewed by the PWR Owner's Group Materials Subcommittee (MSC) and comments have been incorporated.

Subsequent letters from EPRI-MRP will provide additional proposed text revisions from Westinghouse.

Sincerely,

B. C. Rudell	Anne Demma
Chairman, Integration Committee	Program Manager
EPRI-Materials Reliability Program	EPRI- Materials Reliability Program

Cc: Joe Holonich, NRC
James Molkenthin, PWROG Program Manager

Docket No. 669

D035
MRR

PWROG
PWR Owners Group

Program Management Office
20 International Drive
Windsor, Connecticut 06095

April 8, 2014

OG-14-135

WCAP-17096-NP, Rev. 2
Project Number 694

Mr. Kyle Amberge, EPRI Project Manager
Electric Power Research Institute (EPRI)
3420 Hillview Avenue
Palo Alto, CA 94304

Subject: PWR Owners Group
Transmittal of Westinghouse Revised Text for Draft WCAP-17096-NP Revision 2 for Transmittal to EPRI for NRC Review, LTR-RIAM-13-97, Revision 1 (PA-MSC-0473R5)

Dear Mr. Amberge:

The purpose of this letter is to provide proposed revised text to the draft WCAP 17096-NP, Revision 2 "Reactor Internals Acceptance Criteria Methodology and Data Requirements" for submittal to the NRC by EPRI (Enclosure 1). Changes were made based on the NRC RAIs, draft Safety Evaluation, and lessons learned from recent plant specific work performed by Westinghouse for the work done under PWROG program PA-MSC-0473. The first set of revised text was provided to EPRI under OG-14-2. As a result of resolving comments in this letter conforming changes need to be done to four other Westinghouse sections. In addition due to revisions of all these appendices, the body of the WCAP requires revision. Another letter will be sent to the NRC containing this revised material. The schedule is being developed.

Westinghouse would like to note that the title and component description of CE-ID-9 has changed. The title and component description went from "Lower Flange Weld" to "Lower Flange Flexure Weld." This was done to more accurately reflect what is being inspected. The new title does not agree with MRP-227-A but Westinghouse plans to carry this change through when MRP-227 is revised.

The PWROG would like to request that we are kept on distribution, via letter, once the revised text sections from Westinghouse are submitted to the Staff. Enclosure 1 to this letter provides the revised text sections received from Westinghouse.

If you have any questions feel free to contact Mr. Jim Molkenthin of the PWR Owners Group Project Management Office at (860) 731-6727.

Regards,

Norman J. Stringfellow

Jack Stringfellow
Chief Operating Officer & Chairman
Pressurized Water Reactor Owners Group
Southern Nuclear Operating Company

NJS:JPM:las

Enclosures (1) – LTR-RIAM-13-97, Revision 1

cc: PWROG Steering Committee
PWROG Licensing Committee
PWROG Program Management Office
J. Rowley, USNRC
S Stuchell, USNRC
J. Andrachek, Westinghouse
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S. Speicher, Westinghouse
PWROG Management Committee
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M. DeVan, AREVA, Inc.
B. Grambau, AREVA, Inc.
A. Demma, EPRI
R. Lott, Westinghouse
J. McKinley, Westinghouse
M. Semmler, Westinghouse
P. Paden, Westinghouse

Westinghouse

To: James P. Molkenthin
cc: Cheryl L. Boggess
Randy G. Lott

From: Reactor Internals Aging Management
Ext: (412) 374-2427
Fax: (724) 940-8565

Date: April 3, 2014

Your ref: N/A
Our ref: LTR-RIAM-13-97, Rev. 1

Subject: **Updates to WCAP-17096-NP Sections for Westinghouse and CE-Designed Plants**

Attachment A: Westinghouse Updates Related to Topical Report WCAP-17096-NP, Revision 2, "Reactor Internals Acceptance Criteria Methodology and Data Requirements"

References:
1. PWROG Project Authorization, PA-MSC-0473, Rev. 5, "Reactor Internals Acceptance Criteria Methodology and Data Requirements," October 2013. (Available from PWROG website.)
2. Westinghouse Letter, LTR-RIAM-13-97, Rev. 0, "Updates to WCAP-17096-NP Sections for Westinghouse and CE-Designed Plants," December 11, 2013.

Reference 2 was transmitted to the PWROG Material Subcommittee (MSC) for review and comment in December 2013. Contained in Reference 2 were updated sections and corresponding revised flowcharts for Appendices C, D, E, and F of WCAP-17096-NP, which are listed below. Comments were received from the MSC and Westinghouse developed proposed resolutions to these comments.

The proposed resolutions were sent to the MSC for acceptance on February 17, 2014. All proposed resolutions were found acceptable except one. A commenter proposed an alternate solution which Westinghouse found acceptable. As a result, all comments have been resolved. The comments and their resolution are electronically attached to this document in EDMS as Attachment B.

Attachment A contains updated sections and the corresponding revised flowcharts for Appendices C, D, E, and F in WCAP-17096-NP. These are Westinghouse and Combustion Engineering (CE) sections that required updates. Some of the sections have been renumbered, as can be seen in the attached revised Table of Contents for Appendices C, D, E, and F of WCAP-17096-NP. The renumbering was necessary to accommodate the elevation of some locations from "Expansion" to "Primary" status as a result of the NRC's review of MRP-227. Some of the updated sections contained in the attachment contain reference numbers. These numbers correspond to the references in WCAP-17096-NP, revision 2. Updating the WCAP is part of the scope under PWROG project authorization, PA-MSC-0473 [1]. This letter includes the following updated sections:

CE-ID: 2	Core Shroud Assembly (Welded) – Core Shroud Plate-Former Plate Weld
CE-ID: 2.1	Core Shroud Assembly (Welded) – Remaining Axial Welds
CE-ID: 3	Core Shroud Assembly (Welded – Full Height) – Shroud Plates
CE-ID: 3.1	Core Shroud Assembly (Welded) – Remaining Axial Welds, Ribs and Rings
CE-ID: 6	Core Support Barrel Assembly – Upper (Core Support Barrel) Flange Weld
CE-ID: 6.1	Core Support Barrel Assembly – Lower Core Barrel Flange

CE-ID: 6.2	Core Support Barrel Assembly – Upper Cylinder (Including Welds)
CE-ID: 6.3	Core Support Barrel Assembly – Upper Core Barrel Flange
CE-ID: 6.4	Lower Support Structure – Lower Core Support Beams
CE-ID: 7	Core Support Barrel Assembly – Lower Cylinder Girth Welds
CE-ID: 7.1	Core Support Barrel Assembly – Core Barrel Assembly Axial Welds
CE-ID: 9	Core Support Barrel Assembly – Lower Flange Flexure Weld
CE-ID: 12	Control Element Assembly – Instrument Guide Tubes
CE-ID: 12.1	Control Element Assembly – Remaining Instrument Guide Tubes
CE-ID: 13	Lower Support Structure – Deep Beams
W-ID: 1	Control Rod Guide Tube Assembly – Guide Plates (Cards)
W-ID: 2.1	Upper Internals Assembly – Upper Core Plate
W-ID: 2.2	Lower Internals Assembly – Lower Support Forging or Casting
W-ID: 3.1	Core Barrel Assembly – Core Barrel Outlet Nozzle Welds
W-ID: 10	Thermal Shield Assembly – Thermal Shield Flexures

Please transmit this information, except the comment resolution spreadsheet, to EPRI for submittal to the NRC for their review. Upon completion of the review, EPRI should transmit all NRC comments back to Michael Semmler. A completion date of April 18, 2014 is requested.

If EPRI or the NRC has any questions or desires further information, please contact Michael Semmler by either phone at (412) 374-2427 or email at semmlemg@westinghouse.com.

Authored by: ELECTRONICALLY APPROVED[1]

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Patricia C. Paesano, Manager
Reactor Internals Aging Management

[1] ***Electronically approved records are authenticated in the electronic document management system.***

Attachment A

Westinghouse Updates Related to Topical Report WCAP-17096-NP, Revision 2, "Reactor Internals Acceptance Criteria Methodology and Data Requirements"

Revised Table of Contents for Appendix C of WCAP-17096-NP

Combustion Engineering Primary and Expansion Components

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[1]Attachment A of this letter contains this WCAP-17096 section.

CE-ID: 2 **Core Shroud Assembly (Welded)**

Core Shroud Plate-Former Plate Weld

Category:	Primary	Applicability:	Plant designs with core shrouds assembled in two vertical sections
Degradation Effect:	Cracking (IASCC), Aging Management (IE)		
Expansion Link:	Remaining axial welds		
Function:	1. Direct coolant flow.		

Inspection

Method: Enhanced visual (EVT-1) examination no later than two refueling outages from the beginning of the license renewal period and subsequent examination on a 10-year interval.

Coverage: Axial and horizontal weld seams at the core shroud re-entrant corners as visible from the core side of the shroud, within six inches of central flange and horizontal stiffeners. See MRP-227 Figures 4-12 and 4-14.

Observable Effect: The specific relevant condition is a detectable crack-like surface indication.

Inputs and Assumptions

There are several inputs and assumptions that are critical to the development of acceptance criteria for the core shroud welds. These items are stated below:

- The inspections identified in MRP-227-A are intended to provide a sampling of potential locations of degradation. Under this approach, inspection of one side (surface) of the weld is intended to provide an adequate sampling for monitoring of IASCC.
- The change in resistance to fracture of the core shroud welds can be correlated to the accumulated fluence at each weld location. Welds that are subject to low fluence are considered to have a high degree of resistance to fracture. Correspondingly, those welds subject to high fluence have lower resistance to fracture. This region is expected to experience high fluence levels.
- It is assumed that the primary mode of crack growth to be expected in this region is irradiation assisted stress corrosion cracking.
- The prediction of crack growth is based on the stress intensity factor, K, calculated using linear elastic fracture mechanics. The rate of crack growth is dependent on the amount of neutron fluence that the weld is expected to accumulate over the licensed operating lifetime. Since there has been no experience of IASCC initiated cracks in operating PWRs to date, growth rates developed for the prediction of IASCC in BWRs are assumed to be appropriate for prediction of crack growth due to IASCC in PWR reactor internals.
    - For weld locations subjected to fluence less than or equal to $5x10^{20}$ n/cm^2 (E>1MeV), the boiling water reactor (BWR) hydrogen water chemistry (HWC) crack growth equation specified in paragraph C-8520 of Appendix C of Section XI of the 2010 edition of the ASME Boiler and Pressure Vessel Code is appropriate. This crack growth rate model is consistent with the model in BWRVIP-14a, which was previously reviewed and approved by the NRC.
    - For fluence levels above $5x10^{20}$ n/cm^2 (E>1MeV), the BWR HWC

CE-ID: 2 **Core Shroud Assembly (Welded)**

Core Shroud Plate-Former Plate Weld

crack growth equation specified in equation 6-5 of MRP-227-A is appropriate.

- Acceptance criteria can be developed for the entire 60-year license of a given plant by using predicted end-of-license fluence values. However, if there are changes to these fluence projections, such as in the event of a power uprate or change in core loading pattern, it would be necessary to confirm that the inputs selected based on fluence, such as IASCC growth rate and fracture toughness, remain applicable until the end of the 60-year license.

Failure

Failure Mechanism: Cracking (IASCC)

Failure Effect:

1. Damage to peripheral fuel assemblies.
2. Through-wall crack provides leak path through shroud.

Failure Criteria: An existing flaw is unacceptable if the flaw length projected at the next inspection cycle is beyond the allowable crack length. .

No observable damage in corresponding sections of peripheral fuel assemblies.

Methodology

Goal: Demonstrate that the cracking mechanism will not result in growth beyond the allowable crack length over the planned inspection interval.

Data Requirements:

1. Surface crack length, as determined by visual inspection:
    a. The 2007 edition of the ASME Code Section XI: IWA-3330(a) and Figure IWA-3330-1 provide requirements for the minimum allowable separation distance that will allow multiple cracks to be treated individually. This approach is part of the guidance in this report. The requirement in Section XI is that the ligament between adjacent cracks must be greater than half of the thickness of the material. If this criterion is not met, the individual crack lengths and the length of the ligament between the cracks must be summed. This total length is then compared to the allowable length.
2. Flaw Depth
    a. For one-sided visual inspections, the flaw is assumed to be through-wall.
    b. Supplemental examinations may be used to determine depths of specific flaws as the basis for a flaw-specific evaluation, if needed.
3. Estimate of fast neutron fluence at crack location.
4. Steady-state normal operating stresses to be used to calculate IASCC crack growth rates.
    a. Axial stresses based on normal mechanical loads are required for horizontal flaws.
    b. Circumferential stresses based on normal mechanical loads are required for axial flaws.
    c. Stresses which have an insignificant net-through-wall value (average stress is near zero), such as weld residual stresses and thermal stresses due to local through-wall temperature gradients are considered to have

CE-ID: 2 **Core Shroud Assembly (Welded)**

Core Shroud Plate-Former Plate Weld

minimal impact on the effective crack growth rates in through-wall flaws.

d. Secondary weld residual and thermal stresses need to be considered in determination of through-wall crack growth rates in partial through-wall flaws, whose dimensions would have to be determined with supplemental UT examinations.

5. Limiting externally applied transient stresses to be used to calculate allowable flaw lengths.

   a. More detailed load-deformation histories may be required for elastic-plastic or limit load calculations.

Analysis:

All analyses require an assumption of the IASCC crack growth expected over the upcoming period of service. The methodology is based on analysis of a through-wall flaw with weld residual and thermal stresses relieved. The crack growth rate models will be based on K dependent crack growth under hydrogen water chemistry conditions. In order to apply the acceptance criteria to a full 10-year inspection interval, follow-up action is required to verify the assumptions used in the predicted crack-growth rate. A re-inspection of the indication at a future specified outage, for example, would provide data that could be used to satisfy this verification requirement. Evaluate impact of fatigue crack growth on observed flaw. Failure of the welds is assumed to occur when unstable crack growth is initiated from the analyzed flaw. Three options are outlined for determining the limiting allowable flaw length, based on neutron dose. Analysis methods are suggested for both pre-inspection and generic analysis (Suggested Pre-Inspection Analysis) and for flaws observed in-service (Suggested Flaw Specific Analysis), where more detailed characteristics of the flaw and its location are known. In all cases, a more detailed evaluation may be completed using a semi-elliptic surface flaw, but such an evaluation would require more detailed inspection by UT. /

Fluence Range (n/cm^2 E>1MeV)	Dose (dpa)	MRP-227-A Requirement	Suggested Pre-Inspection Analysis	Suggested Flaw Specific Analysis
$\leq 3 \times 10^{20}$	≤ 0.5	Limit Load	LEFM using 150 ksi√in for fracture toughness or Limit Load	Limit Load
$> 3\times10^{20}$ - 3×10^{21}	> 0.5 - 5	LEFM or EPFM	LEFM using 112 ksi√in for fracture toughness or EPFM	EPFM
$> 3\times10^{21}$ - 1×10^{22}	> 5 – 15	LEFM using 50 ksi√in for fracture toughness	LEFM using 50 ksi√in for fracture toughness	LEFM using 50 ksi√in for fracture toughness
$>1\times10^{22}$	> 15	LEFM using 34.6 ksi√in for fracture toughness	LEFM using 34.6 ksi√in for fracture toughness	LEFM using 34.6 ksi√in for fracture toughness

Different evaluation options may be used depending upon the plant-specific fluence levels at the location of the weld being evaluated. Option 1, though conservative, can be

CE-ID: 2 **Core Shroud Assembly (Welded)**

Core Shroud Plate-Former Plate Weld

used for all fluence levels.

Option 1: LEFM Analysis

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. For normal and upset loading conditions, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 2.77.
e. For the governing emergency or faulted loading condition, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 1.39.

Option 2: EPFM Analysis (for neutron dose levels > 0.5 dpa but < 5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. Develop the (J/T) material curve from the material J-R curve.
e. The $J_{applied}$ curve must include a safety factor of 2.77 for normal and upset conditions, and a factor of 1.39 for emergency and faulted conditions.
f. The intersection of the material and applied (J/T) curves indicates the instability point. The flaw size at instability is determined from the $J_{applied}$ versus flaw size curve.
g. The flaw size at instability must be larger than the flaw size from (b), for the flaw to be acceptable.

The intersection of the material and applied (J/T) curves indicates the instability point. The load at instability is determined from the $J_{applied}$ versus load curve.

Option 3: Limit Load Analysis (For neutron fluence < $3x10^{20}$ n/cm^2 at E>1 MeV or dose less than approximately 0.5 dpa) This region is expected to experience high fluence levels so it is unlikely that this option will be applicable.

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the

CE-ID: 2 **Core Shroud Assembly (Welded)**

Core Shroud Plate-Former Plate Weld

threshold for fatigue crack growth.

d. Determine the bending moment (M) that can be tolerated as a function of the postulated flaw length.

e. The applied moment, increased by a factor of 1.39 (for emergency and faulted conditions) or 2.77 (for normal and upset conditions) must be less than the limit moment (from step d) for the flaw length determined in (b), for the flaw to be acceptable.

Acceptance Criteria: The weld continues to perform its functional requirements with the projected flaw length at the end of the inspection interval.

Approach: Limit load, EPFM or LEFM analysis

CE-ID: 2.1 **Core Shroud Assembly (Welded)**

Remaining Axial Welds

Category:	Expansion	Applicability:	Plant designs with core shrouds assembled in two vertical sections
Degradation Effect:	Cracking (IASCC), Aging Management (IE)		
Expansion Link:	Core shroud plate-former plate weld.		
Function:	1. Maintain core geometry. 2. Direct coolant flow.		

Inspection

Method:	Enhanced visual (EVT-1) examination. Re-inspection every ten years following initial inspection.
Coverage:	Axial weld seams other than the core shroud re-entrant corner welds at the core mid-plane.
Observable Effect:	The specific relevant condition is a detectable crack-like surface indication.

Inputs and Assumptions

There are several inputs and assumptions that are critical to the development of acceptance criteria for the RV Internals weld locations. These items are stated below:

- The inspections identified in MRP-227-A are intended to provide a sampling of potential locations of degradation. Under this approach, inspection of one side (surface) of the weld is assumed to provide an adequate sampling for monitoring of Irradiation Assisted Stress Corrosion Cracking (IASCC).
- The change in resistance to fracture of the remaining axial welds can be correlated to the accumulated fluence at each weld location. Welds that are subject to low fluence are considered to have a high degree of resistance to fracture. Correspondingly, those welds subject to high fluence have lower resistance to fracture.
- It is assumed that the primary mode of crack growth to be expected in this region is stress corrosion cracking.
- The prediction of crack growth is based on the stress intensity factor, K, calculated using linear elastic fracture mechanics. The rate of crack growth is dependent on the amount of neutron fluence that the weld is expected to accumulate over the licensed operating lifetime. Since there has been no experience of IASCC initiated cracks in operating PWRs to date, growth rates developed for the prediction of IASCC in boiling water reactors (BWRs) are assumed to be appropriate for prediction of crack growth due to IASCC in PWR reactor internals.
  - For weld locations subjected to fluence less than or equal to $5x10^{20}$ n/cm^2 (E>1MeV), the BWR hydrogen water chemistry (HWC) crack growth equation specified in paragraph C-8520 of Appendix C of Section XI of the 2010 edition of the ASME Boiler and Pressure Vessel Code is appropriate. This crack growth rate model is consistent with the model in BWRVIP-14a, which was previously reviewed and approved by the NRC.
  - For fluence levels above $5x10^{20}$ n/cm^2 (E>1MeV), the BWR HWC crack growth equation specified in equation 6-5 of MRP-227-A is

CE-ID: 2.1 **Core Shroud Assembly (Welded)**

Remaining Axial Welds

appropriate.

- Acceptance criteria can be developed for the entire 60-year license of a given plant by using predicted end-of-license fluence values. However, if there are changes to these fluence projections, such as in the event of a power uprate or change in core loading pattern, it would be necessary to confirm that the inputs selected based on fluence, such as IASCC growth rate and fracture toughness, remain applicable until the end of the 60-year license.

Failure

Failure Mechanism: Cracking (IASCC)

Failure Effect:

1. Core damage caused by event – require maintenance of coolable geometry.
2. Damage to peripheral fuel assemblies.
3. Through-wall crack provides leak path through shroud.

Failure Criteria: Actively growing through-wall flaws may require mitigation.

An existing flaw is unacceptable if the flaw length projected at the next inspection cycle is beyond the allowable crack length.

Methodology

Goal: Demonstrate that the cracking mechanism will not result in growth beyond the allowable crack length over the planned inspection interval.

Data Requirements:

1. Surface crack length as determined by visual inspection
   a. The 2007 edition of the ASME Code Section XI: IWA-3330(a) and Figure IWA-3330-1 provide requirements for the minimum allowable separation distance that will serve as the basis for guidance in this report. The requirement in Section XI is that the ligament between adjacent cracks must be greater than half of the thickness of the material. If this criterion is not met, the individual crack lengths and the length of the ligament between the cracks must be summed. This total length is then compared to the allowable length.
2. Flaw Depth
   a. For one-sided visual inspections, the flaw is assumed to be through-wall.
   b. Supplemental examinations may be used to determine flaw depth, for a flaw-specific criterion, if needed.
3. Estimate of fast neutron fluence at crack location.
4. Steady-state normal operating stresses to be used to calculate IASCC crack growth rates.
   a. Horizontal stresses based on normal mechanical loads are required for axial flaws.
   b. Stresses which have an insignificant net-through-wall value (average stress is near zero), such as weld residual stresses and thermal stresses due to local through-wall temperature gradients are considered to have minimal impact on the effective crack growth rates in through-wall flaws.

CE-ID: 2.1 **Core Shroud Assembly (Welded)**

Remaining Axial Welds

c. Secondary weld residual and thermal stresses need to be considered in determination of circumferential and through-wall crack growth rates in partial through-wall flaws, whose dimensions would have to be determined with supplemental UT examinations.

5. Limiting externally applied transient stresses to be used to calculate allowable flaw lengths. For example, stresses arising from pressure, mechanical and thermal loads would be included in this calculation,

   a. More detailed load-deformation histories may be required for elastic-plastic or limit load calculations, if these calculations are necessary.

Analysis:

All analyses require an assumption of the IASCC crack growth expected over the upcoming period of service. The methodology is based on analysis of a through-wall flaw with weld residual and thermal stresses relieved. The crack growth rate models will be based on K dependent crack growth under hydrogen water chemistry conditions. In order to apply the acceptance criteria to a full 10-year inspection interval, follow-up action is required to verify the assumptions used in the predicted crack-growth rate. A re-inspection of the indication at a future specified outage, for example, would provide data that could be used to satisfy this verification requirement. Evaluate impact of fatigue crack growth on observed flaw. Failure of the weld is assumed to occur when unstable crack growth is initiated from the analyzed flaw. Three options are outlined for determining the limiting allowable flaw length, based on neutron dose. Analysis methods are suggested for both pre-inspection and generic analysis (Suggested Pre-Inspection Analysis) and for flaws observed in-service (Suggested Flaw Specific Analysis), where more detailed characteristics of the flaw and its location are known. In all cases, a more detailed evaluation may be completed using a semi-elliptic surface flaw, but such an evaluation would require more detailed inspection by UT.

Fluence Range (n/cm^2 E>1MeV)	**Dose (dpa)**	**MRP-227-A Requirement**	**Suggested Pre-Inspection Analysis**	**Suggested Flaw Specific Analysis**
$\leq 3 \times 10^{20}$	≤ 0.5	Limit Load	LEFM using 150 ksi√in for fracture toughness or Limit Load	Limit Load
$> 3\times10^{20}$ - 3×10^{21}	> 0.5 - 5	LEFM or EPFM	LEFM using 112 ksi√in for fracture toughness or EPFM	EPFM
$> 3\times10^{21}$ - 1×10^{22}	> 5 – 15	LEFM using 50 ksi√in for fracture toughness	LEFM using 50 ksi√in for fracture toughness	LEFM using 50 ksi√in for fracture toughness
$>1\times10^{22}$	> 15	LEFM using 34.6 ksi√in for fracture toughness	LEFM using 34.6 ksi√in for fracture toughness	LEFM using 34.6 ksi√in for fracture toughness

Different evaluation options may be used depending upon the plant-specific fluence levels at the location of the weld being evaluated. Option 1, though conservative, can be used for all fluence levels.

CE-ID: 2.1 **Core Shroud Assembly (Welded)**

Remaining Axial Welds

Option 1: LEFM Analysis

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. For normal and upset loading conditions, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 2.77.
e. For the governing emergency or faulted loading condition, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 1.39.

Option 2: EPFM Analysis (for neutron dose levels > 0.5 dpa but < 5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. Develop the (J/T) material curve from the material J-R curve.
e. The $J_{applied}$ curve must include a safety factor of 2.77 for normal and upset conditions, and a factor of 1.39 for emergency and faulted conditions.
f. The intersection of the material and applied (J/T) curves indicates the instability point. The flaw size at instability is determined from the $J_{applied}$ versus flaw size curve.
g. The flaw size at instability must be larger than the flaw size from (b), for the flaw to be acceptable.

The intersection of the material and applied (J/T) curves indicates the instability point. The load at instability is determined from the $J_{applied}$ versus load curve.

Option 3: Limit Load Analysis (For neutron fluence < $3x10^{20}$ n/cm^2 at E>1 MeV or dose less than approximately 0.5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. Determine the bending moment (M) that can be tolerated as a function of the

CE-ID: 2.1 **Core Shroud Assembly (Welded)**

Remaining Axial Welds

postulated flaw length.

e. The applied moment, increased by a factor of 1.39 (for emergency and faulted conditions) or 2.77 (for normal and upset conditions) must be less than the limit moment (from step d) for the flaw length determined in (b), for the flaw to be acceptable.

Acceptance Criteria: The weld continues to perform its functional requirements with the projected flaw length at the end of the inspection interval.

Approach: Limit load, EPFM or LEFM analysis

CE-ID: 3 Core Shroud Assembly (Welded – Full Height)

Shroud Plates

Category:	Primary	Applicability:	Plant designs with core shrouds assembled with full-height shroud plates
Degradation Effect:	Cracking (IASCC)		
Expansion Link:	Remaining axial welds, ribs, and rings.		
Function:	1. Maintain core geometry. 2. Direct coolant flow.		

Inspection

Method:	Enhanced visual (EVT-1) examination no later than two refueling outages from the beginning of the license renewal period and subsequent examination on a ten-year interval.
Coverage:	Axial weld seams at the core shroud re-entrant corners, at the core mid-plane (±three feet in height) as visible from the core side of the shroud. See MRP-227, Figure 4-13.
Observable Effect:	The specific relevant condition is a detectable crack-like surface indication.

