TR-105696-R11 (BWRVIP-03NP) Revision 11: BWR Vessel and Internals Project

Reactor Pressure Vessel and Internals
Examination Guidelines

1016584NP

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PRODUCT DESCRIPTION

In 1990, a visual examination of the core shroud of a Swiss boiling water reactor (BWR) revealed the presence of intergranular stress corrosion cracking. Since that event, examinations of other BWR vessel internal components have revealed an industry-wide cracking problem. In 1994, domestic BWR-owning utilities formed the Boiling Water Reactor Vessel & Internals Project (BWRVIP), which is chartered to support a program addressing the problems of reactor internals, internal attachments, vessel welds, and vessel nozzles. Most international BWR owners have become members. This annual report defines inspection standards and documented inspection techniques for BWR vessel internal components.

Results and Findings

Procedure standards have been developed for ultrasonic, visual, and eddy current inspection. Many inspection techniques have been demonstrated and documented. In support of these demonstrations, realistic mockups of reactor internal components have been manufactured with controlled flaws. BWR owners can use these documented techniques to inspect their vessel internal components in compliance with BWRVIP guidance.

Challenges and Objectives

In-service inspection program managers and BWR vessel internals program managers use this document to ensure that their components are inspected in compliance with BWRVIP guidance.

Applications, Value, and Use

The information contained in this report is applied by all BWR owners in the preparation for and during refueling outages. It is updated annually.

EPRI Perspective

This report provides the BWR fleet with inspection options for all of the safety-related vessel internal components, and provides a stable mechanism for documenting the capability of the evolving inspection technology. It is the sole resource for internals inspection information for BWR owners.

Approach

The BWRVIP strives to make effective inspection techniques available by developing inspection standards that can ensure the structural integrity of the components and providing demonstrated, documented techniques for effectively examining the susceptible components.

Keywords
BWRVIP
NDE
Internals
Inspection
Ultrasound
Vessel

EXECUTIVE SUMMARY

This document presents findings and products of the Inspection Focus Group of the Boiling Water Reactor Vessel and Internals Project (BWRVIP). An overview of the structure of the BWRVIP is presented, with an outline of the goals and approach of the Focus Group.

The Inspection Focus Group has developed guideline documents which establish protocols for utilities and nondestructive evaluation (NDE) vendor companies to follow in order to gain access to BWRVIP-owned mockups; to perform formal demonstrations of NDE techniques using BWRVIP mockups; and to perform their own demonstrations of NDE techniques or inspection tooling in a manner acceptable to the Focus Group. These documents are included in their entirety.

The Focus Group has conducted extensive investigations and demonstrations of NDE techniques appropriate for inspection of BWR internals. These efforts have included the design, fabrication, and inspection of a series of realistic mockups containing realistic simulations of the degradation mechanisms of concern. These investigations result in the development of evaluation factors, which are numerical values, related to the uncertainties inherent in delivering and executing an NDE technique in a BWR. These evaluation factors are combined with the actual results of an inspection to form input into a fracture-mechanics assessment of the component's serviceability.

The Focus Group's activities are ongoing. The various components of BWR vessels and internals are being addressed in concert with other technical Committee efforts. For components addressed to date, this report includes data on mockup fabrication, NDE uncertainty measurements and evaluation factors, and procedure standards for ultrasonic examination, eddy current examination, and visual examination.

This is a living document. Updates to the included data on components that have already been addressed, and new report sections on components that have not yet been addressed, will be supplied as they are developed. A history of changes is included within the document.

HISTORY OF CHANGES TO THIS DOCUMENT REVISION 11

This is a living document. Updates to the included data will be added as they are developed. Minor or editorial changes may not appear in this summary listing of significant changes. This document supersedes the November 21, 1994, Inspection Committee document *BWR-VIP Core Shroud NDE Uncertainty & Procedure Standard* and *Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03)* (EPRI Report TR-105696, October 1995). The changes listed below supersede the affected paragraphs of *TR-105696-R10 (BWRVIP-03) Revision 10: Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines* (EPRI Report 1014993, December 2007).

Affected Section(s)	Description of Change
xxxi	Updated the Inspection Focus Group roster.
2.6, Para. 3.3	Clarified requirement for qualifications of UT analysis personnel with regard to automated versus manual IGSCC qualifications.
2.6, Para. 4.2	Updated UT technique parameters to include key elements associated with application of phased array techniques.
2.6, Para. 4.3	Added guidance to assist with updates of UT hardware and software for evaluating impact on published BWRVIP demonstrations.
2.6, Para. 9.1	Clarified requirement for UT data analyst to review examination data quality.
Table 4.4.2-1	Updated to reflect new NDE technique demonstration.
4.4.58	New section: new NDE technique demonstration.
6.3.1.6	New section: new NDE mockups for core spray.
10.3.3	Updated to reflect the addition of an NDE mockup for the jet pump downcomer mixer weld.
10.4.19–10.4.21	New sections: new NDE technique demonstrations.

HISTORY OF CHANGES TO THIS DOCUMENT REVISION 10

This is a living document. Updates to the included data will be added as they are developed. Minor or editorial changes may not appear in this summary listing of significant changes. This document supersedes the November 21, 1994, Inspection Committee document *BWR-VIP Core Shroud NDE Uncertainty & Procedure Standard* and *Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03)* (EPRI Report TR-105696, October 1995). The changes listed below supersede the affected paragraphs of *TR-105696-R9 (BWRVIP-03) Revision 9: Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines* (EPRI Report 1013394, December 2006).

Affected Section(s)	**Description of Change**
xxvii	Updated the Inspection Focus Group roster.
2.5, Para. 2.3	Clarified requirement for performing a VT-1 or VT-3 in accordance with a BWRVIP document versus in accordance with the utility's ASME Section XI requirements.
2.5, Para. 3.6	Changed the definition of Enhanced VT-1 (EVT-1) from requiring ½ mil resolution to requiring the capability of resolving the ASME Code Section XI VT-1 0.044 inch characters.
2.5, Para. 5.1	Deleted the requirement for the ½ mil SRCS and added the requirement for ASME Code Section XI VT-1 0.044 inch characters as a required SRCS.
2.5, Para. 6.3.2	Updated to reflect requirement for resolving the ASME Code Section XI VT-1 0.044 inch characters.
2.5, Para. 6.5.5	Added requirement for camera motion (speed) during examination to not exceed 0.5 inch/sec.
2.5, Para. 6.5.6	Changed requirement for camera angle to not exceed 30 degrees from perpendicular to the surface.
Table 4.4.2-1	Updated to reflect new NDE technique demonstrations and included reference to vertical welds in the applicable weld(s) column.

4.4.47–4.4.57	New sections: new NDE technique demonstrations.
5.4.40–5.4.46	New sections: new NDE technique demonstrations.
Table 6.4.2-1	Updated to reflect new NDE technique demonstrations.
6.4.40–6.4.43	New sections: new NDE technique demonstrations.
10.4.18	New section: new NDE technique demonstration.

HISTORY OF CHANGES TO THIS DOCUMENT REVISION 9

This is a living document. Updates to the included data will be added as they are developed. Minor or editorial changes may not appear in this summary listing of significant changes. This document supersedes the November 21, 1994, Inspection Committee document *BWR-VIP Core Shroud NDE Uncertainty & Procedure Standard* and *Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03)* (EPRI Report TR-105696, October 1995). The changes listed below supersede the affected paragraphs of *TR-105696-R8 (BWRVIP-03) Revision 8: Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines* (EPRI Report 1011689, December 2005).

Affected Section(s)	**Description of Change**
xxvii	Updated the Inspection Focus Group roster.
Chapter 1	Updated to include NEI 03-08 Implementation Requirements.
Table 4.4.2-1	Updated to reflect new NDE technique demonstrations.
4.4.42–4.4.46	New sections: new NDE technique demonstrations.
5.3.2	Added two new shroud support mockups.
Table 6.4.2-1	Updated to reflect new NDE technique demonstrations.
6.4.36–6.4.39	New sections: new NDE technique demonstrations.
10.4.14	Corrected errata.
10.4.15–10.4.17	New sections: new NDE technique demonstrations.

HISTORY OF CHANGES TO THIS DOCUMENT REVISION 8

This is a living document. Updates to the included data will be added as they are developed. Minor or editorial changes may not appear in this summary listing of significant changes. This document supersedes the November 21, 1994, Inspection Committee document *BWR-VIP Core Shroud NDE Uncertainty & Procedure Standard* and *Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03)* (EPRI Report TR-105696, October 1995). The changes listed below supersede the affected Paragraphs of *TR-105696-R7 (BWRVIP-03) Revision 7: Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines* (EPRI Report 1009910, December 2004).

Affected Section(s)	**Description of Change**
xxv	Updated the Inspection Focus Group roster.
2.5, Para. 4.3	Added guidance for visual examination training, regarding detection and reporting of unusual crud deposits on the vessel interior or internals.
2.5, Para. 6.3.2	Clarified EVT-1 guidance to require that the resolution targets must be seen as a dark object; detection only of the bright, glinting reflection of the lights is not adequate.
2.6, Para. 3.1	Clarified UT personnel requirements to include CP-189 in addition to ASNT-TC-1A.
2.6, Para. 3.3	Corrected errata.
2.6, Para. 7.3	Clarified discussion of one-sided UT access. This change was also made in many report sections documenting individual technique demonstrations.
2.6, Para. 7.5	Clarified requirement for adequate recording of transducer position data in ultrasonic examination.
2.6, Para. 11.0	New paragraph, providing background information on UT with one-sided access.

2.7, Para. 3.1	Clarified ET personnel requirements to include CP-189 in addition to ASNT-TC-1A.
4.4.36, 5.4.21	Corrected errata.
4.4.37–4.4.41	New sections: New NDE technique demonstrations.
4.7.6–4.4.7	New sections: New delivery system demonstrations.
5.4.37–5.4.39	New sections: New NDE technique demonstrations.
5.6.4	New section: New delivery system demonstration.
10.3.5	Added documentation of new jet pump beam mockups.
10.4.1	Modified discussion of single-side access, for consistency with similar discussions elsewhere in the document.
10.4.11–10.4.14, 10.5.2	New sections: New NDE technique demonstrations.
10.6.4	New section: New delivery system demonstration.

HISTORY OF CHANGES TO THIS DOCUMENT REVISION 7

This is a living document. Updates to the included data will be added as they are developed. Minor or editorial changes may not appear in this summary listing of significant changes. This document supersedes the November 21, 1994 Inspection Committee document *BWR-VIP Core Shroud NDE Uncertainty & Procedure Standard* and *Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03)* (EPRI Report TR-105696, October 1995). The changes listed below supersede the affected Paragraphs of *TR-105696-R6 (BWRVIP-03) Revision 6: Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines*, (EPRI Report 1008061, December 2003).

Affected Section(s)	**Description of Change**
xxxiii	Updated the Inspection Focus Group roster.
Chapter 1	Replaced all references to Inspection Committee with Focus Group.
2.5, Para. 3.5	Removed recording medium, water clarity, and lighting from list of key elements.
2.5, Para. 6.2	Changed title from Minimum Water Clarity to Environmental Conditions.
2.5, Para. 6.2.2	Added lighting conditions as an environmental condition, along with water clarity.
2.6, Para. 3.3, 4.1	Clarified UT qualifications that are required for standby liquid control welds and recognizes the recent availability of qualified manual examiners.
2.6, Para. 5.2	Clarified acceptability of normal variation in transducer frequency.
4.3.1.8, 4.3.1.9	New sections: Added documentation of new mockups BWRVIP-SSC-1 and BWRVIP-H6OH.
4.4.2	Added new Demonstration References for UT Demonstrations 33 and 34.

4.4.35, 4.4.36	New sections: New NDE technique demonstrations.
5.3.2	Changed the word six to seven in the first line of the third paragraph.
5.4.21	Corrected an erratum and clarified the description of a technique's performance.
5.4.29–36	New sections: New NDE technique demonstrations.
10.2	Added a paragraph providing VT-1 guidance for viewing jet pump wedges.
11.1	Updated BWRVIP-27 to BWRVIP-27A where necessary.
11.2.3, 11.2.4	Updated guidance for SLC examination to include all allowable inspection alternatives: volumetric every ten years, surface examination every other outage, or enhanced leakage inspection every outage. Enhanced leakage inspection is to be performed with the insulation removed.

HISTORY OF CHANGES TO THIS DOCUMENT REVISION 6

This is a living document. Updates to the included data will be added as they are developed. Minor or editorial changes may not appear in this summary listing of significant changes. This document supersedes the November 21, 1994 Inspection Committee document *BWR-VIP Core Shroud NDE Uncertainty & Procedure Standard* and the October 1995 document *Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03).* The changes listed below supersede the affected paragraphs of *TR-105696R5 (BWRVIP-03) Revision 5: Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines*, *December 2002*.

Affected Section(s)	**Description of Change**
xix	Updated the Inspection Focus Group roster.
5.4.27 – 5.4.28	New sections: New NDE technique demonstrations.
5.6.3	New section: New NDE delivery system demonstration.
6.4.32 - 6.4.35	New sections: New NDE technique demonstrations.
All NDE technique and delivery system demonstrations	Added the publication date of each demonstration.
Many UT demonstrations	Where appropriate, added a note stating the need to ultrasonically examine stainless steel and nickel-alloy welds from both directions if possible. (The same note was already present in generic form in Section 2.6, the UT Standard. This action identifies more clearly which UT technique demonstrations it applies to.)

HISTORY OF CHANGES TO THIS DOCUMENT REVISION 5

This is a living document. Updates to the included data will be added as they are developed. Minor or editorial changes may not appear in this summary listing of significant changes. This document supersedes the November 21, 1994 Inspection Committee document *BWR-VIP Core Shroud NDE Uncertainty & Procedure Standard* and the October 1995 document *Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03).* The changes listed below supersede the affected paragraphs of *TR-105696R4 (BWRVIP-03) Revision 4: Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines.*

Affected Section(s)	**Description of Change**
xvii	Updated the Inspection Focus Group roster.
2.5, Para. 8.1.2	Clarifies documentation of EVT-1 examination coverage to recognize access limitations. Documentation must include an estimate of the percentage of the examination area that was covered with EVT-1 quality.
2.6 and 2.7, Para. 2.4	New paragraphs. References ASNT CP-189 in addition to SNT-TC-1A for qualification and certification of examination personnel.
2.6, Para. 3.3	Clarifies qualification requirements for personnel performing UT. Provides personnel qualification requirements for examining standby liquid control welds, and for determining whether flaws have propagated into the pressure vessel. Deleted Paragraph 3.3.3.2, which was made redundant by this change.
2.6, Para. 7.3	New paragraph. States the need to ultrasonically examine stainless steel and nickel-alloy welds from both directions.
4.4.2, 6.4.2	Updated demonstration tables.
4.4.33–4.4.34	New sections: New NDE technique demonstrations.
4.7.5	New section: New NDE delivery system demonstration.
6.3.1.4	Added documentation of core spray tee box mockup BWRVIP-N.
6.4.18, 6.4.19 and 6.4.24	Withdrew UT demonstrations for core spray hidden weld P9 because of recent findings from a new, more comprehensive set of mockups.
6.4.26–6.4.31	New sections: New NDE technique demonstrations.
10.4.10	New section: New NDE technique demonstration.

HISTORY OF CHANGES TO THIS DOCUMENT REVISION 4

This is a living document. Updates to the included data will be added as they are developed. Minor or editorial changes may not appear in this summary listing of significant changes. This document supersedes the November 21, 1994 Inspection Committee document *BWR-VIP Core Shroud NDE Uncertainty & Procedure Standard* and the October 1995 document *Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03)*. The changes listed below supersede the affected paragraphs of *TR-105696R3 (BWRVIP-03) Revision 3 December 2000: Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines*.

Affected Section(s)	Description of Change
xvii	Updated the Committee roster.
2.6, Para. 3.3	Clarifies prerequisite for UT data analysis personnel: their IGSCC qualification must be on non-overlaid components.
4.1, 5.1, 6.1, 7.1, 8.2, 9.2, 10.2, 11.2, 12.2, 13.2	Clarifies that examination procedures must be appropriate to the specific configuration of the plant. Previously "utility-specific" procedures were called for. This change of wording is intended to remove any suggestion that the procedures must be tied administratively to the specific utility.
4.4.2, 6.4.2	Updated demonstration tables.
4.4.29–4.4.32	New sections: New NDE technique demonstrations.
5.3.5	New section: Description of BWR/2 H8/H9 mockups.
5.4.23–5.4.26	New sections: New NDE technique demonstrations.
5.6.2	New section: New NDE delivery system demonstration.
6.4.21–6.4.25	New sections: New NDE technique demonstrations.
8.4.4	New section: New NDE technique demonstration.
TOC, Figure 6.3.1.5-1, 11.2.3	Correction of errata.

HISTORY OF CHANGES TO THIS DOCUMENT REVISION 3

This is a living document. Updates to the included data will be added as they are developed. Minor or editorial changes may not appear in this summary listing of significant changes. This document supersedes the November 21, 1994 Inspection Committee *document BWR-VIP Core Shroud NDE Uncertainty & Procedure Standard* and the October 1995 *document Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03).* The changes listed below supersede the affected paragraphs of the December 1999 document *Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03) Revision 2.*

Affected Section(s)	**Description of Change**
1	Updated the Committee roster.
2.5, Para. 8.1.3	For EVT-1, recommends that the method of measuring flaw length (estimation or ruler) be recorded.
5.3.4	Updated the description of shroud support mockups.
5.4.21, 5.4.22	New sections: New NDE technique demonstrations.
6.2.2, 9.2, 10.2	Updates status of hidden welds.
6.3.1.5	New section: description of BWR/6 core spray mockup.
6.4.20	New section: New NDE technique demonstration.
10.4.9, 10.5.1	New sections: New NDE technique demonstrations.
13.3	Updated the status of control rod guide tube mockup.

