Nondestructive Evaluation: Inspection and Mitigation of Alloy 82/182 Butt Welds

Focus on Full Structural and Optimized Weld Overlays

1020282

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Technical Update, October 2009

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PRODUCT DESCRIPTION

This report conveys the current status and technical merits of the results derived from the Inspection and Mitigation of Alloy 82/182 Butt Welds project funded by the Materials Executive Oversight Group (MEOG), Materials Reliability Program (MRP), and Nondestructive Evaluation Center (NDEC). The project was constructed and approved for funding to support the utility members in their efforts to meet the commitments set forth in the MRP-169 guideline. It was recognized that there was a gap and mockups would need to be fabricated in order to address the potential configurations stemming from the push for optimized weld overlays (OWOLs) on larger diameter components. The resultant mockups are being used to develop and qualify procedures, ultrasonic techniques, and personnel. In addition, the mockups and associated ultrasonic development activities are helping to support utility members in formulating a basis for relief requests (RRs) to the NRC as well as helping to shape ASME Code requirements for inspection, acceptance, and evaluation of OWOL applications.

Results and Findings

This project presents many technological challenges, which are approaching and, in some cases eclipsing, the bounds of current physics and technology that is available. Current inspection techniques and some advanced developmental techniques were used during this project. The results varied and produced mixed levels of success according to the objectives. Some of the objectives have presented challenges that will serve as future opportunities to develop advanced ultrasonic techniques. The details of results are described in this report.

Challenges and Objectives

Many utilities have chosen full structural overlays as a way to mitigate smaller diameter Alloy 82/182 butt welds considering that these overlays can be applied within normal outage schedules. As the industry moves forward with its implementation of MRP-169, large-diameter components and welds containing unique geometries will need to be addressed, which will require the application of thinner overlays (that is, OWOLs) in order to fit within current outage schedules. These thinner overlays will require inspection below the presently qualified upper 25% of the base material under the overlay.

The proposed objectives for this project are as follows:

- To develop code criteria and RRs needed for the qualification of NDE procedures and personnel relative to the inspection of OWOLs
- To develop procedures for the examination of OWOL components
- To develop procedures for the examination of cast components with OWOL applied
- To document stress and strain data measurements in order to support the design and application of OWOL for large-diameter, thick-walled components
- To expand currently qualified PDI overlay procedures

Applications, Value, and Use
The nuclear industry faces many challenges regarding the advancement of technology to prolong the life of the existing operating fleet. One of the many important areas of concern is the repair/replacement activities, which allow for the continued safe and extended operation of power plants, coupled with the appropriate qualified nondestructive evaluation (NDE) inspection techniques to prove the integrity of vital plant components. Meeting the objectives of this project will have significant positive financial and operational impact on these existing nuclear facilities.

EPRI Perspective
The Electric Power Research Institute (EPRI) has a broad range of expertise in the areas needed to support this project's objectives. EPRI participates on various ASME Code committees that help shape and protect the nuclear industry's operating interests. Our collaborative nature allows EPRI access to multiple channels of information—such as the NRC, inspection and repair vendors, or other utility members—and serve as a focal point for sharing information with our members. EPRI is also in the unique position of having the only approved ASME Section XI, Appendix VIII qualification program in the world, making it a strong organization positioned to facilitate and implement change.

Approach
The goals outlined to meet the objectives of this project are as follows:

- Goal 1: Fabricate PDI samples that would support the needs of the industry relative to OWOL ultrasonic inspections
- Goal 2: Fabricate PDI samples that would support the needs of the industry relative to OWOL stress and strain data measurements
- Goal 3: Fabricate PDI samples that would support the needs of the industry relative to expanding the FSWOL ultrasonic inspection thickness range
- Goal 4: Generate a generic template for the RR associated with OWOL application and inspection
- Goal 5: Prove and qualify ultrasonic inspection techniques below the upper 25% of the base material volume currently in ASME Code and accepted by the NRC (postulated depth to the upper 50% of the base material region)
- Goal 6: Prove and qualify ultrasonic inspection techniques to interrogate cast stainless steel below an OWOL or FSWOL
- Goal 7: Expand EPRI WOL procedure PDI-UT-8 for the inspection of WOL thickness up to 1.65 in. (4.19 cm)

Keywords
ASME
Dissimilar metal weld (DMW)
Full structural weld overlay (FSWOL)
NRC
Optimized weld overlay (OWOL)
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CONTENTS

10 INTRODUCTION

In the past few years, the nuclear power industry has been taking significant proactive measures to further ensure the safety of their operating power plants as well as safely extend the operating life of these facilities. In particular, there has been a focus on the PWR units, many of which had used Alloy 82/182 weld material during their construction. After many years of operating these nuclear facilities, it has been learned that Alloy 82/182 weld metal can become susceptible to pressurized water stress corrosion cracking (PWSCC) during the course of a plant's operating life. The weld joints that contain the susceptible Alloy 82/182 weld metal are subject to frequent ultrasonic inspections to ensure the integrity of the component. These inspections are carried out by individuals who have been tested and certified through the Electric Power Research Institute (EPRI) Performance Demonstration Initiative (PDI) program; which is an approved ASME Section XI, Appendix VIII [1] qualification program. In addition, both the procedures and the equipment used to perform these inspections are demonstrated and qualified under the same approved PDI program.

While performing routine inspections, during refueling outages, the frequency of indications in the susceptible material began to increase on an outage season by outage season basis. This drove the industry to establish 1) *in situ* repairs for components that exhibited indications and 2) preemptive measures for like components that were depicted as potential high-risk candidates. The repair mechanism applied is an ASME-approved design full structural weld overlay (FSWOL). The nature of this repair dictates the need for an accompanying PDI-qualified ultrasonic inspection technique. Personnel performing these examinations must be certified by the PDI program as well as perform the procedures and equipment.

Current qualified procedures and inspection techniques for in-service examinations of FSWOLs are subject to meeting the requirement of interrogating the entire defined ASME Code examination volume (Code Case N-740-2) [2] . The *examination volume lower bound* is defined as the upper 25% of the substrate, which usually includes two base metals joined by a welded joint. The *outboard bounds of the volume* are defined as 1/2 in. outboard of each of the weld joint toes, or 1/2 in. outboard of the furthest extend of a detected in-service indication (see Figure 1-1).

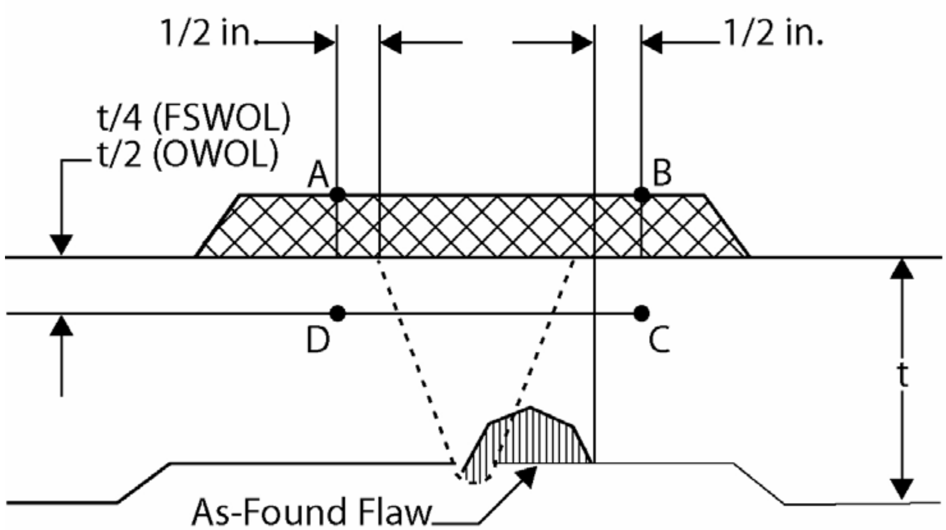

Figure 10-1
Defined full structural weld overlay examination volume (t/4) and proposed optimized weld overlay examination volume (t/2)