Inputs and Assumptions

There are several inputs and assumptions that are critical to the development of acceptance criteria for the RV Internals weld locations. These items are stated below:

- The inspections identified in MRP-227-A are intended to provide a sampling of potential locations of degradation. Under this approach, inspection of one side (surface) of the weld is assumed to provide an adequate sampling for monitoring of Irradiation Assisted Stress Corrosion Cracking (IASCC).
- The change in resistance to fracture of the shroud plates welds can be correlated to the accumulated fluence at each weld location. Welds that are subject to low fluence are considered to have a high degree of resistance to fracture. Correspondingly, those welds subject to high fluence have lower resistance to fracture.
- It is assumed that the primary mode of crack growth to be expected in this region is stress corrosion cracking.
- The prediction of crack growth is based on the stress intensity factor, K, calculated using linear elastic fracture mechanics. The rate of crack growth is dependent on the amount of neutron fluence that the weld is expected to accumulate over the licensed operating lifetime. Since there has been no experience of IASCC initiated cracks in operating PWRs to date, growth rates developed for the prediction of IASCC in boiling water reactors (BWRs) are assumed to be appropriate for prediction of crack growth due to IASCC in PWR reactor internals.
  - For weld locations subjected to fluence less than or equal to $5x10^{20}$ n/cm^2 (E>1MeV), the BWR hydrogen water chemistry (HWC) crack growth equation specified in paragraph C-8520 of Appendix C of Section XI of the 2010 edition of the ASME Boiler and Pressure Vessel Code is appropriate. This crack growth rate model is consistent with the model in BWRVIP-14a, which was previously reviewed and approved by the NRC.
  - For fluence levels above $5x10^{20}$ n/cm^2 (E>1MeV), the BWR HWC

CE-ID: 3 **Core Shroud Assembly (Welded – Full Height)**

Shroud Plates

crack growth equation specified in equation 6-5 of MRP-227-A is appropriate.

- Depending on the magnitude of cyclic loads, such as thermal transients, additional crack growth as a result of these loads may need to be considered.
- Acceptance criteria can be developed for the entire 60-year license of a given plant by using predicted end-of-license fluence values. However, if there are changes to these fluence projections, such as in the event of a power uprate or change in core loading pattern, it would be necessary to confirm that the inputs selected based on fluence, such as IASCC growth rate and fracture toughness, remain applicable until the end of the 60-year license.

Failure

Failure Mechanism: Cracking (IASCC)

Failure Effect:

1. Core damage caused by event – require maintenance of coolable geometry.
2. Damage to peripheral fuel assemblies.
3. Through-wall crack provides leak path through shroud.

Failure Criteria: Actively growing through-wall flaws may require mitigation.

An existing flaw is unacceptable if the flaw length projected at the next inspection cycle is beyond the allowable crack length.

Methodology

Goal: Demonstrate that the cracking mechanism will not result in growth beyond the allowable crack length over the planned inspection interval.

Data Requirements:

1. Surface crack length as determined by visual inspection
   a. The 2007 edition of the ASME Code Section XI: IWA-3330(a) and Figure IWA-3330-1 provide requirements for the minimum allowable separation distance that will serve as the basis for guidance in this report. The requirement in Section XI is that the ligament between adjacent cracks must be greater than half of the thickness of the material. If this criterion is not met, the individual crack lengths and the length of the ligament between the cracks must be summed. This total length is then compared to the allowable length.
2. Flaw Depth
   a. For one-sided visual inspections, the flaw is assumed to be through-wall.
   b. Supplemental examinations may be used to determine flaw depth, for a flaw-specific criterion, if needed.
3. Estimate of fast neutron fluence at crack location.
4. Steady-state normal operating stresses to be used to calculate IASCC crack growth rates.
   a. Vertical stresses based on normal mechanical loads are required for horizontal flaws.
   b. Horizontal stresses based on normal mechanical loads are required for vertical flaws.

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Shroud Plates

c. Stresses which have an insignificant net-through-wall value (average stress is near zero), such as weld residual stresses and thermal stresses due to local through-wall temperature gradients are considered to have minimal impact on the effective crack growth rates in through-wall flaws.

d. Secondary weld residual and thermal stresses need to be considered in determination of circumferential and through-wall crack growth rates in partial through-wall flaws, whose dimensions would have to be determined with supplemental UT examinations.

5. Limiting externally applied transient stresses to be used to calculate allowable flaw lengths. For example, stresses arising from pressure, mechanical and thermal loads would be included in this calculation,

   a. More detailed load-deformation histories may be required for elastic-plastic or limit load calculations, if these calculations are necessary.

Analysis:

All analyses require an assumption of the IASCC crack growth expected over the upcoming period of service. The methodology is based on analysis of a through-wall flaw with weld residual and thermal stresses relieved. The crack growth rate models will be based on K dependent crack growth under hydrogen water chemistry conditions. Fatigue crack growth has been assumed to be negligible. In order to apply the acceptance criteria to a full 10-year inspection interval, follow-up action is required to verify the assumptions used in the predicted crack-growth rate. A re-inspection of the indication at a future specified outage, for example, would provide data that could be used to satisfy this verification requirement.

Failure of the shroud plate weld is assumed to occur when unstable crack growth is initiated from the analyzed flaw. Three options are outlined for determining the limiting allowable flaw length, based on neutron dose. Analysis methods are suggested for both pre-inspection and generic analysis (Suggested Pre-Inspection Analysis) and for flaws observed in-service (Suggested Flaw Specific Analysis), where more detailed characteristics of the flaw and its location are known. In all cases, a more detailed evaluation may be completed using a semi-elliptic surface flaw, but such an evaluation would require more detailed inspection by UT.

CE-ID: 3 Core Shroud Assembly (Welded – Full Height)

Shroud Plates

Fluence Range (n/cm^2 E>1MeV)	Dose (dpa)	MRP-227-A Requirement	Suggested Pre-Inspection Analysis	Suggested Flaw Specific Analysis
$\leq 3 \times 10^{20}$	≤ 0.5	Limit Load	LEFM 150 using ksi√in for fracture toughness or Limit Load	Limit Load
$> 3\times10^{20} - 3\times10^{21}$	> 0.5 - 5	LEFM or EPFM	LEFM using 112 ksi√in for fracture toughness or EPFM	EPFM
$> 3\times10^{21} - 1\times10^{22}$	> 5 – 15	LEFM using 50 ksi√in for fracture toughness	LEFM using 50 ksi√in for fracture toughness	LEFM using 50 ksi√in for fracture toughness
$>1\times10^{22}$	> 15	LEFM using 34.6 ksi√in for fracture toughness	LEFM using 34.6 ksi√in for fracture toughness	LEFM using 34.6 ksi√in for fracture toughness

Different evaluation options may be used depending upon the plant-specific fluence levels at the location of the weld being evaluated. Option 1, though conservative, can be used for all fluence levels.

Option 1: LEFM Analysis

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. For normal and upset loading conditions, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 2.77.
e. For the governing emergency or faulted loading condition, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 1.39.

Option 2: EPFM Analysis (for neutron dose levels > 0.5 dpa but < 5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. Develop the (J/T) material curve from the material J-R curve.

CE-ID: 3 **Core Shroud Assembly (Welded – Full Height)**

Shroud Plates

e. The $J_{applied}$ curve must include a safety factor of 2.77 for normal and upset conditions, and a factor of 1.39 for emergency and faulted conditions.

f. The intersection of the material and applied (J/T) curves indicates the instability point. The flaw size at instability is determined from the $J_{applied}$ versus flaw size curve.

g. The flaw size at instability must be larger than the flaw size from (b), for the flaw to be acceptable.

The intersection of the material and applied (J/T) curves indicates the instability point. The load at instability is determined from the $J_{applied}$ versus load curve.

Option 3: Limit Load Analysis (For neutron fluence < $3x10^{20}$ n/cm^2 at E>1 MeV or dose less than approximately 0.5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.

b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. Determine the bending moment (M) that can be tolerated as a function of the postulated flaw length.

e. The applied moment, increased by a factor of 1.39 (for emergency and faulted conditions) or 2.77 (for normal and upset conditions) must be less than the limit moment (from step d) for the flaw length determined in (b), for the flaw to be acceptable.

Acceptance Criteria: The shroud plate welds continues to perform its functional requirements with the projected flaw length at the end of the inspection interval.

Approach: Limit load, EPFM or LEFM analysis

CE-ID: 3.1 **Core Shroud Assembly (Welded)**

Remaining Axial Welds, Ribs and Rings

Category:	Expansion — Applicability: Plant designs with core shrouds assembled with full-height shroud plates
Degradation Effect:	Cracking (IASCC), Aging Management (IE)
Expansion Link:	Shroud plates of welded core shroud assemblies
Function:	Maintain dimensional stability of core shroud plus ribs and rings

Inspection

Method:	Enhanced visual (EVT-1) examination. Re-inspection every ten years following initial inspection.
Coverage:	Axial weld seams other than the core shroud re-entrant corner welds at the core mid-plane plus ribs and rings.
Observable Effect:	The specific relevant condition is a detectable crack-like surface indication.

Inputs and Assumptions

There are several inputs and assumptions that are critical to the development of acceptance criteria for the remaining axial welds, ribs, and rings locations. These items are stated below:

- The inspections identified in MRP-227-A are intended to provide a sampling of potential locations of degradation. Under this approach, inspection of one side (surface) of the weld, rib or ring is assumed to provide an adequate sampling for monitoring of Irradiation Assisted Stress Corrosion Cracking (IASCC).
- The change in resistance to fracture of the remaining axial welds, ribs, and rings welds can be correlated to the accumulated fluence at each weld location. Welds that are subject to low fluence are considered to have a high degree of resistance to fracture. Correspondingly, those welds subject to high fluence have lower resistance to fracture. The remaining axial welds, ribs and rings are expected to be highly irradiated.
- It is assumed that the primary mode of crack growth to be expected in this region is stress corrosion cracking.
- The prediction of crack growth is based on the stress intensity factor, K, calculated using linear elastic fracture mechanics. The rate of crack growth is dependent on the amount of neutron fluence that the weld, rib or ring is expected to accumulate over the licensed operating lifetime. Since there has been no experience of IASCC initiated cracks in operating PWRs to date, growth rates developed for the prediction of IASCC in boiling water reactors (BWRs) are assumed to be appropriate for prediction of crack growth due to IASCC in PWR reactor internals.
    - For weld, rib or ring locations subjected to fluence less than or equal to $5x10^{20}$ n/cm^2 (E>1MeV), the BWR hydrogen water chemistry (HWC) crack growth equation specified in paragraph C-8520 of Appendix C of Section XI of the 2010 edition of the ASME Boiler and Pressure Vessel Code is appropriate. This crack growth rate model is consistent with the model in BWRVIP-14a, which was previously reviewed and approved by the NRC.
    - For fluence levels above $5x10^{20}$ n/cm^2 (E>1MeV), the BWR HWC

CE-ID: 3.1 **Core Shroud Assembly (Welded)**

Remaining Axial Welds, Ribs and Rings

crack growth equation specified in equation 6-5 of MRP-227-A is appropriate.

- Depending on the magnitude of cyclic loads, such as thermal transients, additional crack growth as a result of these loads may need to be considered.
- Acceptance criteria can be developed for the entire 60-year license of a given plant by using predicted end-of-license fluence values. However, if there are changes to these fluence projections, such as in the event of a power uprate or change in core loading pattern, it would be necessary to confirm that the inputs selected based on fluence, such as IASCC growth rate and fracture toughness, remain applicable until the end of the 60-year license.

Failure

Failure Mechanism: Cracking (IASCC)

Failure Effect:

1. Core damage caused by event – require maintenance of coolable geometry.
2. Damage to peripheral fuel assemblies.
3. Through-wall crack provides leak path through shroud.

Failure Criteria: Actively growing through-wall flaws may require mitigation.

An existing flaw is unacceptable if the flaw length projected at the next inspection cycle is beyond the allowable crack length.

No observable damage in corresponding sections of peripheral fuel assemblies.

Methodology

Goal: Demonstrate that the cracking mechanism will not result in growth beyond the allowable crack length over the planned inspection interval.

Data Requirements:

1. Surface crack length as determined by visual inspection
   a. The 2007 edition of the ASME Code Section XI: IWA-3330(a) and Figure IWA-3330-1 provide requirements for the minimum allowable separation distance that will serve as the basis for guidance in this report. The requirement in Section XI is that the ligament between adjacent cracks must be greater than half of the thickness of the material. If this criterion is not met, the individual crack lengths and the length of the ligament between the cracks must be summed. This total length is then compared to the allowable length.
2. Flaw Depth
   a. For one-sided visual inspections, the flaw is assumed to be through-wall.
   b. Supplemental examinations may be used to determine flaw depth, for a flaw-specific criterion, if needed.
3. Estimate of fast neutron fluence at crack location.
4. Steady-state normal operating stresses to be used to calculate IASCC crack growth rates.
   a. Vertical stresses based on normal mechanical loads are required for horizontal flaws.
   b. Horizontal stresses based on normal mechanical loads are required for

CE-ID: 3.1 **Core Shroud Assembly (Welded)**

Remaining Axial Welds, Ribs and Rings

Vertical flaws.

c. Stresses which have an insignificant net-through-wall value (average stress is near zero), such as weld residual stresses and thermal stresses due to local through-wall temperature gradients are considered to have minimal impact on the effective crack growth rates in through-wall flaws.

d. Secondary weld residual and thermal stresses need to be considered in determination of circumferential and through-wall crack growth rates in partial through-wall flaws, whose dimensions would have to be determined with supplemental UT examinations.

5. Limiting externally applied transient stresses to be used to calculate allowable flaw lengths. For example, stresses arising from pressure, mechanical and thermal loads would be included in this calculation.

   a. More detailed load-deformation histories may be required for elastic-plastic or limit load calculations, if these calculations are necessary.

Analysis:

All analyses require an assumption of the IASCC crack growth expected over the upcoming period of service. The methodology is based on analysis of a through-wall flaw with weld residual and thermal stresses relieved. The crack growth rate models will be based on K dependent crack growth under hydrogen water chemistry conditions. Fatigue crack growth has been assumed to be negligible. In order to apply the acceptance criteria to a full 10-year inspection interval, follow-up action is required to verify the assumptions used in the predicted crack-growth rate. A re-inspection of the indication at a future specified outage, for example, would provide data that could be used to satisfy this verification requirement.

Failure of the weld is assumed to occur when unstable crack growth is initiated from the analyzed flaw. Three options are outlined for determining the limiting allowable flaw length, based on neutron dose. Analysis methods are suggested for both pre-inspection and generic analysis (Suggested Pre-Inspection Analysis) and for flaws observed in-service (Suggested Flaw Specific Analysis), where more detailed characteristics of the flaw and its location are known. In all cases, a more detailed evaluation may be completed using a semi-elliptic surface flaw, but such an evaluation would require more detailed inspection by UT.

CE-ID: 3.1 Core Shroud Assembly (Welded)

Remaining Axial Welds, Ribs and Rings

Fluence Range (n/cm^2 E>1MeV)	Dose (dpa)	MRP-227-A Requirement	Suggested Pre-Inspection Analysis	Suggested Flaw Specific Analysis
≤ 3 $x10^{20}$	≤ 0.5	Limit Load	LEFM using 150 ksi√in for fracture toughness or Limit Load	Limit Load
> $3x10^{20}$ - $3x10^{21}$	> 0.5 - 5	LEFM or EPFM	LEFM using 112 ksi√in for fracture toughness or EPFM	EPFM
> $3x10^{21}$ - $1x10^{22}$	> 5 – 15	LEFM using 50 ksi√in for fracture toughness	LEFM using 50 ksi√in for fracture toughness	LEFM using 50 ksi√in for fracture toughness
>$1x10^{22}$	> 15	LEFM using 34.6 ksi√in for fracture toughness	LEFM using 34.6 ksi√in for fracture toughness	LEFM using 34.6 ksi√in for fracture toughness

Different evaluation options may be used depending upon the plant-specific fluence levels at the location of the weld, rib or ring being evaluated. Option 1, though conservative, can be used for all fluence levels.

Option 1: LEFM Analysis

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. For normal and upset loading conditions, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 2.77.
e. For the governing emergency or faulted loading condition, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 1.39.

Option 2: EPFM Analysis (for neutron dose levels > 0.5 dpa but < 5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. Develop the (J/T) material curve from the material J-R curve.

CE-ID: 3.1 **Core Shroud Assembly (Welded)**

Remaining Axial Welds, Ribs and Rings

e. The $J_{applied}$ curve must include a safety factor of 2.77 for normal and upset conditions, and a factor of 1.39 for emergency and faulted conditions.

f. The intersection of the material and applied (J/T) curves indicates the instability point. The flaw size at instability is determined from the $J_{applied}$ versus flaw size curve.

g. The flaw size at instability must be larger than the flaw size from (b), for the flaw to be acceptable.

The intersection of the material and applied (J/T) curves indicates the instability point. The load at instability is determined from the $J_{applied}$ versus load curve.

Option 3: Limit Load Analysis (For neutron fluence < $3x10^{20}$ n/cm^2 at E>1 MeV or dose less than approximately 0.5 dpa). This option is unlikely due to the anticipated fluence levels.

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.

b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. Determine the bending moment (M) that can be tolerated as a function of the postulated flaw length.

e. The applied moment, increased by a factor of 1.39 (for emergency and faulted conditions) or 2.77 (for normal and upset conditions) must be less than the limit moment (from step d) for the flaw length determined in (b), for the flaw to be acceptable.

Acceptance Criteria: The weld, rib or ring continues to perform its functional requirements with the projected flaw length at the end of the inspection interval.

Approach: Limit load, EPFM or LEFM analysis

CE-ID: 6 **Core Support Barrel Assembly**

Upper (Core Support Barrel) Flange Weld

Category:	Primary Applicability: All plants
Degradation Effect:	Cracking (Stress Corrosion Cracking [SCC])
Expansion Link:	Core Support Barrel Assembly: Lower Core Barrel Flange, Upper Cylinder (Including Welds), Upper Core Barrel Flange, Lower Support Structure – Lower Core Support Beams
Function:	Primary core support structure

Inspection

Method:	Enhanced visual (EVT-1) examination no later than two refueling outages from the beginning of the license renewal period. Subsequent examinations on a 10-year interval.
Coverage:	100% of the accessible surfaces of the upper flange weld. A minimum of 75% of the total weld length (examined + unexamined) must be examined from either the inner or outer diameter for inspection credit. See MRP-227-A Figure 4-15.
Observable Effect:	The specific relevant condition is a detectable crack-like surface indication.

Inputs and Assumptions

There are several inputs and assumptions that are critical to the development of acceptance criteria for the RV internals upper (core support barrel) flange weld locations. These items are stated below:

- The inspections identified in MRP-227-A are intended to provide a sampling of potential locations of degradation. Under this approach, inspection of one side (surface) of the weld is assumed to provide an adequate sampling for monitoring of SCC.
- The change in resistance to fracture of the RV upper (core support barrel) flange weld can be correlated to the accumulated fluence at each weld location. Welds that are subject to low fluence are considered to have a high degree of resistance to fracture. Correspondingly, those welds subject to high fluence have lower resistance to fracture.
- It is assumed that the primary mode of crack growth to be expected in this region is stress corrosion cracking.
- The prediction of crack growth is based on the stress intensity factor, K, calculated using linear elastic fracture mechanics. The rate of crack growth is dependent on the amount of neutron fluence that the weld is expected to accumulate over the licensed operating lifetime. Since there has been no experience of SCC initiated cracks in operating PWRs to date, growth rates developed for the prediction of SCC in boiling water reactors (BWRs) are assumed to be appropriate for prediction of crack growth due to SCC in PWR reactor internals.
    - For weld locations subjected to fluence less than or equal to $5\text{x}10^{20}$ n/cm^2 (E>1MeV), the BWR hydrogen water chemistry (HWC) crack growth equation specified in paragraph C-8520 of Appendix C of Section XI of the 2010 edition of the ASME Boiler and Pressure Vessel Code is appropriate. This crack growth rate model is consistent with the model in BWRVIP-14a, which has been previously reviewed by the NRC.

CE-ID: 6 **Core Support Barrel Assembly**

Upper (Core Support Barrel) Flange Weld

- For fluence levels above $5x10^{20}$ n/cm^2 (E>1MeV), the BWR HWC crack growth equation specified in equation 6-5 of MRP-227-A is appropriate.
- Depending on the magnitude of cyclic loads, such as thermal transients, additional crack growth as a result of these loads may need to be considered
- Acceptance criteria can be developed for the entire 60-year license of a given plant by using predicted end-of-license fluence values. However, if there are changes to these fluence projections, such as in the event of a power uprate or change in core loading pattern, it would be necessary to confirm that the inputs selected based on fluence, such as SCC growth rate and fracture toughness, remain applicable until the end of the 60-year license.

Failure

Failure Mechanism: Cracking (SCC)

Failure Effect: Potential loss–of-core support.

Failure Criteria: Actively growing through-wall flaws may require mitigation.

An existing flaw is unacceptable if the flaw length projected at the next inspection cycle results in a potential loss-of-core support.

Methodology

Goal: Demonstrate that the cracking mechanism will not result in growth beyond the allowable crack length over the planned inspection interval.

Data Requirements:

1. Surface crack length, as determined by visual inspection:
   a. The 2007 edition of the ASME Code Section XI: IWA-3330(a) and Figure IWA-3330-1 provide requirements for the minimum allowable separation distance that will allow multiple cracks to be treated individually. This approach is part of the guidance in this report. The requirement in Section XI is that the ligament between adjacent cracks must be greater than half of the thickness of the material. If this criterion is not met, the individual crack lengths and the length of the ligament between the cracks must be summed. This total length is then compared to the allowable length.
2. Flaw Depth
   a. For one-sided visual inspections, the flaw is assumed to be through-wall.
   b. Supplemental examinations may be used to determine depths of specific flaws as the basis for a flaw-specific evaluation, if needed.
3. Confirmation that fast neutron fluence at upper core support barrel flange weld is below $3x10^{20}$ n/cm^2 (E> 1 MeV).
4. Steady-state normal operating stresses to be used to calculate SCC crack growth rates.
   a. Axial stresses based on normal mechanical loads are required for circumferential flaws.
   b. Stresses which have an insignificant net-through-wall value (average stress is near zero), such as weld residual stresses and thermal stresses

CE-ID: 6 **Core Support Barrel Assembly**

Upper (Core Support Barrel) Flange Weld

due to local through-wall temperature gradients are considered to have minimal impact on the effective crack growth rates in through-wall flaws.

c. Secondary weld residual and thermal stresses need to be considered in determination of circumferential and through-wall crack growth rates in partial through-wall flaws, whose dimensions would have to be determined with supplemental UT examinations.

5. Limiting externally applied transient stresses to be used to calculate allowable flaw lengths. Stresses arising from pressure, mechanical and thermal loads would be included in this calculation.

    a. More detailed load-deformation histories may be required for elastic-plastic or limit load calculations, if these calculations are necessary.

Analysis:

All analyses require an assumption of the SCC crack growth expected over the upcoming period of service. The methodology is based on analysis of a through-wall flaw with weld residual and thermal stresses relieved. The crack growth rate models will be based on K dependent crack growth under hydrogen water chemistry conditions. Fatigue crack growth has been assumed to be negligible. In order to apply the acceptance criteria to a full 10-year inspection interval, follow-up action is required to verify the assumptions used in the predicted crack-growth rate. A re-inspection of the indication at a future specified outage, for example, would provide data that could be used to satisfy this verification requirement. For detailed crack growth models used, see "Inputs and Assumptions" above.

Failure of the upper core support barrel flange weld is assumed to occur when unstable circumferential crack growth is initiated from the analyzed flaw. Two options are outlined for determining the limiting allowable flaw length, based on neutron dose. Analysis methods are suggested for both pre-inspection or generic analysis (Suggested Pre-Inspection Analysis) and for flaws observed in-service (Suggested Flaw Specific Analysis), where more detailed characteristics of the flaw and its location are known. In all cases, a more detailed evaluation may be completed using a semi-elliptic surface flaw, but such an evaluation would require more detailed inspection by UT.

Fluence Range (n/cm^2 E>1MeV)	Dose (dpa)	MRP-227-A Requirement	Suggested Pre-Inspection Analysis	Suggested Flaw Specific Analysis
$\leq 3 \times 10^{20}$	≤ 0.5	Limit Load	LEFM using 150 ksi$\sqrt{in}$ as fracture toughness or Limit Load	Limit Load

Different evaluation options may be used depending upon the plant-specific fluence levels at the location of the weld being evaluated. Option 1, though conservative, can be used for all fluence levels.

Option 1: LEFM Analysis

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.

b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.

CE-ID: 6 **Core Support Barrel Assembly**

Upper (Core Support Barrel) Flange Weld

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. For normal and upset loading conditions, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 2.77.

e. For the governing emergency or faulted loading condition, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 1.39.

Option 2: Limit Load Analysis (For neutron fluence $< 3x10^{20}$ n/cm^2 at E>1 MeV or less than approximately 0.5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.

b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. Determine the bending moment (M) that can be tolerated as a function of the postulated flaw length.

e. The applied moment, increased by a factor of 1.39 (for emergency and faulted conditions) or 2.77 (for normal and upset conditions) must be less than the limit moment (from step d) for the flaw length determined in (b), for the flaw to be acceptable.

Acceptance Criteria: The upper core support barrel flange weld continues to perform its functional requirements with the projected flaw length at the end of the inspection interval.

Approach: Limit load or LEFM analysis

CE-ID: 6.1 **Core Support Barrel Assembly**

Lower Core Barrel Flange

Category:	Expansion	Applicability:	All plants
Degradation Effect:	Cracking (SCC, Fatigue)		
Primary Link:	Upper (core support barrel) flange weld		
Function:	Primary core support structure		

Inspection

Method:	Enhanced visual (EVT-1) examination. Re-inspection every ten years following initial inspection.
Coverage:	100% of accessible welds and adjacent base metal. See MRP-227-A, Figure 4-15.
Observable Effect:	The specific relevant condition is a detectable crack-like surface indication.

Inputs and Assumptions

There are several inputs and assumptions that are critical to the development of acceptance criteria for the RV Internals lower core barrel flange. These items are stated below:

- The inspections identified in MRP-227-A are intended to provide a sampling of potential locations of degradation. Under this approach, inspection of one side (surface) of the weld is assumed to provide an adequate sampling for monitoring of SCC.
- It is assumed that these welds experience low fluence. The change in resistance to fracture of the RV lower core barrel flange can be correlated to the accumulated fluence at each weld location. Welds that are subject to low fluence are considered to have a high degree of resistance to fracture. Correspondingly, those welds subject to high fluence have lower resistance to fracture.
- It is assumed that the primary mode of crack growth to be expected in this region is stress corrosion cracking.
- The prediction of crack growth is based on the stress intensity factor, K, calculated using linear elastic fracture mechanics. The rate of crack growth is dependent on the amount of neutron fluence that the weld is expected to accumulate over the licensed operating lifetime. Since there has been no experience of SCC initiated cracks in operating PWRs to date, growth rates developed for the prediction of SCC in boiling water reactors (BWRs) are assumed to be appropriate for prediction of crack growth due to SCC in PWR reactor internals.
    - For weld locations subjected to fluence less than or equal to 5×10^{20} n/cm^2 (E>1MeV), the BWR hydrogen water chemistry (HWC) crack growth equation specified in paragraph C-8520 of Appendix C of Section XI of the 2010 edition of the ASME Boiler and Pressure Vessel Code is appropriate. This crack growth rate model is consistent with the model in BWRVIP-14a.
    - For fluence levels above 5×10^{20} n/cm^2 (E>1MeV), the BWR HWC crack growth equation specified in equation 6-5 of MRP-227-A is appropriate.
- Depending on the magnitude of cyclic loads, such as thermal transients,

CE-ID: 6.1 **Core Support Barrel Assembly**

Lower Core Barrel Flange

additional crack growth as a result of these loads may need to be considered.

- Acceptance criteria can be developed for the entire 60-year license of a given plant by using predicted end-of-license fluence values. However, if there are changes to these fluence projections, such as in the event of a power uprate or change in core loading pattern, it would be necessary to confirm that the inputs selected based on fluence, such as SCC growth rate and fracture toughness, remain applicable until the end of the 60-year license.