HISTORY OF CHANGES TO THIS DOCUMENT REVISION 2

This is a living document. Updates to the included data will be added as they are developed. Minor or editorial changes may not appear in this summary listing of significant changes. This document supersedes the November 21, 1994 Inspection Committee document *BWR-VIP Core Shroud NDE Uncertainty & Procedure Standard* and the October 1995 document *Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03).* The changes listed below supersede the affected paragraphs of the March 1999 document *Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03) Revision 1.*

Affected Section(s)	Description of Change
1	Updated the Committee roster.
2.6, Paragraph 3.3	Modified the personnel qualification requirements for selected examinations.
3.0	Correction: Changed heading numbers to correspond with rest of the document.
4.3.1.7	New section: Description of new mockup BWRVIP-H1.
4.4.28	New section: New NDE technique demonstration.
5.4.20	New section: New NDE technique demonstration.
6.3.1.2	Correction: Figure 6.3.1.2-4 correct image inserted.
6.4.18-19	New sections: New NDE technique demonstrations.
8.4.3	New section: New NDE technique demonstration.

HISTORY OF CHANGES TO THIS DOCUMENT
REVISION 1

This is a living document. Updates to the included data on components that had already been addressed, and new report sections on components that had not yet been addressed, will be added as they are developed. Minor or editorial changes may not appear in this listing. This document supersedes the November 21, 1994 Inspection *Committee document BWR-VIP Core Shroud NDE Uncertainty & Procedure Standard* and the October 1995 document *Boiling Water Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03).*

Affected Section(s)	**Description of Change**
1	Updated the Committee roster and Acknowledgments.
2.1 - 2.4	Changes to administrative procedures, made necessary by discontinuation ofreferenced Inspection Committee working groups. Revised key elements for visual inspection.
2.5	New section: “Generic Standards for Visual Examination of Reactor Pressure Vessel Internals, Components, and Associated Repairs.”
2.6	New section: “Generic Standards for Ultrasonic Examination of BWR Vessel Internal Components.”
2.7	New section: “Generic Standards for Eddy Current Examination of BWR Vessel Internal Components.”
3.0	New section: “Demonstration of Accuracy of Flaw Length Measurement by Visual Examination.” This section replaces the existing Section 3.
3.0	Correction: Changed heading numbers to correspond with rest of the document.
4	Added reference to generic NDE standards, Sections 2.5 – 2.7.
4.3	Added documentation of new mockups.

4.4.19 – 4.4.26, 4.6.5 – 4.6.6, 4.7.3	New sections: Documentation of NDE demonstrations conducted since issuance of prior documents.
4A, 4B, 4C	Deleted. Shroud-specific NDE standards deleted, references to generic standards in Sections 2.5 – 2.7 added.
5	Added reference to generic NDE standards, Sections 2.5 – 2.7.
5.3	Added documentation of new mockups.
5.4.10 – 5.4.18	New sections: Documentation of NDE demonstrations conducted since issuance of prior documents.
6	New section: Core Spray Piping and Sparger. These components had not been addressed in prior documents, except for Section 6A, “Standards for Visual Inspection of Core Spray Piping, Spargers, and Associated Components.”
6A	Section 6A, “Standards for Visual Inspection of Core Spray Piping, Spargers, and Associated Components,” is now deleted and Section 2.5 is referenced instead. New Section 6A: “Investigation of Core Spray Internal Piping Overlay Inspection.”
7	New section: Top Guide.
8	New section: Core Plate.
9	New section: LPCI Coupling.
10	New section: Jet Pump Assembly.
11	New section: Standby Liquid Control.
12	New section: Vessel Attachments.
13	New section: Lower Plenum.
14	New section: Vessel Penetrations.

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* This section, its subsections, and all associated figures and tables are not proprietary. All sections that are NOT marked with an asterisk, their subsections, and associated figures and tables, are proprietary.

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1
BWRVIP OVERVIEW AND BACKGROUND

In 1990 a visual examination (VT) of the core shroud of a Swiss boiling water reactor (BWR) revealed the presence of cracking adjacent to one of the horizontal welds. A boat sample was taken, and its analysis identified the flaw mechanism as intergranular stress corrosion cracking (IGSCC). Since that event, examinations of other BWR shrouds have revealed an industry-wide problem with IGSCC and irradiation-assisted stress corrosion cracking (IASCC) associated with core shroud welds. As a result of this and degradation of other in-vessel components, domestic BWR-owning utilities have formed the Boiling Water Reactor Vessel and Internals Project (BWRVIP), which is chartered to support a program addressing the problems of reactor internals, internal attachments, vessel welds, and vessel nozzles. The inspection guidance provided herein supplements mandated examinations so that BWR owners can assure safety and assess component integrity in support of business decisions.

1.1 BWRVIP

BWRVIP was established by executive participants from each domestic BWR-owning utility. The BWRVIP's technical program is managed by the Electric Power Research Institute (EPRI). The Executive Operating Committee of BWRVIP oversees the activities of BWRVIP's five technical committees and focus groups:

- The Assessment Committee
- The Inspection Focus Group
- The Repair Focus Group
- The Mitigation Committee
- The Integration Committee

The Inspection Focus Group is tasked with producing nondestructive evaluation (NDE) techniques for assessing the integrity of the affected components. This document presents findings and products of the Inspection Focus Group.

1.2 BWRVIP Inspection Focus Group

The Focus Group comprises NDE and inservice inspection (ISI) representatives of BWR utilities, and is supported by EPRI task managers, the EPRI NDE Center, and NDE vendor company representatives. The Focus Group established the NDE Methods Working Group and the Qualification and Data Management Working Group to perform and direct activities in support of its goals.

The Focus Group is chartered to ensure the availability of effective, predictable, and cost-effective inspection techniques to determine the condition of BWR vessel welds, internals, vessel attachments, and penetrations which are potentially susceptible to degradation.

To satisfy this charter, the Focus Group has set the following goals:

- To provide demonstrated, documented NDE techniques for effectively examining the susceptible components.
- To develop inspection standards that can ensure the structural integrity of the components.
- To liaise with regulatory agencies on inspection issues.
- To develop and maintain an internal budget and financial controls.
- To develop short, medium, and long range plans based on utility inspection needs.
- To interface with the other Committees of BWRVIP.
- To provide training, when necessary, to support the industry's inspection needs.

This document presents the Focus Group's activities toward the first two goals. It provides measurements of the uncertainty of NDE techniques as applied to examinations of BWR internal components, to be included with flaw size measurements in calculations of the serviceability of components for subsequent operation; guidance for utilities or vendors to perform measurements of uncertainty that can be recognized by the Focus Group; standards for NDE procedures for examination of internal components; and a referenceable vehicle for regulatory review and approval.

1.3 General Approach to Inspection Support

The Assessment Committee and Repair Focus Group identify those structures that require inspection because of their safety function, susceptibility to degradation, or pre- and post-repair inspection needs. The degradation mechanism, likely flaw locations and orientations, and the degradation severity that must be detected are also identified. The Inspection Focus Group then develops, demonstrates, and documents NDE techniques capable of establishing component and component repair integrity. Alternatively, the Focus Group may witness and document such demonstrations by NDE vendor companies.

The design and fabrication of realistic component mockups are an important part of the Inspection Focus Group's program. The mockups are designed to represent the materials and welding techniques used in the original construction of the components. Intentional defects in the mockups are of the size, location, and orientation of concern, and are designed to resemble the suspect degradation mechanism in their response to NDE techniques.

The Inspection Focus Group also supports BWR internals inspections by providing specific training to spread the knowledge that has been gained through individual plant experiences. Training courses in visual and ultrasonic examination of core shroud welds, and in access and other inspection issues for internal components located below the core plate, have been offered or are planned.

The Focus Group has provided on-site advisory support to requesting member utilities during their internals inspection outages. EPRI and the EPRI NDE Center, directed by the Focus Group, have assisted in on-site advisory support and also have performed off-site data reviews and supporting laboratory work

1.4 Implementation Requirements

In accordance with the requirements of Nuclear Energy Institute (NEI) 03-08, Guideline for the Management of Materials Issues, this report is considered to be "needed."

2
GENERAL PROCEDURES

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2.1 Guidelines for Use of BWRVIP Mockups

1.0 Purpose

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2.0 Reference

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3.0 Guidelines for Usage

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4.0 Guidelines for Use Prioritization

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2.2 Protocol for NDE Technique Demonstrations on BWRVIP Mockups

1.0 Purpose

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2.0 Responsibilities

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3.0 Prerequisites

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4.0 Demonstration Plan

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5.0 Demonstration Process

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6.0 Results Reporting and Documentation

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2.3 Guidelines for Determining NDE Technique Uncertainty

1.0 Purpose

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2.4 Guidelines for Determining Inspection Tool Positioning Uncertainty

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3.0 Responsibilities

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4.0 Guidelines for Uncertainty Measurements

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5.0 Demonstration Plan

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7.0 Documentation

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2.5 Generic Standards for Visual Inspection of Reactor Pressure Vessel Internals, Components, and Associated Repairs

1.0 Purpose

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2.0 Scope

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3.0 Definitions

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4.0 Personnel Training/Experience

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5.0 Equipment Requirements

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6.0 Inspection Requirements

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7.0 Evaluation of Indications

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8.0 Documentation of Results

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Figure 2.5.8.1-1. System Setup

2.6 Generic Standards for Ultrasonic Examination of BWR Vessel Internal Components

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3.0 Personnel

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4.0 Technique Demonstrations

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5.0 Equipment

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6.0 Calibration

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11.0 Examination of Stainless Steel and Nickel-Alloy Welds with Single-Sided Access

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2.7 Generic Standards for Eddy Current Examination of BWR Vessel Internal Components

1.0 Scope

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2.0 References

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3.0 Personnel

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4.0 Technique Demonstration

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5.0 Equipment

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6.0 Calibration

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7.0 Examination

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8.0 Recording

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9.0 Evaluation

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10.0 Reporting

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3
DEMONSTRATION OF ACCURACY OF FLAW LENGTH MEASUREMENT BY VISUAL EXAMINATION

3.1 Summary

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3.2 Demonstration

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3.2.1 Vendors

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3.2.2 Mockups

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3.2.3 Flaws

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3.2.4 Cameras

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3.2.5 Measurement Techniques

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3.3 Sizing Performance

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3.3.1 Estimation

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Table 3.3.1-1. Sizing Performance of Length Estimation Techniques

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3.3.2 Measurement by Ruler

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Table 3.3.2-1. Sizing Performance of Length Measurement by Ruler

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4
SHROUD

4.1 Summary

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Table 4.1-1. Where to Find Evaluation Factors for the Shroud

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4.2 Inspection Considerations

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4.3 Applicable Mockups

Several mockups have been prepared or adapted to support shroud NDE investigations. These mockups are used for UT and ET development. The mockups are designed to represent the materials and welding techniques used in the original construction of the shrouds. The largest and most important of them are the cracked shroud weld mockups, but there are some smaller, special-purpose ones also.

4.3.1 Shroud Weld Mockups

The most important of these mockups are the BWRVIP-X series, which are mockups that include fatigue cracks. It would be ideal to have mockups containing actual IGSCC or IASCC, which are the primary shroud cracking mechanisms observed in plant. However, laboratory production of IGSCC is very time-consuming and is not very controllable in terms of the extent and size of cracking achieved. The fatigue cracks in the BWRVIP-X series can be produced relatively quickly, are precisely controllable in their shape and dimension, and are representative of IGSCC in some important respects. The width (tightness) dimension of the crack opening is similar to or smaller than that of IGSCC in stainless steel piping. The crack locations and orientations are representative of those observed in BWR shrouds, and the dynamic response from the crack faces as ultrasonic beams are scanned across them is qualitatively very similar to the responses of cracks that have been scanned in plant.

4.3.1.1 NDE Center's Original H3 Mockup

Ring-to-cylinder weld, single-J SAW, ring thickness 3", cylinder thickness 1.5". Contains two saw-cut notches and an EDM notch in the ring material adjacent to the weld crown; for H3, this is above the weld on the inside surface. Also contains two solidification cracks within the weld and connected to the weld crown surface. This mockup was built for a utility-specific need in 1993.

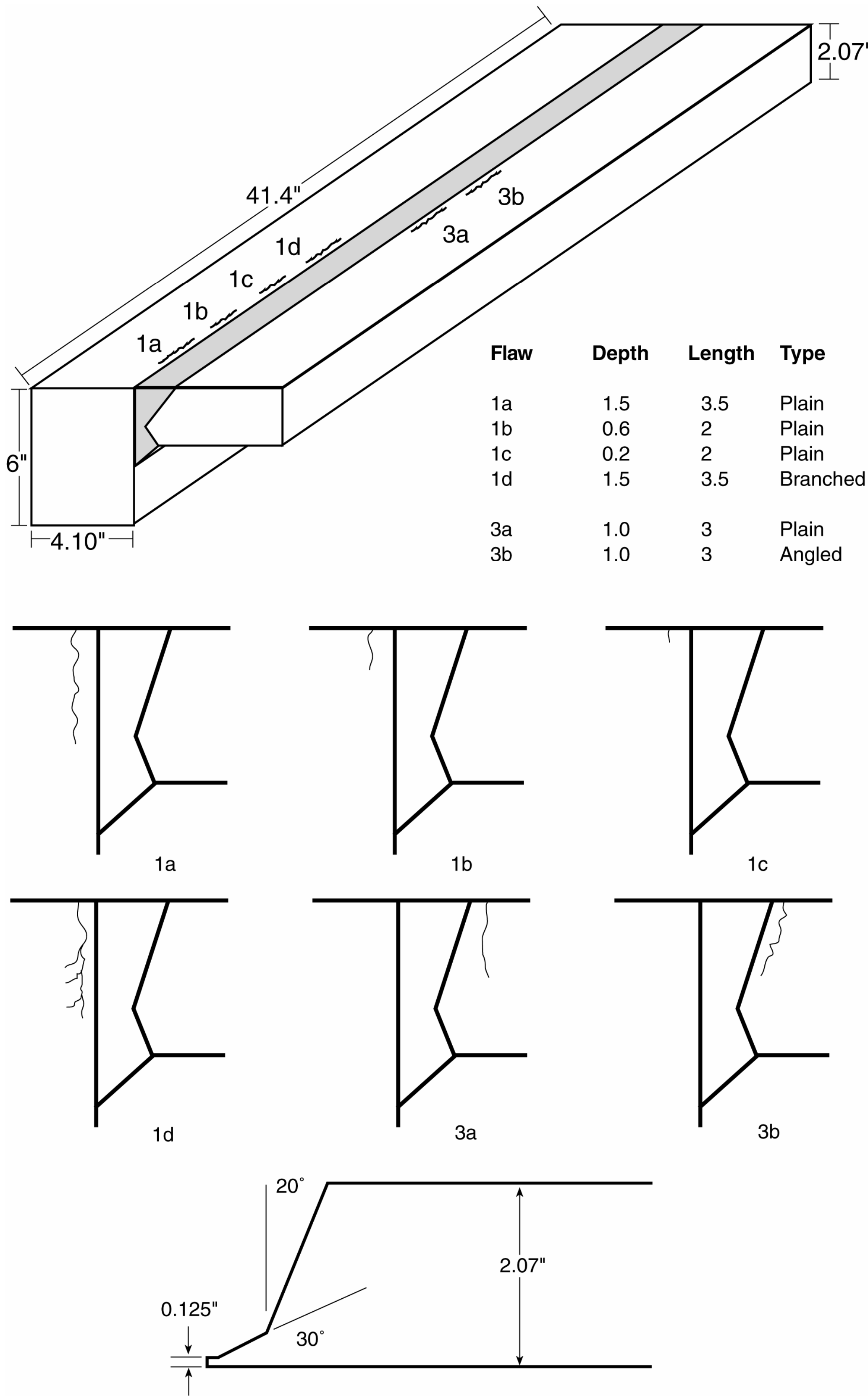
4.3.1.2 Utility H3 and H4 Mockups

A utility built these two mockups for its own use in the fall of 1993. Both mockups contain EDM notches only.

4.3.1.3 Shroud Block BWRVIP-A: Ring-to-Cylinder

BWRVIP-A is a ring-to-cylinder, single-J SAW joint, ring thickness 4", cylinder thickness 2". The finished weld length is 41.4". Shroud curvature is not included so that this mockup can simulate all ring-to-cylinder welds, namely H1, H2, H3, and middle cylinder-to-core plate support ring. For a few plants this also represents the ring-to-lower cylinder weld (BWR/2s) or the central middle cylinder-to-central flange weld (couple of BWR/3s). Contains six fatigue cracks adjacent to weld crown. Four are in the ring and the other two are in the cylinder as shown in Figure 4.3.1.3-1. A cross section of the weld is shown in Figure 4.3.1.3-2.

Replication measurements were performed to determine the dimension of the crack openings. The opening dimension varied along the length of each crack. The minimum opening observed at any point on any of the cracks was 0.00008 inch and the maximum was 0.004 inch. The average opening dimension was about 0.0002 inch for each crack. These values are smaller than those obtained by microscopic examination of IGSCC in laboratory and field-removed specimens of stainless steel piping [2, 3].



