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MRP Materials Reliability Program **MRP 2019-023**

September 3, 2019

EPRI Docket No. 99902021

U.S. Nuclear Regulatory Commission
One White Flint North
Mail Stop: 0-12-D2
11555 Rockville Pike
Rockville, Maryland 20852-2738

Subject: Transmittal of MRP-227-A-Related Interim Inspection Guidance Regarding PWR Core Barrel

References:
1. Letter from Joseph Holonich (NRC) to Brian Burgos (EPRI), dated August 6, 2019 [ML19198A179]

In response to NRC's August 6, 2019 letter (Reference 1) requesting that EPRI provide a copy of industry-developed interim inspection guidance related to PWR core barrel welds, attached please find one copy of the EPRI letter MRP 2019-009, dated 7/17/2019, entitled "Interim Guidance Regarding MRP-227-A and MRP-227, Revision 1 PWR [Pressurized Water Reactor] Core Barrel and Core Support Barrel Inspection Requirements." As discussed during the May 21-22, 2019 NRC-industry materials exchange meeting, this guidance was developed by industry in response to recent inspection results and operating experience.

If you have any questions, please contact Brian Burgos at 724-610-8559, or Kyle Amberge at 704-595-2039.

Sincerely,

Mike Hoehn II, Ameren-Missouri
MRP Research Integration Committee Chair

Brian Burgos, Program Manager
EPRI-MRP

cc: MRP RIC Members
PMMP Members

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NRR

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MRP Materials Reliability Program MRP 2019-009

Date: July 17, 2019

To: PMMP Members
MRP Research Integration Committee Members

From: Mike Hoehn II, Ameren, MRP RIC Chairman
Brian Burgos, EPRI, MRP Program Manager

Subject: Transmittal of NEI-03-08 "Good Practice" Interim Guidance Regarding MRP-227-A and MRP-227, Revision 1 PWR Core Barrel and Core Support Barrel Inspection Requirements

During the spring 2018 MRP-227-A inspection of the core support barrel (CSB) welds at St. Lucie Unit 1, a Combustion Engineering (CE)-designed pressurized water reactor (PWR), visual indications of cracking were observed (Ref. EPRI letter MRP 2018-028[1]). These indications were located adjacent to the middle girth weld (MGW) and middle axial weld (MAW) of the CSB, in and near the high neutron fluence core beltline region. A supplemental volumetric inspection of the area confirmed that the indications were flaws with some depth and that none of the flaws had propagated through-wall. These inspection findings are consistent with the risk ranking categorizations documented in the reactor internals "heat maps" (MRP 2018-018[2]) and in MRP-191, Revision 2[3].

The indications were dispositioned by an engineering evaluation, and St. Lucie Unit 1 returned to power for another cycle of operation. Most of the flaws observed in the St. Lucie Unit 1 CSB were oriented perpendicular to the MAW, similar to so-called "off-axis" cracks observed at several boiling water reactor (BWR) plants in recent years. BWR off-axis flaws have been linked to potential causes including construction and field-fabrication issues or aging-related degradation (Ref. EPRI letter BWRVIP 2016-030[4] and EPRI technical report BWRVIP-302[5]). An apparent cause investigation has been performed by the utility. The apparent cause for the flaws in the St. Lucie Unit 1 CSB has not been confirmed. Follow up work will include confirmatory re-inspection to validate the crack growth rate assumptions.

Based on the operating experience at St. Lucie Unit 1, the following NEI 03-08 "Good Practice" interim guidance for MRP-227-A has been developed. A technical basis supporting this guidance is provided in

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[1] MRP 2018-028, "Notification of Recent PWR Core Barrel Operating Experience and Recommended Plant Actions," 8/9/2018.
[2] MRP 2018-018, "PWR Reactor Materials Degradation "Heat Maps" for the Westinghouse/Combustion Engineering Designs," 7/13/2018.
[3] *Materials Reliability Program: Screening, Categorization, and Ranking of Reactor Internals Components for Westinghouse and Combustion Engineering PWR Design (MRP-191, Revision 2)*. EPRI, Palo Alto, CA: 2018. 3002013220.
[4] BWRVIP 2016-030, "Core Shroud Off-Axis Cracking Interim Inspection & Flaw Evaluation Guidance," 3/4/2016.
[5] *BWRVIP-302: BWR Vessel and Internals Project, Examination of a Boat Sample Removed from the Core Shroud at Hatch Unit 1*. EPRI, Palo Alto, CA: 2016. 3002008370.

Attachment 1. A summary of the Westinghouse safety assessment[6] is provided in Attachment 2. Inspections performed to address this operating experience are to be conducted in accordance with MRP-228[7] and this interim guidance.

This guidance is effective at all Westinghouse-designed and CE-designed US PWR units as of **February 1, 2020**. Barrel axial weld inspections meeting the requirements of MRP-227 and MRP-228 performed by US PWR units prior to issuance of this interim guidance are considered acceptable for meeting the requirements herein. Note that as additional operating experience and other data are gathered, further guidance with revised requirements for barrel weld inspection may be appropriate. Utility owners should continue to monitor industry developments.

Interim Guidance - NEI 03-08 "Good Practice" Recommendations

The plants have been categorized into two groups for this interim guidance:

- Group 1: The CE-designed PWR units with CSB stress and geometry similar to St. Lucie Unit 1 are listed in Table 1.
- Group 2: The Westinghouse-designed and CE-designed plants that are not included in Group 1 (see Table 1).

Westinghouse and CE: Plants should perform EVT-1, eddy current, or ultrasonic examinations on the core barrel (CB) (Westinghouse) or CSB (CE). The inspections should be performed on a "best effort" basis in accordance with the requirements of MRP-228. The examinations should use existing inspection tooling, to the maximum extent practical, and per the following requirements:

a. Inspection coverage:
    i. Group 1: 100% of the accessible weld lengths from the barrel outer diameter for the MAW and the lower axial weld (LAW) (minimum coverage of 75% of the total weld length for each weld) and 3/4-inch of base metal on each side of the weld; see Table 2.
    ii. Group 2: Dependent on plant design and accessibility limitations; see Table 2.
b. Initial inspection timing: During the next refueling outage after the effective date of this interim guidance in which the barrel is planned to be removed for pre-planned inspection of the CSB MGW (CE plants) or CB lower girth weld (LGW) (Westinghouse plants) (girth welds in the core beltline) in accordance with MRP-227-A requirements. For plants operating beyond two refueling outages from the beginning of the license renewal period and that have completed the initial inspections of the Primary barrel welds, the initial axial weld inspection is to be coincident with the subsequent Primary girth weld examination. Barrel axial weld inspections meeting the requirements of MRP-227 and MRP-228 performed by US PWR units prior to issuance of this interim guidance are considered acceptable for meeting the requirements herein.
c. Re-inspection requirement: The re-inspection requirement for a weld with no relevant conditions will be addressed in a future revision to MRP-227. However, if one or more relevant conditions are identified, the subsequent examination should be determined in accordance with the acceptance criteria methodology in WCAP-17096-NP-A or a plant-

[6] PWR Owners Group report PWROG-17084-P, Revision 1, dated March 2019, "Core Barrel Girth and Flange Weld Aging Management Strategy - Probability and Consequences of Failures". (PWROG Proprietary)

[7] *Materials Reliability Program: Inspection Standard for Pressurized Water Reactor Internals–2018 Update (MRP-228, Rev. 3)*. EPRI, Palo Alto, CA: 2015. 3002010399.

specific equivalent. (Note that WCAP-17684-P, Revision 1 provides generic acceptance criteria for Westinghouse and CE plants)

d. Examination acceptance criteria: The specific relevant condition is a "detectable crack-like surface indication" in accordance with Section 5 of MRP-227-A, or plant-specific equivalent.
e. Evaluation requirements: Relevant conditions should be addressed per the "Implementation Requirements" of MRP-227-A, Section 7. WCAP-17096-NP-A provides approved methodologies for engineering evaluations to disposition examination results.
f. Reporting requirement: Within 6 months of completing the outage in which these examinations are implemented, the plant should report on the results, including extent of examination coverage, the details of any indications found, and the preliminary assessment of acceptability. This report should use the MRP-227 reporting template and may be integrated with the report for other MRP-227 inspections if performed in the same outage.

Notes for the NEI 03-08 "Good Practice" requirements for Group 1 and 2 plants:

1. A plant-specific assessment of access limitations and locations of these welds should be performed by the utility to assist in these inspections; for example, review of video recordings of prior visual inspections could provide useful information on weld locations.
2. Allowable inspection methods include enhanced visual (EVT-1), eddy current, or ultrasonic techniques in accordance with MRP-228; the visual (VT-3) method is not a recommended technique, because VT-3 is not considered an adequate method for detection of tight SCC flaws.
3. The inspection coverage requirements in Table 2 are also shown in a decision tree format in Figure 7 to graphically illustrate the relationship between the coverage requirements.

If there are any questions or concerns related to this interim guidance, please contact Tim Wells (205-992-7460, tgwells@southernco.com), Kyle Amberge (704-595-2039, kamberge@epri.com) or the undersigned.

Sincerely,

Mike Hoehn II
MRP RIC Chair
Ameren

Brian Burgos
MRP Program Manager
Electric Power Research Institute

Attachments:

Attachment 1: "Technical Basis Supporting PWR Core Barrel Weld Interim Guidance on MRP-227-A," Westinghouse Electric Co. letter LTM-AMLR-19-4, Rev.1, dated 4/2/2019

Attachment 2: "Core Barrel Weld Cracking Issue Safety Significance Evaluation," Westinghouse Electric Co. letter LTR-AMLR-19-45, dated 6/25/2019

Table 1: List of Affected CE/Westinghouse PWR Units

Group 1: CE-designed units with CSB stress level and geometry similar to St. Lucie Unit 1	Group 2: Other PWR units
Millstone Unit 2 Calvert Cliffs Unit 1 Calvert Cliffs Unit 2 St. Lucie Unit 1	All remaining CE and Westinghouse-designed plants (including international units)†

† This guidance is applicable for both domestic U.S. and international units. It is recognized that implementation requirements under NEI 03-08 may not be applicable to some international units. Therefore, for units for which NEI 03-08 implementation requirements are not applicable, this guidance is provided for information only.

Table 2: Inspection Coverage Guidance for Group 1 and Group 2 PWR Units

Row	Unit Design	Neutron Shielding	Axial Weld Location	Inspection Coverage for Axial Welds
1	Group 1 (CE)	No thermal shield or neutron panels	Axial weld locations are known and accessible	100% of the accessible weld lengths from the barrel outer diameter for the MAW and the LAW (minimum coverage of 75% of the total weld length for each weld) and 3/4-inch of base metal on each side of the weld (see Figure 1) †
2	Group 2 (CE or Westinghouse)	Thermal shield or no thermal shield	Axial weld locations are known and accessible	100% of the accessible weld lengths from the barrel outer diameter for the MAW and the LAW (minimum coverage of 75% of the total weld length for each weld) and 3/4-inch of base metal on each side of the weld (see Figure 1 and Figure 2) †
3			Axial weld locations are known but partially inaccessible	100% of the accessible weld lengths from the barrel outer diameter for the MAW and the LAW and 3/4-inch of base metal on each side of the weld **AND** a vertical zone on each side of the inaccessible portion of the barrel containing the known location of the axial weld; each zone should be a minimum of 3/4-inch wide and cover the full distance parallel to the inaccessible height of the weld (see Figure 3)†
4			Axial weld locations are unknown	100% of the accessible barrel outer diameter in two 6-inch minimum wide zones around the circumference of the barrel (see Figure 4): 1. One at an elevation approximately halfway between the upper girth weld (UGW) and the MGW (CE)/LGW (Westinghouse) 2. One at an elevation approximately halfway between the MGW (CE)/LGW (Westinghouse) and the lower flange weld (LFW) **OR** 100% of the accessible barrel outer diameter in at least six separate, 3/4-inch wide bands evenly spaced between the UGW and the MGW (CE)/LGW (Westinghouse) and at least six separate, 3/4-inch wide bands evenly spaced between the MGW (CE)/LGW (Westinghouse) and the LFW †

† If a relevant condition is found, the extent of condition must be determined as directed by the plant corrective action program.

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Table 2: Inspection Coverage Guidance for Group 1 and Group 2 PWR Units (continued)

Row	Unit Design	Neutron Shielding	Axial Weld Location	Inspection Coverage for Axial Welds
5	Group 2 (Westinghouse)	Neutron panels	Axial weld locations are known and not behind neutron panels	100% of the accessible weld lengths from the barrel outer diameter for the MAW and the LAW (minimum coverage of 75% of the total weld length for each weld) and 3/4-inch of base metal on each side of the weld (see Figure 2) †
6			Axial weld locations are known and located behind neutron panels	100% of the accessible weld lengths from the barrel outer diameter for the MAW and LAW (portion that is accessible above or below the neutron panel) and 3/4-inch of base metal on each side of the weld **AND** two 3/4-inch minimum wide zones of the barrel outer diameter adjacent to each neutron panel that covers the weld; including, at a minimum, both long, vertical edges of the panel up to the girth weld and either the top edge for MAW or the bottom edge for LAW (see Figure 5)†
7			Axial weld locations are unknown and not visible	Inspect 3/4-inch minimum wide zones on the barrel outer diameter adjacent to all four sides of all four of the neutron panels **AND** Inspect bands around the circumference of the barrel with a minimum coverage of 50% of the full circumference for each band, using one of the following options: 1. One 6-inch minimum wide band at an elevation approximately halfway between the UGW and the LGW and one 6-inch minimum wide band at an elevation approximately halfway between the LGW and the LFW (see Figure 6) **OR** 2. At least six separate, 3/4-inch wide bands evenly spaced between the UGW and LGW and at least six separate, 3/4-inch wide bands evenly spaced between the LGW and the LFW†

† If a relevant condition is found, the extent of condition must be determined as directed by the plant corrective action program.

