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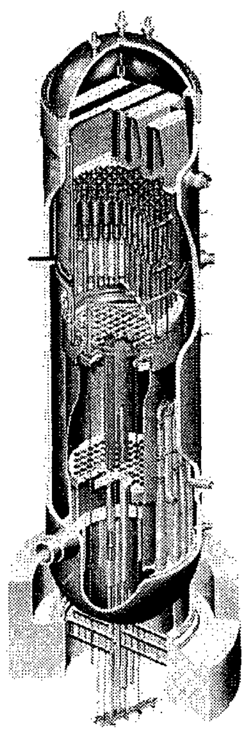
BWRVIP-34NP-A: BWR Vessel and Internals Project

Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping



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Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping

1016377NP

Final Report, March 2008

EPRI Project Manager
B. Carter

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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This report was prepared by

Electric Power Research Institute (EPRI)
3420 Hillview Avenue
Palo Alto, CA 94304

This report describes research sponsored by the EPRI and its BWRVIP participating members.

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

BWRVIP-34NP-A: BWR Vessel and Internals Project, Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping. EPRI, Palo Alto, CA: 2008. 1016377NP.

This report is based on the following previously published report:

BWR Vessel and Internals Project, Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping (BWRVIP-34). EPRI, Palo Alto, CA: 1997. TR-108198, authored by Structural Integrity Associates, GE Nuclear Energy, the BWRVIP Repair Committee and EPRI.

REPORT SUMMARY

The Boiling Water Reactor Vessel and Internals Project (BWRVIP), formed in June 1994, is an association of utilities focused exclusively on boiling water reactor (BWR) vessel and internals issues. This report summarizes the results of the design and analysis activities and the testing programs conducted to provide BWR utilities with a contingency repair option for internal core spray piping for BWR2/6 plants. A previous version of this report was published as BWRVIP-34 (TR-108198). This report (BWRVIP-34-A) incorporates changes proposed by the BWRVIP in response to U.S. Nuclear Regulatory Commission (NRC) Requests for Additional Information, recommendations in the NRC Safety Evaluation (SE) and other necessary revisions identified since the previous publication of the report. All changes except typographical errors are marked with margin bars. In accordance with a NRC request, the SE is included here as an appendix and the report number includes an "A" indicating the version of the report accepted by the NRC staff.

Background

Core spray line/sparger cracking was first detected in 1978 during routine in-vessel visual inspections. NRC IE Bulletin 80-13 requires visual inspections that exceed ASME Code requirements. Because core spray piping is important to reactor integrity, the BWRVIP has made development of the core spray inspection and evaluation (I&E) guidelines, and repair design criteria a high priority. Current repair and/or replacement options such as mechanical clamps or welded straps require plant owners to either commit significant funds for a repair or replacement in advance of known need, or accept the risk of a major outage extension if cracking requiring repair prior to startup is identified.

Objective

- To evaluate the feasibility of applying weld overlay repairs underwater to affected welds in the core spray piping.
- To provide the design basis, design requirements, technical basis and methodology for a part circumference weld overlay repair for internal core spray piping.

Approach

The project team first evaluated the use of partial weld overlays for repair of core spray piping and determined that it represents a viable option to existing methods. The team next executed a project to develop, demonstrate and qualify the overlay technique. The project consisted of three activities: development of design methodologies, leakage assessment techniques, and a weld test program; development of the required welding processes; and a remote tooling feasibility study and remote tooling conceptual design.

Results

A detailed design for the weld overlay was developed and a procedure for implementation of the design by utilities was devised. The design was tested by performing underwater welding at appropriate depths on simulated pieces of core spray piping. Test results indicate that the structural integrity of the weld, as well as post-weld material properties, are suitable for the intended repair. Results of the tooling study indicated that there would be no inherent impediments to development of remote application tooling for the process. Due to project constraints, development of the remote tooling was not pursued. However, as demonstrated in the test program, the overlay repair can be applied by divers with acceptable results.

EPRI Perspective

The project has resulted in the development and qualification of a design for part circumference core spray weld overlay repairs. The design takes advantage of recent advances in underwater welding technology, meets the BWRVIP Core Spray Repair Design Criteria (BWRVIP-19), and has a significant advantage over previously available methods as a contingency repair.

Keywords

Boiling Water Reactor
Core Spray Piping
Repair
Stress Corrosion Cracking
Vessel and Internals
Weld Overlay

RECORD OF REVISIONS

Revision Number	Revisions
BWRVIP-34	Original Report (TR-108198).
BWRVIP-34-A	The report as originally published (TR-108198) was revised to incorporate changes proposed by the BWRVIP in responses to NRC Requests for Additional Information, recommendations in the NRC Safety Evaluation (SE), and other necessary revisions identified since the last issuance of the report. All changes except corrections to typographical errors are marked with margin bars. In accordance with a NRC request, the SE is included here as an appendix and the report number includes an "A" indicating the version of the report accepted by the NRC staff. Non-essential format changes were made to comply with the current EPRI publication guidelines. Appendix M added: NRC Safety Evaluation. Details of the revision can be found in Appendix N.

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1
INTRODUCTION

Important Note to 2008 Revision

The design analysis documented in this report was developed in 1997 and is generally consistent with Section XI of the ASME Boiler and Pressure Vessel Code (Code) in place at that time. Since that time, a number of changes have been made to the Code which will affect some of the details of the analyses. While the general design principles documented in the report are still valid, any analyses used in the design of core spray weld overlay repairs shall be in accordance with the latest Edition and Addenda of the ASME Code including Section IX and Section XI as identified in the Owner's ISI Inspection Plan and with applicable Code Cases (e.g., N-516 and N-504-2) that are endorsed in Regulatory Guide 1.147. Further, Code Cases N-504-2 and N-516 are referenced throughout this report. The reader should understand that these Cases have since been revised and, in part, incorporated into Section XI. The reader must use the requirements of, and the Cases applicable to, the Edition and Addenda of Section XI identified in the Owner's ISI Inspection Plan.

Section 3.2 includes an example where the design approach used in the report differs from the Code requirements. The analysis in Section 3.2 does not incorporate a Z-factor correction as required by the Code for flux welds such as SMAW and FCAW welds. However, any future design would need to include that correction should the applicable Code so require.

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1.1 Purpose

The purpose of this document is to:

- Provide the design basis and design requirements for a part circumference weld overlay repair for internal core spray piping.
- Provide the technical basis and methodology for evaluation of core spray leakage when part circumference overlay repairs are applied.
- Provide the materials and welding qualification performed to demonstrate this repair technique.
- Provide the evaluation performed to confirm the inspectability of part circumference overlay repairs.

1.2 Background

Core spray line/sparger cracking was first detected in 1978 during routine in-vessel visual inspections. As the cracking was found to be more widespread in subsequent years, and recognizing the nature of stress corrosion cracking, the NRC issued IE Bulletin 80-13, which requires visual inspections that exceed ASME Code requirements. Plants have been performing inspections to the IE Bulletin 80-13 requirements for many years, and have continued to find and address core spray line/sparger cracking.

Recently, the BWRVIP prepared a safety assessment of BWR internals as a follow-on to the activities completed on shroud cracking. In the evaluation of internal core spray piping and spargers and the consequences of internal core spray pipe cracking, it was clear that inspection is an important part of assuring internal core spray piping integrity, and thus the ability to achieve safe shutdown for worst case scenarios. As a result, the BWRVIP made development of the core spray inspection and evaluation (I&E) guidelines, and repair and replacement design criteria a high priority for 1996. Core Spray I&E Guidelines (BWRVIP-18), Repair Design Criteria (BWRVIP-19), and Replacement Design Criteria (BWRVIP-16) have been issued and submitted to the NRC for review.

In parallel with the development of repair and replacement design criteria, members of the BWRVIP Repair Committee evaluated vendor designs and capability for repair and/or replacement of cracked core spray piping. Summary conclusions from this evaluation were:

- To date, repair options for cracked locations have been limited to installation of welded straps, or more recently, specially designed clamps. In some cases, piping or spool replacement has been undertaken.
- Technically adequate repair and replacement options are currently available from multiple vendors.
- Currently available repair and replacement options are economically viable for planned repair or replacement (i.e. the need for a repair or replacement is known several months in advance of the required installation date).

- Currently available repair and replacement options have very large economic disadvantages when utilized as a contingency repair. These are:
  - High design, fabrication and tooling costs
  - Long lead time

Effectively, these factors require a plant owner to either commit significant funds for a repair or replacement in advance of known need, or accept the risk of a major outage extension if cracking requiring repair prior to startup, is identified.

1.2.1 Initial Feasibility Study

The BWRVIP Repair Committee conducted an initial study to evaluate the feasibility of applying weld overlay repairs underwater to affected welds in the core spray piping. Such weld overlay repairs would take advantage of the recent advances in underwater welding technology, would meet the BWRVIP Repair Design Criteria (BWRVIP-19) and would have a significant economic advantage as a contingency repair.

The results of the feasibility study confirmed that part circumference overlay repairs, meeting repair design requirements, could be developed.

1.2.2 Repair Design, Qualification and Demonstration

Following the completion of the initial feasibility study the BWRVIP Repair Committee elected to pursue development of the part circumference weld overlay repair as a viable option for the repair of core spray piping welds. It was also recognized by the Repair Committee that both underwater welding and part circumference weld overlays have other potential in-vessel repair applications; thus continued development could be beneficial for other potential repair locations.

A team of three organizations was assembled to implement this program, with overall project management provided by the BWRVIP Repair Committee. The team consisted of the following:

1. Structural Integrity Associates: Responsible for development of design methodologies, leakage assessment techniques, and test definition.
2. EPRI-Repair and Replacement Applications Center (RRAC): Responsible for development of the required welding processes based upon their innovations in underwater welding technology, and for performing all required mechanical and materials testing.
3. General Electric Company: Responsible for the remote tooling feasibility study and remote tooling conceptual design.

The Project Team was successful in completing the above tasks. After reviewing project status, the Repair Committee elected not to proceed with remote application tooling development, beyond the conceptual design stage, for the following reasons:

- It was unlikely that tooling could be designed, fabricated, qualified and demonstrated prior to the start of spring 1997 outages.

- Tooling development costs are high.
- Not enough time was available, prior to the spring 1997 outages, to adequately resolve a potential concern regarding the weldability of lower elevation core spray piping locations, due to the possibility of irradiation damage at the lower locations (welds 4c, 4d, 5, 6, 7, 8a, 8b in Figure 2-1). In particular the potential for damage due to thermal neutron fluence was considered. A separate BWRVIP project is underway to study this issue.

Although the remote tooling was not developed, the Project Team completed all work necessary to support diver applied weld overlay repairs on locations from the nozzle T-Box through the upper elbows (junction box through welds 4a and 4b in Figure 2-1).

1.3 Report Scope and Organization

This report summarizes the results of the design and analysis activities and the testing programs conducted in support of this program. With the permission of RRAC, results of their testing activities are addressed in this report, with results included as Appendices.

The report was developed to support potential repair needs by providing BWR owners with a contingency repair option that meets the following objectives:

- Available to support spring 1997 outages
- Meet BWRVIP Core Spray Repair Design Criteria (BWRVIP-19)
- Minimal lead time and outage critical path impact
- Minimal contingency cost

1.3.1 Scope

This report is applicable to the repair of internal core spray piping for BWR2 through BWR6 plants. Only welds that are accessible for weld repair, as defined in Section 2.0 of this report, are considered. Because of the decision to defer development of remote tooling for weld application, only the welds that are accessible to a diver (nozzle T-box and first elbow), can be repaired with an overlay at the time this report is submitted. It should be noted, however, that this report addresses all welds (nozzle T-box through shroud penetration) so that if remote application tooling is subsequently developed, all accessible welds will then be repairable, with appropriate consideration of potential fluence effects.

1.3.2 Organization

Sections 2.0 through 8.0 of this report provide the technical basis and qualification of the part circumference weld overlay repair.

Section 2.0 of the report summarizes the components and locations which are considered in the underlying analysis.

Section 3.0 describes the method for structural design of the weld overlay repairs which will assure adequate structural strength in the repair. The method can be applied to specific plant repair designs by simple variation of the generic parameters without requiring extensive plant specific analyses.

Section 4.0 provides a generic method for evaluating the leakage through the unoverlayed portion of the cracked component as a function of applied loads and overlay design. Individual plants can use these methods to evaluate the potential reduction in core spray capacity and resulting peak clad temperature (PCT) penalties which would result from application of part circumferential weld overlay repairs.

Section 5.0 provides a discussion of the potential for irradiation effects on the weldability of core spray piping.

Section 6.0 addresses weld process qualification and provides confirmation that:

- A weld overlay could be effectively applied under water at depths of up to 50 feet, using either the automatic flux core arc welding (FCAW) or the manual shielded metal arc welding (SMAW) processes developed by RRAC, with reliable weld quality.
- The as-deposited weld overlay material is resistant to IGSCC, as indicated by as-deposited ferrite levels and by constant extension rate (CERT) tests. It also provides confirmation that base material adjacent to the repair is not significantly sensitized due to repair application.
- The as-deposited under water weld metal exhibits sufficient toughness, and that the as-deposited material properties are not significantly reduced compared to the in-air properties.

Section 7.0 summarizes the development of ultrasonic examination capability on sample weld overlays by the EPRI NDE Center. This section demonstrates that weld overlays can be examined effectively and defines the surface preparation criteria.

Section 8.0 presents the summary and conclusions of this study, including results of the design activities and RRAC testing.

In the Appendices to this report, test results are included for completeness and ease of reference. The appendices also include the results of qualification activities for each welding process, procurement specifications for weld material and procedural considerations for in-plant implementation.

1.4 Implementation Requirements

This report describes one method of performing welded repairs to certain BWR internal components. Should the method described in this report be utilized, the requirements in the report shall be considered "needed" in accordance with Nuclear Energy Institute (NEI) 03-08, "Guideline for the Management of Materials Issues."

2
COMPONENT DESCRIPTIONS

This section of the report identifies the candidate welds on the internal core spray piping which are considered for underwater, partial circumferential weld repair. The configuration of FitzPatrick (BWR 4) forms the basis for some of the detailed information contained herein, and is used as the basis for repair design development.

As shown in report BWRVIP-15 [1], most BWR 3, 4 and 5 plants have a core spray piping configuration similar to that of the FitzPatrick plant. However, there are certain plant unique differences. For example, FitzPatrick has an extra weld in one downcomer pipe which has been repaired with a sleeve coupling. Also, some plants have 5 inch Schedule 40 pipe, while others have 6 inch Schedule 40 pipe. The BWR 2's have a completely different geometry than that of the BWR 3, 4 and 5 plants, but weld configurations are very similar, except at the shroud connection. The geometry for the BWR 6 plants is also different than that for the BWR 3, 4 and 5's, with field fit-up coupling, junction box, and shroud attachment geometry being the major difference. Plant specific differences are inconsequential in relation to the development of a generic weld repair concept. Therefore, in lieu of considering these plant unique differences, only "common" geometry is considered herein.

Weld repairs will be considered for welds P2, P3, P4a, P4b, P4c, P4d, P5, P6, P7, P8a, and P8b as shown in Figure 2-1 (from Figures 2-2 and 2-14 of the BWRVIP-18 report [2]). Weld P2 connects the cover to the junction box, weld P3 connects the header to the junction box, and the P4 welds are pipe to elbow welds. Welds P5, P6 and P7 are field fit-up coupling welds, and welds 8a and 8b are the sleeve to pipe welds and sleeve to shroud welds, respectively. All other welds are inaccessible for weld repair, and have not been considered in this study.

For FitzPatrick, the pipe to elbow welds are of a standard 5 inch, Schedule 40 design, and do not need further description. For the other welds, figures are included herein to define the geometry considered:

- Figure 2-2 – Welds P2 and P3
- Figure 2-3 – Welds P5, P6 and P7
- Figure 2-4 – Welds P8a and P8b