Flaw	Depth	Length	Type
1a	1.5	3.5	Plain
1b	0.6	2	Plain
1c	0.2	2	Plain
1d	1.5	3.5	Branched
3a	1.0	3	Plain
3b	1.0	3	Angled

Figure 4.3.1.3-1. Design of Shroud Mockup BWRVIP-A

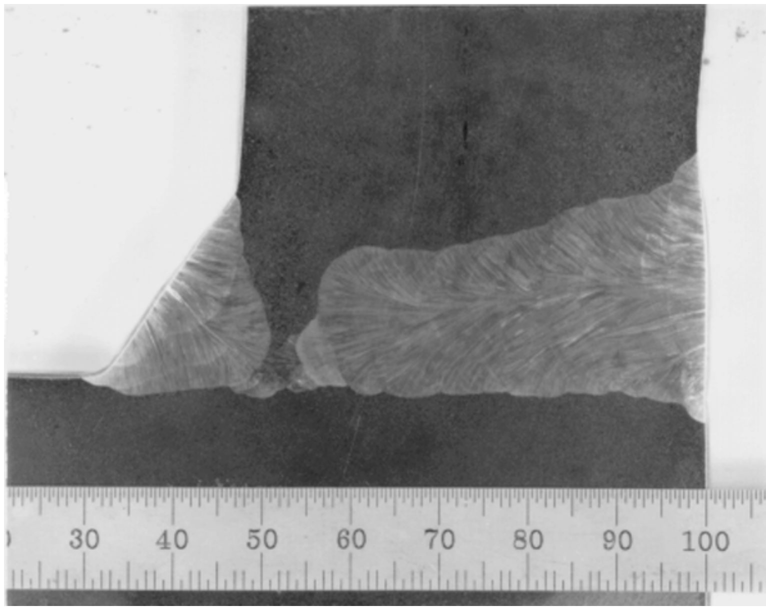


Figure 4.3.1.3-2. Cross Section of Weld in Mockup BWRVIP-A

4.3.1.4 Shroud Block BWRVIP-B: Ring-to-Cylinder

Like BWRVIP-A, this is a ring-to-cylinder weld. The population of ring-to-cylinder SAW welds in the BWR fleet contains significant numbers of several different weld end preparations; BWRVIP-B has a double-V single-sided (“K”) 30° prep. The ring is 4-inches thick and the cylinder is 2-inches thick. Finished weld length is 42". Shroud curvature is not included.

BWRVIP-B contains six fatigue cracks adjacent to toes of the “fillet” in the corner formed by the ring and the cylinder. Four of the cracks are open to the ring surface and turn to follow the weld fusion line per expectation based on chemical susceptibility and residual stress. Two are open to the cylinder surface, one following the prep and one normal to the surface. The design of BWRVIP-B is shown in Figure 4.3.1.4-1. A cross section of the weld is shown in Figure 4.3.1.4-2.

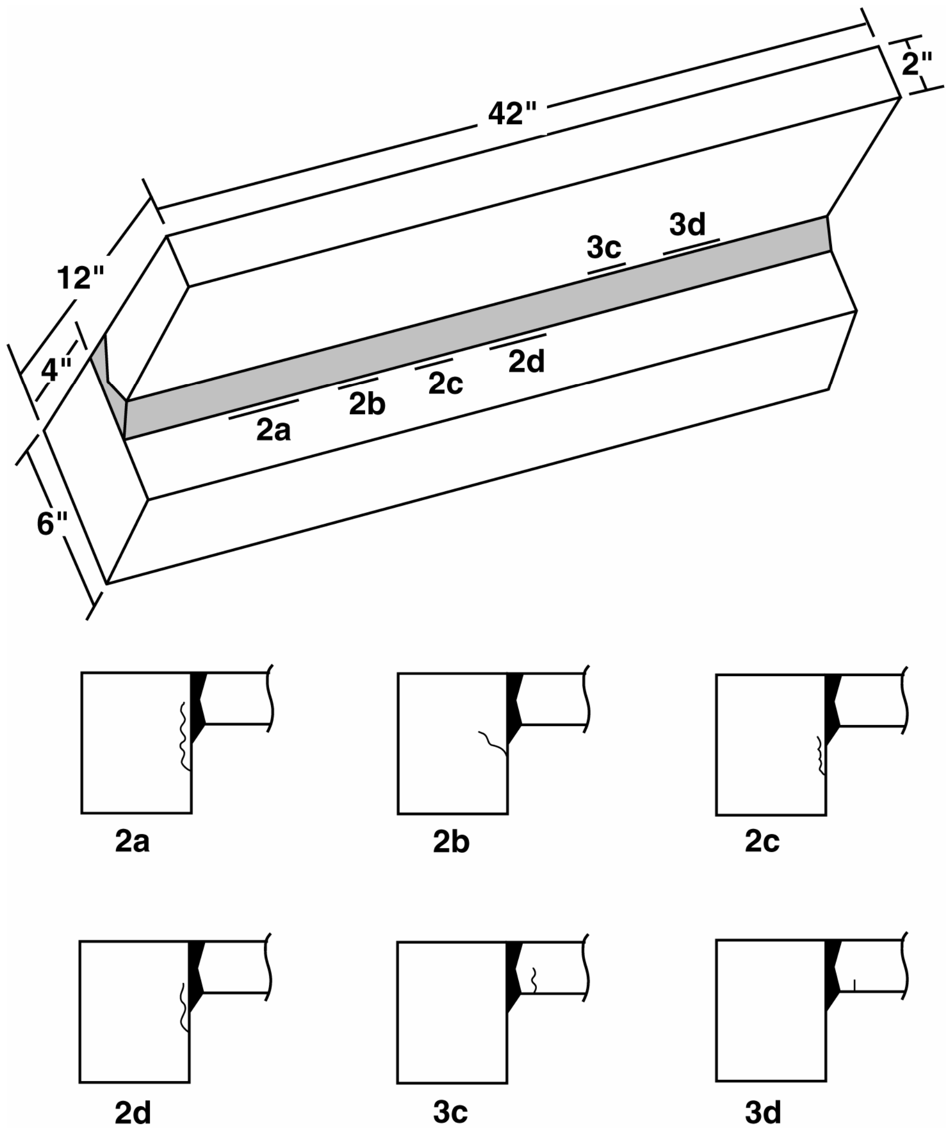


Figure 4.3.1.4-1. Design of Shroud Mockup BWRVIP-B

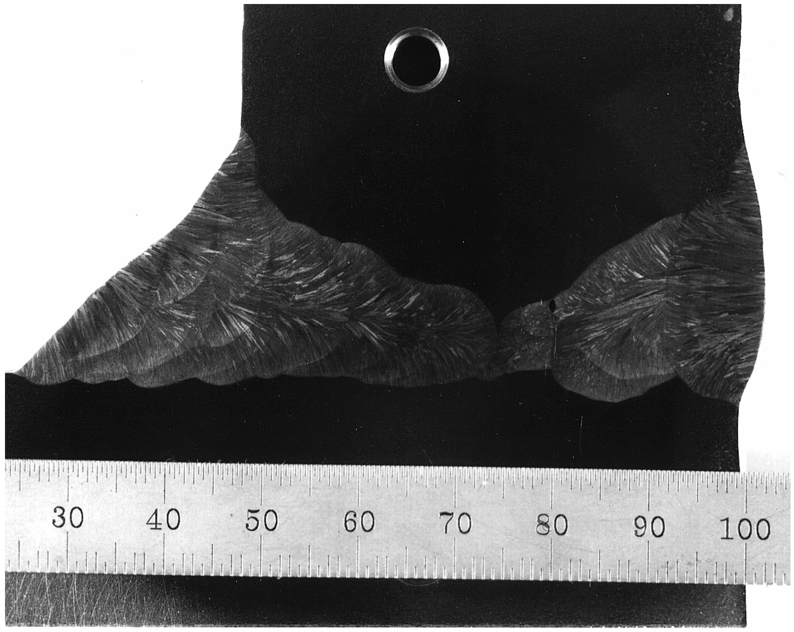


Figure 4.3.1.4-2. Cross section of Weld in Mockup BWRVIP-B

4.3.1.5 Shroud Block BWRVIP-C: Cylinder-to-Cylinder

This is a cylinder-to-cylinder shroud weld mockup. It represents double-V, double-sided SAW horizontal and vertical beltline welds. BWRVIP-C contains six fatigue cracks. The design of BWRVIP-C is shown in Figure 4.3.1.5-1. A cross section of the weld is shown in Figure 4.3.1.5-2.

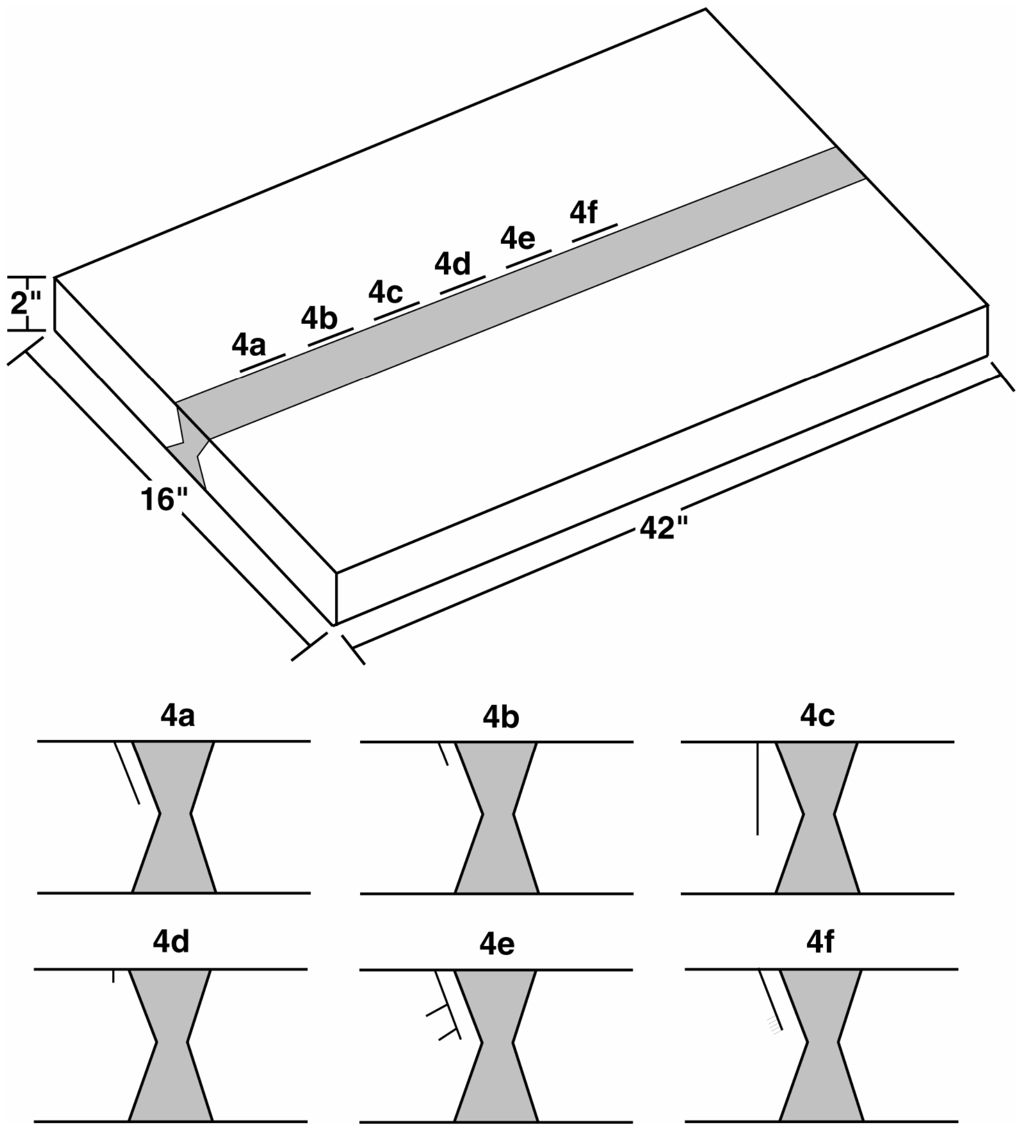


Figure 4.3.1.5-1. Design of Shroud Mockup BWRVIP-C

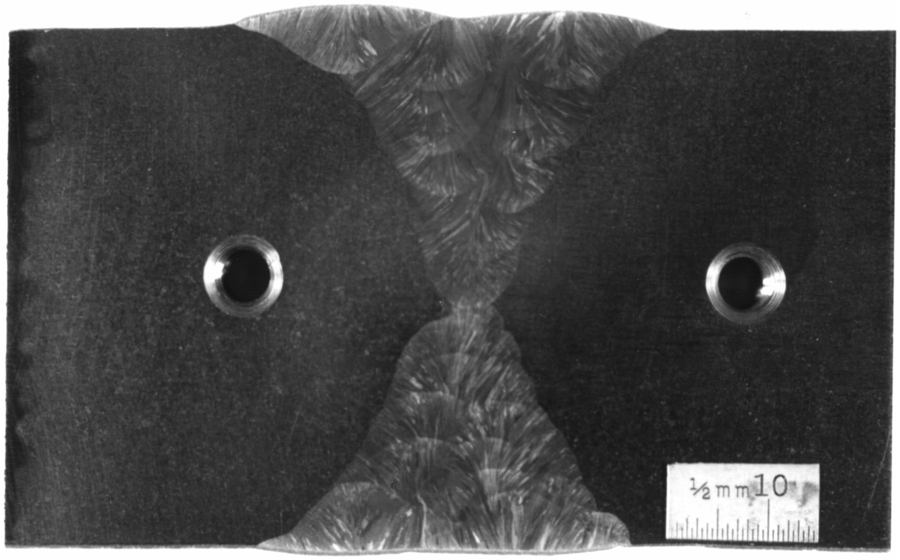


Figure 4.3.1.5-2. Cross Section of Weld in Mockup BWRVIP-C

4.3.1.6 Shroud Mockup BWRVIP-G and H: Ring Segment Welds

The shroud flange ring above weld H1, the top guide support ring between welds H2 and H3, and the core plate support ring between welds H5 and H6 (or H6A and H6B) all may be fabricated from arc-shaped segments cut out of plate. The segments were welded together end-to-end using SAW and the rings were then machined to size. Shroud repairs of the tie-rod type can compensate for complete failure of all circumferential shroud welds, but require that the ring segments welds be intact, if not necessarily unflawed.

Mock-ups BWRVIP-G and -H represent ring segment welds. The controlled cracks in the mock-ups simulate the orientation of cracking in BWR shroud circumferential weld heat-affected zones (HAZ), which has been observed to turn and follow the HAZ of the ring segment weld.

The inspection orientation is unusual. The surface most accessible for probe contact is the surface in the vessel axial/azimuth plane, normal to the vessel radius, which is also normal to the weld axis; the probe is scanned on a weld cross sectional plane. Therefore, the flaw's dimension parallel to the weld, normally considered its "length", is normal to the scanning surface instead of being parallel to it, and must be measured using what are normally considered to be depth-sizing techniques.

The design for BWRVIP-G and BWRVIP-H is shown in Figure 4.3.1.6-1. A typical cross section of the weld is shown in Figure 4.3.1.6-2. A typical drawing of the ring segment weld is shown in Figure 4.3.1.6-3.

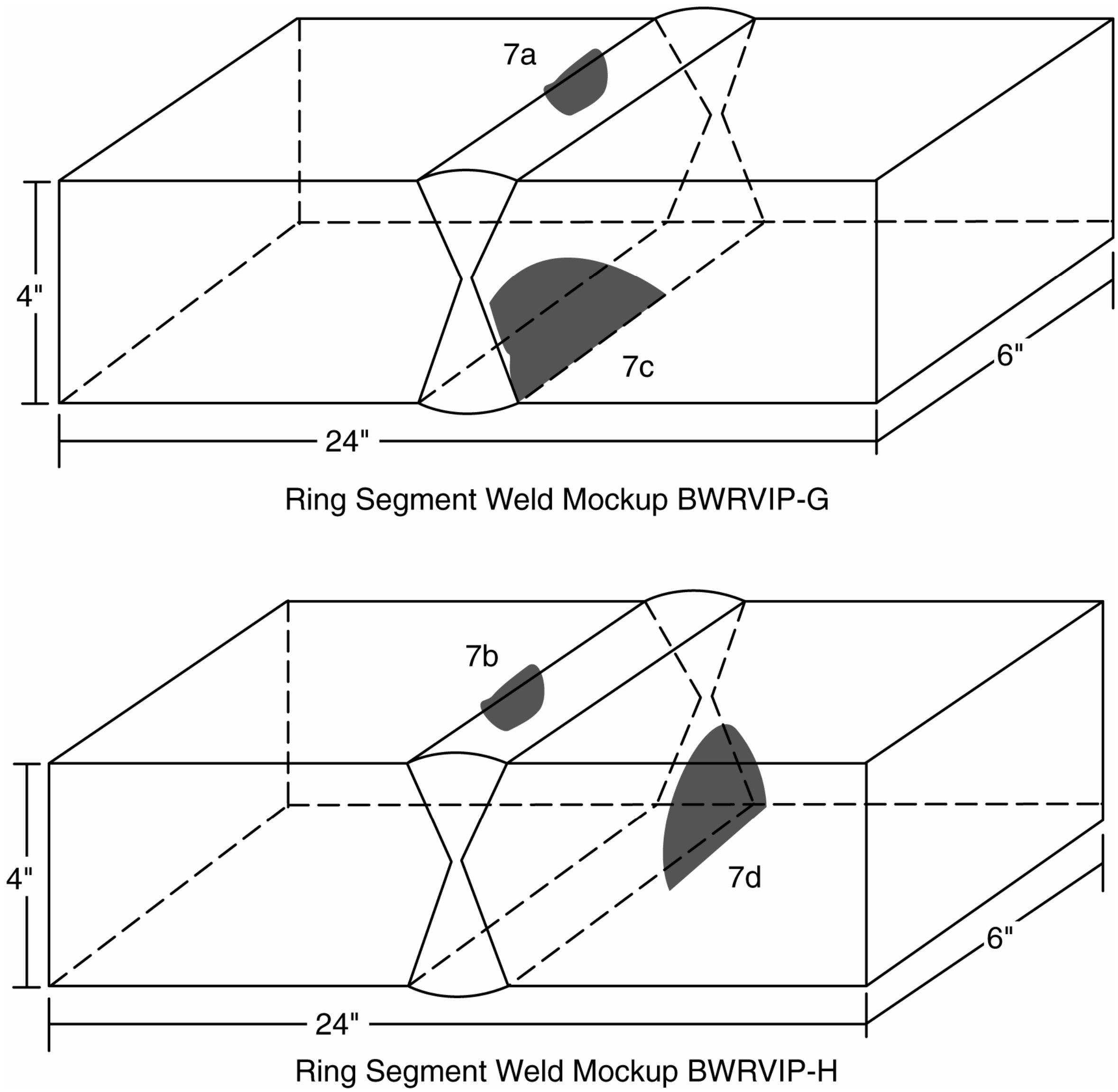


Figure 4.3.1.6-1. Mockup BWRVIP-G and BWRVIP-H, Representing the Ring Segment Weld

