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BWR Vessel and Internals Project BWR Core Shroud Inspection and Flaw Evaluation Guidelines (BWRVIP-76NP)

BWR Vessel and Internals Project BWR Core Shroud Inspection and Flaw Evaluation Guidelines (BWRVIP-76NP)

TR-114232NP

Final Report, January 2000

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The report is a corporate document that should be cited in the literature in the following manner:

BWR Vessel and Internals Project: BWR Core Shroud Inspection and Flaw Evaluation Guidelines (BWRVIP-76NP), EPRI, Palo Alto, CA, and BWRVIP: 1999. TR-114232NP.

REPORT SUMMARY

The Boiling Water Reactor Vessel and Internals Project (BWRVIP), formed in June 1994, is an association of utilities focused exclusively on BWR vessel and internals issues. This BWRVIP report provides guidelines for inspecting and evaluating BWR core shrouds.

Background

Core shroud cracking, first detected in 1990, has been found in a significant number of BWRs. As an initial response in 1994, the BWRVIP developed guidelines for inspecting circumferential welds (BWRVIP-01). Subsequently, additional guidelines have been developed for re-inspecting circumferential welds (BWRVIP-07) and inspecting vertical welds (BWRVIP-63) in repaired and un-repaired shrouds. The recommendations in each guideline have been modified somewhat in the intervening years based on industry experience and evaluations performed by NRC.

Objective

To combine inspection recommendations in the three previously published guidelines into a single, comprehensive report.

Approach

A focus group was formed to oversee development of the new Guideline. Once an initial draft had been prepared, the focus group reviewed it to ensure that it was comprehensive, accurate, and straightforward to implement. Review comments were incorporated, and the Guideline was reviewed by a broader cross section of utility experts. Additional improvements were made based on this final review.

Results

The Guidelines represent an integrated approach to inspecting BWR core shrouds. Schedules and techniques are presented for inspecting circumferential welds, vertical welds, and ring segment welds in repaired and un-repaired shrouds. Guidance also is included for inspecting repair hardware in repaired shrouds. In addition, flaw evaluation methods are included for evaluating any degradation found during inspections.

EPRI Perspective

When implemented by utilities, the combined inspection recommendations in this Guideline will ensure that core shroud integrity is maintained with respect to all essential safety functions. The recommendations in this report supersede the previous recommendations in reports BWRVIP-01, BWRVIP-07, and BWRVIP-63.

TR-114232NP

Keywords
Boiling water reactor
Flaw evaluation
Inspection strategy
Core shroud
Stress corrosion cracking
Vessel and internals

ACKNOWLEDGMENTS

The members of the BWRVIP Core Shroud Focus Group, listed below, are gratefully acknowledged for their efforts which led to the successful completion of this document.

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This report is based on three, previously published BWRVIP reports. Those reports and their authors are:

"BWR Vessel and Internals Project, BWR Core Shroud Inspection and Flaw Evaluation Guidelines, Revision 2 (BWRVIP-01)," EPRI Report TR-107079, October 1996, developed by GENE. Principal investigator T. Caine.

"BWR Vessel and Internals Project, Guidelines for Reinspection of BWR Core Shrouds (BWRVIP-07)," EPRI Report TR-105747, February 1996, developed by SIA. Principal investigators A. Giannuzzi, G. Stevens and J. Johnson (IES).

"BWR Vessel and Internals Project, Shroud Vertical Weld Inspection and Evaluation Guidelines (BWRVIP-63)," EPRI Report TR-113170, June 1999, developed by GENE. Principal investigators S. Ranganath and R. Stark.

The original draft of this report was prepared by R. Gamble of Sartrex Corp.

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EXECUTIVE SUMMARY

Cracking has been detected in the vicinity of core shroud welds at several domestic and overseas boiling water reactors (BWRs). Visual (VT) and ultrasonic (UT) examinations of the shroud weld areas have detected indications in both horizontal and vertical welds.

In June 1994, the BWR Vessel and Internals Project (BWRVIP) was formed to address integrity issues arising from inservice degradation of core internals, including the core shroud. Since that time, the BWRVIP has published three reports which present guidelines for inspecting and evaluating core shroud integrity. Those reports are:

- "BWR Core Shroud Inspection and Flaw Evaluation Guidelines, Revision 2 (BWRVIP-01)," October 1996
- "Guidelines for Reinspection of BWR Core Shrouds (BWRVIP-07)," February 1996
- "Shroud Vertical Weld Inspection and Evaluation Guidelines (BWRVIP-63)," June 1999

This report combines the guidance of the three reports above and, in addition, incorporates information from NRC reviews and safety evaluations. Consolidating the industry developed procedures for inspection and flaw evaluation, as well as the information from NRC reviews and safety evaluations, into one report ensures that a unified, regulatory accepted approach will be implemented for evaluating and maintaining BWR core shroud integrity.

The consolidated report defines generic acceptance standards and inspection intervals for horizontal and vertical welds in repaired and un-repaired core shrouds, and procedures for determining plant specific inspection intervals when the generic acceptance standards are not applicable. The report also includes generic inspection intervals and acceptance standards for radial ring welds, repair hardware and repair anchorages in repaired core shrouds.

The consolidated report contains several changes made to the previously published reports. These changes incorporate generic approaches and provide a unified and regulatory accepted approach for ensuring the integrity of BWR core shrouds. The changes include:

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1 INTRODUCTION

This report presents inspection requirements and evaluation procedures for cracking that may occur in repaired and un-repaired core shrouds of boiling water reactors (BWR). The report combines the guidance in the previously published BWRVIP Guidelines:

- "BWR Core Shroud Inspection and Flaw Evaluation Guidelines, Revision 2 (BWRVIP-01)," October 1996 [1]
- "Guidelines for Reinspection of BWR Core Shrouds (BWRVIP-07)," February 1996 [2]
- "Shroud Vertical Weld Inspection and Evaluation Guidelines, (BWRVIP-63)," June 1999 [3]

The report also incorporates information from NRC requests for additional information and safety evaluations [4-6] related to BWRVIP-07.

The remainder of this section presents background information and the objectives and scope of the report, including a summary of changes compared to previous versions of the reports. Sections 2 and 3 present overviews of the inspection strategies and evaluation procedures for welds in un-repaired and repaired shrouds, respectively. Flaw evaluation methods, as well as the bases for the inspection guidelines, are described in appendices.

Appendix A contains the core shroud design features, while Appendix B summarizes the classification of the susceptibility of the core shroud to inservice cracking. Appendix C provides the bases for determining generic inspection intervals for horizontal welds in repaired and un-repaired shrouds. Appendix D provides evaluation procedures that can be used to define a plant specific inspection interval for horizontal welds when the generic criteria are not applicable. The bases for the generic acceptance standards and inspection intervals applicable to vertical welds are presented in Appendix E and the weld/plant specific inspection interval evaluation procedure for vertical welds is summarized in Appendix F. Appendices G, H, I and J provide additional information related to flaw evaluations. Demonstration of compliance with the License Renewal Rule is included in Appendix K.

1.1 Background

BWRs designated BWR/2 through BWR/6 were designed with a cylindrical core shroud as illustrated in Figure 1-1. The shroud directs coolant flow through the core, helps maintain fuel alignment to ensure the control rods can be inserted into the core, and, with the exception of BWR/2s, forms part of the boundary that maintains coolant level in the core following a loss of coolant accident. The core shroud design and fabrication are summarized in Appendix A.

Core shroud cracking was first discovered in an overseas BWR in 1990. Subsequently, visual (VT) and ultrasonic (UT) examination techniques have detected cracking in core shrouds in a number of domestic and overseas BWRs. Crack indications have been found in heat affected zones of both horizontal and vertical welds. The predominant form of cracking is circumferentially oriented indications located in the heat-affected zones of horizontal welds. Limited cracking has also been observed in vertical welds.

The majority of the cracking has been identified as intergranular stress corrosion cracking (IGSCC). Irradiation assisted stress corrosion cracking (IASCC) has also been observed in the core beltline region (weld H4, see Fig. 1-1). The shrouds are fabricated using either Type 304 or Type 304L austenitic stainless steel, and cracking has been detected in core shrouds fabricated from either material.

Initially, BWR owners were apprised of the cracking through GE SILs and RICSILs and NRC Information Notices [7-11]. As a result of an increased number of detected shroud cracks, the BWR Owners' Group (BWROG) in April 1994 published a report entitled "BWR Core Shroud Evaluation" [12]. This report provided a conservative, generic screening methodology to evaluate core shroud flaw indications on a plant-specific basis.

In June 1994, executives from domestic BWR owners formed the BWR Vessel and Internals Project (BWRVIP) to address integrity issues arising from inservice degradation of core internals, including the core shroud.

In July 1994, the NRC issued Generic Letter (GL) 94-03 [13], which required all BWR licensees to inspect their core shrouds at the next scheduled refueling outage. A plant-specific safety evaluation also was required to support continued operation of the plant until the inspections could be performed.

In response to GL 94-03, flaw acceptance criteria for horizontal welds in un-repaired shrouds were submitted to NRC in reports "BWR Core Shroud Inspection and Flaw Evaluation Guidelines," September 2, 1994 [14], and "BWR Core Shroud Inspection and Flaw Evaluation Guidelines," Rev. 1, March, 1995 [15]. These guidelines grouped core shrouds into three categories (A, B, or C) based on the expected susceptibility to cracking. The basis for defining the core shroud categories is summarized in Appendix B.

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The results of the NRC review of these documents were presented in Safety Evaluation Reports issued on December 28, 1994 [16] and June 16, 1995 [17], respectively. During this time several BWR owners implemented repairs to the core shrouds.

On February 29, 1996 the BWRVIP submitted to the NRC "Guidelines for Reinspection of BWR Core Shrouds (BWRVIP-07) [2]. The purpose of this report was to provide a uniform industry approach to reinspection that would ensure the structural and functional integrity of repaired or un-repaired core shrouds. The NRC reviewed this report, and requested additional information [4,5]. Responses to the NRC requests for information were provided on October 21, 1996 [18] and November 26, 1997 [19]. Based on these responses, the NRC, on April 27, 1998 [6], issued Supplement 1 to the Safety Evaluation "Guidelines for Reinspection of BWR Core Shrouds (BWRVIP-07). The safety evaluation accepted the industry inspection strategy and evaluation procedure, subject to some industry actions, which are incorporated in this report. Finally, on November 7, 1999 the NRC issued an errata [22] which affects reinspection requirements. The contents of the errata are also incorporated in this report.

Recently, industry completed the report "Shroud Vertical Weld Inspection and Evaluation Guidelines (BWRVIP-63)" [3]. This report describes the inspection strategy and acceptance criteria for vertical welds in un-repaired and repaired core shrouds. This report includes the technical basis for the acceptance standards and provides weld specific evaluation procedures for conditions where the acceptance standards cannot be met.

1.2 Objectives and Scope

The objective of this report is to provide a regulatory accepted, unified industry approach for inspecting horizontal, vertical and radial ring welds in repaired and un-repaired BWR core shrouds, and repair components and anchorage in repaired shrouds. This approach will ensure that the structural and functional integrity of the core shroud is maintained, while the impact of core shroud inspections on plant outage schedules and plant resources is minimized.

