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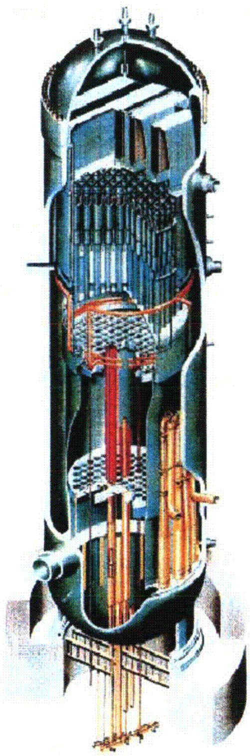
BWRVIP-251NP: BWR Vessel and Internals Project

Technical Bases for Revision of the BWRVIP-18 Core Spray Inspection Program



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BWRVIP-251NP: BWR Vessel and Internals Project

Technical Bases for Revision of the BWRVIP-18 Core Spray Inspection Program

1022842NP

Final Report, May 2012

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

An Inspection Optimization Focus Group (IOFG) has been created to support optimization program activities. Collectively, these participants represent a wide spectrum of BWR experience, including nondestructive evaluation (NDE) technology application, mitigation technologies, structural assessment, BWRVIP program development, and design and application of repair hardware.

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REPORT SUMMARY

Background

Fleet-wide implementation of BWR Vessel and Internals Project (BWRVIP) Inspection and Evaluation Guidelines has generated a substantial amount of inspection data for many BWR reactor vessel internals. This ever-increasing field inspection data set can be used to better assess the actual susceptibility of various component locations to degradation. In many cases, the inspection trends point toward stabilizing conditions in which fewer new indications are being detected and growth of older indications is slowing or has stopped. The BWRVIP inspection optimization project uses current field data as a basis for reassessment of current BWRVIP Inspection and Evaluation Guideline requirements.

Since first published in 1996, the reinspection program contained in BWRVIP-18 for core spray piping, spargers, and associated supports has remained largely unchanged. This inspection program was based on relatively few field inspection data, and the resulting requirements have subsequently been found to be, in several cases, overly conservative.

Objective

- To present a proposed revision to the core spray internals inspection program contained in BWRVIP-18, Revision 1

Approach

The project team, with the oversight and guidance of the BWRVIP Inspection Optimization Focus Group (IOFG), surveyed all domestic plants to obtain information related to core spray internals inspection history, examination methods, and current inspection criteria. The survey was comprehensive, addressing all core spray internal welds in the domestic fleet and collecting not only data on the current status of core spray welds but also historical inspection data and nondestructive evaluation (NDE) coverage data. These survey results are the primary data source used to guide development of proposed revisions to the existing BWRVIP-18 inspection program requirements. The survey data were supplemented by generic flaw tolerance evaluations that were used to augment the technical basis for revision of BWRVIP-18.

Results

The inspection results demonstrate that although cracking of core spray internals has occurred and continues to occur sporadically, there are no data that indicate a detrimental trend in new cracking. Most locations are experiencing relatively fewer new cracks in recent years. Many "creviced" piping weld locations have performed better than previously anticipated, with few flaws occurring and no large flaws observed to date. Performance of L-Grade materials is shown to be very good, regardless of weld configuration. No new cracking or substantial crack growth of major sparger welds has been observed for many years. Growth of existing flaws is found to be slowing, and observed crack growth rates support the current BWRVIP position that $5x10^{-5}$ in. per year ($3.53x10^{-10}$ meters per second) represents a reasonable upper-end value.

Based on these favorable data, this report presents a proposed revision to the BWRVIP-18 reinspection program that balances program requirements based on survey data and generic flaw tolerance evaluations. The proposed revision extends reinspection intervals where appropriate, most notably for creviced and tee box-to-pipe piping welds, creviced L-Grade piping welds, and sparger welds. Conversely, the proposed program retains the reinspection intervals for rotating sample welds and shortens the reinspection interval permitted for noncreviced L-Grade piping welds.

Additional provisions of the proposed program offer counterbalances to increased reinspection intervals. The proposed program includes more detailed supplemental examination criteria, scope expansion criteria when new cracks are identified, and minimum coverage requirements for using ultrasonic examination (UT) reinspection intervals. Finally, where supported by component integrity evaluations, the proposed program permits the use of UT-based reinspection intervals where only one-sided UT with supplemental EVT-1 is possible.

Revision to reinspection requirements based on collection and analysis of inspection data provides a realistic and comprehensive approach for optimizing inspection programs.
The results of this work provide an optimized program that decreases inspection burden, while simultaneously ensuring that locations found to have higher intergranular stress corrosion cracking (IGSCC) susceptibility continue to receive appropriate focus and that the level of safety provided by the existing inspection program recommended in BWRVIP-18 is maintained.

Keywords
Boiling water reactor (BWR)
Core spray
Inspection strategy
Intergranular stress corrosion cracking (IGSCC)
Vessel and internals

ACRONYMS AND ABBREVIATIONS

Acronym	Meaning
ASME	American Society of Mechanical Engineers
Avg	Average
BWR	Boiling Water Reactor
BWRVIP	Boiling Water Reactor Vessel and Internals Project
CFR	Code of Federal Regulations
CGR	Crack Growth Rate
EPRI	Electric Power Research Institute
EVT	Enhanced Visual Testing
HAZ	Heat Affected Zone
ID	Inside Diameter
I&E	Inspection & Evaluation
IGSCC	Intergranular Stress Corrosion Cracking
IOFG	Inspection Optimization Focus Group
ksi	1000 Pounds per Square Inch
LSR	Lower Section Replacement (weld status)
NA	Not Applicable
NDE	Non-destructive Examination
NEI	Nuclear Energy Institute
NPS	Nominal Pipe Size
NRC	Nuclear Regulatory Commission

Acronym	Meaning
O	Original, No Repair (weld status)
OD	Outside Diameter
PB	Piping Bracket
R^2	Coefficient of Determination
RC	Repair, Clamped (weld status)
RPV	Reactor Pressure Vessel
RW	Repair, Welded (weld status)
SB	Sparger Bracket
SCC	Stress Corrosion Cracking
SE	Safety Evaluation
Sect	Section
U.S.	United States
UT	Ultrasonic Testing
VT	Visual Testing

DEFINITIONS

The following definitions are provided to clarify some of the terminology used within this report. This listing is not intended to be a comprehensive glossary of technical terms, but rather a key listing of terms specifically applicable to core spray internals optimization.

304SS is an abbreviation used to describe austenitic stainless steel (type 304) components containing up to 0.08% C.

Coefficient of Determination (R^2 ***)*** is a statistic that provides some information regarding goodness of fit between a real data set and a data model (e.g., linear, logarithmic). Within this technical basis report, the R2 statistic is included to illustrate patterns of performance observed in the core spray weld performance data.

Creviced welds refer to core spray piping system welds included in the BWRVIP-18 category "creviced and tee box-to-pipe welds." The design of these welds includes an internal crevice or other feature that results in a potential for increased susceptibility to crack initiation. Table 7-3 contains a categorization of the individual weld locations.

Initiation rate is defined as the rate of change in the percentage of weld locations identified to have IGSCC flaws over time. For core spray, this is the percentage of welds having new flaws occur per unit time (years). This rate is estimated from field survey data, but also requires that a crack growth rate be assumed.

L-Grade is an abbreviation used to describe austenitic stainless steel components specified to have reduced carbon content; 0.03% max.

Lower section replacement (LSR) is a term describing replacement of a core spray downcomer pipe and associated sleeve coupling (welds P5, P6, and P7), the lower elbow (welds P4c and P4d), and the shroud collar region (BWR/3-5 welds P8a and P8b). Lower section replacement designs may also structurally replace S1 and S2 major sparger welds. The design and fabrication of the replacement assembly is such that there are no welds requiring inspection per BWRVIP-18. Shop welds are solution annealed to remove weld residual stresses. The replacement assembly is mechanically fastened to the existing core spray internals. Lower section replacements are inspected based on guidance provided by the lower section replacement designer, not BWRVIP-18.

Mechanical repair is a term describing structural replacement of a weld by a mechanically fastened assembly, such as a clamp. Mechanical repairs without IGSCC susceptible welds are inspected based on guidance provided by the repair replacement designer, not BWRVIP-18.

Shroud collar region refers to the connection of the core spray piping to the shroud.

Sleeve coupling region refers to the core spray piping downcomer coupling and associated field welds.

Sparger, Major Sparger Welds is a term used to denote sparger welds S1, S2, and S4. The S1 weld is the sparger tee box cover plate weld. The S2 weld is the sparger tee box to sparger arm weld. The S4 weld is the sparger arm to end cap weld.

Sparger, Minor Sparger Welds is a term used to denote sparger welds S3a, S3b, and S3c. These welds are associated with sparger orifices and drains.

Supplemental examination refers to the use of a secondary examination technique in addition to the primary examination technique. Supplemental examination by UT is used when new flaws in core spray piping welds are detected by EVT-1. Supplemental EVT-1 is used to address core spray pipe weld HAZs that cannot be examined by a demonstrated UT technique.

Tee-box region refers to the connection of thermal sleeve piping to horizontal distribution pipes at a tee or tee-box. This region includes welds P2, P3, P2a, P2b, P3a, and P3b.

Uncreviced welds refer to core spray piping system welds included in the BWRVIP-18 category "rotating sample of other piping welds". This group includes butt welded piping to fitting welds, such as P4 piping to elbow welds and BWR/6 P2a/P2b piping to tee welds.

Welded repair is a term describing structural replacement of a weld by a support piece that is installed by welding to the existing core spray piping. Field welding to existing core spray internals results in sensitization of the HAZ region surrounding the repair weld. As a result, repair welds are inspected per BWRVIP-18 using the criteria applicable to the repaired weld.

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1 INTRODUCTION

1.1 Purpose

This report presents a proposed revision to the core spray internals re-inspection program contained in BWRVIP-18, Revision 1 and provides the technical bases supporting the revision.

1.2 Optimization Project Background

The Boiling Water Reactor Vessel and Internals Project (BWRVIP) was formed in 1994 to proactively address emerging cracking of BWR internal components. Early in the project, a comprehensive assessment of the reactor internals was performed from the perspectives of safety consequences and degradation modes. Inspection & Evaluation (I&E) Guidelines were developed to address these issues. A conservative approach was employed due to the absence of substantial field inspection data. Many years later following implementation of the BWRVIP I&E Guidelines a substantial amount of inspection data for many BWR reactor vessel internals has been generated. Evaluation of this field inspection data, combined with flaw tolerance methods, can be used to assess the current susceptibility of various component locations to degradation and to optimize inspection programs. The BWRVIP inspection optimization project, initiated in 2009, uses these tools to reassess I&E Guideline requirements. BWRVIP-236 [11] describes the inspection optimization program approach and key program elements. The report also documents the results of screening performed to determine which BWRVIP I&E Guidelines should be considered for optimization and establishes a priority listing of guidelines for optimization.