Although FSWOLs are used and effective as a mitigation technique, they have been applied only to smaller diameter (~14 in. or less) components in PWR fleets. In essence, these smaller diameter FSWOLs and the optimized weld overlay (OWOL) virtually coincide in design. This means that the design thickness and width of the FSWOL is about equal to that of the OWOL design. This is important to note because the same does not hold true for the larger diameter components, in which there can be a significant difference—up to a 50% reduction of thickness—between the FSWOL and OWOL designs. The need for OWOL on larger diameter components is crucial in meeting the needs of the industry and the demand to keep outage schedules to a minimum. With the high demand and importance of the OWOL design comes the need to redefine the ASME Code examination volume. The newly proposed volume maintains the outboard dimension from each weld toe but increases the amount of base material that must be examined from the upper 25% of substrate thickness to the upper 50% of the substrate thickness (see Figure 1-1).

In order to support the industry need for the application of OWOL on larger diameter components, it was necessary to fabricate mockups representing large-diameter field components, evaluate current and new ultrasonic techniques, expand currently qualified PDI procedures, and assist in proposing ASME Code revisions and relief requests (RRs).

Conversion Factors Used in This Report

The following are the conversion factors used to convert values between English and SI units for units used in this report:

- 1 in. = 25.4 mm
- 1 in. = 2.54 cm

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BACKGROUND

EPRI report 1015009, *Materials Reliability Program: Primary System Piping Butt Weld Inspection and Evaluation Guideline (MRP 139) Revision 1*, [3] lays the groundwork for the way that utility members will go about inspecting, evaluating, and constructing a schedule for mitigating the susceptible Alloy 82/182 weld material currently in service in the PWR's operating fleet. This Alloy 82/182 weld material was used in a wide variety and multiple locations of component weld configurations. Diameters range from 2 to 36 in. pipe-to-nozzle or pipe-to-elbow configurations. If cracking is present, one of the most technically sound mitigation techniques is to perform the application of a FSWOL. This is accomplished by applying layers of weld metal—the height and width of FSWOL that are determined by design and finite element analysis (FEA)—to the outside diameter (OD) of the component coupled by an Alloy 82/182 weld groove joint. The FSWOL has two main functions: 1) to act as a physical structural enhancement to the welded joint configuration based on simply adding structural wall thickness over the susceptible area and 2) to apply compressive stresses in both the axial and circumferential directions, at the inside diameter (ID) of the component. These two characteristics function as the repair mechanism for a cracked component.

It has been recognized that although FSWOLs are technically sound for repair and mitigation, their application on larger diameter components will have a significant impact on utility outage schedule and cost. Keeping in mind these demands of condensed outage schedules and associated costs, EPRI report 1012843, *Materials Reliability Program: Technical Basis for Preemptive Weld Overlays for Alloy 82/182 Butt Welds in PWRs (MRP-169)* [4], provides the technical basis for the application of OWOL as a preemptive or mitigation/repair technique.

Up to this point, the EPRI PDI program had only FSWOL mockups of smaller diameters in its library of test samples. The industry need for OWOL design on larger diameter components was recognized by Materials Executive Oversight Group (MEOG), MRP, and EPRI, which resulted in the cofunding allocated to meet the objectives and goals of this project.

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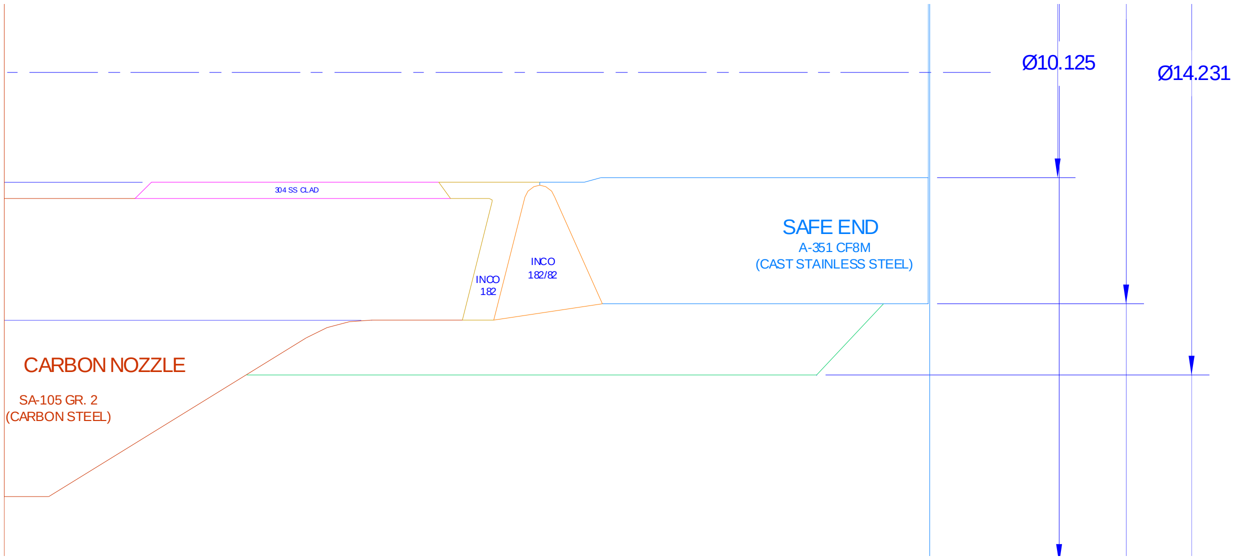
MOCKUP DESIGN AND FABRICATION

Configuration Selection and Design Consideration

In April 2007, a series of meetings was held at EPRI that included participants from EPRI, Structural Integrity Associates, and Welding Services Incorporated (WSI) to discuss the selection of components to be built and the fabrication methods to be used. To address industry concerns, it was decided to fabricate three configurations with OWOL applied (see Figures 3-1 to 3-3).

Specimen 1: Shutdown Cooling Nozzle

This mockup represents a carbon steel nozzle to cast stainless steel (CSS) safe-end configuration joined by an Alloy 82/182 dissimilar metal weld (DMW) joint, with an OWOL of Alloy 52M weld material. It also contains a small, short taper of the weld crown that creates a transition under the OWOL.