To accomplish this objective, information from the four previously listed sources has been combined into this single document. The consolidated report contains several changes made to the previously published reports. These changes incorporate generic approaches and provide a unified and regulatory accepted approach for ensuring the integrity of BWR core shrouds. The changes include:

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The inspection criteria provided in this document are intended to allow all BWR utilities to develop appropriate and conservative plant specific inspection plans. The Assessment Committee plans to monitor the results of all core shroud inspections so that new information obtained from these inspections can be factored into subsequent revisions of this document, as appropriate.

The recommendations in this Guideline provide inspections necessary to ensure shroud intergrity for continued safety and replace the inspection recommendations of GE SILS. However, SILS may contain other information relative to operational performance and field experience that may assist licensees with investment protection, cost management and optimization of operational performance. Each Licensee should review the current SILS, and stay cognizant of any future changes, for information that may affect reactor operation or performance.

The inspection recommendations described in Sections 2 and 3 of this report and Appendices A, B, D, E, F, G, H, I and J were compiled under the EPRI QA Program described in the EPRI QA Program Manual, Revision 2, dated July 19, 1999 which complies with the provisions of 10CFR50 Appendix B and 10CFR21.

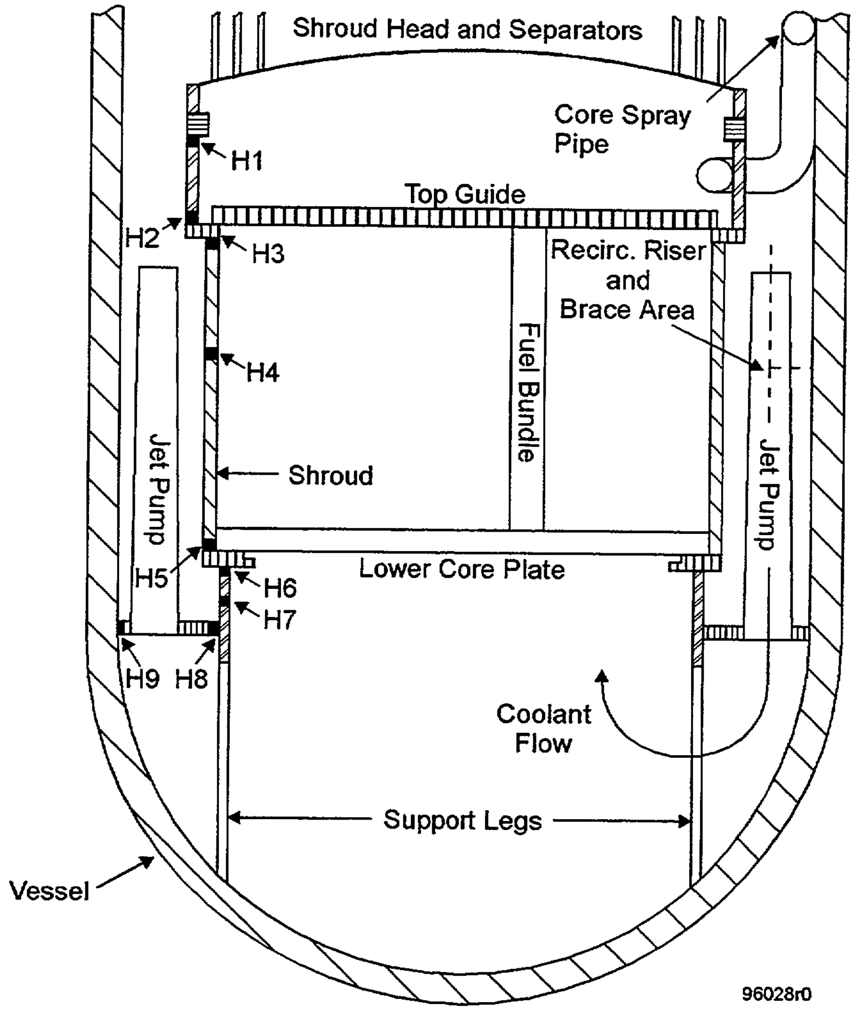

Figure 1-1
Typical BWR Core Shroud

2
INSPECTION STRATEGY FOR WELDS IN UN-REPAIRED SHROUDS

2.1 Overview

This section presents inspection and evaluation strategies for horizontal and vertical welds in un-repaired core shrouds. The inspection strategy makes no distinction between baseline inspection and reinspection. The inspection scope, procedures and interval, and the evaluation procedures are the same regardless of the time at which the inspection was or will be performed.

The inspection strategy for un-repaired shrouds depends on the material, coolant conductivity, and operating time used to define the shroud categories identified in Appendix B. A summary of the shroud categories and an overview of the associated inspection requirements are presented in Figure 2-1.

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2.2 Inspection Strategies for Horizontal Welds in Un-repaired Core Shrouds

Figures 2-2 and 2-3 present the inspection strategy for horizontal welds in Category B and C shrouds, respectively. In the event that the generic acceptance standards in Figures 2-2 and 2-3

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2.2.1 Overview of Inspection Approach

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A roadmap to performing the plant specific analyses is provided in the flow charts of Figures 2-2 and 2-3.

2.2.2 Inspection Methods

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All inspections shall be in accordance with BWRVIP-03 (Reference 21).

2.3 Inspection Strategy for Vertical Welds in Un-Repaired Category C Shrouds

2.3.1 Overview of Inspection Approach

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2.3.2 Inspection Methods

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Inspections must be performed using these methods in accordance with the requirements of BWRVIP-03.

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The specific inspection recommendations and acceptance criteria for vertical welds are described in Section 2.3.3. The analyses, which form the basis for the acceptance criteria, are detailed in Appendix E.

2.3.3 Inspection Strategy

This section presents the inspection strategies for vertical welds in Category C un-repaired BWR core shrouds.The inspection strategies are discussed below and are summarized in Figures 2-4 and 2-5. These strategies are applicable to vertical welds lying between horizontal welds H1 and H7.

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Figure 2-1
Core Shroud Classification, and Vertical and Horizontal Weld Inspection Programs for Un-repaired BWR Core Shrouds

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Figure 2-2
Inspection and Inspection Interval for Horizontal Welds in Un-repaired Category B Core Shrouds

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Figure 2-3
Inspection and Inspection Interval for Horizontal Welds in Un-repaired Category C Core Shrouds

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Figure 2-4
Procedure for Screening Horizontal Welds to Define the Inspection Scope for Vertical Welds in Category C Un-repaired Shrouds

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Figure 2-5
Acceptance Standards and Inspection Interval for Inspection of Vertical Welds in Category C Un-repaired Shrouds

Table 2-1
Core Shroud Inspection Intervals for Category B and C Plants (in years)

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3
INSPECTION STRATEGY FOR WELDS IN REPAIRED SHROUDS

3.1 Scope

This section presents inspection and evaluation strategies for horizontal and vertical welds, radial ring welds, and repair components and anchorage in repaired shrouds. The inspection strategy described here makes no distinction between baseline inspection and reinspection. The inspection scope, procedures and interval, and the evaluation procedures are the same regardless of the time at which the inspection was or will be performed.

Inspection of repaired core shrouds is intended to provide confirmation of the continued integrity of the repaired shroud. The inspection requirements in this section are applicable to shroud repairs that meet the BWRVIP Shroud Repair Design Criteria [20], with any exceptions to those criteria specifically approved by NRC as provided for in that document.

The inspection requirements in ASME Section XI for core support structures also apply. The Code Edition and Addenda used shall be that specified in the licensee's ISI program. Alternately, licensees may use later NRC-approved Editions subject to the provisions of 10CFR50.55(g)(4)(iv).

The licensee shall develop an inspection program based on the recommendations in this section. The licensee shall consider such things as repair vendor recommendations, industry experience, and degradation mechanisms as well as the critical components and features of the repair design itself.

3.2 Overview of Inspection Strategy for Repaired Shrouds

An overview of the inspection strategy for horizontal and vertical welds in repaired shrouds is presented in Figure 3-1.

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3.3 Vertical Welds in Repaired Shrouds

The inspection requirements for vertical welds in repaired shrouds are discussed below and are shown in Figures 3-2 and 3-3.

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3.4 Inspection Strategy for Radial Ring Welds in Repaired Shrouds

For repaired shrouds, inspection of certain ring welds may be required because they can be important for structural stiffness in some core shroud repair designs.

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3.5 Repair Component Inspections (Repair Assemblies and Other Components Added as Part of the Repair)

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3.6 Repair Anchorage Inspections

The inspection requirements for repair anchorage are as follows:

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Figure 3-1
Overview of Inspection Requirements for Horizontal and Vertical Welds in Repaired Core Shrouds

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Figure 3-2
Inspection Strategy Options for Vertical Welds in Repaired Shrouds

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Figure 3-3
Acceptance Standards and Inspection Intervals for Inspection of Vertical Welds in Repaired Shrouds

4
REPORTING REQUIREMENTS

4.1 Implementation of the I&E Guidelines

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4.2 Inspection Results

Results of inspections recommended by this I&E guidelines shall be reported to the BWRVIP. This information will be summarized by the BWRVIP and provided to the NRC. Individual reporting by the Licensee is not required.

4.3 Analytical Evaluations of Inspection Results

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REFERENCES

1. "BWR Core Shroud Inspection and Flaw Evaluation Guidelines, Revision 2 (BWRVIP-01)," EPRI Report TR-107079, October 1996.

2. "Guidelines for Reinspection of BWR Core Shrouds (BWRVIP-07)," EPRI Report TR-105747, February 1996.

3. "Shroud Vertical Weld Inspection and Evaluation Guidelines (BWRVIP-63)," EPRI Report TR-113170, June 1999.

4. Letter from C.E. Carpenter, Jr. (NRC) to J.T. Beckham, Jr. (BWRVIP Chairman), "Request for Additional Information – Review of BWR Vessel and Internals Project Proprietary Report, "BWR Vessel and Internals Project, Guidelines for Reinspection of BWR Core Shrouds (BWRVIP-07)," May 21,1996.

5. Letter from Gus C. Lainas (NRC) to Carl Terry (BWRVIP) Chairman, "Transmittal of NRC Staff's Safety Evaluation of the BWR Vessel and Internals Project BWRVIP-07 Report (TAC No. M94959)," September 15, 1997.

6. Letter from Gus C. Lainas (NRC) to Carl Terry (BWRVIP) Chairman, "Final Supplement to the Safety Evaluation of the BWR Vessel and Internals Project BWRVIP-07 Report," April 27, 1998.

7. GE RICSIL 054, Revision 1, "Core Shroud Cracks," July 1993.

8. GE SIL 572, Revision 1, "Core Shroud Cracks," October 1993.

9. GE RICSIL 068, Revision 2, "Update on Core Shroud Cracking," May 1994.

10. NRC Information Notice 93-79, "Core Shroud Cracking at Beltline Region Welds in BWRs," September 1993.

11. NRC Information Notice 94-42 and Supplement 1, "Cracking in the Lower Region of the Core Shroud in BWRs," July 1994.

12. "BWR Core Shroud Evaluation," Report GE-NE-523-148-1193, April 1994.

13. NRC Generic Letter 94-03, dated July 25, 1994. Re: Intergranular Stress Corrosion Cracking of Core Shrouds in Boiling Water Reactors.

14. "BWR Core Shroud Inspection and Evaluation Guidelines," Report GENE –523-113-0894, September 2, 1994.

15. "BWR Core Shroud Inspection and Flaw Evaluation Guidelines," Report GENE –523-113-0894, Rev. 1, March 1995.