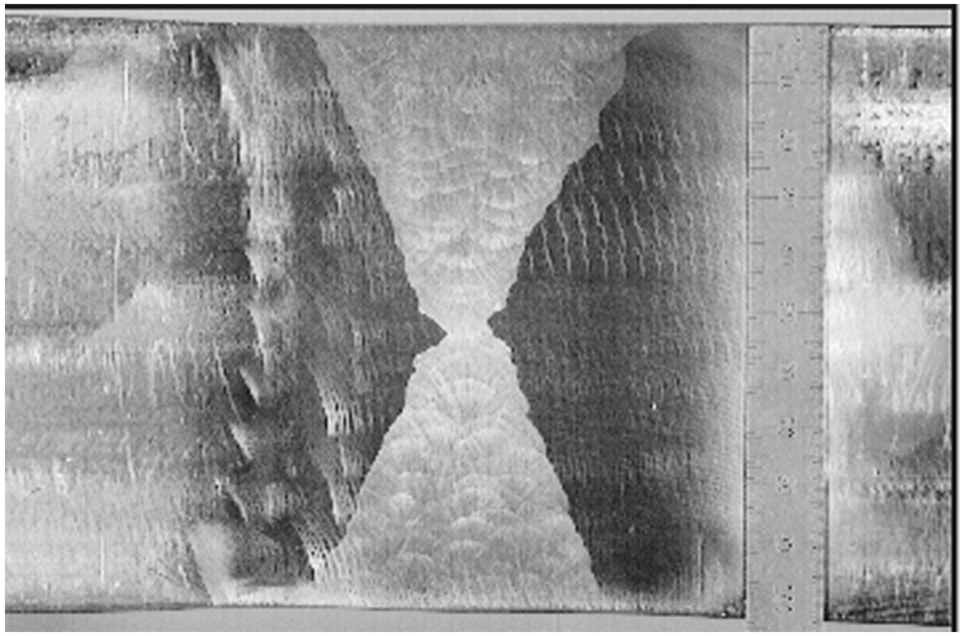


Figure 4.3.1.6-2. Cross Section of Mockup BWRVIP-G and BWRVIP-H

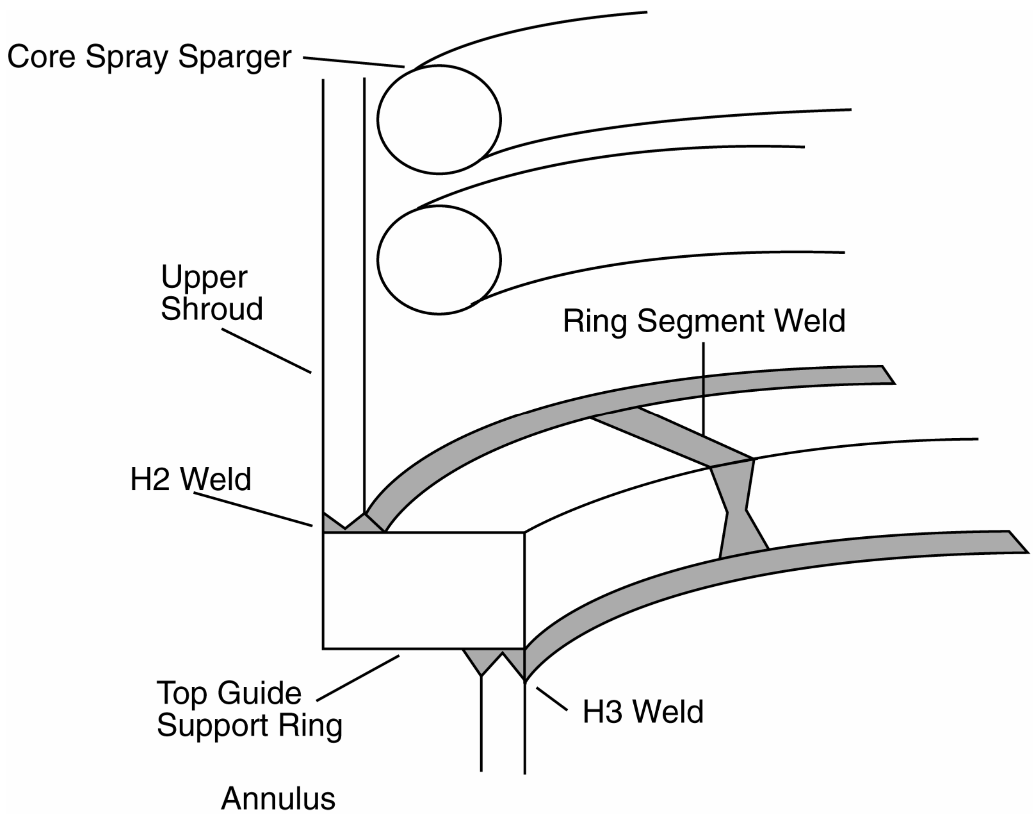


Figure 4.3.1.6-3. Shroud Ring Segment Weld

4.3.1.7 Shroud Mockup BWRVIP-H1: Shroud Weld H1

Mockup BWRVIP-H1 (see Figure 4.3.1.7-1 on page 4-127) was fabricated to support demonstration of a new inspection technique for weld H1. Mockups BWRVIP-A and BWRVIP-B also represent weld H1, but a new mockup of different dimensions was necessary to support an accurate demonstration of the new technique.

The eight fatigue cracks in the mockup represent circumferentially oriented IGSCC in the upper HAZ of weld H1. The mockup also includes two sets of shroud head bolt lugs, included to assess the influence of lugs on the cracks' ultrasonic response.

4.3.1.8 Shroud Mockup BWRVIP-SSC1: Shroud Scallops

Mockup BWRVIP-SSC1 (see Figures 4.3.1.8-1,-2, and -3) is a section from the shroud of a cancelled BWR/6. Eight EDM notches have been added. Their sizes are shown in Table 4.3.1.8-1. The purpose of the mockup is to demonstrate the effect of the scallop geometry on flaw response when the shroud is scanned on the inside surface.

Table 4.3.1.8-1. Notches in Mockup BWRVIP-SSC-1

Notch	Length	Depth	Location	Rotation
1	1.0	0.25	Above weld, not in the scallop	None
2	0.8	0.25	Above weld, in scallop near edge	Rotated to remain parallel with fusion line
3	1.0	0.25	Above weld, center of scallop	None
4	1.3	0.25	Below weld, in scallop near edge	Rotated to remain parallel with fusion line
5	0.75	0.10	Above weld, not in the scallop	None
6	0.55	0.10	Above weld, in scallop near edge	Rotated to remain parallel with fusion line
7	0.75	0.10	Above weld, center of scallop	None
8	0.95	0.10	Below weld, in scallop near edge	Rotated to remain parallel with fusion line

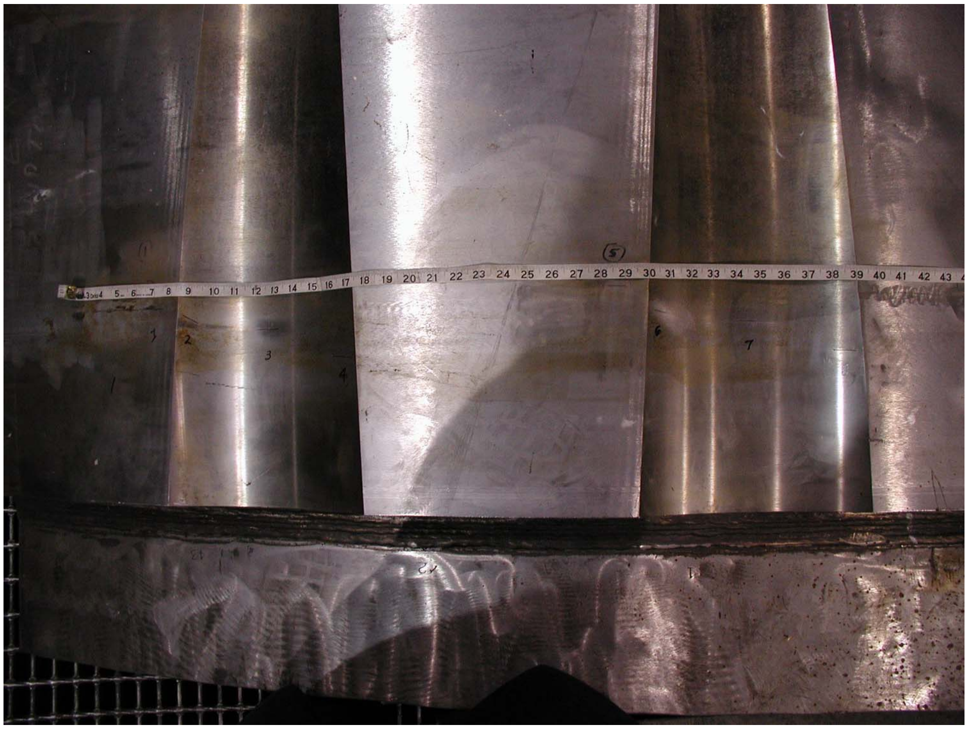


Figure 4.3.1.8-1. Mockup BWRVIP-SSC1

Figure 4.3.1.8-2. Mockup BWRVIP-SSC1; Detail of Notches 1-4

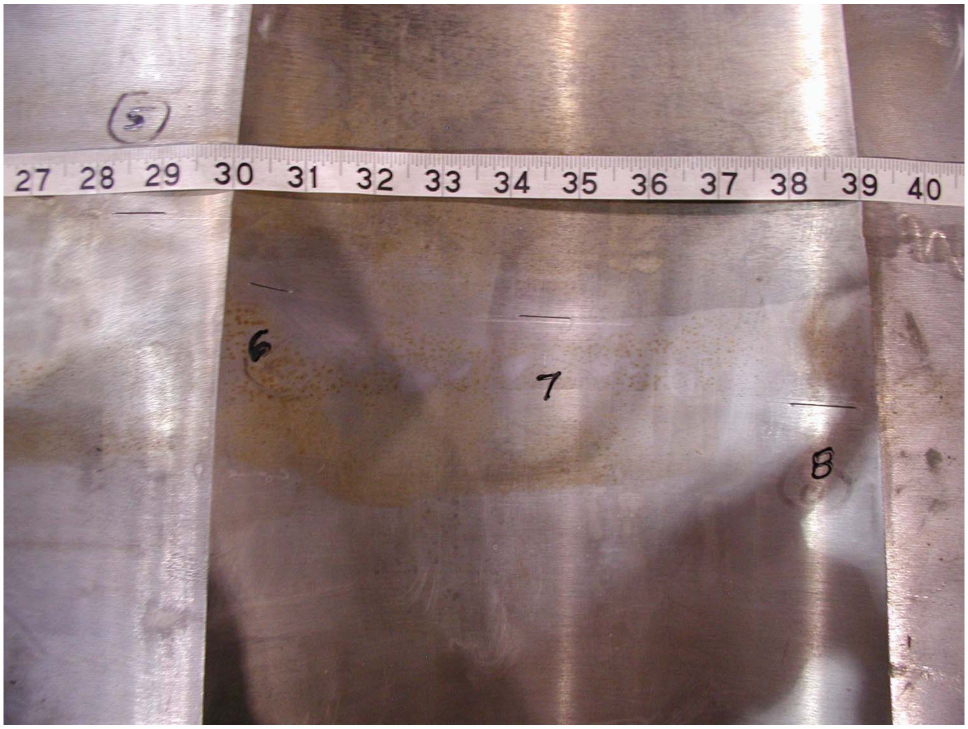


Figure 4.3.1.8-3. Mockup BWRVIP-SSC1; Detail of Notches 5-8

4.3.1.9 Shroud Mockup BWRVIP-H6OH: Overhanging Core Plate Support Ring

Mockup BWRVIP-H6OH represents the geometry of the circumferential weld joining the core plate support ring to the lower shroud cylinder in those shrouds that have an “overhang” at this position. Figure 4.3.1.9-1, a construction photograph from a BWR/5 under construction, illustrates this configuration.

A drawing of the mockup is shown in Figure 4.3.1.9-2 on page 4-128. The mockup contains 11 cracks. Five cracks are located at the radially-outward toe of the weld on the core plate support ring side, and the other six are located at the radially-inward toe on the core plate support ring side. At each toe, some of the cracks propagate in the vessel vertical direction, and some cracks propagate horizontally along the weld fusion line.

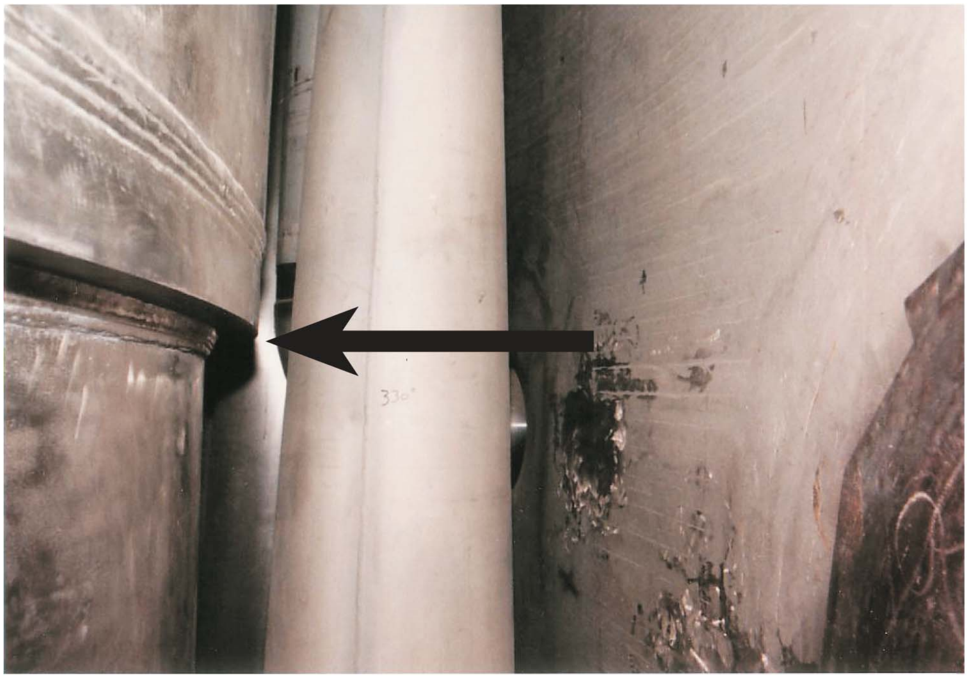


Figure 4.3.1.9-1. Illustration of the Overhanging Configuration of Weld H6b

4.3.2 Special Purpose Mockups

Several mockups were used to help define the impact of specific potential sources of NDE uncertainty.

4.3.2.1 Surface Roughness

A piece of stainless plate about 1" x 6" x 10" has been roughened on one surface to simulate three distinct surface conditions observed in boat samples removed from plant core shrouds. These conditions resulted from machining of the core plate support ring. The mockup contains side-drilled holes and EDM notches. This mock-up is shown in Figure 4.3.2.1-1.