Failure

Failure Mechanism: Cracking (SCC, Fatigue)

Failure Effect: Potential loss-of-core support.

Failure Criteria: Actively growing through-wall flaws may require mitigation.

An existing flaw is unacceptable if the flaw length projected at the next inspection cycle allows a potential loss-of-core support.

Methodology

Goal: Demonstrate that the cracking mechanism will not result in growth beyond the allowable crack length over the planned inspection interval.

Data Requirements:

1. Surface crack length as determined by visual inspection
    a. The 2007 edition of the ASME Code Section XI: IWA-3330(a) and Figure IWA-3330-1 provide requirements for the minimum allowable separation distance that will serve as the basis for guidance in this report. The requirement in Section XI is that the ligament between adjacent cracks must be greater than half of the thickness of the material. If this criterion is not met, the individual crack lengths and the length of the ligament between the cracks must be summed. This total length is then compared to the allowable length.
2. Flaw Depth
    a. For one-sided visual inspections, the flaw is assumed to be through-wall.
    b. Supplemental examinations may be used to determine flaw depth, for a flaw-specific criterion, if needed.
3. Estimate of fast neutron fluence at crack location.
4. Steady-state normal operating stresses to be used to calculate SCC crack growth rates.
    a. Axial stresses based on normal mechanical loads are required for circumferential flaws.
    b. Stresses which have an insignificant net-through-wall value (average stress is near zero), such as weld residual stresses and thermal stresses due to local through-wall temperature gradients are considered to have minimal impact on the effective crack growth rates in through-wall flaws.
    c. Secondary weld residual and thermal stresses need to be considered in determination of circumferential and through-wall crack growth rates in partial through-wall flaws, whose dimensions would have to be

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Lower Core Barrel Flange

determined with supplemental UT examinations.

5. Limiting externally applied transient stresses to be used to calculate allowable flaw lengths. Stresses arising from pressure, mechanical and thermal loads would be included in this calculation.
    a. More detailed load-deformation histories may be required for elastic-plastic or limit load calculations, if these calculations are necessary.

Analysis:

All analyses require an assumption of the SCC crack growth expected over the upcoming period of service. The methodology is based on analysis of a through-wall flaw with weld residual and thermal stresses relieved. The crack growth rate models will be based on K dependent crack growth under hydrogen water chemistry conditions. Fatigue crack growth has been assumed to be negligible. In order to apply the acceptance criteria to a full 10-year inspection interval, follow-up action is required to verify the assumptions used in the predicted crack-growth rate. A re-inspection of the indication at a future specified outage, for example, would provide data that could be used to satisfy this verification requirement. For detailed crack growth models used, see "Inputs and Assumptions" above.

Failure of the lower core barrel flange weld is assumed to occur when unstable circumferential crack growth is initiated from the analyzed flaw. Two options are outlined for determining the limiting allowable flaw length, based on neutron dose. Analysis methods are suggested for both pre-inspection and generic analysis (Suggested Pre-Inspection Analysis) and for flaws observed in-service (Suggested Flaw Specific Analysis), where more detailed characteristics of the flaw and its location are known. In all cases, a more detailed evaluation may be completed using a semi-elliptic surface flaw, but such an evaluation would require more detailed inspection by UT.

Fluence Range (n/cm^2 E>1MeV)	**Dose (dpa)**	**MRP-227-A Requirement**	**Suggested Pre-Inspection Analysis**	**Suggested Flaw Specific Analysis**
$\leq 3 \times 10^{20}$	≤ 0.5	Limit Load	LEFM using 150 ksi$\sqrt{in}$ for fracture toughness or Limit Load	Limit Load

Different evaluation options may be used depending upon the plant-specific fluence levels at the location of the weld being evaluated. Option 1, though conservative, can be used for all fluence levels.

Option 1: LEFM Analysis

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. For normal and upset loading conditions, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the

CE-ID: 6.1 **Core Support Barrel Assembly**

Lower Core Barrel Flange

material by a factor of at least 2.77.

e. For the governing emergency or faulted loading condition, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 1.39.

Option 2: Limit Load Analysis (For neutron fluence < $3x10^{20}$ n/cm^2 at E>1 MeV or dose less than approximately 0.5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.

b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. Determine the bending moment (M) that can be tolerated as a function of the postulated flaw length.

e. The applied moment, increased by a factor of 1.39 (for emergency and faulted conditions) or 2.77 (for normal and upset conditions) must be less than the limit moment (from step d) for the flaw length determined in (b), for the flaw to be acceptable.

Acceptance Criteria: The lower core barrel flange weld continues to perform its functional requirements with the projected flaw length at the end of the inspection interval.

Approach: Limit load or LEFM analysis

CE-ID: 6.2	**Core Support Barrel Assembly Upper Cylinder (Including Welds)**	
Category:	Expansion	Applicability: All plants
Degradation Effect:	Cracking (Stress Corrosion Cracking [SCC]), Aging Management (IE)	
Primary Link:	Upper (core support barrel) flange weld	
Function:	Primary core support structure	

Inspection

Method:	Enhanced visual (EVT-1) examination. Re-inspection every ten years following initial inspection.
Coverage:	100% of the accessible surfaces of the welds and adjacent base metal. See MRP-227-A Figure 4-15.
Observable Effect:	The specific relevant condition is a detectable crack-like surface indication.

Inputs and Assumptions

There are several inputs and assumptions that are critical to the development of acceptance criteria for the RV internals core support barrel upper cylinder (including welds). These items are stated below:

- The inspections identified in MRP-227-A are intended to provide a sampling of potential locations of degradation. Under this approach, inspection of one side (surface) of the weld is assumed to provide an adequate sampling for monitoring of SCC.
- The change in resistance to fracture of the core support barrel upper cylinder can be correlated to the accumulated fluence at each weld location. Welds that are subject to low fluence are considered to have a high degree of resistance to fracture. Correspondingly, those welds subject to high fluence have lower resistance to fracture.
- It is assumed that the primary mode of crack growth to be expected in this region is stress corrosion cracking.
- The prediction of crack growth is based on the stress intensity factor, K, calculated using linear elastic fracture mechanics. The rate of crack growth is dependent on the amount of neutron fluence that the weld is expected to accumulate over the licensed operating lifetime. Since there has been no experience of SCC initiated cracks in operating PWRs to date, growth rates developed for the prediction of SCC in boiling water reactors (BWRs) are assumed to be appropriate for prediction of crack growth due to SCC in PWR reactor internals.
    - For weld locations subjected to fluence less than or equal to $5x10^{20}$ n/cm^2 (E>1MeV), the BWR hydrogen water chemistry (HWC) crack growth equation specified in paragraph C-8520 of Appendix C of Section XI of the 2010 edition of the ASME Boiler and Pressure Vessel Code is appropriate. This crack growth rate model is consistent with the model in BWRVIP-14a, which was previously reviewed by the NRC.
- Depending on the magnitude of cyclic loads, such as thermal transients, additional crack growth as a result of these loads may need to be considered.
- Acceptance criteria for indications detected using a visual exam can be

CE-ID: 6.2 **Core Support Barrel Assembly**

Upper Cylinder (Including Welds)

developed based on an assumed through-wall flaw with a length that is uniform through the wall thickness. If it can be shown that the critical crack length for a through wall flaw is less than that for a part through wall flaw, then this assumption is reasonable and conservative, because no information is available on the flaw depth from such a visual examination.

- When developing flaw acceptance criteria based on a through-wall flaw, the crack growth due to SCC can be predicted using only the externally applied stresses. This simplification can be made because the average of the thermal and residual stresses across the crack face is zero. Therefore, these stresses are considered to have an insignificant contribution to the average crack growth across the through-wall crack front.
- Acceptance criteria can be developed for the entire 60-year license of a given plant by using predicted end-of-license fluence values. However, if there are changes to these fluence projections, such as in the event of a power uprate or change in core loading pattern, it would be necessary to confirm that the inputs selected based on fluence, such as SCC growth rate and fracture toughness, remain applicable until the end of the 60-year license.

Failure

Failure Mechanism: Cracking (SCC)

Failure Effect: Potential loss–of-core support.

Failure Criteria: Actively growing through-wall flaws may require mitigation.

An existing flaw is unacceptable if the flaw length projected at the next inspection cycle results in a potential loss-of-core support.

Methodology

Goal: Demonstrate that the cracking mechanism will not result in growth beyond the allowable crack length over the planned inspection interval.

Data Requirements:

1. Surface crack length as determined by visual inspection
   a. The 2007 edition of the ASME Code Section XI: IWA-3330(a) and Figure IWA-3330-1 provide requirements for the minimum allowable separation distance that will serve as the basis for guidance in this report. The requirement in Section XI is that the ligament between adjacent cracks must be greater than half of the thickness of the material. If this criterion is not met, the individual crack lengths and the length of the ligament between the cracks must be summed. This total length is then compared to the allowable length.
2. Flaw Depth
   a. For one-sided visual inspections, the flaw is assumed to be through-wall.
   b. Supplemental examinations may be used to determine flaw depth, for a flaw-specific criterion, if needed.
3. Estimate of fast neutron fluence at crack location and confirm it is less than $3x10^{20}$ n/cm^2.
4. Steady-state normal operating stresses to be used to calculate SCC crack growth

CE-ID: 6.2 **Core Support Barrel Assembly**

Upper Cylinder (Including Welds)

rates.

a. Axial stresses based on normal mechanical loads are required for circumferential flaws.

b. Stresses which have an insignificant net-through-wall value (average stress is near zero), such as weld residual stresses and thermal stresses due to local through-wall temperature gradients are considered to have minimal impact on the effective crack growth rates in through-wall flaws.

c. Secondary weld residual and thermal stresses need to be considered in determination of circumferential and through-wall crack growth rates in partial through-wall flaws, whose dimensions would have to be determined with supplemental UT examinations.

5. Limiting externally applied transient stresses to be used to calculate allowable flaw lengths. Stresses arising from pressure, mechanical and thermal loads would be included in this calculation.

   a. More detailed load-deformation histories may be required for elastic-plastic or limit load calculations, if these calculations are necessary.

Analysis:

All analyses require an assumption of the SCC crack growth expected over the upcoming period of service. The methodology is based on analysis of a through-wall flaw with weld residual and thermal stresses relieved. The crack growth rate models will be based on K dependent crack growth under hydrogen water chemistry conditions. Fatigue crack growth has been assumed to be negligible. In order to apply the acceptance criteria to a full 10-year inspection interval, follow-up action is required to verify the assumptions used in the predicted crack-growth rate. A re-inspection of the indication at a future specified outage, for example, would provide data that could be used to satisfy this verification requirement. For detailed crack growth models used, see "Inputs and Assumptions" above.

Failure of the upper cylinder is assumed to occur when unstable crack growth is initiated from the analyzed flaw. Two options are outlined for determining the limiting allowable flaw length. Analysis methods are suggested for both pre-inspection or generic analysis (Suggested Pre-Inspection Analysis) and for flaws observed in-service (Suggested Flaw Specific Analysis), where more detailed characteristics of the flaw and its location are known. In all cases, a more detailed evaluation may be completed using a semi-elliptic surface flaw, but such an evaluation would require more detailed inspection by UT.

Fluence Range (n/cm^2 E>1MeV)	Dose (dpa)	MRP-227-A Requirement	Suggested Pre-Inspection Analysis	Suggested Flaw Specific Analysis
$\leq 3 \times 10^{20}$	≤ 0.5	Limit Load	LEFM using 150 ksi√in Fracture Toughness Value or Limit Load	Limit Load

Different evaluation options may be used depending upon the plant-specific fluence levels at the location of the weld being evaluated.

Option 1: LEFM Analysis

a. Establish initial crack length (and depth if determined by supplemental

CE-ID: 6.2 **Core Support Barrel Assembly**

Upper Cylinder (Including Welds)

examinations) based on inspection results.

b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. For normal and upset loading conditions, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 2.77.

e. For the governing emergency or faulted loading condition, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 1.39.

Option 2: Limit Load Analysis (For neutron fluence < $3x10^{20}$ n/cm^2 at E>1 MeV or dose less than approximately 0.5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.

b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. Determine the bending moment (M) that can be tolerated as a function of the postulated flaw length.

e. The applied moment, increased by a factor of 1.39 (for emergency and faulted conditions) or 2.77 (for normal and upset conditions) must be less than the limit moment (from step d) for the flaw length determined in (b), for the flaw to be acceptable.

Acceptance Criteria: The upper core support barrel cylinder continues to perform its functional requirements with the projected flaw length at the end of the inspection interval.

Approach: Limit load or LEFM analysis

CE-ID: 6.3 **Core Support Barrel Assembly**

Upper Core Barrel Flange

Category:	Expansion	Applicability:	All plants
Degradation Effect:	Cracking (SCC)		
Primary Link:	Upper (core support barrel) flange weld		
Function:	Primary core support structure		

Inspection

Method:	Enhanced visual (EVT-1) examination. Re-inspection every ten years following initial inspection.
Coverage:	100% of accessible bottom surface of the flange. See MRP-227-A, Figure 4-15.
Observable Effect:	The specific relevant condition is a detectable crack-like surface indication.

Inputs and Assumptions

There are several inputs and assumptions that are critical to the development of acceptance criteria for the RV internals upper core barrel flange. These items are stated below:

- The inspections identified in MRP-227-A are intended to provide a sampling of potential locations of degradation. Under this approach, inspection of one side (surface) of the weld is assumed to provide an adequate sampling for monitoring of SCC.
- The change in resistance to fracture of the RV upper core barrel flange can be correlated to the accumulated fluence at each weld location. Welds that are subject to low fluence are considered to have a high degree of resistance to fracture. Correspondingly, those welds subject to high fluence have lower resistance to fracture.
- It is assumed that the primary mode of crack growth to be expected in this region is stress corrosion cracking.
- The prediction of crack growth is based on the stress intensity factor, K, calculated using linear elastic fracture mechanics. The rate of crack growth is dependent on the amount of neutron fluence that the weld is expected to accumulate over the licensed operating lifetime. Since there has been no experience of SCC initiated cracks in operating PWRs to date, growth rates developed for the prediction of SCC in boiling water reactors (BWRs) are assumed to be appropriate for prediction of crack growth due to SCC in PWR reactor internals.
- For weld locations subjected to fluence less than or equal to $5x10^{20}$ n/cm^2 (E>1MeV), the BWR hydrogen water chemistry (HWC) crack growth equation specified in paragraph C-8520 of Appendix C of Section XI of the 2010 edition of the ASME Boiler and Pressure Vessel Code is appropriate. This crack growth rate model is consistent with the model in BWRVIP-14a, which was previously reviewed by the NRC.
    - For fluence levels above $5x10^{20}$ n/cm^2 (E>1MeV), the BWR HWC crack growth equation specified in equation 6-5 of MRP-227-A is appropriate.
- Depending on the magnitude of cyclic loads, such as thermal transients, additional crack growth as a result of these loads may need to be considered.

CE-ID: 6.3 **Core Support Barrel Assembly**

Upper Core Barrel Flange

- Acceptance criteria for indications detected using a visual exam can be developed based on an assumed through-wall flaw with a length that is uniform through the wall thickness. If it can be shown that the critical crack length for a through wall flaw is less than that for a part through wall flaw, then this assumption is reasonable and conservative, because no information is available on the flaw depth from such a visual examination.
- When developing flaw acceptance criteria based on a through-wall flaw, the crack growth due to SCC can be predicted using only the externally applied stresses. This simplification can be made because the average of the thermal and residual stresses across the crack face is zero. Therefore, these stresses are considered to have an insignificant contribution to the average crack growth across the through-wall crack front.
- Acceptance criteria can be developed for the entire 60-year license of a given plant by using predicted end-of-license fluence values. However, if there are changes to these fluence projections, such as in the event of a power uprate or change in core loading pattern, it would be necessary to confirm that the inputs selected based on fluence, such as SCC growth rate and fracture toughness, remain applicable until the end of the 60-year license.

Failure

Failure Mechanism: Cracking (SCC)

Failure Effect: Potential loss-of-core support.

Failure Criteria: Actively growing through-wall flaws may require mitigation.

An existing flaw is unacceptable if the flaw length projected at the next inspection cycle results in a potential loss-of-core support.

Methodology

Goal: Demonstrate that the cracking mechanism will not result in growth beyond the allowable crack length over the planned inspection interval.

Data Requirements:

1. Surface crack length as determined by visual inspection
   a. The 2007 edition of the ASME Code Section XI: IWA-3330(a) and Figure IWA-3330-1 provide requirements for the minimum allowable separation distance that will serve as the basis for guidance in this report. The requirement in Section XI is that the ligament between adjacent cracks must be greater than half of the thickness of the material. If this criterion is not met, the individual crack lengths and the length of the ligament between the cracks must be summed. This total length is then compared to the allowable length.
2. Flaw Depth
   a. For one-sided visual inspections, the flaw is assumed to be through-wall.
   b. Supplemental examinations may be used to determine flaw depth, for a flaw-specific criterion, if needed.
3. Estimate of fast neutron fluence at crack location and confirm it is less than $3x10^{20}$ n/cm^2.
4. Steady-state normal operating stresses to be used to calculate SCC crack growth

CE-ID: 6.3 **Core Support Barrel Assembly**

Upper Core Barrel Flange

rates.

a. Axial stresses based on normal mechanical loads are required for circumferential flaws.

b. Stresses which have an insignificant net-through-wall value (average stress is near zero), such as weld residual stresses and thermal stresses due to local through-wall temperature gradients are considered to have minimal impact on the effective crack growth rates in through-wall flaws.

c. Secondary weld residual and thermal stresses need to be considered in determination of circumferential and through-wall crack growth rates in partial through-wall flaws, whose dimensions would have to be determined with supplemental UT examinations.

5. Limiting externally applied transient stresses to be used to calculate allowable flaw lengths. Stresses arising from pressure, mechanical and thermal loads would be included in this calculation.

   a. More detailed load-deformation histories may be required for elastic plastic or limit load calculations, if these calculations are necessary.

Analysis:

All analyses require an assumption of the SCC crack growth expected over the upcoming period of service. The methodology is based on analysis of a through-wall flaw with weld residual and thermal stresses relieved. The crack growth rate models will be based on K dependent crack growth under hydrogen water chemistry conditions. Fatigue crack growth has been assumed to be negligible. In order to apply the acceptance criteria to a full 10-year inspection interval, follow-up action is required to verify the assumptions used in the predicted crack-growth rate. A re-inspection of the indication at a future specified outage, for example, would provide data that could be used to satisfy this verification requirement. For detailed crack growth models used, see "Inputs and Assumptions" above.

Failure of the flange is assumed to occur when unstable crack growth is initiated from the analyzed flaw. Two options are outlined for determining the limiting allowable flaw length, based on neutron dose. Analysis methods are suggested for both pre-inspection or generic analysis (Suggested Pre-Inspection Analysis) and for flaws observed in-service (Suggested Flaw Specific Analysis), where more detailed characteristics of the flaw and its location are known. In all cases, a more detailed evaluation may be completed using a semi-elliptic surface flaw, but such an evaluation would require more detailed inspection by UT.

Fluence Range (n/cm^2 E>1MeV)	**Dose (dpa)**	**MRP-227-A Requirement**	**Suggested Pre-Inspection Analysis**	**Suggested Flaw Specific Analysis**
$\leq 3 \times 10^{20}$	≤ 0.5	Limit Load	LEFM using 150 ksi$\sqrt{in}$ Fracture Toughness Value or Limit Load	Limit Load

Option 1: LEFM Analysis

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.

b. The final crack dimensions are calculated by adding 10 years of crack growth

CE-ID: 6.3 **Core Support Barrel Assembly**

Upper Core Barrel Flange

under normal loading conditions.

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. For normal and upset loading conditions, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 2.77.

e. For the governing emergency or faulted loading condition, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 1.39.

Option 2: Limit Load Analysis (For neutron fluence < $3x10^{20}$ n/cm^2 at E>1 MeV or dose less than approximately 0.5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.

b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. Determine the bending moment (M) that can be tolerated as a function of the postulated flaw length.

e. The applied moment, increased by a factor of 1.39 (for emergency and faulted conditions) or 2.77 (for normal and upset conditions) must be less than the limit moment (from step d) for the flaw length determined in (b), for the flaw to be acceptable.

Acceptance Criteria: The upper core barrel flange continues to perform its functional requirements with the projected flaw length at the end of the inspection interval.

Approach: Limit load or LEFM analysis

CE-ID: 6.4 Lower Support Structure
Lower Core Support Beams

Category:	Expansion	Applicability:	All plants except those with core shrouds assembled with full-height shroud plates
Degradation Effect:	Cracking (SCC, Fatigue) including damaged or fractured material		
Expansion Link:	Upper (core support barrel) flange weld		
Function:	Support the weight of the core through the core support columns.		

Inspection

Method:	Visual (EVT-1) examination. Re-inspection every ten years following initial inspection.
Coverage:	100% of accessible surfaces. A minimum of 75% coverage of the entire examination area is required (including both the accessible and inaccessible portions). See MRP-227-A, Figures 4-16 and 4-30.
Observable Effect:	The specific relevant condition is a detectable crack-like surface indication.

Inputs and Assumptions

There are several inputs and assumptions that are critical to the development of acceptance criteria for the RV Internals lower core support beam weld locations. These items are stated below:

- The inspections identified in MRP-227-A are intended to provide a sampling of potential locations of degradation. Under this sampling scheme, inspection of one side (surface) of the weld is intended to provide an adequate sampling for monitoring of SCC.
- The change in resistance to fracture of the RV lower core support beam welds can be correlated to the accumulated fluence at each weld location. Welds that are subject to low fluence are considered to have a high degree of resistance to fracture. Correspondingly, those welds subject to high fluence have lower resistance to fracture. This component is expected to have low fluence.
- The prediction of crack growth is based on the stress intensity factor, K, calculated using linear elastic fracture mechanics. The rate of crack growth is dependent on the amount of neutron fluence that the weld is expected to accumulate over the licensed operating lifetime. Since there has been no experience of SCC initiated cracks in operating PWRs to date, growth rates developed for the prediction of SCC in BWRs are assumed to be appropriate for prediction of crack growth due to SCC in PWR reactor internals.
  - For weld locations subjected to fluence less than or equal to 5×10^{20} n/cm^2 (E>1MeV), the boiling water reactor (BWR) hydrogen water chemistry (HWC) crack growth equation specified in paragraph C-8520 of Appendix C of Section XI of the 2010 edition of the ASME Boiler and Pressure Vessel Code is appropriate. This crack growth rate model is consistent with the model in BWRVIP-14-A, which was previously reviewed and approved by the NRC.
  - For fluence levels at or above 5×10^{20} n/cm^2 (E>1MeV), the BWR HWC

CE-ID: 6.4 **Lower Support Structure**
Lower Core Support Beams

crack growth equation specified in equation 6-5 of MRP-227-A is appropriate.

- Depending on the magnitude of cyclic loads, such as thermal transients, additional crack growth as a result of these loads may need to be considered.
- Acceptance criteria for indications detected using a visual exam were developed based on an assumed through-wall flaw with a length that is uniform through the wall thickness. If it can be shown that the critical crack length for a through wall flaw is less than that for a part through wall flaw, then this assumption is reasonable and conservative, because no information is available on the flaw depth from such a visual examination.
- If when developing flaw acceptance criteria based on a through-wall flaw it can be shown that the average of the thermal and residual stresses across the crack face is zero, then these stresses are considered to have an insignificant contribution to the average crack growth across the through-wall crack front and the crack growth due to SCC can be predicted using only the externally applied stresses.
- Acceptance criteria can be developed for the entire 60-year license of a given plant by using predicted end-of-license fluence values. However, if there are changes to these fluence projections, such as in the event of a power uprate or change in core loading pattern, it would be necessary to confirm that the inputs selected based on fluence, such as SCC growth rate and fracture toughness, remain applicable until the end of the 60-year license.

Failure

Failure Mechanism: Cracking (Fatigue, SCC)

Failure Effect: Potential loss of core support

Failure Criteria: Actively growing flaws require mitigation. Require determination of crack growth mechanism.

An existing flaw is unacceptable if the flaw length projected at the next inspection cycle allows a potential loss of core support.

Methodology

Goal: Demonstrate stability of the lower support structure and that the cracking mechanism will not result in growth beyond the allowable crack length over the planned inspection interval.

Data Requirements:

1. Surface crack length, as determined by visual inspection:
   a. The 2007 edition of the ASME Code Section XI: IWA-3330(a) and Figure IWA-3330-1 provide requirements for the minimum allowable separation distance that will allow multiple cracks to be treated individually. This approach is part of the guidance in this report. The requirement in Section XI is that the ligament between adjacent cracks must be greater than half of the thickness of the material. If this

CE-ID: 6.4 **Lower Support Structure**
Lower Core Support Beams

criterion is not met, the individual crack lengths and the length of the ligament between the cracks must be summed. This total length is then compared to the allowable length.

2. Flaw Depth
    a. For one-sided visual inspections, the flaw is assumed to be through-wall.
    b. Supplemental examinations may be used to determine depths of specific flaws as the basis for a flaw-specific evaluation, if needed.
3. Confirmation that fast neutron fluence at lower core support beam is below $3x10^{20}$ n/cm^2 (E> 1 MeV).
4. Steady-state and applicable operating transient stresses to be used to calculate SCC and fatigue crack growth rates.
    a. When a flaw is assumed to be through-wall, secondary weld residual and local thermal stresses do not need to be considered in determination of average crack growth rates (see assumptions).
    b. For a flaw-specific part-through flaw evaluation when the flaw depth is known , secondary weld residual and thermal stresses need to be considered in determination of local circumferential and through-wall crack growth rates.
5. Limiting transient stresses to be used to calculate allowable flaw lengths.
    a. More detailed load-deformation histories may be required for elastic-plastic or limit load calculations.

Analysis:

All analyses require an assumption of the SCC crack growth expected over the upcoming period of service. The methodology is based on analysis of a through-wall flaw with weld residual and thermal stresses relieved. The crack growth rate models will be based on K dependent crack growth under hydrogen water chemistry conditions. In order to apply the acceptance criteria to a full 10-year inspection interval, follow-up action is required to verify the assumptions used in the predicted crack-growth rate. A re-inspection of the indication at a future specified outage, for example, would provide data that could be used to satisfy this verification requirement. For detailed crack growth models used, see "Inputs and Assumptions" above.

Failure of the welds is assumed to occur when unstable crack growth is initiated from the analyzed flaw. Two options are outlined for determining the limiting allowable flaw length, based on neutron dose. Analysis methods are suggested for both pre-inspection or generic analysis (Suggested Pre-Inspection Analysis) and for flaws observed in-service (Suggested Flaw Specific Analysis), where more detailed characteristics of the flaw and its location are known. In all cases, a more detailed evaluation may be completed using a semi-elliptic surface flaw, but such an evaluation would require more detailed inspection by UT.

CE-ID: 6.4 **Lower Support Structure**
Lower Core Support Beams

Fluence Range (n/cm^2 E>1MeV)	Dose (dpa)	MRP-227-A Requirement	Suggested Pre-Inspection Analysis	Suggested Flaw Specific Analysis
$\leq 3 \times 10^{20}$	≤ 0.5	Limit Load	LEFM using 150 ksi√in for fracture toughness or Limit Load	Limit Load

Different evaluation options may be used depending upon the plant-specific fluence levels at the location of the weld being evaluated. Option 1, though conservative, can be used for all fluence levels.

Option 1: LEFM Analysis

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.

b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. For normal and upset loading conditions, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 2.77.

e. For the governing emergency or faulted loading condition, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 1.39.