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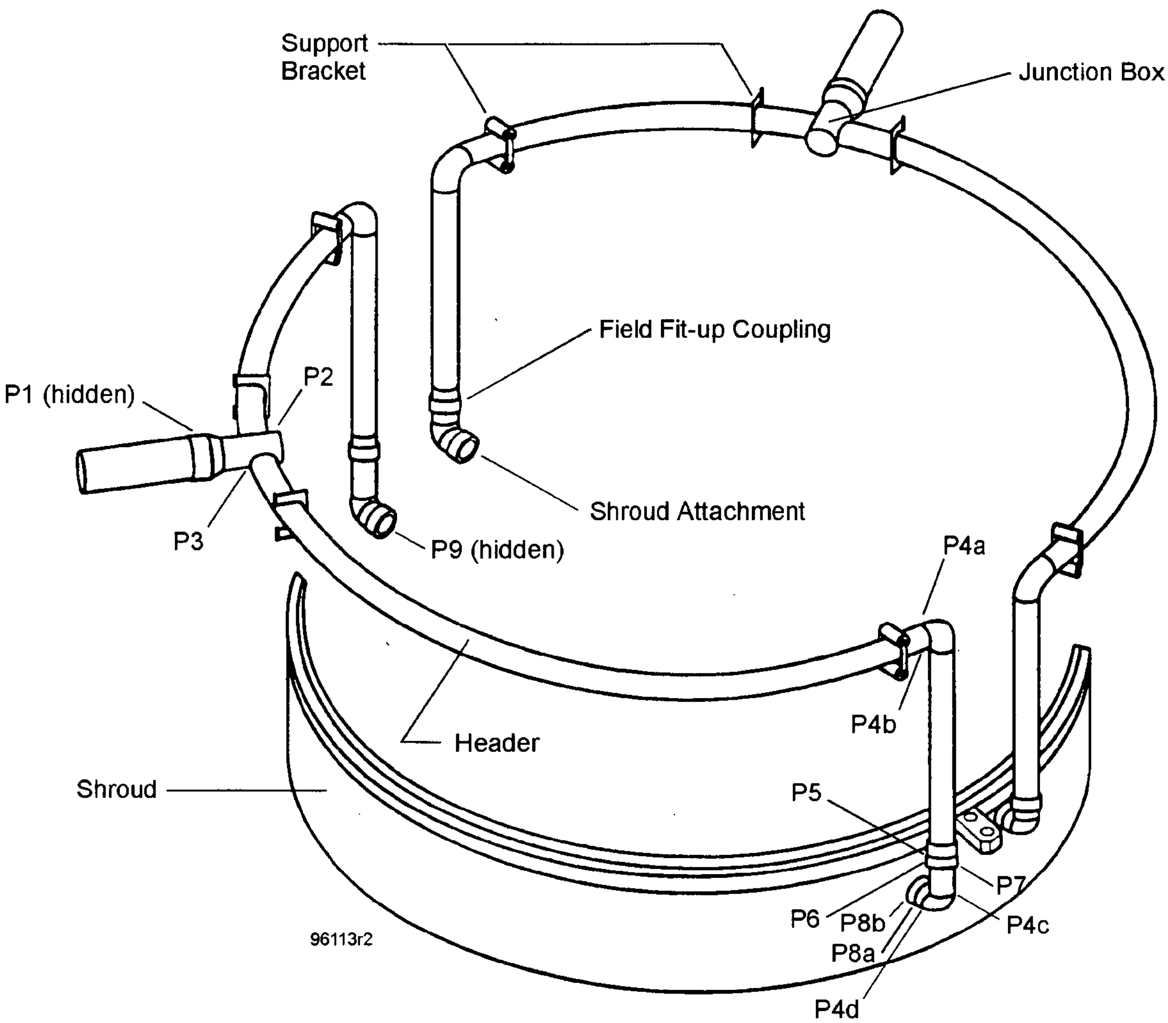
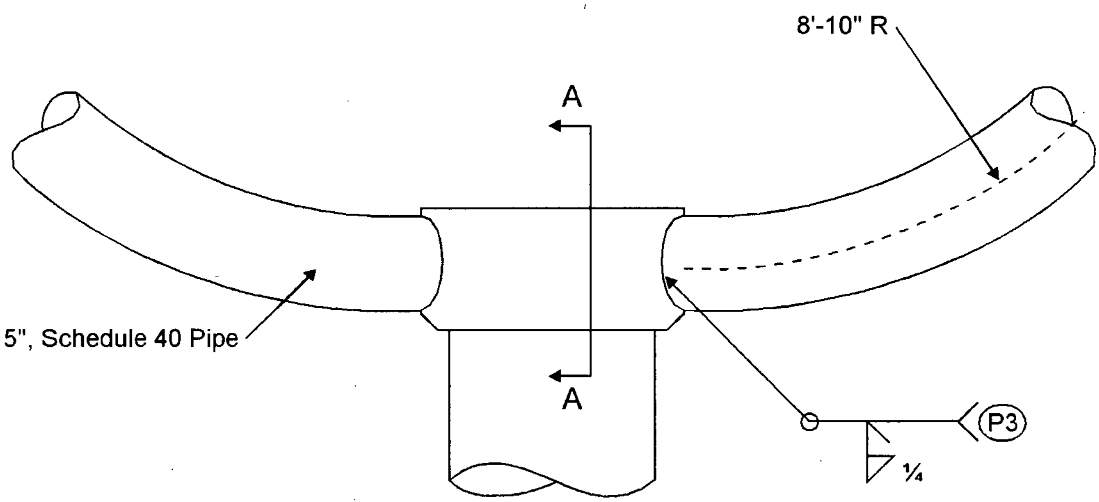
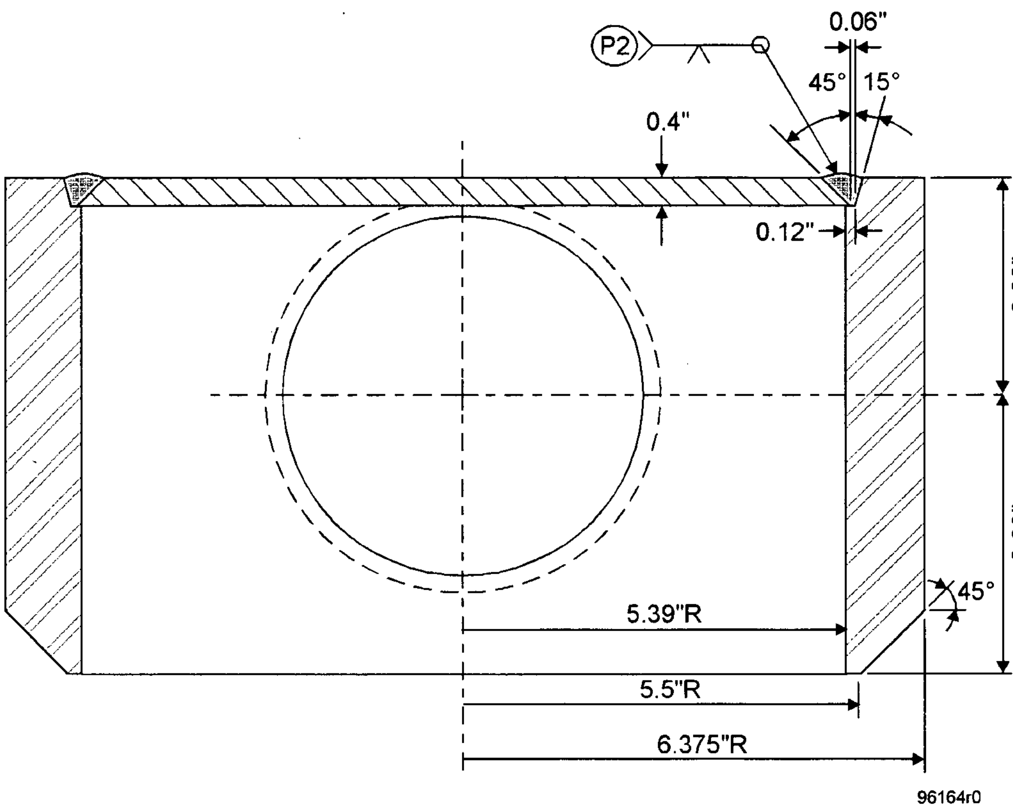


Figure 2-1
Typical BWR/3-5 Core Spray Piping Configuration





Section A-A

Figure 2-2
Typical Junction Box Details

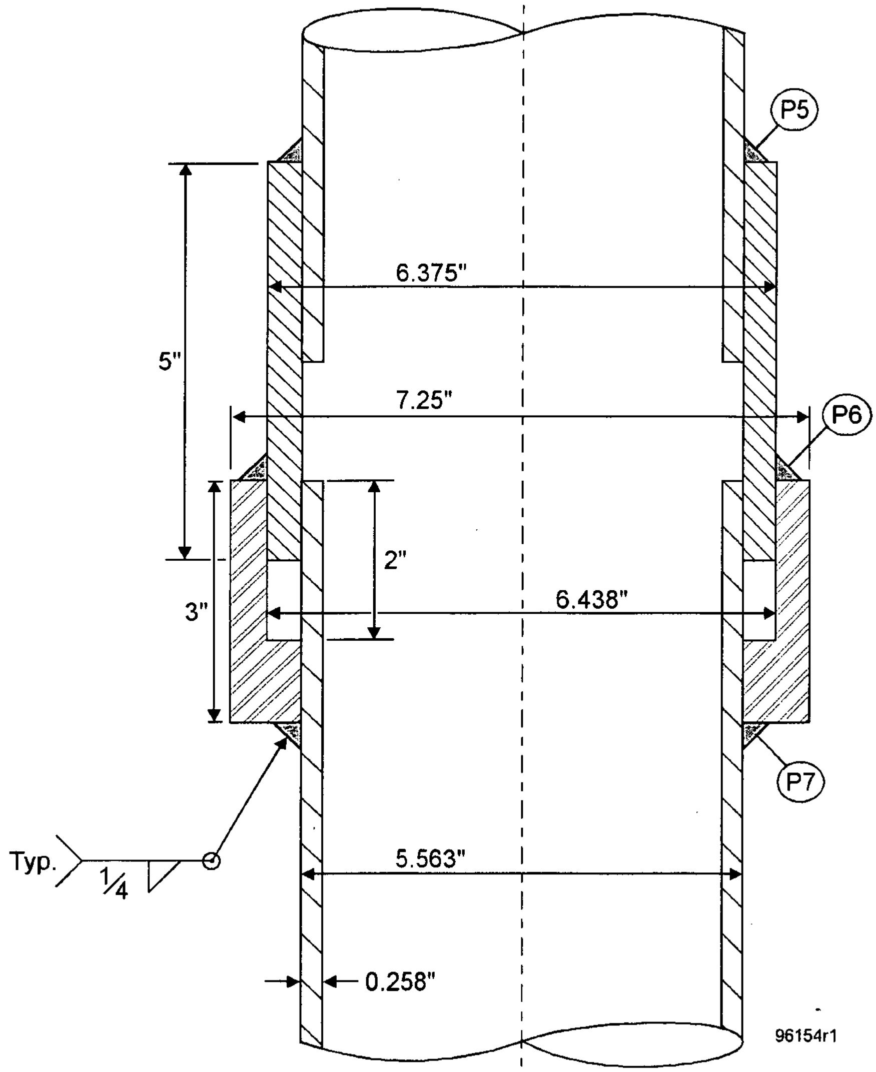


Figure 2-3
Typical Field Fit-Up Coupling Details

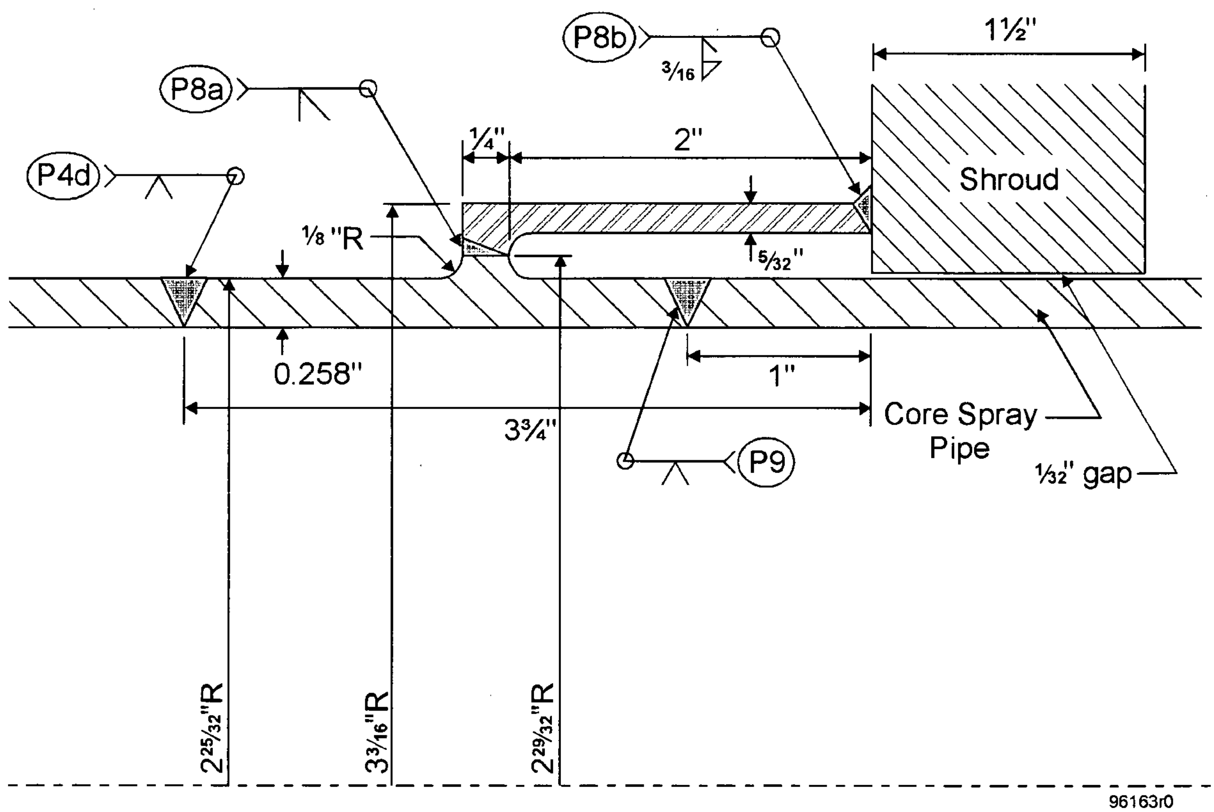


Figure 2-4
Typical Shroud Attachment Detail

3 WELD OVERLAY DESIGN BASIS

Note: This section describes methods for determining the weld overlay length and thickness required to meet structural criteria. Additional length and width may be required in order to allow satisfactory UT inspections to be performed. Considerations related to inspection are discussed on Section 7.

3.1 Introduction

The design of core spray piping weld overlay repairs is limited by the fact that many of the weld locations in such piping are located close to the reactor vessel wall or the core shroud, so that access around the full circumference of the repair location is limited by the small clearances.

Because of these access restrictions, the weld overlay repairs are, in some cases, limited to a circumferential extent of less than 360 degrees. Consequently, some requirements that are unique to this repair (in addition to those in BWRVIP-19) were identified:

1. The weld overlay repair is required to provide structural adequacy in the repaired location, assuming that the original pipe girth weld was cracked entirely through the component wall, and that the crack extended completely around the circumference of the pipe. Because of the limited clearance present in many of the candidate repair locations, the weld overlay was required to develop the required structural capability in significantly less than 360 degrees of circumferential extent.
2. Because the repair could extend around only a part of the circumference due to the limited clearances, some portion of the original component was assumed to be left with a through wall crack through which some amount of core spray flow could leak into the annulus, thus removing such leakage flow from the ECCS capacity of the system. A method for predicting the magnitude of such leakage needed to be developed to allow plants to evaluate the ECCS penalty which they would have to take if such repairs were applied. Consequently, limiting leakage flow became a factor in the weld overlay design.

Conceptual designs of the weld overlay repairs for the various core spray piping welds are shown in Figures 3-1 through 3-4. The stresses at the various weld locations may vary from plant-to-plant.

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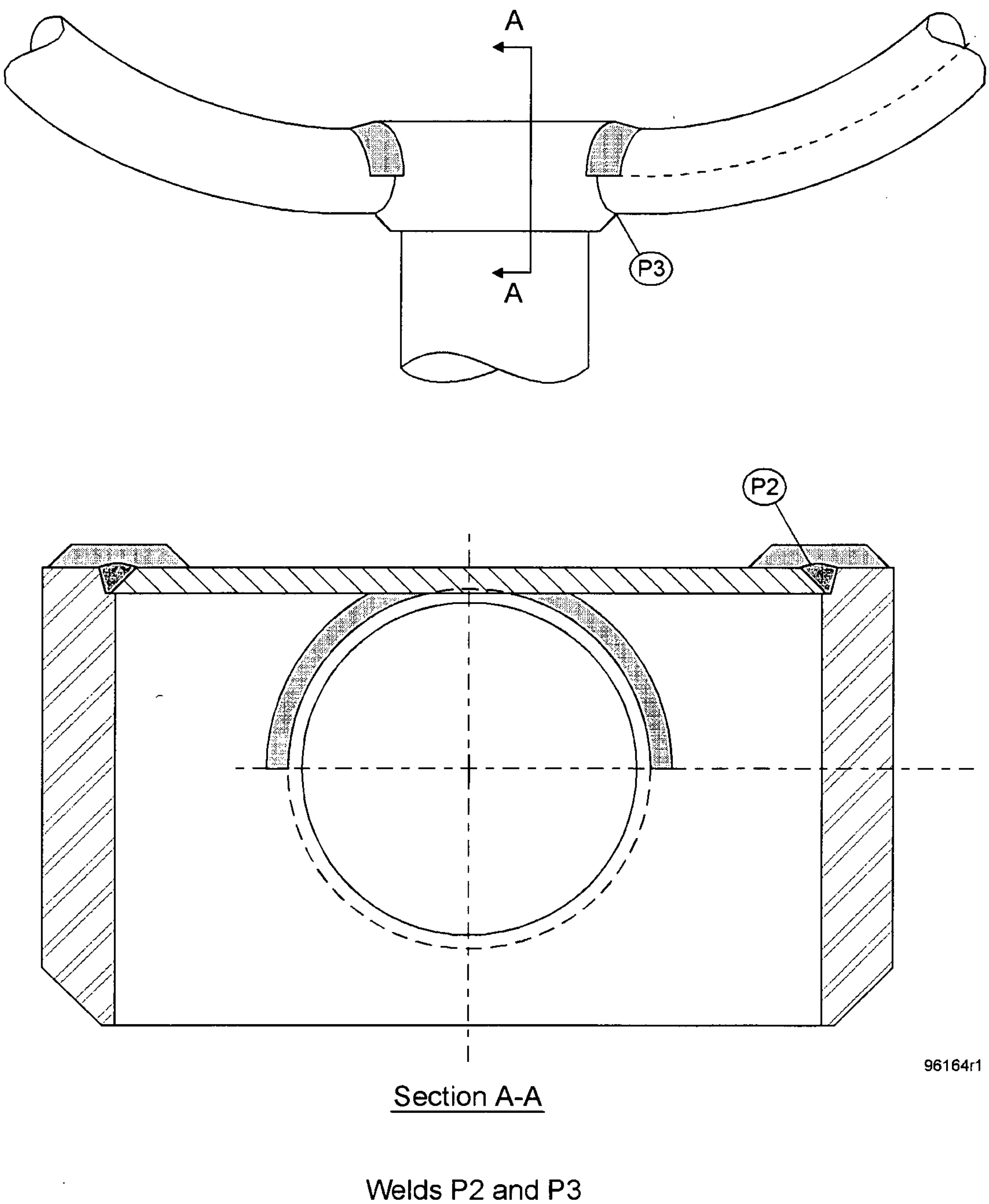
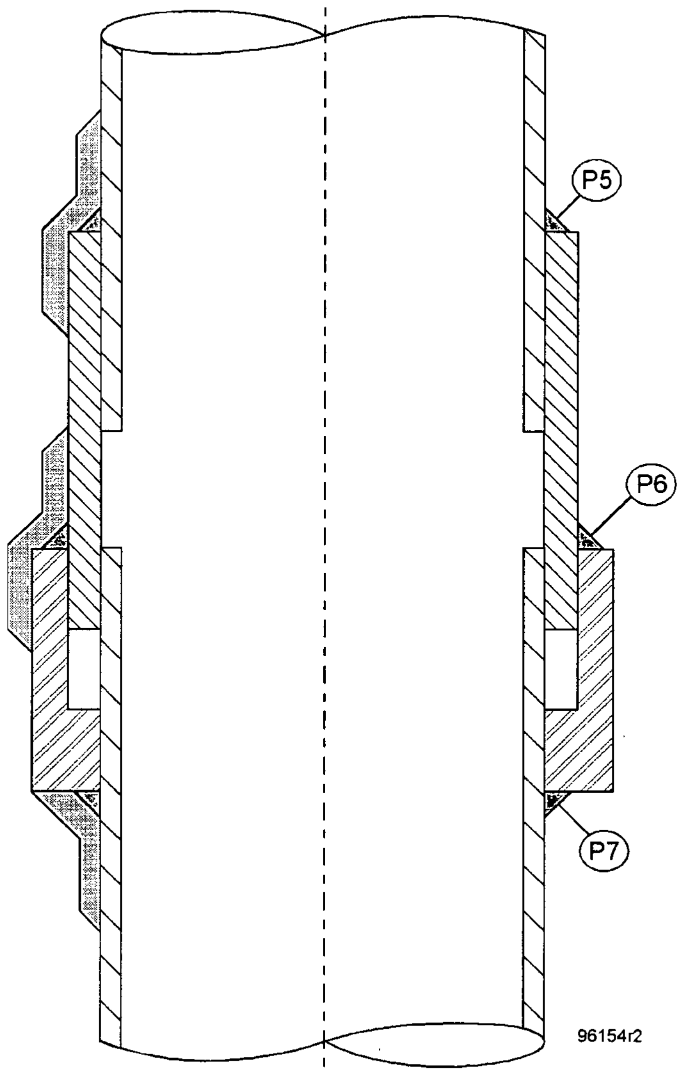
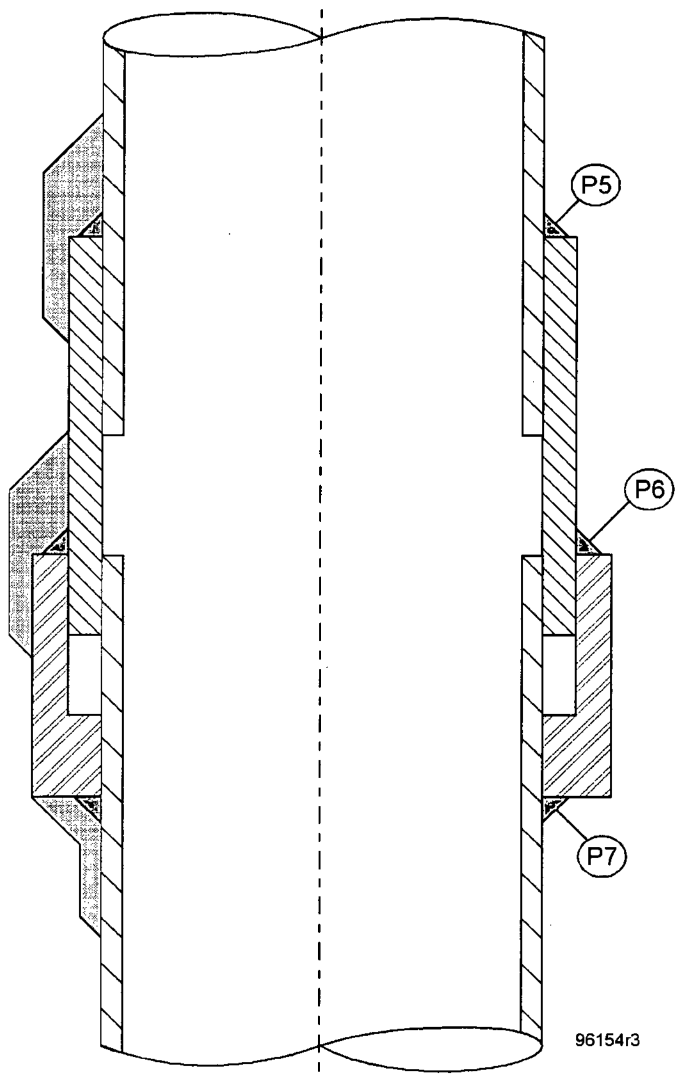