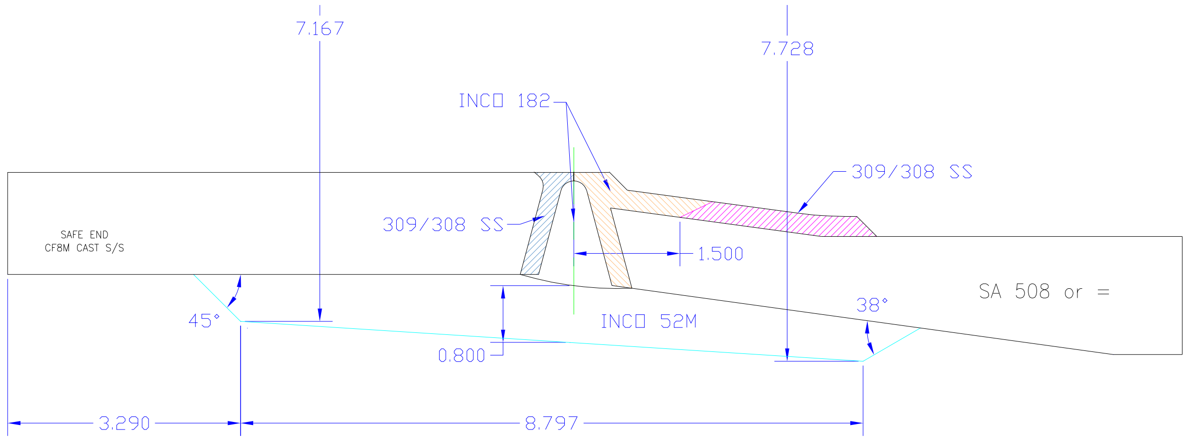


Component diameter: nozzle: 13.09 in., safe end: 12.75 in.
Component thickness (nominal): nozzle: 1.44 in., safe end 1.31 in.
Overlay thickness (nominal): nozzle weld overlay (WOL): 0.57 in., safe end WOL 0.74 in.
Demonstrated range: 1.46 in. (WOL T: 0.74 in. + 50% nozzle T: 0.72 in.)

Figure 12-1
Cross-section of shutdown cooling nozzle optimized weld overlay mockup

Specimen 2: Surge Nozzle

This mockup represents a carbon steel nozzle to CSS safe-end configuration joined by an Alloy 182 and 308/309 buttered DMW joint, with an OWOL of Alloy 52M weld material. It also contains a long, tapered surface under the OWOL that creates a transition. In addition, the OWOL itself is tapered in order to minimize the overlay design thickness.



Component diameter: nozzle: 14.00 in., safe end: 13.00 in.
Component thickness (nominal): nozzle: 1.61 in., safe end: 1.43 in.
Overlay thickness (nominal): nozzle: 0.57 in., safe end: 0.67 in.

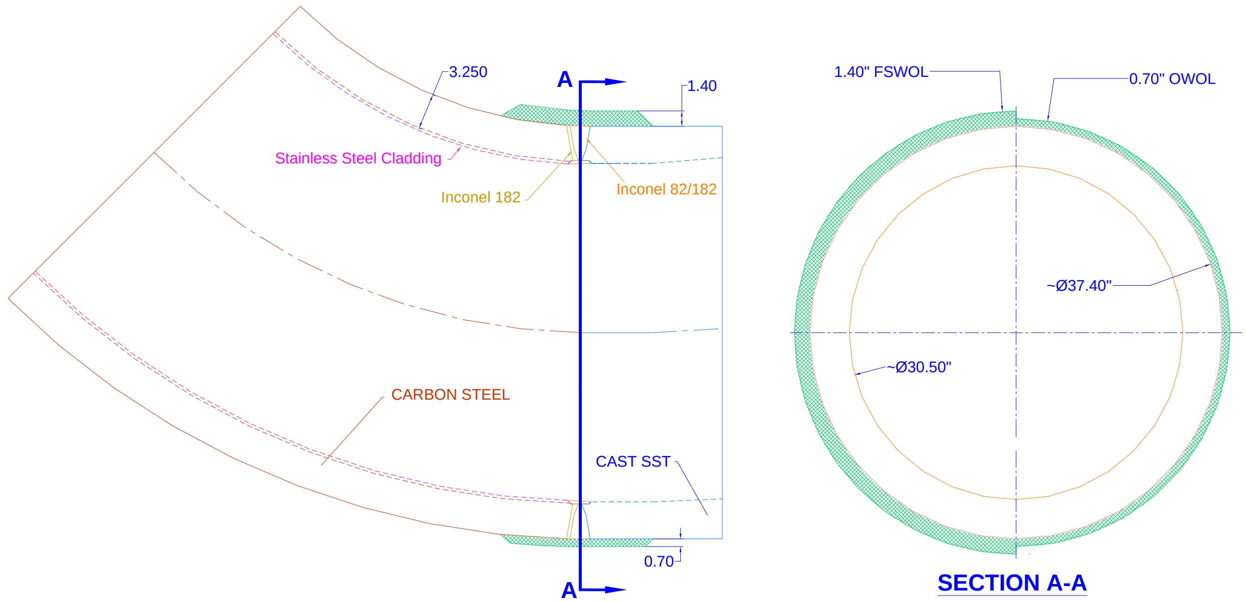
Figure 12-2
Cross-section of surge nozzle optimized weld overlay mockup

Specimen 3: Reactor Coolant Pump Nozzle

This mockup serves a dual purpose. In general, it represents a carbon steel nozzle to CSS safe-end configuration joined by an Alloy 82/182 DMW joint, with an OWOL of Alloy 52M weld material. It also contains an elbow to represent several configurations of this size that exist in the PWR fleet.

Specific design considerations were given to this mockup so that it could serve as both an OWOL sample and a FSWOL sample, thereby allowing for it to serve the dual purpose of extending the thickness range of the qualified PDI FSWOL procedure to 1.65 in. and for developing and qualifying OWOL ultrasonic inspection techniques.

Specific design consideration was also given, in particular, to the application of the overlay for this specimen. This was because of its being the configuration to be used for measurements and evaluation of the stress and strain imparted on the specimen by the OWOL. The actual overlay application was performed by WSI and was performed in accordance with the WSI Quality Assurance Program and in a manner that replicated a field installation of an overlay. Welding parameters, techniques, and equipment were made to simulate these conditions in order to obtain the most accurate stress and strain measurements possible. See EPRI report 1016602, *Materials Reliability Program: Technical Basis for Preemptive Weld Overlays for Alloy 82/182 Butt Welds in PWRs (MRP-169) Revision 1* [5], for the results of the stress and strain measurements taken.



Component OD (nominal): nozzle/safe end: 37.4 in.
Component thickness (nominal): nozzle: 3.75 in., safe end: 3.75 in.
OWOL thickness (nominal): nozzle/safe end: 0.70 in.
FSWOL thickness (nominal): nozzle/safe end: 1.40 in.

Figure 12-3
Cross-section and end view of dual-purpose reactor coolant pump full structural weld overlay and optimized weld overlay mockup

The successful completion of fabricating these three mockups supports and satisfies the following project goals:

- Goal 1: Fabricate PDI samples that would support the needs of the industry relative to OWOL ultrasonic inspections
- Goal 2: Fabricate PDI samples that would support the needs of the industry relative to OWOL stress and strain data measurements
- Goal 3: Fabricate PDI samples that would support the needs of the industry relative to expanding the FSWOL ultrasonic inspection thickness range

All specimens were completed and delivered to EPRI by February 2008.

Flaw Design Selection and Consideration

Note: Because these samples are all blind (that is, secure samples) in which the flaw size and location are not open knowledge; this section will use generic references and illustrations.

After the configuration selection and design were solidified, EPRI was charged with the task of flaw design, distribution, and fabrication. In order to satisfy the project's goals, multiple flaw-making techniques were used, along with various placements, in the DMW, the weld butter, or the CSS base material.