Option 2: Limit Load Analysis (For neutron fluence < 3×10^{20} n/cm^2 at E>1 MeV or dose less than approximately 0.5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.

b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. Determine the bending moment (M) that can be tolerated as a function of the postulated flaw length.

   The applied moment, increased by a factor of 1.39 (for emergency and faulted conditions) or 2.77 (for normal and upset conditions) must be less than the limit moment (from step d) for the flaw length determined in (b), for the flaw to be acceptable.

Acceptance Criteria: The lower core support beam welds continue to perform their functional requirements with the projected flaw length at the end of the inspection interval.

Approach: Limit load or LEFM analysis

CE-ID: 7 **Core Support Barrel Assembly**

Lower Cylinder Girth Welds

Category:	Primary	Applicability:	All plants
Degradation Effect:	Cracking (SCC, IASCC), Aging Management (IE)		
Expansion Link:	Lower Cylinder Axial Welds		
Function:	Primary core support structure		

Inspection

Method:	Enhanced visual (EVT-1) examination no later than two refueling outages from the beginning of the license renewal period. Subsequent examination on a ten-year interval.
Coverage:	100% of accessible surfaces of the lower cylinder welds. See MRP-227-A, Figure 4-15.
Observable Effect:	The specific relevant condition is a detectable crack-like surface indication.

Inputs and Assumptions

There are several inputs and assumptions that are critical to the development of acceptance criteria for the RV Internals lower cylinder girth welds locations. These items are stated below:

- The inspections identified in MRP-227-A are intended to provide a sampling of potential locations of degradation. Under this approach, inspection of one side (surface) of the weld is assumed to provide an adequate sampling for monitoring of SCC and/or Irradiation Assisted Stress Corrosion Cracking (IASCC).
- The change in resistance to fracture of the RV core barrel welds can be correlated to the accumulated fluence at each weld location. Welds that are subject to low fluence are considered to have a high degree of resistance to fracture. Correspondingly, those welds subject to high fluence have lower resistance to fracture.
- It is assumed that the primary mode of crack growth to be expected in this region is stress corrosion cracking.
- The prediction of crack growth is based on the stress intensity factor, K, calculated using linear elastic fracture mechanics. The rate of crack growth is dependent on the amount of neutron fluence that the weld is expected to accumulate over the licensed operating lifetime. Since there has been no experience of SCC/IASCC initiated cracks in operating PWRs to date, growth rates developed for the prediction of SCC/IASCC in boiling water reactors (BWRs) are assumed to be appropriate for prediction of crack growth due to SCC/IASCC in PWR reactor internals.
  - For weld locations subjected to fluence less than or equal to 5×10^{20} n/cm^2 (E>1MeV), the BWR hydrogen water chemistry (HWC) crack growth equation specified in paragraph C-8520 of Appendix C of Section XI of the 2010 edition of the ASME Boiler and Pressure Vessel Code is appropriate. This crack growth rate model is consistent with the model in BWRVIP-14a.
  - For fluence levels above 5×10^{20} n/cm^2 (E>1MeV), the BWR HWC crack growth equation specified in equation 6-5 of MRP-227-A is appropriate.
- Depending on the magnitude of cyclic loads, such as thermal transients, additional crack growth as a result of these loads may need to be considered

CE-ID: 7 **Core Support Barrel Assembly**

Lower Cylinder Girth Welds

- Acceptance criteria can be developed for the entire 60-year license of a given plant by using predicted end-of-license fluence values. However, if there are changes to these fluence projections, such as in the event of a power uprate or change in core loading pattern, it would be necessary to confirm that the inputs selected based on fluence, such as SCC/IASCC growth rate and fracture toughness, remain applicable until the end of the 60-year license.

Failure

Failure Mechanism: Cracking (SCC, IASCC), Aging Management (IE)

Failure Effect: Potential loss-of-core support.

Failure Criteria: Actively growing through-wall flaws may require mitigation.

An existing flaw is unacceptable if the flaw length projected at the next inspection cycle results in a potential loss-of-core support.

Methodology

Goal: Demonstrate that the cracking mechanism will not result in growth beyond the allowable crack length over the planned inspection interval.

Data Requirements:

1. Surface crack length as determined by visual inspection
   a. The 2007 edition of the ASME Code Section XI: IWA-3330(a) and Figure IWA-3330-1 provide requirements for the minimum allowable separation distance that will serve as the basis for guidance in this report. The requirement in Section XI is that the ligament between adjacent cracks must be greater than half of the thickness of the material. If this criterion is not met, the individual crack lengths and the length of the ligament between the cracks must be summed. This total length is then compared to the allowable length.
2. Flaw Depth
   a. For one-sided visual inspections, the flaw is assumed to be through-wall.
   b. Supplemental examinations may be used to determine flaw depth, for a flaw-specific criterion, if needed.
3. Estimate of fast neutron fluence at crack location.
4. Steady-state normal operating stresses to be used to calculate SCC/IASCC crack growth rates.
   a. Axial stresses based on normal mechanical loads are required for circumferential flaws.
   b. Stresses which have an insignificant net-through-wall value (average stress is near zero), such as weld residual stresses and thermal stresses due to local through-wall temperature gradients are considered to have minimal impact on the effective crack growth rates in through-wall flaws.
   c. Secondary weld residual and thermal stresses need to be considered in determination of circumferential and through-wall crack growth rates in partial through-wall flaws, whose dimensions would have to be determined with supplemental UT examinations.

CE-ID: 7 **Core Support Barrel Assembly**

Lower Cylinder Girth Welds

5. Limiting externally applied transient stresses to be used to calculate allowable flaw lengths. Stresses arising from pressure, mechanical and thermal loads would be included in this calculation.
    a. More detailed load-deformation histories may be required for elastic-plastic or limit load calculations, if these calculations are necessary.

Analysis:

All analyses require an assumption of the SCC/IASCC crack growth expected over the upcoming period of service. The methodology is based on analysis of a through-wall flaw with weld residual and thermal stresses relieved. The crack growth rate models will be based on K dependent crack growth under hydrogen water chemistry conditions. Fatigue crack growth has been assumed to be negligible. In order to apply the acceptance criteria to a full 10-year inspection interval, follow-up action is required to verify the assumptions used in the predicted crack-growth rate. A re-inspection of the indication at a future specified outage, for example, would provide data that could be used to satisfy this verification requirement. For detailed crack growth models used, see "Inputs and Assumptions" above.

Failure of the lower cylinder girth welds is assumed to occur when unstable circumferential crack growth is initiated from the analyzed flaw. Three options are outlined for determining the limiting allowable flaw length, based on neutron dose. Analysis methods are suggested for both pre-inspection or generic analysis (Suggested Pre-Inspection Analysis) and for flaws observed in-service (Suggested Flaw Specific Analysis), where more detailed characteristics of the flaw and its location are known. In all cases, a more detailed evaluation may be completed using a semi-elliptic surface flaw, but such an evaluation would require more detailed inspection by UT.

Fluence Range (n/cm^2 E>1MeV)	Dose (dpa)	MRP-227-A Requirement	Suggested Pre-Inspection Analysis	Suggested Flaw Specific Analysis
$\leq 3 \times 10^{20}$	≤ 0.5	Limit Load	LEFM using 150 ksi√in for fracture toughness or Limit Load	Limit Load
$> 3\times10^{20}$ - 3×10^{21}	> 0.5 - 5	LEFM or EPFM	LEFM using 112 ksi√in for fracture toughness or EPFM	EPFM
$> 3\times10^{21}$ - 1×10^{22}	> 5 – 15	LEFM 50 ksi√in	LEFM using 50 ksi√in for fracture toughness	LEFM 50 ksi√in
$>1\times10^{22}$	> 15	LEFM 34.6 ksi√in	LEFM using 34.6 ksi√in for fracture toughness	LEFM 34.6 ksi√in

Different evaluation options may be used depending upon the plant-specific fluence levels at the location of the weld being evaluated. Option 1, though conservative, can be used for all fluence levels.

Option 1: LEFM Analysis

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.

CE-ID: 7 **Core Support Barrel Assembly**

Lower Cylinder Girth Welds

b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. For normal and upset loading conditions, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 2.77.

e. For the governing emergency or faulted loading condition, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 1.39.

Option 2: EPFM Analysis (for neutron dose levels > 0.5 dpa but < 5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.

b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. Develop the (J/T) material curve from the material J-R curve.

e. The $J_{applied}$ curve must include a safety factor of 2.77 for normal and upset conditions, and a factor of 1.39 for emergency and faulted conditions.

f. The intersection of the material and applied (J/T) curves indicates the instability point. The flaw size at instability is determined from the $J_{applied}$ versus flaw size curve.

g. The flaw size at instability must be larger than the flaw size from (b), for the flaw to be acceptable.

The intersection of the material and applied (J/T) curves indicates the instability point. The load at instability is determined from the $J_{applied}$ versus load curve.

Option 3: Limit Load Analysis (For neutron fluence < $3x10^{20}$ n/cm^2 at E>1 MeV or dose less than approximately 0.5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.

b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. Determine the bending moment (M) that can be tolerated as a function of the postulated flaw length.

e. The applied moment, increased by a factor of 1.39 (for emergency and faulted conditions) or 2.77 (for normal and upset conditions) must be less than the limit moment (from step d) for the flaw length determined in (b), for the flaw to be acceptable.

CE-ID: 7 **Core Support Barrel Assembly**

Lower Cylinder Girth Welds

Acceptance Criteria: The lower cylinder girth welds continue to perform their functional requirements with the projected flaw length at the end of the inspection interval.

Approach: Limit load, EPFM, or LEFM analysis

CE-ID: 7.1 Core Support Barrel Assembly

Core Barrel Assembly Axial Welds

Category:	Expansion	Applicability:	All plants
Degradation Effect:	Cracking (SCC)		
Primary Link:	Core barrel assembly girth welds		
Function:	The core barrel assembly axial welds contribute to the overall structural integrity of the core barrel.		

Inspection

Method:	Enhanced visual (EVT-1) examination, with initial and subsequent examination dependent on the results of core barrel assembly girth weld examinations.
Coverage:	100% of one side of the accessible surface weld and adjacent base metal surfaces for the weld with the highest calculated operating stress. See MRP-227-A, Figure 4-15.
Observable Effect:	The specific relevant condition is a detectable crack-like surface indication.

Inputs and Assumptions

There are several inputs and assumptions that are critical to the development of acceptance criteria for the RV internals core barrel assembly axial welds locations. These items are stated below:

- The inspections identified in MRP-227-A are intended to provide a sampling of potential locations of degradation. Under this approach, inspection of one side (surface) of the weld is assumed to provide an adequate sampling for monitoring of SCC.
- The change in resistance to fracture of the RV core barrel axial welds can be correlated to the accumulated fluence at each weld location. Welds that are subject to low fluence are considered to have a high degree of resistance to fracture. Correspondingly, those welds subject to high fluence have lower resistance to fracture.
- It is assumed that the primary mode of crack growth to be expected in this region is stress corrosion cracking.
- The prediction of crack growth is based on the stress intensity factor, K, calculated using linear elastic fracture mechanics. The rate of crack growth is dependent on the amount of neutron fluence that the weld is expected to accumulate over the licensed operating lifetime. Since there has been no experience of SCC initiated cracks in operating PWRs to date, growth rates developed for the prediction of SCC in boiling water reactors (BWRs) are assumed to be appropriate for prediction of crack growth due to SCC in PWR reactor internals.
    - For weld locations subjected to fluence less than or equal to $5x10^{20}$ n/cm^2 (E>1MeV), the BWR hydrogen water chemistry (HWC) crack growth equation specified in paragraph C-8520 of Appendix C of Section XI of the 2010 edition of the ASME Boiler and Pressure Vessel Code is appropriate. This crack growth rate model is consistent with the model in BWRVIP-14a.
    - For fluence levels above $5x10^{20}$ n/cm^2 (E>1MeV), the BWR HWC crack growth equation specified in equation 6-5 of MRP-227-A is appropriate.

CE-ID: 7.1

Core Support Barrel Assembly

Core Barrel Assembly Axial Welds

- Depending on the magnitude of cyclic loads, such as thermal transients, additional crack growth as a result of these loads may need to be considered.
- Acceptance criteria can be developed for the entire 60-year license of a given plant by using predicted end-of-license fluence values. However, if there are changes to these fluence projections, such as in the event of a power uprate or change in core loading pattern, it would be necessary to confirm that the inputs selected based on fluence, such as SCC growth rate and fracture toughness, remain applicable until the end of the 60-year license.

Failure

Failure Mechanism: Cracking (SCC)

Failure Effect: Potential for stress redistribution within the core barrel, which could initiate or accelerate circumferential crack growth in the core barrel.

Failure Criteria: Actively growing through-wall flaws may require mitigation.

An existing flaw is unacceptable if the flaw length projected at the next inspection cycle results in a potential loss-of-core support.

Methodology

Goal: Demonstrate that the cracking mechanism will not result in growth beyond the allowable crack length over the planned inspection interval.

Data Requirements:

1. Surface crack length as determined by visual inspection
   a. The 2007 edition of the ASME Code Section XI: IWA-3330(a) and Figure IWA-3330-1 provide requirements for the minimum allowable separation distance that will serve as the basis for guidance in this report. The requirement in Section XI is that the ligament between adjacent cracks must be greater than half of the thickness of the material. If this criterion is not met, the individual crack lengths and the length of the ligament between the cracks must be summed. This total length is then compared to the allowable length.
2. Flaw Depth
   a. For one-sided visual inspections, the flaw is assumed to be through-wall.
   b. Supplemental examinations may be used to determine flaw depth, for a flaw-specific criterion, if needed.
3. Estimate of fast neutron fluence at crack location.
4. Steady-state normal operating stresses to be used to calculate SCC crack growth rates.
   a. Hoop stresses based on normal mechanical loads are required for axial flaws.
   b. Stresses which have an insignificant net-through-wall value (average stress is near zero), such as weld residual stresses and thermal stresses due to local through-wall temperature gradients are considered to have minimal impact on the effective crack growth rates in through-wall flaws.
   c. Secondary weld residual and thermal stresses need to be considered in

CE-ID: 7.1 Core Support Barrel Assembly

Core Barrel Assembly Axial Welds

determination of axial and through-wall crack growth rates in partial through-wall flaws, whose dimensions would have to be determined with supplemental UT examinations.

5. Limiting externally applied transient stresses to be used to calculate allowable flaw lengths. Stresses arising from pressure, mechanical and thermal loads would be included in this calculation.
   a. More detailed load-deformation histories may be required for elastic-plastic or limit load calculations, if these calculations are necessary.

Analysis:

All analyses require an assumption of the SCC crack growth expected over the upcoming period of service. The methodology is based on analysis of a through-wall flaw with weld residual and thermal stresses relieved. The crack growth rate models will be based on K dependent crack growth under hydrogen water chemistry conditions. Fatigue crack growth has been assumed to be negligible. In order to apply the acceptance criteria to a full 10-year inspection interval, follow-up action is required to verify the assumptions used in the predicted crack-growth rate. A re-inspection of the indication at a future specified outage, for example, would provide data that could be used to satisfy this verification requirement. For detailed crack growth models used, see "Inputs and Assumptions" above.

Failure of the axial welds is assumed to occur when unstable axial crack growth is initiated from the analyzed flaw. Three options are outlined for determining the limiting allowable flaw length, based on neutron dose. Analysis methods are suggested for both pre-inspection or generic analysis (Suggested Pre-Inspection Analysis) and for flaws observed in-service (Suggested Flaw Specific Analysis), where more detailed characteristics of the flaw and its location are known. In all cases, a more detailed evaluation may be completed using a semi-elliptic surface flaw, but such an evaluation would require more detailed inspection by UT.

Fluence Range (n/cm^2 E>1MeV)	Dose (dpa)	MRP-227-A Requirement	Suggested Pre-Inspection Analysis	Suggested Flaw Specific Analysis
$\leq 3 \times 10^{20}$	≤ 0.5	Limit Load	LEFM using 150 ksi√in for fracture toughness or Limit Load	Limit Load
$> 3 \times 10^{20} - 3 \times 10^{21}$	> 0.5 - 5	LEFM or EPFM	LEFM using 112 ksi√in for fracture toughness or EPFM	EPFM
$> 3 \times 10^{21} - 1 \times 10^{22}$	> 5 – 15	LEFM 50 ksi√in	LEFM using 50 ksi√in for fracture toughness	LEFM 50 ksi√in
$> 1 \times 10^{22}$	> 15	LEFM 34.6 ksi√in	LEFM using 34.6 ksi√in for fracture toughness	LEFM 34.6 ksi√in

Different evaluation options may be used depending upon the plant-specific fluence levels at the location of the weld being evaluated. Option 1, though conservative, can be used for all fluence levels.

CE-ID: 7.1 **Core Support Barrel Assembly**

Core Barrel Assembly Axial Welds

Option 1: LEFM Analysis

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. For normal and upset loading conditions, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 2.77.
e. For the governing emergency or faulted loading condition, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 1.39.

Option 2: EPFM Analysis (for neutron dose levels > 0.5 dpa but < 5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. Develop the (J/T) material curve from the material J-R curve.
e. The $J_{applied}$ curve must include a safety factor of 2.77 for normal and upset conditions, and a factor of 1.39 for emergency and faulted conditions.
f. The intersection of the material and applied (J/T) curves indicates the instability point. The flaw size at instability is determined from the $J_{applied}$ versus flaw size curve.
g. The flaw size at instability must be larger than the flaw size from (b), for the flaw to be acceptable.

The intersection of the material and applied (J/T) curves indicates the instability point. The load at instability is determined from the $J_{applied}$ versus load curve.

Option 3: Limit Load Analysis (For neutron fluence < $3x10^{20}$ n/cm^2 at E>1 MeV or dose less than approximately 0.5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. Determine the bending moment (M) that can be tolerated as a function of the postulated flaw length.
e. The applied moment, increased by a factor of 1.39 (for emergency and faulted

CE-ID: 7.1 **Core Support Barrel Assembly**

Core Barrel Assembly Axial Welds

conditions) or 2.77 (for normal and upset conditions) must be less than the limit moment (from step d) for the flaw length determined in (b), for the flaw to be acceptable.

Acceptance Criteria: The upper and lower core barrel cylinder axial welds continue to perform their functional requirements with the projected flaw lengths at the end of the inspection interval.

Approach: Limit load, EPFM, or LEFM analysis

CE-ID: 9 Core Support Barrel Assembly Lower Flange Flexure Weld

Category:	Primary	Applicability:	All plants where flexures exist
Degradation Effect:	Cracking (fatigue)		
Expansion Link:	None		
Function:	Primary core support structure		

Inspection

Method: If fatigue life cannot be demonstrated by time-limited aging analysis (TLAA), enhanced visual (EVT-1) examination is required no later than two refueling outages from the beginning of the license renewal period. Subsequent examination is required on a 10-year interval.

Coverage: Examination coverage to be defined by evaluation to determine the potential location and extent of fatigue cracking. See MRP-227-A Figure 4-16 (flange and flexure).

Observable Effect: The specific relevant condition is a detectable crack-like indication.

Inputs and Assumptions

There are several inputs and assumptions that are critical to the development of acceptance criteria for the RV Internals Core Support Barrel weld locations. These items are stated below:

- The inspections identified in MRP-227-A are intended to provide a sampling of potential locations of degradation. Under this approach, inspection of one side (surface) of the weld is intended to provide an adequate sampling for monitoring of fatigue.
- The change in resistance to fracture of the RV core barrel welds can be correlated to the accumulated fluence at each weld location. Welds that are subject to low fluence are considered to have a high degree of resistance to fracture. Correspondingly, those welds subject to high fluence have lower resistance to fracture.
- The prediction of crack growth is based on the stress intensity factor, K, calculated using linear elastic fracture mechanics. The rate of crack growth is dependent on the amount of neutron fluence that the weld is expected to accumulate over the licensed operating lifetime. Since there has been no experience of SCC initiated cracks in operating PWRs to date, growth rates developed for the prediction of SCC in BWRs are assumed to be appropriate for prediction of crack growth due to SCC in PWR reactor internals.
    - o For weld locations subjected to fluence less than or equal to $5\text{x}10^{20}$ n/cm^2 (E>1MeV), the boiling water reactor (BWR) hydrogen water chemistry (HWC) crack growth equation specified in paragraph C-8520 of Appendix C of Section XI of the 2010 edition of the ASME Boiler and Pressure Vessel Code is appropriate. This crack growth rate model is consistent with the model in BWRVIP-14-A, which was previously reviewed and approved by the NRC.
    - o For fluence levels at or above $5\text{x}10^{20}$ n/cm^2 (E>1MeV), the BWR HWC crack growth equation specified in equation 6-5 of MRP-227-A is appropriate.
- Depending on the magnitude of cyclic loads, such as thermal transients,

CE-ID: 9 **Core Support Barrel Assembly**

Lower Flange Flexure Weld

additional crack growth as a result of these loads may need to be considered.

- Acceptance criteria for indications detected using a visual exam can be developed based on an assumed through-wall flaw with a length that is uniform through the wall thickness. If it can be shown that the critical crack length for a through wall flaw is less than that for a part through wall flaw, then this assumption is reasonable and conservative, because no information is available on the flaw depth from such a visual examination.
- Acceptance criteria can be developed for the entire 60-year license of a given plant by using predicted end-of-license fluence values. However, if there are changes to these fluence projections, such as in the event of a power uprate or change in core loading pattern, it would be necessary to confirm that the inputs selected based on fluence, such as SCC growth rate and fracture toughness, remain applicable until the end of the 60-year license.

Failure

Failure Mechanism: Fatigue

Failure Effect: Loss of core support

Failure Criteria: TLAA cannot demonstrate the fatigue usage factor is less than 1.0 at the next inspection and EVT-1 inspection determines that an existing flaw is present that is projected to exceed an allowable length which would cause violation of the functional requirements of the lower support structure prior to the next inspection.

Methodology

Goal:

1. TLAA – demonstrate weld fatigue usage factor is less than 1.0 for all normal and upset conditions while considering environmental effects.
2. If TLAA determines fatigue usage factor may exceed 1.0 or utility chooses to perform inspection in lieu of performing TLAA:
   a. Pre Inspection: Perform a fracture mechanics evaluation to calculate the maximum allowable crack length that can be tolerated during the current inspection.
   b. Post Inspection: Perform a fracture mechanics evaluation to demonstrate that observed flaws will not exceed the maximum allowable crack length for current licensing basis (CLB) before the next inspection interval is reached.

TLAA Methodology:

Data Requirements:

1. Operating loads (e.g. dead weight, pressure, flow, thermal)
2. Functional requirements of the lower support structure
3. ASME Design Fatigue Curves
4. Potential fatigue loading and cycles.
5. Operating temperatures
6. NUREG-CR-6909

CE-ID: 9 Core Support Barrel Assembly

Lower Flange Flexure Weld

Analysis:

1. Develop a model of the lower internals, including the core support barrel, core support barrel lower flange, and the lower support structure in sufficient detail to determine the stresses in the CSB lower flange flexure weld.
2. Determine the stresses due to the mechanical and thermal loads for normal, upset, and faulted conditions.
3. Determine the cumulative usage factor for 60 years operating life using the most recent ASME fatigue curves, and incorporate environmental effects using the fatigue evaluation procedure of Section A3 of NUREG-CR-6909.
4. If the cumulative usage factor is less than 1.0 no inspection is required.

Fracture Mechanics Evaluation Methodology for EVT-1 Inspection Acceptance Criteria:

1. For pre-inspection analysis assume a flaw is present at the most limiting location in the weld. For evaluation of a discovered flaw, evaluate a flaw at the location and orientation of the existing flaw.
2. Perform a fracture mechanics evaluation to determine the maximum permissible flaw size as described below.

Data Requirements:

1. Surface crack length determined by visual inspection
   a. The 2007 edition of the ASME Code Section XI: IWA-3330(a) and Figure IWA-3330-1 provide requirements for the minimum allowable separation distance that will serve as the basis for guidance in this report. The requirement in Section XI is that the ligament between adjacent cracks must be greater than half of the thickness of the material. If this criterion is not met, the individual crack lengths and the length of the ligament between the cracks must be summed. This total length is then compared to the allowable length.
2. Flaw Depth
   a. For one-sided visual inspections, the flaw is assumed to be through-wall.
   b. Supplemental examinations may be used to determine flaw depth.
3. Fast neutron fluence at crack location, or confirmation that fast neutron fluence at lower core barrel flange weld is below $3x10^{20}$ n/cm^2 (E> 1 MeV).
4. Steady-state and applicable operating transient stresses to be used to calculate SCC and fatigue crack growth rates.
   a. Axial stresses based on normal mechanical loads are required for circumferential flaws.
   a. Stresses which have an insignificant net-through-wall value (average stress is near zero), such as weld residual stresses and thermal stresses due to local through-wall temperature gradients are considered to have minimal impact on the effective crack growth rates in through-wall flaws.
   b. Secondary weld residual and thermal stresses need to be considered in determination of circumferential and through-wall crack growth rates in partial through-wall flaws, whose dimensions would have to be

CE-ID: 9 **Core Support Barrel Assembly**

Lower Flange Flexure Weld

determined with supplemental UT examinations.

5. Limiting externally applied transient stresses to be used to calculate allowable flaw lengths.
    a. More detailed load-deformation histories may be required for elastic-plastic or limit load calculations.

Analysis:

All analyses require an assumption of the crack growth expected over the upcoming period of service. The methodology is based on analysis of a through-wall flaw with weld residual and thermal stresses relieved. The crack growth rate models will be based on K dependent crack growth under hydrogen water chemistry conditions. In order to apply the acceptance criteria to a full 10-year inspection interval, follow-up action is required to verify the assumptions used in the predicted crack-growth rate. A re-inspection of the indication at a future specified outage, for example, would provide data that could be used to satisfy this verification requirement. For detailed crack growth models used, see "Inputs and Assumptions" above.

Depending on the magnitude of cyclic loads, such as thermal transients, additional crack growth as a result of these loads may need to be considered.

Failure of the weld is assumed to occur when unstable circumferential crack growth is initiated from the analyzed flaw. Two options are outlined for determining the limiting allowable flaw length, based on neutron dose. Analysis methods are suggested for both pre-inspection or generic analysis (Suggested Pre-Inspection Analysis) and for flaws observed in-service (Suggested Flaw Specific Analysis), where more detailed characteristics of the flaw and its location are known. In all cases, a more detailed evaluation may be completed using a semi-elliptic surface flaw, but such an evaluation would require more detailed inspection by UT.

Fluence Range (n/cm^2 E>1MeV)	**Dose (dpa)**	**MRP-227-A Requirement**	**Suggested Pre-Inspection Analysis**	**Suggested Flaw Specific Analysis**
$\leq 3 \times 10^{20}$	≤ 0.5	Limit Load	LEFM using 150 ksi$\sqrt{in}$ Fracture Toughness Value or Limit Load	Limit Load

Different evaluation options may be used depending upon the plant-specific fluence levels at the location of the weld being evaluated. Option 1, though conservative, can be used for all fluence levels.

Option 1: LEFM Analysis

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

CE-ID: 9 **Core Support Barrel Assembly**

Lower Flange Flexure Weld

d. For normal and upset loading conditions, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 2.77.

e. For the governing emergency or faulted loading condition, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 1.39.