16. Letter from B.W. Sheron, Director- Division of Engineering, U.S. Nuclear Regulatory Commission, to J.T. Beckman, Chairman-BWRVIP dated December 28, 1994: Evaluation of "BWR Shroud Cracking Generic Safety Assessment," Rev.1, GENE-523-A10794, August 5, 1994 and "BWR Core Shroud Inspection and Evaluation Guidelines," Report GENE –523-113-0894, September 2, 1994.

17. Letter from B.W. Sheron, Director- Division of Engineering, U.S. Nuclear Regulatory Commission, to J.T. Beckman, Chairman-BWRVIP dated June 16, 1995: Evaluation of "BWR Core Shroud Inspection and Evaluation Guidelines," Report GENE –523-113-0894, Rev. 1, dated March 1995, and "BWRVIP Core Shroud NDE Uncertainty and Procedure Standard," dated November 22, 1994.

18. Letter from Robin Dyle (Technical Chairman BWRVIP Assessments Committee) to C.E. Carpenter (NRC), "Response to NRC Request for Additional Information on BWRVIP-07," October 21, 1996.

19. Letter from Vaughn Wagoner (Technical Chairman BWRVIP Integration Committee) to C.E. Carpenter (NRC), "Response to NRC Staff Safety Evaluation of the BWR Vessel and Internals Project BWRVIP-07 Report," November 26, 1997.

20. "BWR Vessel and Internals Project, Core Shroud Repair Design Criteria, Rev. 2 (BWRVIP-02)," EPRI Report TR-112642, March 1999.

21. "Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03) Revision 1," EPRI Report TR-105696-R1, March 1999.

22. Letter from William H. Bateman, Chief, Materials and Chemical Engineering Branch, Office of Nuclear Reactor Regulation, to Carl Terry, BWRVIP Chairman, dated November 3, 1999: "Errata in Revised BWRVIP-07 Report Table 1."

A
CORE SHROUD DESIGN

A.1 Design

As illustrated in Figure 1-1, the core shroud is a welded assembly typically composed of three austenitic stainless steel cylindrical shell sections and three rings. The three rings are the shroud head flange, top guide support ring, and core plate support ring. The top cylindrical shell (between welds H1 and H2) connects the shroud head flange to the top guide support ring. The longest cylindrical portion (between welds H3 and H5) connects the top guide support ring to the core plate support ring. The bottom cylindrical shell (between welds H6 and H7) connects the core plate support ring to the shroud support cylinder. The shroud support legs are located at the bottom edge of the shroud support cylinder (a few plants, supported on the cantilever principle, do not have support legs).

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There can be significant differences between core shroud designs and fabrication conditions. These differences include diameter, wall thickness, number of horizontal welds in the core beltline, number of vertical welds, material type (304 vs. 304L) and carbon content, ring fabrication (single piece forging vs. segmented welded plate pieces), and tapered lower cylindrical shell vs. straight lower cylindrical shell. Sketches of the various shroud configurations are provided in [A-1].

A.2 References

A-1. Responses to NRC Questions on Core Shroud and Reactor Internals "GE Report for BWROG," GENE-523-A114P-0894, August 1994.

B
CRACKING SUSCEPTIBILITY FACTORS AND CORE SHROUD CLASSIFICATION

B.1 Cracking Susceptibility Factors

Cracking susceptibility factors were determined to identify conditions that likely would result in cracking near heat affected zones of welds in BWR core shrouds. The susceptibility factors are used to define inspection requirements that ensure adequate margins will be maintained between inspection intervals.

The pattern of cracking indicated from field inspections appears consistent with the stress corrosion cracking (SCC) susceptibility criteria (Water Chemistry, Material Carbon Content, Fabrication History, Neutron Fluence and Hot Operating Time) described in SIL 572, Revision 1 [B-1] and the BWROG report [B-2]. A brief discussion and summary of the variables that can influence susceptibility to SCC are presented in the remainder of this section.

B.1.1 Fabrication History

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B.1.2 Neutron Fluence

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B.1.3 Water Chemistry

Extensive SCC testing has shown that SCC initiation and growth are strongly dependent on the electrochemical corrosion potential (ECP) on the surface of a component. ECP depends on the level of oxidants, such as oxygen and peroxide, in the reactor water. However, there is no historical database of ECP or the levels of oxidants at the shroud surfaces, so ECP cannot be used as a factor for susceptibility grouping.

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B.1.4 Material Carbon Content

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B.1.5 Hot Operating Time

As with any stress corrosion phenomenon, the frequency and extent of core shroud weld cracking would be expected to correlate with hot operating time. Plant data for hot operating time, defined as the time spent with reactor coolant above 200°F, is not readily available. Consequently, SCC susceptibility was correlated with on-line years, which is a close approximation of time above 200°F.

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B.1.6 Conclusion

Based on the preceding discussion, several conclusions can be drawn from the available inspection results relative to the susceptibility grouping factors:

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B.2 Core Shroud Categories

Based on the information presented in Section 2.2 the following core shroud categories have been defined for developing inspection strategies for core shroud welds.

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B.3 References

B-1. GE SIL 572, Revision 1, "Core Shroud Cracks," October 1993.

B-2. "BWR Core Shroud Evaluation," Report No. GE-NE-523-148-1193, April 1994.

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Figure B-1
Extent of Cracking versus Mean Conductivity for the First 5 Cycles

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Figure B-2
Extent of Cracking versus On-line Years

C
BASES FOR INSPECTION INTERVAL: HORIZONTAL WELDS

C.1 Introduction

The objectives of the core shroud inspections are to determine the extent of crack growth in the shroud welds during the preceding operating interval, and monitor the structural integrity of the core shroud. These objectives can be accomplished by defining inspection intervals during which existing cracks in the core shroud will not grow to unacceptable lengths.

The purpose of the work in this appendix was to perform generic fracture mechanics analyses to define conservative, generic inspection intervals. The remaining ligament approach specified by the BWR Vessels & Internals Project (VIP) Assessment Subcommittee [C-1] was used in this work. Both limit load and linear elastic fracture mechanics (LEFM) methodologies were evaluated, with the intent of examining the sensitivity of the analyses to the various assumptions made.

A primary objective of this evaluation was focused on determining inspection intervals that are based on near-bounding, yet reasonably conservative, input and assumptions that ensure required minimum safety factors are maintained. The final result would be reinspection intervals that can be used by plant owners as effective criteria for establishing whether continued operation without repair for a predefined time interval is acceptable. A natural conclusion to these results also would be determination of the point in time when repair is considered to be a necessity.

This appendix documents the results of the generic analyses performed, including a description of the methodology and assumptions used. The results of these analyses provide a final set of graphs and tables that establish the time until the allowable safety factor is reached as a function of detected cracking.

C.2 Overview Of Generic Analyses Performed

This section provides an overview of the generic analyses performed as a part of this work.

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C.3 Generic Evaluation Input and Assumptions

C.3.1 Use of Faulted Loading Conditions.

The normal stresses in the core shroud are very low. The main loading on the core shroud during normal operation is the pressure load due to the pressure drop across the core plate and shroud head. Typical longitudinal membrane stresses in the core shroud welds due to pressure loading are less than about 0.5 ksi for welds above the core plate and less than about 1.0 ksi for welds below the core plate.

The greatest challenge to the structural integrity of the core shroud occurs during faulted loading conditions (e.g., the safe shutdown earthquake (SSE) or recirculation line break).

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C.3.2 Core Shroud Integrity

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C.3.3 Material Strength and Shroud Geometry

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C.3.4 Crack Growth Rate and NDE Uncertainty

C.3.5 Number, Extent and Distribution of Cracks and in the Core Shroud

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Table C-1
Defect Rates in Inaccessible Regions of Core Shroud Welds

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Table C-2
Crack Length Assumptions Used to Determine Reinspection Intervals

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Based on the above discussion, the assumptions and conditions used in the generic fracture mechanics analyses are considered to result in conservative estimates of crack growth and core shroud integrity.

C.3.6 Summary of Input to Limit Load and LEFM Analyses

The inputs used for this evaluation are summarized in Table C-3, and the cases analyzed are summarized in Table C-4. Flaws assumed for this evaluation were all equally spaced, with a quantity and length as shown in Table C-4.

Table C-3
Geometry and Stress Data

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Table C-4
Parameters Used

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C.4 Computational Results

C.4.1 Results From Generic Limit Load Analyses

This section presents the results of the limit load analyses, which used the methodology described in the Section C.2, and the input from Tables C-3 and C-4.

The computational results, obtained from the DLL program using a coarse (i.e., 1° increment) mesh, are shown in Figures C-1 through C-3 for the 1 ksi, 3 ksi and 6 ksi stress levels, respectively. The results are presented in terms of minimum safety factor as a function of time. The allowable safety factor for faulted conditions is also shown on the plots for reference purposes. These plots form the basis for establishing inspection intervals as a function of the amount of cracking detected (assuming at least 50 percent of the circumference is inspected) based on limit load methodology.

C.4.2 Results From Generic LEFM Analyses

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Figure C-1
Results of Limit Load Evaluation for 1 ksi Stress Level

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Figure C-2
Results of Limit Load Evaluation for 3 ksi Stress Level

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Figure C-3
Results of Limit Load Evaluation for 6 ksi Stress Level

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Table C-5
LEFM Results for Different Flaw Distributions

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Figure C-4
Results of LEFM Evaluation for 1 ksi Stress Level

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Figure C-5
Results of LEFM Evaluation for 3 ksi Stress Level

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Figure C-6
Results of LEFM Evaluation for 6 ksi Stress Level

C.4.3 Summary of Generic Limit Load and LEFM Analyses Results

The final results of the limit load analyses shown in Figures C-1 through C-3, and the LEFM analyses shown in Figures C-4 through C-6, are expressed in terms of the minimum safety factor as a function of time for three stress levels. These results provide the basis for establishing the inspection intervals based on the stress level and the amount of cracking found during inspections.

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Table C-6
Analysis Results for 1 ksi Stress Level[4]

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Table C-7
Analysis Results for 3 ksi Stress Level[4]

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Table C-8
Analysis Results for 6 ksi Stress Level[4]

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C.5 Generic Inspection Intervals

The results shown in Tables C-6 through C-8 contain the information used to define the generic inspection intervals.

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Table C-9
Core Shroud Inspection Intervals for Category B and C Plants (in years)

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C.6 References

C-1. General Electric Report No. GENE-523-113-0894, Revision 1, "BWR Core Shroud Inspection and Flaw Evaluation Guidelines," March 1995.

C-2. General Electric Report No. GENE-523-113-0894, Supplement 1, "BWR Core Shroud Distributed Ligament Length Computer Program," September 1994, Version 10/07/94.

C-3. EPRI NDE Center Report by Greg Selby, Stan Walker and Jeff Landrum, "BWR-VIP Core Shroud NDE Uncertainty & Procedure Standard," Prepared for Boiling Water Reactor Vessel & Internals Project Inspection Subcommittee, November 21, 1994.

C-4. ASME Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection.

C-5. "BWR Core Shroud Inspection and Flaw Evaluation Guidelines," GENE-523-113-0894, Rev. 1, General Electric Company, March 1995. Prepared for BWRVIP Assessment Committee.

C-6. "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping," NUREG-0313, Rev. 2, Nuclear Regulatory Commission, 1988.