1.3 BWRVIP-18 Development and Revision History

Core spray cracking was first detected in 1978 and was found to be more widespread in subsequent years. In response, the NRC issued IE Bulletin 80-13, "Cracking in Core Spray Spargers" [14] requiring visual inspections of a better quality than those required by the ASME Code. Prior to issuance of BWRVIP guidelines, most plants had been performing inspections to the IE Bulletin 80-13 requirements for many years, and in the process many plants have found and addressed core spray cracking incidents.

The BWR internals safety assessment documented in BWRVIP-06, Revision 1-A [2] concluded that inspection was an important part of assuring core spray integrity. As a result, the BWRVIP developed a core spray inspection and evaluation guideline. BWRVIP-18, *BWR Vessel and Internals Project, BWR Core Spray Internals Inspection and Flaw Evaluation*

Guidelines [5] was published in July of 1996 as EPRI Report TR-106740 and was subsequently implemented by utilities.

The final Safety Evaluation (SE) of BWRVIP-18 was issued in December of 1999. In March of 2005, the BWRVIP submitted BWRVIP-18-A [6] to the NRC for review. In September of that year, BWRVIP-18-A was approved by the NRC.

BWRVIP-18, Revision 1 [7] was published in October of 2008. This revision adds inspection and flaw evaluation guidelines for "hidden" core spray piping welds. The approach for hidden core spray piping welds utilizes inspection results from similar accessible welds to assess the condition of inaccessible welds.

Since first published in 1996, the inspection program for core spray piping, spargers, and associated supports has remained largely unchanged.

1.4 Core Spray Inspection Program Optimization

There are a number of aspects that contribute to the optimization of the BWRVIP-18 inspection program requirements for core spray internals. A majority of core spray piping and sparger weld locations have been inspected multiple times. Thus, inspections have resulted in a robust set of data that is available for analysis. Although a number of indications have been reported, the inspection data indicate that the most significant cracking occurred relatively early in fleet operation and that no failures of piping, spargers or supports have occurred.

In some cases, the BWRVIP-18 inspection requirements have been found to be very conservative based on current field data. For example, creviced L-Grade core spray piping welds are currently reinspected at the same frequency as 304SS creviced core spray piping welds based on the assumption that the presence of a crevice would result in similar IGSCC behavior. Field data indicate this is not the case. In fact, the data indicate that L-Grade material performs better than 304SS in creviced weld locations. In other cases, early cracking events that influenced the development of inspection requirements have been found to be limited in nature with no recent cracking occurring. For example, a number of significant IGSCC indications were identified in major sparger welds in the 1980s. However, no new cracks have been identified for many years.

Implementation of core spray inspections requires a significant amount of utility resources. Reinspection of creviced core spray piping welds is currently performed every outage (using EVT-1) or every other outage (using UT). Reinspection of sparger welds is performed every other outage. A rotating sample of other creviced welds is examined during each inspection such that all welds are examined over a period of several outages. Optimization of the core spray internals inspection program allows for adjustments to these inspection requirements that will improve utilization of industry resources.

1.5 Implementation Requirements

This report is provided for information only. Therefore, the implementation requirements of Nuclear Energy Institute (NEI) 03-08 Revision 2, *Guideline for the Management of Materials Issues* [15], are not applicable.

The revised inspection frequencies described in this report should not be implemented until they are published in a revision to BWRVIP-18.

2 TECHNICAL APPROACH

Optimization of the BWRVIP-18, Rev. 1 core spray internals inspection program [7] included the following activities:

- Collection of field inspection data *(information on flawed and unflawed welds, as well as on inspection methods used and coverage values achieved)*
- Evaluation of crack initiation and growth data for flawed welds
- Evaluation of flaw tolerance of typical welds
- Evaluation of NDE methods and coverage

The results of these activities are used as inputs supporting development of proposed revisions to the BWRVIP-18 reinspection program. Figure 2-1 illustrates the use of these elements in the optimization process.

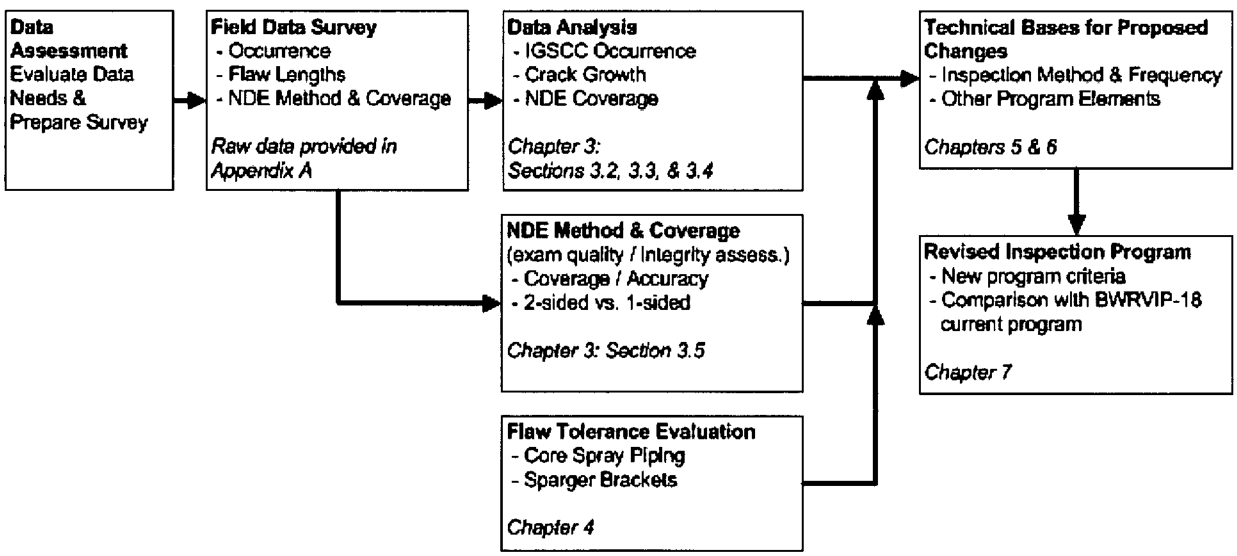

Figure 2-1
Summary of Core Spray Inspection Optimization Elements

The BWRVIP maintains a database that captures a summary of field inspection data. This information is updated every two years and currently published in BWRVIP-242 [12]. A review of this information led to the recommendation that collection of more detailed inspection data would be necessary to develop supporting information to optimize the core spray internals inspection requirements. To address this recommendation, the BWRVIP

performed a comprehensive survey of U.S. BWRs to collect data on flawed welds. Information on NDE methods used and coverage values achieved was also collected and evaluated for all core spray internals welds. One hundred percent of U.S. plants responded to the survey request.

For each flawed weld, the survey requested utilities to provide information about each flaw including the inspection year, flaw length, and inspection method for the most recent inspection of the weld, the second most recent inspection, and for the inspection when the flaw was first detected. Additionally, the current status of the weld was requested. Welds can be characterized as 1) unflawed, 2) flawed & repaired (by either a mechanical or a welded repair solution), 3) flawed & unrepaired (i.e., fit for service without repair), 4) replaced, or 5) pre-emptively replaced (i.e., replaced as part of a lower section replacement). Using this approach, the BWRVIP obtained a comprehensive understanding of the percentage of welds in the fleet containing flaws, the total flaw lengths, service times to flaw detection, and the nature and number of repairs implemented for core spray internals. A summary of the raw data from the survey is presented in Appendix A.

The data on flawed welds can be applied in a number of ways to assess relative susceptibility to IGSCC, including evaluation of service times to crack initiation, rates of crack initiation, crack growth rates and crack growth propensities. These evaluations and the associated results are presented in Chapter 3.

As a complement to collection and evaluation of field inspection data, flaw tolerance evaluations were performed for selected core spray internals locations to better determine structural margins and assess the reasonableness of various inspection intervals. Flaw tolerance evaluations were performed for a generic core spray pipe weld and for a sparger bracket to shroud weld. These cases were selected because they can be applied generally to the majority of locations where cracks of substantial length have occurred. These flaw tolerance evaluations, presented in Chapter 4, are valuable to illustrate the significant structural margins associated with core spray internals.

The above information and analyses were used to develop proposed revisions to the inspection program. Additional considerations for development of the revised inspection program include the objectives of providing appropriate credit for the various examination approaches allowed, promoting development and use of improved NDE technologies, and ensuring that the program requirements are reasonable from a practical implementation perspective considering all outage schedules. Weld categories, terms, and the overall structure of the BWRVIP-18 inspection program for core spray internals are retained where possible.

The technical bases supporting revision of the inspection program for each weld category are presented in Chapter 5. Revisions to inspection intervals are qualitatively based on review of all the available data. The use of a specific quantitative evaluation result as the fundamental basis for inspection criteria was not deemed appropriate. However, the results of the quantitative evaluations were used to corroborate the adequacy of the proposed inspection program. For example, flaw tolerance evaluations result in estimated service times to minimum margin. However, use of these estimated service times for locations where few

cracks have occurred and where field inspection data indicates limited propensity for development of large flaws results in overly conservative inspection intervals. Inspection interval revisions also consider the influence of additional program requirements, such as supplemental examination and scope expansion requirements. Finally, inspection intervals and rotating sample requirements also consider that inspection data is evaluated on a fleet-wide basis, such that if significant adverse trends were to be identified in one unit, all other units in the fleet would be made aware of this trend and would take appropriate actions if recommended by the BWRVIP.

Revisions to inspection intervals must also consider examination methods and the relative amount of confidence in component integrity that is provided by the examinations. The survey data provided information for the evaluation of these issues. Since examination technologies and coverage reporting approaches have matured over time, emphasis was placed on the most recent inspection data. Further, when evaluating EVT-1 coverage, only examinations with coverage reported consistent with BWRVIP-03 Revision 10 [1] (or later revision) were included. For core spray piping welds, UT examination is capable of interrogating both the ID and OD surfaces and therefore UT provides better information regarding overall confidence in weld integrity than EVT-1. As a result, BWRVIP-18 specifies different inspection intervals for EVT-1 and UT and requires that if the longer UT intervals are to be utilized, a weld must be inspected by UT from both sides. The revised program also differentiates between UT and EVT-1 exams, but makes use of the field data to demonstrate that a high level of confidence in component integrity can be achieved for certain welds even when two-sided UT cannot be applied. This fact is reflected in the proposed inspection program. This credit for UT inspection intervals, along with minor revisions to supplemental examination and scope expansion criteria are discussed in Chapter 6.

Chapter 7 contains a summary of the revised inspection program, along with a comparison to the current BWRVIP-18 program.