Option 2: Limit Load Analysis (For neutron fluence < $3x10^{20}$ n/cm^2 at E>1 MeV or dose less than approximately 0.5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.

b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.

c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.

d. Determine the bending moment (M) that can be tolerated as a function of the postulated flaw length.

e. The applied moment, increased by a factor of 1.39 (for emergency and faulted conditions) or 2.77 (for normal and upset conditions) must be less than the limit moment (from step C) for the flaw length determined in (b), for the flaw to be acceptable.

Acceptance Criteria: TLAA demonstrates that fatigue usage factor remains less than 1.0 for all normal and upset conditions throughout the license extension period.

If inspection is required based on TLAA results, projected crack growth does not violate lower support structure functional requirements.

Approach: TLAA (plant specific) to assess the need for inspection.

If inspection is required or selected, determine allowable flaw length using fracture mechanics evaluation.

CE-ID: 12 **Control Element Assembly**

Instrument Guide Tubes

Category:	Primary	Applicability:	All plants with instrument guide tubes in the CEA shroud assembly.

Degradation Effect: Cracking (SCC, fatigue) that results in missing supports or separation at the welded joint between the tubes and supports

Expansion Link: Remaining instrument guide tubes within the CEA shroud assemblies

Function: Define path for insertion of in-core instrumentation.

Inspection

Method: Visual (VT-3) examination, no later than two refueling outages from the beginning of the license renewal period. Subsequent examination on a 10-year interval.

Plant-specific component integrity assessments may be required if degradation is detected and remedial action is needed.

Coverage: 100% of tubes in peripheral CEA shroud assemblies (i.e., those adjacent to the perimeter of the fuel alignment plate). See MRP-227 Figure 4-18.

Observable Effect: Missing or broken supports.

Failure

Failure Mechanism: Cracking

Failure Effect:
1. Potential loose parts
2. Inability to insert/withdraw instrumentation

Failure Criteria:
1. Potential uncontained loose parts
2. Inability to maintain minimum in-core instrumentation

Methodology

Goal: Demonstrate ability to insert instrumentation.

Data Requirements: Instrumentation requirements for plant.

Analysis:
1. Evaluate stability of failed instrument guide tube. Any section that could potentially detach and become a loose part or otherwise interfere with plant operation should be removed or stabilized.
2. Any instrument guide tube with an observable crack will be assumed to have failed.

Acceptance Criteria:
1. Configuration of unfailed guide tubes should be sufficient to allow adequate core monitoring.
2. No margin is required for this item. If the instrumentation is functional at start-up, the plant can be operated.

Approach: Pass/Fail inspection with established minimum number of instrumentation tubes. Based directly on plant specifications.

CE-ID: 12.1 **Control Element Assembly**

Remaining Instrument Guide Tubes

Category:	Expansion	Applicability:	All plants with instrument guide tubes in the CEA shroud assembly

Degradation Effect: Cracking (SCC, fatigue) that results in missing supports or separation at the welded joint between the tubes and supports

Expansion Link: Peripheral instrument guide tubes within the CEA shroud assemblies

Function: Define path for insertion of in-core instrumentation.

Inspection

Method: Visual (VT-3) examination. Re-inspection every ten years following initial inspection..

Coverage: 100% of tubes in CEA shroud assemblies. See MRP-227-A Figure 4-18.

Observable Effect: Missing or broken supports

Failure

Failure Mechanism: Cracking

Failure Effect:
1. Potential loose parts
2. Inability to insert/withdraw instrumentation

Failure Criteria:
1. Potential uncontained loose parts
2. Inability to maintain minimum in-core instrumentation

Methodology

Goal: Demonstrate ability to insert instrumentation.

Data Requirements: Instrumentation requirements for plant.

Analysis:
1. Evaluate stability of failed instrument guide tube. Any section that could potentially detach and become a loose part or otherwise interfere with plant operation should be removed or stabilized.
2. Any instrument guide tube with an observable crack will be assumed to have failed.

Acceptance Criteria:
1. Configuration of unfailed guide tubes should be sufficient to allow adequate core monitoring.
2. No margin is required for this item. If the instrumentation is functional at start-up, the plant can be operated.

Approach: Pass/Fail inspection with established minimum number of instrumentation tubes. Based directly on plant specifications.

CE-ID: 13 Lower Support Structure

Deep Beams

Category:	Primary	Applicability:	All plants with core shrouds assembled with full-height shroud plates
Degradation Effect:	Cracking (fatigue) that results in a detectable surface-breaking indication in the welds or beams. Aging Management (IE)		
Expansion Link:	None		
Function:	Primary core support structure		

Inspection

Method:	Enhanced visual (EVT-1) examination, no later than two refueling outages from the beginning of the license renewal period. Subsequent examination on a 10-year interval, if adequacy of remaining fatigue life cannot be demonstrated.
Coverage:	Examine beam-to-beam welds in the axial elevation from the beam top surface to four inches below. See MRP-227 Figure 4-19.
Observable Effect:	Fatigue crack growth along welds at beams. Check for a detectable surface-breaking indication in the welds or beams.

Inputs and Assumptions

There are several inputs and assumptions that are critical to the development of acceptance criteria for the deep beam locations. These items are stated below:

- The inspections identified in MRP-227-A are intended to provide a sampling of potential locations of degradation. Under this approach, inspection of one side (surface) of the weld is intended to provide an adequate sampling for monitoring of fatigue.
- The change in resistance to fracture of the deep beam welds can be correlated to the accumulated fluence at each weld location. Welds that are subject to low fluence are considered to have a high degree of resistance to fracture. Correspondingly, those welds subject to high fluence have lower resistance to fracture.
- The prediction of crack growth is based on the stress intensity factor, K, calculated using linear elastic fracture mechanics. The rate of crack growth is dependent on the amount of neutron fluence that the weld is expected to accumulate over the licensed operating lifetime. Since there has been no experience of SCC initiated cracks in operating PWRs to date, growth rates developed for the prediction of SCC in BWRs are assumed to be appropriate for prediction of crack growth due to SCC in PWR reactor internals.
    - For weld locations subjected to fluence less than or equal to 5×10^{20} n/cm^2 (E>1MeV), the boiling water reactor (BWR) hydrogen water chemistry (HWC) crack growth equation specified in paragraph C-8520 of Appendix C of Section XI of the 2010 edition of the ASME Boiler and Pressure Vessel Code is appropriate. This crack growth rate model is consistent with the model in BWRVIP-14a, which was previously reviewed and approved by the NRC.
    - For fluence levels at or above 5×10^{20} n/cm^2 (E>1MeV), the BWR HWC crack growth equation specified in equation 6-5 of MRP-227-A is appropriate.

CE-ID: 13 **Lower Support Structure**

Deep Beams

- Since the degradation effect is fatigue, low and high cycle fatigue crack growth should be evaluated. Inputs to consider include the magnitude of cyclic loads, such as thermal transients.
- Acceptance criteria can be developed for the entire 60-year license of a given plant by using predicted end-of-license fluence values. However, if there are changes to these fluence projections, such as in the event of a power uprate or change in core loading pattern, it would be necessary to confirm that the inputs selected based on fluence, such as SCC growth rate and fracture toughness, remain applicable until the end of the 60-year license.

Failure

Failure Mechanism: Cracking (fatigue)

Failure Effect: Loss of fuel assembly alignment

Failure Criteria: TLAA cannot demonstrate the fatigue usage factor is less than 1.0 at the next inspection and EVT-1 inspection determines that an existing flaw is present that is projected to exceed an allowable length which would cause violation of the functional requirements of the lower support structure prior to the next inspection.

Methodology

Goal:

1. TLAA – demonstrate weld fatigue usage factor is less than 1.0 for all normal and upset conditions while considering environmental effects.
2. If TLAA determines fatigue usage factor may exceed 1.0 or utility chooses to perform inspection in lieu of performing TLAA:
   a. Pre Inspection: Perform a fracture mechanics evaluation to calculate the maximum allowable crack length that can be tolerated during the current inspection.
   b. Post Inspection: Perform a fracture mechanics evaluation to demonstrate that observed flaws will not exceed the maximum allowable crack length for current licensing basis (CLB) before the next inspection interval is reached.

TLAA Methodology:

Data Requirements:

1. Operating loads (e.g. dead weight, pressure, flow, thermal)
2. Functional requirements of the lower support structure
3. ASME Design Fatigue Curves
4. Potential fatigue loading and cycles.
5. Operating temperatures
6. NUREG-CR-6909

Analysis:

1. Develop a model of the lower internals, including the core support barrel, core support barrel lower flange, and the lower support structure in sufficient detail to determine the stresses in the deep beams.
2. Determine the stresses due to the mechanical and thermal loads for normal, upset, and faulted conditions.
3. Determine the cumulative usage factor for 60 years operating life using the most recent ASME fatigue curves, and incorporate environmental effects using the

CE-ID: 13 Lower Support Structure

Deep Beams

fatigue evaluation procedure of Section A3 of NUREG-CR-6909

4. If the cumulative usage factor is less than 1.0 no inspection is required.

Fracture Mechanics Evaluation Methodology for EVT-1 Inspection Acceptance Criteria:

1. For pre-inspection analysis assume a flaw is present at the most limiting location in the weld. For evaluation of a discovered flaw evaluate a flaw at the location and orientation of the existing flaw.
2. Perform a fracture mechanics evaluation to determine the maximum permissible flaw size as described below.

Data Requirements:

1. Surface crack length determined by visual inspection
   a. The 2007 edition of the ASME Code Section XI: IWA-3330(a) and Figure IWA-3330-1 provide requirements for the minimum allowable separation distance that will serve as the basis for guidance in this report. The requirement in Section XI is that the ligament between adjacent cracks must be greater than half of the thickness of the material. If this criterion is not met, the individual crack lengths and the length of the ligament between the cracks must be summed. This total length is then compared to the allowable length.
2. Flaw Depth
   a. For one-sided visual inspections, the flaw is assumed to be through-wall.
   b. Supplemental examinations may be used to determine flaw depth.
3. Fast neutron fluence at crack location, or confirmation that fast neutron fluence at the deep beams is below $3x10^{20}$ n/cm^2 (E> 1 MeV).
4. Steady-state and applicable operating transient stresses to be used to calculate SCC and fatigue crack growth rates.
   a. Horizontal stresses based on normal mechanical loads are required for vertical flaws.
   b. Secondary weld residual and thermal stresses need to be considered in determination of circumferential and through-wall crack growth rates in partial through-wall flaws.
5. Limiting externally applied transient stresses to be used to calculate allowable flaw lengths.
   a. More detailed load-deformation histories may be required for elastic-plastic or limit load calculations.

Analysis:

All analyses require an assumption of the crack growth expected over the upcoming period of service. The methodology is based on analysis of a through-wall flaw with weld residual and thermal stresses relieved. The crack growth rate models will be based on K dependent crack growth under hydrogen water chemistry conditions. In order to apply the acceptance criteria to a full 10-year inspection interval, follow-up action is required to verify the assumptions used in the predicted crack-growth rate. A re-inspection of the indication at a future specified outage, for example, would provide data

CE-ID: 13 **Lower Support Structure**

Deep Beams

that could be used to satisfy this verification requirement.

Failure of the deep beams is assumed to occur when unstable crack growth is initiated from the analyzed flaw. Two options are outlined for determining the limiting allowable flaw length, based on neutron dose. Analysis methods are suggested for both pre-inspection and generic analysis (Suggested Pre-Inspection Analysis) and for flaws observed in-service (Suggested Flaw Specific Analysis), where more detailed characteristics of the flaw and its location are known. In all cases, a more detailed evaluation may be completed using a semi-elliptic surface flaw, but such an evaluation would require more detailed inspection by UT.

Fluence Range (n/cm^2 E>1MeV)	Dose (dpa)	MRP-227-A Requirement	Suggested Pre-Inspection Analysis	Suggested Flaw Specific Analysis
$\leq 3 \times 10^{20}$	≤ 0.5	Limit Load	LEFM using 150 ksi$\sqrt{in}$ for fracture toughness or Limit Load	Limit Load

Different evaluation options may be used depending upon the plant-specific fluence levels at the location of the weld being evaluated. Option 1, though conservative, can be used for all fluence levels.

Option 1: LEFM Analysis

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. For normal and upset loading conditions, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 2.77.
e. For the governing emergency or faulted loading condition, the final stress intensity factor (K) for the flaw size from (b) must be lower than the fracture toughness for the material by a factor of at least 1.39.

Option 2: Limit Load Analysis (For neutron fluence < 3×10^{20} n/cm^2 at E>1 MeV or dose less than approximately 0.5 dpa)

a. Establish initial crack length (and depth if determined by supplemental examinations) based on inspection results.
b. The final crack dimensions are calculated by adding 10 years of crack growth under normal loading conditions.
c. Ensure that the ΔK resulting from flow-induced vibration (FIV) is below the threshold for fatigue crack growth.
d. Determine the bending moment (M) that can be tolerated as a function of the

CE-ID: 13 **Lower Support Structure**

Deep Beams

postulated flaw length.

e. The applied moment, increased by a factor of 1.39 (for emergency and faulted conditions) or 2.77 (for normal and upset conditions) must be less than the limit moment (from step d) for the flaw length determined in (b), for the flaw to be acceptable.

Acceptance Criteria: The deep beams continue to perform their functional requirements with the projected flaw length at the end of the inspection interval.

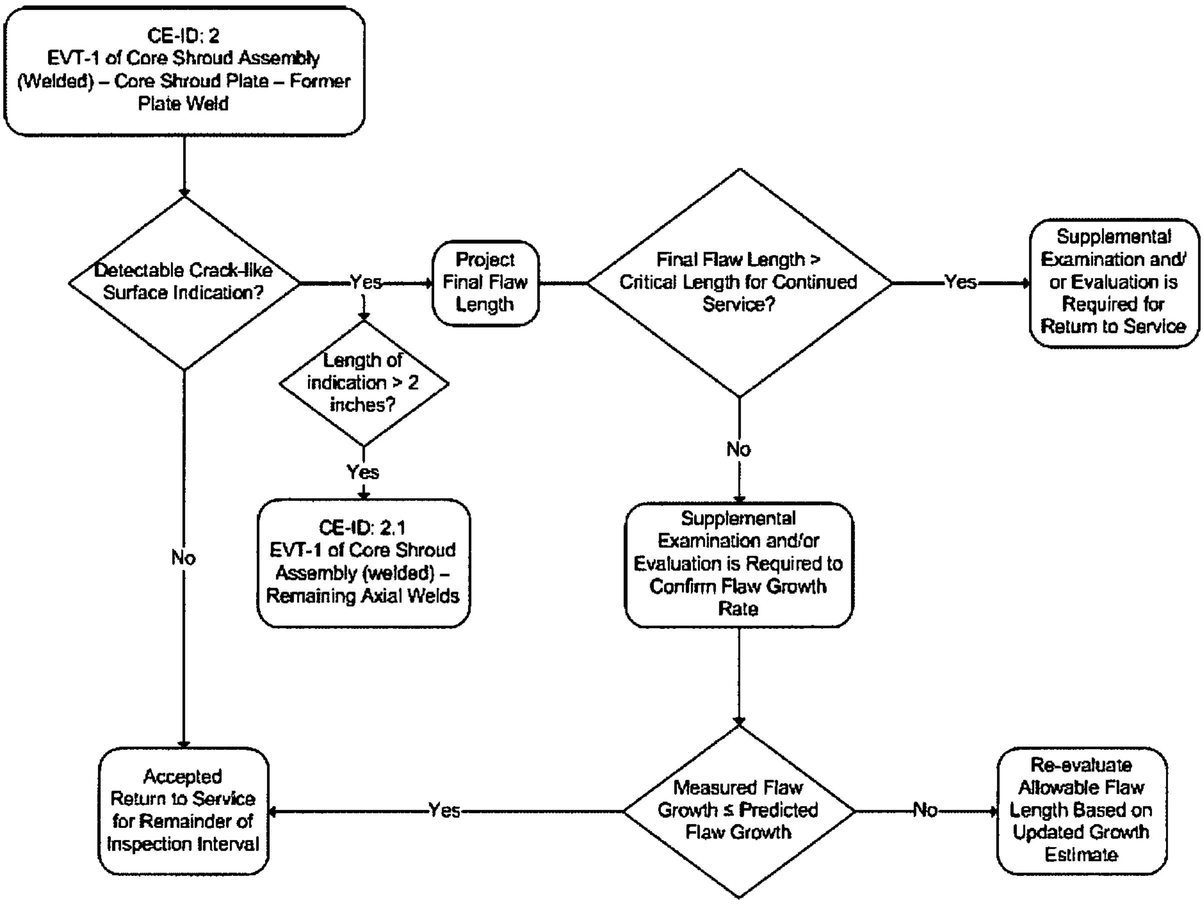
Approach: Limit load or LEFM analysis

Revised Table of Contents for Appendix D of WCAP-17096-NP

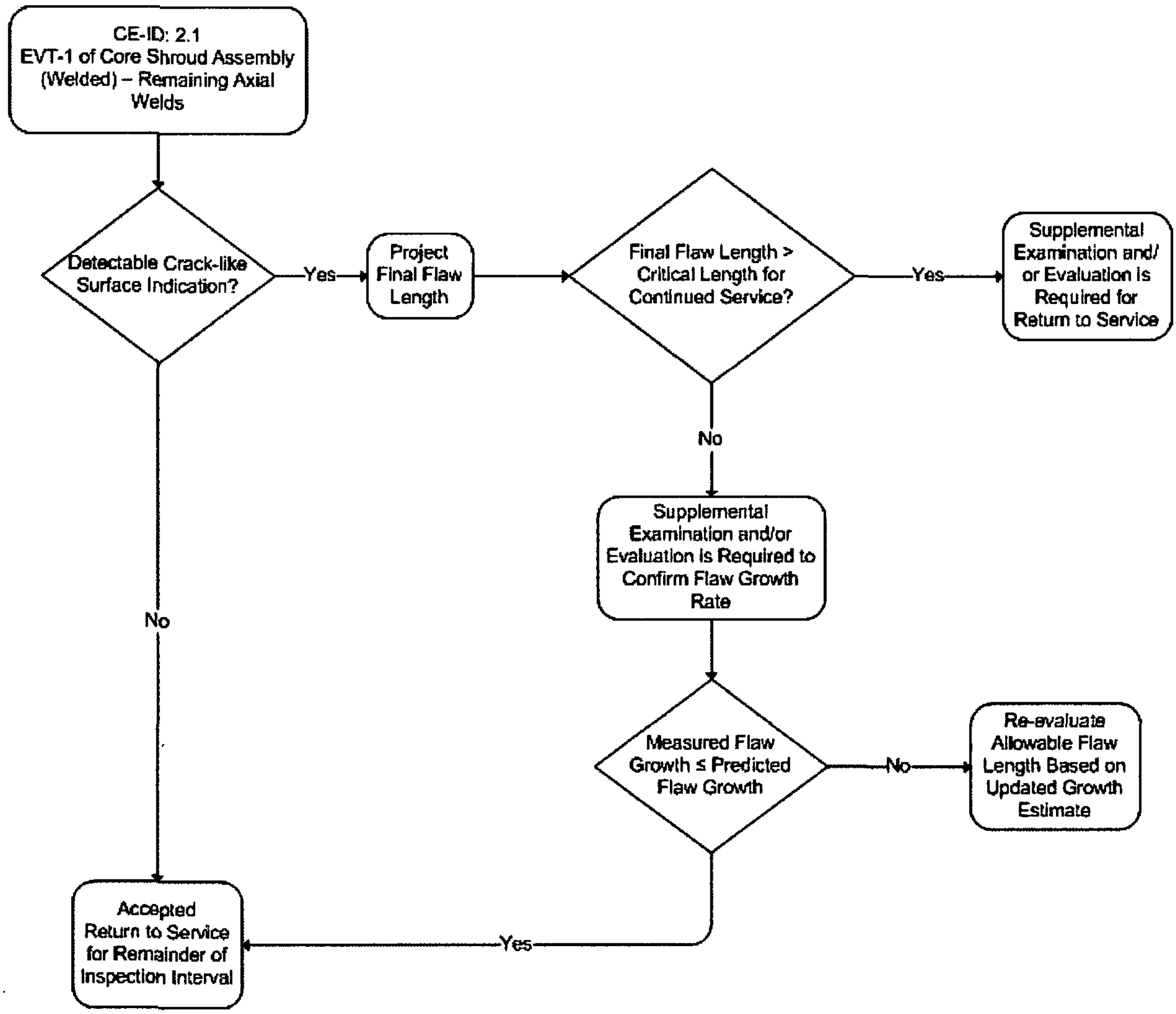
Combustion Engineering Primary and Expansion Components

[1]Attachment A of this letter contains this WCAP-17096 section.

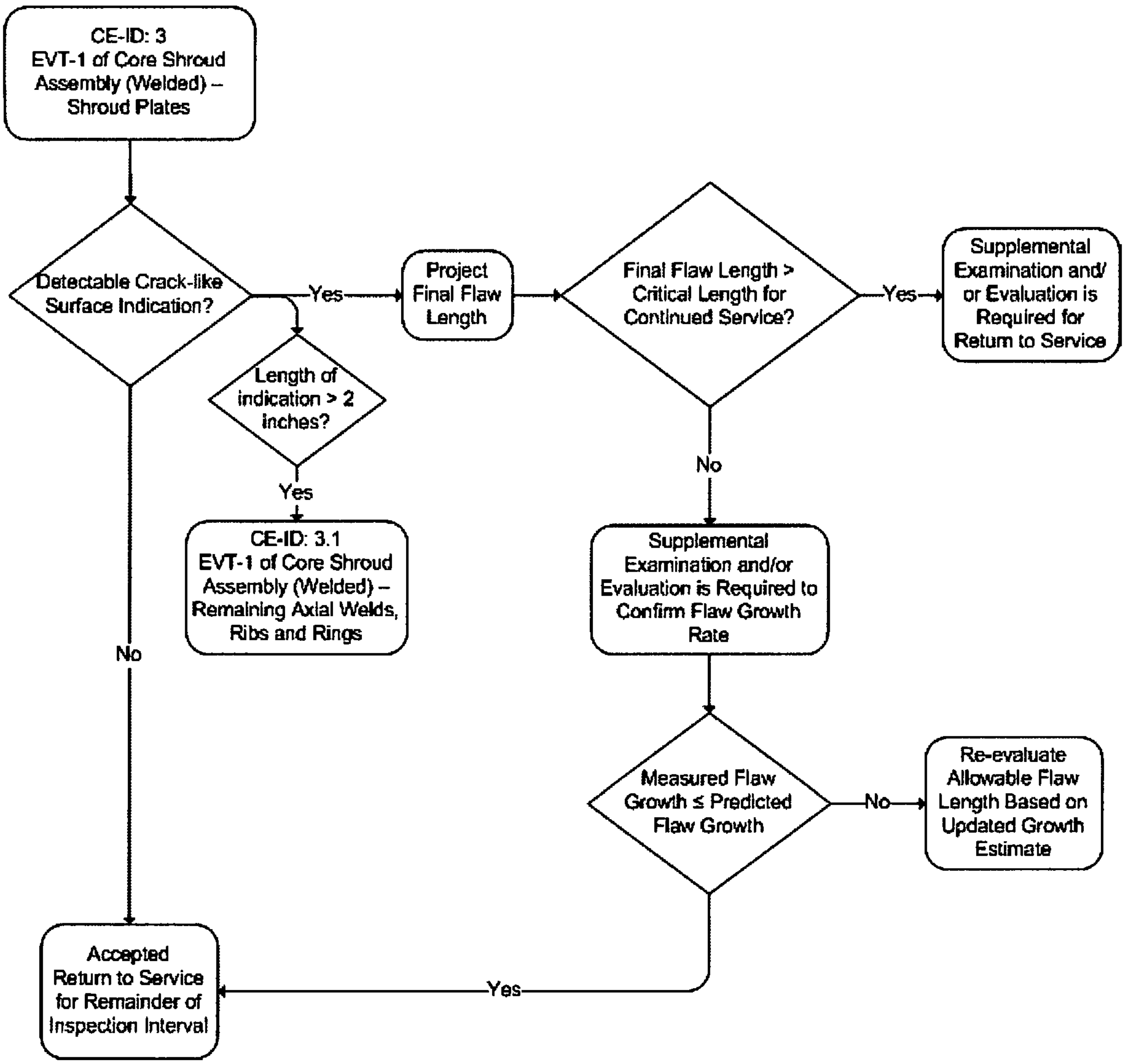
CE-ID: 2
Core Shroud Assembly (Welded) – Core Shroud Plate-Former Plate Weld



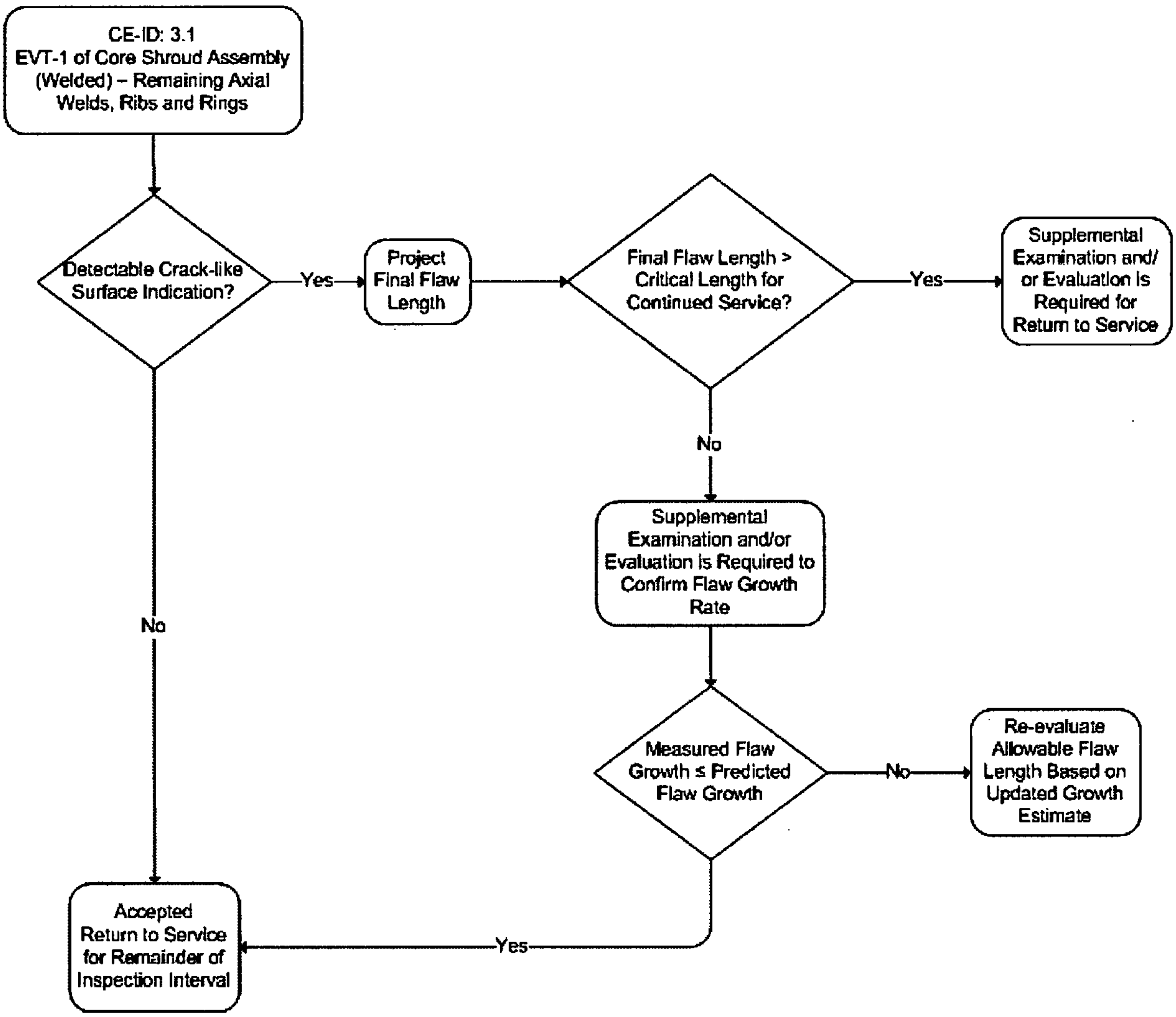
CE-ID: 2.1
Core Shroud Assembly (Welded) – Remaining Axial Welds