Flaw Types 1 and 2: Ultrasonic Technique Development and Qualification for Optimized Weld Overlay

Figures 3-4 and 3-5 display general flaw information about the nature of the approximate 50% through-wall flaws that were fabricated in the mockups. These types of flaws were used to support the following projects goals:

- Goal 1: Fabricate PDI samples that would support the needs of the industry relative to OWOL ultrasonic inspections
- Goal 5: Prove and qualify ultrasonic inspection techniques below the upper 25% of the base material volume currently in ASME Code and accepted by the NRC (postulated depth to the upper 50% of the base material region)

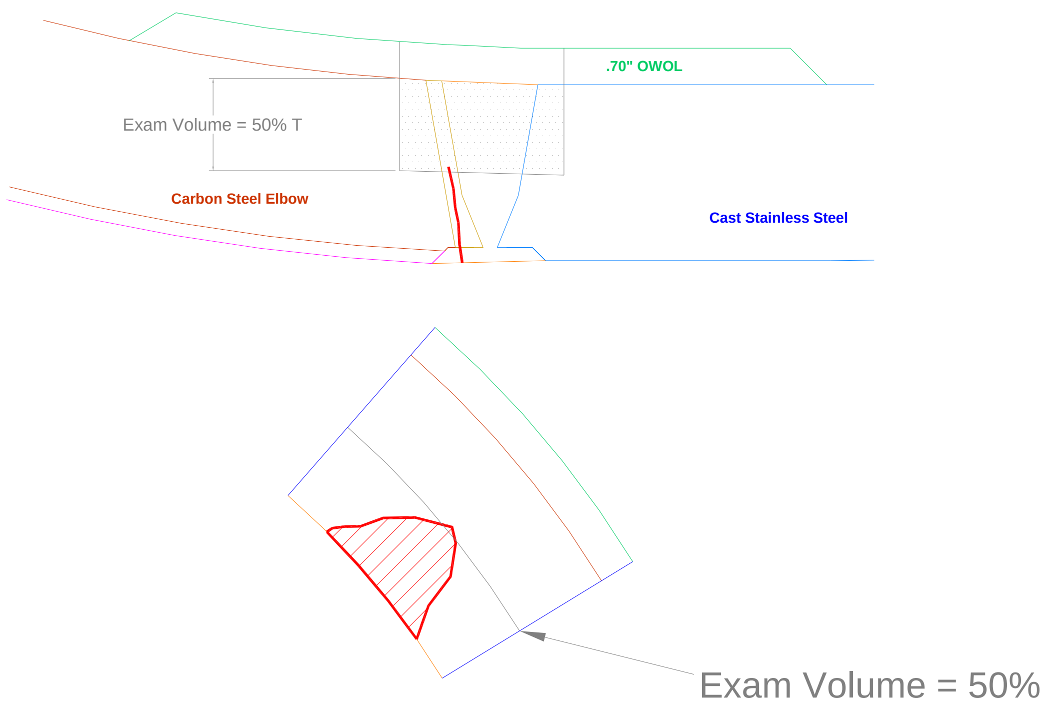
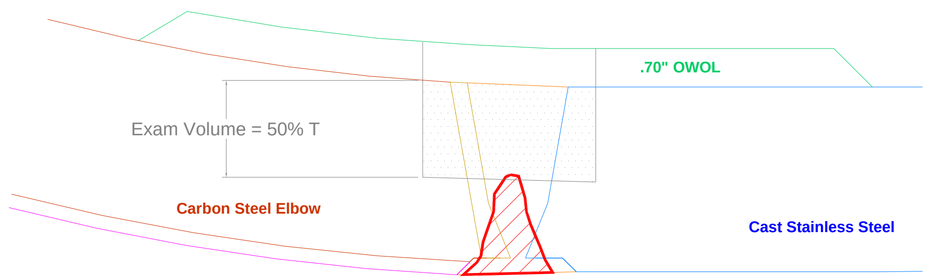


Figure 12-4
Flaw type 1: Cross-section and end view of circumferential flaw at ~50% base material with optimized weld overlay



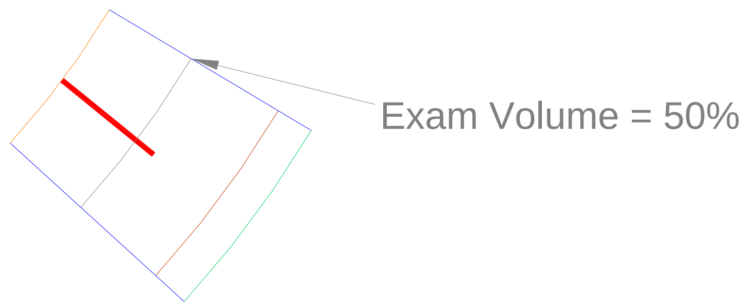


Figure 12-5
Flaw type 2: Cross-section and end view of axial flaw at ~50% base material with optimized weld overlay

Flaw Types 3 and 4: Ultrasonic Technique Development and Qualification for Cast Substrate with Full Structural Weld Overlay

Figures 3-6 and 3-7 display general flaw information about the nature of the approximate 75% through-wall flaws that were fabricated in the mockups. These types of flaws were used to support the following projects goals:

- Goal 6: Prove and qualify ultrasonic inspection techniques to interrogate cast stainless steel below an OWOL or FSWOL
- Goal 7: Expand EPRI WOL procedure PDI-UT-8 [6] for the inspection of WOL thickness up to 1.65 in.

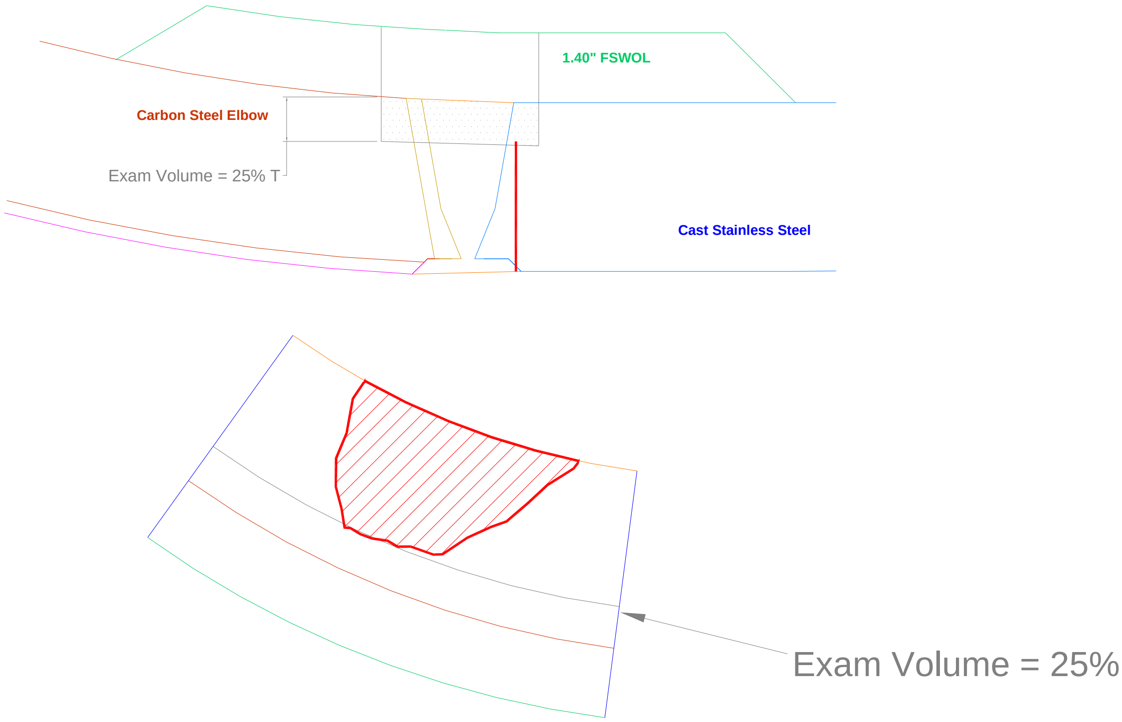


Figure 12-6
Flaw type 3: Cross-section and end view of circumferential flaw at ~75% base material in cast stainless steel substrate with full structural weld overlay