D
PLANT SPECIFIC EVALUATION PROCEDURE: HORIZONTAL WELDS

This appendix provides the methodology and guidance which can be used to determine the uncracked ligament lengths needed at the circumferential welds to ensure adequate structural margins. Ideally, the azimuths of the ligament lengths may be symmetric in the plane of the weld. However, access limitations may cause the ligament lengths available for inspection to be distributed randomly along the weld (e.g., see Figure D-3). Therefore, the methodology and guidance provided in this section describe the general case that covers all possible distributions of ligament, and considers proximity rules (see Appendix G).

The minimum amount of ligament (L_{min}) required in order to operate for "n" years prior to the next inspection is given as:

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D.1 Fluence Levels and Fracture Mechanics Methods

The shroud material (austenitic stainless steel) is inherently ductile and, therefore, in most cases, the structural integrity analysis can be performed entirely on the basis of limit load. The only case for the use of other techniques such as LEFM or EPFM would be when the irradiation-induced changes in the material fracture toughness properties are judged to be significant. Properties relevant to material fracture toughness include yield and ultimate tensile strengths, uniform elongation and upper-shelf Charpy energy. Therefore, the trends in these properties as a function of fluence level were reviewed to determine a fluence value above which the use of LEFM or EPFM techniques would be necessary.

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D.1.1 Approach to Evaluate High Fluence Welds

The fluence on the core shroud welds varies significantly in the azimuthal and axial directions. Figures D-1 and D-2 show typical azimuthal and axial fluence profiles for the beltline region of a shroud, respectively. From these figures we can see that the peak fluence locations are limited in length. Consequently, it is evident that the limit load criteria can still be applied to evaluate large portions of the weld.

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Figure D-1
Azimuthal Fluence Profile at Shroud Inner Radius at the Axial Midplane

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Figure D-2
Axial Fluence Profile at Shroud Inner Radius at Maximum Azimuthal Position

D.2 Limit Load Method

Figure D-3 shows a schematic representative plan view of an asymmetric distributed uncracked ligament. It is assumed that there are 1,2,...i,...n ligament lengths and that the i[th] length is of thickness 't_i' and extends from an azimuth of θ_{i1} to θ_{i2}. The ligament length 'l_i' of the ith ligament is related to azimuth angles θ_{i1} and θ_{i2} by the following relationship:

$$l_i = (D/2) \bullet (\theta_{i1} - \theta_{i2}) \quad \text{(eq. D-3)}$$

where, D is the diameter of the shroud. The calculation of moment 'M' that this ligament configuration can resist is somewhat complicated since it is not clear as to which azimuthal orientation of the neutral/central axis would produce the least value of bending moment, 'M'.

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D.3 LEFM Method

For a through-wall flaw in an "infinite" plate, the stress intensity factor K is given by the following:

$$K = \sigma\sqrt{(\pi a)} \qquad \text{(eq. D-11)}$$

where, σ is the remote membrane stress and a is the half crack length.

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D.4 EPFM Methodology

The EPFM based concepts developed by Paris and Hutchinson and incorporated into EPRI handbooks [D-5, D-6, D-7] can be used in lieu of the conservative LEFM approach in which only the crack initiation is considered.

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D.5 Safety Factors

In the screening criteria document [D-10], safety factors of 2.77 for normal (Level A) / upset (Level B) conditions and 1.39 for emergency (Level C)/ faulted (Level D) conditions were used in the evaluation of circumferential welds. These safety factor values are consistent with Section XI values.

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There are several conservatisms used in the flaw evaluation methodology described in this section in addition to the safety factors used in the structural margin evaluation. Table D-1 presents a list of these conservatisms.

D.6 References

D-1. "Design Criteria for Irradiated Type-304 Stainless Steel in BWR Applications," GE Report No. NEDE-20364, June 1974.

D-2. "Evaluation of BWR Top-Guide Integrity," EPRI Report No. NP-4767, November 1986.

D-3. Rooke, D.P. and Cartwright, D.J., "Compendium of Stress Intensity Factors," The Hillingdon Press (1976).

D-4. Tada, H., Paris, P. and Irwin, G., "The Stress Analysis of Cracks Handbook," Del Research Corporation (1985).

D-5. "An Engineering Approach for Elastic-Plastic Fracture Analysis," EPRI Report No. NP-1931, July 1981.

D-6. "Advances in Elastic-Plastic Fracture Analysis," EPRI Report No. NP-3607, August 1984.

D-7. "Elastic-Plastic Fracture Analysis of Through-Wall and Surface Flaws in Cylinders," EPRI Report No. NP-5596, January 1988.

D-8. R.S. Barsoum, R.W. Loomis and B.D. Stewart, "Analysis of Through Cracks in Cylindrical Shells by the Quarter Point Elements," International Journal of Fracture, Vol. 15, No.3, June 1979.

D-9. S. Ranganath and H.S. Mehta, "Engineering Methods for the Assessment of Ductile Fracture Margin in Nuclear Power Plant Piping," ASTM STP 803 (1983).

D-10. GE RICSIL 054, Revision 1, "Core Shroud Cracks", July 1993.

D-11. "BWR Vessel and Internals Project, Reactor Pressure Vessel and Internals Examination Guidelines (BWRVIP-03) Revision 1," EPRI Report 105696-R1, March 1999.

D-12. "BWRVIP Vessel and Internals Project, BWR Core Shroud Distributed Ligament Length (DLL) Computer Program (Version 2.1) (BWRVIP-20)," EPRI Report AP-107283, December 1996.

D-13. "BWR Vessel and Internals Project, Evaluation of Crack Growth in BWR Stainless Steel RPV Internals (BWRVIP-14)," EPRI Report TR-105873, March 1996.

D-14. Draft Regulatory Guide 1053, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence," US Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, September 1999.

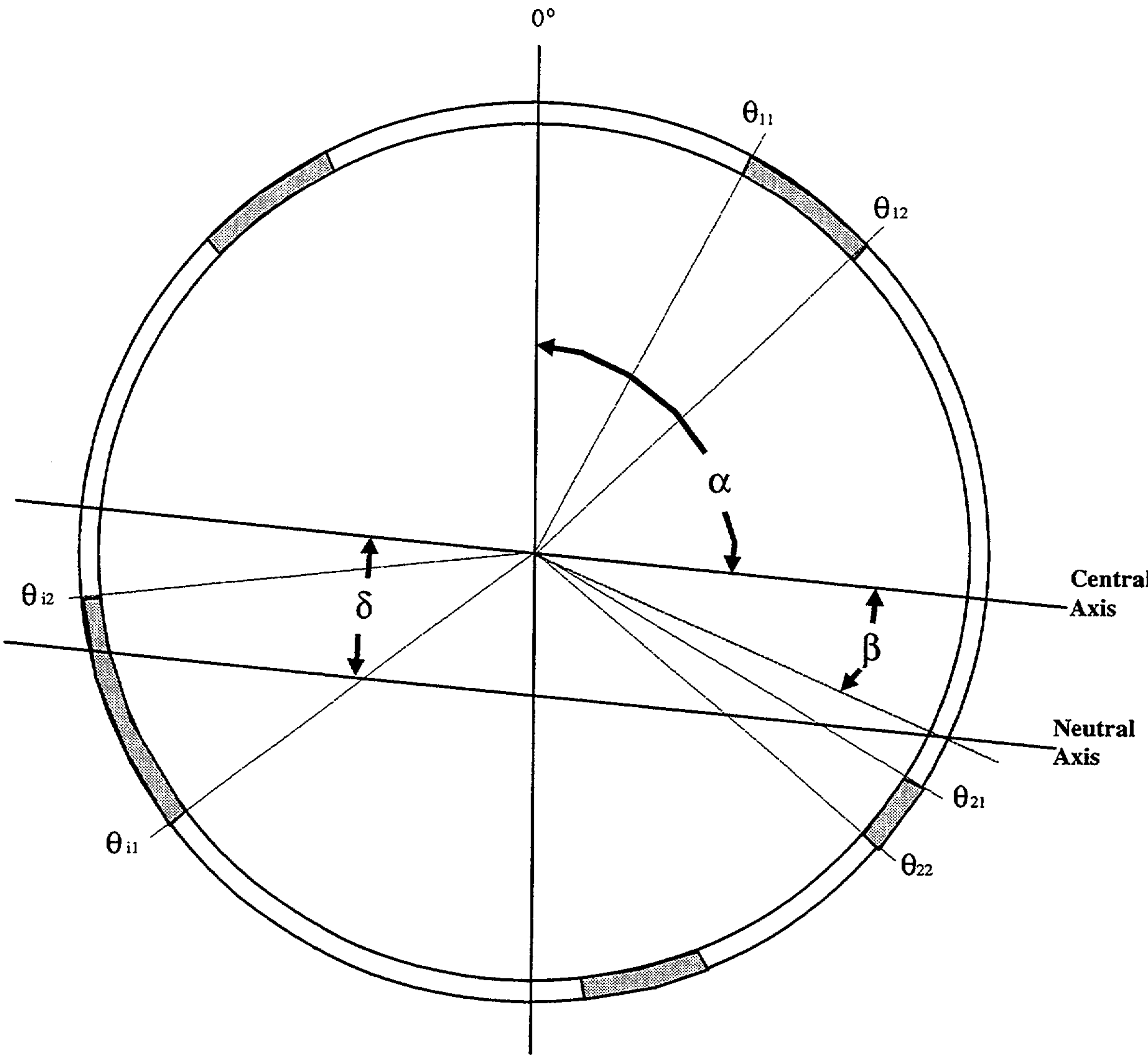

Figure D-3
Schematic of Non-Symmetric Ligament Distribution

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Figure D-4
J-R Curves for Two Irradiated Stainless Steel Specimens at Fluence of $8x10^{20}$ n/cm^2

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Figure D-5
Curvature Correction Factor G_m for Circumferential Flaw

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Figure D-6
Solution for Equi-Distant Equi-Length Flaws

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Figure D-7
Schematic of (J/T) Approach

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Figure D-8
Shroud Weld with 360° Crack

Table D-1
Conservatisms Included in Flaw Evaluation Methodology

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E
ANALYTICAL BASIS FOR SCREENING AND ACCEPTANCE CRITERIA FOR VERTICAL WELDS

This Appendix outlines the generic analyses which were performed in order to determine the inspection strategies given in Sections 2 and 3. Included in this Appendix are four cases. The first case (Case A) provides an allowable through-wall flaw in a vertical weld. This is intended to show the amount of uncracked ligament needed in the vertical weld, given no credit for the circumferential weld. The second case (Case B) provides an allowable through-wall flaw in the circumferential weld at the intersection with the vertical weld, given no credit for the vertical weld. The final two cases provide allowable flaws while taking credit for partial through-wall cracking in either the vertical weld (Case C) or the circumferential weld (Case D).

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The structural analysis of the vertical weld consists of two methods: (1) limit load analysis, and (2) Linear Elastic Fracture Mechanics (LEFM). The technical approach for these two methods is described below.

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These analyses are intended to give generic guidelines for inspection requirements. As such, for each case, several different shroud geometries were evaluated, and generic recommendations were made based on these analyses.