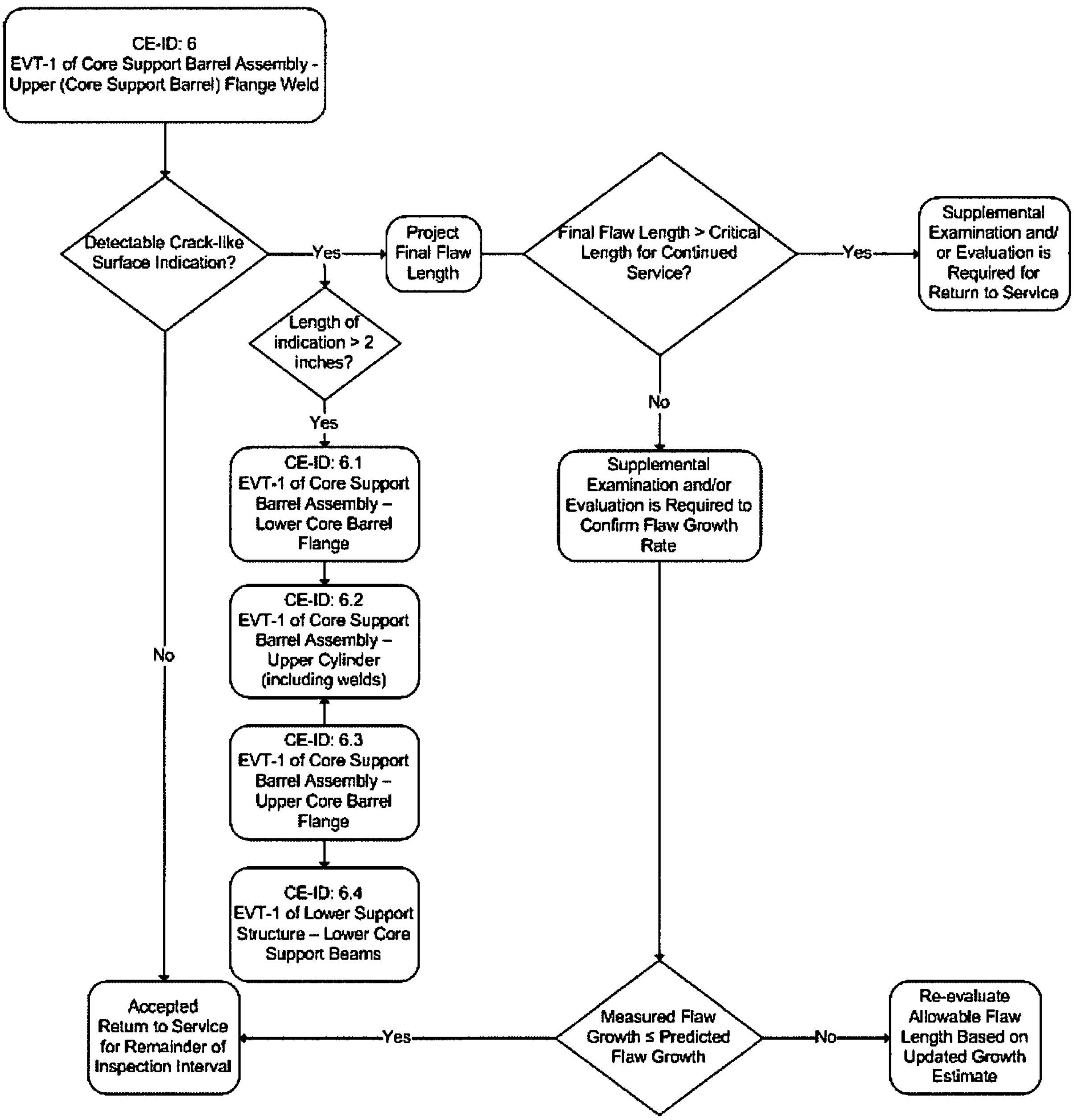
CE-ID: 3
Core Shroud Assembly (Welded – Full Height) – Shroud Plates



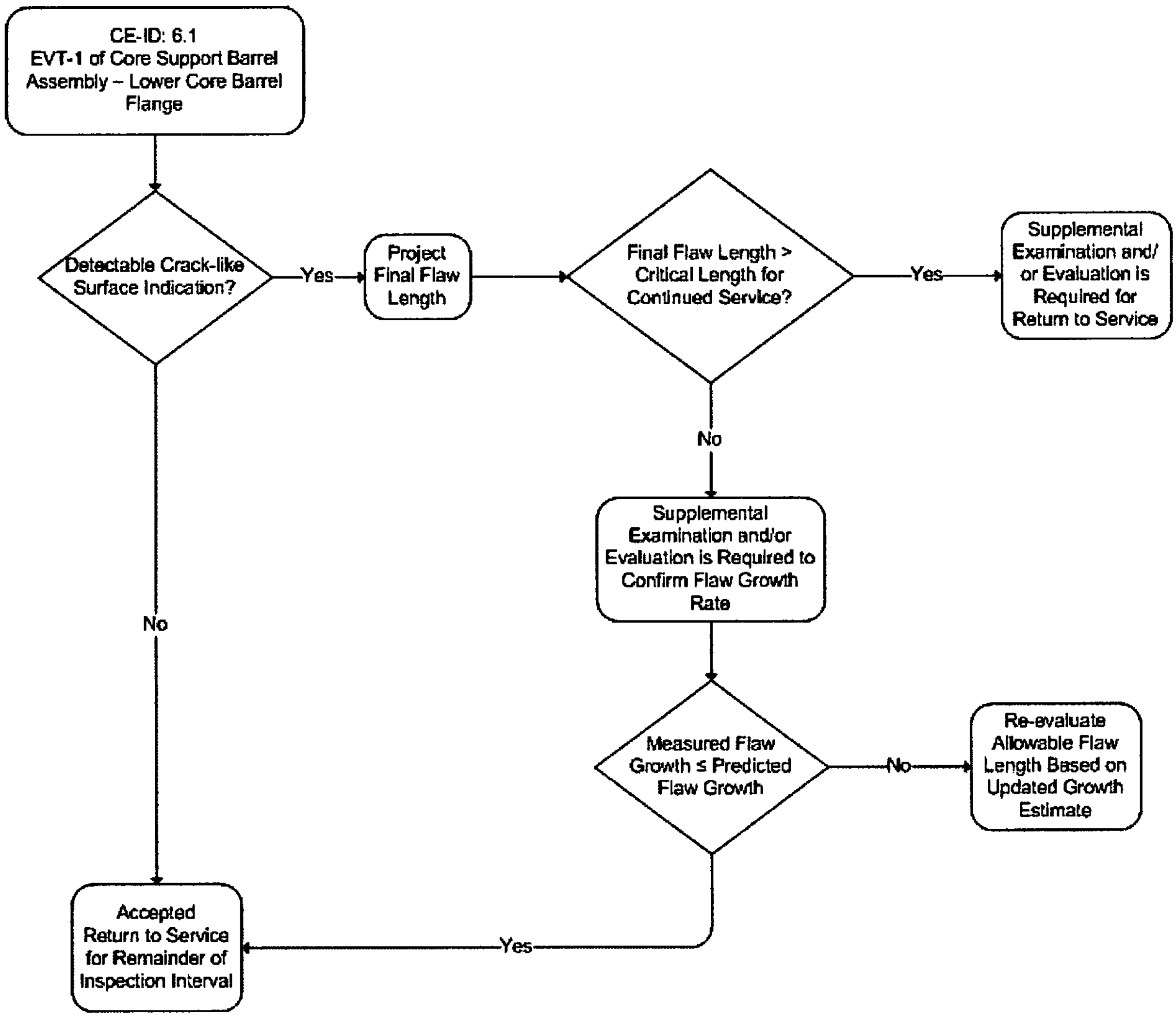
CE-ID: 3.1
Core Shroud Assembly (Welded) – Remaining Axial Welds, Ribs and Rings



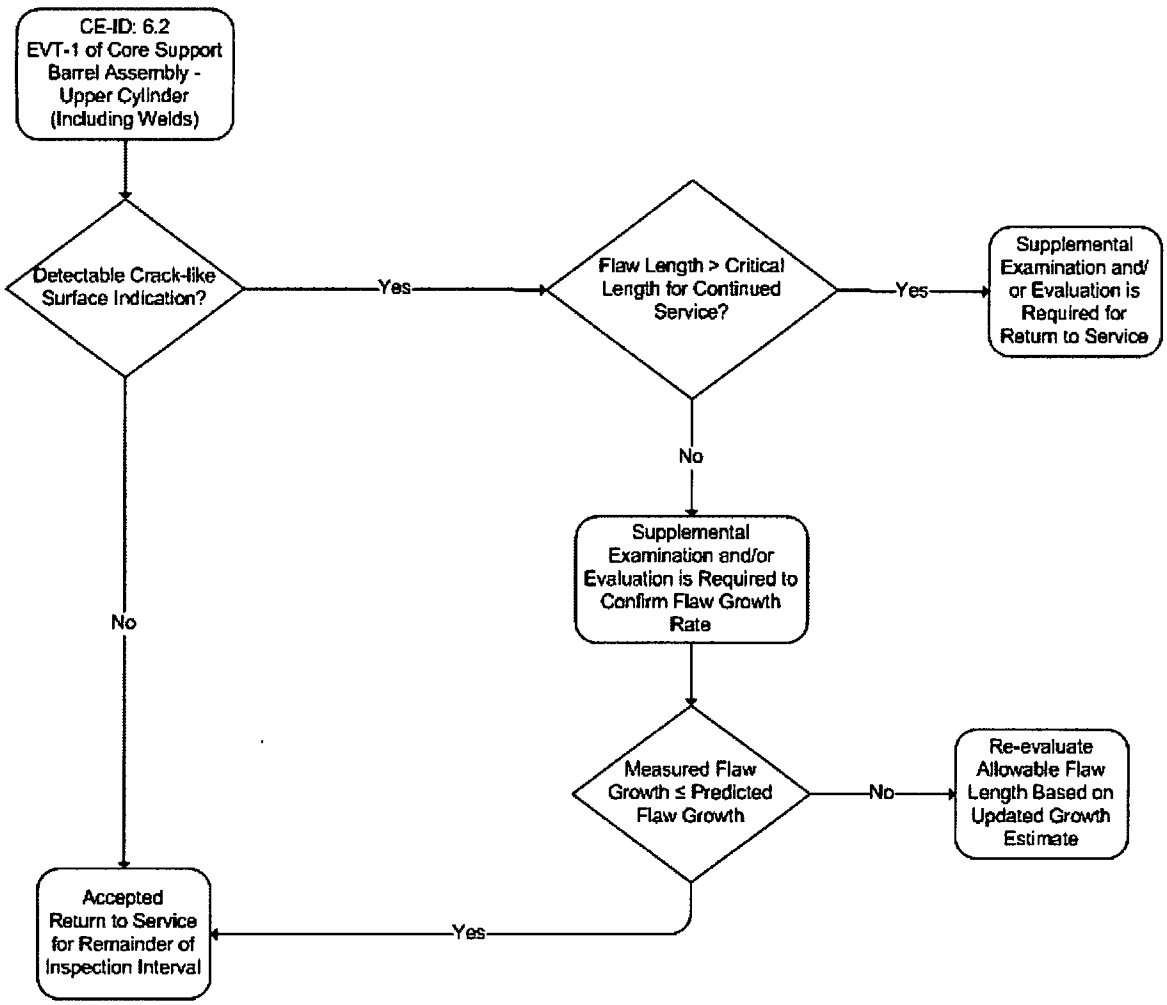
CE-ID: 6
Core Support Barrel Assembly – Upper (Core Support Barrel) Flange Weld



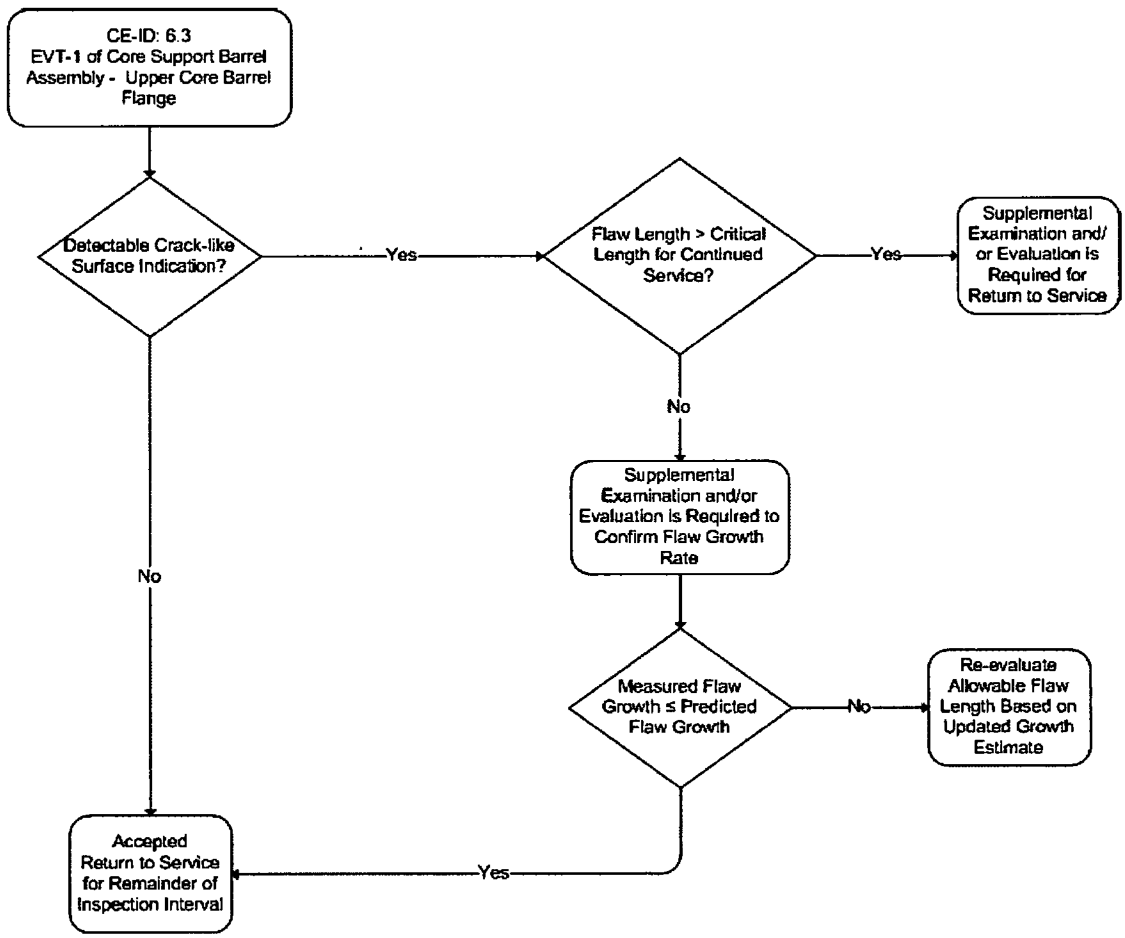
CE-ID: 6.1
Core Support Barrel Assembly – Lower Core Barrel Flange



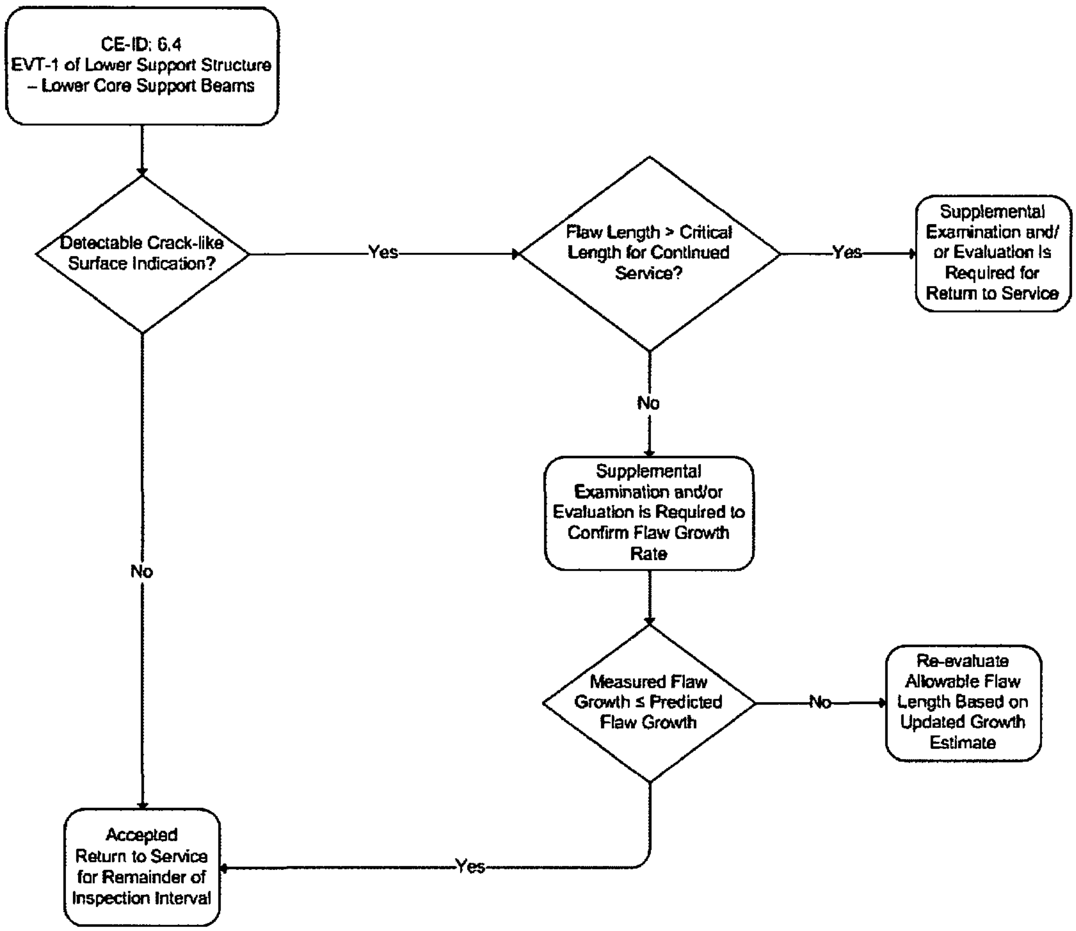
CE-ID: 6.2
Core Support Barrel Assembly – Upper Cylinder (Including Welds)



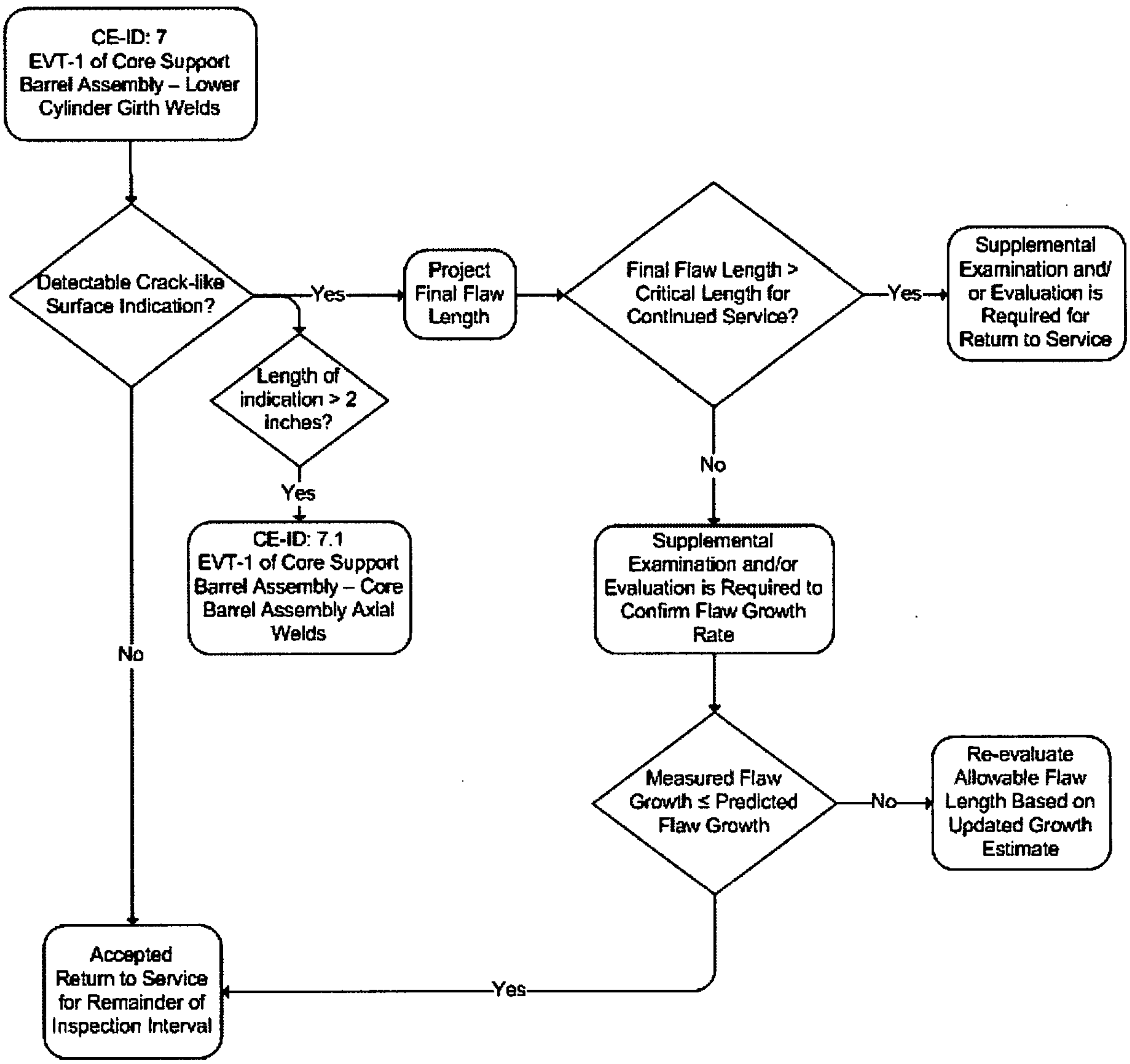
CE-ID: 6.3
Core Support Barrel Assembly – Upper Core Barrel Flange



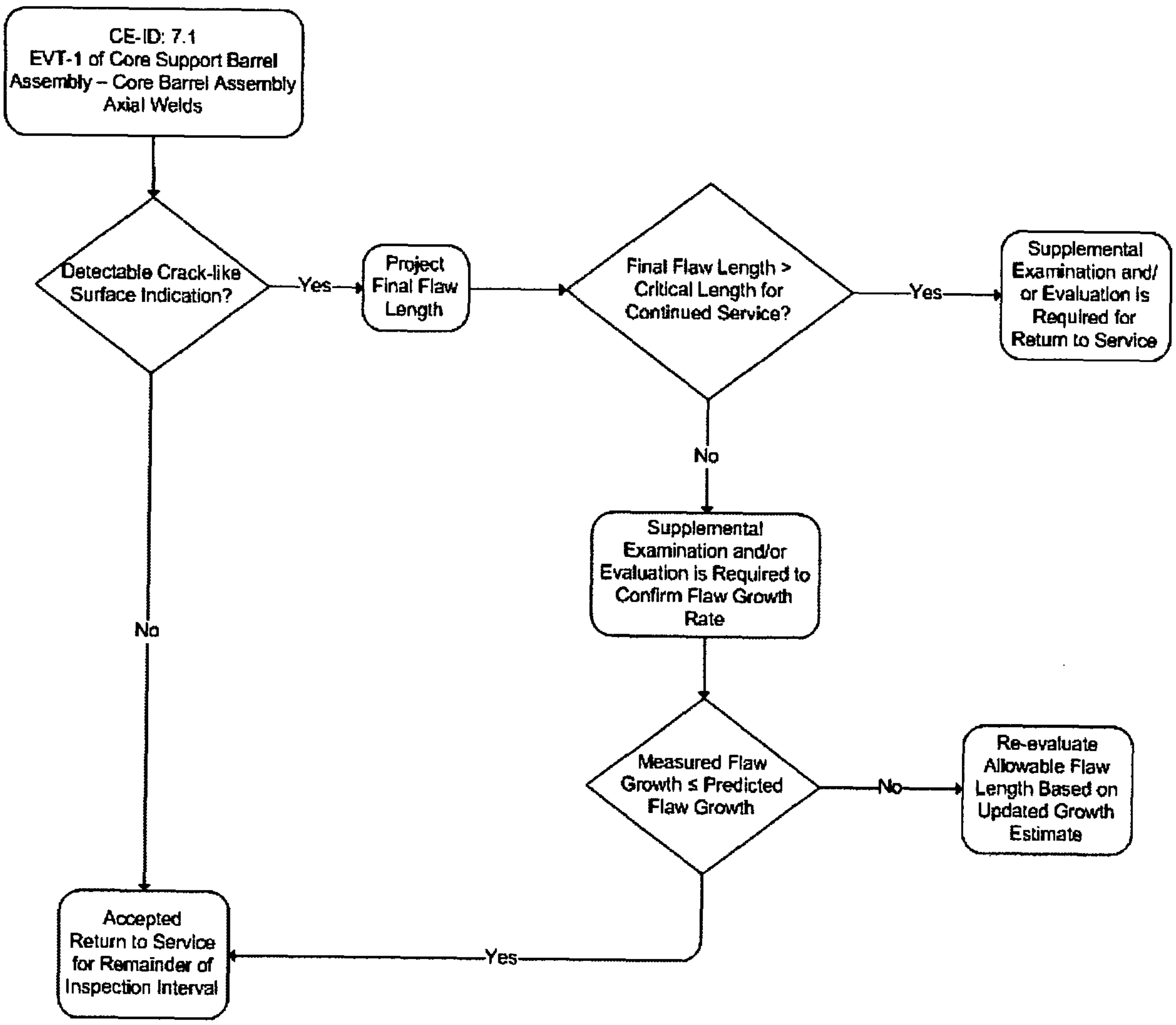
CE-ID: 6.4
Lower Support Structure – Lower Core Support Beams