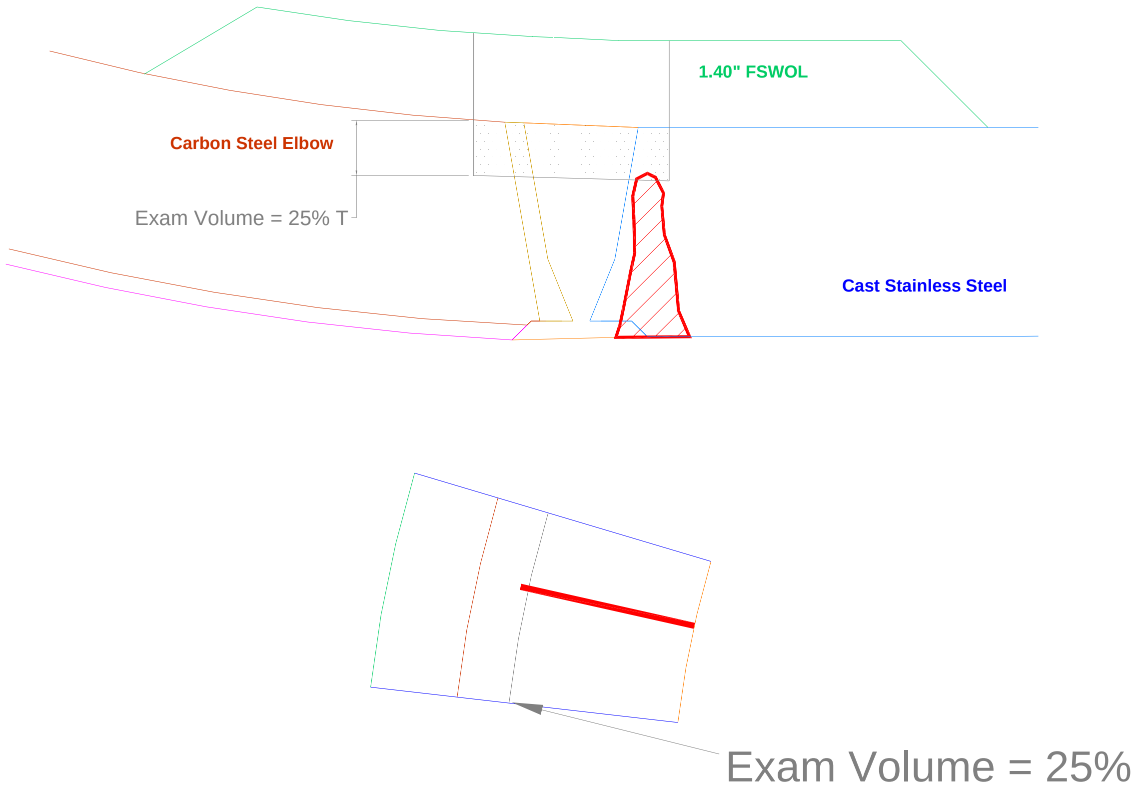


Figure 12-7
Flaw type 4: Cross-section and end view of axial flaw at ~75% base material in cast stainless steel substrate with full structural weld overlay

Flaw Types 5 and 6: Overlay Procedure Inspection Thickness Range Increase

Figures 3-8 and 3-9) display general flaw information about the nature of the approximate 75% through-wall flaws that were fabricated in the mockups. These types of flaws were used to support the following projects goal:

- Goal 7: Expand EPRI WOL procedure PDI-UT-8 [6] for the inspection of WOL thickness up to 1.65 in.

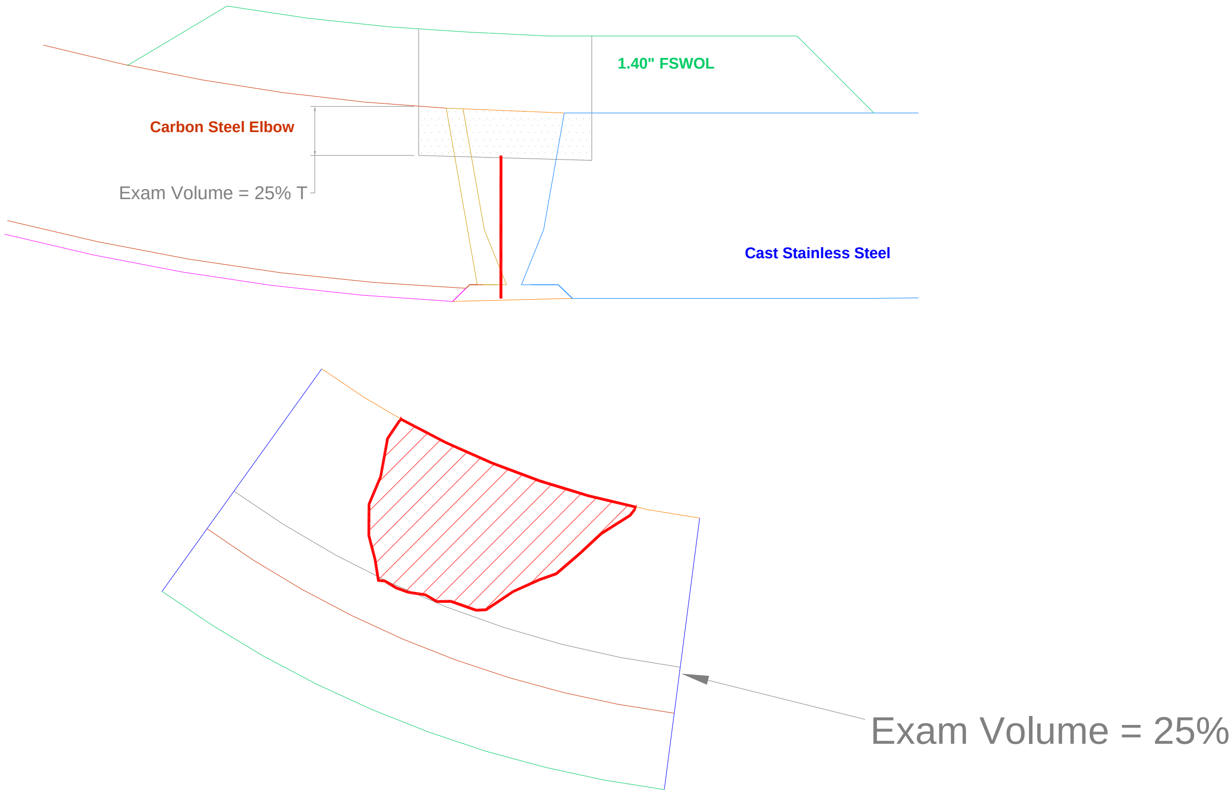


Figure 12-8
Flaw type 5: Cross-section and end view of circumferential flaw at ~75% weld material with full structural weld overlay