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E.1 Case A: Allowable Through-Wall Flaw in Vertical Weld (Through-Wall Crack in Circumferential Weld over Entire Length)

This case, shown in Figure E-1, calculates the allowable through-wall flaw in the vertical weld, taking no credit for the integrity of the circumferential weld (cracks are represented in the figures by bold lines). The technical purpose of this case was to show how much through-wall cracking could occur in the vertical weld, while still maintaining structural margin. For this case, it was assumed that there was no cracking in the vertical weld at the intersection with the circumferential weld. Both LEFM and limit load methodologies were used to determine the allowable cracking. The technical basis and the results are included in the following.

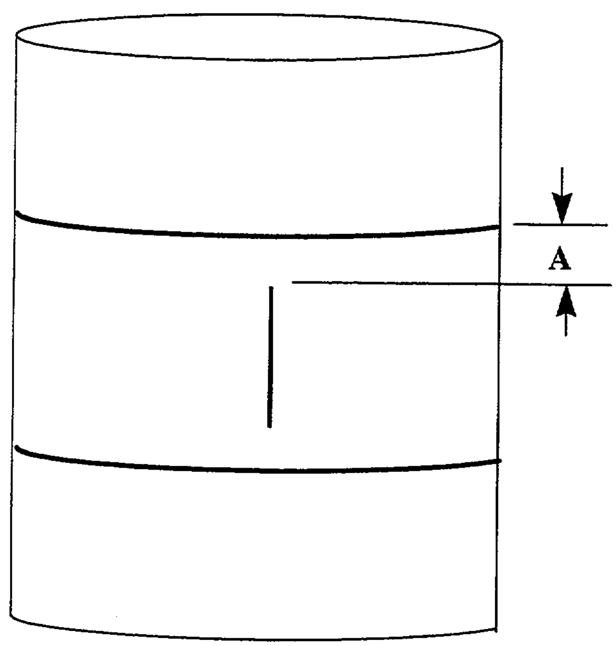

Figure E-1
Case A

E.1.1 LEFM Analysis

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E.1.2 Limit Load Analysis

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E.1.3 Results

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E.2 Case B: Allowable Through-Wall Flaw in Circumferential Weld (Through-Wall Crack in Vertical Weld over Entire Length)

Similar to Case A, this analysis, shown in Figure E-2, assumes no intersecting cracking at the vertical/circumferential weld intersection. The purpose of this analysis is to show how much uncracked ligament must exist at the intersection, given that the vertical weld is entirely cracked, and the remaining circumferential weld is cracked through-wall. The LEFM and limit load technical bases and results are included in the following.

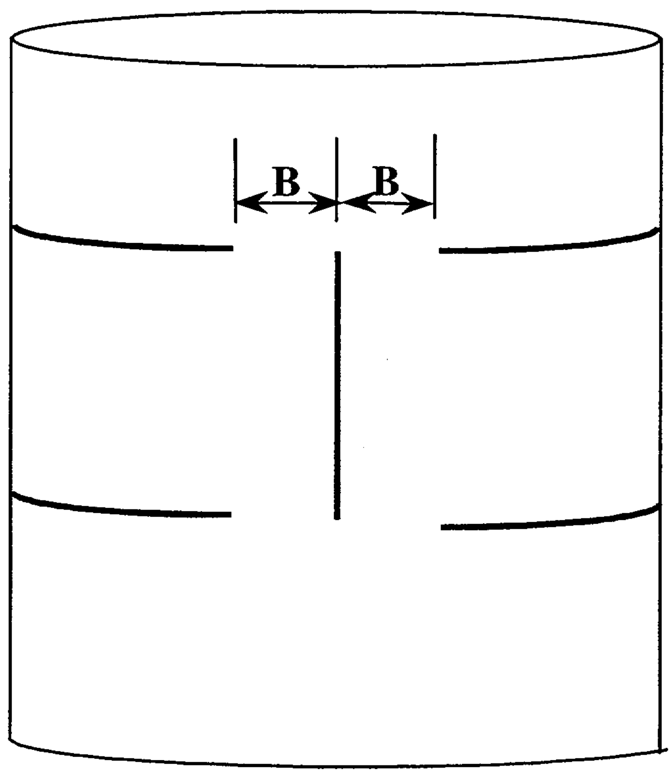

Figure E-2
Case B

E.2.1 LEFM Analysis

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E.2.2 Limit Load Analysis

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E.2.3 Results

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E.3 Case C: Allowable Part Through-Wall Flaw in Vertical Weld (Through-Wall Crack in Circumferential Weld over Entire Length)

This case was performed to address cracking in the intersection of the circumferential and vertical welds. For this case, partial credit was taken for part through-wall cracking in the vertical weld. This would allow for cracking to occur at the intersection, provided that the flaw depths do not exceed a specified amount. The allowable flaw depth is calculated over the entire length of the vertical weld. Similar to Case A, no credit was taken for the circumferential weld for this case.

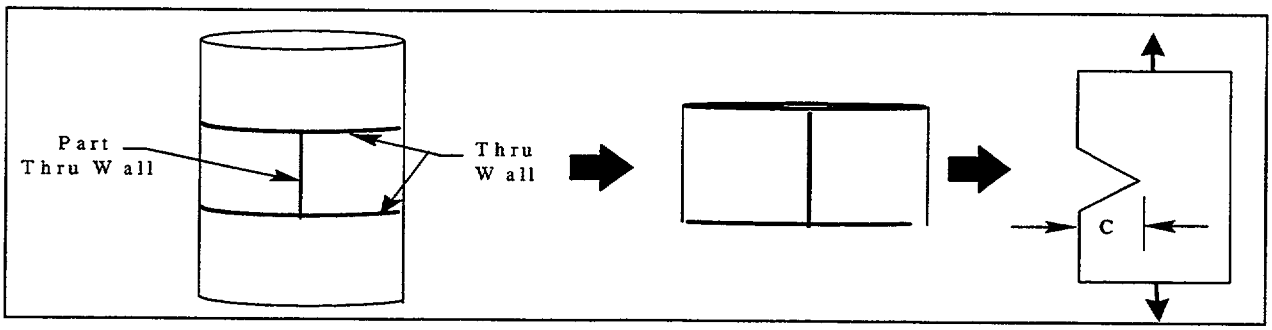

Figure E-3
Case C

E.3.1 LEFM Analysis

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E.3.2 Limit Load Analysis

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E.3.3 Results

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E.4 Case D: Allowable Part Through-Wall Flaw in Circumferential Weld (Through-Wall Crack in Vertical Weld over Entire Length)

This analysis assumes a part through-wall flaw in the circumferential weld and a complete through-wall flaw in the vertical weld. Consequently, the evaluation determines the allowable crack depth of the circumferential weld.

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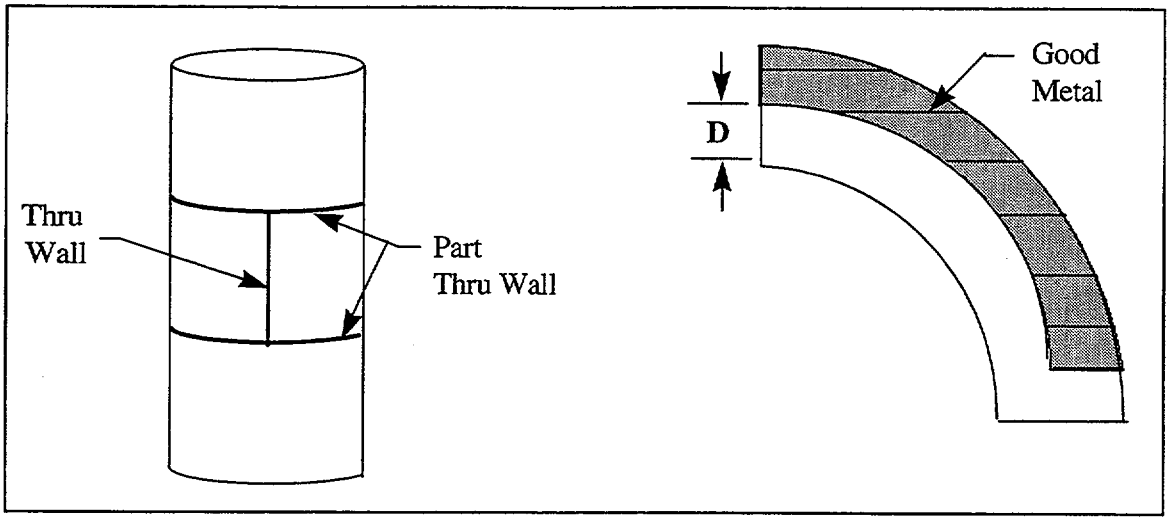

Figure E-4
Case D

E.4.1 LEFM Analysis

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E.4.2 Limit Load Analysis

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E.4.3 Results

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E.5 References

E-1. ASME Boiler and Pressure Vessel Code, Section XI, Appendix C, American Society of Mechanical Engineers, 1989 Edition.

E-2. "BWR Vessel and Internals Project, BWR Core Shroud Inspection and Flaw Evaluation Guidelines, Revision 2 (BWRVIP-01)," EPRI Report TR-107079, October 1996.

F
EVALUATION OF VERTICAL WELD INDICATIONS

In the event that the acceptance standards in Sections 2 and 3 are not met, methods for the evaluation and dispositioning of flaws are required. This section describes the suggested procedures for evaluating indications found in the vertical welds. Different methods are proposed for varying degrees of cracking. For vertical weld indications that do not intersect a circumferential weld, the evaluation can be done using closed form solutions, assuming a free standing cylinder. For indications that intersect the circumferential welds, more extensive hand calculations are required.

The methodologies for the closed form solutions which cover a broad range of cracking scenarios are outlined in this section. For cracking scenarios which are not bounded by the cases presented here, evaluations will have to be performed on a plant-specific basis and may include more detailed hand calculations or finite element analyses.

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F.1 Vertical Weld Cracks that Do Not Intersect Circumferential Welds

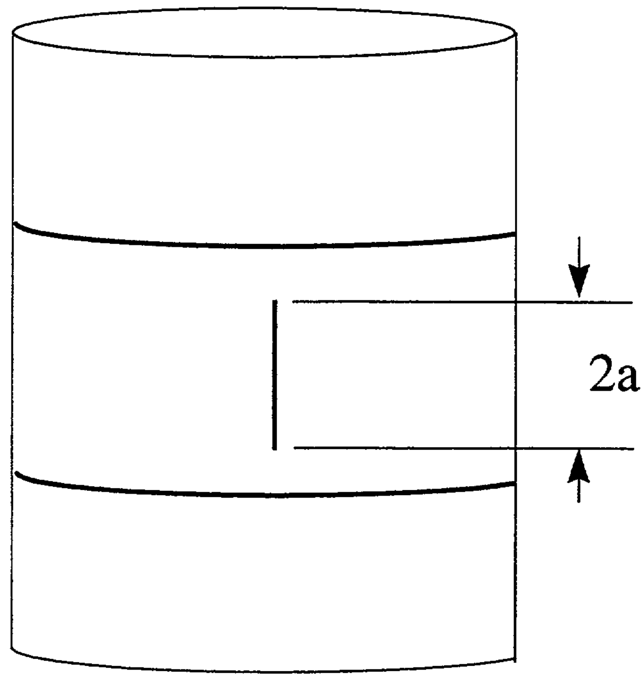

Figure F-1
Vertical Weld Cracks that Do Not Intersect Circumferential Welds

Assuming that there is no cracking in the vertical weld at the intersection with the circumferential weld (as shown in Figure F-1), the crack can be analyzed assuming an axial crack in a finite width cylindrical shell.