Figure 3-1
Overlay Design: Welds P2 and P3



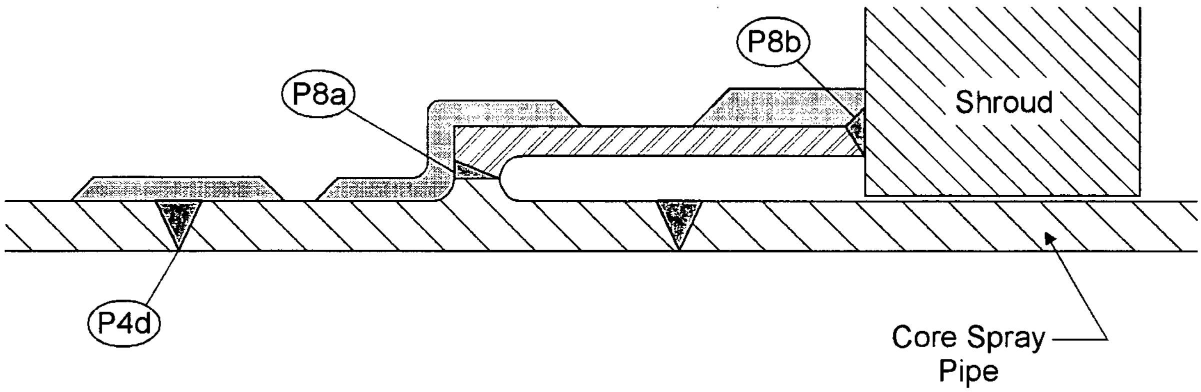
Welds P5, P6, and P7 - Option 1 (Preferred)

Figure 3-2
Overlay Design: Welds P5, P6, and P7 - Option 1 (Preferred)



Welds P5, P6, and P7 - Option 2

Figure 3-3
Overlay Design: Welds P5, P6, and P7 - Option 2



Welds P4d, P8a, and P8b

Figure 3-4
Overlay Design: Welds P4d, P8a, and P8b

3.1.1 Assumptions

The following assumptions have been applied to the design of the core spray weld overlay repairs.

1. The overlays have been designed assuming the original pipe wall to be cracked through-wall for the entire circumference at the location of the girth weld to be repaired.
2. The accessible circumferential extent for application of the overlay is less than 360°. Overlays dimensions were determined by parametrically varying the overlay circumferential extent (150°, 180°, 210° and 240°) for various stress combinations.
3. Load combinations considered in the design meet the recommendation of the BWRVIP-19 Core Spray Piping Repair Design Criteria [13].
4. The overlay repairs will be applied using stainless steel E-308L, E-309L, or E-316L type weld metal or similar material, which is highly ductile.
5. Net section plastic collapse is the applicable failure criterion for these overlay repairs.

3.1.2 Design Criteria

The objective of this section is to develop methods for determining the thickness and length of a part circumference overlay considering the membrane and bending stresses acting on the pipe. This analysis assumes net section plastic collapse as the failure criterion since the overlay material is expected to be a high toughness stainless steel weld material.

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The present application of the part circumference overlay is for the BWR core spray piping inside the vessel, though the methodology presented in this section can be applied on a generic basis.

3.1.3 Methodology

Several tasks were performed to develop the methodology for design of the weld overlays to meet the design criteria established above. The results of these tasks are presented in the following subsections.

Task 1 - Development of Analytical Method

The net section plastic collapse methodology provided in Appendix C of ASME Section XI is applicable to overlays applied symmetrically over the entire circumference. A similar net section collapse methodology is developed in this report to establish the thickness of these part circumference overlays. A methodology is also developed to use net section plastic collapse to determine the length of the overlay based on net section collapse in shear.

Task 2 - Supplemental Finite Element Analyses

For some of the complex configurations such as welds P3 and P8a, the results of Task 1 were supplemented by detailed finite element analyses using the ANSYS [8] program to confirm the structural adequacy of the overlays.

Task 3 - Development of Overlay Dimensions

The results of Tasks 1 and 2 were used to provide, in tabular form, overlay dimensions (thickness and length) for each configuration as a function of circumferential extent of the overlay and the applied stresses.

3.1.4 Procedure for Overlay Design

The following procedure can be used for plant specific calculation of the required weld overlay dimensions.

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3.2 Derivation of Net Section Collapse Methodology for Determination of Overlay Thickness

As noted above, weld overlays designed for other applications (e.g. recirculation system pipe repairs) have generally been applied around the entire circumference of the repair location. In the case of the core spray piping, the weld overlay will be applied asymmetrically, covering only a portion of the circumference. Consequently, it is necessary to develop net section collapse analytical methods for application to this type of geometry. This is derived based on the geometry and parameters illustrated in Figure 3-5.

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Figure 3-5
Net Section Collapse Geometry

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3.3 Example Problem: Weld Overlay Thickness Determination

To implement the above methodology, a spreadsheet was developed to perform the required calculations. The following input, which is typical of core spray piping dimensions, was used for demonstration purposes:

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Table 3-1
Required Overlay Thickness (in.) Level (A/B)

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Table 3-2
Required Overlay Thickness (in.) Level (C/D)

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3.4 Determination of Required Overlay Length

The overlay length can be determined by using Equation 3-2 with the following substitutions.

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Table 3-3
Required Overlay Half Length, L/2 (in.), Level (A/B)

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Table 3-4
Required Overlay Half Length, L/2 (in) Level (C/D)

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Figure 3-6
Weld Overlay Dimensions

4
LEAKAGE CALCULATION FOR PART CIRCUMFERENTIAL WELD OVERLAYS

4.1 Introduction

Section 3 of this report describes the techniques used to derive weld overlay repair design thickness and length using net section collapse methods. These methods produce repairs which are adequate to assure structural integrity of the repaired location for the life of the piping (assuming no degradation due to flaw growth). However, since the proposed weld overlay repairs extend around only a portion of the circumference, while assuming a 360 degree through wall flaw, the unoverlayed portion of the circumference may contain a through wall crack through which some core spray flow could potentially leak, thus reducing the flow which is available for the core spray function. To demonstrate the adequacy of part circumferential weld overlay repairs for application to internal core spray piping locations, it is necessary to evaluate the magnitude of such leakage so that the effects of reduced core spray capacity can be considered and so that repair designs can be developed which limit leakage to acceptable values. The purpose of the present section is to develop techniques for evaluation of core spray leakage in the presence of such cracks.

BWRVIP-18, Core Spray I&E Guidelines [2], gives guidance for the determination and evaluation of leakage through unrepaired flaws in core spray piping (Sections 5.1.5, 5.1.6, and A.1.4 of that report). It is expected that this evaluation will be performed for unrepaired flaws and combined with the evaluation performed for flaws repaired by weld overlay to assess the overall acceptability of the core spray piping leakage during events when core spray operation is postulated.

Additional evaluation of leakage effects during normal operation is required by BWRVIP-19 [16], Section 8.1, for repaired piping.

4.2 Leakage Determination During Accident Operation

4.2.1 Effects of Weld Overlay Application

Leakage through the unrepaired cracks in part circumference weld overlay repaired locations is a function of the pressure differential across the crack and of the crack opening area.

Weld overlay application can potentially produce a permanent crack opening displacement due to shrinkage of the weld material upon cooling. One limiting condition on the application of weld overlay repairs is, therefore, that the crack opening displacement resulting from a repair cannot produce an unacceptably large initial crack displacement with resulting large leakage.

In order to assess the effects of weld overlay application on potential leakage, a series of tests was performed by RRAC. Underwater weld overlay repairs of severed pipe sections were applied in steps on 5 inch and 6 inch piping, and the maximum crack opening displacements in the unrepaired cracks were measured. Weld overlays applied in both the axial and circumferential directions were evaluated.

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4.2.2 Methodology for Core Spray Bypass Leakage Determination

Section 4.2.3 summarizes a procedure for assessing the core spray bypass leakage which would result from repair of a 360° through wall flaw in core spray piping with a part-circumference weld overlay repair, as described in Section 3.0.

The leakage evaluation is conducted using the computer program PICEP [10]. This computer program has been developed by the Electric Power Research Institute and is widely accepted in the nuclear industry for leak rate calculations.

4.2.3 Procedure for Core Spray Leakage Calculation

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Table 4-1 presents typical leakage results for two cases using the same geometry and stresses as are considered in the sample problem in Section 3.

Table 4-1
Sample Leakage Calculation Results

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4.3 Evaluation of Total System Leakage

In order to evaluate the acceptability of predicted leakage from a given repair location it is necessary for each plant to determine the total leakage from the core spray line into the RPV annulus. This will typically include leakage from:

- T-box Vent Hole (BWRVIP-18 [2], Section 5.1.5)
- Thermal sleeve and nozzle safe end ID slip fit (where applicable)
- Unrepaired flaws (BWRVIP-18 [2], Section 5.1.5)
- Repaired flaws (For example, calculated as above)

Acceptance criteria for this total leakage should be consistent with the plant's licensing basis LOCA analysis and needs to be defined on a plant specific basis. Definition of the criteria may consider:

- Margin between surveillance testing and LOCA assumptions
- Penalty for surveillance testing flow instrument inaccuracy
- Assessment of change in PCT due to change in core spray flow
- Core spray flow reductions included in the LOCA analysis (typically 10%)
- Determination of more realistic flow rates based on pre-operational pump curves and pressure drops

Note that taking credit for some of the above may require revision of site surveillance procedures, Tech Specs, FSAR, or LOCA Analysis and may require an NRC submittal under 10CFR50.

4.4 Typical Leakage Evaluation: Normal Operation

4.4.1 Determination

A determination of the amount of core flow which bypasses the steam separator and passes directly to the annulus via the core spray piping during normal plant operation should be made. This bypass leakage may come from repaired or unrepaired flaws in the core spray piping and from the inlet T-box vent hole.

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4.4.2 Assessment

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4.5 Typical Leakage Evaluation: Accident Operation

4.5.1 Determination

The leakage from repaired and unrepaired core spray piping flaws, T-Box vent hole, and thermal sleeve should be calculated using the methods outlined in this document or other appropriate guidance. These methods may result in values similar to these:

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4.5.2 Assessment

Plant specific LOCA analyses will contain the assumptions made for core spray flow and the resulting fuel peak clad temperature (PCT) for the most limiting accident. Tech Specs and surveillance procedures will reflect test requirements which ensure that the LOCA assumptions are met. It must be shown that the total leakage from the core spray line, in combination with any other appropriate reductions in available core spray flow (e.g., test accuracy), does not cause an unacceptable increase in PCT for any licensing basis accident.

A simple example of this analysis would be:

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4.6 Conclusions

The application of part circumferential weld overlays requires consideration of the effects of leakage through the unoverlayed portion of the piping weld as well as consideration of the structural capability of the repair. The above methods show that the predicted leakage through an individual repair can be calculated. The sample problem shows that for sufficiently long (circumferentially) weld overlays, the predicted magnitude of such leakage is not large. However, specific evaluation by each plant will be required to assess leakage at repair locations in the context of other plant limitations.

5
IRRADIATION EFFECTS ON WELDABILITY

NOTE:** **The previous content of Section 5 has been deleted in its entirety.

Certain portions of the core spray piping may be sufficiently irradiated such that welding using conventional techniques could result in underbead cracking. Current guidance for performing welded repairs to irradiated components is provided in BWRVIP-97 [17]. That report provided guidance for determining when special welding techniques are required as well as suggesting techniques for accomplishing successful welds on irradiated material. The requirements in BWRVIP-97 (or future revisions to BWRVIP-97) shall be met when performing overlay repairs to core spray piping.

6 MATERIALS AND WELDING QUALIFICATION

Note to 2008 Revision:

Subsequent to the initial publication of this report, the BWRVIP published a Material Guideline (BWRVIP-84, Reference 16) that provides material specifications for use in repairs to BWR internals. Any core spray weld overlay repair design must be consistent with the requirements of BWRVIP-84 as well as the Core Spray Repair Design Criteria (BWRVIP-19-A, Reference 15).

The qualification of the underwater weld overlay technology involves qualification of materials and welding processes for this application. The major materials issues requiring attention for this underwater welding process are related to the structural soundness of the weld overlay, the toughness of the overlay, and the IGSCC resistance of the overlay and adjoining base metal heat affected zone. Two different material types were evaluated in this qualification program and two different under water welding processes were examined. The materials evaluated were primarily austenitic stainless steel weld metal. Some early development also addressed nickel based weld metal, although this material will not be applied on stainless steel core spray piping. The welding processes included automatic flux core arc welding (FCAW) and manual shielded metal arc welding (SMAW). Testing involved ferrite determination for the stainless steel weld deposit, fracture toughness testing of a groove weld specimen for each material type deposited underwater, intergranular stress corrosion cracking susceptibility tests using the constant extension rate test (CERT) technique for the weld deposit, sensitization tests of the heat affected base metal, and the required ASME Code mechanical property tests to produce a Welding Procedure Specification. The following sections of this chapter describe the results of the testing involved in the demonstration of the two welding processes for underwater welding of core spray piping in the BWR environment.

As a result of cost, schedule and radiation fluence concerns (as discussed in Section 5.0), a change in near term strategy was implemented late in the test program. It was determined that the best opportunity to have a field ready process for the Spring 1997 outages was to implement a manual SMAW weld overlay process in lieu of the FCAW process. This would enable weld overlay repair of locations in the core spray piping which were not subjected to the high thermal neutron fluence and which are diver accessible.

The primary focus was on qualification of the SMAW process. However, FCAW parameters were also developed, and these results are also presented here. The SMAW process qualification activity considered only austenitic stainless steel electrodes. As in the case of the FCAW process, the composition of the electrodes has been selected with the focus on maximizing the ferrite level and thereby maximizing the IGSCC resistance of the overlay. Details of the FCAW and SMAW process parameters and welding qualification activities are presented in Appendices.

6.1 Welding Materials and Processes

Two welding processes were examined in this program. These were the FCAW and the SMAW processes. Details of the process parameters, welding materials, coatings, shield or cover gas and specific weld filler chemistries are presented in Appendix B for the FCAW process and in Appendix C for the SMAW process. The weld materials which were evaluated included the stainless steel weld metals Types 308L, 309L and 316L. In the final testing, 308L material was used with the FCAW process, and 309L and 316L were used with SMAW. Some of the stainless steel alloys were modified slightly with additional Cr or Mo to enhance IGSCC resistance or to elevate the ferrite level. Carbon and nickel levels were also controlled to elevate the ferrite level.

The initial development activity was performed using the FCAW process due to the desire for remote application. The results of the process were quite good as illustrated in Appendix B. In particular, the use of a shield gas enabled welding at depths of 50 feet underwater, with good weld quality and toughness. It was determined that Type 308L stainless steel filler would be evaluated in the FCAW program, welding underwater at depths as great as 50 feet.