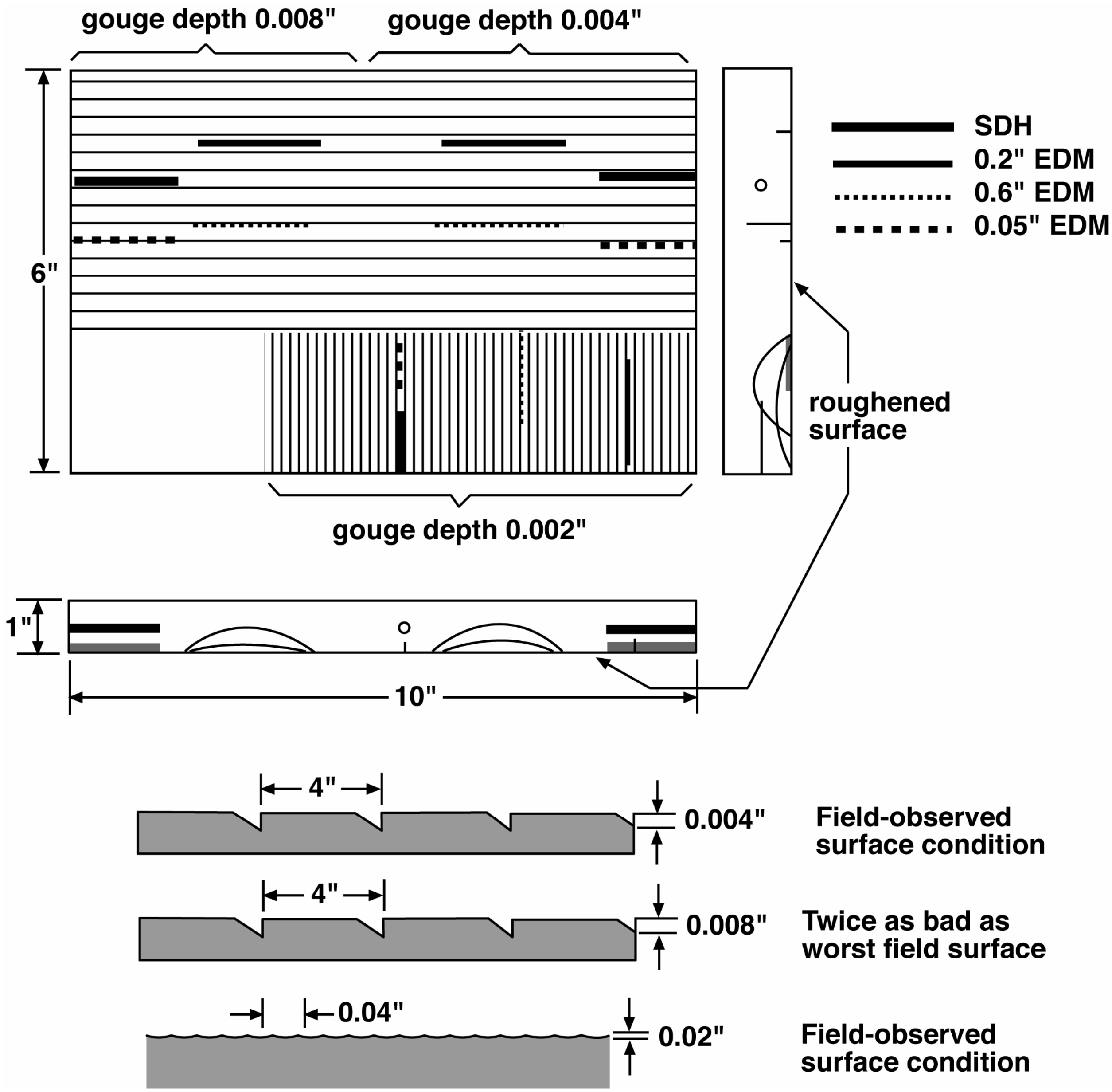


Figure 4.3.2.1-1. Surface Roughness Mockup

4.3.2.2 Multiple Parallel Cracks

Visual examinations of several core shroud welds have revealed instances of distinct multiple cracks parallel to horizontal welds. In one of the boat samples removed from a core plate support ring, as many as four separate, parallel cracks have been observed at a single azimuth. The deepest cracking tends to be the cracking closest to the weld. There is concern that the shallower cracking farther from the weld may degrade the ability of UT to characterize accurately the deeper cracking.

A mockup with parallel EDM notches was used to assess the impact of this condition on UT. It contains four notches with the depth and spacing of the four cracks observed in the boat sample, as shown in Figure 4.3.2.2-1.

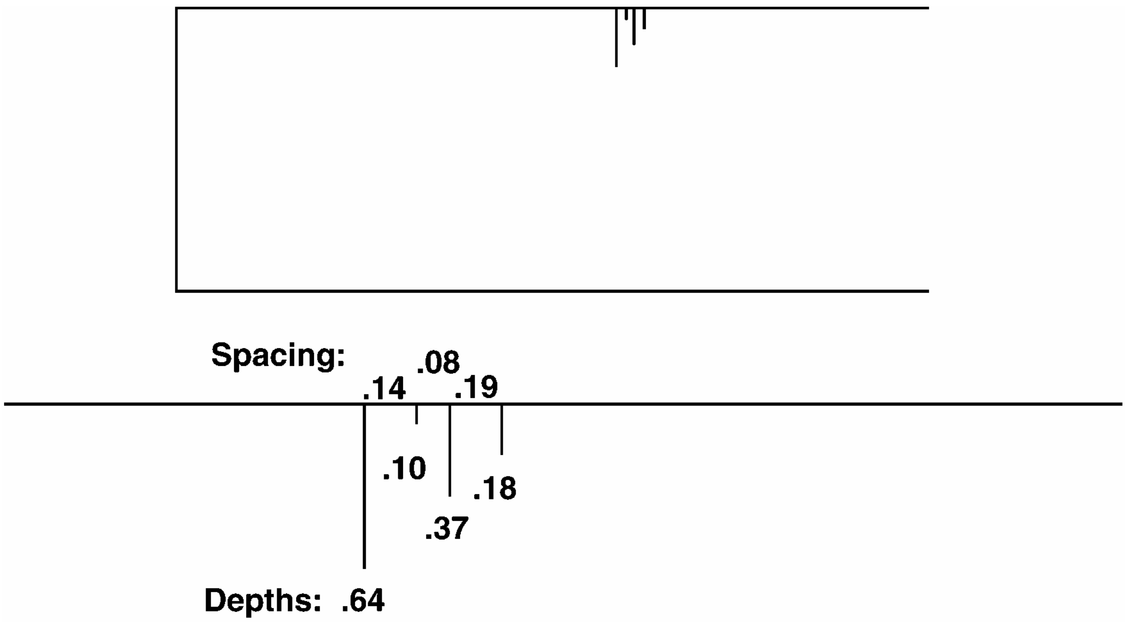


Figure 4.3.2.2-1. Mockup With Multiple, Parallel EDM Notches

4.3.2.3 EDM Notches in Weld Toe

A sample of BWR recirculation outlet piping was used for investigating the effectiveness of ET for detection of flaws located in the unfavorable geometry of the weld crown toe. The sample selected had a weld crown configuration that resembles that of the available shroud weld mockups. There was a bit of diametrical shrinkage and undercut at the weld crown toe. EDM notches were placed in the bottom of the narrow trough formed by this combination of effects. The notches were 0.02-inch, 0.05-inch, and 0.20-inch deep and were oriented parallel to the weld.

4.4 UT Technique Demonstrations for Core Shroud Welds

Demonstrations have been performed by the NDE Center and by several vendors.

4.4.1 General Findings for UT

Investigations of shroud UT have included a review of field UT data, UT experiments on shroud weld and other mockups, and demonstrations by NDE vendor companies. The investigations support the use of UT for characterizing shroud welds, measurement of flaw characterization uncertainty, and a UT procedure standard.

4.4.1.1 Detection of Shallow Reflectors

The ability of UT techniques to detect shallow cracking connected to the examination surface is an important factor in assessing the serviceability of a shroud weldment. This capability is different for each probe.

The creeping wave probe is capable of detecting very shallow defects. This probe was used to detect EDM notches 0.05-inch and 0.02-inch deep in the diametrical shrink area of a stainless steel pipe weld selected for the geometrical similarity of its weld crown to that of mockup BWRVIP-A. The signal-to-noise ratio (SNR) was at least 14 dB. The sensitivity is comparable or better for flaws connected to the opposite surface, when scanning on the shroud cylinder.

Dual probes configured to focus at a certain depth in the component are not optimized for sensitivity to shallow flaws connected to the scanning surface, yet still can be effective for their detection. For example, a dual, 4 MHz, 60° longitudinal-wave probe configured to focus at 0.8-inch depth was used to examine mockup BWRVIP-A. Detection of crack 1c, at 0.2-inch deep the shallowest crack in BWRVIP-A, was unambiguous.

Single-element probes may also have difficulties with shallow flaws connected to the examination surface. Their presence may be obscured by irrelevant indications generated within the wedge, which are not present for dual probes. Single-element shear-wave probes can detect shallow reflectors connected to the examination surface at the full vee path, which is only available when scanning on the shroud cylinder.

4.4.1.2 Detection of Skewed Reflectors

Shroud weld scans are normally conducted with the sound beams directed perpendicular to the weld. Circumferential cracking near horizontal shroud welds has been observed to be nominally parallel to the weld, but it frequently exhibits a tendency to meander. In a manually-scanned experiment on crack 1c in BWRVIP-A, the creeping wave probe was skewed until the signal disappeared into the baseline noise and the probe skew angle was measured. The probe was skewed 30 degrees one direction and 38 degrees in the other direction before losing the ultrasonic signal. This experiment shows that cracks up to about 35-degrees off axis can be detected with the creeping wave probe.

4.4.1.3 Effect of Multiple Parallel Defects

The mockup shown in Figure 4.3.2.2-1 was examined using a dual, 4 MHz, 60° longitudinal-wave probe configured to focus at 0.8-inch depth. The probe was scanned on the surface to which the notches are connected. The 0.10-inch deep notch was not detected. The three remaining notches were all detected and sized without difficulty.

4.4.1.4 Effect of Roughness of Scanning Surface

Visual examination records from several plants show that some core plate support rings and top guide support rings bear distinct and regular machining marks on their surfaces. To determine whether this roughness could potentially degrade the effectiveness of UT when the probes are scanned on these surfaces, the dimensions of the machining marks were obtained from photographs of boat samples removed from the core plate support rings of two BWR plants. The surface of a test plate was scored in a precise fashion to reproduce the two measured surface conditions. A third area was prepared with a surface twice as rough as the worst surface present in any of the available boat sample pictures. A smooth area in a separate plate was used as a control. EDM notches and side-drilled holes were machined into each area. The test plate is shown in Figure 4.3.2.1-1.

Measurements using 60° longitudinal-wave, 45° shear-wave, and creeping-wave probes showed that the surface roughnesses obtained from the boat samples did not degrade detection and sizing performance on the EDM notches. In some cases the response amplitude was reduced by several dB but the SNR was not degraded significantly.

Recorded data from field examinations of BWR core shrouds, including an examination of the area where one of the reference surface boat samples was removed, were reviewed and the baseline noise levels noted. Baseline noise levels observed during the NDE Center's scans of mockup BWRVIP-A were also noted. The sensitivities of all the scans, including those of the roughness mockup, were nearly identical (within 3 dB). In all cases, the baseline noise level was about 10% of full screen height.

4.4.2 UT Demonstration Summary

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Table 4.4.2-1. UT Demonstration Summary

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Table 4.4.2-1. UT Demonstration Summary (continued)

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Table 4.4.2-1. UT Demonstration Summary (continued)

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4.4.3 UT Demonstration 1

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4.4.4 UT Demonstration 2

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4.4.5 UT Demonstration 3

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Figure 4.4.5-1. Principle of Operation of Creeping-Wave Probes

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Figure 4.4.5-2. Principle of Operation of LLT Technique

4.4.6 UT Demonstration 4

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4.4.7 UT Demonstration 5

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4.4.9 UT Demonstration 7

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4.4.10 UT Demonstration 8

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4.4.11 UT Demonstration 9

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4.4.12 UT Demonstration 10

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4.4.13 UT Demonstration 11

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4.4.14 UT Demonstration 12

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4.4.15 UT Demonstration 13

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4.4.16 UT Demonstration 14

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4.4.17 UT Demonstration 15

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4.4.18 UT Demonstration 16

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Table 4.4.18-1. Definition of Scan Patterns Used in UT Demonstration 16

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Table 4.4.18-2. Results of UT Demonstration 16

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4.4.19 UT Demonstration 17

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4.4.20 UT Demonstration 18

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4.4.21 UT Demonstration 19

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4.4.22 UT Demonstration 20

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4.4.23 UT Demonstration 21

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4.4.24 UT Demonstration 22

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4.4.25 UT Demonstration 23

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4.4.26 UT Demonstration 24

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4.4.27 UT Demonstration 25

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Table 4.4.27-1. Sizing Performance and Evaluation Factors for UT Demonstration 25

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4.4.28 UT Demonstration 26

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Figure 4.4.28-1. Configuration of H1 Inspection Using Array Probe at the Top of the Shroud Flange

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Figure 4.4.28-2a. First Focus Position in Each Electronic Scan Line

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Figure 4.4.28-2b. Last Focus Position in Each Electronic Scan Line

4.4.29 UT Demonstration 27

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4.4.30 UT Demonstration 28

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4.4.31 UT Demonstration 29

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4.4.32 UT Demonstration 30

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4.4.33 UT Demonstration 31

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4.4.34 UT Demonstration 32

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4.4.35 UT Demonstration 33

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4.4.36 UT Demonstration 34

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Table 4.4.36-1. Crack Location and Orientation Categories in Mockup BWRVIP-H6OH

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4.4.37 UT Demonstration 35

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4.4.38 UT Demonstration 36

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4.4.39 UT Demonstration 37

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4.4.40 UT Demonstration 38

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Figure 4.4.40-1. Illustration of Sector-Scan Examination of Weld H2 and Full-Vee Linear-Scan Examination of Weld H3

4.4.41 UT Demonstration 39

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Table 4.4.41-1. Linear Scans Performed in Various Shroud Inspection Situations

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4.4.42 UT Demonstration 40

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Table 4.4.42-1. Sizing Performance and Evaluation Factors for UT Demonstration 40

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4.4.43 UT Demonstration 41

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4.4.44 UT Demonstration 42

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4.4.45 UT Demonstration 43

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4.4.46 UT Demonstration 44

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Figure 4.4.46-1. GE Immersion UT Technique for Weld H1

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4.4.47 UT Demonstration 45

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4.4.48 UT Demonstration 46

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4.4.49 UT Demonstration 47

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4.4.50 UT Demonstration 48

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4.4.51 UT Demonstration 49

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Figure 4.4.51-1. Configuration of H1 Inspection Using Array Probe at the Top of the Shroud Flange

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4.4.52 UT Demonstration 50

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4.4.53 UT Demonstration 51

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4.4.54 UT Demonstration 52

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4.4.55 UT Demonstration 53

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Table 4.4.55-1. Crack Location and Orientation Categories in Mockup BWRVIP-H6OH

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Table 4.4.56-1. Crack Location and Orientation Categories in Mockup BWRVIP-H6OH

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4.4.57 UT Demonstration 55

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Figure 4.4.57-1. Probe Scan Line Locations for Mockup BWRVIP-A

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Figure 4.4.57-2. Probe Scan Line Locations for Mockup BWRVIP-B

4.4.58 UT Demonstration 56

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Figure 4.4.58-1. BWRVIP-A and BWRVIP-B Scan Surface

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Figure 4.4.58-2. BWRVIP-A and BWRVIP-B (H3 and H6/H6B) Scan Surface

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Figure 4.4.58-3. BWRVIP-C (H4/H5) Flaws Connected to the Scan Surface

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Figure 4.4.58-4. BWRVIP-C (H4/H5) Flaws Connected Opposite to the Scan Surface

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4.5 VT Technique Demonstrations for Core Shroud Welds

VT investigations have included experiments in a deep water tank, development of a resolution standard, and development of a series of workshops for VT examination personnel.

4.5.1 VT General Findings

Crack length measurement uncertainty has two components. First, the length can be measured only over that part of the crack which is visible. If part of the crack is not seen — because of poor cleaning or extreme tightness, for example — the length measurement will be correspondingly inaccurate. Second, since the cameras and lights are manipulated manually on the ends of long poles or ropes, length measurement becomes in large part an exercise in estimating distance from visible landmarks such as shroud lugs.

4.5.1.1 Training

The Committee conducted two workshops for utility personnel to train the trainer for shroud visual examinations. The first workshop was held August 17, 1994, with 18 participants. The second workshop was held September 8, 1994, with 20 participants.

The lessons learned by utilities who have visually detected shroud cracking have been assembled into a one-day training course. Excerpts from videotape records of actual shroud visual examinations were assembled to illustrate cracking characteristics to look for, necessary surface cleaning, lighting conditions, camera sensitivity and distance, and other important VT parameters.

The NDE Center has documented participation in this course with transcripts and CEUs for all who have completed the training.

4.5.2 VT Demonstration 1

Applicable welds:	H1-H6B; vertical shroud welds
Performed by:	BWRVIP Inspection Committee
Resolution:	0.0005" wire
Manipulation:	Manual, using poles and ropes
Length error:	2.32" RMS
Length evaluation factor:	1.16"
Published:	Revision 0, October 1995

It is expected that variations in crack tightness will affect the capability of the visual method to determine the actual length of the cracking. Experiments have been made at the NDE Center on camera resolution using 0.0005-inch diameter stainless steel wires. Three cameras were lowered into a 20-foot deep, water-filled tank. Various lighting intensities, camera angles, and camera-to-object distances were evaluated. The 0.0005-inch wires were placed on the white background of the tank, on a stainless steel shroud mockup, and on a rusted section of carbon steel. Each of the wires was detectable with each of the cameras utilized. The wire on the painted surface was easily detected at about 16 inches with each camera system. The wire on the stainless steel shroud mockup was difficult to detect and required much manipulation of the camera before the wire was seen. The wire on the carbon steel was easily detected by reflection of the light from the external lights on the cameras. This particular detection was related to light reflection and not to contrast or to the type of steel. Care should be taken to ensure that the detection of the 0.0005-inch diameter wire is essentially representative of detection of a crack of the same width.

Visual examination of shrouds is typically performed from the refueling bridge by manipulating a camera attached to a pole or ropes (much like a string puppet). Location of the view observed from the camera is then limited to an operator's assessment of where the camera is pointed and where the camera is located within the top guide cell. At times, physical objects exist at known locations within the reactor and estimates of distance from these objects may result in a more accurate measurement.