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F.1.1 LEFM Analysis

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F.1.2 Limit Load Analysis

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F.2 Vertical Weld Cracks that Intersect Circumferential Welds

The previous evaluation methodology dealt with indications in the vertical weld that do not intersect the circumferential weld. For the case of intersecting indications in the vertical and circumferential weld, the analyses are more extensive. Several methodologies can be used to assess vertical weld indications that intersect circumferential weld indications. These methodologies are outlined in the following sections.

F.2.1 360 Degree Through-Wall Flaw in Intersecting Circumferential Weld; Part Through-Wall Flaw in Vertical Weld

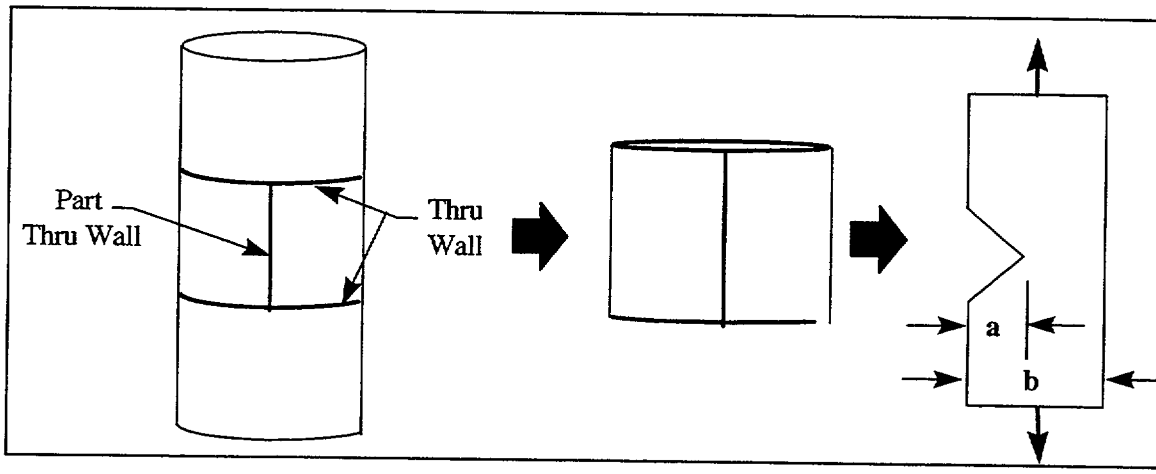

Figure F-2
360 Degree Through-Wall Flaw in Intersecting Circumferential Weld; Part Through-Wall Flaw in Vertical Weld

For this case (shown in Figure F-2), no credit is taken for the intersecting circumferential welds. This case is treated as a free standing cylinder.

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Figure F-3
Compound Crack

F.2.2 360 Degree Part Through-Wall Flaw in Circumferential Weld; Through-Wall Flaw in Intersecting Vertical Weld

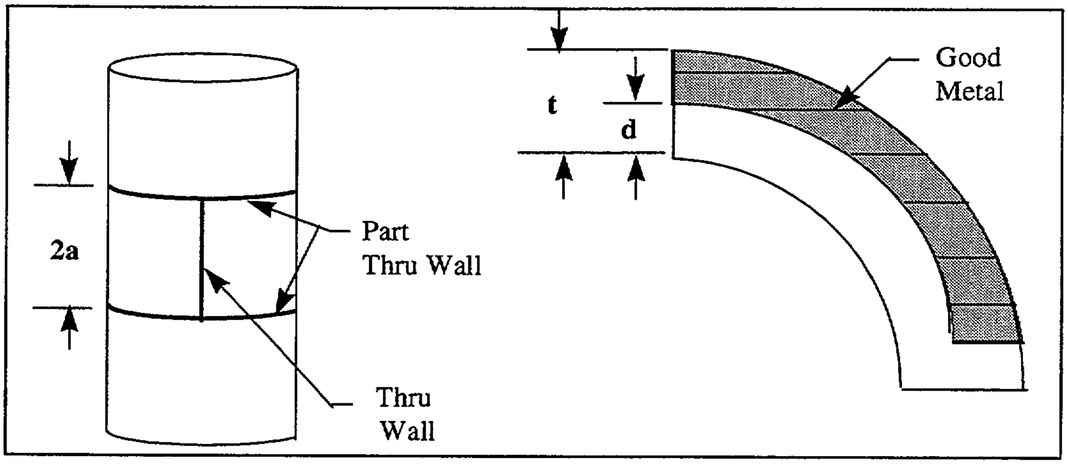

Figure F-4
360 Degree Part Through-Wall Flaw in Circumferential Weld; Through-Wall Flaw in Intersecting Vertical Weld

For this case, the entire circumferential weld is assumed to be cracked to a part through-wall depth. The vertical weld is assumed to be cracked through-wall. The LEFM and limit load analyses for this case is provided below.

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F.3 Leakage

To this point, the flaw evaluation has outlined the analyses used to evaluate the structural margin of the flaw indications.

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The effects of leakage from cracks on the thermal hydraulics safety evaluation must be performed on a plant specific basis. The evaluation methodology is presented in the following.

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Figure F-5
Leak Rate vs. Axial Crack Length

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F.4 Flaw Evaluation Assumptions for Cracking in Uninspected Regions

In performing plant specific evaluations, assumptions must be made regarding the amount of cracking in uninspected regions of the weld. For purposes of these evaluations, the defect rates shown in Table F-1 should be assumed.

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Table F-1
Defect Rates in Uninspected Regions of Core Shroud Vertical Welds

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F.5 Conclusions

The methodologies presented in this section provide closed form solutions to evaluate cracking in a vertical weld. The methodologies differ according to the severity of the cracking in the vertical weld. It should be noted that in some cases, due to the severity of cracking in the vertical weld, the simplified solutions will not yield acceptable results. For these cases, more detailed, plant specific finite element analyses may be used. Guidance on performing these detailed analyses is provided in Section F.6.

F.6 Plant Specific Flaw Evaluation Methodology

This section provides additional guidelines and fundamental criteria for plant specific flaw evaluation outside the bounds of the three cases presented in the previous sections of this Appendix.

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F.7 References

F-1. Hiroshi Tada and Paul C. Paris, "Application of Fracture Proof Design Methods Using Tearing Instability Theory to Nuclear Piping," NUREG/CR 3464, September 1983.

F-2. Hiroshi Tada, Paul C. Paris, and George R. Irwin, "The Stress Analysis of Cracks Handbook - Second Edition," Paris Productions Incorporated, St. Louis, Missouri, 1985.

F-3. Letter from Jack Fox to Keith Wichman of USNRC, ANS-58.2 Working Group Comments on NUREG-1061 Volume 3, April 22, 1985.

G
PROXIMITY RULES FOR PLANT-SPECIFIC FLAW EVALUATION

This Appendix describes the flaw proximity rules that can be used to determine the effective flaw lengths from the shroud inspection data. The rules specifically treat the circumferential welds.

G.1 Determination of the Effective Flaw Length

The effective flaw lengths are based on ASME Code, Section XI proximity criteria as presented in Subarticle IWA-3300. Indications are considered to be in the same plane if the perpendicular distance between the planes is less than two times the shroud thickness (2T). When two indications are close to each other, rules are established to combine them based on proximity. These rules are described here.

G.2 Proximity Rules

The flaw combination methodology used here is based on the ASME Code, Section XI proximity rules concerning neighboring indications. Under the rules, if two surface indications are in the same plane and are within two times the depth of the deepest indication, then the two indications must be considered as one indication.

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G.2.1 Case A: Circumferential Flaw - No Axial Flaw

This case applies when two circumferential indications are considered.

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G.2.2 Case B: Circumferential Flaw - Axial Flaw

This case applies when both a circumferential and an axial flaw are being considered.

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G.3 Application of Effective Flaw Length Criteria

The application of the effective length criteria is applied to two adjacent indications at a time. Figure G-4 is a schematic which illustrates the process.

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Figure G-1
ASME Code Proximity Criteria

(a)

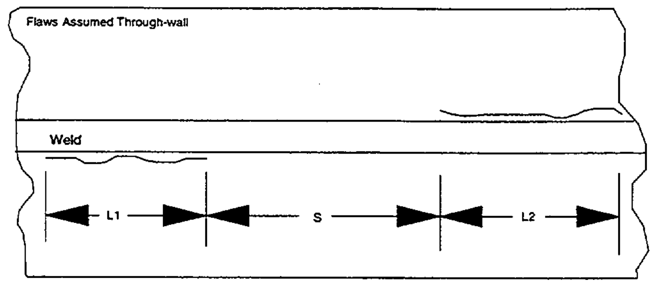

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Figure G-2
Application of Proximity Procedure to Neighboring Circumferential Flaws

(a)

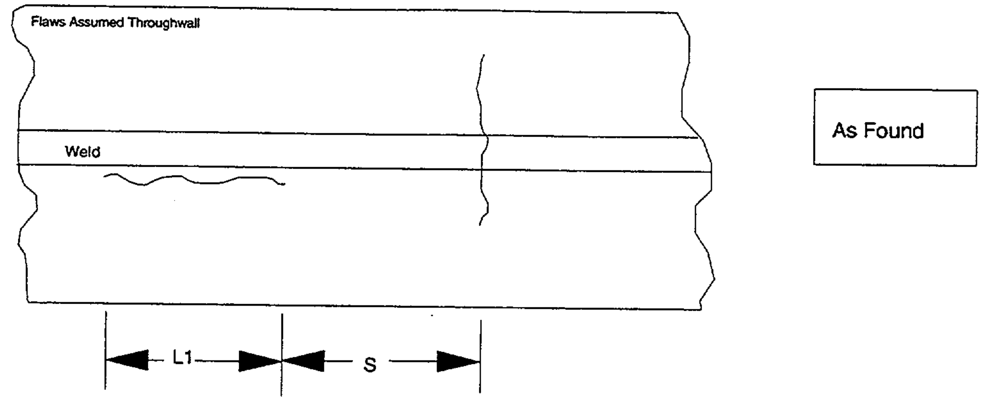

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Figure G-3
Application of Proximity Procedure to Neighboring Axial and Circumferential Flaws

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Figure G-4
Process for Determining Effective Circumferential Flaw Length

H
A STATISTICAL METHOD FOR ESTIMATING THE CRACKING IN INACCESSIBLE REGIONS OF CORE SHROUD WELDS

H.1 Introduction

Stress corrosion cracking (SCC) has been found in core shroud welds at several U.S. and foreign BWRs (Figure H-1). As a result, the NRC has required BWR licensees to perform inspections of the core shroud circumferential welds. BWRs have been categorized by the BWRVIP into Categories A, B, or C depending on their relative susceptibility to core shroud cracking, with Category A being the least susceptible to cracking and Category C being the most susceptible.

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Initial evaluations assumed that inaccessible regions of the core shroud weld are fully (100 percent) cracked. For core shroud welds with significant cracking, this is a reasonable (and conservative) assumption. However, for core shroud welds with minor or no cracking in the inspected regions, this assumption is not realistic and could lead to unnecessary actions, particularly if the inaccessible region is large.