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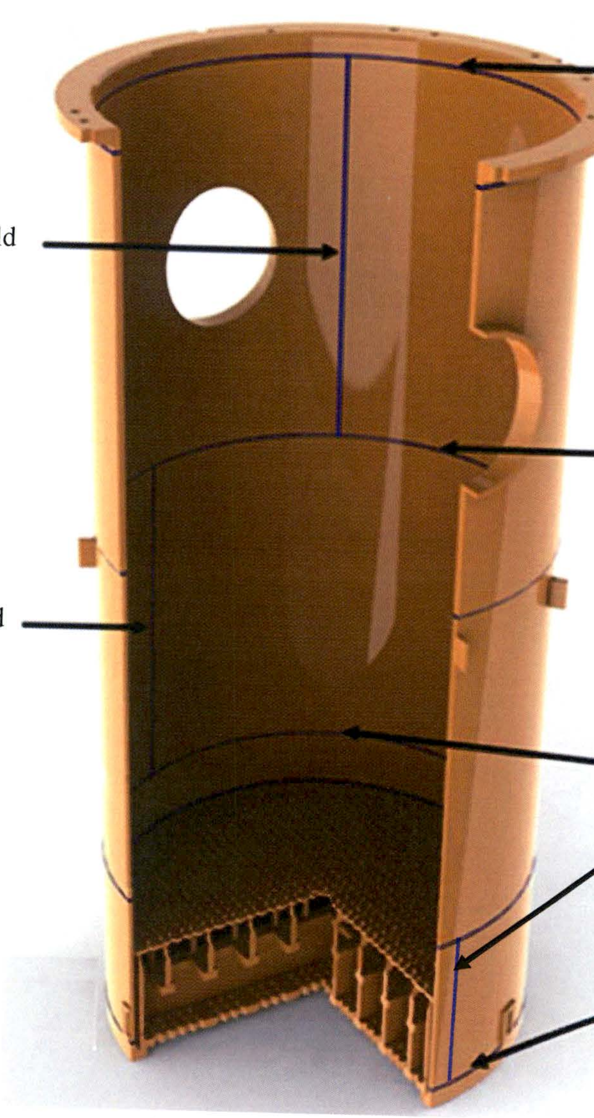

Figure 1: Example of CE Core Support Barrel Weld Identification

(Note that the core shroud assembly, which fully covers the CSB inner diameter in the core beltline region, is not shown)

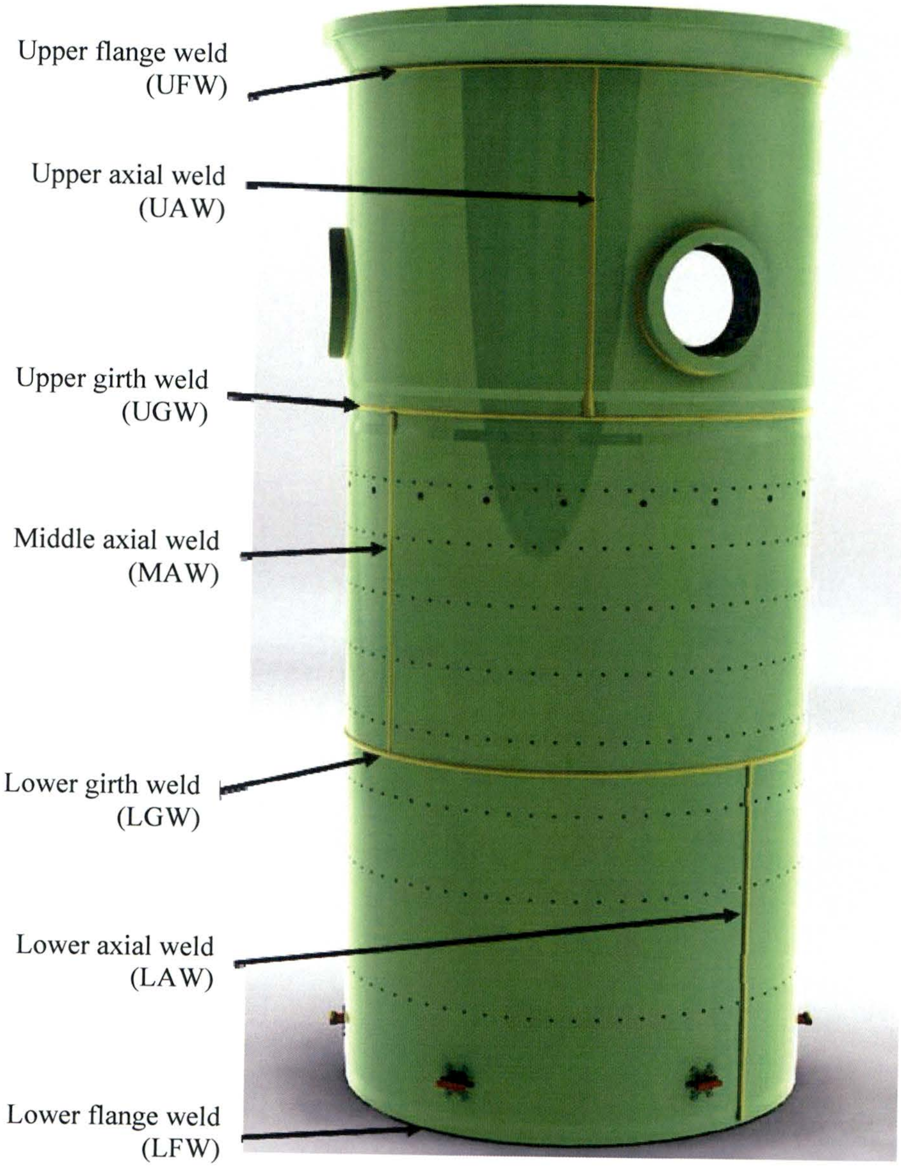

Figure 2: Example of Westinghouse Core Barrel Weld Identification

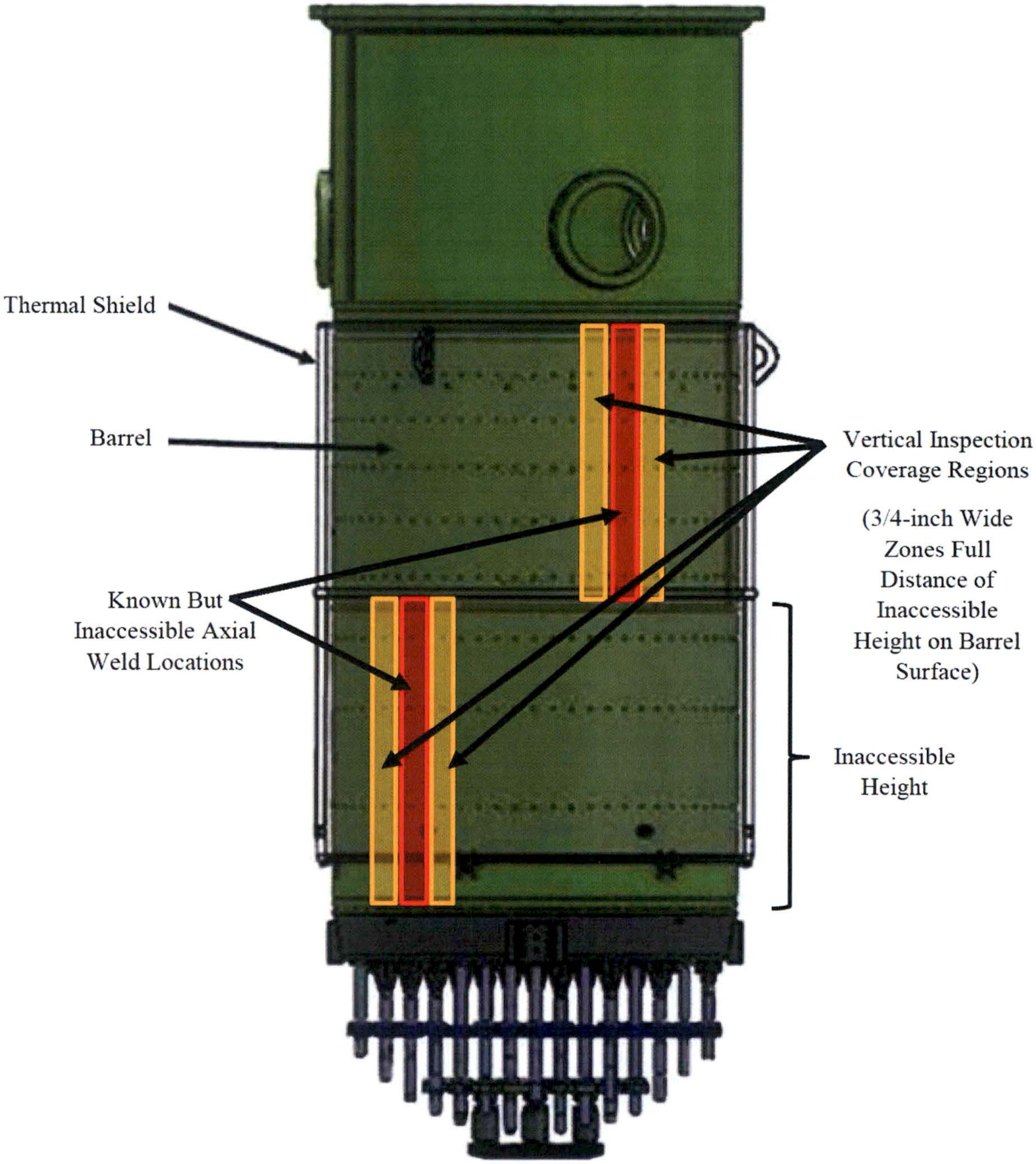

Figure 3: CE or Westinghouse Thermal Shield Inspection Option – Known Partially Inaccessible Axial Weld Locations

(Note that the figure illustrates an example of the Westinghouse thermal shield configuration)

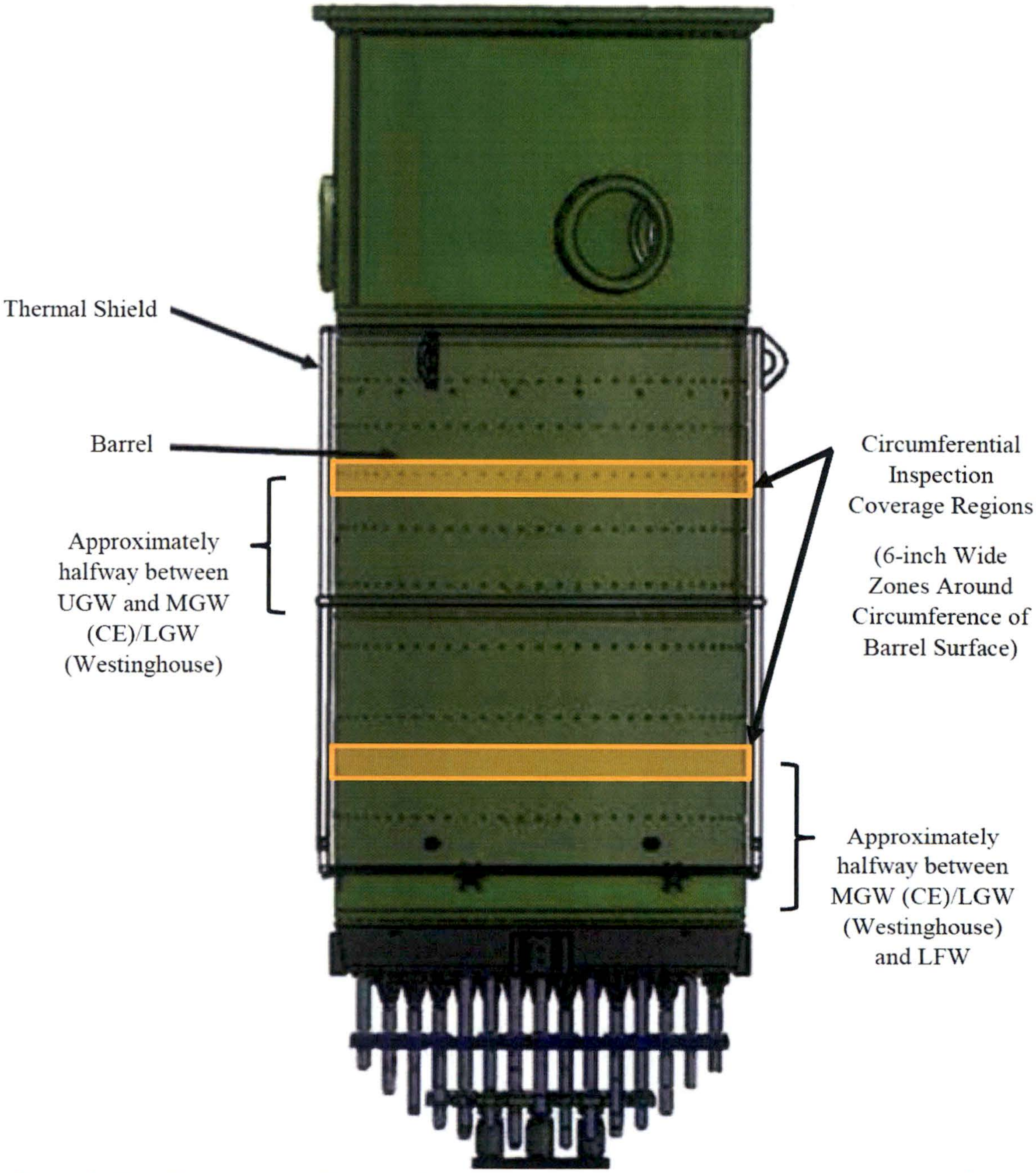

Figure 4: CE or Westinghouse Thermal Shield Inspection Option – Unknown Axial Weld Locations

(Note that the figure illustrates an example of the Westinghouse thermal shield configuration)

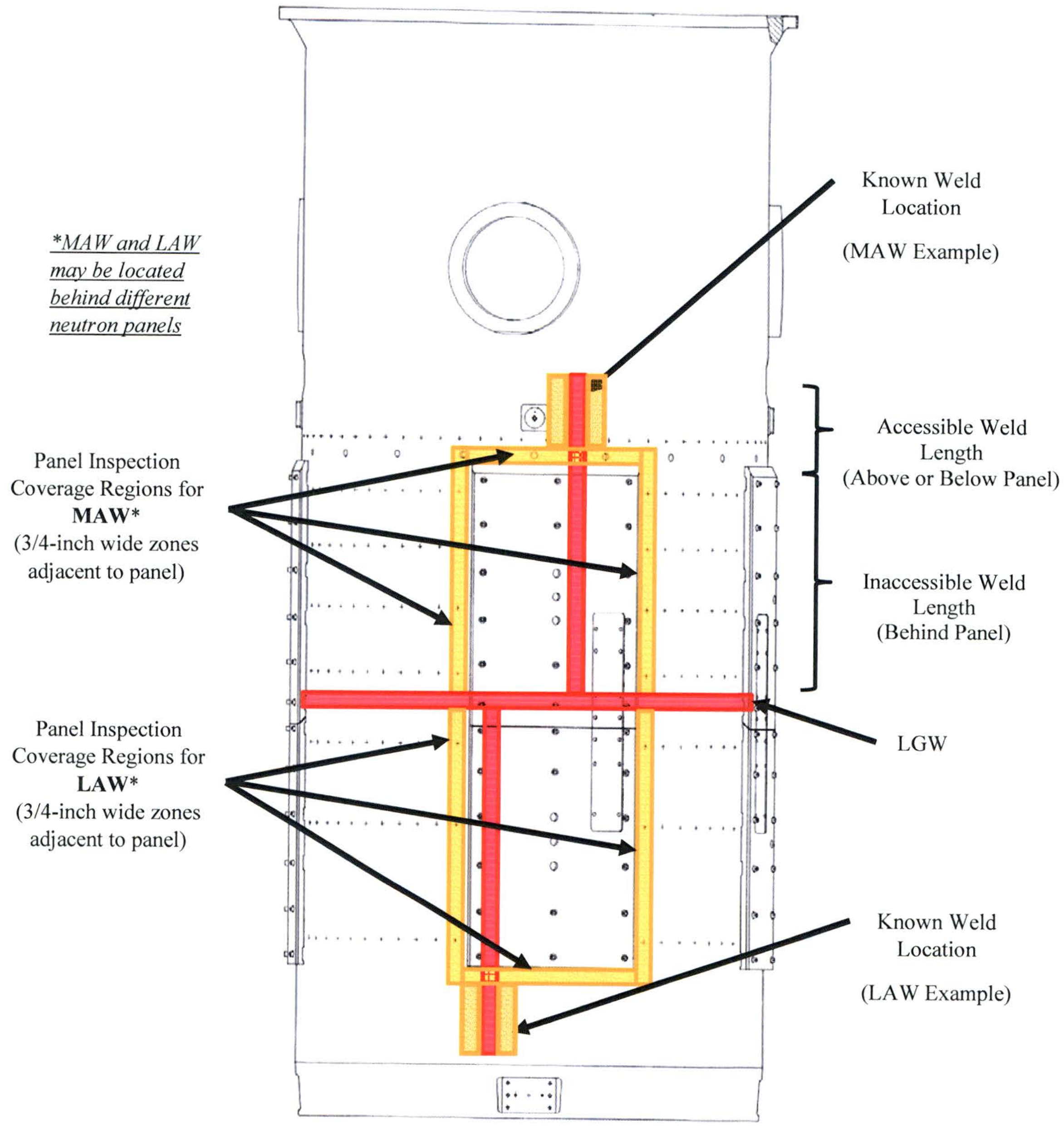

Figure 5: Example of Westinghouse Neutron Panel Inspection Option – Known Partially Inaccessible Axial Weld Locations