The accuracy of this system has been assessed by having two individuals, experienced in shroud visual examinations, manipulate a camera in a similar fashion in a 20-foot deep, water-filled tank at the NDE Center. Strips of tape (1/8-inch wide) were placed near the bottom of the tank and their actual lengths measured. Fifteen strips of tape, from 3.4-inches to 141-inches long, were placed on the inside surface of the tank. Ten strips of tape, from 3.2-inches to 46-inches long, were placed on the outside surface of a shroud mockup within the tank. The shroud mockup was stainless steel and consisted of a vessel wall, jet pumps, and the shroud wall.

The results of the length measurements (see Table 4.5.2-1) show that, in general, the indications tended to be undersized. The average error of the 25 measurements was -0.79 inch, while the average of the absolute value of the errors was 1.81 inch. The average undersize was 1.91 inch, with the maximum undersize being 5.81 inches out of a true length of 71.06 inches. The average oversize was 1.60 inch, with the maximum oversize being 14.75 inches out of a true length of 47.5 inches. The RMS error of the entire data set was 2.32 inches.

Length measurement errors were also considered as a percentage of the actual length. This method of analysis is perhaps a bit misleading because length measurement errors do not seem to be related to actual length. This results in some very high percentages for the short indications. As shown in Figure 4.5.2-1, once the flaws are at least about 12-inches long, the error is always less than 10% of the true length.

This experiment only determined the amount of uncertainty in defining the lengths of unambiguous indications. The resolution of the system in defining the end points of cracks was not considered in these measurements.

Table 4.5.2-1. Data and Analysis from Shroud VT Demonstration 1

Visual exam of shroud -- NDEC demo 8/31/94

True length	Measured	Error	Abs. Error	Sq. Error	Neg. Errors	Pos. Errors
141.25	146	4.75	4.75	22.5625	0	4.75
47.5	48.25	0.75	0.75	0.5625	0	0.75
71.0625	65.25	-5.8125	5.8125	33.7852	-5.8125	0
5.875	5.25	-0.625	0.625	0.3906	-0.625	0
100.25	97.25	-3	3	9.0000	-3	0
16.4375	15	-1.4375	1.4375	2.0664	-1.4375	0
72.4375	68.5	-3.9375	3.9375	15.5039	-3.9375	0
32.9375	31	-1.9375	1.9375	3.7539	-1.9375	0
16.75	17.5	0.75	0.75	0.5625	0	0.75
12.375	10	-2.375	2.375	5.6406	-2.375	0
3.4375	3.25	-0.1875	0.1875	0.0352	-0.1875	0
10.8125	12	1.1875	1.1875	1.4102	0	1.1875
51.6875	53	1.3125	1.3125	1.7227	0	1.3125
23.9375	23.75	-0.1875	0.1875	0.0352	-0.1875	0
60.25	58.7	-1.55	1.55	2.4025	-1.55	0
34.25	36.8	2.55	2.55	6.5025	0	2.55
19.75	17.25	-2.5	2.5	6.2500	-2.5	0
46	44.85	-1.15	1.15	1.3225	-1.15	0
13.125	10.4	-2.725	2.725	7.4256	-2.725	0
3.1875	2.75	-0.4375	0.4375	0.1914	-0.4375	0
29	28.75	-0.25	0.25	0.0625	-0.25	0
4.625	3.5	-1.125	1.125	1.2656	-1.125	0
16	17.25	1.25	1.25	1.5625	0	1.25
7.875	4.6	-3.275	3.275	10.7256	-3.275	0
15.875	16.1	0.225	0.225	0.0506	0	0.225
Total error		-19.7375	45.2875		-32.5125	12.7750
Average error		-0.7895	1.8115		-1.9125	1.5969
Standard Deviation		2.2287				
		Sum Sq Error		134.7927		
		Avg Sq Error		5.3917		
		RMS Error		**2.3220**		

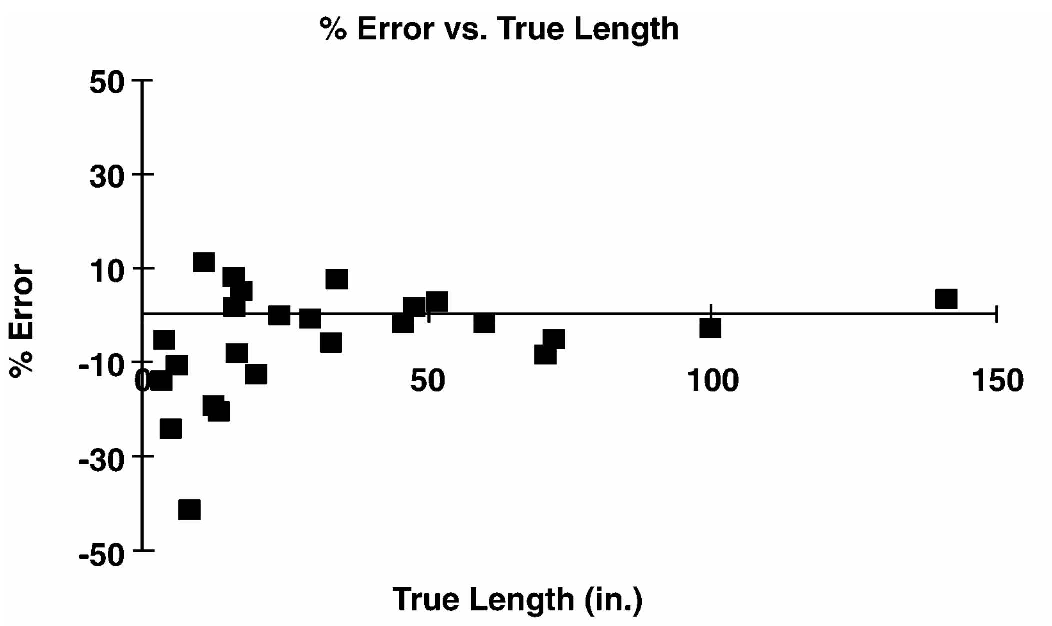

Figure 4.5.2-1. VT Length Measurement Performance on Simulated Cracks (Pieces of Tape) in NDE Center's 20-foot-deep Water Tank

4.6 ET Technique Demonstrations for Core Shroud Welds

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4.6.1 ET General Findings

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Figure 4.6.1-1. Cross-Wound ET Probe

4.6.1.1 Detection of Skewed Reflectors

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4.6.1.2 Effect of Scanning on a Rough Surface

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Figure 4.6.1.2-1. Eddy Current Image of Surface Roughness Mockup

4.6.1.3 Scan Pattern

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4.6.2 ET Demonstration 1

Applicable welds:	H1-H6B; vertical shroud welds
Company:	EPRI NDE Center
Probe:	Cross-wound, ~ 0.1 inch diameter
Frequency:	300 kHz
Technique:	C-scan imaging of amplitude and phase
Scan increment:	0.05 inch
Length error:	+0.098" average, 0.125" RMS (conventional image)
Length error:	-0.0015" average, 0.082" RMS (derivative image)
Length evaluation factor:	0.062" (conventional image)
Length evaluation factor:	0.041" (derivative image)
Published:	Revision 0, October 1995

4.6.2.1 Crack Length Measurement

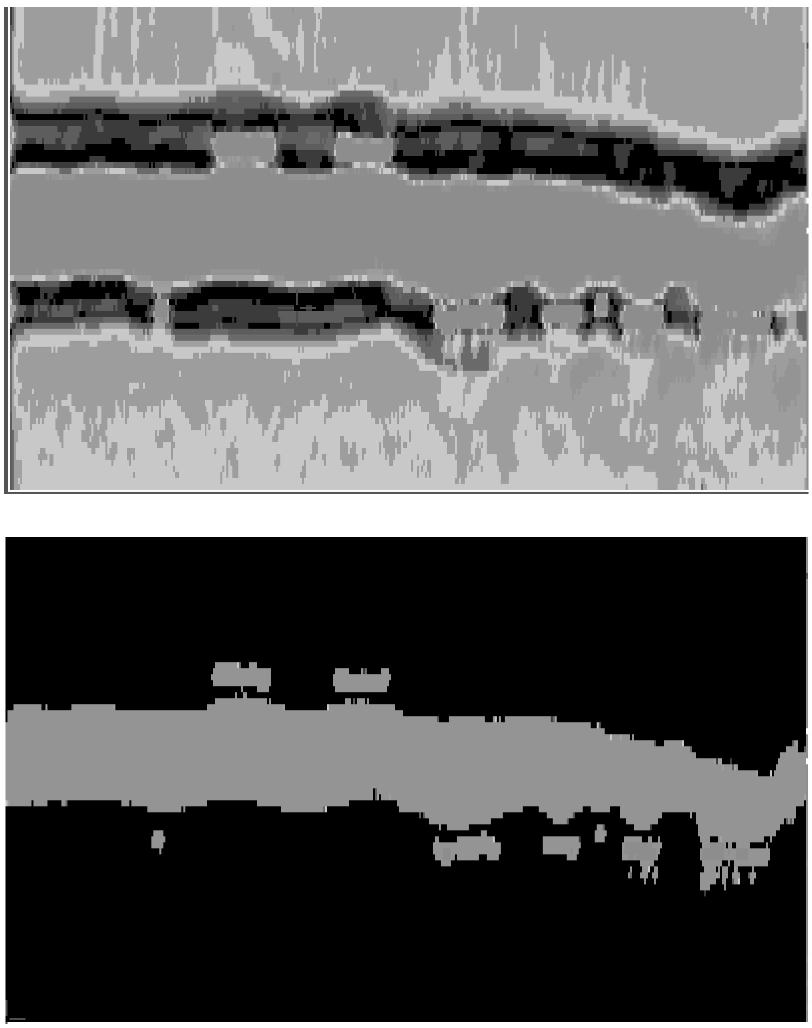
Experiments were conducted with the cross-wound surface probe to determine the length accuracy on BWRVIP-A. All data was acquired using an Amdata IntraSpect/ET computerized data acquisition and imaging system. The use of an imaging system permits the data to be evaluated by reviewing phase and amplitude C-scan presentations that show the ET data from large areas of the weld at once so the analyst can better discriminate anomalous signals. The ability to image the data and to look at both signal phase and amplitude information is important because the ET method is sensitive to other mechanical and metallurgical characteristics of the weld not associated with known flaws. These characteristics include geometric effects, probe-to-material spacing (lift-off), and permeability variations associated with the inherent weld properties.

All cracks were detected. The indications were analyzed using the C-scan images obtained on Amdata's IntraSpect/ET system. The system includes a feature that allows spatial derivative C-scan images to be produced. The gradient of the signal can be shown in addition to its normal values. This permits defects such as cracks, which show a very rapid rate of change in either vertical amplitude or phase angle, to be displayed more clearly in the presence of noise (i.e., lift-off, conductivity shifts, etc.). Using the derivative of the amplitude display, the lengths were measured on all 6 cracks and the average error was found to be -0.0015 inch, with an RMS error of 0.082 inch. Using a more conventional analysis process, the phase image was displayed in a non-derivative manner and the lengths of the cracks were measured. The average error on the 6 cracks was found to be +0.0985 inch with an RMS error of 0.125 inch.

4.6.2.2 Optimum Parameters for ET Imaging

A careful selection of the imaging parameters and display threshold levels are necessary to obtain an ET C-scan image which presents flaw indications clearly while minimizing the visibility of irrelevant indications. For BWRVIP-A, data was acquired using a balance or null point established on an unflawed region of the mockup in an area clearly away from any influence of the weld's mechanical or metallurgical effects. At this setting, excellent flaw detection and discrimination of flaws located in the base material region can be achieved. To optimize the C-scans for a good analysis of the heat affected zone and weld region, it was necessary to change the balance point for these specific areas. Both amplitude and phase C-scans were used to provide confirmation of flawed areas. Figure 4.6.2.2-1 shows the amplitude and phase C-scans for BWRVIP-A, balanced at a point in the heat affected zone. At some point during analysis of the C-scans, it may be useful to employ an amplitude threshold to help eliminate signals caused by noise. For BWRVIP-A, this was achieved by using the amplitude response from an EDM notch (0.005 wide, 0.040 deep, and 0.250 inch long) contained in the calibration standard.

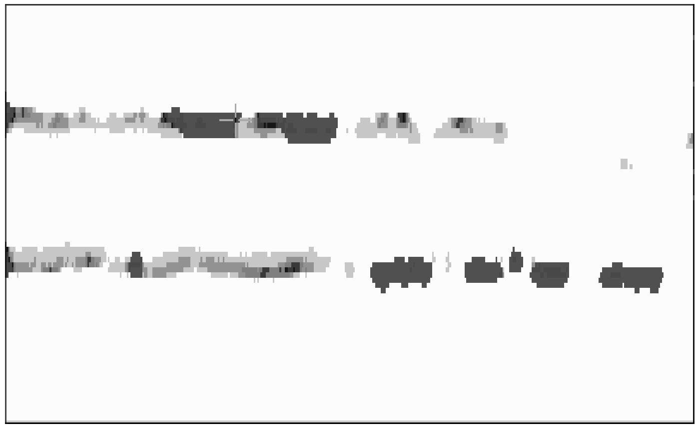
In addition to reviewing the amplitude and phase C-scans, the ET signal response (Lissajous pattern) should be analyzed for any area that appears suspicious from the C-scans. The signal response from other frequencies may also be used as an aid in evaluation. BWRVIP-A was also scanned using 600 kHz and excellent detection and discrimination were achieved.



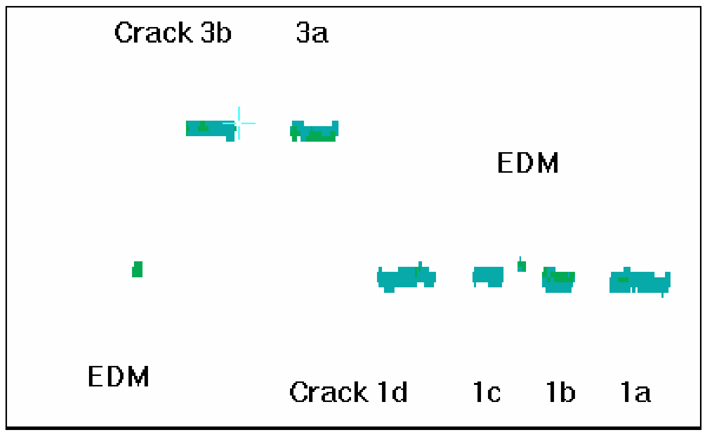
a

b

Figure 4.6.2.2-1. Amplitude and Phase Eddy Current Images of Mockup BWRVIP-A. (a) Amplitude, raw. (b) Amplitude, thresholded



c



d

Figure 4.6.2.2-1 (continued). Amplitude and Phase Eddy Current Images of Mockup BWRVIP-A. (c) Phase, raw. (d) Phase, thresholded

4.6.3 ET Demonstration 2

Applicable welds:	H1-H6B; vertical shroud welds
Company:	R/Dtech
Probe:	Pancake, 0.09-inch diameter
Technique:	C-scan imaging of amplitude
Length error:	+0.24" average, 0.50" RMS
Length evaluation factor:	0.25"
Published:	Revision 0, October 1995

BWRVIP-A was scanned by R/Dtech using a Tecrad TC5700 multi-function NDE system, a Tecrad Tomoscan imaging system, and a 0.090-inch diameter pancake coil. The scans were performed from the cracked surfaces on each side of the weld.

R/Dtech personnel performed the scans and analyzed the data. Each of the six cracks was identified. Though the analyst did not report more than the six cracks that were actually present, indications similar to the crack indications were present in the data at the fusion line of the weld. Since no objective criteria were submitted to support the analyst's flaw/non-flaw decisions, it is considered that the demonstration was successful with respect to flaw detection but was incomplete with regard to flaw discrimination.

A review of the true crack lengths versus the detected crack lengths by ET performed with this system showed that the uncertainty is greater than that determined for the cross-wound probe reported above. With the R/Dtech analysis, the average error was +0.24 inch and the RMS error was 0.50 inch.

4.6.4 ET Demonstration 3

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4.6.4.1 Data Acquisition

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4.6.4.2 Data Evaluation

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4.6.5 ET Demonstration 4

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4.6.6 ET Demonstration 5

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Figure 4.6.6-1. Eddy Current Surface Probe

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Figure 4.6.6-2. Eddy Current Responses from Ring Segment Weld Mockup

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Figure 4.6.6-3. Eddy Current Responses Obtained from Surface Flaws of Various Depths

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Figure 4.6.6-4. Shroud Mockup Containing Rough Weld Surface

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Figure 4.6.6-5. Eddy Current Response From Shroud Mockup with Rough Weld Surface

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4.7 Delivery System Demonstrations for Core Shroud Welds

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4.7.1 Delivery System Demonstration 1

Manipulator:	OD Tracker
Manufacturer:	GE
Demonstration mockup:	GE Training Center, San Jose
Length error contribution:	0.5% of measured length (single placement of the scanner) 1° of azimuth (multiple placements)
Length evaluation factor:	0.25% of measured length (single placement of the scanner) 0.5° of azimuth (multiple placements)
Published:	Revision 0, October 1995

This scanner rides on the steam dam above the H1 weld and carries different arms and scan heads for each horizontal weld. The probe position uncertainty may be a function of both the uncertainty of the position of the main body of the scanner, and a different uncertainty associated with each of the arms specialized for individual welds. The uncertainty associated with the scanner was determined to be 0.037 inch out of a total travel of 6.935 inch (or about 1/2%). When the scanner arm was returned to the origin, it was within 0.0005 inch each time.

The largest uncertainty associated with this delivery system is probably associated with the placement of the scanner on the shroud. The OD Tracker is placed on the steam dam and driven to contact with a set of shroud lugs. The arm then scans while the main body remains stationary. The main body is then driven to the next set of shroud lugs, without encoders.