A statistical method has been developed for estimating the cracking in inaccessible regions of the core shroud welds

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H.2 Methodology

H.2.1 Assumptions

The methodology for estimating the defect rate in inaccessible regions of core shroud welds is based on the following two assumptions:

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H.2.2 Example

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H.3 Results of Analyses for Core Shroud Welds

The above methodology was applied to inaccessible regions of the core shroud welds in order to estimate the degree of cracking in inaccessible regions. Calculations were performed for assumed inaccessible arc lengths from 2.5 to 50 percent of the total circumference of the weld (9 to 180 degrees), and assumed weld defect rates from 10 to 90 percent. The method of calculation was as follows.

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Table H-1
Defect Rates in Inaccessible Regions of Core Shroud Welds

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H.4 Example Problem

The following example illustrates how Table H-1 can be used to calculate the length of flawed material in inaccessible regions in a core shroud weld with SCC.

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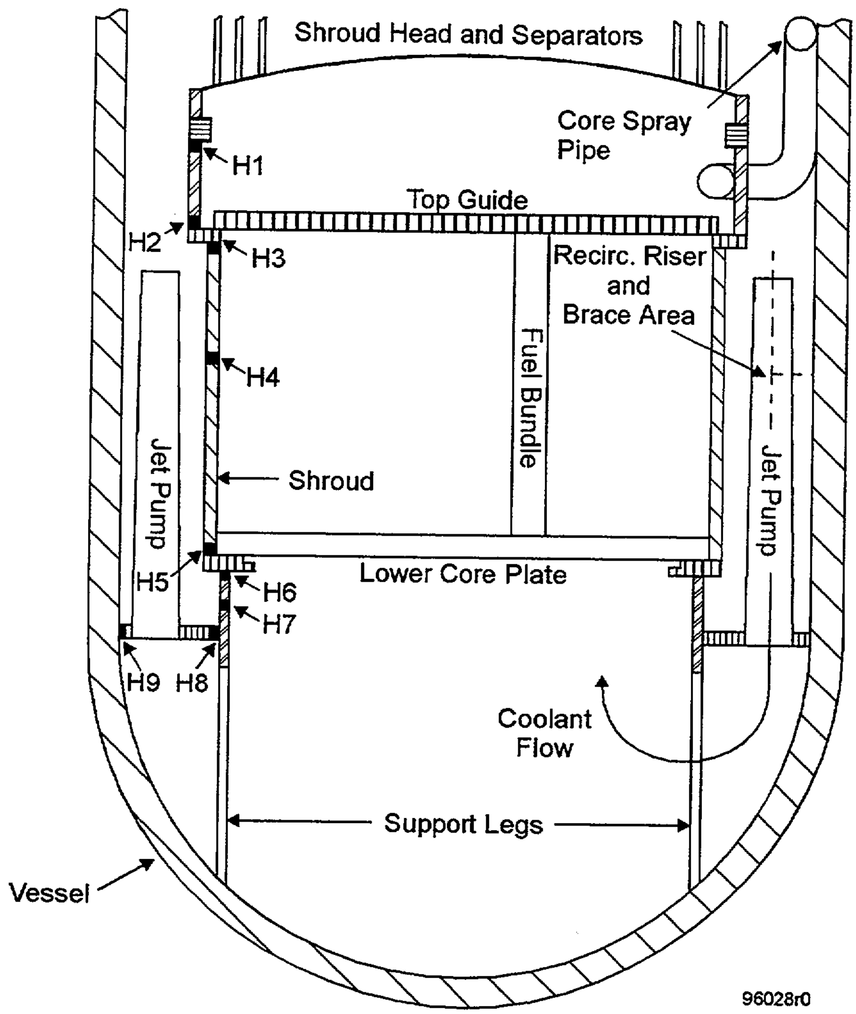

Figure H-1
Typical BWR Core Shroud

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**Figure H-2
Example Excel Spreadsheet Calculation**

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Figure H-3
Defect Rate in Inaccessible Region vs. Length of Inaccessible Region as a Function of Defect Rate in Inspected Region

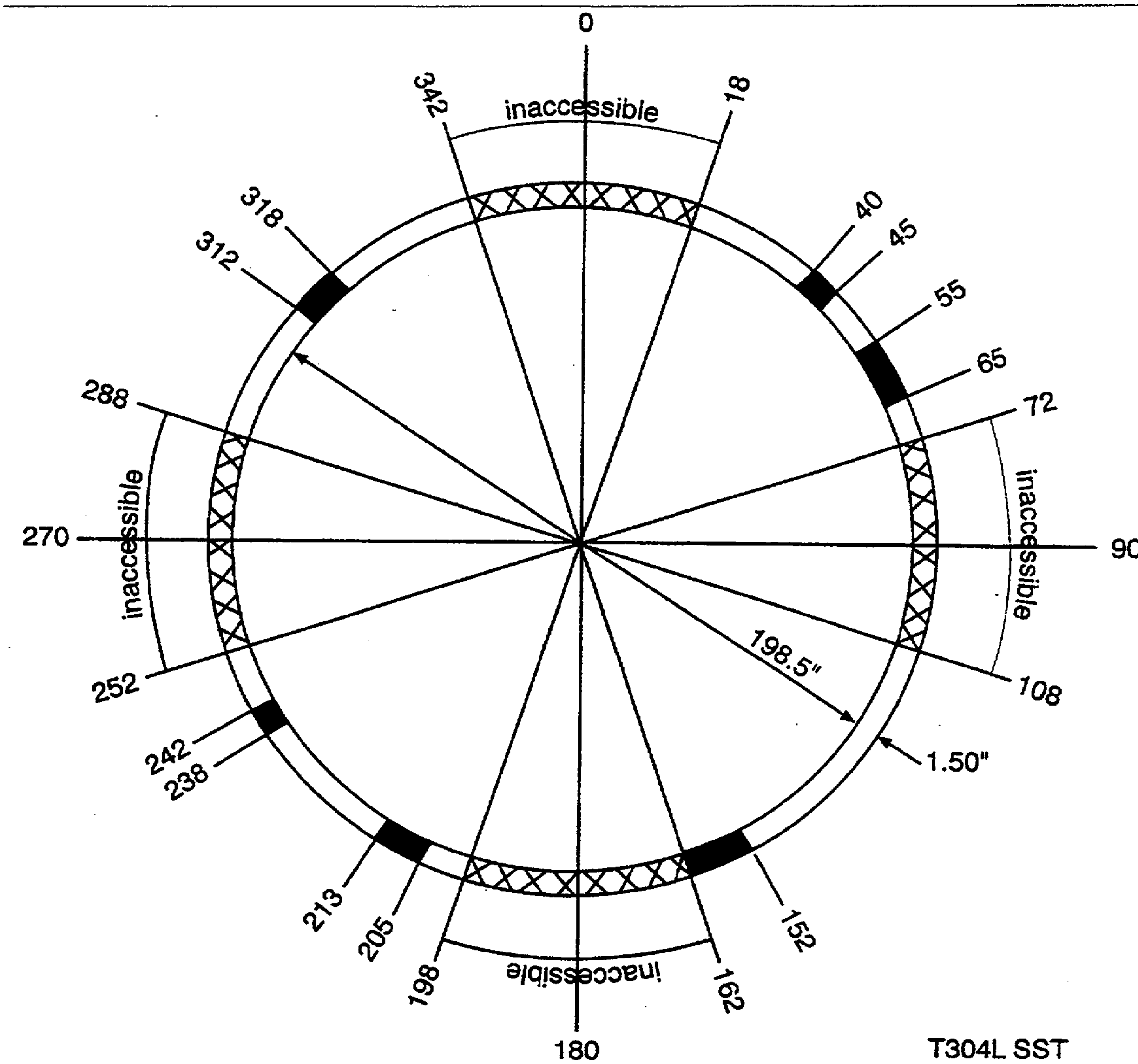

Figure H-4
Typical Core Shroud Weld H5

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CALCULATION OF AVERAGE CRACK DEPTH

This appendix provides an example of the calculation of "average crack depth at EOI (End of Interval)" as defined in Sections 2 and 3.

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J
USE OF FILLET WELD FOR ESTABLISHING ALLOWABLE FLAW DEPTH

J.1 Issue

Complete circumferential cracking at varying depths has been observed in 304 stainless steel shrouds in the top guide support ring H3 weld region and the core plate support ring H5 weld region in several BWRs. Such cracking has been mainly in the welded plate rings and has been attributed to a combination of cold work and unfavorable end grain orientation. Figure J-1 shows typical cracking observed in the ring. In most cases, the ring is welded to the shroud cylinder with a full penetration weld and a fillet weld. The fillet weld is important, not from the perspective of strength contribution, but from crack growth considerations. Credit is not taken for the fillet weld when determining the stresses which apply at a given location. However, since cracking in the rings is expected to follow the weld heat affected zone, the total crack extension that can be tolerated before the crack leads to shroud separation is the shroud wall thickness, t_{shroud}, plus the length of the fillet weld leg, t_{fillet}.

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J.2 Crack-Free Fillet Weld Confirmation

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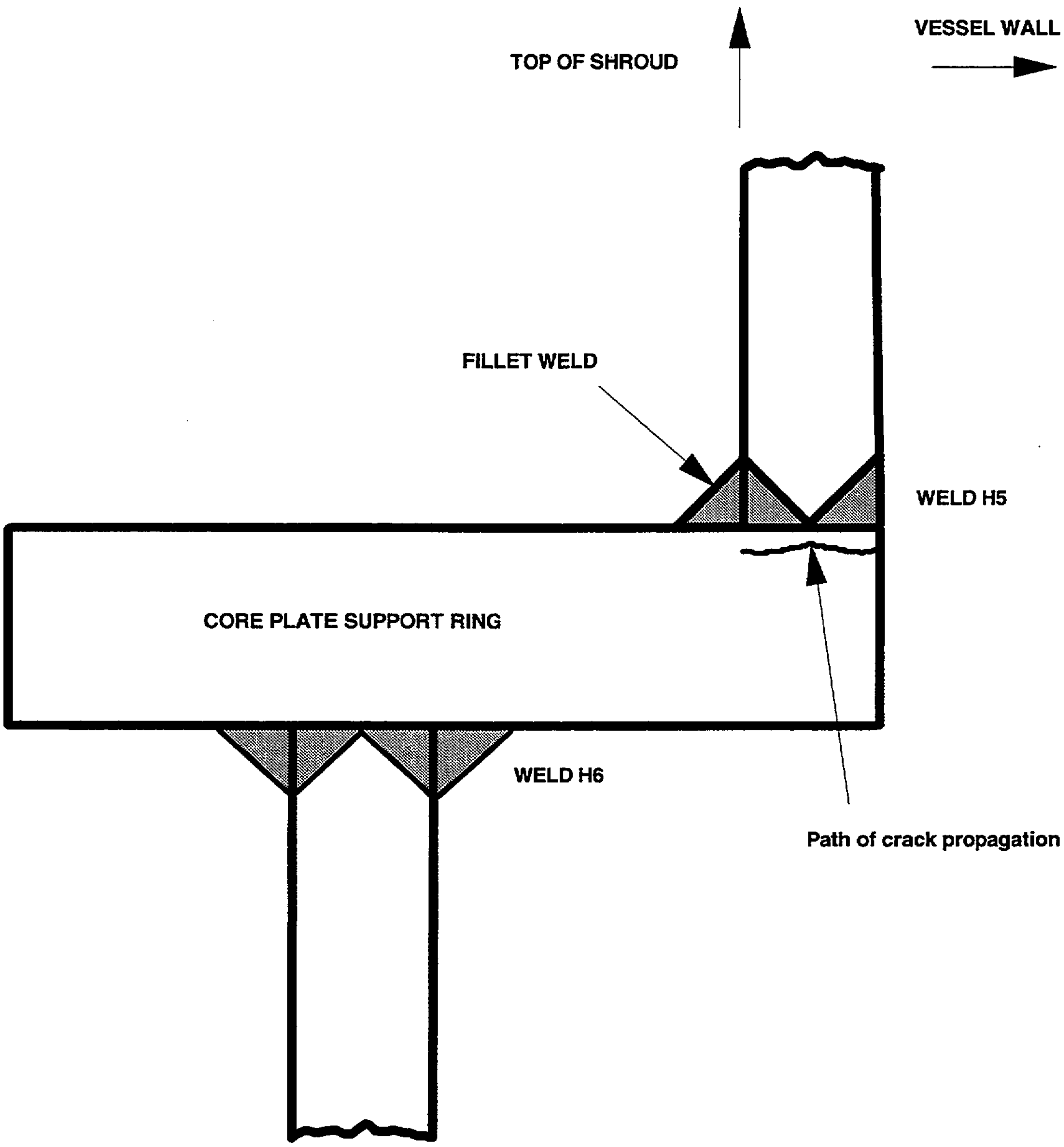