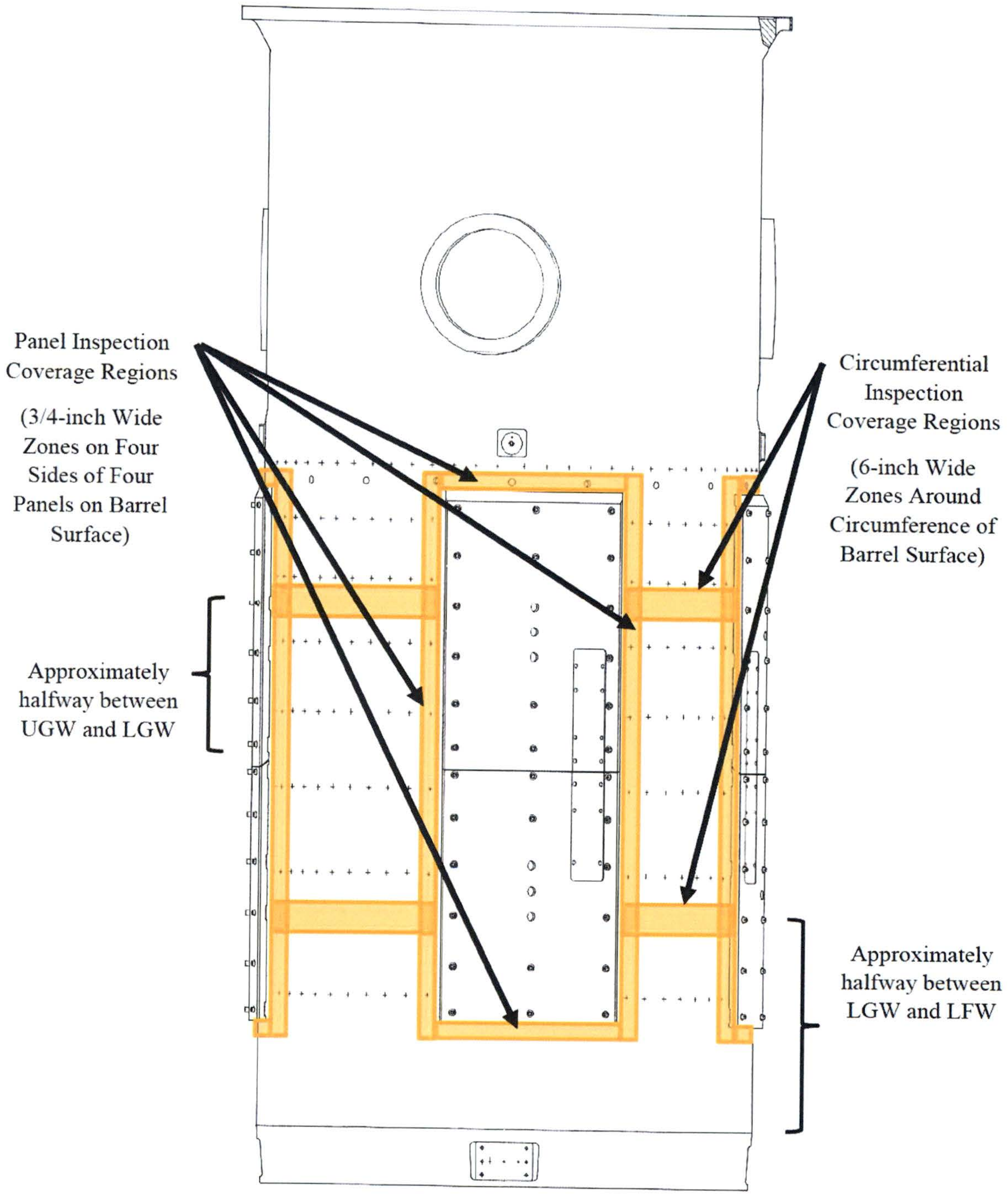

Figure 6: Example of Westinghouse Neutron Panel Inspection Option – Unknown Axial Weld Locations

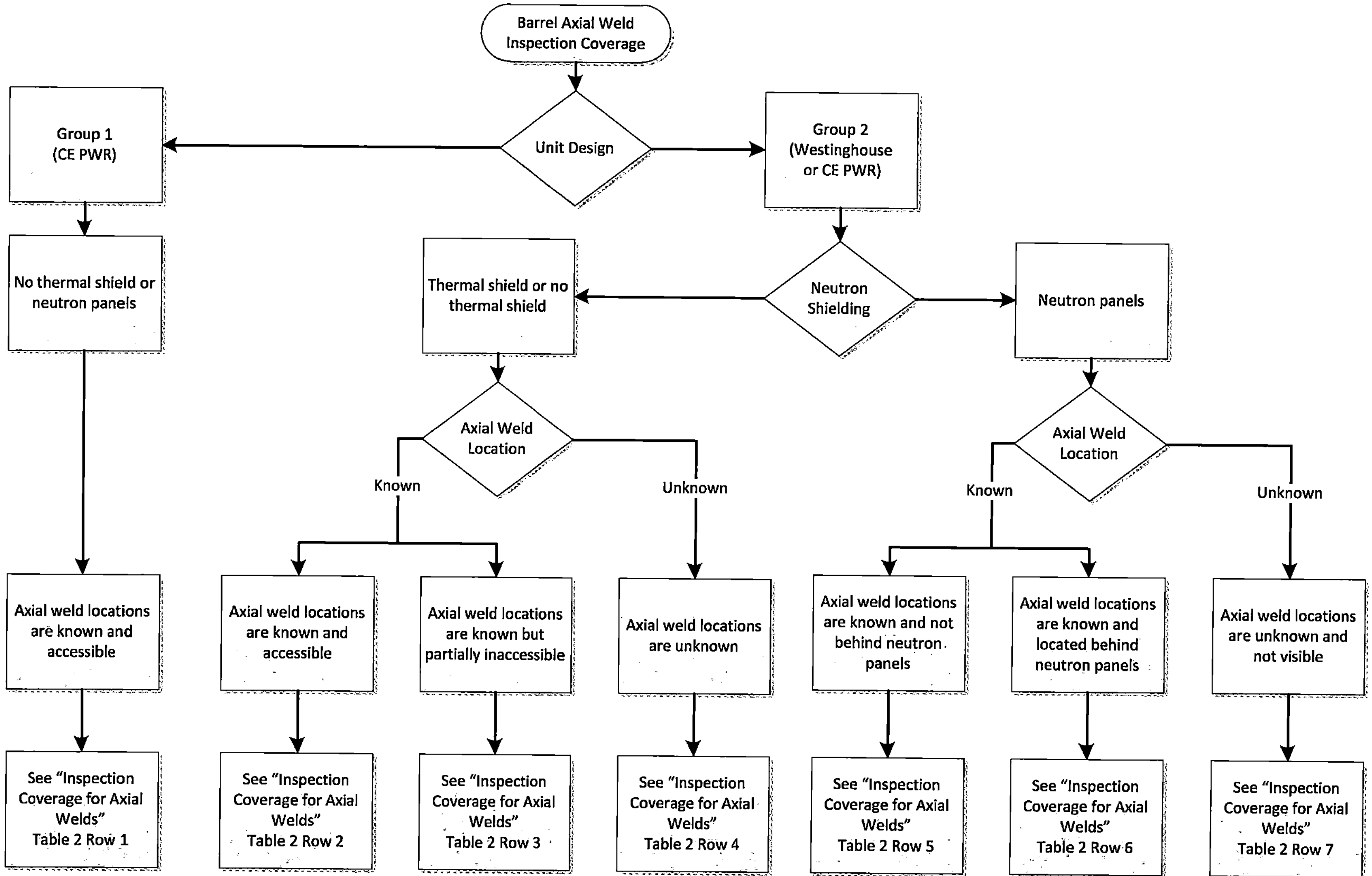

Figure 7: Barrel Axial Weld Inspection Coverage Decision Tree

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Technical Basis Supporting PWR Core Barrel Weld Interim Guidance on MRP-227-A

Prepared for EPRI by
Brad A. Minman
Joshua K. McKinley
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Melanie R. Fici
Westinghouse Electric Company

Ref: Westinghouse Electric Co. letter LTR-AMLR-19-4, Rev. 2, dated 6/19/2019

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Westinghouse

To: Keith E. Newmyer Date: June 19, 2019

cc:

From: Aging Management and License Renewal Your ref:

Phone: 412-374-3391 Our ref: LTR-AMLR-19-4 Rev. 2

Subject: Technical Basis Supporting Core Barrel Weld Interim Guidance

References:

1. EPRI Letter, MRP 2018-028, "Notification of Recent PWR Core Barrel Operating Experience and Recommended Plant Actions," August 9, 2018.

In response to core support barrel assembly indications identified at St. Lucie Unit 1 during the spring 2018 outage, the Electric Power Research Institute (EPRI) Materials Reliability Program (MRP) and the Pressurized Water Reactor Owners Group (PWROG) established the Core Barrel Focus Group to evaluate the operating experience (OE). The OE was communicated to the pressurized water reactor (PWR) fleet in MRP 2018-028 [1]. One of the goals of the focus group was to develop fleet wide interim guidance to address the OE.

This letter provides a technical basis supporting interim guidance for MRP-227 inspections of Westinghouse core barrel assembly and Combustion Engineering core support barrel assembly welds.

Revision 2 of this letter incorporates changes based on additional comments received from members of the Core Barrel Focus Group.

For questions or additional information, please contact the undersigned.

Authored by: ELECTRONICALLY APPROVED*
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Technical Basis Supporting Barrel Weld Interim Guidance

1 BACKGROUND

During the spring 2018 outage at St. Lucie Unit 1 (a Combustion Engineering (CE)-designed plant), enhanced visual inspections of the core support barrel (CSB) assembly girth welds were performed according to the requirements of MRP-227-A [1] and MRP-228 [2]. The inspection identified crack-like surface indications at the CSB assembly welds [3]:

- One vertically oriented indication at the middle girth weld
- Forty-five indications adjacent to the middle axial weld

The majority of the middle axial weld indications were oriented perpendicular to the weld [28] – circumferential to the barrel. A supplemental volumetric examination to characterize the indications was subsequently performed. The examination confirmed that the visually identified indications did not extend through the CSB thickness.

The potential for cracking of CE-designed CSBs and Westinghouse-designed core barrels (CB) was acknowledged in the MRP-227-A inspection and evaluation guidelines; however, the observed condition at St. Lucie Unit 1 was inconsistent with expectations for number, location, and orientation of the indications. The observed condition was inconsistent with expectations due to:

1) the number of flaws identified whereas prior to the operating experience (OE), the likelihood of failure (degradation) was expected to be low,
2) the presence of flaws at the middle axial weld when it was expected that girth welds would be the primary indicator of barrel cracking, and
3) the cracks were oriented perpendicular to the weld rather than parallel to the weld as would be expected for the aging mechanism identified in MRP-227-A for the barrel welds.

In response to the CSB assembly indications, the Electric Power Research Institute (EPRI) Materials Reliability Program (MRP) and the Pressurized Water Reactor Owners Group (PWROG) established the Core Barrel Focus Group to evaluate the OE. The OE was communicated to the pressurized water reactor (PWR) fleet in MRP 2018-028 [4]. One of the goals of the focus group was to develop fleet-wide interim guidance to address the potential for similar degradation in other plants and plant designs.

The PWROG developed a safety assessment for a hypothetical, beyond design basis, event in which complete or partial circumferential separation of the barrel occurs during normal and upset plant conditions or because of a faulted event. The safety assessment, published in PWROG-17084-P [5], concluded that inclusion of faulted conditions in weld cracking criteria to address barrel separation is a commercial asset management issue. This conclusion was because separation of the barrel during a faulted event was considered in the design of the reactor (e.g., automatic rod insertion and the secondary core support or core stop lugs). It was also concluded that separation of the barrel during normal and upset operating conditions is outside the plant design basis. This was a result of detectability concerns and uncertainties surrounding the condition of the internals after such an event. This conclusion for normal and upset conditions was consistent with the safety significance ranking developed in the basis of MRP-227.

While the postulated complete separation of the barrel during normal or upset operating conditions is outside of the design basis of the reactor internals, OE and flaw growth rates predicted from BWR experience and laboratory testing indicate that complete separation is expected to be highly unlikely. This supports the aging management approach for the barrel, which is based on monitoring for the aging mechanisms that could lead to a safety concern. This approach is consistent with the safety significance ranking used in the basis of MRP-227 and is intended to identify degradation prior to becoming a safety concern.

The OE at St. Lucie Unit 1 warranted a review for potential impacts to the MRP-227 guidance for barrel welds. The purpose of this report is to provide a technical basis for MRP-227 interim guidance on the Westinghouse CB assembly and CE CSB assembly axial welds in the core beltline region. Interim guidance is currently under development by the Core Barrel Focus Group and will require a technical basis for the inspection type, coverage, and initial inspection timing. Re-inspection timing and expansion requirements will be addressed in a future revision to MRP-227. This report examines inspection requirements and provides a technical basis supporting interim guidance.

Revision 2 incorporates changes based on additional comments received from members of the Core Barrel Focus Group.

2 BARREL DESIGN

The barrel is a large thick-walled cylinder that supports the core and other reactor internals components. The barrel base materials are Type 304 austenitic stainless steel. It consists of plates rolled and welded into three cylindrical shell sections. The three sections are the upper, middle, and lower barrels. The shell sections are welded at their ends and to the flanges at either end to form the complete barrel. The weld locations in the Westinghouse CB assembly and the CE CSB assembly are illustrated in Figure 1 and Figure 2, respectively. These locations of the axial welds on these figures are only schematic and may vary from plant to plant. In some cases, two separate axial welds were used on a cylindrical shell section.

The barrel supports the lower internals assembly and the core plate, upon which the fuel assemblies rest. The upper end of the barrel, at the barrel flange, is suspended from a ledge on the reactor vessel while the lower end of the barrel is restrained by the radial support system.

The primary function of the barrel is to support the core. Lateral support is provided for the upper and lower core plate locations. The barrel provides a passageway for the reactor coolant flow, directing flow into the core and after leaving the core directing the flow to the outlet nozzles.

There are design and fabrication differences between Westinghouse and CE barrels. Differences include diameter, thickness, length, neutron shielding attachments, and fabrication techniques. A thermal shield or neutron panels attached externally to the barrel provide neutron shielding of the reactor vessel. Some CE reactor internals were initially designed with a thermal shield while others never had a thermal shield installed. Westinghouse-designed reactor internals use a thermal shield or four neutron panels. The thermal shield provides shielding for 360° of the vessel while the neutron panels provide shielding at strategically located positions around the vessel.

The barrel in a PWR is analogous to the boiling water reactor (BWR) core shroud. There are high-level similarities between the PWR barrels and BWR shrouds. The similarities include design, function, materials, and stress levels. A comparison of BWR core shroud and PWR barrel designs and experience with cracking in austenitic stainless steel is provided in [6].