The test coupon welding using the austenitic stainless steel filler involved multiple objectives, to assure that the process was suitable and ready for in-plant welding in the spring of 1997. Welding at depth and in all positions needed to be demonstrated. That demonstration was successfully completed for the austenitic stainless steel filler using the FCAW process (Appendix B) and the manual SMAW process (Appendix C). Another primary objective was to produce coupons suitable for fracture toughness testing, for sensitization testing, for Code mechanical property tests and for ferrite level evaluations. The results of tests performed for FCAW and SMAW processes are shown in Appendices D-I, and are summarized below.

6.2 Stress Corrosion and Sensitization Tests

In order to qualify the materials and processes as IGSCC resistant for austenitic stainless steel weld metal, a series of stress corrosion tests of the weld deposit and sensitization tests of the pipe heat affected zone were performed for the weld deposits. The testing was performed on specimens taken from all-weld-metal coupons welded using the FCAW process and from coupons welded using the SMAW process. The objective of these tests was to demonstrate that these weld metals, as deposited in the underwater welded condition, would show the same outstanding resistance to IGSCC as low carbon, ferrite controlled austenitic stainless steel weld metal welded in an inert gas environment in air.

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6.3 Ferrite Level Evaluation

For austenitic stainless steel weld metal, the ferrite phase is extremely important in contributing to the overlay IGSCC resistance of the alloy in the oxidizing BWR environment. In early research performed by the General Electric Company for EPRI [3], investigators determined that a minimum level of ferrite could convey essential immunity to IGSCC in the laboratory tests, provided that the carbon level in the austenitic stainless steel weld metal was sufficiently low. Subsequently, investigators reported that combinations of sufficient ferrite and sufficiently low carbon were observed to produce excellent IGSCC resistance of cast austenitic stainless steels and weld metal in welded pipe tests and in CERT tests [4]. The authors reported that both low carbon and the presence of critical quantities of ferrite in CF3, CF3A and CF8 cast material are shown to promote high resistance to IGSCC.

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6.4 Mechanical Properties

The design thickness of the weld overlay repair for core spray piping depends upon the expected properties of the as deposited weld overlay. The welding conditions particular to underwater welding can result in reduced mechanical properties compared to similar welds made in air. In particular, the fracture toughness and the mechanical properties of the weld deposit must be determined, since these properties have a strong impact on the weld overlay design.

Historically, flux shielded austenitic stainless steel welds have been designed using lower fracture toughness (J_{IC}) values due to the observed reduced toughness of these deposits, in some cases, when compared to bare wire processes (such as the gas shielded processes). This difference in toughness, as discussed in Paragraph IWB-3640 and Appendix C of Section XI of the ASME Boiler and Pressure Vessel Code [6], results in greater required design thickness for lower toughness overlays.

One objective of this qualification program was to examine the fracture toughness of the proposed weld deposits to determine the appropriate analysis and design criteria and to demonstrate, if possible, that the as deposited weld overlay material would achieve high toughness. Additionally, the mechanical properties of the weld deposit were determined to demonstrate that the minimum ASME Code properties were achieved, since welding underwater and at depth can potentially degrade these properties as well.

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6.5 Conclusions

The FCAW and SMAW processes were evaluated in this program for use in the underwater welding application for repair of core spray piping in the BWR environment. The welding qualification program involved examination of different welding parameters, welding materials, determination of IGSCC susceptibility by considering weld deposit properties (soundness and ferrite level) and base metal properties (sensitization of the HAZ). The following highlights the program results:

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A recommended procurement specification for underwater wet FCAW and SMAW welding material is presented for information in the appendices.

7
INSPECTION OF CORE SPRAY INTERNAL PIPING WELD OVERLAYS

In accordance with BWRVIP-19-A [15] ("Internal Core Spray Piping and Sparger Repair Design Criteria"), the repair designer is responsible for specifying inspections of the weld overlay repair consistent with the intent of BWRVIP-18 [2] ("BWR Core Spray Internals Inspection and Flaw Evaluation Guidelines"). In defining these inspections, specific consideration should be given to inspection of the underlying cracks in the HAZ of the base metal as well as the possibility of crack initiation in any crevice-like areas that may be created at the periphery of the overlay due to weld undercut. Cracks initiated at these peripheral locations may be difficult to detect using visual techniques and ultrasonic inspection may be required. In the event that UT is chosen for future, periodic inspections, it may be useful to perform a baseline UT inspection immediately subsequent to installation of the repair.

Should UT inspection be chosen, it may be necessary to include additional length in the design of the weld overlay to allow proper contact for the transducer package in order to effectively interrogate all regions of interest. In addition, it may be necessary to provide additional thickness to the as-deposited overlay to allow for any surface finishing required to properly prepare the weld surface for UT examinations. Guidelines for proper surface finishing can be found in Reference 14.

Ultrasonic examination of weld overlays for piping repair have been performed routinely since the late 1980s. Existing standards for examination of these overlays [14] call for the use of high-angle longitudinal-wave probes for detection of cracking and side-wall lack of fusion, and zero-degree probes for detection of lack of bond between the overlay and the parent material. These standards also recommend that the as-welded surface of the overlay be improved by machining or grinding until the surface finish is 250 microinches RMS or better, and a 1/32 inch per inch flatness should be obtained. (That is, a one-inch block with a 1/32-inch wire attached to its midpoint should rock back and forth using the wire as a fulcrum; there should be no dips in the surface severe enough to allow the block to sit flat.)

The inspectability of the underwater (wet) FCAW and SMAW overlay repairs for core spray piping was evaluated by acquiring appropriate ultrasonic probes and building realistic mockups, and then performing examinations and documenting the results. Ultrasonic examinations were performed on five core spray overlay mockups, some containing controlled, artificial defects. Detailed reporting of the measurements will appear in BWRVIP-03, Reactor Pressure Vessel and Internals Examination Guidelines, Revision 1. The results support the following conclusions:

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8 CONCLUSIONS

This study demonstrates that part circumference weld overlay repairs applied underwater using austenitic stainless steel weld metal are an effective and technically defensible option for the repair of cracking found in reactor internal core spray piping. The structural adequacy of such repairs has been demonstrated, as has the IGSCC resistance of weld overlay materials in the as applied condition, for two underwater welding processes: automatic remote flux cored arc welding (FCAW) and manual shielded metal arc welding (SMAW).

A methodology for assessment of leakage through the unoverlayed portion of postulated 360 degree through wall flaws has been developed for application to plant specific cases. Sample problems using this methodology demonstrate that expected leakage is low in an absolute sense, assuming a sufficient weld overlay design. The acceptability of any predicted leakage flow for any particular application in a plant needs to be evaluated on a plant specific basis, considering plant specific margins and other sources of leakage.

Tests have been conducted to demonstrate that underwater applied part circumference weld overlays are ultrasonically inspectable and that typical flaws are detectable. In most cases surface improvement of the as-welded surface will be required to permit reliable ultrasonic inspection.

All activities discussed above were conducted to requirements consistent with existing BWRVIP guidance [1, 2, 13].

The results of the various activities summarized above support the conclusion that underwater-applied weld overlay repairs which extend less than 360 degrees around the repair location in internal core spray piping are effective as permanent repairs for such locations. (Full circumference weld overlay repairs are, of course, also acceptable).

9 REFERENCES

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4. ASTM, "Stainless Steel Coatings," ASTM STP756, November, 1980.
5. U. S. Nuclear Regulatory Commission, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping," NUREG-0313, Revision 2, January 1988.
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A
WELD OVERLAY SHRINKAGE AND CRACK OPENING DISPLACEMENT MEASUREMENTS

Entire Appendix -
EPRI Proprietary Information

B

WELDING PARAMETERS AND PROCEDURES FOR FCAW PROCESS - QUALIFICATION WELDS

Entire Appendix -
EPRI Proprietary Information

C

WELDING PARAMETERS AND PROCEDURES FOR SMAW PROCESS - QUALIFICATION WELDS

Entire Appendix -
EPRI Proprietary Information

D
CERT TEST RESULTS FOR FCAW AND SMAW - ALL WELD METAL COUPONS

Entire Appendix -
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E
SENSITIZATION TEST RESULTS ASSOCIATED WITH UNDERWATER FCAW AND SMAW PROCESSES

Entire Appendix -
EPRI Proprietary Information

F

FERRITE LEVEL DETERMINATION FOR FCAW PROCESS

Entire Appendix -
EPRI Proprietary Information

G
FERRITE LEVEL DETERMINATION FOR SMAW PROCESS

Entire Appendix -
EPRI Proprietary Information

H
FRACTURE TOUGHNESS RESULTS FOR FCAW WELDMENTS

Entire Appendix -
EPRI Proprietary Information

I
FRACTURE TOUGHNESS RESULTS FOR SMAW WELDMENTS

Entire Appendix -
EPRI Proprietary Information

J
RECOMMENDED UNDERWATER ELECTRODE PROCUREMENT SPECIFICATION

Entire Appendix -
EPRI Proprietary Information

K
MOCKUP PREPARATION FOR NDE DEVELOPMENT

Entire Appendix -
EPRI Proprietary Information

L
CONSIDERATIONS FOR CORE SPRAY WELD OVERLAY REPAIR PROCEDURE

Entire Appendix -
EPRI Proprietary Information

M
NRC SAFETY EVALUATION

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

June 27, 2007

Rick Libra, BWRVIP Chairman
DTE Energy
Fermi Nuclear Plant (M/S 280 OBA)
6400 N. Dixie Highway
Newport, MI 48166-9726

SUBJECT: SAFETY EVALUATION OF PROPRIETARY EPRI REPORT, "BWR VESSEL AND INTERNALS PROJECT, TECHNICAL BASIS FOR PART CIRCUMFERENCE WELD OVERLAY REPAIR OF VESSEL INTERNAL CORE SPRAY PIPING (BWRVIP-34)"

Dear Mr. Libra:

The Nuclear Regulatory Commission (NRC) staff has completed its review of the Electric Power Research Institute (EPRI) proprietary report, "BWR Vessel and Internals Project, Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping (BWRVIP-34)," dated May 1997. This report was submitted for NRC staff review and approval by letter dated May 22, 1997, and supplemented by letters dated March 30, 1998, November 1, 2004, and July 18, 2006. The BWRVIP also submitted the non-proprietary version of this report by letter dated May 22, 1997.

The BWRVIP-34 report provides a generic weld repair concept that includes design basis and design requirements for a part circumference weld overlay repair for internal core spray piping; the technical basis and methodology for evaluation of core spray leakage when part circumference overlay repairs are applied; the materials and welding qualification performed to demonstrate this repair technique; and the evaluation performed to confirm the inspectability of part circumference overlay repairs.

The NRC staff has reviewed your submittal and the staff's safety evaluation is attached. The staff requests that the BWRVIP submit the-A version of the BWRVIP-34 report within 180 days of receipt of this letter. Please contact John Honcharik of my staff at (301) 415-1157 if you have any further questions regarding this subject.

Sincerely,

Matthew A. Mitchell, Chief
Vessels & Internals Integrity Branch
Division of Component Integrity
Office of Nuclear Reactor Regulation

Enclosure:
Safety Evaluation

cc: BWRVIP Service List

U. S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
SAFETY EVALUATION OF EPRI PROPRIETARY REPORT TR-108198
"BWRVIP VESSEL AND INTERNALS PROJECT,
TECHNICAL BASIS FOR PART
CIRCUMFERENCE WELD OVERLAY REPAIR OF VESSEL INTERNAL
CORE SPRAY PIPING (BWRVIP-34)"

1.0 INTRODUCTION

1.1 Background

By letter dated May 22, 1997, the Boiling Water Reactor Vessel and Internals Project (BWRVIP) submitted for staff review and approval the Electric Power Research Institute (EPRI) proprietary and non-proprietary versions of Report TR-108198, "BWR Vessel and Internals Project, Technical Basis For Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping (BWRVIP-34)," dated May 1997. It was supplemented by letters dated March 30, 1998, November 1, 2004, and July 18, 2006, in response to the staff's request for additional information (RAI) by letters dated December 14, 1997, October 7, 2004, and March 16, 2006, respectively. The BWRVIP-34 report provides a generic weld repair concept that includes design basis and design requirements for a part circumference weld overlay repair for internal core spray piping; the technical basis and methodology for evaluation of core spray leakage when part circumference overlay repairs are applied; the materials and welding qualification performed to demonstrate this repair technique; and the evaluation performed to confirm the inspectability of part circumference overlay repairs.

The BWRVIP-34 report was submitted as a means of exchanging information with the staff for the purpose of supporting generic regulatory improvements related to the repair of core spray piping. The review of this report was suspended in 1998 due to the staff's concerns related to weldability of irradiated piping. The BWRVIP has since developed guidance for performing weld repairs on irradiated piping, as documented in "Guidelines for Performing Weld Repairs to Irradiated BWR Internals (BWRVIP-97)," November 2001. The staff is currently reviewing BWRVIP-97. Therefore, all applicable information, guidance, and discussions of weldability of irradiated materials previously mentioned in the BWRVIP-34 report will be addressed during the review of BWRVIP-97.

1.2 Purpose

The staff reviewed the BWRVIP-34 report to determine whether it will provide an acceptable technical justification for the repair of the subject safety-related reactor vessel (RV) internal components. The proposed repair follows the American Society of Mechanical Engineers (ASME) Code Case N-504, "Alternative Rules for Repair of Class 1, 2, and 3 Austenitic Stainless Steel Piping," Section XI, Division 1. The review assessed the design objectives, structural evaluation, system evaluation, materials, fabrication and installation considerations, as well as inspection and testing requirements.

ENCLOSURE

1.3 Organization of this Report

Because the BWRVIP-34 report is proprietary, this safety evaluation (SE) was written to not repeat proprietary information contained in the report. The staff does not discuss, in any detail, the provisions of the guidelines or the parts of the guidelines which it finds acceptable. A brief summary of the contents of the subject report is given in Section 2 of this SE, with the evaluation presented in Section 3. The conclusions are summarized in Section 4. The presentation of the evaluation is structured according to the organization of the BWRVIP-34 report.

2.0 SUMMARY OF BWRVIP-34 REPORT

The BWRVIP-34 report addresses the following topics in this order:

- Component Descriptions and Typical System Configurations – Identifies welds that are considered candidates for underwater part circumferential weld overlay repairs and provides drawings of the configurations of typical core spray internal piping.
- Weld Overlay Design Basis – Defines assumptions, criteria and the methodology for performing the underwater part circumferential weld overlay piping.
- Leakage Calculation for Part Circumference Weld Overlays – Specifies the methodology to be used to determine leakage through the unrepaired cracks in the part circumferential weld overlay repairs during normal and accident conditions.
- Irradiation Effects on Weldability – Discusses the effects of helium content in the material to be welded, and the effect that boron impurities (which transmutates under high radiation flux to produce helium) in the base material have on weldability. It should be noted that based on the development of BWRVIP-97, which addresses weldability of irradiated materials, all discussions and guidance on this issue will be addressed in BWRVIP-97.
- Materials and Welding Qualification – Describes the welding materials and processes used, stress corrosion and sensitization tests to be performed, and evaluations of ferrite levels and mechanical properties to be performed prior to installing the part circumferential weld overlay repairs.
- Inspection of Core Spray Internal Piping Weld Overlays – Reviews the inspection requirements detailed in the latest revision of BWRVIP-03, "Reactor Pressure Vessel and Internals Examination Guidelines."

3.0 STAFF EVALUATION

Core spray line/sparger cracking due to intergranular stress corrosion cracking (IGSCC) was first detected in 1978 during routine in-vessel visual examinations. The staff issued Bulletin 80-13, "Cracking in Core Spray Spargers," dated May 12, 1980, which required augmented inspections of the core spray lines/spargers to detect cracking. BWR licensees have been performing these augmented inspections, and have continued to find cracking in the core spray lines/spargers. Licensees have repaired or replaced the cracked core spray components.

The repair options have been limited to installation of welded straps or specially designed clamps. The industry finds the current repair/replacement options economically viable for planned repair or replacement. However, these options, when utilized as a contingency repair, can have economic disadvantages. A plant owner must commit to a potential repair for planning purposes, or accept the risk of a significant outage extension if cracking that requires repair is discovered prior to startup. In response to these concerns, the BWRVIP repair committee has proposed weld overlay repairs that would have a significant economic advantage as a contingency repair.

3.1 Section 2.0 - Components Description and Typical System Configurations

This section identifies the welds on the internal core spray piping that are accessible for underwater, part circumferential weld repair. The welds that are considered accessible and within the scope of this report include welds P2, P3, P4a, P4B, P4c, P4d, P5, P6 P7, P8a and P8b as defined in Figure 2-1 of the BWRVIP-34 report. There are certain plant-specific differences in geometry of the core spray piping and in clearances between the piping and major components, i.e., the RV and core shroud. These plant-specific differences are likely to be inconsequential as far as the development of a generic weld repair concept. The report, instead of considering these plant-specific differences, considered the core spray piping geometry at one specific plant as a "common" geometry. Therefore, BWRVIP-34 requires that the differences in clearances must be addressed on a plant-specific basis while implementing the weld repair concept presented in this report. The staff finds this section adequately describes the applicable locations that are accessible for this type of weld repair, and that plant-specific clearances must be addressed on a plant-specific basis because these clearances play a role in determining the thickness and length of a part circumference weld overlay as discussed in Section 3 of the BWRVIP-34 report.

3.2 Section 3.0 - Weld Overlay Design

The design of the core spray piping weld overlay repairs is restricted by the space limitations of the piping being located close to the RV wall or the core shroud, thereby necessitating a partial weld overlay with less than 360 degrees around the circumference of the pipe. Due to this limited access, the part circumference (less than 360 degrees) weld overlay repair has to be designed to have the required structural capability for repairing an assumed 360 degree crack around the circumference of the pipe. The design of the weld overlay repair is intended to meet the BWRVIP core spray design criteria in BWRVIP-19 report, "Internal Core Spray Piping and Sparger Repair Design Criteria," and is based on the guidance in the ASME Code and Code Case N-504.