Figure J-1
Schematic of Anticipated Crack Growth in Shroud Ring

K

GUIDELINES FOR INSPECTION OF BWR CORE SHROUDS: DEMONSTRATION OF COMPLIANCE WITH THE TECHNICAL INFORMATION REQUIREMENTS OF THE LICENSE RENEWAL RULE (10 CFR 54.21)

The purpose of Appendix D is to demonstrate that the inspection guidelines provide the necessary information to comply with the technical information requirements pursuant to paragraphs 54.21[a] and [c], and 54.22, and the NRC's findings under 54.29[a] of the license renewal rule (Reference K.8.[1]). It is intended that the NRC's review and approval of Appendix K will allow utilities the option to incorporate the inspection guidelines and this Appendix by reference in a plant-specific integrated plant assessment (IPA) and time-limited aging analysis (TLAA) evaluation. If a license renewal applicant confirms that the latest version of the inspection guidelines reviewed by the NRC applies to their plant's current licensing basis (CLB), and that the results of the Appendix D IPA and TLAA evaluations are in effect at their plant, then no further review by the NRC of the matters described herein is needed.

K.1 Description of the BWR Core Shroud and Intended Functions

The core shroud is typically composed of three cylindrical shell sections and three rings. The three rings are the shroud head flange, top guide support ring and core plate support ring. The top cylindrical shell connects the shroud head flange to the top guide support ring. The longest cylindrical portion connects the top guide support ring to the core plate support ring. The bottom cylindrical shell connects the core plate support ring to the shroud support cylinder. The shroud support legs are located at the bottom of the shroud support cylinder (a few plants use cantilever supports rather than support legs). A typical core shroud assembly is shown in Figure 1-1 of the inspection guidelines. There are variations in the number of welds with the different plant designs. The design, materials, operating, environmental, and other technical information is contained in Appendices A and B.

The core shroud is required to ensure the capability to shut-down the reactor and maintain it in a safe shut-down condition (54.4(a)(1)(ii)) and prevent or mitigate the consequences of accidents that could result in potential offsite exposure comparable to 10 CFR 100 guidelines (54.4(a)(1)(iii)). Therefore, the intended functions for the core shroud are to:

1) Provide a partition to separate the upward flow of the coolant through the core from the downward recirculation flow;

2) Maintain fuel alignment such that control rods can be inserted; and

3) Form part of the boundary to maintain water level in the core after a LOCA.

The intended functions are preserved under normal, upset, emergency, and faulted conditions Appendix D.6 identifies the safety factors that need to be considered to determine that stress levels for the various operating conditions are consistent with the CLB. The applied loads and load combinations are described in the BWR Vessel and Internals Project Document No. BWRVIP-02.

K.2 Core Shroud Components Subject to Aging Management Review

Paragraph 54.21(a)(1) of the rule provides the requirements for identifying the core shroud components that are subject to aging management review. To satisfy the requirements of 54.21(a)(1), the guidance provided in the NEI industry guideline (Reference K.8.[2]) was used to identify the passive components and then to identify those that are long-lived. For the core shroud, a screening methodology was not needed to make these determinations. All of the components in the core shroud assembly are passive and long-lived. Therefore, the complete core shroud assembly (see Figure 1-1) is subject to aging management review. The aging management review of the shroud head flange bolted connection is included in the review of the top guide assembly.

K.3 Management of Aging Effects (54.21[a][3])

(a) Description of Aging Effects

For the purpose of this Appendix, the BWR Reactor Pressure Vessel Industry Report (Reference K.8.[3]) and the responses to the NRC's questions on the Industry Report are used to identify the aging mechanisms for the core shroud. Aging mechanisms are the causes of the aging effects. The NUREG 1557 (Reference K.8.[4]) is used to establish the correlation between the aging effects and their associated aging mechanisms. If the industry report concludes that the aging mechanism is significant, then the associated aging effect is included in this aging management review. Using this methodology, it was determined that crack initiation and growth, due to stress corrosion cracking, is the only aging effect that requires aging management review for the core shroud. This conclusion is consistent with the scope and intent of the reinspection guidelines.

The causes of the stress corrosion cracking and a susceptibility assessment for the core shroud (including fabrication history, water chemistry, material carbon content, neutron fluence and hot operating time) are provided in Appendix B.1. Based on the susceptibility considerations described in Appendix B.1, the various BWR shrouds are placed in three categories (from highest to lowest susceptibility). The categories consider the material specification (Type 304 or 304L), method of fabrication (welded plate rings or forged rings), and operating history relative to coolant conductivity.

(b) Assessment of Aging Effects and Programs

<u>Inspection of Un-repaired Core Shrouds</u>

As discussed in Section 2, the extent of inspection required for a given plant is determined based on three susceptibility factors which can be readily evaluated: hot operating time, conductivity and shroud material type and fabrication features. The three "condensed" categories (A, B and C) defined in Figure 2-1 were used in the shroud inspections and flaw evaluations. Eventually all shroud inspections, and plants demonstrating compliance with the requirements of the license renewal rule, will be inspected to the inspection criteria for categories B or C.

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As described in Section 2.3, there are other welds and welded components attached to the shroud, such as vertical welds and ring segment welds. The supporting technical basis for inspection of these welds is further evaluated in the inspection guidelines. The inspection criteria for vertical welds are shown in Figure 2-4 and 2-5.

<u>Reinspection of Repaired Core Shrouds</u>

Section 3.0 of the inspection guidelines addresses the inspection requirements for weld in repaired core shrouds. Inspection is intended to provide periodic confirmation of the integrity of the repaired shroud. The licensee is required develop an inspection program incorporating the requirements of the inspection guidelines. In addition, the program shall consider the repair vendor recommendations, industry experience, aging effects, and the critical components and features of the repair design.

(c) Demonstration that the Effects of Aging are Adequately Managed

Crack initiation and growth, due to stress corrosion cracking, is the only aging effect for the core shroud that requires aging management review for license renewal. This aging effect will be managed by incorporating the inspection strategies described in Section 2.0 (un-repaired shrouds) and Section 3.0 (repaired shrouds), when appropriate, in the plant specific inspection plans. The strategies are based on current knowledge of the shroud cracking issue and inspection experience at various plants. It provides a staged approach with respect to the inspection effort and associated analyses that are logically expanded, as necessary, to confirm the core shroud structural integrity. As more inspections are performed, specific aspects of implementing the inspection strategy may be further refined and incorporated in the plant specific inspection plans.

Implementation of the inspection strategy provided in the inspection guidelines and the resulting plant specific inspection plans during the extended operating period will provide a verification of the core shroud structural integrity requirements. Therefore, there is reasonable assurance that crack initiation and growth will be adequately managed so that the intended functions of the core shroud will be maintained consistent with the CLB in the extended operating period.

K.4 Time Limited Aging Analyses (54.21[c][1])

The six criteria contained in the NEI industry guideline (Reference K.8.[2]) were applied to identify the time limited aging analysis (TLAA) issues. That is, those calculations and analyses that:

1) Involve the core shroud assembly

2) Consider the effects of aging

3) Involve time-limited assumptions defined by the current operating term

4) Were determined to be relevant in making a safety determination

5) Involved conclusions or provide the basis for conclusions related to the capability of the core shroud to perform its intended function, and

6) Are incorporated or contained by reference in the CLB.

The generic fracture mechanics analyses described in Appendix D of the inspection guidelines are used to determine inspection intervals for core shrouds. The methodology and assumptions used in these analyses result in the following potential TLAA issues. The applicant may be required to evaluate these issues in a plant-specific analysis.

- The length of time evaluated in the analyses.
- LEFM is required if specified fluence level threshold values are exceeded during the extended operating period.
- The effects of BWR industry operating experience on the number of postulated flaws assumed in the analyses.
- The applicable crack growth rates are shown to be greater than $5x10^{-5}$ in/hr.

If a plant-specific analysis identified by an applicant meets all six criteria above, then this analysis will be considered a TLAA for license renewal and evaluated by the applicant. At a minimum, the plant-specific analyses of the core shroud for fatigue will be reviewed by the applicant to determine if the TLAA criteria apply.

K.5 Exemptions (54.21[c][2])

Exemptions associated with the core shroud that contain TLAA analysis issues will be identified and evaluated for license renewal by individual applicants.

K.6 Technical Specification Changes or Additions (54.22)

There are no generic changes or additions to technical specifications associated with the core shroud as a result of this aging management review to ensure that the effects of aging are adequately managed. Individual applicants will identify plant-specific changes.

K.7 Demonstration that Activities will Continue to be Conducted in Accordance with the CLB (54.29[a])

Sections K.1, K.2, and K.3 address the requirements 54.21(a) of the rule. The core shroud components that are subject to aging management review are identified and it is demonstrated that the effects of aging are adequately managed.

Sections K.4 and K.5 address the requirements of 54.21(c) of the rule. Plant-specific time limited aging analyses (TLAAs) and exemptions that require evaluation will evaluated by the applicant.

Section K.6 addresses the requirements of 54.22 of the rule. There are no generic technical specification changes or additions necessary to manage the effects of aging for the core shroud during the period of extended operation.

Therefore, actions have been identified and have been or will be taken by utilities with BWR plants, such that there is reasonable assurance that the activities authorized by license renewal for the core shroud will continue to be conducted in accordance with the CLB.

K.8 References

1. Title 10 of the Code of Federal Regulations, Part 54, "Requirements for License Renewal of Operating Licenses for Nuclear Power Plants,"(60 Federal Register 22461), May 8, 1995.

2. Nuclear Energy Institute Report NEI 95-10 (Rev. 0), Industry Guideline for Implementing the Requirements of 10 CFR Part 54 the License Renewal Rule.

3. NUMARC 90-03, BWR Reactor Pressure Vessel Internals License Renewal Industry Report, Revision 1, June 1992.

4. NUREG 1557, Summary of Technical Information and Agreements from Nuclear Management and Resources Council Industry Reports Addressing License Renewal, October 1996.

Targets:
Nuclear Power

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TR-114232NP

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