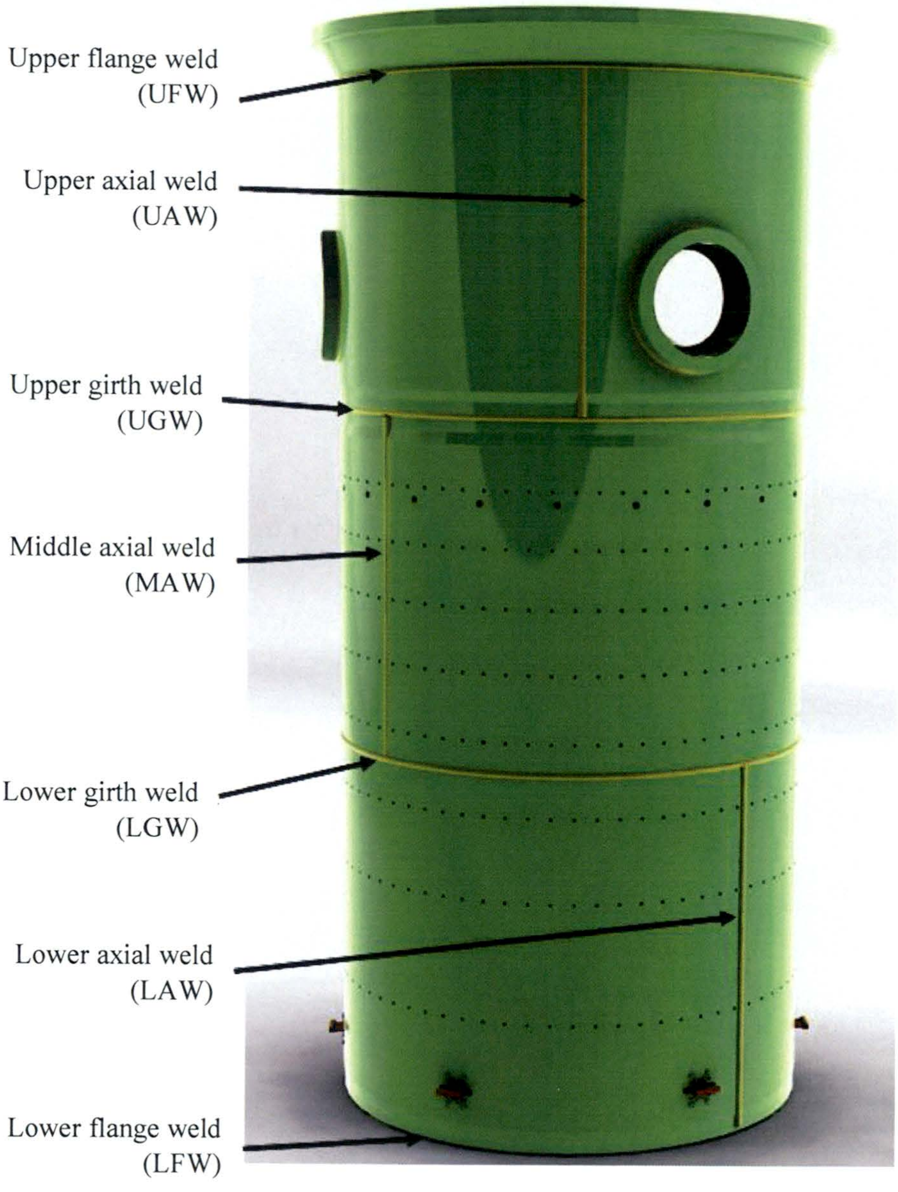

Figure 1: Westinghouse CB Assembly Welds

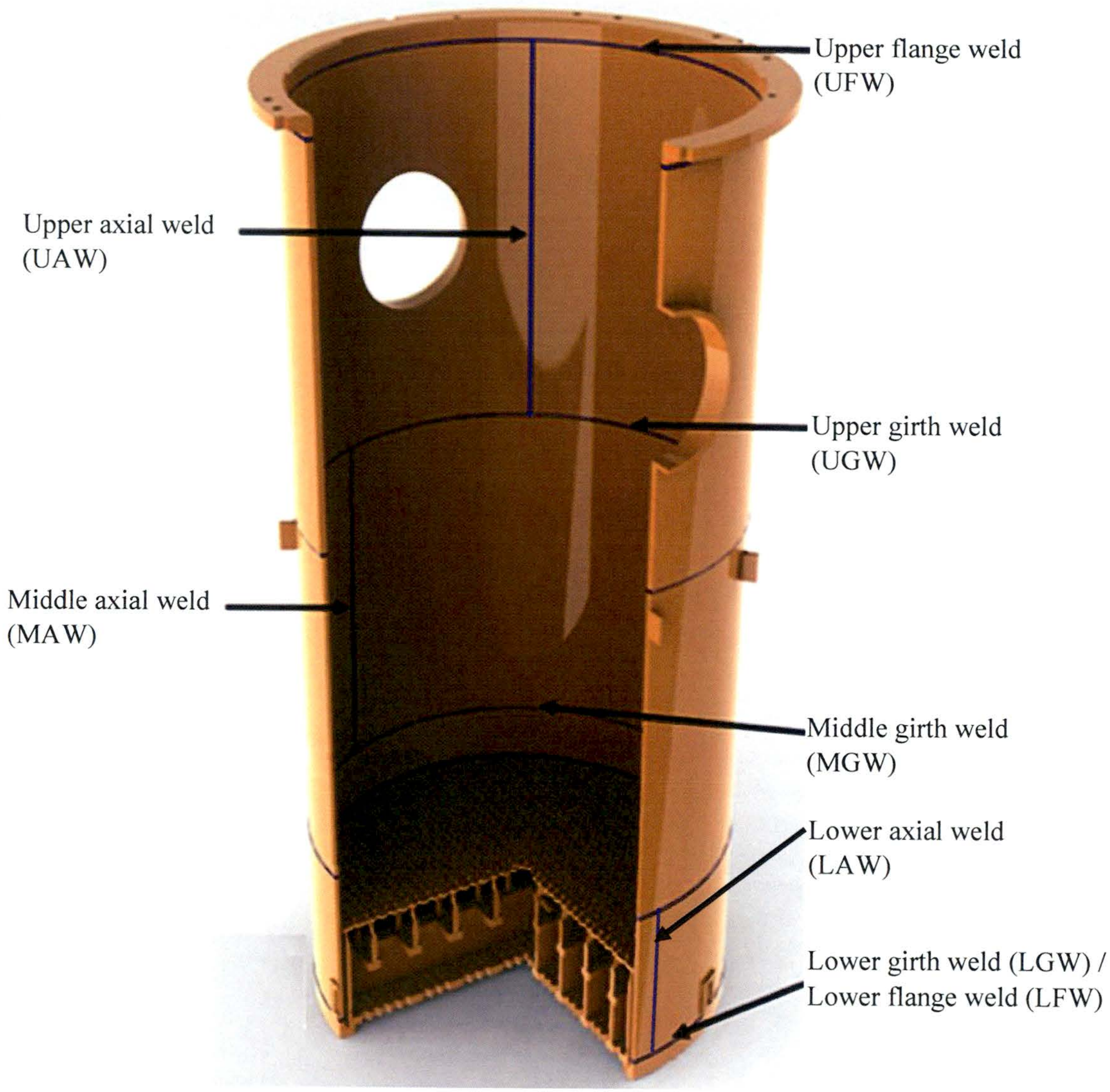

Figure 2: CE CSB Assembly Welds

3 INSPECTION TYPE

The MRP-227-A [1] inspection and evaluation guidelines specify an enhanced visual (EVT-1) examination for PWR CSBs (CE) and CBs (Westinghouse). These inspections are to be conducted in accordance with the requirements of the MRP-228 inspection standard [2]. For many years, boiling water reactors (BWRs) have experienced degradation similar to the CE CSB OE in the analogous BWR component: core shrouds [6, 7, 8]. Inspections of BWR core shrouds have been conducted using EVT-1, but eddy current testing (ET) and ultrasonic testing (UT) have also been used. These three inspection methods are considered in this section for use in monitoring for cracking degradation in PWR barrels.

3.1 EVT-1 INSPECTION FOR BARREL CRACKING

An EVT-1 inspection according to the MRP-228 inspection standard [2] identified CSB weld degradation at St. Lucie Unit 1 during the spring 2018 outage. Since 2011, nineteen PWR units have performed MRP-227-A EVT-1 examinations of the Westinghouse and CE barrel flange and girth welds. For all units except St. Lucie Unit 1, the examinations did not identify indications in these barrel welds. At St. Lucie Unit 1, an examination of the middle girth weld and the three axial welds resulted in the identification of multiple indications in the middle axial weld and one indication in the girth weld [3].

The EVT-1 visual examination has a history of use in BWR applications [19]. Visual examinations specified for BWR components have inspection requirements designed to ensure quality examinations and to minimize uncertainty. The inspection requirements of MRP-227 were modeled after those developed by the BWR Vessel and Internals Project (BWRVIP[1]) in order to achieve the same goals. BWRVIP-03 [7] provides specific requirements and recommendations for underwater visual examinations of reactor pressure vessel internals and components in BWRs. Specifically, BWRVIP-03 [7] credits EVT-1 as the visual examination method. Requirements for personnel training and experience, equipment, inspection, evaluation, and documentation are provided. These requirements are similar to the requirements specified in the MRP-228 inspection standards for the EVT-1 visual examination method. For example, in MRP-228 [2], the demonstrations for system performance require resolution cards that include, at a minimum, 0.044-inch characters without ascenders or descenders, while BWRVIP-03 [7] specifies the 0.044-inch character requirement only. This is consistent with ASME Code Section XI VT-1 requirements [10]. Furthermore, requirements on camera angle and camera speed and overlap are identical. Based on the BWR experience, EVT-1 continues to be an accepted method for detection of stress corrosion cracking (SCC).

For a remote EVT-1 examination, MRP-228 specifically 1) provides generic requirements for equipment and training of personnel, 2) requires a surface condition assessment, and 3) imposes limitations on camera angle and scan speed. These requirements ensure the quality of the inspection and help to minimize the flaw detection and sizing uncertainty. For purposes of demonstrating EVT-1 examination system performance, the resolution capabilities of the examination equipment and technique must be established using a resolution card under environmental conditions representative of the examination area. These resolution checks are performed prior to and after completion of the examination or whenever an

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[1] BWRVIP is an industry project consisting of domestic and international BWR-owning utilities chartered to support a program addressing the problems of reactor internals, internal attachments, vessel, welds, and vessel nozzles.

essential variable changes. According to MRP-228 [2], the process must be capable of resolving "lowercase characters without ascenders or descenders (for example, a, c, e, o), with character heights no greater than 0.044-inch at the maximum examination distance." It is noted that alternative resolution standards may be used if system performance is equal to or higher than that demonstrated by the 0.044-inch characters described in MRP-228.

Any remote visual examination system or technique for underwater visual examinations has limitations that must be considered when assessing the adequacy of the system to detect the conditions that may affect the structural integrity of reactor internals components. Equipment resolution, light levels, lighting angles, surface conditions, magnification, contrast between flaw and component, time spent examining, and human factors all influence reliability of the visual examination technique [9]. The MRP-228 inspection standard provides generic standards for the EVT-1 technique to control the quality of the examination and minimize uncertainty with the examination itself.

The barrel weld inspection OE described above has generally been positive. The OE with confirmed cracking demonstrates that the EVT-1 examination can acceptably detect cracking consistent with the aging mechanisms of concern when performed under the guidance of MRP-227-A and in accordance with the requirements of MRP-228. Regarding the OE, a supplemental volumetric examination was performed to characterize the flaws. Although there were variations identified between the visual and volumetric examination data, the EVT-1 examination provided a strong indication of an apparent aging mechanism.

Reference [11] documents the results of a study on the performance of currently used remote visual examination procedures for the detection of surface flaws. Information in [11] provides additional support to the basis for continued use of EVT-1 as a reliable method to detect cracking in PWR barrels. The round robin testing discussed in [11] focused on remote visual examinations (EVT-1) of simulated geometry features and surface conditions that may be found on reactor components.

The ability to reliably detect a crack can be attributed to two important flaw characteristics, crack opening dimension (COD) and crack length. Results in [11] indicated that cracks with a COD of 27 μm had an 80% probability of detection (POD). When considering statistical uncertainty, the POD corresponding to a COD of 27 μm decreases to approximately 75% based on the lower 95% confidence limit (see Figure 7-23 of [11]). These results were inclusive of all simulated surface features in the testing, which included weld toes, weld ripples, weld crowns, and tooling and grinding marks. The POD for flaws on flat plates with no surface features is expected to be higher due to negative impact of nearby surface features on detectability. As an example, the detection rate for flaws located in regions free from surface features, i.e., the heat-affected zone, was 20 to 60% higher than the rate with surface features, see Figure 7-13 of [11].

For crack length, a value of 30 mm was associated with an 80% POD. When considering statistical uncertainty, the POD corresponding to a crack length of 30 mm decreases to approximately 75% based on the lower 95% confidence limit (see Figure 7-24 of [11]).

COD is not a measure of the structural significance of a flaw and is not considered in flaw acceptance criteria calculations. However, COD does have a significant influence on detectability. Per Figure 7-10 of [11], below approximately 20 μm COD, detection rates were less than 55% and as low as 33% and per [11], "many cracks with a COD of around 15 to 20 μm were not detected regardless of length." COD greater than or equal to 25 μm had detection rates above 85% per Figure 7-11 of [11].

On the other hand, flaw length (and flaw depth) does influence the stress in the remaining cross-section and flaw length is used in flaw calculations. Figure 7-24 in [11] indicates that POD decreases to 60% for crack lengths as small as approximately 6 mm. Detection rates were 58% to 67% for flaw lengths between

6 mm and 15 mm, see Figure 7-12 of [11]. Considering all flaw lengths in the study, the POD was comparatively high (greater than approximately 60% and approached 90% with increasing flaw length).

The overall conclusion of [11] was that the current remote visual examination methods for vessel internals inspections are capable of detecting all but the smallest of flaws. A notable conclusion of [11] is that COD had a stronger effect on crack detection than crack length. This was not unexpected because the COD could have exceeded the resolution capability of the examination systems.

Generic flaw acceptance criteria for welds in CE and Westinghouse designed barrels were developed in WCAP-17684-P [12] in accordance with MRP-227-A [1]. The methodology used in WCAP-17684-P was based on a previous revision of the evaluation methodologies (WCAP-17096-NP-A [13]) credited in MRP-227. The purpose of WCAP-17684-P [12] was to provide direction for disposition of plant-specific inspection findings and provide a basis for plant operation during the period of monitoring and assessment. For Westinghouse CB welds in high fluence regions (LGW, MAW, LAW), conservative calculations for allowable flaw sizes indicated that the limiting allowable flaw size was approximately 0.25 inch in length per [12]. Similarly, for CE CSB welds (MGW, MAW, LAW), the limiting allowable flaw size was approximately 0.50 inch in length. These allowable sizes correspond to the single flaw "18-month allowable length with margin" value for the limiting faulted condition stress state as reported in [12]. Per [11], the smallest flaws, approximately 6mm (~0.24 inch) in length, had a POD of approximately 60%. The POD for a flaw approximately 0.25 inch in length is expected to be marginally higher than 60%. The POD for a flaw approximately 0.50 inch in length would be approximately 65%. As shown in Figure 7-24 of the round robin test report [11], a POD of 80% was reached for a flaw approximately 30 mm (1.18 inch) in length.

The statistics from the round robin study show that there is a substantial but not guaranteed probability for detecting flaws exceeding the smallest acceptable flaws in the generic acceptance criteria. These acceptable flaw sizes were conservatively calculated in WCAP-17684-P [12] using the highest stresses and neutron fluence levels generic to all of the similar plants as well as a conservative flaw depth assumption (through wall). Plant-specific evaluations are expected to increase the allowable crack lengths by an order of magnitude. For the only current MRP-227 OE with barrel cracking, it is almost certain that a 60% POD would have resulted in the inspection detecting many of the large number of individual flaws observed. Detected flaws with crack lengths less than the "18-month allowable length with margin" value would not prevent return to service in the outage in which the flaw was detected. If an aging mechanism is active, such that an undetected flaw could actively be growing, it could be expected that the undetected flaw may grow to a length such that it would be identified in a subsequent inspection. Then, at that time, it is expected that the aging management strategies of MRP-227 would go in effect. If a flaw is too small to be detected and it is not actively growing, then the undetected flaw would be of no concern based on WCAP-17684-P [12] and the round robin study [11].

The safety assessment in PWROG-17084-P [5] evaluated a postulated, beyond design basis, event in which complete barrel separation occurs based on a circumferentially oriented flaw in the barrel. PWROG-17084-P concluded that there is no safety-related reason to consider faulted conditions in the development of acceptance criteria for cracking of barrel welds and that inclusion of barrel weld cracking based on faulted conditions in the development of acceptance criteria strictly addresses commercial asset management concerns. Considering the conservatisms in the calculated flaws in WCAP-17684-P [12], as well as the conclusions of PWROG-17084-P [5], it is concluded that the limiting faulted condition based acceptable flaws from WCAP-17684-P [12] relative to the moderately expected POD are not significant reasons to discredit EVT-1 as an acceptable method for examination for barrel welds.