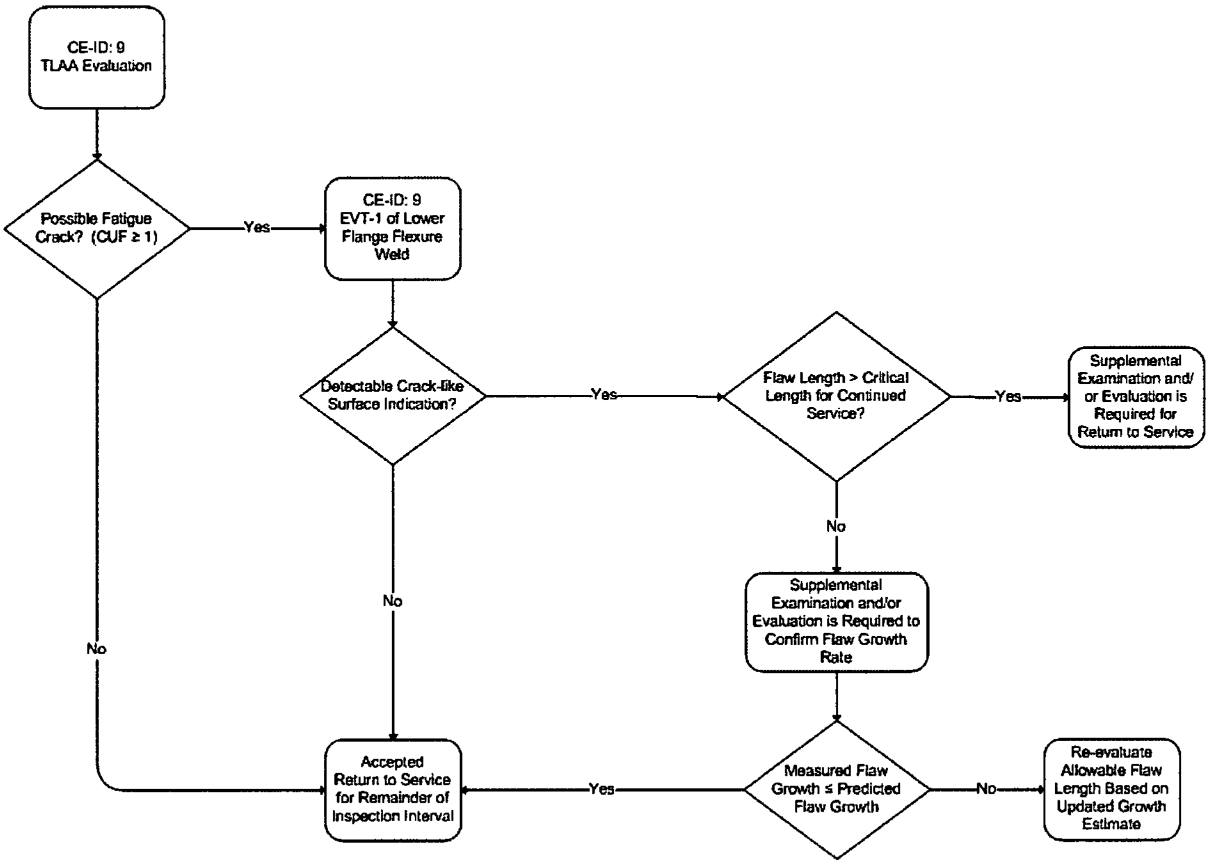
CE-ID: 7
Core Support Barrel Assembly – Lower Cylinder Girth Welds



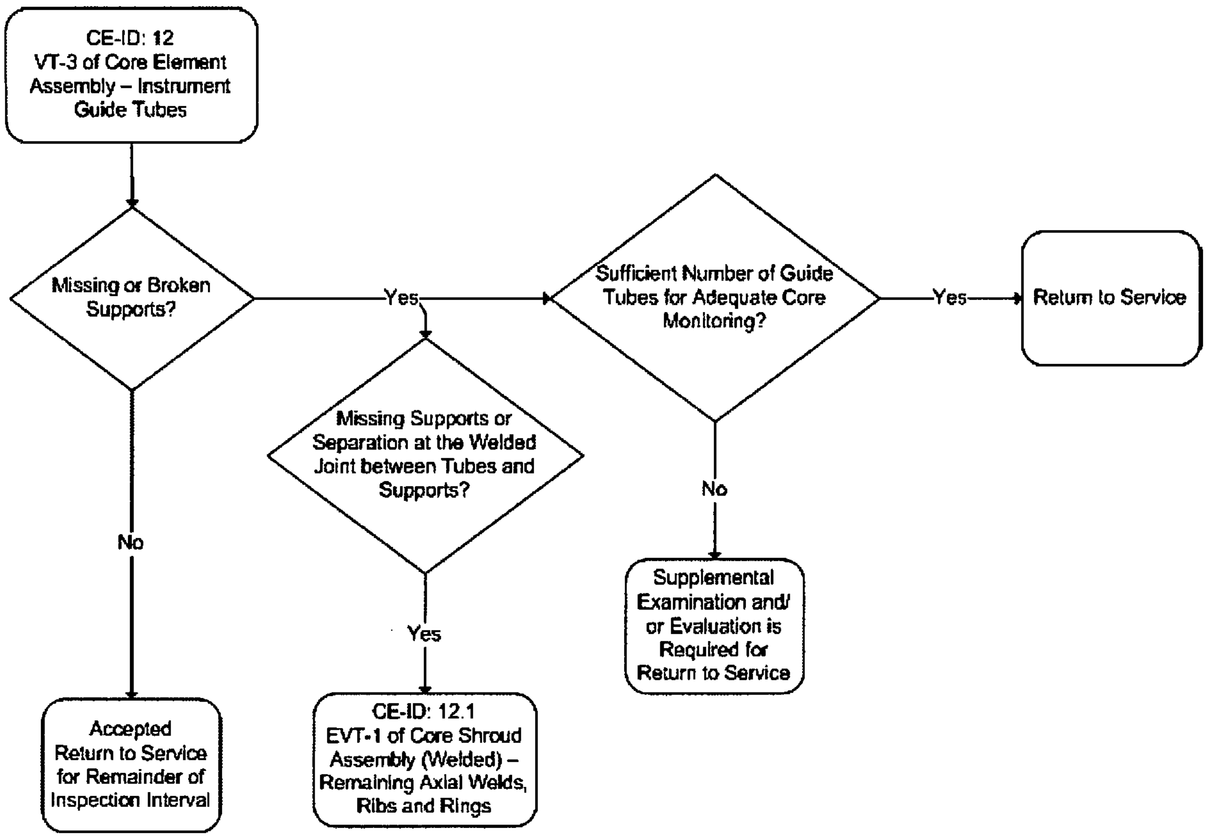
CE-ID: 7.1
Core Support Barrel Assembly – Core Barrel Assembly Axial Welds



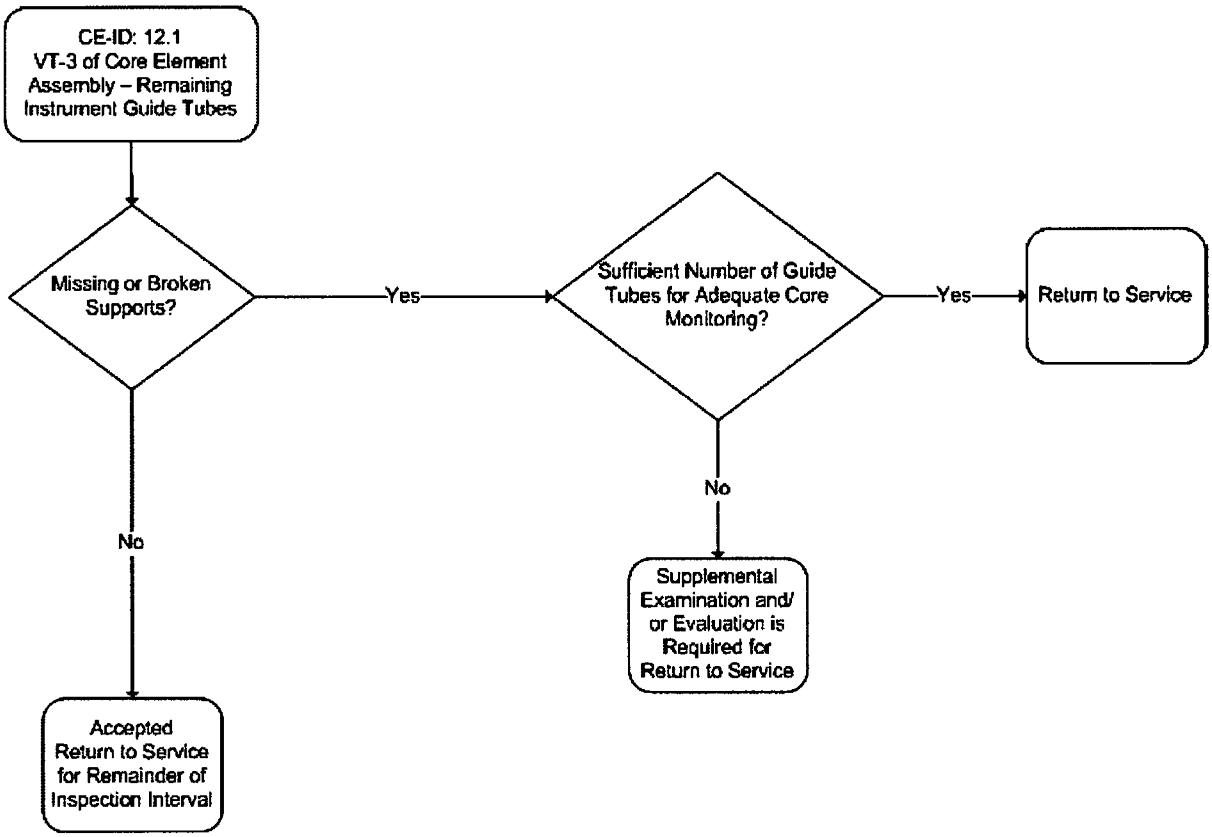
CE-ID: 9
Core Support Barrel Assembly – Lower Flange Flexure Weld



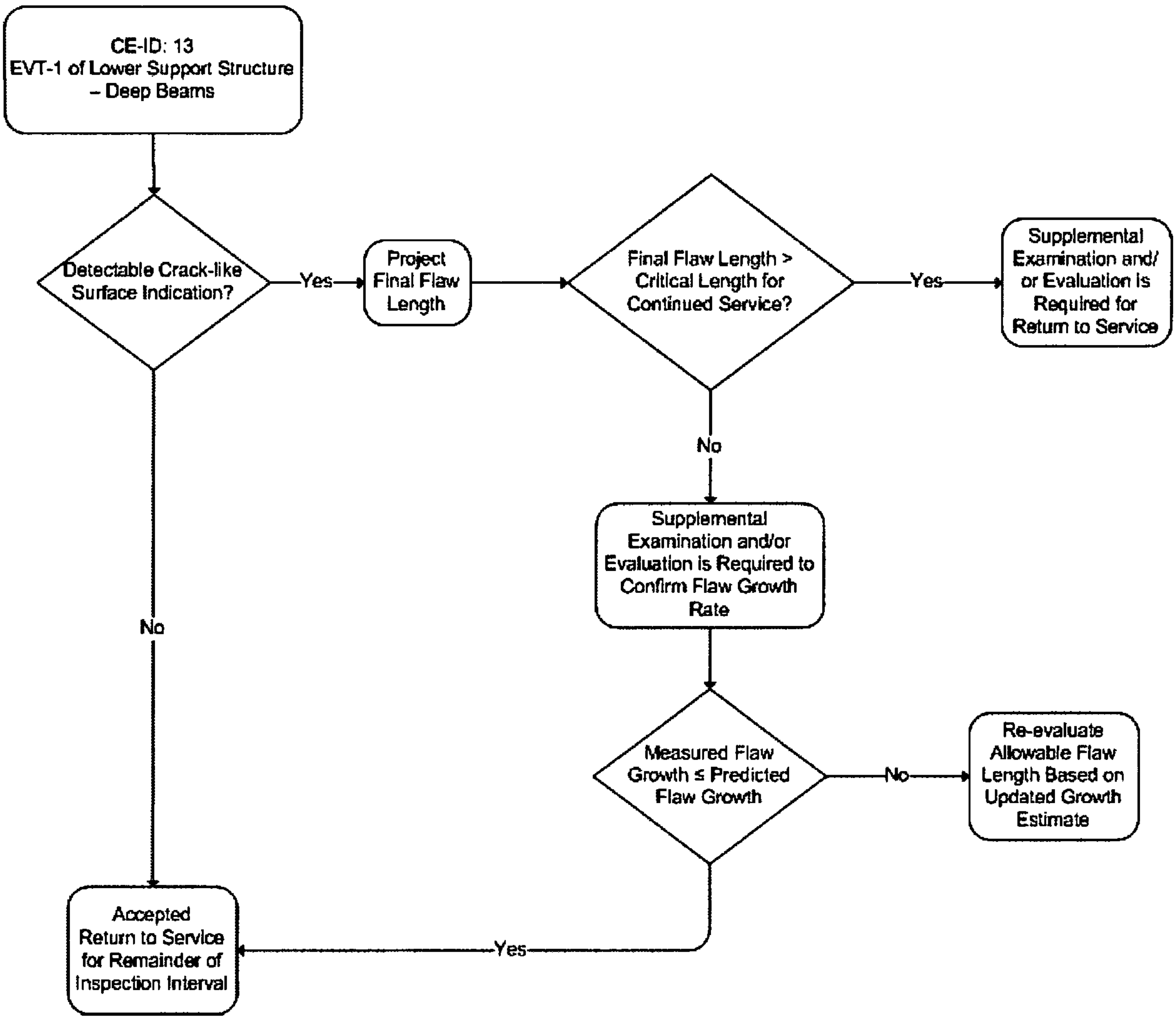
CE-ID: 12
Control Element Assembly – Instrument Guide Tubes



CE-ID: 12.1
Control Element Assembly – Remaining Instrument Guide Tubes



CE-ID: 13
Lower Support Structure – Deep Beams



Revised Table of Contents for Appendix E of WCAP-17096-NP

Westinghouse Primary and Expansion Components

[1]Attachment A of this letter contains this WCAP-17096 section.

W-ID: 1 **Control Rod Guide Tube Assembly**

Guide Plates (Cards)

Category: Primary Applicability: U.S. Domestic Plants

Degradation Effect: Loss of Material (Wear)

Expansion Link: None

Function: The control rod guide tube assembly provides alignment and an insertion path for the control rods through the upper internals. The guide tubes house guide cards and a continuous guidance section below the guide cards to provide alignment and an insertion path for control rod assemblies and to support the control rods when withdrawn.

Inspection

Method: Calibrated optical technique that is capable of measuring guide card ligament thickness and slot opening width. See Figure 1. Recommended accuracy is ±0.010 inch, however less accuracy is allowed if associated reduction in projected continued operation is recognized as discussed in Section 4.3 (c.) of WCAP-17451-P, Rev. 1.

Each utility shall perform an initial "baseline" examination measurement based on the generic inspection schedule provided in WCAP-17451-P, Rev. 1. Inspections shall be performed earlier than the generic schedule for plants as noted in Section 5.4 of WCAP-17451-P, Rev. 1. No wear measurements prior to 2015 are required. Alternate wear measurement schedules may be developed based on the guidance provided in WCAP-17451-P, Rev. 1.

Coverage: The recommended minimum number of guide tubes to be inspected ranges from 76% to 87% depending on the reactor design as described in WCAP-17451-P, Rev. 1. Alternative coverage requirements may be developed following the guidance given in WCAP-17451-P, Rev. 1.

The inspection scope shall include at least the lower six guide cards per guide tube and, when needed, the top of the continuous guidance sheaths or C-tubes. The four innermost rodlet holes per guide card and continuous section shall be inspected.

Observable Effect: The observable effect of wear is the shortening of the guide card and continuous section sheath or C-tube ligaments at the four innermost rodlet holes where the shortest ligaments exist. After complete wear of the ligaments has occurred, continued wear will cause the slot width at the end of the ligaments to widen until they become at least 100 percent of the rodlet diameter and allow the rodlet to become unsupported by the guide card or some partial length of the continuous section member.

Failure

Failure Mechanism: The guidance holes in the guide cards are distorted by wear (loss of material). The largest amounts of wear are typically observed in lowest guide card levels.

Failure Effect: Wear of ligaments and opening of slots can cause loss of guidance and escape of the rodlet into the open center area of the guide tube. If enough consecutive guide cards lose guidance, the rodlet could plastically deform during accident conditions and prevent the rod cluster control assembly (RCCA) from inserting during a rod drop or during downward stepping. Wear-through along part of the length of a continuous guidance member could cause gouging and jamming of a rodlet and lead to prevention of insertion.

Failure Criteria: If the following numbers of consecutive guide cards are found to have 85 to 100 percent

W-ID: 1 **Control Rod Guide Tube Assembly**

Guide Plates (Cards)

rodlet diameter slot opening (loss of rodlet guidance), the guide tube position should not be relied on to perform a rod insertion function and that subsequent evaluation or corrective actions for that condition are beyond the scope of this criteria:

RCCA	Lower Guide Tube Length (in.)	Number of Guide Cards (n)
17x17	96	5
17x17	125	4
17x17	150	4
15x15	125	4
15x15	150	3
14x14	109, 119	3

If part of the length of a guide tube continuous guidance member is found with 85 to 100 percent rodlet diameter slot opening width for 17x17 guide tubes or 95 to 100 percent ligament depth wear for 14x14 and 15x15 guide tubes, the guide tube operation in a rodded position shall be discontinued.

Methodology

Goal: Prevent operation of guide tubes with greater than the number of consecutive worn-through guide cards listed in the Failure Criteria section and with continuous guidance member wear as described in the Failure Criteria section.

Data Requirements:

- Guide card innermost hole ligament wear depth (or remaining ligament thickness) or slot opening width if ligament thickness is greater than 100 percent worn away
- Continuous guidance member wear if wear at the first guide card above the continuous is projected to wear-through before the time of the next inspection
- Guide tube operational effective full power years (EFPYs) at the time of the inspection or measurement

W-ID: 1 **Control Rod Guide Tube Assembly**

Guide Plates (Cards)

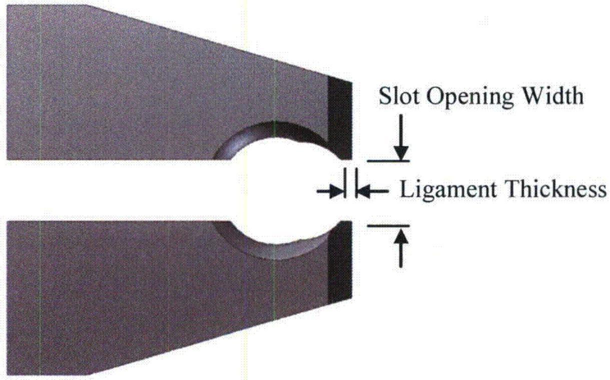


Figure 1 Guide Card Wear Measurements

Analysis:

Operational time extension curves to project guide card wear are provided in WCAP-17451-P, Rev. 1. These curves are designed to allow a user to determine the remaining number of EFPYs (or other time unit) that a guide card can operate until the targeted amount of wear-through occurs. Procedures for operational time extension are also provided in WCAP-17451-P, Rev. 1 for the continuous guidance section. Since wear-through of one or more guide cards is allowed under certain circumstances, procedures are provided in WCAP-17451-P, Rev. 1 to determine operational time extension after wear-through occurs until the allowable number of worn-through guide cards is reached.

Re-inspection intervals are based on the observed extent of wear and the time projected to reach either the Yellow Zone or Red Zone defined in the Acceptance Criteria section.

W-ID: 1 **Control Rod Guide Tube Assembly**

Guide Plates (Cards)

Acceptance Criteria: The basis of the criteria is to prevent rodlet breakout at more than the allowed number of consecutive guide cards listed in the Failure Criteria section. The guide card wear criteria are based on two cases described below for the wear pattern of the consecutive guide cards that are allowed to completely wear through. The guide cards in a guide tube can either wear at similar or different rates and could be experiencing similar (Case 1) or variable (Case 2) wear magnitudes. Based on this wear behavior difference, two different wear criteria are developed. For each case, the measured wear is classified in terms of three criterion zones defined as Green, Yellow and Red as listed in Tables 1 and 2.

Case 1: Similar Guide Card Wear and Wear Rate at Allowable Consecutive Cards

For this case, if the number of allowable consecutive cards shows very similar wear, the basic consideration is that complete breakout should be avoided at any card since consequently, complete breakout could occur simultaneously at many cards during the same cycle of operation. Uniform wear is defined when the allowable number of worn-through cards, n, in the Failure Section reaches a Yellow or Red Zone criteria within the same two cycles.

Case 2: Variable Guide Card Wear and Wear Rate at Allowable Consecutive Cards

For this case, where variable card-to-card ligament wear is observed, the criteria, which allow for multiple worn-through cards, are applicable and are discussed further below.

In Tables 1 and 2 below, the wear criterion zones are defined for Cases 1 and 2 in terms of the following parameters:

W_1 = the nominal unworn guide card (GC) slot width

W_2 = 0.8 x DR

W_3 = 0.85 x DR

DR = the RCCA rodlet diameter

n = number of allowable open guide cards for a particular guide card configuration

Table 1 **Guide Card Wear Criteria Zone – Similar Card to Card Ligament Wear Rate**

Criterion Zone	Measured Slot Width (W_i)
Green Zone	Between W_1 & W_2
Yellow Zone	Between W_2 & W_3
Red Zone	Between W_3 & DR

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Guide Plates (Cards)

Table 2 Guide Card Wear Criteria Zone – Variable Card to Card Ligament Wear Rate	
Criterion Zone	**Range**
Green Zone	Measured slot width under W_3 at all GCs
Yellow Zone	Measured slot width beyond W_3 for one to (n - 1) consecutive guide card holes
Red Zone	Measured slot width beyond W_3 for (n) consecutive guide card holes or ($\geq$ n) non-consecutive cards with one inclusive card between W_2 and DR, whichever is more limiting

The required and recommended actions for each guide card wear criterion zone are defined in Table 3.

Table 3 Guide Card Wear Criteria Zones and Actions	
Criterion Zone	**Recommended or Required Actions**
Green Zone	<u>Recommendations</u>: For any measured ligament and slot width wear in this zone, the next maintenance inspection period will be determined from predictive wear calculations based on the baseline data. The predictive wear calculation will set the next inspection period in the Yellow Zone.
Yellow Zone	<u>Recommendations</u>: For any measured ligament and slot width wear in this zone, consider the following options: • Replace or exchange the guide tube (GT) with a part-length or spare GT • Perform engineering evaluation to determine continued operation • Determine subsequent inspection periods to preclude operation in the Red Zone
Red Zone	<u>Required</u>: For any measured ligament and slot width wear in this zone, rodded use of the GT without modifications shall be discontinued to preclude wear-through at (n+1) guide cards. Note: The initial red criterion of 85 percent allows some margin for uncertainties in the measurements, rodlet wear dimensions, and volumetric wear assumptions.

Table 4 contains lower continuous guidance member criterion zones and recommended or required actions. Acceptance criteria are for wear at the top end of the lower continuous guidance section members where wear is most critical for guidance above the continuous

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Guide Plates (Cards)

section and where rodlet jamming is most likely to occur. A relative view of the wear along the lower continuous guidance section members' length – where ligament depth variations can be viewed – can be video recorded. Parameters for evaluating the wear criterion zones in 17x17 standard, AS, and XL guide tubes are as follows:

W_1 = nominal unworn continuous guidance slot width

W_2 = slot width = 0.75 x DR

W_3 = slot width = 0.85 x DR

W_4 = slot width = DR

DR = RCCA rodlet diameter

Similar criteria for the 14x14 and 15x15 continuous guidance section members are likely possible, but have not been firmly established. Therefore, for the 14x14 and 15x15 guide tubes, the following more conservative criteria are recommended. If it becomes apparent that more relaxed criteria for the continuous guidance members are needed, a plant-specific evaluation would be required if generic development of these criteria has not been established at a later time.

Therefore, in Table 4 for 14x14 and 15x15 guide tubes:

W_1 = zero wear depth

W_2 = ligament wear depth = 75 percent of ligament thickness

W_3 = ligament wear depth = 95 percent of ligament thickness

W_4 = ligament wear depth = 100 percent of ligament thickness

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Guide Plates (Cards)

Table 4	**Continuous Guidance Section Wear Criteria Zones and Actions**	
Criteria Zone	**Zone Range**	**Recommended or Required Actions**
Green Zone	Between W_1 & W_2	Recommendations: For any measured ligament wear in this zone, determine the next maintenance inspection period from predictive wear calculations based on the baseline data. The predictive wear calculation will set the next inspection period in the Yellow Zone. Review rod drop times for possible trending relative to technical specification limits.
Yellow Zone	Between W_2 & W_3	Recommendations: Perform rod drop time trending relative to rod drop technical specification limits. For any measured ligament wear in this zone, consider options such as: • Replace or exchange the GT with a part-length or spare GT • Perform engineering evaluation to determine continued operation • Determine subsequent inspection periods to preclude operation in the Red Zone
Red Zone	Between W_3 & W_4	Required: For any measured ligament wear in this zone, rodded use of the GT without modifications shall be discontinued to prevent either excessive bowing of the rodlet or to prevent the slot width from opening to the point where rodlet break-through can occur along part of the length of the continuous guidance member. Rodlet gouging and jamming could result under such conditions.

Approach: Generic work completed in existing PWROG program WCAP-17451-P Rev. 1.

W-ID: 2.1 **Upper Internals Assembly**

Upper Core Plate

Category:	Expansion	Applicability:	All plants
Degradation Effect:	Cracking (Fatigue), Wear		
Primary Link:	CRGT Lower Flange Weld		
Function:	Primary core support structure		

Inspection

Method: Enhanced visual (EVT-1) examination. Re-inspection every 10 years following initial inspection.

Coverage: 100% of the accessible surfaces. A minimum of 75% coverage of the entire examination area or volume is required (including both the accessible and inaccessible portions.)

Observable Effect: The specific relevant condition is a detectable crack-like surface indication.

Inputs and Assumptions

The acceptance criteria methodology assumes that cracking due to fatigue is the active degradation mechanism and that all other components in the upper internals assembly are in a nominal, non-degraded condition. If additional flaws are found in the upper internals assembly, additional analysis of the as-found assembly is required to determine suitability for return to service.

Failure

Failure Mechanism: Cracking (fatigue), wear

Failure Effect:
1. Loss of core support
2. Difficulty in loading, or removing, fuel due to misalignment of the guide pins.

Failure Criteria: Deflection of the upper core plate with accompanying misalignment of the fuel assembly guide pins, upper core plate alignment pin inserts, or guide tubes beyond the maximum permissible for proper function.

Methodology

Goal: Cracks in the upper core plate are expected to grow from hole-to-hole within the plate. A network of connected cracks is required to allow significant degradation of the plate functionality. The goal is to demonstrate that the cracking which might be present does not violate the functional requirements.

Data Requirements:
1. Operating loads (eg, pressure, flow, and thermal for limiting conditions)
2. Functional requirements for the upper core plate assembly.

Analysis: Determine acceptable flaw pattern.

1. Establish functional requirements for the upper core plate assembly.
   a. During normal operation, the system of support columns resists upper core plate deflection caused by mechanical and thermal loading. The upper core plate requirements may include maximum allowable deflection affecting guide tube and fuel assembly alignment. The upper core plate alignment pins and inserts affect fuel assembly lateral support during earthquakes, LOCA, and

W-ID: 2.1 **Upper Internals Assembly**

Upper Core Plate

other transients. Requirements for these components may also need to be considered.

b. During the limiting accident transient the system must maintain structural integrity.

2. Upper core plate analysis assumptions.
   a. Assume crack initiates in the plate at the location with the highest surface tensile stress.
   b. Assume the crack propagates through the full thickness of the plate through the ligament with highest stress to the adjacent hole.
3. Structural model of upper support structure.