3
INSPECTION DATA EVALUATION

Throughout this report, reference is made to core spray internals weld IDs and weld categories. Identification of welds and weld categories, along with generic figures depicting the three distinct core spray internal designs (BWR/2, BWR/3-5, and BWR/6), are contained in BWRVIP-18 [7].

3.1 Summary of Available Inspection Data

This section presents the results of evaluations of field inspection data. Data through Spring 2010 outages was obtained by surveying BWRVIP utilities. For the most part, discussion of the application of these evaluation results to the proposed revised inspection frequencies is not included in this chapter. Rather, such discussion is deferred to sections 5 and 6. Table 3-1 summarizes the data types collected by the survey. A detailed summary of the survey data can be found in Appendix A.

Table 3-1
Summary of Collected Core Spray Data

Item	Discussion
Material of Construction	Core spray internals materials of construction were requested. Systems are either constructed from straight grade 304 (304SS) or from L-Grade materials (304L, 316L).
Weld Status	Weld status for every core spray weld in the U.S. fleet. Weld status includes: • Unflawed • Flawed & Repaired (*mechanical or welded repairs*) • Flawed & Unrepaired (*fit for continued service without repair*) • Replaced • Pre-emptively Replaced
Inspection Dates	For welds reported as flawed, the years of the most recent inspection, 2nd most recent inspection, and the year when the weld was first determined to contain a flaw. For unflawed welds, the year of the most recent inspection was provided.
Flaw Length	For flawed welds, flaw lengths were requested for the most recent inspection, the second most recent inspection and as sized at the time of flaw discovery.

Item	Discussion
Inspection Techniques and Coverage	For each inspection reported, the examination method (EVT-1, UT, VT-1, or VT-3) was requested, along with the coverage obtained.

3.2 Core Spray Piping Data Evaluation

This section summarizes the field data available for core spray piping welds and provides an evaluation of weld performance to date as indicated by the data. Each of these sections addresses a different aspect of core spray piping weld performance. Overall performance should not be judged based on any single performance aspect, but rather the consideration of all pertinent aspects of performance. The evaluations presented in the following subsections are referenced in Sections 5 and 6, which present technical bases for revision of the BWRVIP-18 inspection program.

3.2.1 Performance Summary

Tables 3-2 and 3-3 summarize IGSCC occurrence data for creviced and uncreviced 304SS core spray piping welds, respectively. Tables 3-4 and 3-5 summarize the IGSCC occurrence data for L-Grade creviced and uncreviced welds, respectively. In each of these tables, the column labeled "flawed" reports the percentage (and *quantity*) of welds determined to be flawed regardless of the current repair or replacement status (i.e., flaws identified are included in this total even if repaired or replaced). Fleet weld populations for each weld ID are based on an estimate of the total number of welds in the U.S. fleet considering typical design configurations for BWR/2, BWR/3-5, and BWR/6 plants, survey responses, and knowledge of the core spray materials of construction for each domestic plant.

For 304SS materials there have been a number of repairs, including both mechanical and welded designs, and replacements, specifically lower section replacements. To highlight these activities, Tables 3-2 and 3-3 contain two additional columns:

- The repaired / replaced column indicates the percentage (and *quantity*) of flawed locations that have been repaired or replaced.
- The quantity of unrepaired flaws remaining in service is the difference between the quantity shown in the flawed column and the quantity shown in the repaired / replaced column.
- The preemptive repair / replace column indicates the percentage (and *quantity*) of locations preemptively repaired or replaced

For L-Grade materials, there have been relatively few repair / replacement activities within the fleet to date. As a result, the "repaired / replaced" and "preemptive repair / replace" columns are not necessary for Tables 3-4 and 3-5.

The results illustrate that cracking of core spray welds is not widespread.

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The complete set of survey data is described in more detail in the following sub-sections.

Table 3-2
304SS Creviced Piping Weld Performance Summary

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Table 3-3
304SS Uncreviced Piping Weld Performance Summary

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Table 3-4
L-Grade Creviced Piping Weld Performance Summary

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Table 3-5
L-Grade Uncreviced Piping Weld Performance Summary

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3.2.2 Flaw Length Measurements (UT vs. EVT-1)

The survey data provided a number of instances where flaw lengths, observable by EVT-1, could be compared with crack lengths sized by UT. Table 3-6 summarizes flaw length information where flaw lengths were reported as measured by both UT and EVT-1, either in the same outage or in adjacent outages, with no more than two years separating the UT and EVT-1 measurements. Figure 3-1 graphically illustrates the resulting distribution. Data presented in Table 3-6 and Figure 3-1 include data points associated with exams performed more recently than 2000. Recent exams are more likely to provide precise information than earlier exams due to improvements in inspection technologies and procedures. Notably, welds meeting the criteria for inclusion in Table 3-6 and Figure 3-1 are all in 304SS piping systems.

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Table 3-6
Flaw Length Measurements – UT vs. EVT-1

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Table 3-7
Flaw Length Measurements – UT Length Measurements Not Visually Confirmed

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Figure 3-1
Core Spray Piping Flaw Length Measurement Ratios, UT vs. VT

3.2.3 Distribution of Flaw Lengths and Propensity for Crack Propagation

Figure 3-2 graphically presents the distribution of flaw length measurements for core spray piping welds for the 304SS creviced weld, 304SS uncreviced weld, and L-Grade weld data sets. Since different core spray designs use different piping diameters (5 inch Schedule 40 or 6 inch Schedule 40) and shroud collars have slightly larger dimensions that the associated piping, flaw sizes are presented as total length (in inches) rather than as percentages of circumference. For reference, the mid-wall circumference of 5 inch and 6 inch piping is 16.7 and 19.9 inches, respectively. A clear difference in the crack length distribution is observed between the data sets.

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Figure 3-2
Cumulative Distribution of Piping Flaw Length Measurements

3.2.4 IGSCC Occurrence Evaluation

Using the field data and knowledge of plant operating years, service times to flaw discovery can be estimated. Figure 3-3 illustrates the distribution of service times to flaw discovery by weld category; creviced 304SS, uncreviced 304SS, and L-grade. This figure presents raw data representing the number of years a plant operated prior to discovery of each flaw and does not account for the number of years a flaw may have existed prior to discovery.

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Figure 3-3
Distribution of Service Times to IGSCC Discovery

In evaluating the data, it was useful to estimate times to IGSCC initiation using IGSCC discovery dates, plant service life information, and generalized assumptions regarding crack growth. This approach offsets the effect of increased inspections, as occurred with BWRVIP-18 baseline examinations on reported cracking. This process was applied only to data points that include both the year in which the crack was first identified and a measurement of the crack length for that examination. It is relatively straightforward to calculate the number of years of service accumulated by the unit when each core spray piping crack was first identified. To estimate service time to initiation, a crack growth rate of $5x10^{-5}$ inches per hour was assumed for creviced welds and a crack growth rate of $2.5x10^{-5}$ inches per hour was assumed for uncreviced welds. These assumptions are reasonable and are supported by crack growth rate estimates presented in Figure 3-5.

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Service time to IGSCC flaw initiation can be roughly estimated using equation 3-1:

$$T_{ini}=T_{disc}-\frac{[l_f]}{[CGR][n]\left[8000\frac{hr}{yr}\right]}$$

Equation 3-1

Where;

> T_{ini} = *Estimated years of service to crack initiation*
>
> T_{disc} = *Estimated years of service to first crack discovery*
>
> l_f = *Flaw length when first discovered*
>
> *CGR = Crack growth rate*
> *($5x10^{-5}$ inches per hour for creviced welds and $2.5x10^{-5}$ inches per hour for uncreviced welds)*
>
> *n = 2 (number of growing crack tips)*

There are a number of uncertainties associated with this approach. First, the crack growth rates assumed are reasonable upper-end values. Review of the resulting times to initiation show the assumptions to be reasonable, since the calculated times to initiation are projected back to near plant start for some locations and few locations fall into "negative" years. Since multiple crack initiation sites are also known to occur, assumption of upper-end crack growth rate values is appropriate for the general purposes of this evaluation. Assumption of an upper-end crack growth rate also conservatively estimates late initiation times for recently identified cracking that may have existed for some years undetected. The result is a tendency to overestimate the number of recent IGSCC initiations.

Second, there are always uncertainties associated with flaw measurement, particularly with measurements made in the late 1980s and early 1990s when the industry had less experience with the application of NDE for detection of IGSCC in reactor internals.

Third, this approach generalizes service time to "years" of service based on the year in which the unit first began commercial operation and the year in which each flaw was detected. Also, service time is estimated at 8,000 hours of hot operating time for every year of commercial operation. For most cases, time has not been subtracted for extended outages. However, where substantial multi-year outage periods were identified these outages have been subtracted from the plant service times. It is recognized that variations occur in operating time from cycle to cycle. However, given other uncertainties associated with this evaluation, this assumption is reasonable. More detailed analysis of plant accumulated service times would not significantly increase the accuracy of the results.

In addition to these uncertainties, note that the data are drawn from a fleet of BWRs having a distribution of accumulated service times. For example, units having L-Grade piping have accumulated service in the range of 20 to 31 years. At higher accumulated service years, the data sets become increasingly sparse. Also note that for some flaws, the available data did not include a measurement of flaw length. These items are excluded from the initiation rate estimate plots (e.g., Figure 3-4).

Regardless of these uncertainties, this approach provides a reasonable way of illustrating crack initiation trends and judging weld performance. Figure 3-4 graphically illustrates the result, with creviced 304SS, uncreviced 304SS, and L-Grade piping welds plotted as separate data sets.

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Figure 3-4
Estimated Service Times to Crack Initiation vs. Percentage of Welds

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3.2.5 Crack Growth Rate Estimates

Where units reported flaw sizes for more than one refueling outage, changes in the flaw length over time can be used to estimate crack growth rates. This evaluation assumes 8,000 hours of hot operating time for every year of commercial operation. This generic assumption is conservative and tends to underestimate the actual operating time and thus overestimate the crack growth rate. A similar assumption has been previously applied by BWRVIP in other crack growth studies (e.g., BWRVIP-174, Rev.1 [10]). Flaw length data reported by the utilities is used without any adjustment (whether measured by UT or by EVT-1). This approach assumes that all flaws extend through-wall and are growing circumferentially around the pipe, including two crack "fronts" for growth. Crack growth rates are estimated as follows:

$$^{da}/_{dt} = (L_x - L_y)/(\Delta t * n)$$

Equation 3-2

da/dt = estimated crack growth rate

L_x = flaw length at year *x (inches)*

L_y = flaw length at year *y (inches)*

Δt = (x – y)(8,000 hours)

n = 2 (number of growing crack tips)

In the available data set, most flaws have only two length data points. In the few cases where three or more flaw length measurements were reported, the majority of these items include more than one inspection where no change in flaw length occurred. In recognition of the uncertainties associated with flaw length measurement and interpretation of the data, only one UT-based crack growth rate and / or one EVT-1 based crack growth rate was estimated for each flaw using the largest span of time possible. This approach minimizes the effect of measurement uncertainties. Figure 3-5 presents the resulting distribution of crack growth rates for the creviced 304SS, uncreviced 304SS, and L-Grade piping weld data sets.