In response to the staff's Supplemental RAI 3-1 in the October 7, 2004, letter and other RAIs, the BWRVIP provided a general statement in its letter dated July 18, 2006, to address the staff's concern about compliance with the current editions of the ASME Code and associated Code Cases approved by the staff. The BWRVIP agreed to modify the BWRVIP-34 report to include a preamble to ensure the overlay design will be in accordance with the current NRC-approved version of the ASME Code and Code Cases. The staff finds adding this preamble acceptable because it ensures that the overlay design will be in accordance with the current NRC-approved version of the ASME Code and Code Cases. In addition, the preamble includes guidance for the use of the Z-factor (correction factor-Z that is used as a stress multiplier for welds fabricated using flux) as appropriate, considerations for designing the length of the overlay repair, evaluation of the effects of residual stresses and water backing, evaluation of the effects of the weld overlay on other welds and components, and the inclusion of a maximum limit on ferrite content (maximum ferrite number (FN) of 12 FN). These other aspects of the preamble have been found acceptable and will be discussed later in the SE. The following is the preamble which will be included in the BWRVIP-34 report.

> The design analysis documented in this report was developed in 1997 and is generally consistent with Section XI of the ASME Boiler and Pressure Vessel Code (Code) in place at that time. Since that time, a number of changes have been made to the Code which will affect some of the details in the analyses. While the general design principles documented in the report are still valid, any analyses used in the design of core spray weld overlay repairs shall be in accordance with the latest Edition and Addenda of the ASME Code including Section IX and Section XI as identified in the Owner's ISI Inspection Plan and with applicable Code Cases (e.g., N-516 and N-504-2) that are endorsed in Regulatory Guide 1.147. Further, Code Cases N-504-2 and N-516 are referenced throughout this report. The reader should understand that these Cases have since been revised and, in part, incorporated into Section XI. The reader must use the requirements of, and the Cases applicable to, the Edition and Addenda of Section XI identified in the Owner's ISI Inspection Plan.
>
> Section 3.2 includes an example where the design approach used in the report differs from the Code requirements. The analysis in Section 3.2 does not incorporate a Z-factor correction as required by the Code for flux welds such as SMAW and FCAW welds. However, any future design would need to include that correction should the applicable Code so require.
>
> Also note that, in applying Code Case N-504-2, special care must be taken in designing the length of the weld overlay repair for each application taking into account both fatigue and IGSCC considerations. The minimum required length of the part-circumference weld overlay is to be determined by analytical demonstration of the effective transfer of longitudinal loads across the defect location by means of shear load transfer between the base metal and the weld overlay material. Code Case N-504-2 does not explicitly define methods for demonstrating that such transfer is adequate to meet applicable Code requirements.
>
> In addition, note that Code Case N-504-2 implements the requirements of NUREG-0313, Rev. 2 and Generic Letter (GL) 88-01. Code Case N-504-2 paragraphs (g) (1), (2) and (3) address the effects of residual stresses in the repair welds, and the effects of water backing in the repaired welds and the effects of the weld overlay on other welds, components, supports, restraints, etc., in the system. Increases in loadings due to weight and shrinkage effects are addressed.
>
> Finally note that, in response to an NRC RAI, the BWRVIP has agreed that the delta ferrite content of weld overlay material for this application shall not exceed 12 FN.

To assure the structural integrity of the core spray system, Section 3.0 of BWRVIP-34 presented methods for determining the thickness and length of part circumference weld overlays fabricated using the automatic flux cored arc welding (FCAW) and the manual shielded metal arc welding (SMAW) processes. The FCAW process produces high toughness welds as demonstrated in Appendix H of the BWRVIP-34 report, whereas the SMAW process produces lower toughness welds as illustrated in Appendix I of the report.

For the FCAW weld overlay, the BWRVIP-34 report provided a methodology and an example analysis using this methodology. The methodology used is based on the structural strength of the overlay using a net section plastic collapse methodology similar to that provided in Appendix C of Section XI to the ASME Code. This method considers only membrane and bending stresses acting on the pipe and not secondary stresses such as expansion stresses. Secondary stresses were not included in the analysis because, for high toughness material, plastic collapse is the anticipated failure mechanism and the secondary stresses are assumed to relax before failure. The example analysis uses a safety factor of 2.77 on primary loads for normal operating and upset conditions, and a safety factor of 1.39 for emergency and faulted conditions. The staff finds the application of the net section plastic collapse methodology for determining the thickness of the FCAW weld overlay acceptable because it is based on the methodology in Appendix C of Section XI to the ASME Code (current edition of ASME Code approved by the staff, as stated in the revised preamble).

The flaw evaluation methodology for piping described in Appendix C of Section XI to the ASME Code does not require the use of a "Z-factor" for gas tungsten arc welds and gas metal arc welds because these welds are fabricated without the use of flux. However, the FCAW process uses flux in the fabrication of welds. The composition of the flux varies from one heat/lot to another and has a significant effect on the notch toughness values of the weld metal. In the staff's October 7, 2004, letter, Supplementary RAI 3-1(b) requested the BWRVIP to provide the justification for not using the Z-factor approach for FCAW welds in the flaw evaluation methodology. In response, the BWRVIP's letter dated November 1, 2004, referred to the proposed preamble and stated that all welding activities including weld design will be in accordance with the ASME Code or with ASME Code cases N-516 and N-504-2, as appropriate. However, instead of following the current version of the ASME Code and using the Z-factor approach for FCAW welds, the analysis in the BWRVIP-34 report took some exceptions to the ASME Code based on the fact that measured material properties exceeded the strength parameters assumed by the ASME Code. In a letter dated March 16, 2006, the staff issued Supplementary RAI 3-4 requesting the BWRVIP to provide further justification for why the Z-factor approach is not needed for the welds fabricated using flux. The staff requested that the justification include the strength parameters assumed by the ASME Code and the measured material properties, including their reliability and applicability. In a letter dated July 18, 2006, the BWRVIP responded that designs of overlays should incorporate a Z-factor if it is required by the current ASME Code. To further clarify the issue, the BWRVIP included a statement concerning the use of the Z-factor in the revised preamble to the report proposed earlier in response to Supplementary RAI 3-1 and other RAIs. The revised preamble is presented in the beginning of Section 3.2 of this SE where the response to Supplementary RAI 3-1 is evaluated. The staff finds the response acceptable because it ensures that the current version of ASME Code will be followed in the design of part circumferential weld overlay repair of core spray piping.

For the SMAW weld overlay, the BWRVIP-34 report provided a similar methodology and an example analysis. The methodology used is also based on the structural strength of the overlay using a net section plastic collapse methodology. However, the staff notes that for the SMAW weld overlay, the anticipated failure mechanism is unstable crack extension that would occur at loads lower than the plastic collapse loads. Therefore, the low toughness SMAW welds should be analyzed by elastic-plastic fracture mechanics methodology. However, these welds can be analyzed by the net section plastic collapse methodology with appropriate correction factors applied. The BWRVIP uses the Z-factor correction approach specified in Appendix C of Section XI to the ASME Code. The technical basis for this approach is discussed in Reference 9 of the BWRVIP-34 report (Reference 5.1 of this SE). Since failure of a SMAW weld overlay is anticipated to occur at lower overall strain levels, secondary stresses such as expansion stresses may not be relaxed and have to be included in the analysis. The BWRVIP-34 report includes expansion stresses with a safety factor of 1.0 along with the primary membrane and bending stresses, and the associated safety factors mentioned in the preceding paragraph. This analysis approach is similar to the methodology in Appendix C of Section XI to the ASME Code. The correction factor (Z) is introduced as a stress multiplier. For the SMAW weld,

$$Z = 1.15\{1 + 0.013(\text{pipe OD} - 4)\}.$$

Reference 5.1 made two modifications to the above-mentioned Z-factor approach based on NRC staff comments: (a) the allowable flaw depth should be limited to 60% of the wall thickness, and (b) the Z-factor should be computed using pipe outside diameter (OD) = 24 inches for pipe sizes less than 24 inches. The second modification was intended to account for uncertainties in determining the thermal expansion stresses for smaller pipe sizes. With these modifications, the Z-factor for a 6-inch core spray pipe would be 1.45 instead of 1.2 as reported in Section 3.2 of the BWRVIP-34 report. In the staff's October 7, 2004, letter, Supplementary RAI 3-1(a) requested that the BWRVIP should explain why these two modifications to the Z-factor are not included in the design for the SMAW weld overlay. In response, the BWRVIP stated that when applying these repairs, the Z-factor will be per Section XI of the then currently approved ASME Code. The staff finds this response acceptable because it ensures the use of Z-factors will be in accordance with the then current NRC approved version of the ASME Code, specifically Appendix C of Section XI (which accounts for the modifications to the Z-factor). The staff also notes that Z-factors used in the BWRVIP-34 report is consistent with the 1998 Edition of the ASME Code.

On Page 3-4 of the BWRVIP-34 report, stress-ratio (SR) is defined as $(P_m + P_b + P_e /SF)/S_m$, where P_m is the primary membrane stress, P_b is the primary bending stress, P_e is the expansion stress, SF is the safety factor and S_m is the design stress intensity at temperature. However, this SR is different from SR of $(P_m + P_b)/S_m$ resulting from a series of derivations shown on Page 3-5 of the BWRVIP-34 report. In a letter dated October 7, 2004, the staff requested in Supplementary RAI 3-1(c) that the BWRVIP confirm that the design tables (Tables 3-1 to 3-4) for the weld overlay repair were obtained by employing $(P_m + P_b)/S_m$ without considering the Z-factor of Appendix C of Section XI of the ASME Code. In response, the BWRVIP confirmed that the design tables in the report were developed without considering the Z-factor, but that future repair designs will be in accordance with the current NRC-approved Code Editions. In a letter dated March 16, 2006, the staff issued Supplementary RAI 3-5 suggesting that BWRVIP include this response to Supplementary RAI 3-1(c) in Section 3.3 of the report. In a letter dated July 18, 2006, the BWRVIP response stated that it agrees with the staff suggestion, and proposed to add the following paragraph at the end of Section 3.2 of the BWRVIP-34 report:

> Note that while the example analysis included here does not incorporate a Z-factor based on the assumption of high toughness weld metal, any repair design utilizing the methods described in this report should incorporate Z-factor if required by the Owner's Edition and Addenda of Section XI as limited by 10 CFR 50.55a. In general, for an SMAW or FCAW overlay, a Z-factor correction would be required.

The staff finds the response acceptable because it ensures that Z-factor will be used if required by the applicable version of the ASME Code.

In Section 3.0, the weld overlay design did not consider the effect of IGSCC on the structural integrity of the repair for the case where the weld overlay is applied to a through-wall flaw, nor did it consider the effect of fatigue crack growth on the structural integrity of the repair for the case where the weld overlay is applied to a surface flaw. In the staff's October 7, 2004, letter, Supplementary RAI 3-1(d) requested that the BWRVIP revise the report to include information regarding (1) the recommended level of inspection effort in classifying a flaw as a through-wall flaw or a surface flaw, and (2) the additional weld overlay thickness to account for IGSCC and fatigue crack growth for through-wall and surface flaws. In its letter dated November 1, 2004, the BWRVIP response stated that no additional thickness is required to account for IGSCC because the overlay weld is fabricated from austenitic stainless steel having low carbon content (0.02 wt% max) and minimum FN value of 7.5. The staff finds this response acceptable because field experience has shown that such weld material is resistant to IGSCC. It should be noted that the BWRVIP proposed a FN range of 7.5 to 12, which provides sufficient delta ferrite content to minimize IGSCC, but limits the delta ferrite to prevent thermal aging of the stainless steel. Therefore, no additional inspection effort is warranted as far as IGSCC growth is concerned. However, through-wall and surface flaws may grow by fatigue and detailed flaw characterization would be required. Thus, fatigue crack growth would warrant additional inspection effort. The staff's concern about fatigue crack growth and inspection has been addressed by the revised preamble to the report submitted in the BWRVIP letter dated July 18, 2006. The revised preamble stated that Code Cases N-504-2 and N-516 that are endorsed in Regulatory Guide 1.147 (RG) will be followed in the design of part circumference weld overlay repair of core spray piping. Code Case N-504-2 requires the licensee to consider potential flaw growth due to fatigue and identifies the specific nondestructive examination of the repair. Therefore, the staff finds that its concern about fatigue cracking of the repair is satisfactorily addressed.

In Section 3.0, it is not clear that the determination of the required weld overlay length, according to the formula presented on Page 3-8 of the BWRVIP-34 report, is appropriate to ensure "shear transfer between the weld overlay and the piping." Therefore, in the staff's letters dated October 7, 2004, and March 16, 2006, Supplementary RAI 3-1(e) and Supplementary RAI 3-6, respectively, requested the BWRVIP to provide additional information on why the determination of the required weld overlay length is appropriate to ensure "shear transfer between the overlay and the piping." The BWRVIP letters dated November 1, 2004, and July 18, 2006, stated that neither Code Case N-504-2 nor Section XI of the ASME Code explicitly address the manner in which shear transfer is calculated. However, the BWRVIP provided the following explanation for how shear was accounted for in the example calculation in the BWRVIP-34 report:

> The lengths calculated by the methods shown on page 3-8 were determined based upon net section collapse methods as included in Appendix C of ASME Section XI. The assumed membrane stress was taken as 0.1 S_m rather than 0.5 S_m however, based upon analysis results of internal/external pressure differential magnitude. This pressure stress magnitude is very small (a few hundred psi). The length is also a function of overlay length in the circumferential direction (angle of coverage), and of the underlying wall thickness. Length is calculated for each side of the weld (considering the radius and wall thickness on each side of a repair location), and for both levels A/B and C/D conditions. The more conservative result is used. It should also be noted that the flow stress in shear is 1/2 of the flow stress in tension, and this effect is included in the calculation.

The staff finds the BWRVIP explanation adequate in accounting for shear in the example calculation presented in the BWRVIP-34 report. In addition, the staff notes that based on the response to Supplementary RAI 3-5 in BWRVIP letter dated July 18, 2006, the BWRVIP-34 report would also require the use of Z-factor correction in determining the overlay length as required by the ASME Code. Therefore, the staff finds the BWRVIP methodology on accounting for shear transfer acceptable. The BWRVIP has also included an appropriate discussion in the revised preamble to the BWRVIP-34 report to ensure that shear is adequately addressed in core spray weld overlay designs. The preamble is presented at the beginning of Section 3.2 of this SE.

The weld overlay design methodology presented in the BWRVIP-34 report follows the requirements of ASME Section XI Code Case N-504, "Alternative Rules for Repair of Class 1, 2, and 3 Austenitic Stainless Steel Piping," Section XI, Division 1, April 30, 1992. However, according to USNRC RG 1.147, Revision 13, dated June 2003, the NRC-approved Code Case N-504-2, dated March 1997, supersedes Code Case N-504. The following is a discussion on how the weld overlay design satisfies the requirements of Code Case N-504-2.

a. Requirement (g)(2) of Code Case N-504-2 states "For repaired welds, the evaluation shall consider residual stresses produced by the weld overlay with other applied loads on the system." The evaluation shall demonstrate that the requirements of IWB-3640 are satisfied for the design life of the repair, considering potential flaw growth due to fatigue and IGSCC. In the staff's letter dated October 7, 2004, Supplementary RAI 3-2(a) requested the BWRVIP to provide an equivalent evaluation for weld overlay repairs of the internal core spray piping. The evaluation should include weld overlay design on a pipe/coupling weld joint. In response, the BWRVIP letter dated November 1, 2004, stated that all repairs will be performed in accordance with the currently-approved ASME Code or with Code Cases N-516 or N-504-2, as appropriate. The staff finds the response acceptable because the licensee will be performing this evaluation at the time of the weld overlay repair.

b. Requirement (g)(3) of ASME Section XI Code Case N-504-2 states "The evaluation of other welds and components in the system [i.e., internal core spray system] shall consider potential increases in loading, including shrinkage effects, due to all weld overlays in the system, and shall identify and record the magnitude and location of the maximum shrinkage stress developed. These welds and components shall meet the applicable stress limits of the Construction Code [Section III to the ASME Code]." In the staff's letter dated October 7, 2004, Supplementary RAI 3-2(b) requested the BWRVIP to provide the maximum shrinkage stress produced due to weld overlay repair, and ensure that welds and components of the "common" internal core spray system meet the applicable stress limits of Section III to the ASME Code. In response, the BWRVIP stated that the maximum shrinkage stress is determined by evaluation of actual repair configuration, the measured shrinkage, number of repairs applied to a specific piping system, and the actual configuration of the repaired piping system. The BWRVIP further stated that the evaluation of the shrinkage stress will be performed after repair application as required by Supplement 1 of GL 88-01. The staff finds the response acceptable because the licensee will be estimating the maximum shrinkage stress after the actual weld overlay repair. Additionally, in a letter dated July 18, 2006, the BWRVIP stated that it will include the consideration of potential increases in loading, including the evaluation of shrinkage stresses in the preamble to the BWRVIP-34 report. The preamble is presented at the beginning of Section 3.2 of this SE, which the staff found acceptable.

Based on the above evaluation, the weld overlay design will include the requirements of Code Case N-504-2 during the licensee's implementation of the BWRVIP-34 weld overlay repair.

Section 3.1.2, "Design Criteria," of the BWRVIP-34 report mentions that the length of an overlay is determined by requiring that the stresses in the overlay meet the net section plastic collapse requirements for shear transfer between the overlay and the piping. In the staff's letter dated December 14, 1997, RAI 1 recommended that the inspectability of defects in the base metal be considered in designing the length of an overlay. The length of an overlay should be large enough so that the growth of the defects in the base metal heat-affected zones can be adequately monitored to ensure that cracking will not affect the integrity of the overlay.

In response to RAI 1, in a letter dated March 30, 1998, the BWRVIP stated that Section 3.1.2 of BWRVIP-34 requires that the minimum length provide sufficient structural reinforcement. However, the BWRVIP acknowledged that additional length may be required to allow for effective inspection. This additional length is determined by the specific inspection technique and process to be used, and should be determined prior to application. The BWRVIP will revise the report to reflect this additional consideration for weld overlay minimum length. The staff finds the response acceptable because it addresses an important additional criterion for determining appropriate minimum weld overlay length, and will be included in the -A version of the BWRVIP-34 report.

In the staff's letter dated December 14, 1997, RAI 10 requested that the BWRVIP describe the residual stress distribution in the overlay weld and the cracked piping, particularly at the inside diameter (ID) surface of the pipe, and at the root of the overlay/seal weld adjacent to a through-wall crack. Compressive residual stresses on the ID surface of the component are desirable in resisting crack initiation and growth, and are recommended in NUREG-0313, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping," Revision 2, January 1988. In its letter dated March 30, 1998, the BWRVIP's response stated that the residual stresses at the inside surface of the uncracked ligament will depend strongly on the extent of the part circumference repair, which is a variable in this technique. The design basis for this repair is that the underlying crack extends entirely around the circumference and is completely through the pipe wall. This is consistent with the standard design basis in Section 4 of NRC NUREG-0313, Revision 2. The BWRVIP concluded that, for this design basis, residual stresses at the inside surface are not relevant, and were not determined since an open crack is assumed at the inside surface.