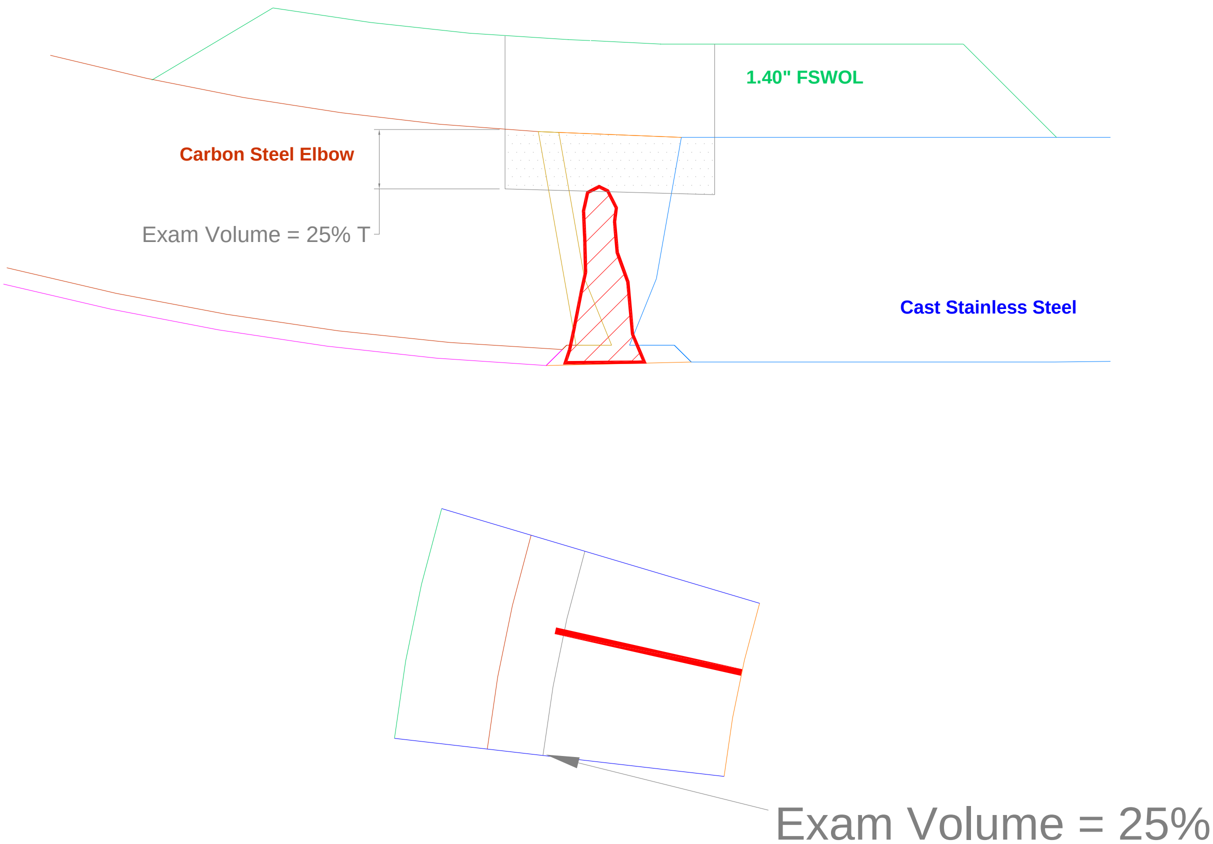


Figure 12-9
Flaw type 6: Cross-section and end view of axial flaw at ~75% weld material with full structural weld overlay

13 INSPECTION TECHNIQUES

General Inspection Method

When mockups are delivered to EPRI from the manufacturer, they undergo a series of measurements to ensure that the specimens were fabricated to specifications. One of the tests that each mockup undergoes is an ultrasonic verification of the flaws and the weld workmanship. Under normal circumstances, search units would be selected based on the manual procedure for the associated component and the area of interest. Because of the unique nature of these samples, additional work was required in order to obtain the best possible data with the equipment and technology available to EPRI at the time. In all cases, both conventional and phased array technology were used in the evaluation of the OWOL mockups. Several techniques were used to detect and characterize the flaws types contained in the OWOL mockups, and this section describes the work performed.

Flaw Types 1 and 2 Inspection Technique

Flaw types 1 and 2 were intended to expand the examination volume down to the upper 50% of the original base material. The expanded examination volume was cause for special consideration to be given to the search unit focus and frequency. With these types of flaws, it was necessary to focus the primary detection search units near the 50% base material boundary. Focusing the search units in the area of interest narrows the sound beam and increases the amount of energy that returns to the search unit and, as a result, increases the amplitude on the display. In addition to frequency requirements specified by PDI-UT-8, search units with lower frequency were used to evaluate their effectiveness in the area of interest.

Flaw Types 3 and 4 Inspection Technique

Flaw types 3 and 4 were intended to evaluate the ability to detect and characterize flaws contained in CSS material with a weld overlay installed on the component. The CSS material causes the greatest challenge when attempting to characterize flaws in this category. Because of the large grain size and the attenuation properties of this material, ultrasonic waves do not propagate well through the material and, as a result, low-frequency search units are most commonly used in an attempt to inspect this material. Along with the search units used on flaw types 1 and 2, a series of search units with much lower center frequencies was tried in order to detect and characterize the type 3 and 4 flaws. An equipment vendor commonly used by EPRI modified and lent EPRI an instrument capable of transmitting and receiving the signals from the low-frequency search units. With the aid of the low-frequency search units and modified instrument, a large amount of data on the flaw types 3 and 4 was collected, which will further assist in evaluating techniques for detecting and characterizing flaws in cast material.

Flaw Types 5 and 6 Inspection Technique

Flaw types 5 and 6 were designed to expand the maximum overlay thickness of existing and newly qualified procedures. The techniques used to evaluate these flaws came from the PDI Generic Procedure for Weld Overlaid Components, PDI-UT-8. The techniques identified in PDI-UT-8 were used and produced results described in Section 5.

14 RESULTS

Flaw Types 1 and 2: Ultrasonic Technique Development and Qualification for Optimized Weld Overlay

Note: Refer to Figures 3-4 and 3-5 for illustration of these flaw types.

Flaw Type 1

Flaw type 1 is a circumferential flaw with a through-wall depth of approximately 50%. This flaw is needed in order to demonstrate and qualify ultrasonic techniques in the upper 50% thickness region of the substrate material after the application of an OWOL.

Ultrasonic techniques were applied and data were taken and analyzed for this flaw type in all three samples described in Section 3. The outcome from this analysis was positive: this flaw type was accurately detected, length sized, and depth sized.

The ultrasonic techniques used to detect and characterize this flaw type are commercially available and can be qualified. This supports and validates the successful inspection of the upper 50% base material region under an OWOL for circumferential flaws.

These results, in part, support the achievement of the following project goal:

- Goal 5: Prove and qualify ultrasonic inspection techniques below the upper 25% of the base material volume currently in ASME Code and accepted by the NRC (postulated depth to the upper 50% of the base material region)

Flaw Type 2

Flaw type 2 is an axial flaw with a through-wall depth of approximately 50%. This flaw is needed in order to demonstrate and qualify ultrasonic techniques in the upper 50% thickness region of the substrate material after the application of an OWOL.