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Figure 3-5
Distribution of Core Spray Piping Weld Crack Growth Rate Estimates

The crack growth estimates presented in Figure 3-5 should be viewed in light of limitations related to uncertainties in NDE technology application. Improvements in NDE technologies and refinements in analyzing UT results represent a significant uncertainty. The occurrence of many negative crack growth rates in the data likely is the result of applying new or improved NDE technologies. Where improved characterization and assessment occur for indications that have changed little, the result can be a "negative" crack growth rate. Even for flaws characterized relatively recently, some negative crack growth rates are seen. Another variable is that new crack initiation can "link-up" with existing cracks, thereby increasing the crack growth rate estimates.

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Figure 3-6
Estimated Crack Growth Rate vs. Mean Service Time (UT Exams of 304SS Welds)

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Figure 3-7
Estimated Crack Growth Rate vs. CGR Measurement Span Time

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3.2.6 BWRVIP-18 Program Effectiveness

Prior sections have focused on core spray piping weld performance. An additional area that should be considered is the effectiveness of the BWRVIP-18 inspection program since implementation. Figure 3-8 presents the percentage of welds identified to have flaws vs. the year of initial discovery. Figure 3-9 plots the measured flaw length at discovery against the year of discovery.

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Figure 3-8
Timeline of Core Spray Piping Weld Flaw Discovery

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Figure 3-9
Timeline of Core Spray Piping Weld Flaw Length Measurements

3.3 Core Spray Sparger IGSCC Data Evaluation

This section summarizes the field data available for core spray sparger welds and provides an evaluation of weld performance to date as indicated by the data. The data and evaluations presented in the following subsections are referenced in sections 5 and 6, which present technical bases for revision of the BWRVIP-18 inspection program.

3.3.1 Performance Summary

Table 3-8 summarizes the IGSCC occurrence data for major sparger welds (S1, S2 and S4). Table 3-9 summarizes the IGSCC data for minor sparger welds (S3a, S3b, and S3c). The distribution of flaw lengths for major sparger welds S1 and S2 is shown in Figure 3-10.

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Table 3-8
Major Sparger Weld Performance Summary

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Table 3-9
Minor Sparger Weld Performance Summary

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Figure 3-10
Cumulative Distribution of Major Sparger Weld Flaw Length Measurements

3.3.2 IGSCC Occurrence Evaluation

Using the field data and knowledge of plant operating years, service times to flaw discovery can be estimated. Figure 3-11 illustrates the overall distribution of service times to flaw discovery for major sparger welds S1 and S2.

Similar to the approach taken for core spray piping welds (see section 3.2.4), a plot of service time to initiation vs. percentage of welds cracked can be developed for major sparger welds. This evaluation includes only data for S1 and S2, since there has been no reported cracking of the S4 weld. Assuming a crack growth rate of $5x10^{-5}$ inches per hour and 8,000 hours per year of hot operating time, service time to IGSCC flaw initiation for sparger welds is roughly estimated using equation 3-2:

$$T_{ini} = T_{disc} - \frac{[l_f]}{[CGR][n]\left[8000\frac{hr}{yr}\right]}$$

Equation 3-3

Where;

T_{ini} = *Estimated years of service to crack initiation*

T_{disc} = *Estimated years of service to first crack discovery*

l_f = *Flaw length when first discovered*

CGR = Crack growth rate (5x10^{-5} inches per hour)

n = 2 (number of growing crack tips)

Figure 3-12 presents the resulting service time to initiation estimates.

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Figure 3-11
Distribution of Service Times to IGSCC Discovery (Sparger Welds S1 & S2)

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Figure 3-12
Estimated IGSCC Initiation Times vs. Percentage of Welds (Sparger Welds S1 & S2)

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3.4 Core Spray Sparger and Piping Bracket IGSCC Data Evaluation

This section summarizes the field data available for core spray piping and sparger brackets and provides an evaluation of weld performance to date as indicated by the data. The data and evaluations presented in the following subsections are referenced in sections 5 and 6, which present technical bases for revision of the BWRVIP-18 inspection program.

3.4.1 Performance Summary

Table 3-9 summarizes the results for BWR/2-5 welded sparger brackets.

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Table 3-10
BWR/2-5 Sparger Bracket (SB) Weld Performance Summary

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Figure 3-13
Cumulative Distribution of Flaw Length Measurements for Shroud Cracking Associated with Sparger Bracket Welds (BWR/2-5)

3.4.2 IGSCC Occurrence Evaluation

Using the field data and knowledge of plant operating years, service times to flaw discovery can be estimated. Figure 3-14 illustrates the overall distribution of service times to flaw discovery for cracking associated with sparger brackets.

Similar to the approach taken for core spray piping welds (Section 3.2.4) and major sparger welds (Section 3.3.2), a plot of service time to initiation vs. percentage of welds cracked can be developed for the observed sparger bracket cracking. Assuming a crack growth rate of 5×10^{-5} inches per hour and 8,000 hours of hot operating time for every year of commercial operation, service time to IGSCC flaw initiation for sparger bracket cracking is roughly estimated using equation 3-3:

$$T_{ini} = T_{disc} - \frac{[l_f]}{[CGR][n]\left[8000\frac{hr}{yr}\right]}$$

Equation 3-4

Where;

T_{ini} = *Estimated years of service to crack initiation*

T_{disc} = *Estimated years of service to first crack discovery*

l_f = *Flaw length when first discovered*

CGR = Crack growth rate ($5x10^{-5}$ *inches per hour)*

n = 2 (number of growing crack tips)

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Figure 3-14
Distribution of Service Times to IGSCC Discovery (BWR/2-5 SB Welds)

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Figure 3-15
Estimated Service Times to Initiation vs. Percentage of SB Welds (BWR/2-5)

3.5 NDE Data Summary

This section presents an evaluation of typical NDE coverage obtained for the various core spray welds. This information is used in Sections 5 and 6 to support inspection program revisions.

Figures 3-16 through 3-20 present the distribution of EVT-1 coverage values obtained for various areas within the core spray system including the tee to tee-box region, pipe to elbow locations, pipe couplings, shroud connection locations, and sparger welds. These distribution plots include data associated with inspections performed in 2008, 2009, and 2010 using coverage rules consistent with BWRVIP-03 Revision 10 [1]. The importance of EVT-1 coverage is considered to be greatest for locations where high coverage UT techniques are not available or where one-sided UT plus supplemental EVT-1 is used as a basis for using UT reinspection intervals. Specifically, coverage associated with BWR/3-5 P2 / P3, P8a / P4d, and P8b locations is important because of the use of this information to support weld integrity evaluations presented in Section 6.2.

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Figure 3-16
Distribution of EVT-1 Coverage for Core Spray Piping Tee Locations

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Figure 3-17
Distribution of EVT-1 Coverage for Core Spray Piping Elbow Locations

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Figure 3-18
Distribution of EVT-1 Coverage for Core Spray Piping Coupling Locations

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Figure 3-19
Distribution of EVT-1 Coverage for Core Spray Piping Shroud Connection Locations

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Figure 3-20
Distribution of Visual Coverage for Core Spray Sparger Locations

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Figure 3-21
Distribution of UT Coverage for Selected Core Spray Piping Locations

4
FLAW TOLERANCE EVALUATION

4.1 Introduction

Generic flaw tolerance evaluations were performed for core spray piping welds and sparger bracket welds. These evaluations assume an initial crack size and calculate the time required for the crack to grow to a size that challenges the structural integrity of the component given certain assumed loads. The flaw tolerance evaluations summarized in this section are not intended to represent the sole or primary basis for any proposed inspection interval. Rather, the results of these evaluations are used to complement other technical bases associated with evaluation of field data and component integrity assessment. Loading conditions used in the evaluations are believed to be representative of the majority of the fleet, but are not necessarily bounding. A generic evaluation for a piping weld is presented in Section 4.2. The sparger bracket analysis is described in Section 4.3. The results are referenced later in Section 5 where the technical bases for revised inspection intervals are presented.

4.2 Core Spray Piping Welds

A series of evaluations were performed to parametrically characterize the flaw tolerance capability of core spray piping. The evaluations considered variations in applied stresses, core spray piping size (5-inch and 6-inch NPS), material of construction (304SS and L-Grade), loading conditions (normal, upset, and faulted), and flaw size and distribution. The core spray piping flaw tolerance analysis results presented below assume the following:

1. Material Configuration & Properties:
    - o 5 inch NPS, schedule 40 piping
    - o 304SS, S_m = 16.9 ksi
    - o Flux-based welds (*Z factor of 1.2*)
2. Loading Conditions (*typical for core spray piping*):
    - o P_m = 0.5 ksi (*membrane stress*)
    - o P_e = 5 ksi (*expansion stress*)
    - o P_b values of 1, 3, and 5 ksi[1] (*bending stress*)
    - o Normal and upset conditions (*safety margin = 2.78*)

---

[1] Values of P_b were parametrically analyzed.

IGSCC behavior:

- Crack growth at $5x10^{-5}$ inches per hour
- Growth of two cracks with four growing crack tips, each at a crack growth rate of $5x10^{-5}$ inches per hour (See Figure 4-1)

The assumed membrane stress (P_m = 0.5 ksi) and thermal expansion stress (P_e = 5.0 ksi) represent reasonable mid-range values and are based on review of a sample of stress reports. Primary bending stress was found to have the most substantial effect on the flaw tolerance results. Primary bending (P_b) stress values of 1, 3, and 5 ksi were varied to include representative low-end, mid-range, and high-end values that were identified by review of a sample of stress reports. There is significant variation P_b across different units as a result of the location-specific nature of seismic loading inputs. In most cases, LEFM analysis was not controlling. As a result, only limit-load failures were considered.