The BWRVIP further stated that at the interface between the base metal and the weld overlay material, the residual stresses in the overlay material are expected to be tensile unless the overlay is very thick. Since the overlay repair itself is part circumference in extent, the residual stress distribution within the weld metal and at the interface between the weld metal and base metal is expected to vary with position, reflecting the asymmetry of the repair. No credit for any residual stress improvement is taken in the design basis for such repairs. Demonstration of IGSCC resistance is tied to the material properties of the weld metal.

The staff considers the residual stresses on the inside surface to be relevant because a crevice may be present under the weld overlay. Field experience indicates that IGSCC can initiate at a crevice even though the material is not sensitized. In the staff's letter dated October 7, 2004, Supplementary RAI 3-3(a) requested the BWRVIP to provide the residual stresses at the inside surface of core spray piping to be repaired by a weld overlay. In its letter dated November 1, 2004, the BWRVIP's response stated that the residual stresses developed on the inside surface due to the weld overlay application will depend on the extent of the overlay around the circumference, and the residual stresses will be developed per the requirements of Code Case N-504-2 on a component-specific, repair-specific basis. The staff finds the response acceptable because the licensee will be estimating the residual stresses at the time of the actual weld overlay repair in accordance with the applicable Code Case.

In the staff's letter dated October 7, 2004, Supplementary RAIs 3-3(b) and (c) requested the BWRVIP to discuss whether any crevices may be introduced on the outside surface of the repaired core spray piping along the periphery of the weld overlay. Since IGSCC can be enhanced due to the presence of any crevice, the staff also requested that the BWRVIP provide an explanation for not performing crevice corrosion tests on weld coupons with a simulated crevice condition. In its letter dated November 1, 2004, the BWRVIP's response stated that crevices may form on the OD surface of the repaired core spray piping along the periphery of the weld overlay, but any IGSCC will be arrested at the structural overlay interface with the core spray pipe due to the high IGSCC resistance of the overlay material. The staff acknowledges that the overlay weld material is required to have low carbon and adequate ferrite contents and, therefore, it is IGSCC resistant. However, IGSCC could initiate at a crevice if residual tensile stresses are present and penetrate the core spray piping wall, away from the repaired crack location, without entering the structural overlay. In other words, the weld overlay repair could introduce new IGSCC-susceptible locations in the core spray piping. In a letter dated March 16, 2006, the staff issued Supplementary RAI 3-8 requesting the BWRVIP to evaluate the possibility of cracking of core spray piping at IGSCC-susceptible locations (i.e., weld overlay periphery) introduced by the weld overlay repair. In its letter dated July 18, 2006, the BWRVIP agreed with the staff that if a crevice were formed due to poor weld fusion or undercut at the weld overlay periphery, the IGSCC-susceptibility of the piping would be increased. However, the BWRVIP noted that workmanship standards of Sections XI and III of the ASME Code do not allow for lack of fusion or cracks and limit undercut to no greater than 1/32-inch. These standards effectively eliminate the creation of a crevice at the weld toe. The BWRVIP further stated that while crevices at weld toes are not expected to occur, the Core Spray Repair Design Criteria in BWRVIP-19-A require that the repair designer specify periodic inspections of the repair that are consistent with the intent of BWRVIP-18-A, "BWR Core Spray Internals Inspection and Flaw Evaluation Guidelines." These inspections would periodically interrogate the overlays and would detect any cracking in a timely manner. To ensure that the area of interest is addressed properly, the BWRVIP proposed to add the following paragraph to Section 7 ("Inspection of Core Spray Internal Piping Weld Overlays") of the BWRVIP-34 report:

> In accordance with BWRVIP-19-A ("Internal Core Spray Piping and Sparger Repair Design Criteria"), the repair designer is responsible for specifying inspections of the weld overlay repair consistent with the intent of BWRVIP-18-A ("BWR Core Spray Internals Inspection and Flaw Evaluation Guidelines"). In defining these inspections, specific consideration should be given to the possibility of crack initiation in any crevice-like areas that may be created at the periphery of the overlay due to weld undercut. Cracks initiated at these locations may be difficult to detect using visual techniques and ultrasonic inspection may be required. In the event that UT is chosen for future, periodic inspections, it may be useful to perform a baseline UT inspection immediately subsequent to installation of the repair.

The staff finds the BWRVIP response acceptable because the proposed paragraph does include adequate guidance for inspecting IGSCC-susceptible locations resulting from weld overlay repairs of core spray piping. The BWRVIP shall include this paragraph in the -A version of the BWRVIP-34 report as suggested.

In addition to the extent of the part circumference weld overlay repair, residual stresses also depend on the underwater welding procedure used. Since the residual stresses produced by underwater welding are different from those produced by in-air welding, the staff, in its letter dated October 7, 2004, issued Supplementary RAI 3-3d requesting that the BWRVIP consider the underwater welding process when determining the residual stress distribution. In its letter dated November 1, 2004, the BWRVIP's response stated that underwater welding will slightly affect the residual stresses, and therefore the staff's concern about underwater welding and residual stress will be addressed by the revised preamble to the report. The revised preamble stated that Code Cases N-516 and N-504-2 will be followed for underwater welding and residual stress determination. The BWRVIP also stated that in general, OD welding with a water-solid ID and fast cooling are beneficial to producing improved ID and through-wall residual stresses. The staff notes that OD welding with a water-solid ID is different than underwater welding of core spray piping where both ID and OD are exposed to water. However, the staff accepts the BWRVIP response because the licensee will be evaluating the residual stresses at the time of the actual weld overlay repair using Code Cases N-516 and N-504-2, and will take into consideration the effects of the core spray piping ID and OD being exposed to water during welding.

The staff finds that the BWRVIP has adequately addressed the design of the weld overlay repair by presenting acceptable methods to be used in determining the length and thickness of a part circumference weld overlay to assure the structural integrity of the core spray piping system.

3.3 Section 4.0 - Leakage Calculation for Part Circumference Weld Overlay

The BWRVIP-34 report discusses how, in some weld overlay repairs, access restrictions limit the circumferential extent of the repair to less than 360-degrees. Because the repair extends around only a part of the circumference, some portion of the original component is assumed to be left with a through-wall crack through which some amount of core spray flow could leak into the annulus, thus removing such leakage flow from the emergency core cooling system (ECCS) capacity of the system. A method for predicting the magnitude of such leakage was developed to allow plants to evaluate the ECCS penalty that they would have to take if such repairs were applied.

The BWRVIP-34 report provides guidance on core spray leakage calculation methods and leakage assessment criteria for the core spray piping and the core spray spargers. Utilities have been performing leakage rate calculations by either using standard fluid equations or developing computer programs. The guidance on leak rate calculation methods provided in the BWRVIP-34 report is based on the EPRI Pipe Crack Evaluation Computer Program . This guidance does not differ from common industry practice.

The staff notes that the amount of leakage calculated is plant-specific and includes leakage from the T-box vent hole, the thermal sleeve and nozzle safe end ID slip fit, and unrepaired and repaired flaws. The staff believes that all leakage should be considered in the loss of coolant accident (LOCA) analysis and evaluated for plant-specific acceptability. The BWRVIP-34 report provides examples of evaluating total system leakage for normal and accident operations. Both examples stress the importance of performing plant-specific LOCA analyses to demonstrate that the total leakage from the core spray line does not cause unacceptable increases in peak cladding temperature for any licensing basis accident. The staff finds this guidance acceptable because it demonstrates a comprehensive approach for consideration of total system leakage.

3.4 Section 5.0 - Irradiation Effects on Weldability

Section 5 discusses irradiation effects on the weldability of the internal core spray piping based on on-going work sponsored by the BWRVIP. The BWRVIP has developed guidance for performing weld repairs on highly irradiated materials in the form of the BWRVIP-97 report, "Guidelines for Performing Weld Repairs to Irradiated BWR Internals," November 2001. In response to the staff's RAIs on weldability of irradiated material, the BWRVIP proposed in its letter dated November 1, 2004, to replace Section 5.0 of the BWRVIP-34 report with a reference to the BWRVIP-97 report. The staff finds this appropriate since it will consolidate the guidance in one report. The staff is currently reviewing the BWRVIP-97 report. Therefore, all applicable information, guidance, and discussions of weldability of irradiated materials previously mentioned in the BWRVIP-34 report will be addressed during the review of the BWRVIP-97 report.

The following are applicable RAIs which are related to core spray partial weld overlay repair (Section 5.0 of the BWRVIP-34 report) that will be addressed during the review of BWRVIP-97, since section 5.0 of the BWRVIP-34 report will now reference the BWRVIP-97 report:

a. Supplemental RAI 97-9 from NRC letter dated March 18, 2004, with the BWRVIP response in a letter dated July 25, 2005

b. RAI 97-1 from NRC letter dated January 8, 2003, with the BWRVIP response in a letter dated July 25, 2005
c. Supplemental RAI 97-10 from NRC letter dated March 18, 2004, with the BWRVIP response in a letter dated July 25, 2005
d. Supplemental RAI-1 from NRC letter dated August 7, 2006, and the BWRVIP response in letter dated October 5, 2006
e. Supplemental RAI 97-11 from NRC letter dated March 18, 2004, with the BWRVIP response in a letter dated July 25, 2005
f. RAI 5-4 from NRC letter dated October 7, 2004, and the BWRVIP response in a letter dated November 1, 2004
g. Supplemental RAI-2 from NRC letter dated August 7, 2006, and the BWRVIP response in a letter dated October 5, 2006
h. Supplemental RAI 6-3(a) in NRC letter dated October 7, 2004, and the BWRVIP response in a letter dated November 1, 2004
i. Supplemental RAI 7-1 from letter dated October 7, 2004, and the BWRVIP response in letters dated November 1, 2004, and July 25, 2005 (renumbered to RAI 34-7.1)
j. Supplemental RAI A-4 from NRC letter dated October 7, 2004, and the BWRVIP response in letters dated November 1, 2004, and July 25, 2005 (renumbered to RAI 34-A-4)

3.5 Section 6.0 - Materials and Welding Qualification

In Section 6, the BWRVIP states that the composition of the welding electrodes has been selected with a focus on maximizing the ferrite level, and thereby maximizing the IGSCC resistance of the weld overlay. Appendix J of the BWRVIP-34 report is the recommended underwater electrode procurement specification. The acceptable range of ferrite content is specified as 8-20 ferrite number (FN) for the FCAW process and 8-25 FN for the SMAW process. Based on the results of laboratory test data, it appears that these welds, especially welds with high ferrite contents, are likely to experience the effects of low-temperature thermal aging. In its letter dated December 14, 1997, the staff's RAI 3 requested that the BWRVIP provide a discussion regarding potential degradation of the welds by low-temperature thermal aging when the ferrite content is at the high end of the specified range. The RAI also requested that the BWRVIP discuss the need to lower the maximum acceptable ferrite content of the repair welds. In its letter dated March 30, 1998, the BWRVIP response referred to the literature related to thermal aging of Grades CF-3, CF-8, and CF-8M cast stainless steels at BWR operating temperature. The staff notes that the thermal aging behavior of austenitic stainless steel weld metals is different than that of cast stainless steels [see References 5.2 and 5.3]. Unaged austenitic stainless steel weld metal has a significantly lower resistance to stable crack growth than unaged cast stainless steel. In addition, the welding process affects fracture toughness of stainless steel welds. Welds fabricated using the SMAW process have a lower fracture toughness than those made using the FCAW process as reported in Section 6.4 of the BWRVIP-34 report. Therefore, in its letter dated October 7, 2004, the staff's RAI 6-1a requested the BWRVIP to discuss low-temperature thermal aging of the SMAW welds when the ferrite content of the weld is in the range of 20-25 FN and include an evaluation of the need to lower the maximum acceptable ferrite content of the repair welds.

In its letter dated November 1, 2004, the BWRVIP refered to the Argonne National Laboratory (ANL) research results for the long-term (>100,000 hours) thermal aging of cast stainless steel Grades CF-3 and CF-8 at 288°C; the results showed that thermal aging is expected to produce a 50% reduction in the room temperature Charpy impact energy of materials with 10% ferrite and an 80% decrease for material with 25% ferrite. The BWRVIP further stated that because of the high initial values of room temperature impact strength of Grades CF-3 and CF-8 materials, even a large decrease in this measure of toughness does not reduce the overall toughness of the overlay repair to unsatisfactory levels. In addition, the BWRVIP proposes to modify the BWRVIP-34 report to place an upper limit of 17 FN for this underwater welding activity. The BWRVIP also states that it was difficult to produce underwater welds with a FN value above 5, and very specific chemistry requirements have been recommended for the welding electrodes to ensure that underwater weld deposits produce a FN above 5. The staff notes that with the use of the recommended electrodes, the BWRVIP appears to be successful in fabricating underwater weld deposits with FN close to 17 (see Table G-6 in the BWRVIP-34 report). The staff notes that the thermal aging results for the Grades CF-3 and CF-8 materials are not applicable to overlay weldments because the ferrite morphology and distribution in the weldments are different than that in CF-3 and CF-8 castings. In addition, unaged austenitic stainless steel weld metal, especially when welds are made using SMAW process, has a significantly lower resistance to stable crack growth than unaged cast stainless steel.

The staff provides the following discussion on the thermal aging results for Type 308 SS welds by Reference 5.3. The welds were fabricated by SMAW process with a ferrite content of 12% by volume. The results show that aging of these welds at 343°C for 20,000 hours caused a significant increase in the ductile-to-brittle transition temperature measured at 68-J level, an increase from -25 to 60°C. The staff notes that the weld overlay repair will be exposed to lower temperatures (288°C). However, the proposed upper limit of 17 FN for the underwater welding activity could make the weld overlay repair susceptible to thermal aging. Therefore, in a letter dated March 16, 2006, the staff issued Supplementary RAI 6-5 requesting the BWRVIP to evaluate thermal aging of a weld overlay repair made with 17FN weld metal. In its letter dated July 18, 2006, the BWRVIP takes a conservative position of limiting the delta ferrite in the weld overlay to 12 FN instead of 17 FN. The BWRVIP has included an appropriate discussion in the revised preamble to BWRVIP-34 report to limit the delta ferrite in the weld overlay to 12FN. The preamble is presented at the beginning of Section 3.2 of this SE. The staff finds this response acceptable because lower ferrite contents and lower operating temperature (288°C) would provide large margins against thermal aging. It should be noted that based on the responses to this and other RAIs, the BWRVIP proposed a FN range of 7.5 to 12, which provides sufficient delta ferrite content to minimize IGSCC, but limits the delta ferrite to prevent thermal aging of the stainless steel. The BWRVIP shall clarify in the -A version of the BWRVIP-34 report that the ferrite content of the weld shall be within the range of 7.5 to 12 FN.

In its letter dated October 7, 2004, the staff's supplementary RAI 6-1(b) requested that the BWRVIP discuss whether low-temperature thermal aging behavior of the SMAW welds fabricated underwater is different than those fabricated in air. In its letter dated November 1, 2004, the BWRVIP response noted that underwater welding actually suppresses the FN, primarily due to the rapid quenching and lack of time for ferrite to form. Consequently, the welds produced underwater will have less tendency than those produced in air to undergo low-temperature thermal aging. The staff agrees with the BWRVIP that since underwater welding produces a lower FN, the thermal aging susceptibility is reduced, because thermal aging susceptibility is directly proportional to FN values.

Section 6.1 of the BWRVIP-34 report includes Type 312 stainless steel weld metal in a group of materials that were selected for evaluation. This material was not referenced in Section 3.0 "Weld Overlay Design Basis." In RAI 4 to its letter dated May 22, 1997, the staff requested that the BWRVIP discuss the service experience with Type 312 stainless steel weld metal in the BWR environment including its susceptibility to IGSCC. In its letter dated March 30, 1998, the BWRVIP stated that Type 312 stainless steel weld metal is a two phase micro-duplex stainless steel with nominal composition of 30% chromium (Cr), 9% nickel (Ni), and 0.15% carbon (C) [Reference 5.4]. This alloy composition produces a two-phase weld deposit with substantial percentages of ferrite, on the order of 15-25%. The BWRVIP refered to a figure in the paper in Reference 5.5 for predicting the susceptibility of a given alloy to IGSCC in the BWR environment as a function of ferrite and carbon contents. In summary, the BWRVIP stated that the IGSCC resistance of duplex stainless steels has been studied extensively in the laboratory, in theoretical investigations, and in coupon or pipe tests. The BWRVIP also stated that these results confirm the field observations that IGSCC in duplex stainless steel weld metal or castings is rare. The BWRVIP contended that these results support the conclusion that Type 312 stainless steel weld metal can be used successfully for underwater core spray pipe weld overlays in the BWR environment. Finally, the BWRVIP stated that the report will be revised to specifically discuss Type 312 material. The staff notes that the BWRVIP does not present any laboratory test results, field experience, or performance predictions related specifically to IGSCC resistance of Type 312 weld metal. The staff reviewed Figures 5 and 6 in Reference 5.5 as suggested in the response to RAI 4, but finds that these figures may not be applicable to Type 312 stainless steel because the carbon content (0.15 wt%) of Type 312 stainless steel is more than two times the maximum carbon content (0.07 wt%) considered in that paper. In Supplementary RAI 6-2(a) to its letter dated October 7, 2004, the staff requested the BWRVIP to provide service experience with Type 312 weld metal including its susceptibility to IGSCC. In addition, in Supplementary RAI 6-2(b), the staff requested that the BWRVIP discuss the effect of low-temperature thermal aging on mechanical properties of Type 312 stainless steel welds and suggested that these properties should be considered for the design of weld overlay repair with Type 312 welds. In its letter dated November 1, 2004, the BWRVIP response stated that Type 312 SS weld metal will not be considered for the underwater weld overlay application due to its high carbon content. The staff finds the response acceptable because it eliminates its concern about aging degradation of underwater weld overlay fabricated with Type 312 weld metal. Therefore, the BWRVIP will delete any reference to Type 312 stainless steel weld metal as it applies to the use in the weld overlay repair.