Due to uncertainties in detecting barrel separation, PWROG-17084-P [5] further concluded that separation during normal or upset operating conditions and subsequent operation in this condition would be outside of the plant design basis. Barrel stresses for normal and upset operating conditions are lower than the stresses for faulted conditions. As a result, the limiting acceptable flaw length is expected to be longer for normal and upset operating conditions (comparable in length to those flaws with a high POD in [11] - 80% POD for a flaw approximately 1.18 inch in length). Since longer flaws have a higher POD for visual examination techniques it is expected that EVT-1 would detect the flaw conditions leading to the safety concerns evaluated in [5] with a high probability.

Based on the usage history of EVT-1 examination in BWR applications, the requirements in MRP-228 that ensure quality visual examinations, the generally positive OE with PWR barrel welds, the fact that EVT-1 identified indications in barrel welds, and the substantial probability of detecting flaws via visual examinations including those similar in length to generic allowable flaw sizes, it is concluded that EVT-1 continues to be applicable for detecting cracking in barrel welds.

3.2 Allowance for ET or UT as Alternatives to EVT-1

MRP-228 [2] describes the general procedures and requirements for non-destructive examination (NDE) of reactor vessel internals components implemented by the inspection program described in MRP-227-A [1] and MRP-227, Revision 1 [14]. MRP-228 provides detailed NDE requirements for visual inspections and ultrasonic testing of bolting; however, it does not directly provide specific requirements for other methods like UT or ET of cracks in plates. Alternative methods are permitted for MRP-227 inspections if the NDE system (personnel, procedures, and equipment) is qualified and the qualification documented. While MRP-228 does not directly qualify other NDE methods (e.g., UT or ET of barrel welds and adjacent base metal), it does provide guidance for qualifying other methods in Section 2.5. These qualifications include a requirement for approving the technical justification for the NDE method.

ET and UT examinations have the capability to identify or characterize flaws in a plate. BWRVIP-03 [7] provides general requirements and recommendations for these NDE techniques for use BWR applications and specifically allows the use of visual, ET, or UT examination for BWR internals core shrouds. Use of these techniques for BWR core shrouds is most relevant to the PWR internals barrels because of the high-level similarities between the PWR barrels and the BWR shrouds [6] in multiple areas:

- Stresses and sources of stress
- Design geometry
- Function
- Materials for the welds and base metal

Because of these similarities between BWR core shrouds and the PWR barrels, it is reasonable to apply ET and UT for the detection of cracking in the CE CSB and the Westinghouse CB. These similarities also permit the use of the same set of qualification requirements when implementing ET or UT with PWR barrels.

Inspections of PWR barrel welds using a permitted and qualified method should be based on the coverage requirements described in Section 4. However, geometry or material properties may have an impact on the ability to use either UT or ET on the weld bead itself. Section 4.5 will examine the coverage limitations for UT and ET in more detail. The initial inspection timing for ET and UT of the barrel welds will be the same as specified for EVT-1 and is discussed further in Section 5. Finally, ET or UT can be used to supplement other examinations (e.g., ET to refine EVT-1 results, UT to find the depth of flaws discovered by EVT-1 or ET, etc.), which will be described in Section 6.

As noted above, MRP-228 includes specific requirements for qualifying NDE techniques other than visual examinations. Therefore, application of the NDE methods for BWR core shrouds to the detection of cracking in PWR barrels must consider the qualification requirements of Section 2.5 of [2], including the requirement for a technical justification in accordance with Section 2.1 of [2]. An update to MRP-228 or interim guidance will be developed that will include the information needed to prepare the required technical justification for UT techniques based on BWRVIP-03. It is expected that the information will include a description of the component, potential damage mechanism, measurement accuracy, process to determine accuracy, calculations of accuracy, and laboratory or demonstration results. Vendors can provide a description of the techniques and essential variables developed for BWRs so that the information provided by EPRI can be used to prepare the technical justification.

4 INSPECTION COVERAGE

Inspection coverage is the second key part of developing guidance for inspection and evaluation of the barrel welds. This section assesses several different aspects of the inspection coverage:

- Impact of the spring 2018 operating experience
- Limitation of the inspection to the welds and the adjacent base metal
- Distance to inspect into the adjacent base metal
- Justification for a one-sided inspection
- Special coverage requirements for ET and UT

4.1 IMPACT OF SPRING 2018 OPERATING EXPERIENCE

As a result of the St. Lucie Unit 1 OE, an evaluation of the inspection coverage requirements, considering barrel surface accessibility, was performed. The current MRP-227, Revision 1 [14] Primary inspection requirements for PWR barrel welds only require inspection of 25% of the circumference of the following welds:

- CE
  - UFW
  - MGW
- Westinghouse
  - UFW
  - LGW

In response to an RAI from the NRC staff while reviewing MRP-227, Revision 1 [16], the industry proposed increasing the coverage requirement for each of these four girth welds to "100% of the accessible weld length of one side" of the particular weld, with a required minimum coverage of 75% of the length for CE-designed plants and 50% for Westinghouse-designed plants. The difference in coverage accounted for the Westinghouse-designed plants with neutron panels, which cannot access the portion of the CB located behind the panels. These changes were in response to the spring 2018 OE, while still accounting for accessibility limitations.

Further interim guidance is needed to address the impact of the spring 2018 OE on welds that are currently Expansion components in MRP-227, Revision 1 [14]. This should particularly affect the axial welds in the core beltline region. Based on the spring 2018 OE, the Westinghouse- and CE-designed PWRs can be divided into two groups and then further subdivided based on the presence of thermal shields and neutron panels, which will obstruct inspection efforts.

4.1.1 Group 1 Plants

The cracking degradation observed in spring 2018 was found at St. Lucie Unit 1 [3]. Although there are no large-scale design differences that point to this degradation phenomenon being unique to CE-designed plants, it was judged that CE plants with similar design or operational histories to this plant should be set apart in their own group. Future interim guidance could consider accelerating the CSB weld inspections required for these plants. Key considerations were the CSB geometry and stress levels. In addition, since St. Lucie Unit 1 experienced a thermal shield failure early in plant life that resulted in extensive CSB cracking and repairs, the two CE-designed plants that experienced this same issue were included in Group 1.

The specific plants in Group 1 are provided in Table 1. The designs and stress levels for these plants are similar, according to WCAP-17499-P [17]. The outer diameters (ODs) of the CSB for the four plants in Group 1 do not have attachments that will block weld inspection accessibility in the core beltline region. Therefore, it is recommended that the inspection coverage for plants in Group 1 be 100% of the accessible weld lengths from the CSB OD with a minimum coverage of 75% of the total weld length for each weld required. This is consistent with the current requirements of the NRC-approved MRP-227-A [1]. This applies to the CE MAW and LAW. The MAW and LAW locations for Group 1 plants are expected to be known or can be determined visually. Nearly 100% inspection coverage of these welds is expected so alternative coverage requirements should be unnecessary.

4.1.2 Group 2 Plants

Given the limited amount of OE currently available for barrel degradation (i.e., barrel cracking has only been observed at one plant), it is reasonable to group the remaining plants that are not quite so similar to St. Lucie Unit 1. These are described as Group 2 plants in Table 1. This group includes the remaining CE-designed plants with and without thermal shields, Westinghouse-designed plants with thermal shields, and Westinghouse-designed plants with neutron panels. Neutron shielding attachments in the core beltline region may affect accessibility of the barrel welds.

The general similarities between the barrels of Group 2 plants and those of Group 1 plants mean that inspection coverage for the core beltline welds must also be evaluated in light of the spring 2018 OE. As with the Group 1 plants, it is recommended that the Primary inspection coverage be increased to 100% of the accessible lengths from the CSB or CB OD of the MAW and LAW for CE and Westinghouse plants. The minimum coverage should also be the same 75% coverage of the total weld length; however, the presence of thermal shields and neutron panels will necessitate alternate inspection strategies for some plants where the 75% coverage is impossible to attain. There are also cases where the axial welds have been machined flush with the base metal of the barrel, and the original fabrication records for the barrel cannot be found or do not include the location of the axial welds. These cases may also require alternative inspection strategies for the core beltline axial welds.

The barrel beltline girth welds have been Primary inspection components under MRP-227 since the publication of the original NRC-approved version, MRP-227-A [1]. Multiple Westinghouse-designed and CE-designed plants have performed inspections of the LGW or MGW, respectively [25, 26, 27, 28]. The beltline girth weld locations are generally known and accessible. Conversely, axial weld locations (particularly the MAW and LAW for both plant designs) may be unknown or inaccessible, so alternative inspection strategies may be required. The needs for guidance vary between plants with thermal shields and those with neutron panels. These will be discussed separately in the following sections.

4.1.2.1 Plants With and Without Thermal Shields

The baffle-former assembly (Westinghouse units) or core shroud assembly (CE units) prevents access to the barrel welds in the beltline region from the inside surface, see Section 4.4. Therefore, inspection of the welds in this region is performed from the outer surface. Three different cases apply for these plants:

1. Axial weld locations are known and accessible for inspection
2. Axial weld locations are known but partially inaccessible (e.g., due to relative position of axial weld and thermal shield attachment points)
3. Axial weld locations are unknown (either by visual appearance or fabrication records)

The first case should have the same coverage requirement as Group 1. Inspect 100% of the accessible weld lengths from the barrel OD with a minimum coverage of 75% of the total weld length for each weld.

This is driven by the OE and the similarities between all CE and Westinghouse-designed barrels previously discussed.

In the second case, for thermal shield plants where axial weld locations are known but partially inaccessible, the starting point for the inspection coverage is the same—100% of the accessible weld lengths from the barrel OD. If the weld location is known and is simply inaccessible, a more focused inspection should be performed limited to regions adjacent to known axial weld locations. This coverage, illustrated in Figure 3, should include a vertical zone on each side of the inaccessible portion of the barrel containing the known location of the axial weld. Each zone should be a minimum of 3/4-inch wide and cover the full distance parallel to the inaccessible height of the weld. This option provides inspection coverage of the accessible portions of the weld and the areas on the barrel closest to the inaccessible portions of the weld, which provides some assurance that any potential cracking has not propagated out of the inaccessible regions.

In the third case, for thermal shield plants where axial weld locations are unknown, an alternate inspection strategy is recommended. One of the following two coverage options can be used:

1. 100% of the accessible barrel OD in two 6-inch minimum wide zones around the circumference of the barrel (see Figure 4):
   a. One at an elevation approximately halfway between the UGW and the MGW (CE)/LGW (Westinghouse).
   b. One at an elevation approximately halfway between the MGW (CE)/LGW (Westinghouse) and the LFW.
2. Inspect at least six (6) separate, 3/4-inch wide bands evenly spaced between the UGW and MGW (CE)/LGW (Westinghouse), and at least six (6) separate, 3/4-inch wide bands evenly spaced between the MGW (CE)/LGW (Westinghouse) and the LFW.

These two approaches have the potential to obtain partial coverage of the MAW and LAW. By imposing an inspection that covers a substantial area around the circumference of the barrel, it is meant to increase the sample area or volume to increase the probability of intersecting a flaw and to offset axial weld area or volume that cannot be inspected due to the unknown weld locations. Similar to the inspection coverage for cases where the welds are known and accessible, it is recommended that the minimum coverage requirement for the individual inspection zones in both cases be 75% of the total zone area (both the accessible and inaccessible portions of the zone area). This is consistent with girth weld requirements in MRP-227-A and provides coverage of a significant portion of the barrel circumference, while still allowing for potential accessibility issues behind the thermal shield.

The MRP-227 inspection and evaluation program has been and continues to be based on a sampling strategy for managing the aging-related degradation of reactor vessel internals. The spring 2018 OE included a large number of indications spaced along the full length of the axial weld. Inspection of a 6-inch band has a significant likelihood of intersecting one or more flaws in another barrel subject to similar degradation and inspection of six (6) separate 3/4-inch bands is expected to result in a higher probability of intersecting a flaw.

The basis for these inspection bands was derived from the OE data from St. Lucie Unit 1. The 45 visual indications at St. Lucie Unit 1 were distributed along the length of the MAW. The circumferential inspection bands cover an area around the entire circumference of the barrel outer surface. The inspection coverage is expected to intersect an axial weld if 100% coverage is achieved (i.e., if the axial weld is not inaccessible because of interference between thermal shield attachments and inspection tooling, etc.). The probability of intersecting a flaw is based on the number of flaws in the length of the axial weld, the distance between each flaw, the width of the band, and the number of bands. For example, the probability of intersecting a single flaw in a representative 100-inch long axial weld for a single 6-inch band is approximately 6% based on a statistical analysis of this scenario. Applying a 6-inch band to the St. Lucie Unit 1 OE would result in an approximately 75% probability of intersecting an indication. Applying six 3/4-inch bands would result in an approximately 80% probability of intersecting an indication. Recommendation of these two alternate inspection techniques for plants that do not know the location of the axial welds is based on probability of intersection calculations and an assumption that degradation in another barrel would be similar to that observed at St. Lucie Unit 1. Based on this discussion, these alternate inspection options for unknown or inaccessible axial welds are deemed acceptable unless additional OE indicates otherwise.

If a flaw is identified, it is expected that an extent of condition evaluation would result in increased coverage of the region. The increased coverage should focus on the vertical direction from any flaws detected, since it is expected that the location of an observed flaw corresponds to an axial weld. For further discussion of supplemental inspection options for extent of condition and other purposes, see Section 6.

4.1.2.2 Plants with Neutron Panels

Only Westinghouse-designed plants have neutron panels attached to the OD of the CB. Four neutron panels are bolted to the outside of the CB, leaving little to no gap between the panel and the barrel. It is not possible to access the CB surface behind the panel without disassembling the neutron panels. The panels cover approximately 40-50% of the CB circumferentially and extend from the bottom to the top of the core beltline region. In addition, the baffle-former assembly prevents access to the CB welds in the beltline region from the inside surface, see Section 4.4. Three different cases apply for these plants:

1. Axial weld locations are known and not behind the neutron panels
2. Axial weld locations are known and located behind the neutron panels
3. Axial weld locations are unknown and not visible

The first axial weld case should have the same coverage requirement as Group 1. Inspect 100% of the accessible weld lengths from the barrel OD with a minimum coverage of 75% of the total weld length for each weld. This is driven by the OE and the similarities between all CE and Westinghouse-designed barrels previously discussed.

The second axial weld case will not support the 75% minimum coverage requirement used for Group 1 plants, since a large portion of the axial weld will be inaccessible behind the neutron panel. In this case, the following alternate inspection is recommended (see Figure 5): 1) inspect 100% of the accessible weld lengths from the barrel OD (portion that is accessible above or below the neutron panel); 2) inspect 3/4-inch minimum wide zones of the CB OD adjacent to each neutron panel that covers the MAW or LAW. The coverage adjacent to each neutron panel should include, at a minimum, the barrel OD along both long, vertical edges of the panel up to the girth weld and either the top edge for MAW or the bottom edge for LAW.

The weld region is expected to be the highest susceptibility portion of the CB due to the potential for weld residual stresses, sensitization, and stress concentration (see subsection 4.2). This is corroborated by the spring 2018 OE, where multiple flaws near the weld were observed [3]. The sampling and lead component strategy of MRP-227 is specifically intended to avoid component disassembly unless absolutely warranted. This was discussed in the response to RAI 4-8 for MRP-227-A [1]. For the second case, inspecting around the neutron panel covering the axial weld monitors for cracks propagating from the axial weld, while avoiding removal of the neutron panel from the barrel. It should be noted that disassembly of the neutron panel would be a significant and high risk effort, including the potential for significant personnel exposure, production of large amounts of radioactive waste, loose parts, and damage to the CB or other nearby components.