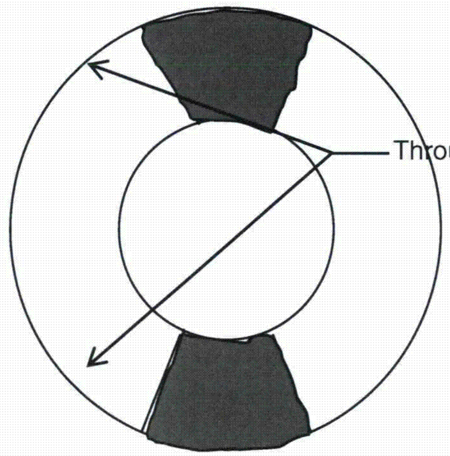

Figure 4-1
Assumed Core Spray Piping Flaws, Two Flaws with Four Growing Crack Tips

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Table 4-1
Generic Core Spray Piping Flaw Tolerance Evaluation Results

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Additional calculations were performed to simulate field inspections in which various amounts of coverage were achieved and no cracking was observed. In these analyses, it was assumed that 10% of the uninspected area was flawed. Crack growth was assumed to continue until ASME Code structural margin requirements were violated. The three cases shown (40%, 75% and 95% coverage) are typical of the range of coverage percentages reported. Table 4-2 highlights the results.

Table 4-2
Effect of Examination Coverage on Flaw Tolerance Results

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In discussing the applicability of the foregoing evaluation, the conservative nature of the input assumptions and approach merit discussion. Regarding crack growth, a significant conservatism applied to crack growth is the assumption of a crack growth rate equal to $5x10^{-5}$ inches per hour. This crack growth rate was established for the purpose of evaluating crack growth of existing flaws, and not for estimating inspection intervals. Additionally, assessment of crack growth rates using survey data indicates that $5x10^{-5}$ inches per hour remains a reasonable upper-end estimate of the crack growth rates potentially occurring in the field. The application of lower CGRs to this analysis would result in linearly greater inspection intervals.

Further, field inspection data indicate that the majority of IGSCC indications currently in service for core spray pipe weld HAZs are not growing, or are growing very slowly. While substantial crack growth has occurred in the HAZ of some core spray piping welds, the typical pattern is for the crack growth to slow and likely arrest as the crack tip moves from a higher stress region to a lower stress region. If more accurate "median" CGRs were assumed rather than assuming crack growth at a constant $5x10^{-5}$ inches per hour, inspection intervals exceeding 12 years could be analytically justified for most locations.

Assumption of two separate growing cracks with four crack tips actively growing at $5x10^{-5}$ inches per hour during the entire duration of the inspection interval is a second conservative assumption. To occur, the cracks must be sufficiently far apart and in the same plane of the

HAZ such that a critical crack size is reached before the two crack tips grow together. Any sub-optimal positioning of the assumed flaws or reduction in the crack growth rate as flaw sizes increase and stresses are relieved would extend the time required to reach a critical crack size.

4.3 Sparger Brackets

The survey results identified a number of cracks associated with SB locations, many of which have significant length. For many units, sparger brackets consist of a thick stainless steel plate, fillet welded to the shroud ID. Figure 4-2 illustrates a typical sparger bracket. These structures have substantial structural integrity and are subject to relatively limited loadings. A sample evaluation was performed to characterize flaw tolerance capability for an assumed stress[2] to assess the reasonableness of the proposed inspection interval. What follows is a summary of the approach, along with discussion regarding the application of the results.

Input conditions to the analysis include:

1. Material Configuration & Properties:
   - 304SS, $\sigma_y = 18.9$ ksi, $\sigma_u = 63.4$ ksi
2. Loading Conditions:
   - $P_m = 2.26$ ksi
   - $P_m + P_b = 5.34$ ksi for the level D seismic[3] condition (*safety factor = 1.39*)
3. IGSCC behavior:
   - Existing 2 inch thru-thickness crack in sparger bracket
   - Crack is located mid-bracket (*and two growing crack tips are assumed*)
   - Crack growth at 5×10^{-5} inches per hour
4. Limit-load equations apply

[2] Applied stress value taken from a representative plant evaluation.

[3] The analysis was performed assuming a Level D seismic event. However, the result is essentially the same as would be obtained if a Level B (upset) event were assumed. The Level D seismic loading is generally twice that for the Level B event, but the structural factor is half as much (1.39 vs. 2.78). Therefore, the results are similar.

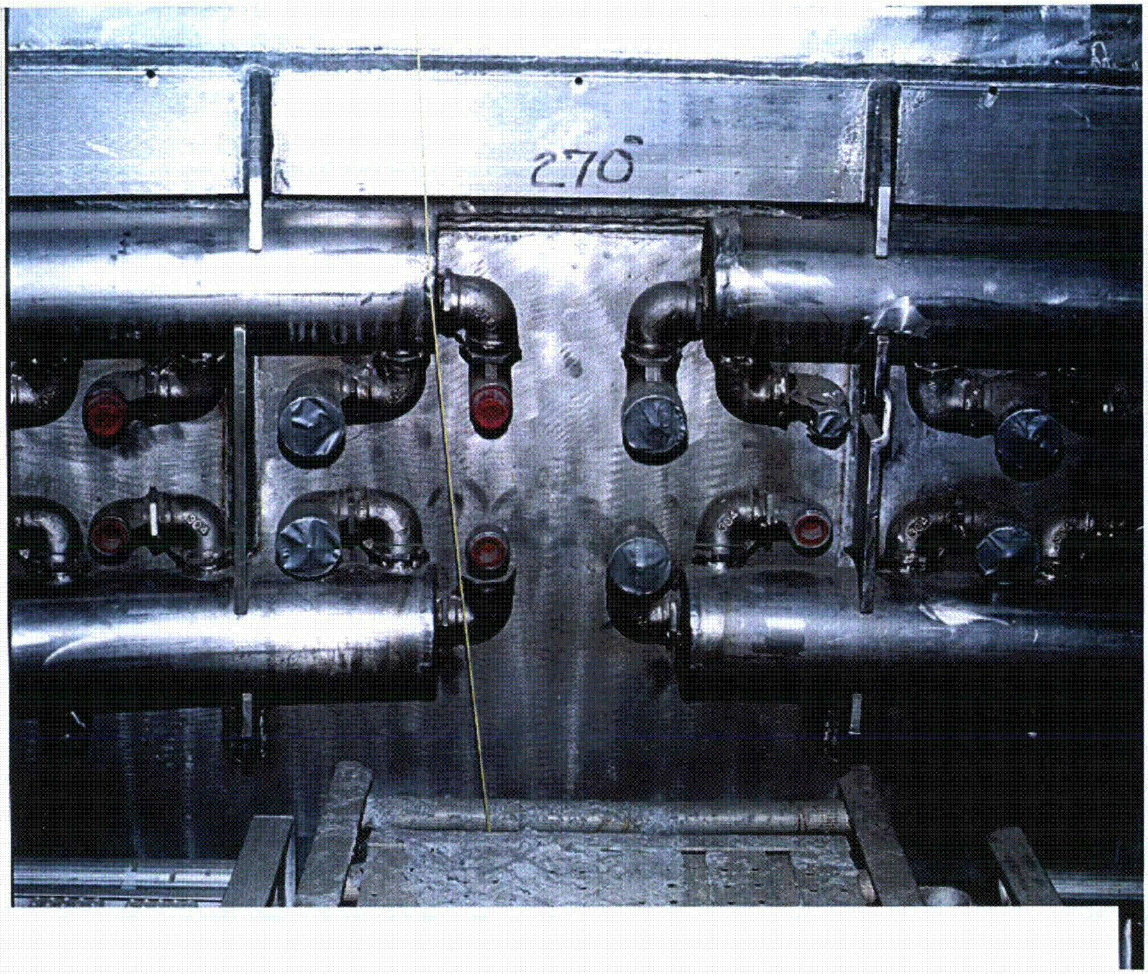

Figure 4-2
Typical Core Spray Sparger & Bracket

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As with the piping analysis, this evaluation includes significant conservatisms associated with crack growth rate, crack location, and crack size. Regarding crack growth, the use of $5x10^{-5}$ inches per hour in the evaluation is conservative, since this value represents a bounding CGR. The use of lower, "median" CGRs would linearly increase the resulting allowable inspection intervals. Regarding crack location, all of the reported sparger bracket cracks are in the shroud-side HAZ and not the bracket itself. Cracking in a shroud-side HAZ has substantially less effect on structural integrity than the assumed cracking in the bracket itself. Further, the cracking is assumed to be in the middle of the bracket, such that crack extension is postulated for both crack tips. Regarding crack size, the crack is assumed to be thru-bracket, indicating a deep crack that extends along the length of the bracket.

Evaluation of cracking in the should-side HAZ would indicate substantially higher structural margins than the evaluation described above. Cracking of the shroud side HAZ would have to

both undercut the weld and extend nearly the entire length of the weld to compromise the structural integrity of the bracket. Only a small amount of uncracked ligament would be necessary to maintain the structural function of the bracket. Further, there is no evidence that cracking that undercuts the weld can occur. Stress evaluation indicates that the cracks are expected to extend radially into the shroud and to be shallow; not extending thru the shroud wall.

5
TECHNICAL BASES FOR CHANGES TO INSPECTION METHODS AND INTERVALS

5.1 Unflawed Weld Inspection Strategy Technical Bases

5.1.1 Creviced and Tee Box-to-Pipe Welds

304SS Piping

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Because the proposed inspection frequency for creviced piping weld locations can be defended independently by either flaw tolerance / crack growth evaluation or by initiation rate evaluation, the BWRVIP maintains that there is a firm basis for concluding that the proposed inspection intervals provide reasonable assurance that the core spray internals will continue to perform their intended function.

L-Grade Piping

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Finally, the implementation of longer inspection intervals for creviced L-Grade core spray piping welds is mitigated by more stringent and comprehensive supplemental examination and scope expansion requirements that are proposed (see Section 6). Should the evaluation of future inspection data indicate a clear fleet-wide adverse trend in IGSCC initiation for L-Grade core spray piping weld HAZs, then actions will be taken to revise the re-inspection program for 304L and 316L core spray piping system weld HAZs as appropriate.

5.1.2 Uncreviced (Rotating Sample) Welds

The inspection program proposed for uncreviced welds requires either more frequent inspection, or unchanged inspection intervals. As such, only limited technical basis information is provided.

304SS Piping

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L-Grade Piping

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Additional discussion of L-Grade core spray piping weld performance is provided in the basis discussion for creviced welds (Section 5.1.1).

5.1.3 Welds with Evidence of Heavy Grinding

BWRVIP-18-A specifically included welds having evidence of heavy grinding, whether creviced or uncreviced, in the group of welds requiring the most frequent inspection. This approach was appropriate at the time because grinding is known to cause local work hardening and increase the propensity for crack initiation. However, there are a number of factors in favor of removing the category.

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Based on the currently available data, no technical basis exists for continuing to maintain this category and there is no evidence indicating that elimination of this category will have an adverse effect on management of core spray internals.

5.1.4 Piping Brackets

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5.1.5 Fastener Lock Welds (BWR/6 location P8, BWR/6 Sparger Brackets)

The BWR/6 shroud to core spray pipe connection uses a mechanical assembly instead of structural welds.