As mentioned, heat input during weld repair is one of the parameters that affects cracking susceptibility of neutron-irradiated stainless steel components due to helium embrittlement. High heat input welding processes generate high temperatures in a larger volume of the component being repaired and, therefore, would cause more cracking due to helium embrittlement as compared to low heat input processes. In Supplementary RAI 6-3(a) to its letter dated October 7, 2004, the staff requested the BWRVIP to include a recommendation for heat input for the FCAW and the SMAW weld overlay repairs in the BWRVIP-34 report. In its letter dated November 1, 2004, the BWRVIP response proposes to remove the discussion on weldability of irradiated stainless steel from the BWRVIP-34 report and refer to the BWRVIP-97 report. The staff finds the response acceptable because it will be evaluating the issue of heat input as its relates to weldability of irradiated material when it reviews the BWRVIP-97 report.

Since the heat input varies with welding position, in Supplementary RAI 6-3(b) to its letter dated October 7, 2004, the staff requested the BWRVIP to explain why no mechanical tests were performed on weld coupons fabricated using the FCAW process in the vertical (3G) position; and on SMAW weld coupons fabricated in the horizontal (2G), vertical (3G), and overhead (4G) positions at a depth of 50 feet. In its letter dated November 1, 2004, the BWRVIP response stated that all welding activities will be in accordance with Code Cases N-516 and N-504-2, as appropriate. The staff finds the response acceptable because Code Case N-516-3 requires that the wet underwater welding procedure be qualified in different welding positions at a qualified depth.

In Supplementary RAI 6-3(c) to its letter dated October 7, 2004, the staff requested the BWRVIP to explain why shrinkage values for weld test coupons that were fabricated in 2G, 3G, and 4G positions at a depth of 50 feet were not measured. In its letter dated November 1, 2004, the BWRVIP response stated that all welding activities will be in accordance with Code Cases N-516 and N-504-2, as appropriate. The staff finds the response acceptable because Code Case N-504-2 requires that shrinkage effects due to all weld overlays in the system be considered in determining the magnitude and location of the maximum shrinkage stress developed in the system being repaired.

In order to be consistent with other BWRVIP repair design procedures, such as the BWRVIP-16, "Internal Core Spray Piping and Sparger Replacement Design," and BWRVIP-19 reports, the staff issued Supplementary RAI 6-4 in its letter dated October 7, 2004, recommending that the BWRVIP include the following requirements in Section 6.0, "Materials and Welding Qualification," of the BWRVIP-34 report:

> Repair and replacement designs for plants which are not designed and constructed in accordance with ASME Section III (and components not subject to Section XI) must meet the individual plant safety analysis report and other plant commitments for RPV internals mechanical design, as stated in Section 6. In that instance, materials must meet the requirements of ASME code cases, ASME Section II specifications, American Society for Testing and Materials (ASTM) specifications, or other material specifications that have been previously approved by the staff. Otherwise, it is recognized that a repair or replacement design that uses a material not meeting these criteria must be submitted to the NRC for approval on a plant specific basis.

In its letter dated November 1, 2004, the BWRVIP response stated that all repairs to core spray piping (including the weld overlays described in the BWRVIP-34 report) are required to be designed and fabricated in accordance with relevant BWRVIP Repair Design Criteria (in this case, the BWRVIP-16 and BWRVIP-19 reports) and BWRVIP Material Guidelines (the BWRVIP-84 report). The BWRVIP further stated that the requirements suggested by the staff are required by Section 3.2 of the BWRVIP-84 report. The staff finds the response acceptable because the BWRVIP has the design requirements specified in other applicable reports. In a letter dated March 16, 2006, the staff issued Supplementary RAI 6-5 requesting the BWRVIP to reference these other reports in Section 6.0 of the BWRVIP-34 reort. In its letter dated July 18, 2006, the BWRVIP agreed with the staff and proposed to include the following paragraph as an introduction to Section 6.0 to the report.

Subsequent to the initial publication of this report, the BWRVIP published a Material Guideline (BWRVIP-84, Reference 15) that provides material specifications for use in repairs to BWR internals. Any core spray weld overlay repair design must be consistent with the requirements of BWRVIP-84 as well as the Core Spray Repair Design Criteria (Reference 13).

The staff finds the response acceptable because BWRVIP will be incorporating a recommendation to use the BWRVIP-19 and BWRVIP-84 report guidelines in the BWRVIP-34 report as requested. It should be noted that the BWRVIP letter dated November 1, 2004, stated that the design basis for the part circumference weld overlay repair of core spray piping is for a permanent repair and it is addressed in the Core Spray Repair Design Criteria (BWRVIP-19-A) which the staff has approved by NRC letter dated March 8, 2006. The staff finds that the BWRVIP has adequately addressed the materials to be used and the welding qualifications to be performed for the weld overlay repairs by assuring that the ASME Code requirements, including Code Cases N-504-2 and N-516, will be met.

3.6 <u>Section 7.0 - Inspection of Core Spray Internal Piping Weld Overlays</u>

Section 7.0 refers to the BWRVIP-03 report for the underwater ultrasonic examinations of core spray overlay mockups. Some of the mockups contained controlled, artificial defects. The results of the mockup examinations presented in Section 7.0 support the conclusion that the partial weld overlay repairs cannot be examined in the as-welded condition. However, these partial weld overlay repairs can be inspected by qualified personnel with improvements of the weld surface condition to meet the existing standards for piping overlays. Therefore, the staff finds it acceptable that these part circumference weld overlays will be inspected by qualified personnel with improvements of the weld surface condition to meet existing standards for piping overlay (EPRI report NP-4720-LD, "Examination of Weld -Overlaid Pipe Joints, October 1986").

In reviewing the inspectability of these partial weld overlay repairs, the NRC notes that References 5.6 and 5.7 found underbead weld cracking, but did not find weld toe cracking in a Type 304 stainless steel specimen containing entrapped helium and repaired by a gas metal arc weld overlay. In Supplementary RAI 7-1 to its letter dated October 7, 2004, the staff requested that the BWRVIP explain whether the inspection methods considered in Section 7.0 are qualified for detecting and sizing underbead cracking. In its letters dated November 1, 2004, and July 25, 2005 (renumbered to RAI 34-7.1), the BWRVIP response stated that the issue of inspection of welds to irradiated material is addressed in the BWRVIP-97 report and not in the BWRVIP-34 report because the discussion on inspection of highly irradiated material is already included in the BWRVIP-97 report. The staff finds this acceptable, and therefore will continue the review of the ability of the inspection methods for detecting and sizing underbead cracking in irradiated material during the review of the BWRVIP-97 report.

3.7 <u>Appendices</u>

The appendices (A through L) to the BWRVIP-34 report provide the weld qualification parameters, testing and test results for the SMAW and FCAW processes, which demonstrate that these welding processes could be used for weld overlay repairs of core spray piping, and meet the ASME Code requirements. In addition, the appendices provide recommended guidelines for procuring welding electrodes for use with the SMAW and FCAW processes in an underwater environment. The staff generally finds that these appendices adequately address the weld qualification and weld material requirements to assure satisfactory weld overlay repairs can be applied on core spray piping. Specific issues are discussed below for some of the applicable appendices.

3.7.1 Appendix A

This appendix describes the mockup testing performed to evaluate weld bead sequencing, the extent of the weld overlay, and verification of any crack extension into the weld overlay repair. The mockups consisted of butt welds in flat pipe cylinders butted together with no gap to simulate cracks. The mockups were coated with zinc oxide to determine the effects on weldability with FCAW. In RAI 5 to letter dated May 22, 1997, the staff requested additional information on "flat cylinders," seal weld, and zinc oxide coating as discussed in Appendix A. In its letter dated March 30, 1998, the BWRVIP clarified the fabrication details of these mockups. The BWRVIP stated that stainless steel (Type 304) mockups discussed in Appendix A were manufactured with 3/8-inch plate and 6-inch schedule 40 pipe (cylinders). All mockups simulated a through-wall circumferential crack by butting two sections of the plate or pipe together. Welding was completed transverse to the crack on the pipe mockups and directly over the crack with the plate material. The term "flat pipe cylinders" refers to pipe sections welded in the flat position with manipulation of the weld head along the axis of the pipe.

The BWRVIP-34 report states that a seal weld is the first weld bead that completely closes the crack. These welds were evaluated for variations in welding conditions that may arise due to limitations in accessibility or manipulation of equipment.

The BWRVIP-34 report states that a zinc oxide coating was applied prior to butting the plates together, which assured a complete coverage of the plates and simulated crack. Seal welds were applied directly over the crack and adjacent to crack. No modification of the welding was necessary due to the zinc oxide coating. No effort was made to closely duplicate the details of the zinc deposition, which occurs in some operating BWRs. However, the fact that welding over the heavy galvanized layer was possible provides an initial indication that the process should be successful in plants with zinc deposits.

The staff finds the results of the mockup testing in Appendix A provide confirmation that welding over cracks can be accomplished, even if the core spray piping is coated with zinc oxide. However, in Supplementary RAI A-1 to its letter dated October 7, 2004, the staff requested that the BWRVIP discuss whether weld overlay repair will leave a crevice geometry in the core spray piping wall underneath the weld. In its letter dated November 1, 2004, the BWRVIP response stated that a crevice geometry will be present in the core spray wall underneath the weld overlay, but any IGSCC, if present, will be arrested in the structural portion of the weld overlay interfacing with the underlying material of core spray piping. The staff finds this acceptable because the weld overlay material is IGSCC resistant due to its low carbon content and minimum FN value of 7.5. Therefore, any IGSCC present at the crevice would not propagate into the overlay material and would not challenge the integrity of weld overlay repair.

3.7.2 Appendix B

Appendix B describes the qualification test parameters used for the automated FCAW process using 308L weld material. In addition, Appendix B states that the test specimens from the qualification welds were made using the FCAW process at a depth 50 feet. However, in Appendix D.1, the specimens for constant extension rate testing (CERT) tests for FCAW process were made at a depth of 30 feet. Underwater weld depth has an effect on the welding arc characteristics and occurrence of weld defects. Increasing the depth can increase the occurrence of weld defects. Therefore, the CERT tests on coupons fabricated at 30 feet may not bound the test results on coupons fabricated at 50 feet. In Supplementary RAI A-3 to its letter dated October 7, 2004, the staff requested that the BWRVIP discuss whether CERT test results for coupons fabricated at 30 feet depth can be used as a bounding value for assessing the corrosion behavior of welds that will be made at 50 feet. In its letter dated November 1, 2004, the BWRVIP response stated that ferrite levels were not affected by depth or pipe wall thickness for underwater welding and therefore the CERT results at 30 feet can be used for welds to be made at a depth of 50 feet. The heat sink is basically the same based on the quantity of water the test specimens were fabricated in and therefore the weld residual stresses would be the same. The BWRVIP further states that the only reason tests were conducted on coupons fabricated at various depths was the level of difficulty in fabricating specimens at 50 feet (hyperbaric chamber) and 30 feet (open dive tank).

However, the staff notes that welding at increasing depths will also increase the number of weld defects. In its letter dated March 16, 2006, the staff requested that the BWRVIP discuss how the increased number of weld defects would affect the CERT test results, and that the BWRVIP-34 report should include guidelines about the use of dry (underwater welding in a dry chamber or habitat that displaces water around the material to be welded) and wet underwater welding for overlay repair in the -A version of the report. In its letter dated July 18, 2006, the BWRVIP response stated that Code Case N-516 recognizes the fact that depth may have some effect on the mechanical properties of welds and requires that the Owner perform welding qualifications for production welds under the same conditions for which the in-plant weld will be performed within certain specified tolerances. These conditions include depth for wet welding and pressure for habitat (dry underwater) welding. In addition, the same welding process must be used for the qualification and the actual repair activity. Consequently, since qualification specimens are fabricated from welds performed under representative conditions (defined by the ASME Code) with the same welding process, the material properties will be accurately representative of the repair weld. The staff agrees with the BWRVIP conclusion that Code Case N-516 does take into account the effect of depth on weld qualification. The BWRVIP further states that since the qualification parameters are adequately addressed by the ASME Code, additional discussion of wet versus dry welding in the -A version of the BWRVIP-34-A report is not required. The staff notes that Code Case N-516-3, dated April 8, 2002, does provide guidelines for welding procedure qualifications and welder performance qualifications for both dry and wet underwater welding, so no additional discussion is needed in the -A version of the BWRVIP-34 report.

3.7.3 Appendix D

This Appendix provides the results of the CERT tests conducted on FCAW and SMAW welds in order to evaluate IGSCC susceptibility of stainless steel filler metals welded underwater in a BWR environment.

In reviewing these results, the staff noted that in Tables D-3 and D-6, the CERT results have shown that a specimen tested in water takes a longer time to fail than a specimen tested in air. However, the reported percentage reduction in area of the specimen tested and failed in water is significantly less than that of the specimen tested and failed in air. In its letter dated March 30, 1998, the BWRVIP discussed why the CERT tests results in Table D-3 and D-6 indicated that a longer time to failure occurred with the specimens tested in the water environment, even though a lower percent area reduction was recorded for these specimens. The BWRVIP provided the CERT test recording charts and concluded that the welds are not susceptible to environmental embrittlement, since there was a lack of secondary cracking, and overall time to failure for all the specimens tested in water was greater than specimens tested in air. The results indicated that both specimens experienced fully ductile failures and that the variations were a result of inclusions or defects in the weld and were not due to environmental embrittlement. Test specimens were archived and are available for further metallographic evaluation if additional information is required. Time to failure could be directly related to defects, grain structure and grain size.

In the staff's review of the test results for coupons 16.1A and 16.1B, it was noted that the ferrite content is low on the weld cover pass when using the electrodes coated with the Cr-Al enamel waterproof coating. In its letter dated March 30, 1998, the BWRVIP response to RAI 11(b) clarified that the term cover passes used in these mockups are additional weld passes on the groove weld, which increased the volume of weld metal necessary to obtain the required test specimens. The ferrite number for the CERT test specimens was measured on the final weld surface of the groove weld. The FN recorded was between 4 to 6 across the length of the weld. The BWRVIP further stated that at the time the test matrix was completed, a FN value of 4-6 was typical for an underwater SMAW weld. The FN value in the intermediate and root passes was not measured in this test report. A later test evaluation with the same electrode and coating measured the FN value on the cross section of the specimen. A FN value of 6.1 was measured near the root and a FN value of 5.2 to 7.1 was measured on intermediate passes. The early low ferrite results led to development of electrodes with enhanced chemistry, which produced as-deposited weldments with higher delta ferrite values. This additional electrode development has achieved a FN value of 8 to 15.

The staff notes that Section D.2 of Appendix D to the BWRVIP-34 report notes a significant reduction (60%) in ductility (percent reduction in cross sectional area) of SMAW welds fabricated and tested in water as compared to those fabricated in water but tested in air. In Supplementary RAI A-2 (a) to its letter dated October 7, 2004, the staff requested that the BWRVIP discuss whether the fracture toughness test results for the SMAW welds reported in Appendix I of the BWRVIP-34 report may be similarly affected. In its letter dated November 1, 2004, the BWRVIP response stated that the fracture toughness results should not be influenced by testing conducted underwater versus testing conducted in air. The staff agrees that the fracture toughness results should not be affected by testing underwater versus in air, especially since the welds tested underwater have not shown any susceptibility to environmental embrittlement.

As mentioned above, the results presented in Section D.2 of Appendix D to the BWRVIP-34 report indicate that the SMAW welds that are fabricated and tested in water have inferior mechanical properties to those fabricated in water but tested in air. Therefore, in Supplementary RAI A-2 (b) to its letter dated October 7, 2004, the staff requested that the

BWRVIP-34 report include a recommendation that the design of weld overlay repair of internal core spray piping use mechanical properties (e.g., yield strength and tensile strength) determined by welds fabricated and tested underwater. In its letter dated November 1, 2004, the BWRVIP response stated that all requirements of Code Case N-516 will be met and, therefore, the required mechanical properties will be used in the design, and therefore will be representative of these weldments.

However, Code Case N-516 refers to determination of only Charpy energy for filler metal qualification and not of yield strength and tensile strength of the weldment. Therefore, in a letter dated March 16, 2006, the staff requested that the BWRVIP address the mechanical properties of yield strength and tensile strength because they are needed to determine the design stress intensity, S_m, used for determination of overlay thickness (see Section 3.4 of the BWRVIP-34 report). The staff also requested that the BWRVIP address whether the proposed high-ferrite contents (17 FN) would affect the material properties of the FCAW and SMAW welds fabricated and tested underwater. In a letter dated July 18, 2006, the BWRVIP further clarified that the mechanical properties testing is required by Code Case N-516. Code Case N-516 refers back to Section XI of the ASME Code, which mandates a procedure qualification that requires the suggested mechanical testing. Per the ASME Code, the tests are performed on samples removed from a weld that is deposited at the appropriate depth in the water environment using the welding process that will be used in the field application. With respect to the ferrite content, the BWRVIP stated that any effect of high ferrite levels on the material properties of the as-deposited weld will be measured in the ASME Code required weld procedure qualification testing. Potential future degradation caused by ferrite will be controlled by limiting the ferrite level to 12 FN as stated in the preamble to the BWRVIP-34 report. The staff finds this acceptable because samples that are tested will be removed from representative weldments and the ferrite content will be limited to reduce potential degradation.

3.7.4 Appendices F and G

Appendix F provides the material specifications for 308L weld material for automatic FCAW, while Appendix G provides the material specifications for 309L, 316L and other stainless steel weld material for manual SMAW.

In Appendices F and G, the reported ferrite content in the test coupons depends on the instrument that was used for the measurement. The reported FN readings measured by the Magne-Gage are much higher than those measured by ferritescope. In RAI 6 to its letter dated May 22, 1997, the staff requested that the BWRVIP provide an explanation of the differences in FN readings measured by the two instruments, and discuss which instrument provides a more reliable reading. In its letter dated March 30, 1998, the BWRVIP stated that the FN value in the test coupons was measured with two instruments; Magne-Gage and ferritescope. The Magne-Gage is primarily used in the lab and is restricted to small specimens oriented in the flat position. The specimens are prepared in accordance with Appendix A (filler metal specification SFA 5.4) to the ASME Code, Section II. The Magne-Gage is the standard for Quality Assurance Test Reports from the consumable weld material manufacturers. The Magne-Gage utilizes a true magnetic reading established by a dial reading at the point the magnet is pulled free of the specimen. In contrast, the ferritescope is a portable instrument that allows FN readings in all positions and does not require coupon preparation (as-welded condition). Unlike the Magne-Gage, an AC or DC current is applied across the surface of the component to obtain an electromagnetic indication of the FN value. The Magne-Gage actually measures the FN value over some depth into the coupon, whereas the ferritescope obtains a reading at the surface of the coupon.