The third axial weld case also will not support the 75% minimum coverage requirement used for Group 1 plants. The third case also does not fit with the inspection around a single neutron panel recommended for the second case. Since the weld location is not known, it could be located behind any one of the four neutron panels or in one of the areas between panels. It is recommended that this inspection be completed in two parts for this case (see Figure 6):

1. Inspect 3/4-inch minimum wide zones on the CB OD adjacent to all four sides of all four of the neutron panels.
2. Inspect bands around the circumference of the CB with a minimum coverage of 50% of the full circumference for each band, using one of the following options:
   a. One 6-inch minimum wide band at an elevation approximately halfway between the UGW and the LGW and one 6-inch minimum wide band at an elevation approximately halfway between the LGW and the LFW.
   b. At least six (6) separate, 3/4-inch wide bands evenly spaced between the UGW and MGW (CE)/LGW (Westinghouse), and at least six (6) separate, 3/4-inch wide bands evenly spaced between the MGW (CE)/LGW (Westinghouse) and the LFW.

The circumferential bands in the second part are similar to the approach for thermal shield plants in that they increase the inspection sample area to increase the probability of identifying a flaw and account for unknown weld locations. The probability of intersection arguments developed for the thermal shield case are the same for neutron panel plants and will not be repeated here. The minimum coverage requirement of 50% of the CB outer circumference for the bands accounts for the fact that the neutron panels cover approximately 40-50% of the CB outer circumference, making that portion of the circumference inaccessible.

The inspection zones around the neutron panels in the first part also increase the sample area to account for unknown weld locations and to monitor for cracks propagating from the axial weld behind the panel. Inspection of the region immediately adjacent to the panels also focuses the examination on the regions closest to the high fluence portions of the barrel. As irradiation-assisted SCC (IASCC) is driven by neutron fluence [18], inspection of the most highly irradiated material focuses the monitoring on the most likely areas to crack. The root cause for the flaws in the St. Lucie Unit 1 CSB has not been determined, so other aging mechanisms could be attributed to the flaws at St. Lucie Unit 1. The flaws at St. Lucie Unit 1 may have been remnants from an earlier fatigue-induced cracking event due to a thermal shield issue; however, IASCC continues to be one of the expected aging mechanisms in MRP-227 for beltline region barrel welds. Therefore, IASCC cannot be ruled out as an aging mechanism for the barrel, and the requirement to monitor the locations susceptible to IASCC should be maintained.

In general, the goal for the additional coverage requirements when weld locations are unknown or inaccessible is to ensure that the sample area is the accessible surfaces closest to the most susceptible locations. These additional coverage requirements are intended to represent the next most likely location in the absence of obtaining coverage of the most likely location. It is noted that the ET examination technique may be used to locate axial welds (see subsection 3.2). With the axial welds located, the inspection coverage requirements described for the first or second case can be applied.

Table 1: Plant Categories

Group 1: CE-designed units with similar CSB stress level and geometry to St. Lucie Unit 1	**Group 2: All other PWR units**
Millstone Unit 2 St. Lucie Unit 1 Calvert Cliffs Unit 1 Calvert Cliffs Unit 2	All remaining CE- and Westinghouse-designed plants (including international units)

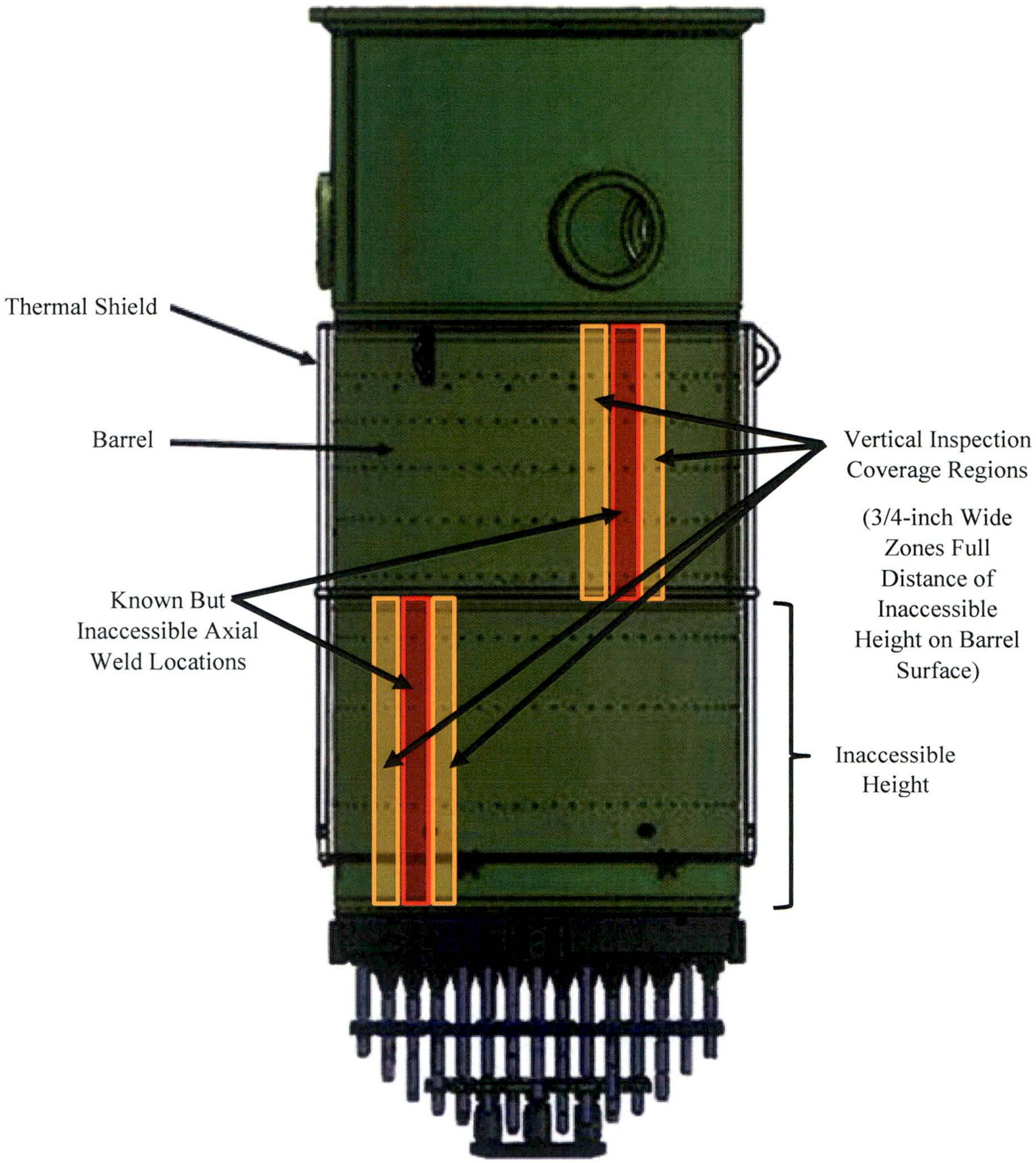

Figure 3: Thermal Shield Plants - Known Partially Inaccessible MAW and LAW Locations (Second Case)

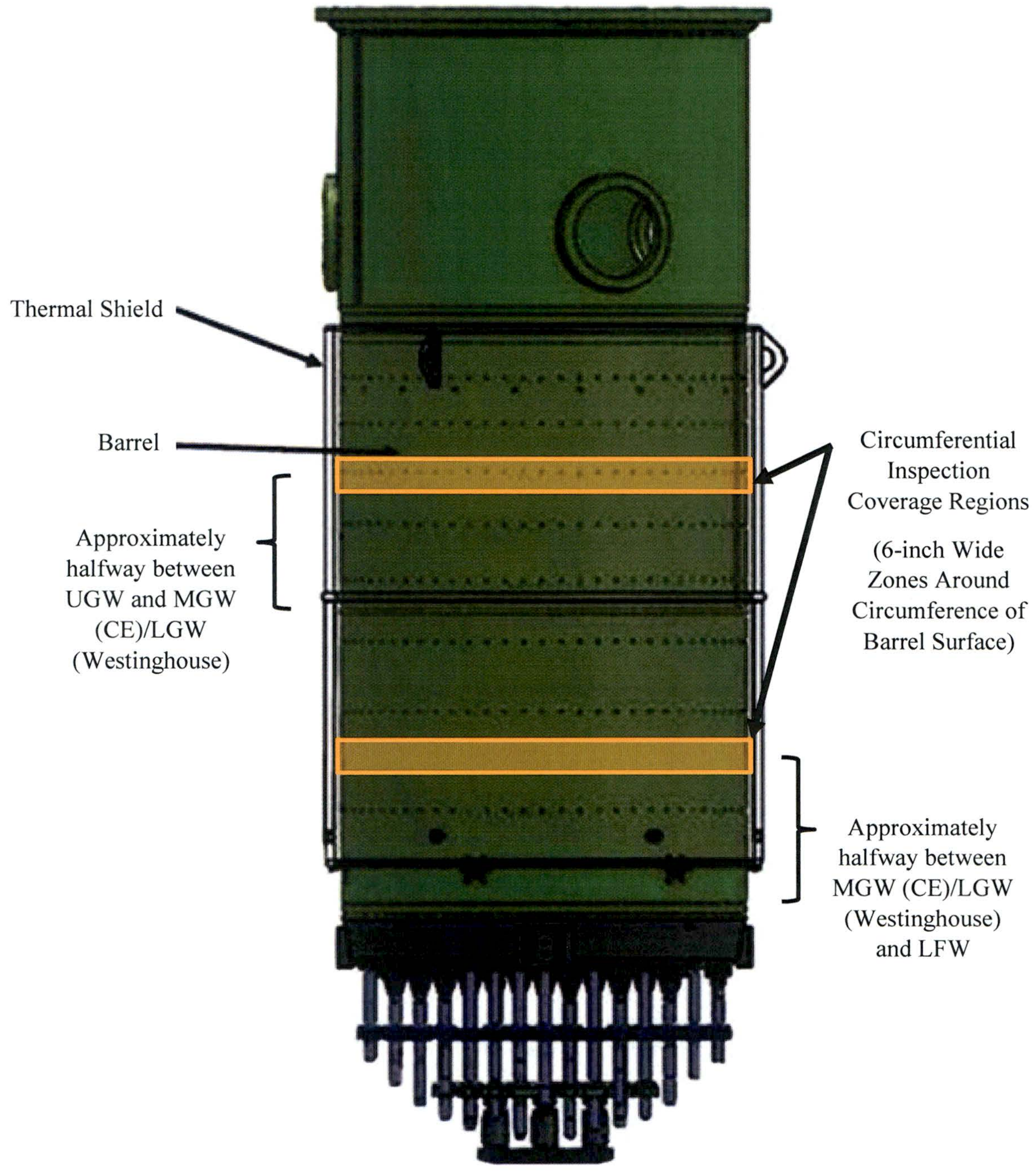

Figure 4: Thermal Shield Plants - Unknown MAW and LAW Locations (Third Case, Using 6-inch Bands)

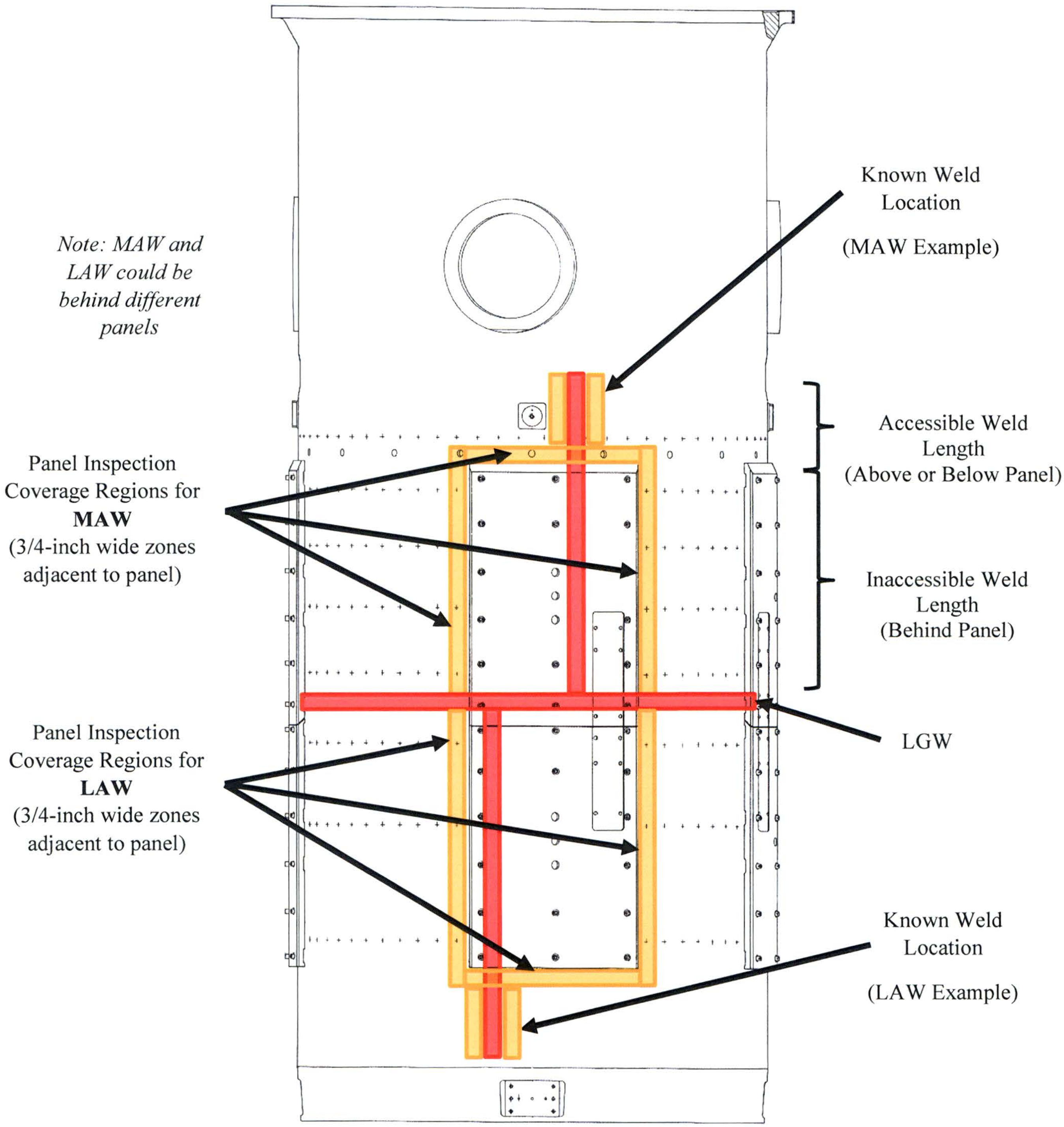

Figure 5: Neutron Panel Plants - Known Partially Inaccessible MAW and LAW Locations (Second Case)