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VT-3, as currently defined by ASME Section XI, paragraph IWA-2213 includes camera resolution requirements sufficient to verify the integrity of the hardware and associated tack welds.[4] High resolution VT-1 or EVT-1, intended for detection and characterization of tight IGSCC cracks, are not necessary to verify the structural integrity of the assembly.

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[4] Unless specific criteria are met, tack weld cracking is not considered to be a detrimental condition. See Section 6.1.2, addressing supplemental examination and scope expansion requirements for additional discussion.

5.1.6 Sparger Major Welds (S1, S2, S4)

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5.1.7 Rotating Sample of Other Sparger Welds (S3a, S3b, S3c)

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5.1.8 BWR/2-5 Welded Sparger Brackets

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5.2 Flawed Weld Inspection Strategy Technical Bases

Currently, BWRVIP-18 requires inspection of all core spray piping welds having prior cracks every refueling outage if inspected by EVT-1 and every other refueling outage if inspected by UT. The current requirement is overly conservative for locations where plant-specific analyses using appropriate safety margins and conservative assumptions show that longer inspection intervals are appropriate. These plant specific analyses should be used as the basis for defining an inspection interval as is done in most other BWRVIP inspection & evaluation guidelines (e.g., core shroud, jet pump, LPCI, etc.) that have been reviewed and approved by NRC.

As a result, the proposed program allows for development of plant-specific inspection intervals based on plant-specific analysis. However, there are several limitations imposed:

- Inspection intervals for core spray piping welds may not exceed the intervals allowed for creviced 304SS piping welds. This is a reasonable limitation because the inspection frequencies established for creviced 304SS piping welds is supported by flaw tolerance evaluation.
- Initial reinspection of a newly identified crack must occur in the next refueling outage if inspected by EVT-1 or within two refueling outages if inspected by UT. This criteria ensures that new cracks are reexamined once before allowing inspection intervals based on a plant specific analysis.
- If unexpected crack growth is detected (i.e., growth exceeding 5×10^{-5} inches per hour), then the weld must again be reexamined in the next refueling outage if inspected by EVT-1 or within two refueling outages if inspected by UT. This provision ensures that extensive time is not allowed between inspections if high crack growth rates are observed.

Plant-specific crack growth rates may not be used. A bounding rate of 5×10^{-5} inches per hour is to be used for all analyses.

6
TECHNICAL BASES FOR CHANGES TO OTHER PROGRAM ELEMENTS

6.1 Supplemental Examination and Scope Expansion Criteria Technical Bases

6.1.1 Supplemental Examination

The baseline examination discussion in BWRVIP-18 Revision 1 [1] provides the following guidance regarding supplemental examination of core spray piping:

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Although implied, these requirements are not explicitly repeated for reinspection. The proposed program clarifies that these requirements apply to reinspection of core spray piping welds.

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6.1.2 Scope Expansion

Proposed changes to scope expansion criteria increase the specificity of the scope expansion criteria. BWRVIP-18 currently specifies scope expansion as follows:

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Proposed scope expansion criteria specify a primary expansion set and a secondary expansion set (described in Section 7.3.2). The specification of primary and secondary expansion set criteria is considered to be a clarification of the existing wording in BWRVIP-18 and does not represent a significant program revision.

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6.2 "Credit for UT Inspection Interval" Technical Bases

The allowed inspection intervals for many welds are longer if UT is used for the inspection rather than EVT-1. The BWRVIP has taken the position that, in order to obtain the longer intervals, both sides of the weld must be inspected by UT. It has become apparent however, that for certain welds, a combination of UT from one side supplemented by a thorough EVT-1 from the other can yield considerable information about the condition of the weld. This section justifies, for selected welds, the use of UT-based inspection intervals when only one side of the weld is inspected by UT.

6.2.1 Background

BWRVIP-18 Revision 1 does not specify any requirements for minimum inspection coverage. However, beginning in 2006, there was a growing recognition that two-sided UT is necessary to effectively detect and characterize indications in both HAZs associated with a circumferential weld in a piping shape. BWRVIP-03, Revision 13 [1] addresses this issue directly in Section 2.6, Para. 7.3, "Beam Direction:

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The current BWRVIP position regarding UT credit for one-sided UT exams of core spray piping is summarized as follows:

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Where mixed UT and EVT-1 are applied as described in BWRVIP-03 to the two HAZs of a core spray piping weld location, EVT-1 of the weld must be performed on the EVT-1

inspection interval. This approach discourages the development and application of high coverage UT. If the "non-UTed" side of the weld has to be inspected with EVT-1 on a more frequent schedule than the UT side, it is efficient for plants to elect to inspect both sides with EVT-1 on the more frequent schedule and avoid UT altogether.

The BWRVIP believes that it is important to promote the application of high coverage UT and to allow appropriate credit for combined application of UT and supplemental EVT-1. As a result, the revised inspection program summarized in Chapter 7 includes a set of weld location specific conditions that if met, are considered adequate to justify use of the longer UT-based inspection intervals even if the UT inspection interrogated only one side of the weld. See Table 7-6. This guidance will both promote the application of UT to core spray piping welds, resulting in improved data for use in future analyses, and benefit utilities by reducing the number of EVT-1 exams required for core spray piping.

The following sections discuss the basis for allowing credit for UT-based inspection intervals for certain core spray piping locations where mixed UT/EVT-1 inspections are performed. In each of these cases, UT is possible from one side of the weld only, resulting in the need for supplemental EVT-1 on the visual examination inspection frequency.

6.2.2 Uncreviced Pipe and Pipe to Elbow Butt Welds (P4a, P4b, P4c)

The P4a, P4b, and P4c locations are common to all BWRs. These locations are uncreviced piping to elbow butt welds.

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Therefore, if the coverage criteria contained in Table 7-6 are met, there is a reasonable basis for using the UT-based inspection intervals for welds P4a, P4b, and P4c.

6.2.3 BWR/3-5 P2 and P3 Welds

The BWR/3-5 piping tee box includes piping welds, P3, and the cover plate partial penetration weld, P2. Figure 6-1 illustrates the configuration of these welds. BWRVIP-18 notes the following for the P2 and P3welds:

"*For weld P2, a crevice is assumed due to the fit-up ledge designed into the weld location, which may not have been consumed during welding.... The P3 connection would tend to see high stresses if cold pulling were done to achieve final positioning of the piping during installation.*"

Due to a lack of two-sided UT coverage, the existing BWRVIP-18 program requires examination by EVT-1 every outage and the far side HAZ must be examined by EVT-1 on a schedule consistent with visual examination.

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Therefore, if the coverage criteria contained in Table 7-6 are met, there is a reasonable basis for using the UT-based inspection intervals for BWR/3-5 welds P2 and P3.

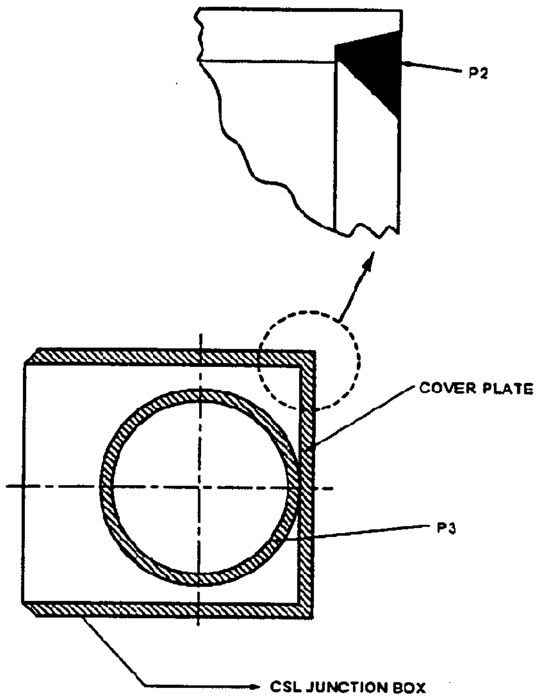

Figure 6-1
BWR/3-5 Tee Box Welds P2 and P3

6.2.4 BWR/6 P2a / P2b Tee Region

The BWR/6 P2a and P2b tee welds are shown in Figure 6-2.

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Therefore, if the coverage criteria contained in Table 7-6 are met, there is a reasonable basis for using the UT-based inspection intervals for BWR/6 welds P2a and P2b.

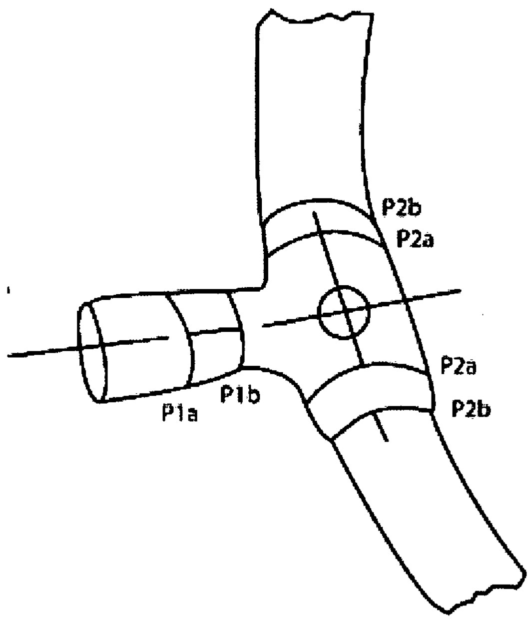

Figure 6-2
BWR/6 P2a & P2b Welds

6.2.5 BWR/3-5 P4d / P8a Weld Region

The P8a and P4d weld area is shown in Figure 6-3. P8a is the weld joining the shroud collar and the inlet pipe section. P4d is the weld joining the lower elbow and inlet pipe section. Inspection results have shown that the downstream side of the P4d weld and the upstream side of the P8a weld tend to run together, with weld metal bridging the area between these two welds. Although not a piping weld, P8a integrity is important because the P9 weld joining the inlet pipe to the sparger tee box is hidden and its condition is unknown.

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Therefore, if the coverage criteria contained in Table 7-6 are met, there is a reasonable basis for using the UT-based inspection intervals for BWR/3-5 welds P8a and P4d.

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Figure 6-3
BWR/3-5 P4d, P8a, and P8b Welds (Shroud Collar Region)

6.2.6 BWR/3-5 P8b Weld

The P8b weld is shown in Figure 6-3. P8b is the weld joining the collar to the core shroud. Although not a piping weld, P8b integrity is important because the P9 weld joining the inlet pipe to the sparger tee box is hidden and as a result, its condition is unknown.

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Therefore, if the coverage criteria contained in Table 7-6 are met, there is a reasonable basis for using the UT-based inspection interval for BWR/3-5 weld P8b.