If the indication being measured is fully contained within a single scan area, not requiring movement of the main body, then only the scanner contributes to length measurement uncertainty. If the indication is long enough to require multiple placements of the scanner, then the placement inaccuracy must be included. Typical drawings show lug placement to be within 1/2 degree of azimuth, which corresponds to about 0.96 inch for a 220-inch diameter shroud. Tolerances for the dimension of the outside of the lug to the centerline are typically +0.095, -0.075 inch. This results in uncertainties of approximately 1 inch.

4.7.2 Delivery System Demonstration 2

Manipulator:	Suction Cup Scanner
Manufacturer:	GE
Demonstration mockup:	GE Training Center, San Jose
Length error contribution:	0.5% of measured length (single placement of the scanner) (application-dependent for multiple placements)
Length evaluation factor:	0.25% of measured length (single placement of the scanner) (application-dependent for multiple placements)
Published:	Revision 0, October 1995

This is a small scanner that is manually positioned and then attaches itself to the shroud wall. This scanner can be placed on the outside or inside surface of the shroud. Probe position uncertainty for this system will include the uncertainty of the encoders or stepping motors carried on the system, and also the uncertainty of the position at which the scanner was mounted. Testing at GE's San Jose facility resulted in essentially the same scanner uncertainty as was observed with the OD Tracker.

The uncertainty associated with the placement of the scanner on the shroud may depend on the availability and selection of landmarks. This uncertainty component must be developed separately as specified in Section 2.4.

4.7.3 Delivery System Demonstration 3

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4.7.4 Delivery System Demonstration 4

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Table 4.7.4-1. Evaluation Factors for Carousel Scanner

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4.7.5 Delivery System Demonstration 5

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4.7.6 Delivery System Demonstration 6

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4.7.7 Delivery System Demonstration 7

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4.7.7.1 Flaw Length Measurement Within a Single Scan

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4.7.7.2 Flaw Length Measurement Using More Than One Scan

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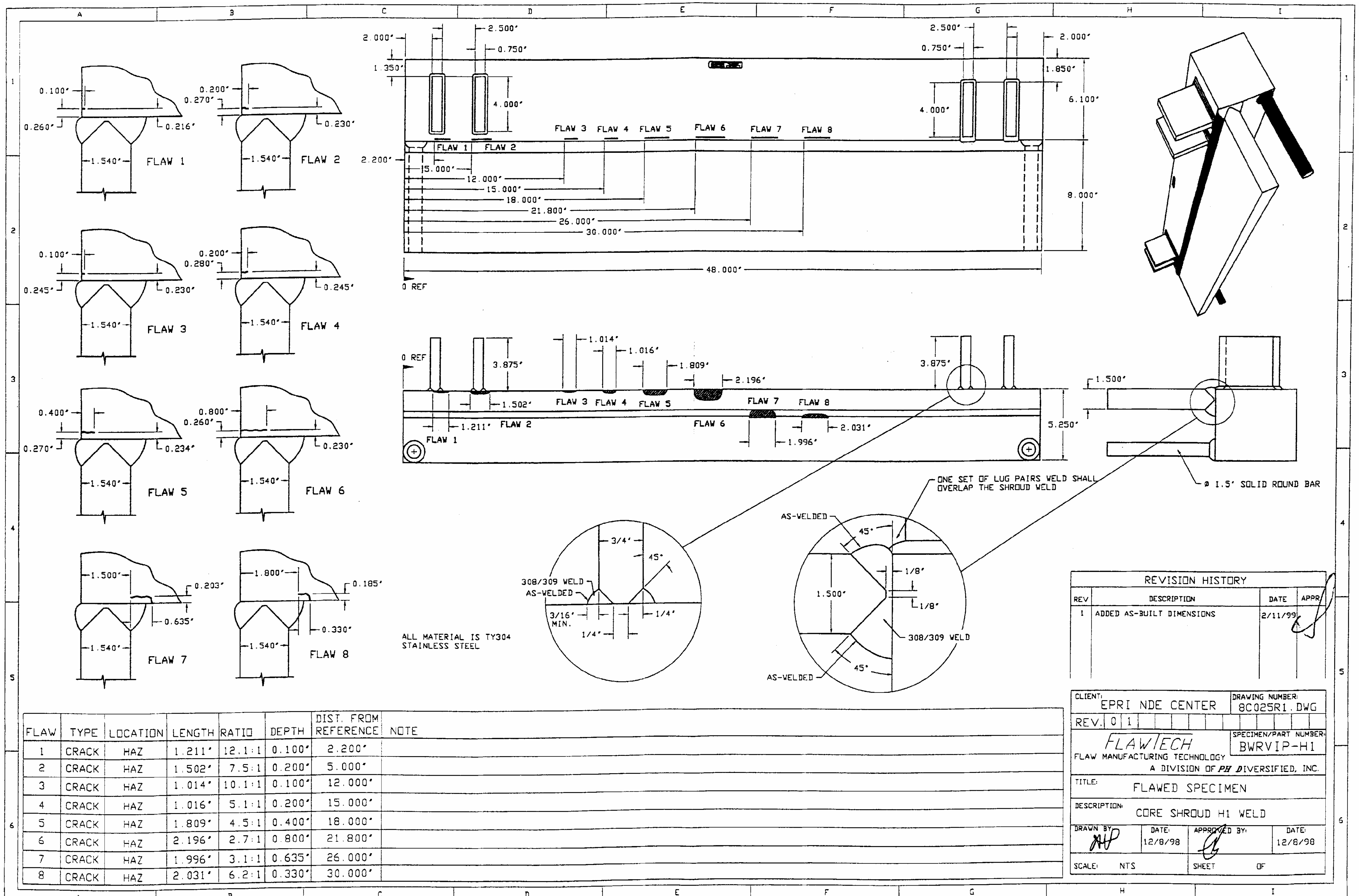
4.8 References

1. Caine, T. A.; Mehta, H. S. *BWR Core Shroud Inspection and Flaw Evaluation Guidelines.* GE Nuclear Energy, San Jose, CA. GENE-523-113-0894. September 1994.

2. MacDonald, D. E. *IGSCC Detection in BWR Piping Using the Minac.* Electric Power Research Institute, Palo Alto, CA. EPRI NP-3828. February 1985.

3. Walker, S. M. Personal Communication to Dr. Mohamad Behravesh, “Report on location and width of IGSCC.” EPRI NDE Center, December 15, 1987.



FLAW	TYPE	LOCATION	LENGTH	RATIO	DEPTH	DIST. FROM REFERENCE	NOTE
1	CRACK	HAZ	1.211"	12.1:1	0.100"	2.200"	
2	CRACK	HAZ	1.502"	7.5:1	0.200"	5.000"	
3	CRACK	HAZ	1.014"	10.1:1	0.100"	12.000"	
4	CRACK	HAZ	1.016"	5.1:1	0.200"	15.000"	
5	CRACK	HAZ	1.809"	4.5:1	0.400"	18.000"	
6	CRACK	HAZ	2.196"	2.7:1	0.800"	21.800"	
7	CRACK	HAZ	1.996"	3.1:1	0.635"	26.000"	
8	CRACK	HAZ	2.031"	6.2:1	0.330"	30.000"	

Figure 4.3.1.7-1. Mockup BWRVIP-H1 Shroud Weld H1

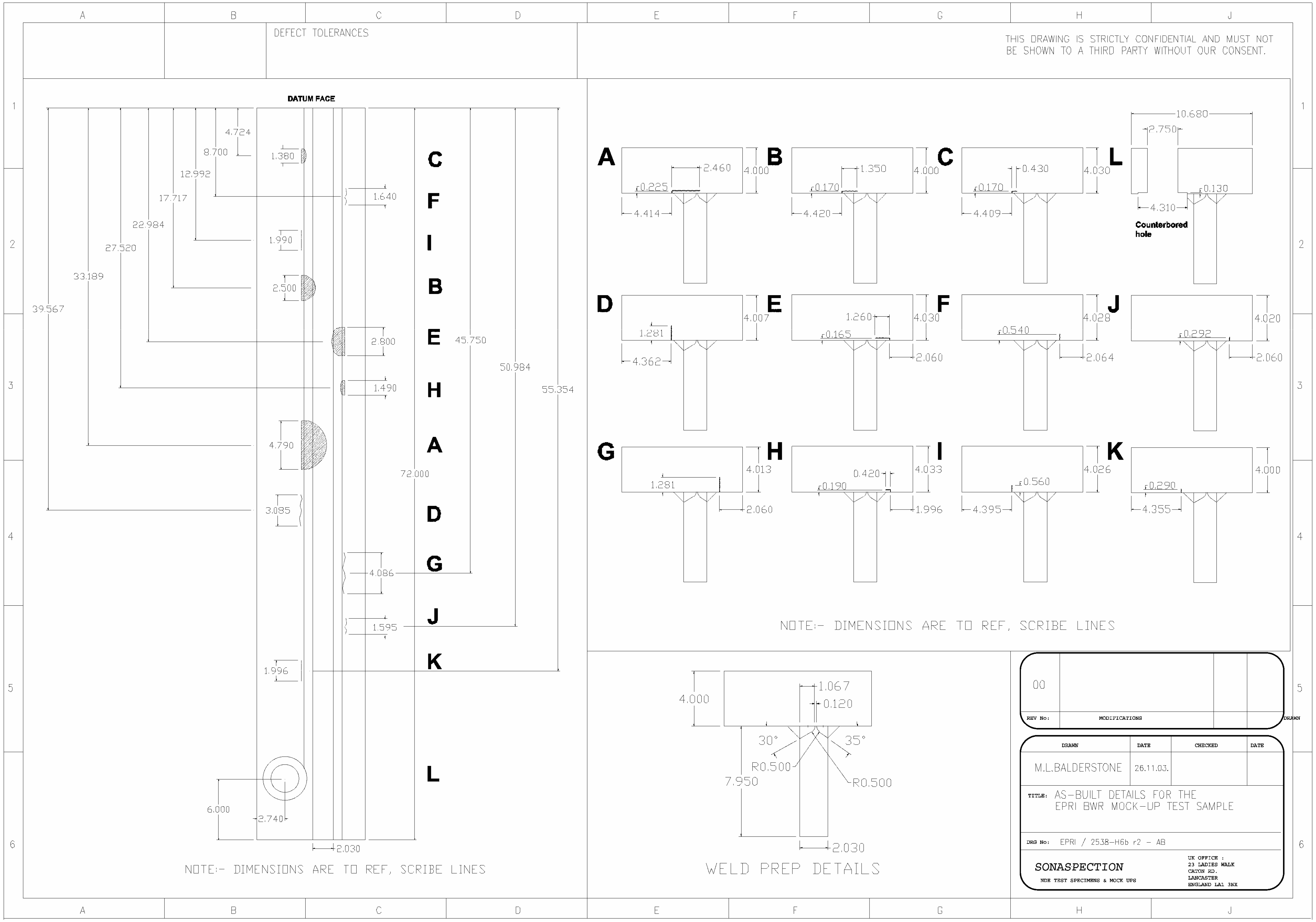


Figure 4.3.1.9-2. BWRVIP-H6OH, Representing the Overhanging Core Plate Support Ring Weld Configuration

5
SHROUD SUPPORT

5.1 Summary

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5.2 Inspection Considerations

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5.2.1 Chicago Bridge & Iron/CBI Nuclear Shroud Supports

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Figure 5.2.1-1. CB&I/CBIN, B&W Shroud Support Configuration

5.2.2 Babcock & Wilcox Shroud Supports

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5.2.3 Combustion Engineering Shroud Supports

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5.2.3.1 Gusset Supports

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Figure 5.2.3.1-1. CE Shroud Support Configuration

5.2.3.2 Cone Skirt Support

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Figure 5.2.3.2-1. BWR/2 Cone Skirt Shroud Support Configuration

5.2.3.3 Heavy Steel Baffle Plate

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Figure 5.2.3.3-1. Hatch Unit 2 Shroud Support Configuration

5.2.4 Inspection Access

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5.3 Applicable Mockups

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5.3.1 Shroud Support Mockup BWRVIP-D: Weld H7

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Figure 5.3.1-1. Configuration of Mockup BWRVIP-D, Representing Weld H7

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Figure 5.3.1-2. Cross Section of Mockup BWRVIP-D

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Figure 5.3.1-3. Distribution of Flaws in Mockup BWRVIP-D

5.3.2 Shroud Support Mockups BWRVIP-E, BWRVIP-E1, and BWRVIP-E2: Weld H9

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Figure 5.3.2-1. Mockup BWRVIP-E, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-1 (continued). Mockup BWRVIP-E, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-1 (continued). Mockup BWRVIP-E, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-1 (continued). Mockup BWRVIP-E, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-1 (continued). Mockup BWRVIP-E, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-1 (continued). Mockup BWRVIP-E, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-1 (continued). Mockup BWRVIP-E, Representing Weld H9: Configuration and Flaw Details.

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Figure 5.3.2-1 (continued). Mockup BWRVIP-E, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-1 (continued). Mockup BWRVIP-E, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-2. Mockup BWRVIP-E1, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-2 (continued). Mockup BWRVIP-E1, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-2 (continued). Mockup BWRVIP-E1, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-2 (continued). Mockup BWRVIP-E1, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-2 (continued). Mockup BWRVIP-E1, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-2 (continued). Mockup BWRVIP-E1, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-2 (continued). Mockup BWRVIP-E1, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-2 (continued). Mockup BWRVIP-E1, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-3. Mockup BWRVIP-E2, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-3 (continued). Mockup BWRVIP-E2, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-3 (continued). Mockup BWRVIP-E2, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-3 (continued). Mockup BWRVIP-E2, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-3 (continued). Mockup BWRVIP-E2, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-3 (continued). Mockup BWRVIP-E2, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-3 (continued). Mockup BWRVIP-E2, Representing Weld H9: Configuration and Flaw Details

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Figure 5.3.2-3 (continued). Mockup BWRVIP-E2, Representing Weld H9: Configuration and Flaw Details

5.3.3 Shroud Support Mockup BWRVIP-F: Weld H8

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Figure 5.3.3-1. Mockup BWRVIP-F, Representing Weld H8: Configuration and Flaw Details

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Figure 5.3.3-1 (continued). Mockup BWRVIP-F, Representing Weld H8: Configuration and Flaw Details

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Figure 5.3.3-1 (continued). Mockup BWRVIP-F, Representing Weld H8: Configuration and Flaw Details

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Figure 5.3.3-1 (continued). Mockup BWRVIP-F, Representing Weld H8: Configuration and Flaw Details

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Figure 5.3.3-1 (continued). Mockup BWRVIP-F, Representing Weld H8: Configuration and Flaw Details

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Figure 5.3.3-1 (continued). Mockup BWRVIP-F, Representing Weld H8: Configuration and Flaw Details

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Figure 5.3.3-1 (continued). Mockup BWRVIP-F, Representing Weld H8: Configuration and Flaw Details

5.3.4 Shroud Support Mockups BWRVIP-P, BWRVIP-Q1, BWRVIP-Q2

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Table 5.3.4-1. Configuration of Cracks in Shroud Support Mockup BWRVIP-P

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Figure 5.3.4-1. Shroud Support Mockup BWRVIP-P

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Table 5.3.4-2. Configuration of EDM Notches in Shroud Support Mockup BWRVIP-Q1

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5.3.5 Shroud Support Mockups BWRVIP-B2SS1 and BWRVIP-B2SS2

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Figure 5.3.5-1. Mockup BWRVIP-B2SS1

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Figure 5.3.5-2. Mockup BWRVIP-B2SS2

5.4 UT Technique Demonstrations for Core Shroud Support Welds

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5.4.1 General Findings for UT

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5.4.1.1 Effect of Alloy 82/182 Weld Material

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5.4.1.2 Effect of Mismatch in the Fit-up of Weld H7

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5.4.2 UT Demonstration 1

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5.4.3 UT Demonstration 2

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5.4.4 UT Demonstration 3

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5.4.5 UT Demonstration 4

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5.4.6 UT Demonstration 5

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Table 5.4.6-1. Definition of Scan Patterns Used in UT Demonstration 5

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Table 5.4.6-2. Results of UT Demonstration 5

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5.4.7 UT Demonstration 6

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5.4.8 UT Demonstration 7

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5.4.9 UT Demonstration 8

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5.4.10 UT Demonstration 9

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5.4.11 UT Demonstration 10

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5.4.12 UT Demonstration 11

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5.4.13 UT Demonstration 12

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5.4.14 UT Demonstration 13

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5.4.15 UT Demonstration 14

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Figure 5.4.15-1. Examination Coverage on Weld H8 Inspected From RPV Outside Surface

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5.4.16 UT Demonstration 15

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5.4.17 UT Demonstration 16

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5.4.18 UT Demonstration 17

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Figure 5.4.18-1. Configuration for Inspecting Weld H10 from the Outside of the Bottom Head of the Pressure Vessel

5.4.19 UT Demonstration 18

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Table 5.4.19-1. Sizing Performance and Evaluation Factors for UT Demonstration 18

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5.4.20 UT Demonstration 19

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5.4.21 UT Demonstration 20

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Table 5.4.21-1. Sizing Performance and Evaluation Factors for Demonstration 20

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5.4.22 UT Demonstration 21

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Table 5.4.22-1. Length Sizing Performance and Evaluation Factors for Demonstration 21

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Table 5.4.22-2. Depth Sizing Performance and Evaluation Factors for Demonstration 21

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5.4.23 UT Demonstration 22

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5.4.24 UT Demonstration 23

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5.4.25 UT Demonstration 24

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5.4.26 UT Demonstration 25

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5.4.27 UT Demonstration 26

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5.4.28 UT Demonstration 27

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Figure 5.4.28-1. Setting the Sensitivity for Inspection of Weld H9