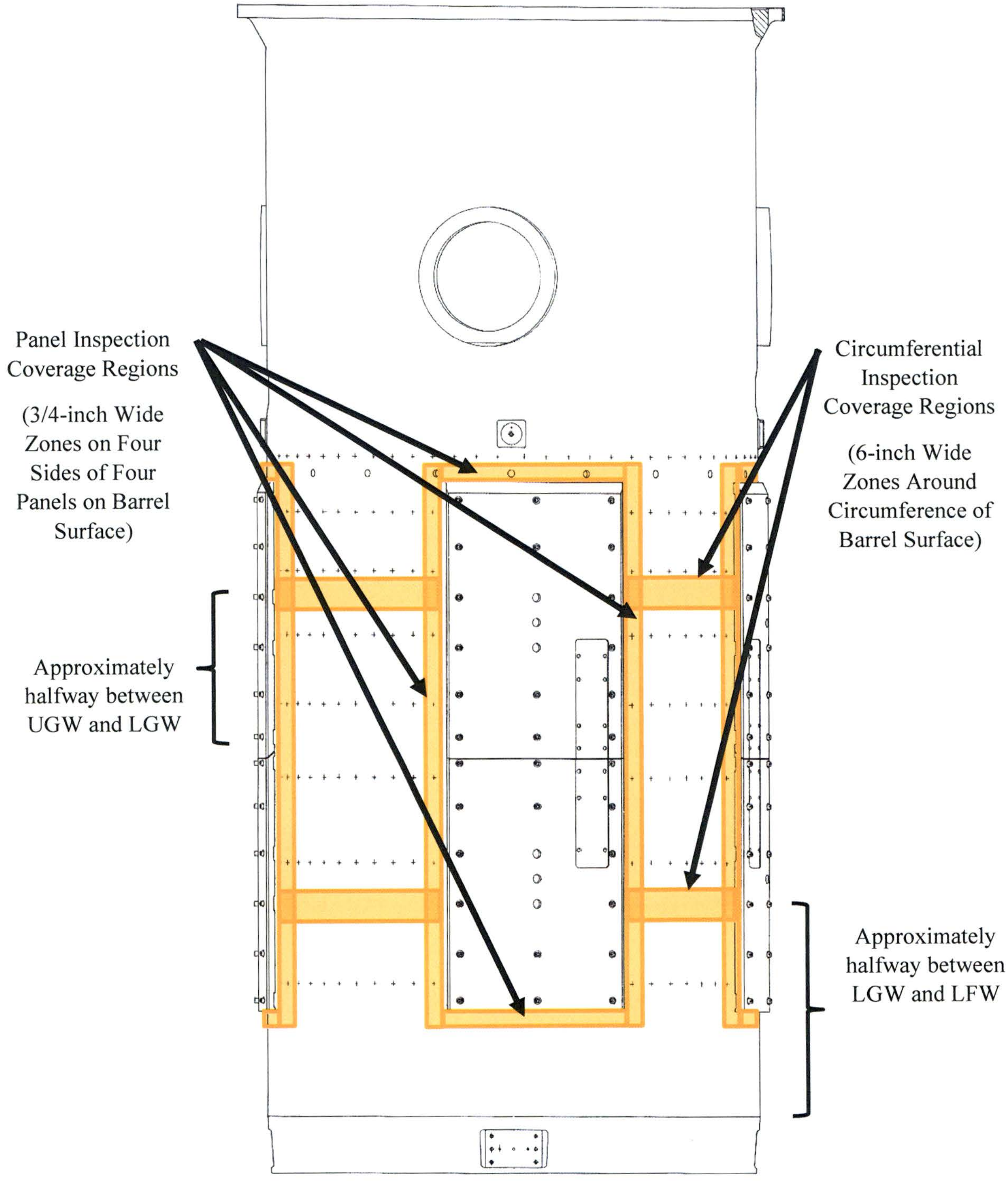

Figure 6: Neutron Panel Plants - Unknown MAW and LAW Locations (Third Case, Using 6-inch Bands)

4.2 LIMITATION OF COVERAGE TO WELDS AND ADJACENT BASE METAL

Limited experience with age-related degradation effects in PWR barrels poses a challenge for stipulating specific location examination requirements. Therefore, a sampling strategy is specified which is an accepted aging management method in MRP-227-A [1]. For barrel coverage, the required sample (i.e., the examination coverage specified in MRP-227-A) is the accessible weld surfaces and adjacent base metal. In general, cracking at the barrel weld joints is expected to be the observable aging effect before cracking in other regions of the barrel and so the examination is focused on the welds.

The effects of welding on increased susceptibility to SCC are well documented. During the welding process, the base metal region adjacent to the weld joint undergoes intense thermal cycling. This region, known as the heat-affected zone, may undergo sensitization and as a result, the potential for the grain boundaries to become crack initiation sites increases [19]. As noted in [6], this phenomenon may be of particular importance in older plants due to the carbon content of the materials used. In addition, the welding process during fabrication of welded structures increases susceptibility by introducing high residual stresses (approaching the material's yield strength) at the weld joint. Lastly, geometry factors, such as the concentration of stress at the weld toe, increase susceptibility. Therefore, cracking due to SCC or IASCC may be expected to occur in the base metal adjacent to a weld because of the increased susceptibility relative to other barrel locations.

The spring 2018 OE indicated that a majority of the detected flaws originated at the weld toe and were oriented perpendicular to the weld in the heat-affected zone. The confirmed detection of cracking at the weld joint is consistent with the expected location. The orientation of most of the observed flaws was unexpected, since weld residual stresses are expected to drive cracking parallel to the weld. In addition, a limited number of flaws were located in the general vicinity of the weld but far enough away to be out of the heat-affected zone. These two observations are not entirely consistent with expectations. They may indicate a potential effect of a non-aging related phenomenon, such as a fabrication effect or the degradation of the thermal shield early in that plant's life. Despite these differences from the expected behavior, the majority of the cracking observed was located in areas included in the proposed inspection coverage. The intent of the MRP-227 inspection and evaluation program is not to identify every potential indication directly but to perform inspection sampling that will detect and monitor an active aging mechanism. The observed OE does not contradict this when considering the current coverage limitation to the weld and 3/4-inch of adjacent base metal on either side of the weld [2, 14].

Guidance in BWRVIP-03 [7] limits surface and volumetric examination coverage to the toe of the weld and adjacent base metal:

> *"...the inspection area shall include, as a minimum, the toe of the weld and... the adjacent base material on each side of the weld."*

The coverage adjacent to the toe of the weld depends on the thickness of the material inspected; the largest distance specified being three-quarters of an inch. Inspection of PWR barrel welds and adjacent base metal is consistent with BWR guidance [1, 14].

Intergranular SCC is a commonly observed phenomenon in BWR core shrouds. In 1990, cracks were observed in the heat-affected zone of a circumferential weld in the beltline region of a foreign BWR core shroud [19]. In 1993, in response to recommendations made after the 1990 BWR core shroud OE, a visual examination of a domestic BWR core shroud identified cracks in the heat-affected zone [19]. Subsequent examinations of the core shroud at other BWR plants identified additional instances of cracking in the heat-affected zones [19]. The BWR experience has shown that portions of the core shrouds most susceptible to SCC are associated with the base metal in areas immediately adjacent to the shroud welds (i.e., the heat-affected zone) [19]. While the service experience between BWR and PWR plants differs [6], the observation of SCC in the heat-affected zone of BWR core shrouds supports the assessment that SCC in PWR barrels is most likely to be observed in the heat-affected zone.

Because the cracking OE is generally consistent with the expected location, which itself is consistent with BWR experience, changes from a sampling strategy of the welds and adjacent base metal for the barrel welds are not warranted. Therefore, the inspection coverage requirements of MRP-227-A should remain applicable (i.e., the examination coverage requirement should include the weld and the adjacent base metal). Inspection of the base metal away from the welds is not included in the current Primary or Expansion component items of MRP-227-A or MRP-227, Revision 1 and addition of a base metal inspection is not required. The distance to inspect from the weld will be assessed in the next section.

4.3 Distance from Weld to Inspect in the Base Metal

The spring 2018 OE indicated that a majority of the detected flaws were located at the weld toe and into the adjacent base metal. In addition, the visual examination and a supplemental volumetric examination identified flaws originating several inches away from the weld toe. Because of this OE, the base metal coverage requirement will be evaluated here.

MRP-227-A [1] specifies adjacent base metal in the examination coverage requirement for Westinghouse CB welds but does not explicitly require a distance from the weld into the base metal (for CE CSB welds adjacent base metal is only sometimes specified).

MRP-228 [2] provides requirements for area of interest in which it states:

> *"For welds, when adjacent base metal is specified in the examination coverage requirement, it is intended to include the base metal heat-affected zone adjacent to the weld. This is generally considered to be the entire width of the weld and 0.75 in. (19.1 mm) of the adjacent base material on each side of the weld."*

MRP-227, Revision 1 [14] summarizes the MRP-228 requirement, while clarifying requirements specified in MRP-227-A [1], with the following statement:

> *"When adjacent base metal is specified in the inspection coverage requirement, it is intended to include the base metal heat affected zone adjacent to the weld. If not otherwise specified, three quarter inch of base metal coverage may be assumed."*

In the area of interest and coverage requirement discussions in MRP-228 [2] and MRP-227, Revision 1 [14], the term heat-affected zone is introduced along with a specific distance assumption. Since MRP-227, Revision 1 [14] does not specify a value for the barrel welds, the three quarter inch base metal assumption may be used.

BWRVIP-03 does not explicitly refer to the heat-affected zone in examination area or volume requirements for surface or volumetric inspection of welds but instead specifies the adjacent base metal on either side of the weld based on a distance measurement from the weld toe. More explicitly, BWRVIP-03 [7] specifies that the inspection area or volume should include three-quarters of an inch of the adjacent base material on each side of the weld for low alloy or stainless steel materials one-half inch or less in thickness. In addition, for materials greater than one-half inch in thickness, the area or volume coverage should include one half inch of the adjacent base material on each side of the weld. The inspection area is specified as a minimum requirement. In comparison to PWR barrels, which have a thickness greater than one-half inch, the BWR coverage requirement for the base metal is less than requirements of MRP-227 [14].

The size of the heat-affected zone is a function of the length of time that a metal is heated, which can be influenced by the rate of heat input and speed of the welding process. An estimate of the width (i.e., perpendicular distance from the weld axis) of the heat-affected zone requires an evaluation of several welding parameters, making such an estimate difficult. Even without this knowledge of how far into the base metal the heat-affected zone extends, it is reasonable to assume that the most susceptible portion of the heat-affected zone is that nearest the weld. This part of the heat-affected zone received the most input heat and would have the largest tensile stresses from weld residual stress, the largest potential for sensitization, and the most potential for weld dilution effects. Based on this reasoning, the current three-quarter inch coverage from the weld toe is reasonable.

The St. Lucie Unit 1 OE [3] also supports continuing the use of the current MRP-227 coverage requirement. A significant number of the observed flaws were at least partially located within the base metal coverage required and in fact, most had end points at the weld toe. Therefore, no change to the size of the base metal coverage requirement is warranted and the three-quarters of an inch coverage requirement adjacent to the weld remains acceptable.

It can be assumed and shall be recommended that confirmed detection of a flaw in the heat-affected zone should trigger an extent of condition evaluation in order to identify conditions in and beyond the heat-affected zone. This is discussed further in Section 6.

4.4 Limitation of Coverage to One Surface of the Weld Joint

Access to the surface of the CB or CSB for weld examinations depends on the weld location and PWR design. Welds in the upper portion of the barrel are nearly 100% accessible from either side, while access to welds in the lower portion is limited. The discussion in this section pertains to inspection coverage for weld joints in the lower portion of the barrel (specifically in and around the beltline region) where accessibility issues exist.

For the OD surface, the barrel welds have different levels of accessibility. CE-designed plants without a thermal shield approach 100% accessibility. CE-designed and Westinghouse-designed plants with a thermal shield have less than 100% accessibility. For these plants, access is obtained via the annulus between the barrel and the thermal shield; however, access for existing inspection tooling may be limited by the thermal shield support lugs and other components like the upper internals alignment keys. Westinghouse-designed plants with neutron panels have even less accessibility. Each PWR in this group has four neutron panels and each panel is closely attached to the CB preventing access to the CB OD surface covered by the panel. Circumferential access is estimated to be 50-60% for girth welds, due to the size of the panels. Access to axial welds located behind neutron panels is essentially nonexistent with current examination methods.

For the inside either diameter (ID) surface, the baffle-former assembly (Westinghouse designs) or the core shroud assembly (CE designs) covers 100% of the ID of the barrel in the beltline region. Access to the inside surface of the lower portion of the barrel would require disassembly or removal of these components. Disassembly and reassembly of these components has a potential to introduce significant risk with no clear benefit and is contrary to the intention of the MRP-227-A [1] and MRP-227, Revision 1 [14] inspection and evaluation guidelines.

Per MRP 2018-011 [6] and RAI 4-8 in MRP 2010-066 [20], a basic assumption in the development of MRP-227 was that component disassembly should be avoided unless absolutely warranted. Therefore, since access to the inner surface of the barrel is not practical, examination of the barrel weld joints from the outside surface, which is more accessible, is the suggested approach. This is consistent with the intent of the inspection strategies in MRP-227-A where a sampling strategy is acceptable for providing confidence that aging effects are adequately managed.

Neither the ID nor the OD can conclusively be identified to be more susceptible to cracking. However, in response to RAI 5 on MRP-227, Revision 1 (sent to the NRC via MRP letter MRP 2018-003 [21] dated January 30, 2018), it was discussed that the normal operating stresses at the LGW and MGW locations were driven by the thermal differential across the barrel wall due to the effects of irradiation. The temperature distribution here causes a net tensile stress on the OD of the barrel, which is higher than the stress at the ID. It is expected that cracking would first appear at a location with the highest fluence and stress, with stress being a more important factor at higher fluence levels [21]. However, the location of highest stress does not correspond to the location of highest dose, which occurs at the barrel ID. Because of these offsetting parameters, and limited cracking data to date, it cannot be conclusively determined the location most susceptible to IASCC. Nevertheless, the stresses are higher at the OD and since stress is a more important factor at high fluence levels, the OD is expected to be slightly more susceptible to cracking than the ID. As noted previously, the inside surface of the lower portion of the barrel is not accessible so access from the outside surface is the preferred approach, which benefits in minimized risk, dose, and cost.

The basis for limiting the examination to the outside surface for accessibility reasons remains consistent with MRP-227-A, which is a sampling approach of the portion of the component that is accessible (see response to RAI 4-8 in MRP 2010-066 [20]). A sampling strategy provides reasonable assurance that the effects of the aging mechanisms are managed during the period of extended operation.

If degradation is observed by the examination, an evaluation should be performed based on the examination results to determine if additional inspection methods (e.g., volumetric) are needed to fully characterize the observed condition. If flaws are detected visually, a volumetric examination may be used to characterize the flaws. Additional uses of a volumetric examination may be to confirm through-thickness cracks or to identify cracks at the inside surface. The OE at St. Lucie Unit 1 included multiple flaws observed on the OD surface of the barrel but only one flaw detected by UT as initiating from the ID of the barrel. This observation is consistent with the OD surface being more susceptible to cracking and suggests that one-sided inspection from the OD is appropriate.

Note that the preceding discussion specifically addresses surface or visual examinations. Volumetric examinations, which can inspect the entire thickness, are not affected by inside surface accessibility issues. Therefore, volumetric examinations may be performed to define the extent of the conditions for engineering evaluation purposes.

4.5 Inspection of Only Adjacent Base Metal When Applying UT or ET

UT or ET examination techniques may not be effective in detecting cracks in the weld metal volume. For example, as discussed in [7], detection and sizing of flaws located in (or adjacent to) welds using UT examination techniques may be challenging if the sound beam has to pass through weld metal to reach the flaw as the weld metal tends to degrade the signal. The large grain size and different orientation of the grains in the weld metal can affect the propagation of the ultrasound by causing attenuation and scattering of the beam [7]. For similar reasons, the microstructure of the weld metal can also affect the ET signal, especially for flaws far below the surface being examined [22].

Detection of cracking in or near welds using ultrasonic examination is recognized as having limited capability. Several investigative studies (summarized in BWRVIP-03 [7]) have reported on the difficulty and ineffectiveness of UT examinations from one edge of a weld to inspect material on the far edge of the weld with the beam passing through the weld metal. For this reason, BWRVIP-03 excludes the weld volume from the examination requirements and provides the guidance that weld joints should be examined on both components joined by the weld when possible. A path for qualifying and applying an ultrasonic examination from one edge of a weld is provided in BWRVIP-03; however, it is only recognized as best effort.

When either the UT or ET technique is used to detect flaws in the CB or CSB, the base metal volumes on both edges of the weld should be examined when possible. For both UT and ET examinations of BWR reactor internals components, BWRVIP-03 [7] specifies the toe of the weld and a portion of the base metal adjacent to the weld with the extent of the area depending on size of the weld. The actual weld metal is not required because of the issues with using these techniques on the weld pool.