Ultrasonic techniques were applied and data were taken and analyzed for this flaw type in all three samples described in Section 3 (see Figures 3-1, 3-2, and 3-3). Note: length sizing of axial flaws is **not** qualified in any existing PDI procedure. Therefore, the focus of this analysis was based only on detection and depth sizing capabilities. The results of this analysis produced a less than desirable outcome.

In all three specimens; no credit could be taken for successfully detecting these axial flaws. Exhaustive measures have been taken in an effort to attempt to reconcile this situation. EPRI embarked on an emergency R&D project to try to understand the physics of such a lack of success in detecting flaws of this nature.

Some initial thoughts were that the nature of the axial flaws used was too conservative, meaning they were very smooth reflectors that are not conducive to generating ultrasonic responses in thicker walled samples (approximately 2.5 in.). Although very conservative; these types of axial flaws are the preferred type that are used and successfully characterized by current ultrasonic techniques in existing PDI DM samples. Using these very conservative flaws and the introduction of the OWOL/FSWOL, combined with an increase in substrate thickness, seems to have exceeded the capabilities of current ultrasonic inspection techniques. This scenario promotes the hypothesis of needing a less conservative (smooth) flaw and investigating using flaws with a rougher face to better simulate actual in-service flaw morphology.

With concurrence and additional funding from the utility member sponsors, EPRI proceeded with this accelerated R&D effort. EPRI contacted Uddcomb, a Swedish engineering company with the capabilities and a qualified technique for producing PWSCC type flaws through their proprietary weld solidification flaw-making process, to fabricate two flaws in an EPRI R&D block. The fabrication methods used to build these types of weld solidification flaws produce a branched-type reflector more similar to an in-service flaw. These flaws were also designed at depths to replicate the ultrasonic metal path that is indicative of the axial flaws at the upper 25% and 50% base material thickness regions in specimen 3. Uddcomb was able to deliver the block to EPRI in early August 2008. EPRI then applied a FSWOL pad over the flaw that was in the upper 25% base material region and an OWOL pad over the flaw that was in the 50% base material region.

EPRI performed identical ultrasonic techniques on the R&D block that was applied on specimen 3 and collected ultrasonic data. The analysis of the data produced similar results to the original analysis that was performed on the data collected from specimen 3. The upper 50% base material region flaw was again not detectable, and therefore, not able to be characterized.

These results, in part, **do not** support the achievement of the following project goal:

- Goal 5: Prove and qualify ultrasonic inspection techniques below the upper 25% of the base material volume currently in ASME Code and accepted by the NRC (postulated depth to the upper 50% of the base material region)

Flaw Types 3 and 4: Ultrasonic Technique Development and Qualification for Cast Substrate with Full Structural Weld Overlay

Note: Refer to Figures 3-6 and 3-7 for illustration of these flaw types.

Flaw Types 3 and 4

Flaw type 3 is a circumferential flaw, and flaw type 4 is an axial flaw. Both flaws have a through-wall depth of approximately 75%. The flaws are wholly contained in the CSS base material. These flaws are needed in order to demonstrate and qualify ultrasonic techniques in the upper 25% thickness region of the substrate material after the application of a FSWOL.

Ultrasonic techniques were applied and data were taken and analyzed for these flaw types in all three samples described in Section 3. The analysis of the collected data proved to show that no flaw-like indications were detectable in any of the specimens by any of the current or advanced ultrasonic techniques available. Known flaws did, in fact, exist in the areas that were interrogated by these ultrasonic techniques.

These results, in whole, **do not** support the achievement of the following project goal:

- Goal 6: Prove and qualify ultrasonic inspection techniques to interrogate cast stainless steel below an OWOL or FSWOL

These results, in part, **do not** support the achievement of the following project goal:

- Goal 7: Expand EPRI WOL procedure PDI-UT-8 [6] for the inspection of WOL thickness up to 1.65 in.

Flaw Types 5 and 6: Overlay Procedure Inspection Thickness Range Increase

Note: Refer to Figures 3-8 and 3-9 for illustration of these flaw types.

Flaw Types 5 and 6

Flaw type 5 is a circumferential flaw, and flaw type 6 is an axial flaw. Both flaws have a through-wall depth of approximately 75%. These flaws are needed in order to demonstrate the ability to expand the WOL thickness range of the currently qualified PDI-UT-8 [6] to 1.65 in.

Ultrasonic techniques were applied and data were taken and analyzed for these flaw types in both specimens 2 and 3 described in Section 3. The outcome from this analysis was positive: these flaw types was accurately detected and characterized.

The ultrasonic techniques used to detect and characterize these flaw types are commercially available and can be qualified. This information supports and validates the successful inspection of the upper 25% base material region under a 1.65 in. WOL thickness for circumferential and axial flaws.

These results, in whole, support the achievement of the following project goal:

- Goal 7: Expand EPRI WOL procedure PDI-UT-8 [6] for the inspection of WOL thickness up to 1.65 in.

Results for flaw types (1–6) varied based on component configuration, wall thickness, and diameter. Table 5-1 is a display of the information per specimen.

Table 14-1
Results matrix of EPRI ultrasonic inspection of specimens 1–3 per flaw types 1–6

Ultrasonic Testing Flaw Type	Specimen 1: Shutdown Cooling Nozzle			Specimen 2: Surge Nozzle			Specimen 3: Reactor Coolant Pump Nozzle		
	Detection	Length Sizing	Depth Sizing	Detection	Length Sizing	Depth Sizing	Detection	Length	Depth Sizing
1 OWOL circ at 50% in weld joint	Yes	*Yes	*Yes	Yes	Yes	Yes	Yes	*Yes	*Yes
2 OWOL ax at 50% in weld joint	No	NA	No	No	NA	No	No	NA	No
3 FSWOL circ at 75% in cast SST	No	No	No	No	No	No	No	No	No
4 FSWOL ax at 75% in cast SST	No	NA	No	No	NA	No	No	NA	No
5 FSWOL circ at 75% in weld joint	^NA	^NA	^NA	Yes	Yes	Yes	Yes	*Yes	*Yes
6 FSWOL ax at 75% in weld joint	^NA	NA	^NA	Yes	NA	Yes	Yes	NA	Yes

* These entries are currently being evaluated for establishing the process of accurately determining actual lengths and depths of the flaws at the given upper 25% and 50% base material depths. This is a process issue and **not** an ultrasonic flaw detection or characterization issue.
^ These entries do not contain types 5 and 6 flaws; therefore evaluation is not possible for specimen 1.

Supporting Relief Request Activities

The culmination of these results is serving to facilitate pilot plants in their efforts to formulate RRs for OWOL applications and inspection. EPRI has been working with utility members Duke Energy and Entergy Nuclear in reviewing draft RRs. Duke Energy has submitted a RR to the NRC and has received a request for additional information (RAI). Duke, with some input from EPRI, is in the process of formulating their response to the NRC.

These in process efforts will eventually support the achievement of the following project goal:

- Goal 4: Generate a generic template for the relief request associated with OWOL application and inspection

15 SUMMARY

The objectives of this project present many technological challenges relative to the application of conventional and advanced ultrasonic techniques for the inspection of an OWOL. Both current and advanced developmental ultrasonic inspection techniques were used during this project. In some cases, these challenges proved to be beyond the physics of the technology that is currently available. The varying levels of success and meeting the objectives of this project will force the development of new advanced ultrasonic techniques and may reshape some of the current approaches for the application of FSWOL and OWOL.