   Develop a model of the upper support structure that may include support columns, upper support weldment, guide tubes, upper core plate alignment pins and inserts, and upper core plate. The model should be capable of modeling a crack connecting holes in the upper core plate (crack tip modeling not required). Sector modeling based on symmetry may be justifiable. Evaluate the resulting deflection of the upper core plate and the alignment of the guide tubes, guide pins and alignment pins/inserts against the functional requirements.
4. Any single observed crack is acceptable if displacement of the upper core plate and alignment of the guide pins and alignment pins/inserts in the FEA model meets the functional requirements.
5. Determine that the observed crack does not cause stresses in the remainder of the upper core plate to exceed applicable limits.
6. If unable to demonstrate the acceptability of a single crack, a detailed flaw analysis is required.
7. Optional determination of margin for additional cracking: Repeat the evaluation for multiple cracks connecting adjacent holes. Determine the number and pattern of connected holes which causes violation of the functional requirements.

Acceptance Criteria: The observed cracking does not cause deflections which violate the upper core plate assembly functional requirements. Fatigue analysis does not predict development of additional cracks in excess of the acceptable flaw pattern during the inspection interval.

Note: Once cracking is observed, re-inspection is required during each subsequent refueling outage unless additional analysis can justify a longer inspection interval.

Approach: FEA (plant specific)

W-ID: 2.2 **Lower Internals Assembly**

Lower Support Forging or Casting

Category:	Expansion Applicability: All plants
Degradation Effect:	Cracking, Aging Management (Thermal Embrittlement in Casting)
Primary Link:	Control rod guide tube (CRGT) lower flange welds
Function:	Primary core support structure

Inspection

Method:	Enhanced visual (EVT-1) examination. Re-inspection every 10 years following initial inspection.
Coverage:	100% of accessible surfaces. See MRP-227-A, Figure 4-33.
Observable Effect:	The specific relevant condition is a detectable crack-like surface indication.

Inputs and Assumptions

The acceptance criteria methodology assumes that all other components in the lower internals assembly are in a normal, non-degraded condition. If additional flaws are found in the lower internals assembly, additional analysis of the as-found condition is required to determine suitability for return to service.

Assume crack initiates at the location with the highest surface tensile stress.

Assume the crack propagates through the full thickness of the forging or casting through the ligament with the highest stress to the adjacent hole.

Failure

Failure Mechanism:	Cracking, Aging Management (Thermal Embrittlement in Casting)
Failure Effect:	Potential loss-of-core support.
Failure Criteria:	An existing flaw is unacceptable if the flaw length projected at the next inspection cycle allows a potential loss-of-core support.

Methodology

Goal: Determine the level of cracking required to weaken the lower support forging or casting to the point that it cannot adequately support the lower core plate.

Data Requirements: Operating loads

Functional requirements for the lower support forging or casting and the lower core plate.

Analysis: Determine acceptable flaw pattern.

1. Establish functional requirements for the lower core plate assembly
   a. During normal operation, the system of support columns resists lower core plate deflection caused by mechanical and thermal loading, The lower core plate has requirements for "flatness" affecting fuel assembly alignment.
   b. During the limiting transient, the system must maintain structural integrity (consult design specification for flatness requirements during transients)
2. Structural model of lower support structure

W-ID: 2.2 **Lower Internals Assembly**

Lower Support Forging or Casting

a. Develop a model of the lower support structure that includes support columns, lower forging or casting, and lower core plate. The deflected shape of the lower support forging or casting will influence the deflection of the lower core plate through the support columns which join them. The model should be capable of modeling a crack connecting holes in the lower core support forging or casting (crack tip modeling not required). Sector modeling based on symmetry may be justifiable. Evaluate the lower core plate against the functional requirements (e.g. deflection of the plate and the alignment of the guide pins).

3. Any single observed crack is acceptable if the FEA model predicts that the functional requirement s of the lower core plate (e.g. deflection of the plate and the alignment of the guide pins) are met.
4. Determine that the observed crack does not cause stresses in the remainder of the lower core support forging or casting to exceed applicable limits.
5. If unable to demonstrate the acceptability of a single crack, a detailed flaw analysis is required.
6. Optional determination of margin for additional cracking: Repeat the evaluation for multiple cracks connecting adjacent holes. Determine the number and pattern of connected holes which causes violation of the functional requirements.

Acceptance Criteria: Current cracking does not cause deflections which violate lower core plate assembly functional requirements or produce loose parts. Analysis does not predict development of additional cracks in excess of the acceptable flaw pattern during the inspection interval.

Note: Once cracking is observed, reinspection is required during each refueling outage unless additional analysis can justify a longer inspection interval.

Approach: FEA (plant specific)

W-ID: 3.1	**Core Barrel Assembly**
	Core Barrel Outlet Nozzle Welds
Category:	Expansion Category: Expansion
Degradation Effect:	Cracking (SCC, Fatigue), Aging Management (IE of Lower Sections)
Primary Link:	Upper Core Barrel Flange Weld
Function:	Maintains position of outlet nozzle

Inspection

Method:	Enhanced visual (EVT-1) examination. Re-Inspection every 10 years following initial inspection.
Coverage:	100% of one side of the accessible surfaces of the selected weld and adjacent base metal. See MRP-227-A, Figure 4-22.
Observable Effect:	The specific relevant condition is a detectable crack-like surface indication.

Failure

Failure Mechanism:	Cracking (SCC)
Failure Effect:	Potential loss of core barrel alignment.
Failure Criteria:	An existing flaw is unacceptable if the flaw length projected at the next inspection cycle allows a potential loss of core barrel alignment.

Methodology

Goal:	Demonstrate that the cracking mechanism will not result in growth beyond the allowable crack length over the planned inspection interval.
Data Requirements:	1. Nozzle weld geometry 2. Primary weld loading
Analysis:	The outlet nozzles are unique among the core barrel welds inspected under MRP-227-A. They do not provide core support and they experience relatively small primary loads. The main loading on the nozzle welds is due to the dilation of the hole in the core barrel from differential thermal expansion and the nozzle forging resisting that dilation. This loading is secondary in nature and would be relieved if a crack were to propagate in this weld. Consequently, they should be able to tolerate large flaws. Determination of the allowable flaw size should ensure that sufficient weld ligament remains at the end of the inspection interval to maintain the position of the outlet nozzle.
Acceptance Criteria:	The remaining weld ligament at the time of the next inspection is sufficient to maintain the position of the outlet nozzle.
Approach:	No set requirement

W-ID: 10 **Thermal Shield Assembly**

Thermal Shield Flexures

Category:	Primary Applicability: All plants
Degradation Effect:	Cracking (fatigue) or Loss of Material (Wear) that results in thermal shield flexures excessive wear, fracture, or complete separation
Expansion Link:	None
Function:	The flexure is the lower structural support for the thermal shield. Flexures hold the thermal shield concentric to the core. The flexure design allows for differential thermal expansion between the core barrel and the thermal shield.

Inspection

Method:	Visual (VT-3) no later than 2 refueling outages from the beginning of the license renewal period. Subsequent examinations on a 10-year interval.
Coverage:	100% of thermal shield flexures. See MRP-227-A Figures 4-29 and 4-36.
Observable Effect:	Crack, displacement, fracture, or component separation. Failure along weld at base of flexure or failure of weld attachment to thermal shield.

Inputs and Assumptions

Assume:

1. Any thermal shield flexure with an observed flaw has failed.
2. No credit for "bumpers" and other redundant structures.

Failure

Failure Mechanism:	Large deflections of the flexure due to thermal cycling may lead to fatigue failures.
Failure Effect:	Failure of flexures contributes to vibration of the thermal shield. Failure can also result in flow blockage, wear, and damage to specimen guides.
Failure Criteria:	Number of unfailed thermal shield flexures must be sufficient to retain structural functionality of the entire thermal shield assembly.

Methodology

Goal:	Determine the number and location of thermal shield flexures that must remain intact to retain structural functionality of the entire thermal shield assembly.
Data Requirements:	• Load: thermal, deadweight, pressure, seismic, FIV, LOCA (if applicable) • Design-specific Geometry • History of transient cycles • Materials of construction
Analysis:	Perform structural assessment to determine the minimum number of flexures required to retain structural integrity. The dynamic response of the thermal shield should be established.

W-ID: 10 Thermal Shield Assembly

Thermal Shield Flexures

Procedure:

1. Construct and benchmark an FEA model of the undamaged core barrel and thermal shield assembly for the plant.
2. Perform a modal analysis to determine the frequencies of at least the first twenty modes (as a minimum the cantilever beam mode and shell modes n = 2, n = 3, and n = 4 should be included).
3. Remove one flexure from the model and determine the effect on the thermal shield mode frequencies and the effect on the structural integrity of the remaining thermal shield supports.
4. If the frequency for a given mode changes, evaluate high cycle fatigue to demonstrate that the endurance limit is not exceeded in the remaining thermal shield supports. Normal operating stresses, including stresses from flow-induced vibration must be considered.
5. Demonstrate that the usage factor for low cycle fatigue in the remaining supports, the top (blocks) and bottom (flexure) supports, including, flexures, blocks, pins, and bolts is less than 1.0 for the interval before the next inspection cycle. Stresses resulting from normal and upset load conditions, including cyclic thermal loads, as well as, seismic and LOCA conditions (LOCA loads may not be required for some plants) must be considered. Increased loading on the core barrel wall should also be addressed.
6. Remove additional flexures from the model and repeat steps 3 through 5 if the results of the frequency and usage factor evaluations are acceptable for the failure of one flexure.

Acceptance Criteria: Failure of a thermal shield flexure is acceptable if it can be demonstrated that the remaining thermal shield supports are structurally acceptable when the flexure is removed from the model. The resulting loads and stresses in the remaining flexures, bolts, and pins must be evaluated to determine the expected time to failure. If the dynamic response of the thermal shield is changed by removal of one flexure, then resulting loads and stresses in the remaining flexures, bolts, and pins must be evaluated to determine the expected time to failure. This will determine the required maximum permissible interval for re-inspection.

Any observation of a failed thermal shield flexure should lead to enhanced vigilance for fatigue and vibration monitoring systems. Enhanced vigilance could involve several approaches, such as, more frequent inspection during outages and neutron noise monitoring. Re-inspection should be performed in the first outage following discovery of a failed flexure and every outage thereafter. If neutron noise monitoring is selected and visual examination during the first outage following discovery finds no additional flaws, further visual examination is not required until the next 10-year inspection as long as neutron noise monitoring is conducted every 30 days and no change in the vibration frequencies is detected.

Neutron noise monitoring has been used at some plants to monitor vibration of the internals during operation. It has the potential to detect the loss of additional flexures as evidenced by changes in the internals vibration frequencies. Neutron noise monitoring uses frequency domain Fast Fourier Transform (FFT) analysis of the signal from existing ex-core neutron detectors to monitor the vibration of the internals structures. Guidelines for measurement system requirements are given in ASME OM-S/G-2007 and CEI/IEC

W-ID: 10 **Thermal Shield Assembly**

Thermal Shield Flexures

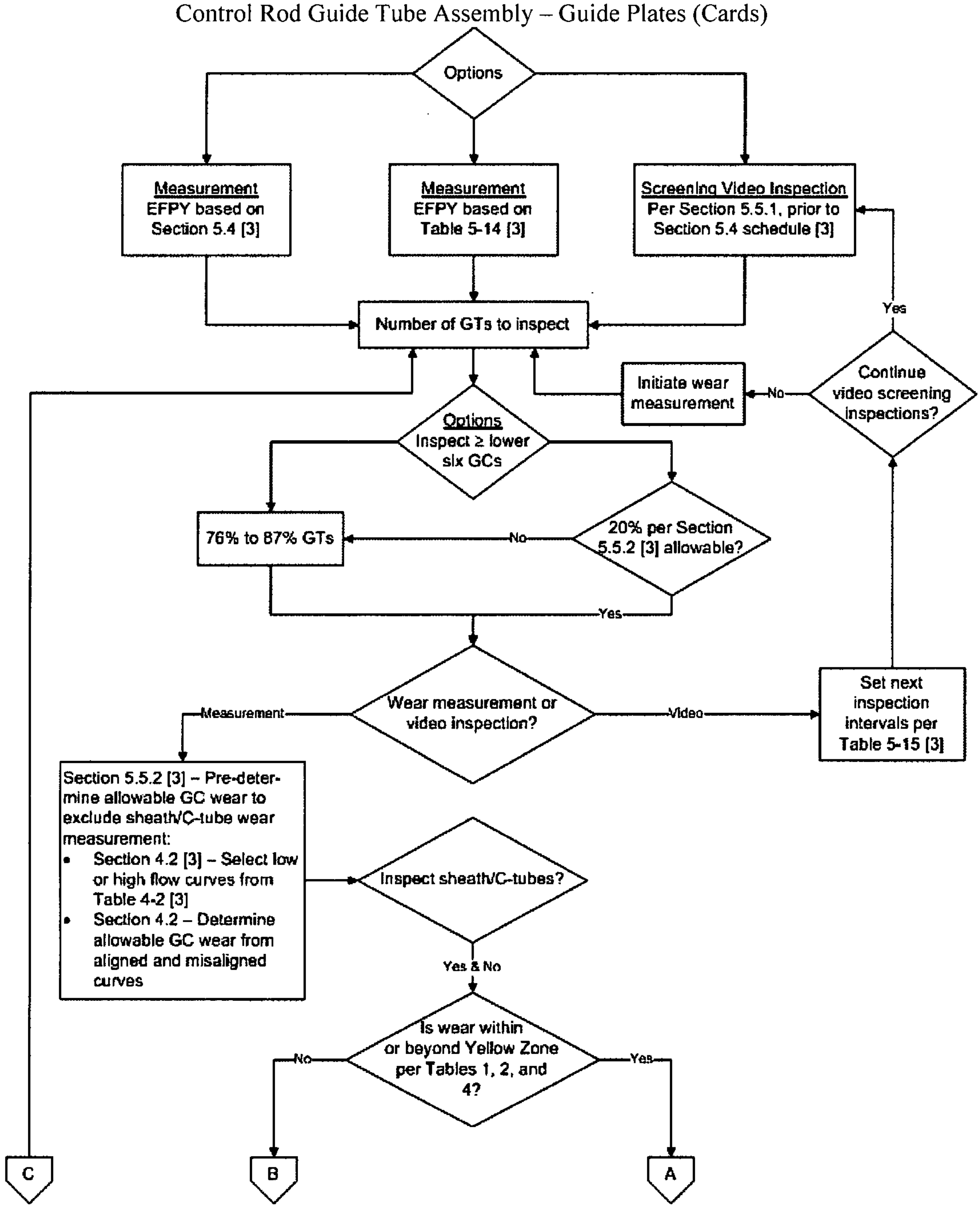
61502. If neutron noise monitoring is selected, it is recommended a neutron noise monitoring survey should be performed every 30 days for the first fuel cycle.

Approach: Plant-specific analysis. Could be adapted from a generic dynamic model.

Revised Table of Contents for Appendix F of WCAP-17096-NP

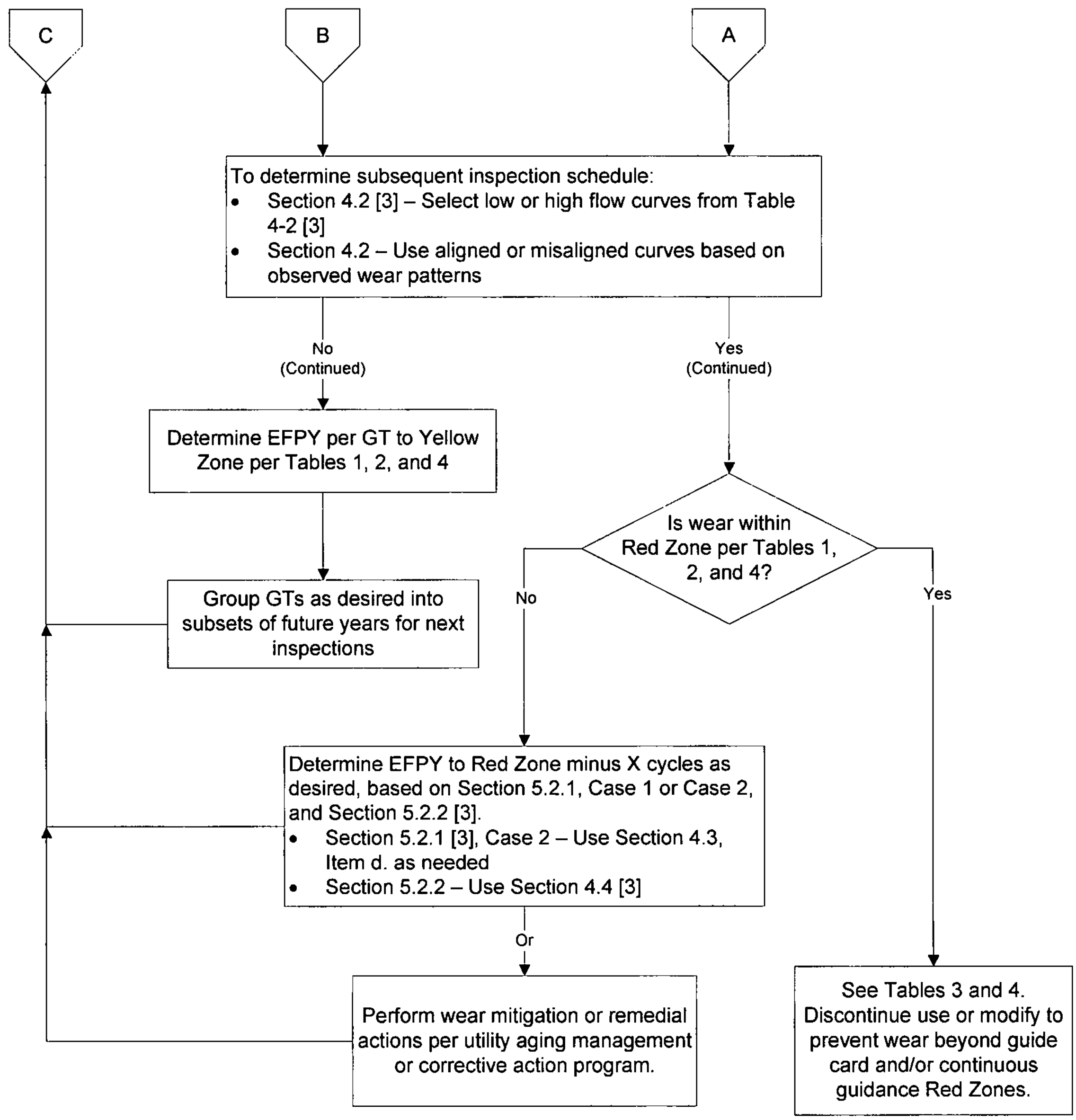
Westinghouse Primary and Expansion Components

W-ID: 1
Control Rod Guide Tube Assembly – Guide Plates (Cards)

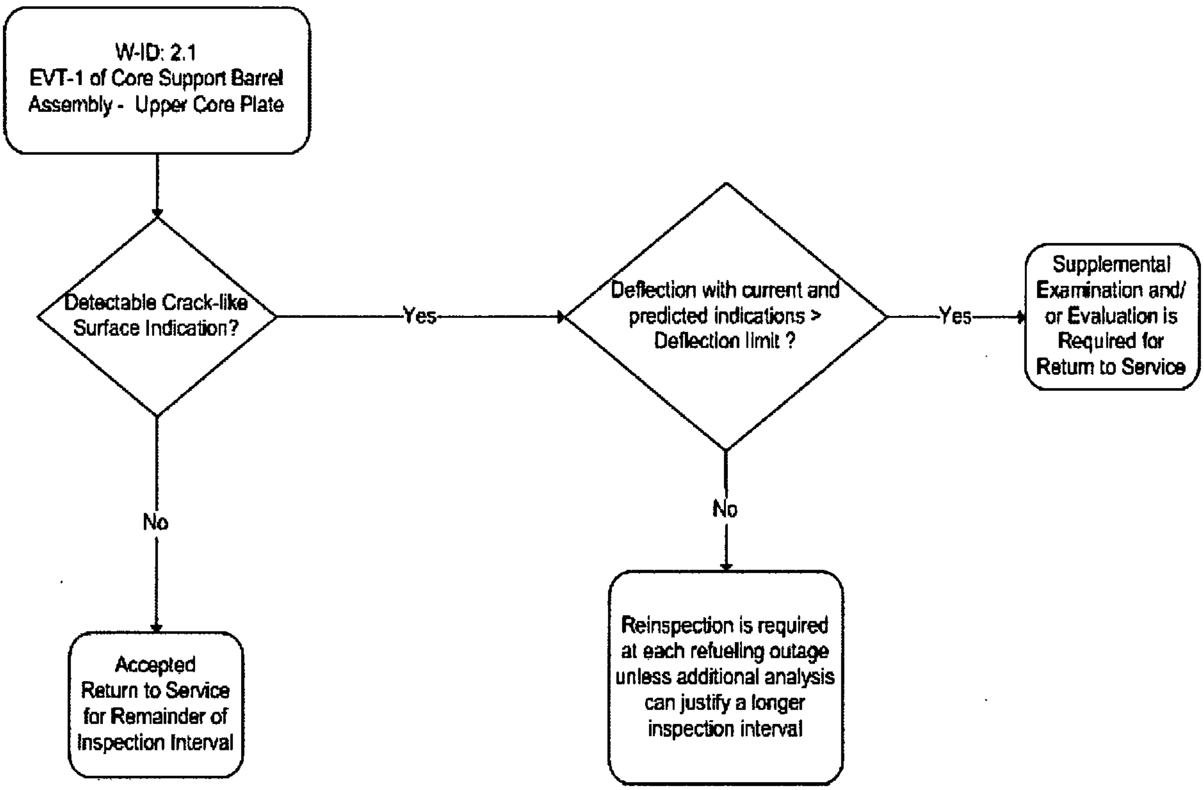


W-ID: 1

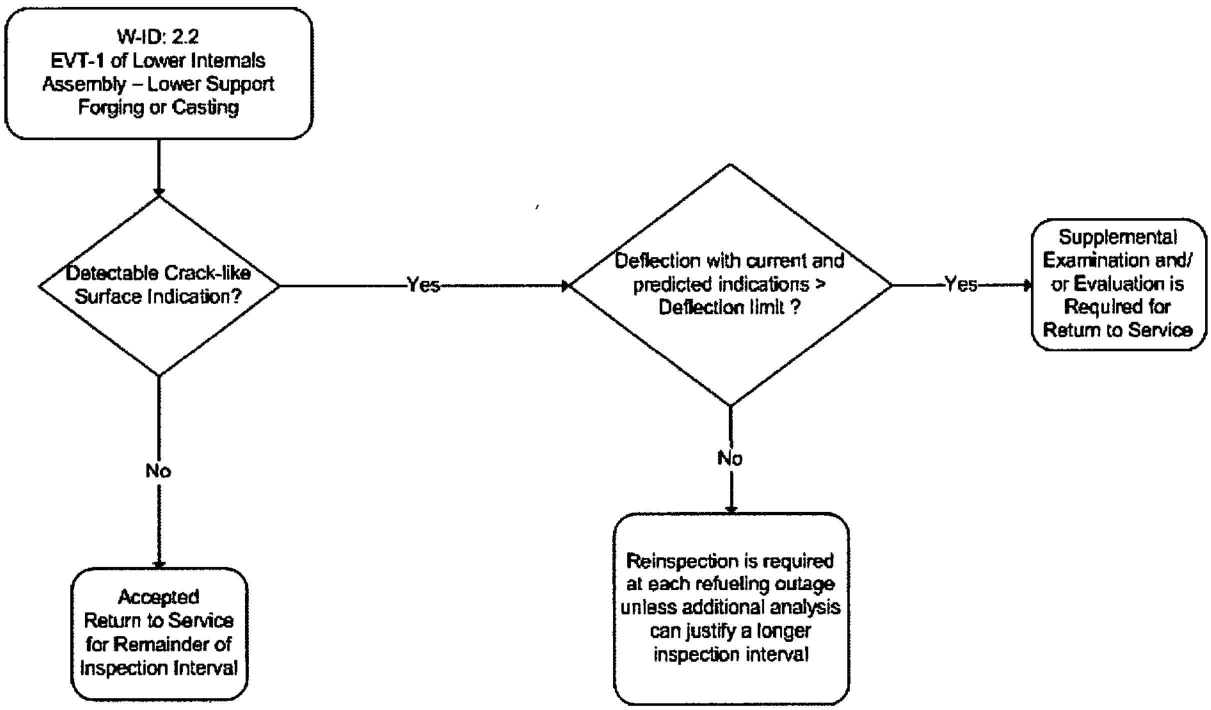
Control Rod Guide Tube Assembly – Guide Plates (Cards) (Cont.)



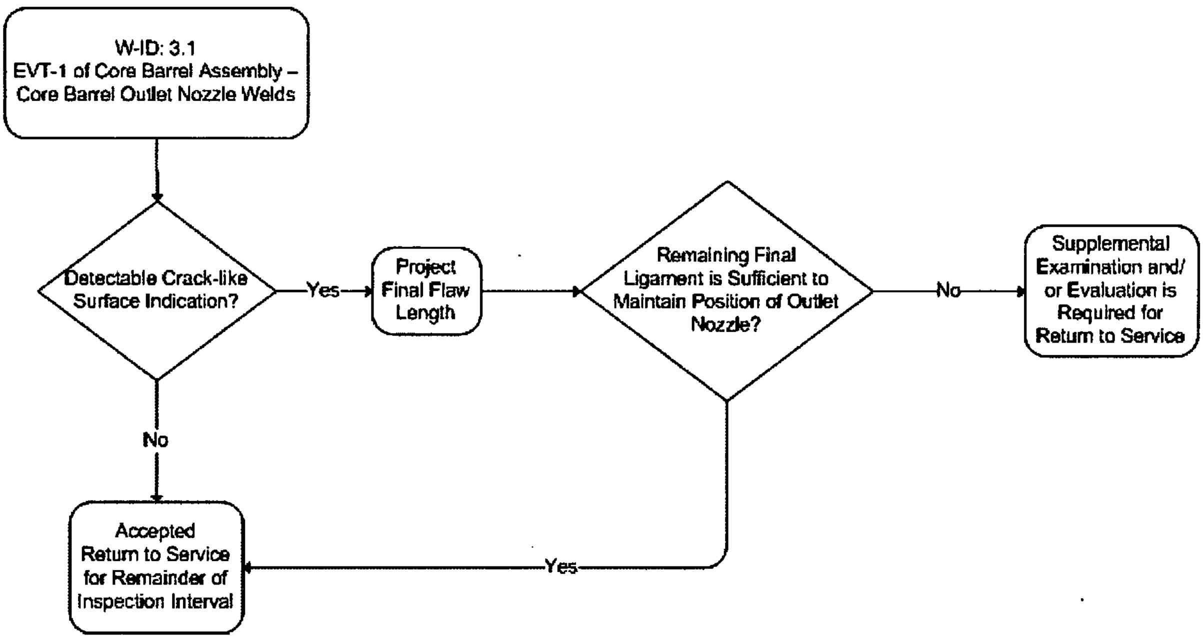
W-ID: 2.1
Upper Internals Assembly – Upper Core Plate



W-ID: 2.2
Lower Internals Assembly – Lower Support Forging or Casting



W-ID: 3.1
Core Barrel Assembly – Core Barrel Outlet Nozzle Welds



W-ID: 10
Thermal Shield Assembly – Thermal Shield Flexures