Both edges of the weld joint in CE-designed CSBs without a thermal shield, and in Westinghouse-designed plants where the axial weld is not behind a neutron panel, are expected to be equally accessible from the OD of the barrel for examination. Therefore, inspection by sending the UT signal through the weld metal will generally not be a consideration. This accessibility may be more limited in plants with a thermal shield or in Westinghouse-designed plants where a neutron panel partially obscures an axial weld. If a best-effort examination using UT results from a signal sent through weld material becomes necessary, the qualification approach in BWRVIP-03 can be used.

UT or ET examination of barrel welds in the core beltline region will have to consider the potential accessibility limitations due to the presence of neutron panels or a thermal shield. The UT or ET coverage that is obtainable from the OD of the barrel for circumferential and axial welds has yet to be determined or demonstrated.

The OE at St. Lucie Unit 1 suggested that a significant number of the indications identified visually were confirmed with a supplemental UT examination. There was no evidence from the UT or visual (EVT-1) examinations that the flaws extended into the weld metal. Therefore, based on OE, limiting UT or ET examinations to inspection of the adjacent base metal is acceptable.

5 INSPECTION TIMING

5.1 INITIAL INSPECTION

Since 2011, the initial baseline inspections of the Primary component CB and CSB assembly flange and girth welds per the requirements of MRP-227 have been performed at multiple PWR units ([25], [26], [27], and [28]). From a review of the inspection results, only one recordable indication was reported (observed adjacent to the MGW at St. Lucie Unit 1 in spring 2018 [3, 28]). Therefore, based on the inspection experience, significant indications of cracking have not been observed for the CB or CSB flange and girth welds. From an OE standpoint, it is appropriate to maintain the current baseline inspection schedule in MRP-227-A for these Primary component welds.

More recently, three U.S. PWRs have performed visual examinations of the axial welds in the CSB assembly. Multiple indications were detected in the heat-affected zone and base metal adjacent to the MAW at St. Lucie Unit 1 [28]. A majority of the indications initiated at the OD surface. The deepest OD flaws were approximately 50%-70% through-wall. Only one indication initiated from the ID surface, which had a through-wall depth below 10%. No axial weld indications were reported for the other two units.

In response to the observed CSB weld indications at St. Lucie Unit 1, the utility had the acceptability of the flaws evaluated [3]. The MGW and MAW indications were dispositioned permitting the plant to operate for an additional cycle.

Figure 7 summarizes the effective full power year (EFPY) and unit age data from [25], [26], [27], and [28] corresponding to the date of the baseline barrel weld inspections. From these data, operating time alone may not be a reliable indicator for barrel flange and girth weld cracking potential, because units similar in age and EFPY to the unit with confirmed cracking showed no indication of cracking in the girth welds inspected. Only three plants have completed EVT-1 inspections of the axial welds, to date. As noted above, only one of these plants identified core barrel weld indications. With only one data point for confirmed detection of cracking for either the girth welds or axial welds and a limited number of axial weld inspections, meaningful assessments cannot be made at this point. Considering the measured crack lengths and the expected growth rates, it is possible that the initiating mechanism for the observed condition at St. Lucie Unit 1 could be related to the early-life thermal shield failure that occurred at that plant and caused earlier CSB cracking. However, without further confirmatory inspections or analysis, the conservative approach is to assume that the flaws observed at St. Lucie Unit 1 could be applicable to all of the units of similar design and age.

The OE with barrel cracking necessitates the determination of an initial inspection schedule for the axial welds. The limited OE available for the axial welds alone does not provide adequate information to support a specific initial inspection timing. However, the axial welds are similar enough to the girth welds that it is reasonable to treat them in the same way as the girth welds until further OE data are gathered. The fact that the St. Lucie Unit 1 flaws could be dispositioned for continued operation also supports this approach. Therefore, the initial inspection timing for the axial welds should be the same as that already established for the MRP-227 Primary component girth welds; that is, "…examination no later than 2 refueling outages from the beginning of the license renewal period."

More generically, the initial inspection is the first refueling outage in which the barrel is planned to be removed for pre-planned inspection of the barrel girth welds in accordance with MRP-227-A requirements. For plants operating beyond two refueling outages from the beginning of the license renewal period and that have completed the initial inspections of the Primary barrel welds, the initial inspection for the axial welds is to be coincident with the subsequent Primary girth weld examination.

Note that the examination acceptance criteria for the MAW and LAW for both PWR designs should become the same as that of the MGW (CE) or LGW (Westinghouse): the specific relevant condition is "a detectable crack-like surface indication" [1].

The basis for maintaining the initial schedule in MRP-227-A for the CB and CSB Primary welds is that the OE does not indicate that cracking is a common aging effect. In addition, the crack growth rate for PWR barrel material is expected to be low [12, 13], so undetected or latent cracks are not expected to grow significantly between now and a point in the future.

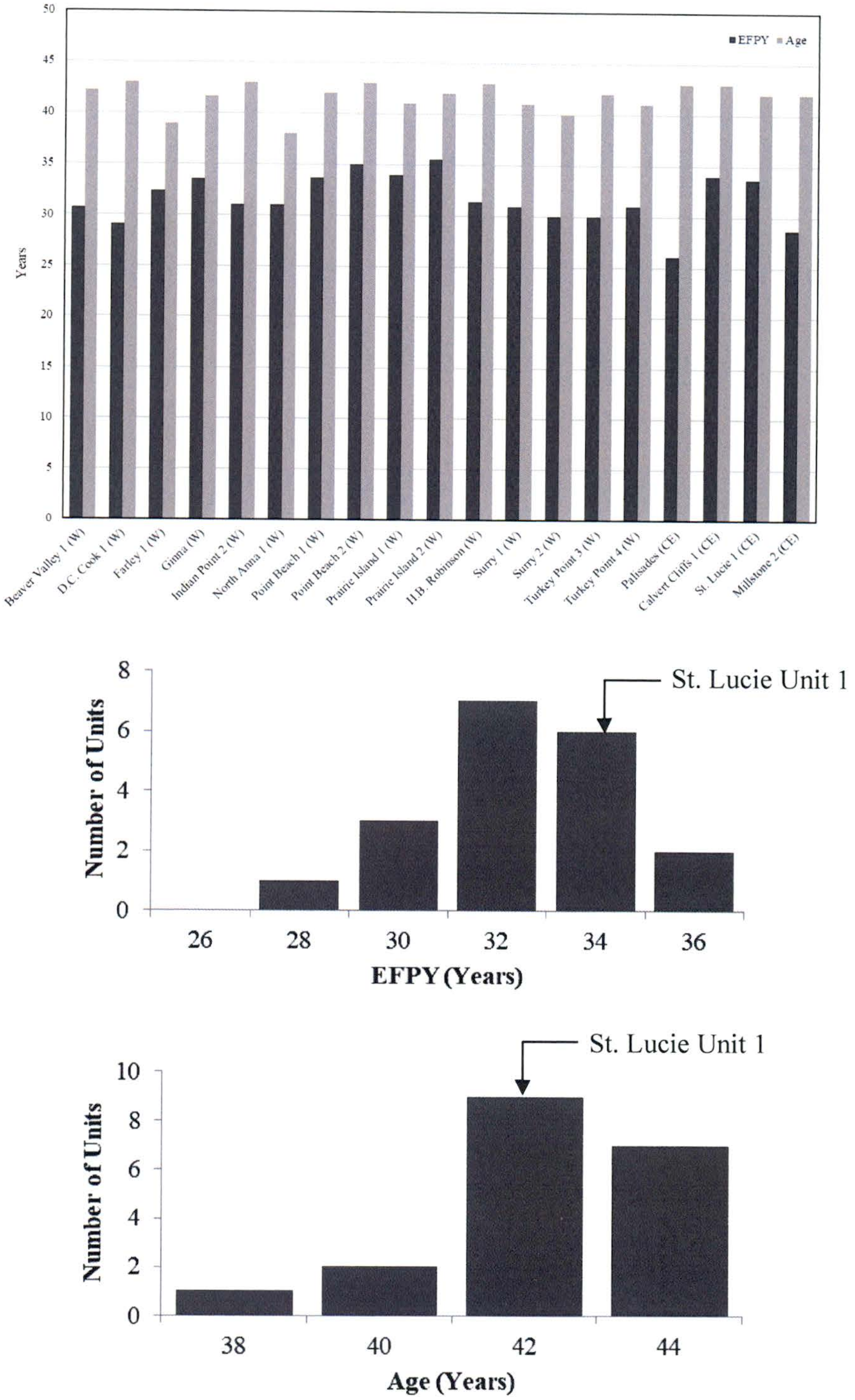

Figure 7: Operating Time at Baseline Barrel Weld Inspections

5.2 RE-INSPECTION INTERVAL

Re-inspection requirements for a plant that finds no relevant indications during the axial weld inspection will be addressed in a future update to MRP-227. This section discusses the re-inspection interval based on flaw evaluation results supporting disposition of a relevant condition. Consistent with terminology in [1], a relevant condition is "a detectable crack-like surface indication."

If a relevant condition is detected, then a formal disposition for acceptability is required in accordance with Section 6 of MRP-227-A [1]. A flaw evaluation in accordance with WCAP-17096-NP-A [13] or WCAP-17684 [12] may be used and should define the acceptance criteria and re-inspection interval (a maximum 10-year interval is permitted). In order to use the acceptance criteria, re-inspection of the indication(s) at the next refueling outage may be required to verify crack growth rate assumptions in flaw evaluations [13], [12]. A flaw evaluation determines the interval for the verification.

The basis for establishing a re-inspection interval with information from a one-sided surface or visual examination is based on the expectation that cracking is more likely on the OD surface due to higher stresses (see subsection 4.4), lack of accessibility to the ID surface, and the general sampling strategy of MRP-227-A [1] and MRP-227, Revision 1 [14]. This is consistent with the OE which indicates that through-wall flaws are not present (per [3], characterization of the flaws using UT data confirmed that none of the indications went through-wall) and that a majority of the indications initiated on the OD surface. Only one indication initiated from the ID surface; the depth was less than 10% through-wall. For flaws detected by surface or visual examination only, the flaws should be assumed as through-wall for evaluation purposes.

Currently, there is little OE regarding crack growth rates for SCC or IASCC in barrels of operating PWRs. As a result, crack growth rates developed for SCC in BWRs have generally been used in the evaluations of flaws in PWR barrels (e.g., see MRP-227-A [1] and WCAP-17684-P [12]). Interim guidance to WCAP-17096-NP-A in PWROG-17071-NP [29] references an EPRI Report on IASCC crack growth rates [30] for an updated crack growth rate model that can be used in weld locations subjected to fluence levels greater than $3x10^{21}$ n/cm^2 (E > 1 MeV). Assumed crack growth rates in WCAP-17684-P are generally low for normal operating conditions, as evidenced by the small difference between 18-month and 10-year allowable flaw sizes. Based on these rates, crack growth at the end of the inspection interval is anticipated to be small and catastrophic crack growth would not be expected. However, as noted above, in the absence of sufficient information on the actual crack growth rate in PWRs, a re-inspection at the next refueling outage is recommended to confirm assumed crack growth rates. If crack growth rate assumptions can be confirmed and justified, then longer re-inspection intervals up to a maximum of 10 years could be acceptable.

The initiating mechanism and root cause for the flaws in the St. Lucie Unit 1 CSB are unknown. Cracking cannot conclusively be attributed to SCC, IASCC, or some other potential mechanism. The flaws that were observed in the CSB were oriented perpendicular to the axial weld similar to "off-axis" flaws observed in BWR core shrouds. Off-axis flaws associated with BWR OE have been linked to a combination of construction or field fabrication issues and aging-related degradation issues. BWRVIP-302 [31] concluded that irradiation appeared to have been a potential factor to the crack evaluated (an off-axis flaw from a boat sample taken from the heat-affected zone of a core shroud weld), but that the crack exhibited characteristics common to both intergranular SCC and IASCC. Furthermore, BWRVIP-302 concluded that it was not possible to separate the influence of the irradiation and non-irradiation factors, which includes contributors such as fabrication-induced cold work. The flaws at St. Lucie Unit 1 may have initiated from the thermal shield failure early in the life of the plant, so this cause cannot be disregarded. Additional evaluations should be considered as OE is obtained, and additional inspection guidance may be considered for future revisions of MRP-227 as OE is obtained.

6 Supplemental Inspection Options

Inspection requirements for the CB/CSB girth welds are provided in MRP-227, Revision 1 [14] with updates to the required weld coverage in response to OE and NRC RAIs in letter MRP 2018-026 [16]. Inspection requirements for the CB/CSB axial welds were outlined earlier in the current report. The coverage achieved for each of these inspections can be limited by parameters including weld accessibility and use of a one-sided surface inspection technique (EVT-1 or ET). The coverage is also limited to the welds and 0.75 inch of base metal on each edge of the weld.

When relevant indications are observed, supplemental inspections to address these coverage issues or to better understand the extent of condition may be implemented by the utility. MRP-227 does not have specific requirements for supplemental inspections and further details on supplemental inspection options are planned for future revisions of MRP-228.

In some instances, the location of the axial welds may not be known and locating these welds may be challenging. For example, ground or machined welds may not be visible. Furthermore, certain welds or portions of those welds may be covered by the thermal shield or neutron panels, which may affect the ability to achieve coverage requirements. ET may be used to locate these welds by detecting signal differences between the base and weld metal materials. Changes in a material's physical properties (e.g., conductivity, grain size, etc.) affects the flow of current. As the probe scans the base and weld metal materials changes in material structure may appear as changes in the signal. An example of such an application is discussed in [15] where it was noted that the ET signal was able to detect weld seams in rails. The observation illustrates effective potential application of using ET for locating welds. With further validation, locating welds with ET methods could likely be extended to PWR barrel weld applications.

7 SUMMARY

CSB weld indication OE resulted in a need to address interim guidance options. This report established a technical basis to support MRP-227 interim guidance for the Westinghouse-designed CB assembly welds and the CE-designed CSB assembly welds. The technical basis addressed the inspection requirements for these components; specifically, the requirements for inspection type, inspection coverage, and initial inspection timing. In addition, potential supplemental options were discussed.

EVT-1 continues to be an acceptable visual examination method for detecting cracking in the barrel welds. Alternatively, UT and ET examinations may be used for the detection of cracking in the barrel welds. These two methods may also supplement the EVT-1 visual examination.

Inspection coverage requirements for the MAW and the LAW are provided to address differences in plant design, unknown axial weld locations, and accessibility limitations. Detailed descriptions of the coverage requirements are provided in Section 4.1. For EVT-1, the inspection area coverage requirements for the accessible welds remain the weld and three-quarters of an inch of the adjacent base metal on each side of the weld. When UT or ET is used as an alternative to EVT-1, the coverage requirement is three-quarters of an inch of the adjacent base metal only. Inspections from the OD of the barrel remain the accepted approach due to accessibility limitations.

It is recommended that an initial inspection of the MAW and LAW be performed at the same time as the first planned MRP-227 Primary barrel weld inspection or, for plants that have already completed those inspections, at the same time as the next planned MRP-227 Primary barrel weld inspection. The timeframe for this initial inspection will remain the same as currently dictated by MRP-227 because the OE does not indicate that cracking is a common aging effect. Re-inspection requirements will be addressed in a future update to MRP-227. However, if one or more relevant conditions are identified, then subsequent examination should be determined in accordance in WCAP-17096-NP-A.

Lastly, supplemental inspections are discussed and potential use cases are identified. Supplemental inspections can be used to characterize a detected flaw or to determine the extent of condition.

This report supports the development of interim guidance for the CE CSB and Westinghouse CB welds in light of the recent OE. As further OE is gathered, the evaluations and conclusions in this report may require revision to address new knowledge about the extent of barrel weld degradation. A re-evaluation of the inspection coverage requirements described herein should be considered as OE is obtained through the inspections.

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