The goals of this project were met with mixed success. In some cases, additional time is needed to investigate advanced ultrasonic techniques. The challenges of performing qualified ultrasonic inspections of OWOL over larger diameter, thick-walled components still commands a high level of ultrasonic technique R&D work. In addition, substantial ASME Code work needs to be performed and submitted to the NRC for approval. In the interim of ASME Code acceptance for OWOL applications, RRs will need to be submitted to and accepted by the NRC.

Utility members, the NRC, EPRI, and nuclear service companies will need to work together to ascertain a mutually beneficial position for the nuclear industry's operating fleet. The successes derived from this project will serve as the platform on which to build.

Mockup Fabrication and Quality Assurance Acceptance

All of the specimens were fabricated by EPRI-approved vendors that are subject to either a direct Quality Assurance (QA) audit perform by EPRI or EPRI's review and acceptance of the Nuclear Procurement Issues Committee audit. All mockups were delivered by February 2008. On delivery, the mockups were processed in accordance with the EPRI Quality Assurance-approved PDI Test Specimen Fabrication Program and its associated Quality Project Instructions. This program is a 10 CFR 50 Appendix B quality program that certifies that the mockup complies with its intended fit, form, and function. Each of the specimens is issued a PDI Certificate of Conformance after all of the QA requirements have been satisfied.

Future Technological Challenges and Opportunities

Optimized Weld Overlay ASME Code Criteria and Relief Request for Inspections

The application of an OWOL on larger diameter, thick-walled components presents some challenges relative to performing ASME Section XI, Appendix VIII qualified ultrasonic inspections. Currently, the ultrasonic inspections proposed for the volume increase from the upper 25% of the base material to the upper 50% has not been wholly successful. The axially orientated flaws placed in this 50% target range of the substrate material have not been able to be detected by currently available ultrasonic techniques. This limits the ability to expand the current PDI-qualified procedures. Because of the lack of success with detecting axial flaws, the ASME Code criteria changes must be revisited to address this limitation. In addition, the submittal of RRs will need to show substantial justification for the proposed handling of potential axial indications.

In May 2009, a draft revision of ASME Boiler and Pressure Vessel Code, Section XI, 2007 Edition, Appendix VIII, Supplement 11, "Qualification Requirements for Full Structural Overlaid Wrought Austenitic Piping Welds," [1] was submitted to the Code committee for review and comment.

Optimized Weld Overlay Ultrasonic Inspection Procedure Development and Qualification

Further investigations are under way to address the kind of procedure qualifications that will be acceptable to form ASME Code criteria and satisfy the NRC. This stems from the mixed amount of success shown in the results of this report relative to flaw detection and characterization. NRC influence and challenges posed by pure physics will have the greatest impact on the direction the industry pursues.

Cast Stainless Steel

CSS has and continues to pose real challenges to the industry. The impact of the physics involved with the application of ultrasonic techniques, relative to the larger grain structure castings, is still too large to overcome. In addition, cases must be studied for each of the casting types: statically cast and centrifugal cast components. Although some common ground between the two forming methods exists, there are some equally challenging differences. Continuing research on this phenomenon is under way at EPRI and some other research institutes in the United States and internationally.

In support of this project's objective, EPRI has used a wide variety of ultrasonic techniques in an effort to develop a successful plan for the inspection of CSS under weld overlaid components. The results of the many attempts to ultrasonically characterize flaws in the CSS were unsuccessful.

In 2009, Pacific Northwest National Laboratory (PNNL) visited EPRI to collaborate on data acquisition and analysis techniques used for inspection of the EPRI specimens containing CSS under weld overlaid components. PNNL brought their own advanced ultrasonic equipment and personnel to perform data collection and analysis. The results derived from this effort were in concurrence with the EPRI findings that ultrasonic flaw characterization is not possible at this time.

Proposed Success Path Based on Current Results

Optimized Weld Overlay ASME Code Criteria and Relief Request for Inspections

The current results produced from this project will, in part, contribute to the ASME Code criteria changes. The current success of detection and characterizing **circumferential** flaws at the upper 50% region of the base material is promising. It allows for some ASME Code criteria to be revised and submitted for NRC approval. Because the ability to detect **axial** flaws in the same upper 50% region of the base material has not yet been able to be demonstrated, it has been decided to forgo proposing any ASME Code criteria changes at this time. Further ultrasonic technique development, in terms of detecting and characterizing axial flaws, is under way. There have been no estimates on duration to achieve success for these flaws.

In support of this approach, design calculations of the OWOL use the **axial** flaw as the limiting factor in its design. Structural Integrity Associates (SIA) has performed weld overlay structural sizing, residual stress, and crack growth evaluations of an OWOL for a typical reactor pressure vessel (RPV) outlet nozzle. The results of these analyses support the proposed hybrid inspection approach in that the OWOL design is found to be **essentially full structural** for axially oriented flaws. The SIA document “MRP-169 OWOL Inspection” [7] provides more detailed information.

The formulation and filing of RRs will wholly depend on the NRC’s acceptance of the approach summarized here.

Optimized Weld Overlay Ultrasonic Inspection Procedure Development and Qualification

Procedure development and qualification will be based on the NRC’s acceptance of the previously described hybrid approach. EPRI has already begun working on procedure development for conventional and phased array ultrasonic techniques. These techniques are relative to the inspection approach that has successfully detected and characterized circumferential flaws down to the upper 50% region of base material and axial flaws down to the upper 25% region of the base material. The start of inspection vendors’ procedure qualifications for this approach will depend on ASME Code criteria revisions and the acceptance by the NRC.

In 2009, as of this report’s publishing date, one inspection vendor has successfully qualified a PDI procedure for the inspection of OWOL components. Several other inspection vendors have plans to complete the same level of PDI procedure qualification in 2009. In addition, vendors have expressed interest and intentions of qualifying the EPRI PA-01 manual phased array procedure for OWOL inspection efforts.

Full Structural Weld Overlay Performance Demonstration Initiative Qualified Ultrasonic Inspection Procedure Expansion

Ultrasonic techniques were applied and data were taken and analyzed for flaws that support expanding the qualified PDI WOL procedure to 1.65 in. as the upper thickness bound.

The ultrasonic techniques used to detect and characterize flaws supporting this procedure thickness range expansion are commercially available and can be qualified. This information supports and validates the successful inspection of the upper 25% base material region under a 1.65 in. WOL thickness for circumferential and axial flaws. Expansion of the PDI-qualified procedure will take place when the need for a vendor to qualify presents itself.

In 2009, as of this report's publishing date, one inspection vendor has attempted to expand a currently qualified PDI procedure. Results are pending.

Currently, based on subject matter expert evaluation, only image-based systems are capable of successfully characterizing flaws to the extent necessary to qualify procedures. This is primarily limited to automated or semi-automated encoded systems. Because of the nature of manual phased array equipment being able to display images of flaw facets, it too is being evaluated for applicability of procedure qualification. Conventional manual ultrasonic techniques might be attempted in the future, based on the success of the manual phased array efforts. In addition, for the qualification of conventional manual ultrasonic testing, there is a need to increase the flaw population and test sets to accommodate these new qualifications, samples of which are currently on order.

Optimized Weld Overlay Stress and Strain Measurements

Refer to MRP-169 (latest revision) [4] for information relative to OWOL stress and strain measurements taken and the results of the analysis performed.

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