The ferritescope was used to get a quick reading in the field during welding operations, primarily to evaluate experimental electrodes. The Magne-Gage was used on the same weldments at a later date for a more accurate reading. The Magne-Gage results were used for final assessment of weld acceptability. Therefore, since the more accurate reading from the Magne-Gage instrument is used to verify the quality of the ferritescope (used in the field), the staff finds that the FN values obtained are reliable.

3.7.5 Appendix J

Appendix J provides requirements for procurement of welding electrodes utilized for the FCAW and SMAW processes in an underwater environment. For the chemical requirements of the weld material, Appendix J allows the FN value to be determined either by chemical analysis or by a magnetic measuring instrument. In its letter dated March 30, 1998, the BWRVIP clarified that it was not the intent of the Appendix J to allow acceptance of the FN value by using the chemical analysis of the weld material in lieu of direct measurement of the as-deposited weld materials. The candidate weld materials are selected based on chemical analysis and certified mill test report (CMTR) FN values, but the actual performance of this material in the underwater application must be demonstrated in the as-welded condition by measurement of delta ferrite (possibly during procedure qualifications rather than for each underwater repair). The staff finds this acceptable, because the FN values will be measured for each of the weld materials used in the as-welded condition (either during the procedure qualifications or in the field).

3.7.6 Appendix K

Appendix K addresses the ability to inspect the weld overlay repair by using mockups welded with the FCAW and SMAW processes. In its letter dated March 30, 1998, the BWRVIP provided clarification of the term "nearly-as-welded" to be a surface that has been modified only by knocking off slag and weld spatter with no intentional alteration of the weld surface quality. However, the "nearly-as-welded" condition was still too rough to permit effective inspection. Regarding the acceptable surface quality for inspection of a weld overlay, the BWRVIP stated that the specimens were not able to be examined effectively until the surface had been improved to meet the criteria for an acceptable surface quality as specified in Reference 14 of the BWRVIP-34 report, "EPRI NP-4720-LD, "Examination of Weld-Overlaid Pipe Joints," dated October 1986. The BWRVIP further stated that the actual overlay thickness should be designed to accommodate the surface preparation necessary for UT inspection and that the BWRVIP-34 report will be revised to reflect this explanation. The staff finds this acceptable since these guidelines have been found to be effective in weld overlay repair of BWR recirculation piping. The results of this testing on mockups show that ultrasonic inspection of the weld overlay repair can be performed to detect lack of bond, porosity, and any potential crack extension from the core spray piping material into the weld overlay repair.

4.0 CONCLUSIONS

The NRC staff has reviewed the BWRVIP-34 report and the supplemental information that was transmitted to the staff by letters dated March 30, 1998, November 1, 2004, and July 18, 2006, and found that the report, as modified and clarified to incorporate the staff's comments above, is acceptable for providing guidance for permanent or temporary underwater part circumference weld overlay repairs of core spray piping. Therefore, the staff has concluded that licensee implementation of the guidelines in the BWRVIP-34 report, as modified to incorporate the resolution of the RAIs as discussed in this SE, will provide an acceptable technical basis for designing underwater part circumference weld overlay repairs of the components addressed in the BWRVIP-34 report based on the following.

- Section 2.0 of the BWRVIP-34 report described the applicable locations that are accessible for this part circumference weld overlay repair, and that plant-specific clearances must be addressed on a plant-specific basis because these clearances play a role in determining the thickness and length of this type of repair.

- Section 3.0 of the BWRVIP-34 report provided the methodology and an example analysis of designing a part circumference weld overlay repair using FCAW and SMAW processes to meet the BWRVIP core spray design criteria in the BWRVIP-16 and BWRVIP-19 reports, and the requirements in Appendix C of Section XI to the ASME Code and Code Cases N-504-2 and N-516. The structural strength of the weld overlay (including length and thickness of the weld) will be determined by using a net section plastic collapse evaluation methodology, and the use of the Z-factor correction in the current version of the ASME Code for weld overlays fabricated with welding processes using flux. In addition, each licensee will perform this evaluation and shall also consider residual stresses (taking into account underwater welding with the piping ID and OD exposed to water during welding) and shrinkage stresses produced by the weld overlay to ensure that the welds and components meet the applicable stress limits of Section III of the ASME Code. Each licensee shall consider potential flaw growth due to fatigue and IGSCC, and identify the specific nondestructive examination of the weld overlay repair. The BWRVIP-34 provided an acceptable method for accounting for shear transfer between the weld overlay and the piping. Each licensee will also determine, prior to performing the weld overlay, any additional length to the weld repair to allow for an effective inspection. The weld overlay repair will use the workmanship standards of Sections XI and III of the ASME Code to minimize the creation of a crevice at the toe of the weld repair, and BWRVIP-19-A will require the licensee to specify periodic inspections of the repair that are consistent with the BWRVIP-18-A guidelines in order to detect any cracking in the weld overlay in a timely manner.

- Section 4.0 of the BWRVIP-34 report provided guidance on performing core spray leakage calculations and leakage assessment criteria which will be performed for each plant-specific application to demonstrate that the total leakage from the core spray piping does not cause unacceptable increases in peak cladding temperature for any licensing basis accident.

- Section 5.0 of the BWRVIP-34 report will reference the BWRVIP-97 report for guidance on weldability of core spray piping (irradiated stainless steel).

- Section 6.0 of the BWRVIP-34 report identified the testing necessary to demonstrate t[h] adequacy of materials and welding processes for underwater welding of core spray piping. The qualification of the underwater welding activities will be in accordance with Code Cases N-516 and N-504-2, and will be qualified for the appropriate welding positions at the required depth. Materials used for the weld repair will be selected in accordance with the guidelines of BWRVIP-84. The report also included results of a demonstration for two welding processes (FCAW and SMAW). The BWRVIP-34 repor will also specify that weld material shall have a delta ferrite content between 7.5 to 12 FN to minimize IGSCC and thermal aging susceptibility.

- Section 7.0 of the BWRVIP-34 report demonstrated that the part circumference weld overlays cannot be inspected in the as-welded condition, but can be inspected by qualified personnel with improvements of the weld surface condition. Therefore, the staff finds it acceptable that these part circumference weld overlays will be inspected b qualified personnel with improvements of the weld surface condition to meet existing standards for piping overlay (EPRI report NP-4720-LD, "Examination of Weld -Overlaid Pipe Joints, October 1986").

The staff notes that the BWRVIP-34 report provided, for information, the results of mockup testing to demonstrate that the SMAW and FCAW processes could be used for these weld overlay repairs and would be able to meet the applicable ASME Code requirements. However the ASME Code requirements for weld procedure and welder qualifications still apply, and would be required to be performed by the licensee when implementing these BWRVIP-34 report guidelines. In addition, the requirements and testing specified in Code Cases N-516 and N-504-2 that are endorsed in RG 1.147 must be performed. These tests include:

- Ferrite determination of the weld deposit.
- Fracture toughness testing for each material type deposited underwater.
- Determine IGSCC susceptibility using CERT tests of the weld deposit.
- Sensitization tests of the heat affected zone (HAZ) (ASTM A-262, Practices A and E).
- Weld procedure specification qualification tests including mechanical testing specified i Section IX of the ASME Code.

In addition, when welding on irradiated core spray piping, the guidelines in the BWRVIP-97 report shall also be implemented, including any additional mockup testing or helium content determination.

The staff notes that Section 8.0 of the BWRVIP-34 report states, "The structural adequacy of such repairs has been demonstrated, as has the IGSCC resistance of weld overlay materials in the as applied condition, for two underwater welding processes: automatic remote flux cored arc welding (FCAW) and manual shielded metal arc welding (SMAW)." In addition, Section 6.4 of the BWRVIP-34 report states, "The design thickness of the weld overlay repair for core spray piping depends upon the expected properties of the as deposited weld overlay....In particular, the fracture toughness and the mechanical properties of the weld deposit must be determined, since these properties have a strong impact on the weld overlay design." Therefore, based on these BWRVIP-34 report guidelines, if licensees intend to use a welding process other than SMAW or FCAW, they must perform the qualification tests required by Section IX of the ASME Code and Code Cases N-516, and additional testing as outlined in the BWRVIP-34 and

BWRVIP-97 reports in order to ensure that weld properties are obtained for use in the determination of the size (length and depth) of the part circumference weld overlay.

The modifications, clarifications, and supplemental information that were provided in response to the staff's RAIs, as addressed in Section 3 of this SE, are summarized below. The staff requests that these modifications, clarifications, and supplemental information be incorporated in the -A version of the BWRVIP-34 report.

a. In response to Supplemental RAI question No. 3-1 in the staff's October 7, 2004, letter, the BWRVIP provided a general statement in its letter dated July 18, 2006, to address the staff's concern about compliance with the current editions of the ASME Code. The BWRVIP agreed to modify the BWRVIP-34 report to include a preamble to ensure the overlay design will be in accordance with the current NRC-approved version of the ASME Code and Code Cases. In addition, the preamble includes the use of the Z-factor, consideration for designing the length of the overlay repair, evaluation of the effects of residual stresses and water backing, the effects of the weld overlay on other welds and components, and the inclusion of a maximum limit on ferrite content of 12 FN. It should be noted that based on the responses to this and other RAIs, the BWRVIP proposed a FN range of 7.5 to 12, which provides sufficient delta ferrite content to minimize IGSCC, but limits the delta ferrite to prevent thermal aging of the stainless steel. The BWRVIP shall clarify in the -A version of the BWRVIP-34 report that the ferrite content of the weld shall be within the range of 7.5 to 12 FN.

b. In response to RAI question No. 3-1(c) in the staff's letter dated October 7, 2004, and Supplemental RAI question No. 3-5, the BWRVIP agreed with the staff's recommendation that the example analysis in the BWRVIP-34 report did not use a Z-factor, but a Z-factor should be used for a repair when required by the ASME Code.

   The BWRVIP will add a paragraph at the end of Section 3.2 of the BWRVIP-34 report as addressed in its letter dated July 18, 2006, regarding Supplemental RAI question No. 3-5.

c. In response to RAI question No. 1 in the staff's letter dated March 30, 1998, the BWRVIP agreed with the staff's recommendation that additional length of the weld overlay may be required to allow effective inspection. Therefore, the BWRVIP agreed to modify Section 3.1.2 in the BWRVIP-34 report accordingly.

d. In response to RAI question No. 3-8 in the staff's letter dated July 18, 2006, the BWRVIP proposed to modify Section 7 of the BWRVIP-34 report to provide guidance for inspecting IGSCC-susceptible locations resulting from weld overlay repair of the core spray piping.

e. In response to RAIs on weldability of irradiated material in the staff's letters dated January 8, 2003, March 18, 2004, and October 7, 2004, the BWRVIP proposed in its letter dated November 1, 2004, to replace Section 5.0 of the BWRVIP-34 report with a reference to the BWRVIP-97 report for all welding on highly irradiated materials and to address all the staff's comments during the review of the BWRVIP-97 report. This is appropriate and will consolidate the guidance in one report. Therefore, the BWRVIP will revise Section 5.0 of the BWRVIP-34 report as addressed in its letter dated

November 1, 2004, to state that all welding on highly irradiated materials shall be in accordance with the BWRVIP-97 report.

f. In response to the staff's Supplementary RAI question No. 6-2(b) in its letter dated November 1, 2004, the BWRVIP proposed that Type 312 stainless steel weld metal will not be considered for the underwater weld overlay application. Therefore, the BWRVIP will delete any reference to Type 312 stainless steel weld metal as it applies to the use in the weld overlay repair.

g. In response to Supplementary RAI question No. 3-8 in the staff's letter dated March 16, 2006, the BWRVIP agreed with the staff's recommendation to include the use of the BWRVIP-19 and BWRVIP-84 report guidelines concerning repair and replacement designs and material specifications. Therefore, the BWRVIP will modify Section 6.0 of the BWRVIP-34 report, as addressed in its letter dated July 18, 2006, regarding Supplementary RAI 3-8.

h. In response to RAI question No. 8 in the staff's letter dated March 30, 1998, the BWRVIP agreed with the staff's recommendation that the term "nearly-as-welded condition" requires further explanation. The BWRVIP agreed to revise the BWRVIP-34 report to further define this term, and state that the actual overlay thickness should be designed to accommodate the surface preparation necessary for UT inspection.

The BWRVIP-34 report is considered by the staff to be acceptable for licensee usage, as modified and approved by the staff, anytime during either the current operating term or during the extended license period. If it is determined during the course of implementing these repair guidelines that implementation cannot be achieved as described in the guideline or that meaningful results are not obtained, then the staff requests that the user notify the BWRVIP with sufficient details to support development of alternative actions. These notifications, as well as planned actions by the BWRVIP, should be summarized and reported to the NRC. It should be noted that a licensee is responsible for reviewing regulatory requirements for repairs to this system. If the repair is an alternative repair to that specified in the regulations, i.e., 10 CFR 50.55a, the licensee will need to pursue the appropriate regulatory action.

5.0 REFERENCES

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5.2 Hale, G. E. and S. J. Garwood 1990. "Effect of Aging on Fracture Behavior of Cast Stainless Steel and Weldments," Material Science and Technology, 6, March 1990, pp. 230-235.

5.3 Alexander, K. B., et al. 1990. "Microscopical Evaluation of Low Temperature Aging of Type 308 Stainless steel Weldments," *Material Science and Technology, 6*, March, pp. 314-320.

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5.5 Hughes, N. R., et al. 1982. "Intergranular Stress Corrosion Cracking Resistance of Austenitic Stainless Steel Castings," *Stainless Steel Castings, ASTM STP 756*,

5.6 Kanne, W. R., et al. 1993. "Metallographic Analysis of Helium-Embrittlement Cracking of Repair Welds in Nuclear Reactor Tanks," *Materials Characterization*, Vol. 30, 1993, pp. 23-34.

5.7 Goods, S. H., and C. W. Karfs 1991. "Helium-Induced Weld Cracking in Low Heat Input GMA Weld Overlays," *Welding Research Supplement*, May 1991, pp. 123-s to 132-s.

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RECORD OF REVISIONS

BWRVIP-34-A	Information from the following documents was used in preparing the changes included in this revision of the report. 1. "BWR Vessel and Internals Project, Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping (BWRVIP-34)," EPRI Report TR-108198, May, 1997. 2. Letter from C. E. Carpenter (NRC) to C. Terry (BWRVIP Chairman), "Proprietary Request for Additional Information – Review of "BWR Vessel and Internals Project, Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping (BWRVIP-34)," (TAC NO. M98880)," December 14, 1997. (BWRVIP Correspondence File Number 97-936A). 3. Letter from V. Wagoner (BWRVIP) to C. E. Carpenter (NRC), "BWRVIP Response to NRC Request for Additional Information on BWRVIP-34 (Reference Project 704)," March 30, 1998. (BWRVIP Correspondence File Number 98-126). 4. Letter from S. Coffin (NRC) to Bill Eaton (BWRVIP Chairman), "Supplementary Request for Additional Information – Review of BWR Vessel and Internals Project Report, BWRVIP-34, Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping," October 7, 2004. (BWRVIP Correspondence File Number 2004-454). 5. Letter from Bill Eaton (BWRVIP) to Meena Khanna (NRC), "Project 704 - BWRVIP Response to NRC Supplementary Request for Additional Information on BWRVIP-34," November 1, 2004. (BWRVIP Correspondence File Number 2004-460). 6. Letter from M. A. Mitchell (NRC) to Bill Eaton (BWRVIP Chairman), "Supplementary Request for Additional Information- "BWR Vessel and Internals Project, Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping (BWRVIP-34)"," March 16, 2006. (BWRVIP Correspondence File Number 2006-230). 7. Letter from Bill Eaton (BWRVIP) to Meena Khanna (NRC), "Project No. 704 - BWRVIP Response to NRC Supplementary Request for Additional Information on BWRVIP-34," July 18, 2006. (BWRVIP Correspondence File Number 2006-342). 8. Letter from M. A. Mitchell (NRC) to Rick Libra (BWRVIP Chairman), "Safety Evaluation of Proprietary EPRI Report, "BWR Vessel and Internals Project, Technical Basis for Part Circumference Weld Overlay Repair of Vessel Internal Core Spray Piping (BWRVIP-34)"," June 27, 2007. (BWRVIP Correspondence File Number 2007-202). Details of the revisions can be found in Table N-1.

Figure N-1
Revision Details

Required Revision	Source of Requirement for Revision	Description of Revision Implementation
Clarify that: • Design must be consistent with the latest Edition and Addenda of the ASME Code as identified in the Owner's ISI Inspection Plan and with applicable Code Cases as endorsed in Regulatory Guide 1.147. • Z-factor must be included in design calculations when required by Code • Shear load transfer must be properly evaluated • Residual stress must be considered • Ferrite shall be limited between 7.5 and 12 FN.	NRC Safety Evaluation (2007-202)	Preamble added to Section 1.
Clarify that while the example design shown in Section 3 does not incorporate a Z-factor, current Code requirements would require that Z-factor be included in certain cases.	NRC Safety Evaluation (2007-202)	Discussion added to end of Section 3.2.
Provide guidance for inspection of overlays.	NRC Safety Evaluation (2007-202)	Discussion added to Section 7.
Clarify that cracks in underlying base metal HAZ should be monitored.	Response to NRC RAI. (98-126)	Discussion added to Section 7.
Clarify that overlay design length should be sufficient to allow for effective ultrasonic inspection.	NRC Safety Evaluation (2007-202)	Discussion added to Section 7.
Clarify that design overlay thickness should be sufficient to allow surface preparation for UT inspection	NRC Safety Evaluation (2007-202)	Discussion added to Section 7.
Delete discussion of additional requirements for repairs to irradiated components (Section 5) and refer to BWRVIP-97 for guidance.	NRC Safety Evaluation (2007-202)	Content of Section 5 replaced with reference to BWRVIP-97.
Clarify that Type 312 weld metal is not considered to be qualified this repair.	NRC Safety Evaluation (2007-202)	Reference to Type 312 deleted from Section 6.1.
Clarify that design must be consistent with BWRVIP-19-A and BWRVIP-84	NRC Safety Evaluation (2007-202)	Discussion added to Section 6.
Clarify meaning of "nearly-as-welded"	NRC Safety Evaluation (2007-202)	Clarification provided in Appendix K.
End of Revisions		

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