7 SUMMARY OF REVISED INSPECTION REQUIREMENTS

Sections 7.1 through 7.4 provide a summary of the proposed revision to the BWRVIP-18 Revision 1 [7] inspection criteria for core spray internals. The proposed revisions address not only inspection schedules for unflawed welds, but also inspection requirements for flawed welds, supplemental examination and scope expansion criteria, and new guidance for application of UT vs. EVT-1 inspection intervals. Technical bases supporting these changes were discussed previously in Chapters 5 and 6.

7.1 Proposed Unflawed Weld Inspection Strategy

Significant changes to the core spray piping and sparger inspection strategy include:

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Table 7-1 and Table 7-2 present the proposed new inspection strategy for core spray piping and sparger, respectively. These tables also include the comparable program elements from the current program in BWRVIP-18. For easy reference, Table 7-3 lists the core spray piping

welds that fall into the categories of "creviced" and "uncreviced" for the three major BWR classes.

Additional inspection strategy changes that may not be readily observed in Tables 7-1 and 7-2 include a change to the inspection interval definition and a clarification of the intent of rotating sample provisions.

BWRVIP-18 currently specifies inspection intervals based on operating cycles. The proposed new criteria use a time-based specification of inspection intervals. This change has the effect of allowing plants with 18-month fuel cycles to inspect less frequently. For example, the current requirement of inspection of rotating sample population welds every 4th cycle results in an inspection interval of 6 years for plants on 18-month fuel cycles. Using the new time-based criterion, the inspection interval would be 8 years, and inspection would be required every 5th cycle. For locations having 16-year inspection intervals, plants on 18-month fuel cycles would inspect every 10th outage, rather than every 8th outage as required by the current program.

Additionally, BWRVIP-18 provides a "25% rotating sample" provision for uncreviced pipe to pipe and pipe to elbow welds. Inspection of 25% of the population is required every inspection interval. This approach does not specifically preclude "reordering" of weld locations (i.e., rearrangement of the welds in the 1st, 2nd, 3rd, and 4th sample sets from one interval to another). The revised program adopts a "50% rotating sample" provision for some welds. This revised rotating sample provision requires inspection of 50% of the weld population in each half of the re-inspection interval. Since reordering would double the time interval between inspections, reordering of welds in 50% rotating sample sets is not allowed.

Table 7-1
Program Comparison: Inspection of Unflawed Core Spray Piping Weld

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Table 7-2
Program Comparison: Inspection of Unflawed Core Spray Sparger Welds

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Table 7-3
Core Spray Piping Weld Categories

Weld Category	BWR/2	BWR/3-5	BWR/6
Creviced and tee box to pipe welds: "creviced" welds			
Tee Box Region	N/A	P2, P3	N/A
Coupling	P5, P6, P7	P5, P6, P7	P3a, P5
Shroud Connection	P8	P8a, P8b	N/A
Rotating sample of other piping welds: "uncreviced" welds			
Tee Region	P2, P3a, P3b	N/A	P1a, P1b, P2a, P2b
Pipe-to-elbow welds	P4a – P4i	P4a, P4b, P4c, P4d	P4a, P4b, P4c, P4d
Pipe-to-coupling welds	N/A	N/A	P3b, P6
Fastener Lock Welds			
Piping to Shroud Connection	N/A	N/A	P8

7.2 Proposed Flawed Weld Inspection Strategy

Under the existing program, structural welds with flaws must be reexamined every 2 years if inspected by EVT-1 or every 4 years if inspected by UT. The revised program allows reinspection intervals for flawed structural welds to be assessed using plant-specific flaw evaluations. However, reinspection intervals may not exceed those established for unflawed welds.

Table 7-4 compares the revised program requirements with the existing BWRVIP-18 program requirements.

Table 7-4
Program Comparison: Reinspection of Welds Having Prior Cracks

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7.3 Proposed Supplemental Examination and Scope Expansion Criteria

7.3.1 Supplemental Examination of Core Spray Piping Welds

For core spray piping welds, both visual and volumetric examination technologies may be effectively applied. When flaws are detected, the application of an additional examination method can provide relevant supplemental information regarding the size and location of the flaw.

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Table 7-5 presents the proposed supplemental examination requirements for core spray piping welds and compares these proposed requirements with the existing program requirements.

Technical basis discussion supporting these supplemental examination criteria is provided Section 6.1.1.

Table 7-5
Program Comparison: Supplemental Examination of Core Spray Piping Welds

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7.3.2 Scope Expansion

The existing BWRVIP-18 program does not include any requirements regarding sample expansion when new flaws are identified. Scope expansion provides an effective method to ensure that when new or unexpected cracking occurs, similar locations are examined in a proactive manner. This approach supports the use of longer inspection frequencies by ensuring that if significant new cracking occurs, the scope of the cracking is assessed in a reasonable time. The new proposed program includes the following scope expansion elements for major structural welds:

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Technical basis discussion supporting these scope examination criteria is provided in Section 6.1.2.

7.4 Credit for UT Inspection Intervals

Current approaches documented in BWRVIP-18 and in BWRVIP-03 [1] require that UT examination intervals can be credited only when UT has been performed from the near side of the weld. Where two-sided UT is not performed, any HAZ not examined by UT must be examined by EVT-1 on the visual examination inspection schedule. The proposed program provides for the use of UT inspection intervals for select core spray piping locations where two-sided UT is not possible, but a substantial basis for component integrity exists based on a combination of UT and EVT-1 inspection. Table 7-6 outlines the proposed criteria. Technical basis discussion supporting these criteria is provided Section 6.2.

Table 7-6
Proposed Criteria for Use of UT Inspection Intervals

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Table 7-6 (continued)
Proposed Criteria for Use of UT Inspection Intervals

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8 CONCLUSIONS

This report described a revision to the BWRVIP core spray piping and sparger inspection and evaluation guidelines. The existing guidelines (BWRVIP-18, Revision 1 [7]) were reviewed in light of extensive field inspection data that has been accumulated for over 15 years. For many weld locations, it was found that the current inspection frequency was overly conservative and longer intervals could be tolerated with no adverse safety consequences. In other instances, it was found that the existing frequencies should be reduced based on available inspection data.

The proposed revision extends inspection intervals where appropriate, most notably for creviced and tee box-to-pipe piping welds and for sparger welds. Conversely, the proposed program retains the inspection intervals for rotating sample welds, and shortens the inspection interval permitted for rotating sample welds in L-Grade piping systems.

Additional provisions of the proposed program offer counterbalances to increased inspection intervals. The proposed program includes more detailed supplemental examination criteria, scope expansion criteria when new cracks are identified (previously not required), and minimum coverage requirements for using UT inspection intervals. Finally, where supported by component integrity bases, the proposed program permits the use of UT-based inspection intervals where only one-sided UT with supplemental EVT-1 is possible.

Appropriate adjustments were made to all inspection frequencies. The result is a revised program supported by field data that offers a substantial reduction in core spray internals inspections while maintaining an appropriate level of safety. This revised inspection program will be incorporated into a revision to BWRVIP-18 which will be submitted to the NRC for review.

9 REFERENCES

1. *TR-105696-R13 (BWRVIP-03) Revision 13: BWR Vessel and Internals Project, Reactor Pressure Vessel and Internals Examination Guidelines.* Electric Power Research Institute, Palo Alto, CA: 2010. 1021007.
2. *BWRVIP-06, Revision 1-A: BWR Vessel and Internals Project, Safety Assessment of BWR Reactor Internals.* Electric Power Research Institute, Palo Alto, CA: 2009. 1019058.
3. *BWRVIP-14-A: BWR Vessel and Internals Project, Evaluation of Crack Growth in BWR Stainless Steel RPV Internals.* Electric Power Research Institute, Palo Alto, CA: 2008. 1016569.
4. *BWRVIP-16-A: BWR Vessel and Internals Project, Internal Core Spray Piping and Sparger Replacement Design Criteria.* Electric Power Research Institute, Palo Alto, CA: 2005. 1012113.
5. *BWRVIP-18: BWR Vessel and Internals Project, BWR Core Spray Internals Inspection and Flaw Evaluation Guidelines.* Electric Power Research Institute, Palo Alto, CA: 1996. TR-106740.
6. *BWRVIP-18-A: BWR Vessel and Internals Project, BWR Core Spray Internals Inspection and Flaw Evaluation Guidelines.* Electric Power Research Institute, Palo Alto, CA: 2005. TR-1011469.
7. *BWRVIP-18, Revision 1: BWR Vessel and Internals Project, BWR Core Spray Internals Inspection and Flaw Evaluation Guidelines.* Electric Power Research Institute, Palo Alto, CA: 2008. 1016568.
8. *BWRVIP-48-A: BWR Vessel and Internals Project, Vessel ID Attachment Weld Inspection and Flaw Evaluation Guidelines.* Electric Power Research Institute, Palo Alto, CA: 2004. 1009948.
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11. *BWRVIP-236: BWR Vessel and Internals Project, Inspection Optimization Program Roadmap.* Electric Power Research Institute, Palo Alto, CA: 2010. 1020730.
12. *BWRVIP-242: BWR Vessel and Internals Project, BWRVIP Inspection Trends, 2010 Update.* Electric Power Research Institute, Palo Alto, CA: 2010. 1020996.

13. *Primary System Corrosion Research Program: EPRI Materials Degradation Matrix, Revision 2*. Electric Power Research Institute, Palo Alto, CA: 2010. 1020987.

14. IE Bulletin 80-13. "*Cracking in Core Spray Spargers*," U.S. NRC. 1980.

15. Nuclear Energy Institute (NEI) 03-08 Revision 2, *Guideline for the Management of Materials Issues*, January 2010.

16. Title 10, United States Code of Federal Regulations, Part 54, "*Requirements for Renewal of Operating Licenses for Nuclear Power Plants*." U.S. Nuclear Regulatory Commission: May 1995.

A
SURVEY DATA

Appendix A contains the field inspection and NDE capability data collected through a survey of domestic BWRs. Core spray data was received for every US BWR, including some data for every core spray weld. The information requested included the current status of all major welds (unflawed, flawed, repaired, replaced). Where welds have identified flaws, repairs, or have been replaced, additional data was requested regarding the flaw length and age. The survey also requested information on typical inspection coverage percentages that were reported for each weld. EVT-1 coverage results are reported as the total coverage for the weld, including all heat affected zones. UT coverage may be reported as either two-sided or one-sided. Where UT coverage is reported as one-sided, the weld HAZ zone associated with the UT exam coverage is noted. Where a number of NDE coverage values are available, the NDE data is reported in a histogram format.

Detailed results are presented on a weld-by-weld basis in Sections A.1 and following. Those sections contain an evaluation of the percentages of welds found to be cracked ("Performance Summary") followed by a table listing details of the flawed welds ("Indication Summary"). Table A-1 lists terms used in the Performance Summaries and Tables A-2 and A-3 list terms used in the Indication Summaries.

Tables A-4 through A-8 provide a quick reference to information on all flaws reported.