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Figure 5.4.28-2. Geometry for Inspection of Weld H8

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Figure 5.4.28-3. Coverage for Inspection of Weld H8

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Figure 5.4.28-4. Some Potential Flaw Locations and Orientations in Weld H8

5.4.29 UT Demonstration 28

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5.4.30 UT Demonstration 29

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Figure 5.4.30-1. Setting the Sensitivity for Inspection of Weld H9

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Figure 5.4.30-2. Geometry for Inspection of Weld H8

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Figure 5.4.30-3. Coverage for Inspection of Weld H8

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Figure 5.4.30-4. Some Potential Flaw Locations and Orientations in Weld H8

5.4.31 UT Demonstration 30

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Figure 5.4.31-1 Example Display Showing Responses of Weld Crown Geometry in Mockup BWRVIP-E

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Figure 5.4.31-2 Response from Flaw 6b in Mockup BWRVIP-E

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5.4.33 UT Demonstration 32

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5.4.35 UT Demonstration 34

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5.4.36 UT Demonstration 35

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Figure 5.4.36-1. Geometry for Inspection of Weld H8

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Figure 5.4.36-2. Coverage for Inspection of Weld H8

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Figure 5.4.36-3. Some Potential Flaw Locations and Orientations in Weld H8

5.4.37 UT Demonstration 36

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5.4.38 UT Demonstration 37

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5.4.39 UT Demonstration 38

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Table 5.4.39-1. Linear Scans Performed in Various Shroud Inspection Situations

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5.4.40 UT Demonstration 39

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5.4.41 UT Demonstration 40

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5.4.42 UT Demonstration 41

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5.4.43 UT Demonstration 42

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5.4.44 UT Demonstration 43

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5.4.45 UT Demonstration 44

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5.4.46 UT Demonstration 45

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5.5 ET Technique Demonstrations for Core Shroud Support Welds

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5.5.1 General Findings for ET

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5.5.2 ET Demonstration 1

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5.6 Delivery System Demonstrations for Core Shroud Support Welds

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5.6.1 Delivery System Demonstration 1

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5.6.2 Delivery System Demonstration 2

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5.6.3 Delivery System Demonstration 3

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5.6.4 Delivery System Demonstration 4

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6
CORE SPRAY PIPING AND SPARGER

6.1 Summary

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6.2 Inspection Considerations

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Figure 6.2-1. Typical BWR/2 Core Spray Piping Configuration

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Figure 6.2-2. Typical BWR/3-5 Core Spray Piping Configuration

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Figure 6.2-3. Typical BWR/6 Core Spray Piping Configuration

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Figure 6.2-4. Typical Core Spray Sparger

6.2.1 Downcomer Sleeve

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6.2.2 Tee Box Assembly

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6.2.3 Shroud Connection Region

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6.3 Applicable Mockups

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6.3.1 Core Spray Mockups

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6.3.1.1 Downcomer Sleeve Joint Mockup (BWRVIP-J)

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Figure 6.3.1.1-1. Mockup BWRVIP-J: Downcomer Slip Joint

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Figure 6.3.1.1-2. Downcomer Sleeve Mockup (BWRVIP-J)

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Figure 6.3.1.1-3. Mockup BWRVIP-J: Downcomer Slip Joint: Configuration

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Figure 6.3.1.1-4. Mockup BWRVIP-J: Downcomer Slip Joint: Flaw Details

6.3.1.2 BWR/2 Shroud Penetration Mockup (BWRVIP-K)

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Figure 6.3.1.2-1. BWRVIP-K Mockup: Shroud Penetration (BWR/2)

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Figure 6.3.1.2-2. BWR/2 Shroud Penetration Mockup (BWRVIP-K)

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Figure 6.3.1.2-3. Mockup BWRVIP-K: BWR/2 Shroud Penetration: Configuration

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Figure 6.3.1.2-4. Mockup BWRVIP-K: BWR/2 Shroud Penetration: Flaw Details

6.3.1.3 BWR/3-5 Shroud Penetration Mockup (BWRVIP-L)

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Figure 6.3.1.3-1. BWRVIP-L Mockup: Shroud Penetration (BWR/3-5)

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Figure 6.3.1.3-2. BWR/3-5 Shroud Penetration Mockup (BWRVIP-L)

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Figure 6.3.1.3-3. Mockup BWRVIP-L: BWR/3-5 Shroud Penetration: Configuration

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Figure 6.3.1.3-4. Mockup BWRVIP-L: BWR/3-5 Shroud Penetration: Flaw Details

6.3.1.4 BWR/3-5 Core Spray Header Tee Box Mockups (BWRVIP-M and -N)

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6.3.1.5 BWR/6 Core Spray Pipe Coupling Assembly Mockup (BWRVIP-CS6)

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Figure 6.3.1.4-1. BWRVIP-M Mockup: Header Tee Box

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Figure 6.3.1.4-2. BWR/3-5 Core Spray Header Tee Box Mockup (BWRVIP-M)

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Figure 6.3.1.4-3. Mockup BWRVIP-M: BWR/3-5 Header Tee Box: Configuration

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Figure 6.3.1.4-4. Mockup BWRVIP-M: BWR/3-5 Header Tee Box: Flaw Details

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Figure 6.3.1.5-1. BWR/6 Core Spray Pipe Coupling Assembly Mockup BWRVIP-CS6: Weld Configuration and Flaw Details

6.3.1.6 BWR/3-6 P4a, P4b, and P4c Pipe-to-Elbow Mockups (BWRVIP-P4-1 and BWRVIP-P4-2)

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Figure 6.3.1.6-1. Photograph of BWRVIP-P4-1 and BWRVIP-P4-2

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Figure 6.3.1.6-2. Flaw Details of BWRVIP-P4-1

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Figure 6.3.1.6-3. Flaw Details of BWRVIP-P4-2

6.4 UT Technique Demonstrations for Core Spray Welds

6.4.1 General Findings for UT

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6.4.1.1 Detection and Sizing of Flaws Parallel to the Weld

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6.4.1.2 Detection of Flaws Transverse to the Weld

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6.4.1.3 Effect of Roughness of Scanning Surface

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6.4.2 UT Demonstration Summary

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Table 6.4.2-1. UT Demonstration Summary

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Table 6.4.2-1. UT Demonstration Summary (continued)

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6.4.3 UT Demonstration 1

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6.4.4 UT Demonstration 2

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6.4.5 UT Demonstration 3

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6.4.6 UT Demonstration 4

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6.4.7 UT Demonstration 5

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6.4.8 UT Demonstration 6

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6.4.9 UT Demonstration 7

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6.4.10 UT Demonstration 8

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6.4.11 UT Demonstration 9

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6.4.12 UT Demonstration 10

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6.4.13 UT Demonstration 11

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6.4.14 UT Demonstration 12

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6.4.15 UT Demonstration 13

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6.4.16 UT Demonstration 14

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6.4.17 UT Demonstration 15

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6.4.18 UT Demonstration 16

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6.4.19 UT Demonstration 17

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6.4.20 UT Demonstration 18

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6.4.21 UT Demonstration 19

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6.4.22 UT Demonstration 20

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6.4.23 UT Demonstration 21

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6.4.24 UT Demonstration 22

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6.4.25 UT Demonstration 23

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6.4.26 UT Demonstration 24

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6.4.27 UT Demonstration 25

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6.4.28 UT Demonstration 26

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6.4.29 UT Demonstration 27

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6.4.30 UT Demonstration 28

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6.4.31 UT Demonstration 29

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6.4.32 UT Demonstration 30

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Figure 6.4.32-1. Correspondence of Flaws in Mockup BWRVIP-J to the Inspection Configuration of BWR/2 Weld P8

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Figure 6.4.32-2. Inability to Detect OD Pipe-Side Flaws Using the Single-stroke Scan Technique

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6.4.34 UT Demonstration 32

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6.4.35 UT Demonstration 33

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Figure 6.4.35-1. Detection Paths for Flaws in Mockup BWRVIP-K

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6.4.37 UT Demonstration 35

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6.4.38 UT Demonstration 36

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6.4.39 UT Demonstration 37

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6.4.40 UT Demonstration 38

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6.4.41 UT Demonstration 39

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6.4.42 UT Demonstration 40

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6.4.43 UT Demonstration 41

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6A

INVESTIGATION OF CORE SPRAY INTERNAL PIPING OVERLAY INSPECTION

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6A.1 Materials

6A.1.1 Probes

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6A.1.2 Ultrasonic Instrument

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6A.1.3 Mockups

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Figure 6A.1.3-1. Mockup BWRVIP-CSRA: Weld Overlay Repair with Cracks Propagating from Existing Throughwall Defects: Configuration and Flaw Details

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Figure 6A.1.3-2. Mockup BWRVIP-CSRC: Weld Overlay Repair with Sidewall Lack of Fusion: Configuration and Flaw Details

6A.2 Surface Condition

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6A.3 Examination Results

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6A.4 Conclusions

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6A.5 References

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7
TOP GUIDE

7.1 Summary

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7.2 Inspection Considerations

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7.2.1 Aligner Pin Assemblies

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Figure 7.2.1-1. Typical Vertical Aligner Pin Assembly

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Figure 7.2.1-2. Aligner Pin Assembly Variations

7.2.2 Hold-Down Assemblies

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Figure 7.2.2-1. Hold-Down Assembly

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Figure 7.2.2-2. Hold-Down Assembly

7.2.3 Wedges

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Figure 7.2.3-1. Lateral Restraint Brackets and Wedges

7.2.4 BWR/6 Hold-Down Studs

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Figure 7.2.4-1. Hold-Down Assembly

7.2.5 Rim-to-Bottom Plate Weld

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Figure 7.2.5-1. Rim-to-Bottom Plate Weld

7.2.6 Grid Beams

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Figure 7.2.6-1. Configuration of Top Guide Grid, Fuel Channels, and Control Blades

7.3 Applicable Mockups

7.3.1 Top Guide Grid Mockup BWRVIP-I

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Figure 7.3.1-1. Configuration of Top Guide Grid Mockup BWRVIP-I

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Figure 7.3.1-2. Top Guide Grid Mockup BWRVIP-I, Plate BWRVIP-I-A: Configuration and Flaw Details

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Figure 7.3.1-3. Top Guide Grid Mockup BWRVIP-I, Plate BWRVIP-I-B: Configuration and Flaw Details

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Figure 7.3.1-4. Top Guide Grid Mockup BWRVIP-I, Plate BWRVIP-I-C: Configuration and Flaw Details

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Figure 7.3.1-5. Top Guide Grid Mockup BWRVIP-I, Plate BWRVIP-I-D: Configuration and Flaw Details

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Figure 7.3.1-6. Top Guide Grid Mockup BWRVIP-I, Plate BWRVIP-I-E: Configuration and Flaw Details

7.4 UT Technique Demonstrations for Top Guide Components

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7.4.1 General Findings for UT

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7.4.1.1 Grid Beams

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7.4.2 UT Demonstration 1

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8
CORE PLATE

8.1 Summary

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8.2 Inspection Considerations

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8.2.1 Rim Hold-Down Bolt Locations

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8.3 Applicable Mockups

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Figure 8.3-1. EDM Notches in Upper and Lower Threaded Regions of Core Plate Bolt Mockup

8.4 UT Technique Demonstrations for Core Plate Rim Hold-Down Bolts

8.4.1 UT Demonstration 1

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8.4.2 UT Demonstration 2

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8.4.3 UT Demonstration 3

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Figure 8.4.3-1. Water Standoff as a Function of Measured Time to First Response From Ring Surface

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Figure 8.4.3-2a. Time Separation Between Bolt Hole Signals and Irrelevant Multiples, as a Function of Water Standoff Distance

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Figure 8.4.3-2b. Time Separation Between Bolt Hole Signals and Irrelevant Multiples, as a Function of Time to First Entry Surface Response

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Figure 8.4.3-3. Time of Signals From the Front and the Back of the Bolt Hole

8.4.4 UT Demonstration 4

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9
LPCI COUPLING

9.1 Summary

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9.2 Inspection Considerations

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9.3 Applicable Mockups

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9.4 UT Technique Demonstrations for LPCI Coupling Welds

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10
JET PUMP ASSEMBLY

10.1 Summary

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10.2 Inspection Considerations

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10.3 Applicable Mockups

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10.3.1 Mockup BWRVIP-U

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10.3.2 Mockup BWRVIP-V

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10.3.3 Mockups BWRVIP-Z3 and BWRVIP-Z3R

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10.3.4 Mockup BWRVIP-Z4

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10.3.5 Jet Pump Beam Mockups

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Figure 10.3.5-1. EPRI Jet Pump Beam Mockup A

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Figure 10.3.5-2. EPRI Jet Pump Beam Mockup B (No Flaws)

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Figure 10.3.5-3. EPRI Jet Pump Beam Mockup C

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Figure 10.3.5-4. Jet Pump Beam Mockup BWRVIP-G2JPB1

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Figure 10.3.5-5. Jet Pump Beam Mockup BWRVIP-G2JPB2

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Figure 10.3.5-6. Jet Pump Beam Mockup BWRVIP-G2JPB3

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Figure 10.3.5-7. Jet Pump Beam Mockup BWRVIP-G2JPB4

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Figure 10.3.5-8. Jet Pump Beam Taper-to-Radius Transition Mockups (Perspective Drawing)

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Figure 10.3.5-9. Jet Pump Beam Taper-to-Radius Transition Mockups (Photo)

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Figure 10.3.5-10. Jet Pump Beam Taper-to-Radius Transition Mockups (Side View Drawing)

10.4 UT Technique Demonstrations

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10.4.1 General Findings for UT

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10.4.2 UT Demonstration 1

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10.4.3 UT Demonstration 2

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10.4.4 UT Demonstration 3

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10.4.5 UT Demonstration 4

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10.4.6 UT Demonstration 5

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10.4.7 UT Demonstration 6

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10.4.8 UT Demonstration 7

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10.4.9 UT Demonstration 8

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10.4.10 UT Demonstration 9

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10.4.11 UT Demonstration 10

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10.4.12 UT Demonstration 11

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10.4.13 UT Demonstration 12

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10.4.14 UT Demonstration 13

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10.4.15 UT Demonstration 14

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Table 10.4.15-1. Examination Sequence

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10.4.16 UT Demonstration 15

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Figure 10.4.16-1. LaSalle 1, Fermi Jet Pump Adapter Configuration

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Figure 10.4.16-2. Demonstration for Weld AD-1

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Figure 10.4.16-3. Demonstration for Weld AD-2

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Figure 10.4.16-4. Demonstration for Weld DF-3

10.4.17 UT Demonstration 16

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10.4.18 UT Demonstration 17

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10.4.19 UT Demonstration 18

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Figure 10.4.19-1. Area BB-2 and BB-3 Examination Technique

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Figure 10.4.19-2. Jet Pump Beam Taper-to-Radius Transition Mockups

10.4.20 UT Demonstration 19

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10.4.21 UT Demonstration 20

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10.5 ET Technique Demonstrations

10.5.1 ET Demonstration 1

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10.5.2 ET Demonstration 2

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10.6 Delivery System Demonstrations

10.6.1 Delivery System Demonstration 1

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10.6.2 Delivery System Demonstration 2

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10.6.3 Delivery System Demonstration 3

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10.6.4 Delivery System Demonstration 4

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Figure 10.3.1-1. Jet Pump Riser Mockup BWRVIP-U: Configuration and Flaw Details

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Figure 10.3.2-1. Jet Pump Riser Mockup BWRVIP-V: Configuration and Flaw Details

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Figure 10.3.3-1. Jet Pump Mixer Mockup BWRVIP-Z3: Configuration and Flaw Details

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Figure 10.3.4-1. Jet Pump Mixer Mockup BWRVIP-Z4: Configuration

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Figure 10.3.4-2. Jet Pump Mixer Mockup BWRVIP-Z4: Flaw Details

11
STANDBY LIQUID CONTROL

11.1 Summary

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11.2 Inspection Considerations

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11.2.1 Nozzle-to-Vessel Weld

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11.2.2 Penetration-to-Vessel Weld

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11.2.3 Nozzle-to-Safe-End Weld

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11.2.4 Penetration-to-Safe-End Extension Weld

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11.3 Applicable Mockups

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11.3.1 Mockup BWRVIP-X1

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11.3.2 Mockup BWRVIP-X2

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11.3.3 Mockup BWRVIP-Y3

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11.3.4 Mockup BWRVIP-Y4

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11.3.5 Mockup BWRVIP-Y5

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11.4 UT Technique Demonstrations for SLC Components

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11.4.1 General Findings for UT

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11.4.2 UT Demonstration 1

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11.4.3 UT Demonstration 2

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Figure 11.3.1-1. SLC Nozzle Mockup BWRVIP-X1: Configuration and Flaw Details

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Figure 11.3.2-1. SLC Nozzle Mockup BWRVIP-X2: Configuration and Flaw Details

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Figure 11.3.3-1. SLC Penetration Mockup BWRVIP-Y3: Configuration and Flaw Details

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Figure 11.3.4-1. SLC Penetration Mockup BWRVIP-Y4: Configuration and Flaw Details

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Figure 11.3.5-1. SLC Penetration Mockup BWRVIP-Y5: Configuration and Flaw Details

12
VESSEL ATTACHMENTS

12.1 Summary

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12.2 Inspection Considerations

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12.3 Applicable Mockups

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12.4 UT Technique Demonstrations for Vessel Attachment Welds

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13
LOWER PLENUM

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13.1 Summary

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13.2 Inspection Considerations

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13.3 Applicable Mockups

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13.4 UT Technique Demonstrations for Lower Plenum Welds

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14
INSTRUMENT PENETRATIONS

14.1 Summary

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14.2 Inspection Considerations

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