Information presented in this appendix represents the independent input of U.S. utilities based on a survey process. As a result, the level of detail presented is not always consistent.

Table A-1
Weld Performance Summary Table Content & Meaning

Column Heading	**Meaning**
Material	Separate rows are provided for 304SS and L-Grade materials.
Percentage (*quantity*) of Welds Flawed	The percentage (and *number*) of welds in the domestic fleet reported as containing one or more IGSCC indications. The total number of welds excludes welds that have been removed from service due to preemptive replacement.
Percentage (*quantity*) of Plants Reporting Flaws	The percentage (and *number*) of domestic BWRs having this weld location and reporting cracking.

For each weld location having reported indications, a listing of weld indication is provided. Table A-2 summarizes the weld indication table content.

Table A-2
Weld Indication Summary Table Content & Meaning

Column Heading	Meaning
ID	Sequential ID number for reference purposes.
Year Identified	Year when the weld was first identified as containing one or more flaws.
Exam Method	The examination technique used at the time of initial flaw identification.
Flaw Length	The total flawed weld length at either the time the weld was last examined or at the time of repair / replacement.
Recent Growth	Identifies welds where there was growth of flaws from the 2nd most recent to the most recent inspection.
Weld Status	Indicates the current status of the weld. See Table A-3 below
Notes	Provides additional information regarding the weld and associated flaw.

For each weld location having reported indications, a listing of weld indication is provided. Table A-3 summarizes the weld indication table content.

Table A-3
Weld Status Key

Weld Status	Meaning	Discussion
O	Original, no repair	The weld is flawed, but remains in service without repair.
RC	Repair, clamped	The weld is flawed and has been structurally replaced by a mechanical repair. BWRVIP-18 examination is no longer required for the weld.
RW	Repair, welded	The weld is flawed and has been structurally replaced by a welded repair. BWRVIP-18 examination is no longer required for the weld, but is required for the repair assembly welds.
LSR	Lower section replacement	The weld has been replaced by a lower section replacement. Lower section replacements use solution annealed materials and are attached using mechanical methods. Examination per BWRVIP-18 is no longer required. Note that welds having LSR status in the indication list tables were flawed at the time of replacement. While some welds are preemptively replaced by LSR, these welds do not appear in the indication list tables.

Additional acronyms used in the weld performance and weld indication summary tables include:

- NP – Not Provided. Indicates that the information was not provided.
- NA – Not Applicable. Used where the table content is not applicable.

Table A-4
Summary of 304SS Creviced Piping Weld Flaw Length Measurements

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Table A-5
304SS Uncreviced Piping Weld Flaw Length Measurements

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Table A-6
L-Grade Piping Weld Flaw Length Measurements

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Table A-7
Sparger Flaw Length Measurements

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Table A-8
Sparger Bracket Flaw Length Measurements

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A.1 P2 (BWR/2)

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Table A-9
Weld P2 (BWR/2) Performance Summary

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A.2 P2 (BWR/3-5)

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Figure A-1
Distribution of Weld P2 (BWR/3-5) EVT-1 Coverage Percentages

Table A-10
Weld P2 (BWR/3-5) Performance Summary

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Table A-11
Weld P2 (BWR/3-5) Weld Indication Listing – 304SS

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Table A-12
Weld P2 (BWR/3-5) Weld Indication Listing – L-Grade

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A.3 P2a and P2b (BWR/6)

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Figure A-2
Distribution of Weld P2a & P2b (BWR/6) EVT-1 Coverage Percentages

Table A-13
Weld P2a / P2b (BWR/6) Performance Summary

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Table A-14
Weld P2a (BWR/6) Weld Indication Listing – L-Grade

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A.4 P3 (BWR/3-5)

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**Figure A-3
Distribution of Weld P3 (BWR/3-5) EVT-1 Coverage Percentages**

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**Figure A-4
Distribution of Weld P3 (BWR/3-5) UT Coverage Percentages (One-Sided: Pipe Side HAZ)**

Table A-15
Weld P3 (BWR/3-5) Performance Summary

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Table A-16
Weld P3 (BWR/3-5) Weld Indication Listing – 304SS

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Table A-17
Weld P3 (BWR/3-5) Weld Indication Listing – L-Grade

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A.5 P3a (BWR/2)

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Figure A-5
Distribution of Weld P3a (BWR/2) EVT-1 Coverage Percentages

Table A-18
Weld P3a (BWR/2) Performance Summary

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A.6 P3a and P5 (BWR/6)

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Figure A-6
Distribution of Weld P3a & P5 (BWR/6) EVT-1 Coverage Percentages

Table A-19
Weld P3a / P5 (BWR/6) Performance Summary

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A.7 P3b (BWR/2)

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Figure A-7
Distribution of Weld P3b (BWR/2) EVT-1 Coverage Percentages

Table A-20
Weld P3b (BWR/2) Performance Summary

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A.8 P3b and P6 (BWR/6)

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Figure A-8
Distribution of Weld P3b & P6 (BWR/6) EVT-1 Coverage Percentages

Table A-21
Weld P3b & P6 (BWR/6) Performance Summary

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A.9 P4a, P4b, and P4c (BWR/2-6)

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Figure A-9
Distribution of Weld P4a, P4b, & P4c (BWR/2-6) EVT-1 Coverage Percentages

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Figure A-10
Distribution of Weld P4a, P4b, & P4c (BWR/2-6) UT Coverage Percentages
(One-Sided: Pipe Side HAZ)

Table A-22
Weld P4a-c (BWR/2-6) Performance Summary

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Table A-23
Weld P4a-c (BWR/2-6) Weld Indication Listing – 304SS

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Table A-24
Weld P4a-c (BWR/2-6) Weld Indication Listing – L-Grade

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A.10 P4d (BWR/3-6)

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Figure A-11
Distribution of Weld P4d (BWR/3-6) EVT-1 Coverage Percentages

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Figure A-12
Distribution of Weld P4d (BWR/3-6) UT Coverage Percentages (One-Sided: Elbow Side HAZ)

Table A-25
Weld P4d (BWR/3-6) Performance Summary

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Table A-26
Weld P4d (BWR/3-6) Weld Indication Listing – 304SS

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A.11 P4d – P4i (BWR/2)

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Figure A-13
Distribution of Weld P4d – P4i (BWR/2) EVT-1 Coverage Percentages

Table A-27
Weld P4d – P4i (BWR/2) Performance Summary

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A.12 P5 (BWR/2-5)

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Figure A-14
Distribution of Weld P5 (BWR/2-5) EVT-1 Coverage Percentages

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Figure A-15
Distribution of Weld P5 (BWR/2-5) UT Coverage Percentages

Table A-28
Weld P5 (BWR/2-5) Performance Summary

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Table A-29
Weld P5 (BWR/2-5) Weld Indication Listing – 304SS

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A.13 P6 (BWR/2-5)

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Figure A-16
Distribution of Weld P6 (BWR/2-5) EVT-1 Coverage Percentages

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Figure A-17
Distribution of Weld P6 (BWR/2-5) UT Coverage Percentages

Table A-30
Weld P6 (BWR/2-5) Performance Summary

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Table A-31
Weld P6 (BWR/2-5) Weld Indication Listing – 304SS

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A.14 P7 (BWR/2-5)

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**Figure A-18
Distribution of Weld P7 (BWR/2-5) EVT-1 Coverage Percentages**

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Figure A-19
Distribution of Weld P7 (BWR/2-5) UT Coverage Percentages

Table A-32
Weld P7 (BWR/2-5) Performance Summary

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A.15 P8 (BWR/2)

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Figure A-20
Distribution of Weld P8 (BWR/2) EVT-1 Coverage Percentages

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Figure A-21
Distribution of Weld P8 (BWR/2) UT Coverage Percentages

Table A-33
Weld P8 (BWR/2) Performance Summary

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A.16 P8 (BWR/6)

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A.17 P8a (BWR/3-5)

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Figure A-22
Distribution of Weld P8a (BWR/3-5) EVT-1 Coverage Percentages

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Figure A-23
Distribution of Weld P8a (BWR/3-5) UT Coverage Percentages (One-Sided: Collar Side HAZ)

Table A-34
Weld P8a (BWR/3-5) Performance Summary

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Table A-35
Weld P8a (BWR/3-5) Weld Indication Listing – 304SS

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A.18 P8b (BWR/3-5)

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Figure A-24
Distribution of Weld P8b (BWR/3-5) EVT-1 Coverage Percentages

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Figure A-25
Distribution of Weld P8b (BWR/3-5) UT Coverage Percentages (One-Sided: Collar Side HAZ)

Table A-36
Weld P8b (BWR/3-5) Performance Summary

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Table A-37
Weld P8b (BWR/3-5) Weld Indication Listing – 304SS

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A.19 Piping Brackets (PB)

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Figure A-26
Distribution of Weld PB (BWR/2-6) EVT-1 Coverage Percentages

A.20 S1 (BWR/2-5)

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**Figure A-27
Distribution of Weld S1 (BWR/2-5) EVT-1 Coverage Percentages**

**Table A-38
Weld S1 (BWR/2-5) Performance Summary**

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**Table A-39
Weld S1 (BWR/2-5) Weld Indication Listing – 304SS**

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A.21 S2 (BWR/2-6)

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Figure A-28
Distribution of Weld S2 (BWR/2-6) EVT-1 Coverage Percentages

Table A-40
Weld S2 (BWR/2-6) Performance Summary

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Table A-41
Weld S2 (BWR/2-6) Weld Indication Listing – 304SS

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Table A-42
Weld S2 (BWR/2-6) Weld Indication Listing – L-Grade

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A.22 S4 (BWR/2-6)

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Figure A-29
Distribution of Weld S4 (BWR/2-6) EVT-1 Coverage Percentages

Table A-43
Weld S4 (BWR/2-6) Performance Summary

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A.23 S3a, S3b, and S3c (BWR/2-6)

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**Figure A-30
Distribution of Weld S3a & S3b (BWR/2-6) VT-1 Coverage Percentages**

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**Figure A-31
Distribution of Weld S3c (BWR/2-6) VT-1 Coverage Percentages**

Table A-44
Weld S3a & S3b (BWR/2-6) Performance Summary

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Table A-45
Weld S3c (BWR/2-6) Performance Summary

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Table A-46
Weld S3a & S3b (BWR/2-6) Weld Indication Listing – 304SS

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A.24 Sparger Brackets (SB)

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Figure A-32
Distribution of Weld S4 (BWR/2-6) VT-1 Coverage Percentages

Table A-47
Weld SB (BWR/2-6) Performance Summary

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Table A-48
Weld SB (BWR/2-5) Weld Indication Listing – 304SS

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Table A-49
Weld SB (BWR/2-5) Weld Indication Listing – L-Grade

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