SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

BOILING WATER REACTOR VESSEL AND INTERNALS PROJECT (BWRVIP) REPORT

"TR-105696-R6 (BWRVIP-03) REVISION 6: BWR [BOILING WATER REACTOR] VESSEL

AND INTERNALS PROJECT, REACTOR PRESSURE VESSEL AND INTERNALS

EXAMINATION GUIDELINES"

BOILING WATER REACTOR VESSEL AND INTERNALS PROJECT

PROJECT NO. 704

1.0 INTRODUCTION

1.1 Background

By letter dated January 6, 2004 (Agencywide Documents and Access Management System (ADAMS) Accession No. ML040440261), the Electric Power Research Institute (EPRI) submitted BWRVIP report "TR-105696-R6 (BWRVIP-03) Revision 6: BWR Vessel and Internals Project, Reactor Pressure Vessel and Internals Examination Guidelines," to the U.S. Nuclear Regulatory Commission (NRC) staff for information only. The NRC staff chose to review BWRVIP, Revision 6, and by letter dated June 23, 2006 (ADAMS Accession No. ML061740566), the NRC staff sent the BWRVIP a request for additional information (RAI). On March 14, 2007, the NRC staff participated in a meeting with representatives from the BWRVIP program to discuss and clarify the RAI questions. By letter dated May 29, 2007 (ADAMS Accession No. ML071510339), the BWRVIP provided a response to the RAI questions.

BWRVIP-03, Revision 6, contains BWR guidelines for voluntary implementation of nondestructive examination (NDE) methods and inspection standards. The guidelines provide demonstration requirements for NDE techniques to ensure reactor pressure vessel internal structural integrity.

The NRC staff has participated in the review of past revisions of BWRVIP-03. The NRC staff issued a safety evaluation (SE) to the EPRI on the acceptability of BWRVIP-03 (initial issuance) on June 8, 1998. Since then, the BWRVIP has selectively updated parts of BWRVIP-03. Each update was identified with a subsequent revision number. These new revisions were submitted to the NRC staff for information only. The specific changes for each revision are listed in BWRVIP-03, Revision 6, under the section of "History of Changes." The BWRVIP-03, Revision 6, provides the methodology, inspection standards, and guidelines for the BWRVIP mockups, describes the protocol of NDE techniques and for demonstrating the NDE techniques, and for determining NDE and positioning tool uncertainties. The methodology, inspection standards, and guidelines are for visual testing (VT), ultrasonic testing (UT), and eddy current testing (ET) methods.

BWRVIP-03, Revision 6, addresses NDE examinations of all components within the scope of the BWRVIP program which are not covered by the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code). The BWRVIP program may augment ASME Code examinations for components covered by ASME Code requirements.

1.2 Purpose

The NRC staff reviewed BWRVIP-03 (initial issuance) in 1998. Since then, the NRC staff have mandated compliance with the ASME Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," Appendix VIII, "Performance Demonstration for Ultrasonic Examination Systems," and have issued NUREG/CR-6860, "An Assessment of Visual Testing" (ADAMS Accession No. ML043630040) and NUREG/CR-6943, "A Study of Remote Visual Methods to Detect Cracking in Reactor Components" (ADAM Accession No. ML073110600). The purpose of this review was to understand the relationship between the BWRVIP-03, Revision 6, NDE guidelines and the NDE changes and improvements that have occurred since the NRC staff's review of BWRVIP-03 (initial issuance) in 1998.

1.3 Organization of this Report

BWRVIP-03, Revision 6, contains proprietary information. Therefore, this SE has been written with the express purpose of avoiding citation of proprietary information. The NRC staff does not discuss in detail the specific provisions of the guidelines nor does it discuss aspects of the guidelines where no issues are identified. A brief summary of the contents of BWRVIP-03, Revision 6, is given in Section 2.0, the evaluation is presented in Section 3.0, and the conclusions are summarized in Section 4.0 of this SE. Any NDE comparisons are made relative to published non-proprietary information.

2.0 SUMMARY OF BWRVIP-03, REVISION 6

The BWRVIP-03, Revision 6, addresses the following topics in the order listed below:

Guidelines and General Standards: This BWRVIP report defines the process for using mockups, describes the protocol for demonstrating the examination techniques, and establishes the process for determining the measurement uncertainty for NDE and positioning tools. Additional information on measurement uncertainty is contained in specific component inspection and evaluation (I & E) BWRVIP reports. The general standards define the minimum recommended NDE for BWR pressure vessel internal components.

Visual Length Accuracy: This BWRVIP report discussed the VT demonstrations used to develop flaw length measurement accuracy for two different techniques; measurement estimations using vessel landmarks and measurement estimations using a ruler.

NDE Demonstrations for Internal Components: This BWRVIP report discussed the NDE demonstrations for 11 internal components: shroud, shroud support, core spray piping and sparger, top guide, core plate, low pressure coolant injection coupling, jet pump assembly, standby liquid control, vessel attachments, lower plenum and instrument penetrations. BWRVIP-03, Revision 6, provides component-specific guidelines for inspection considerations, applicable mockups, and NDE demonstrations.

3.0 EVALUATION

3.1 BWRVIP-03, Revision 6: Treatment of Uncertainty

BWRVIP-03, Revision 6, lists sizing errors for different vendor demonstrations. There are two types of errors: tool positioning for VT and crack sizing for UT and ET. Tool positioning errors are determined with remote or manual tools manipulating video cameras along a known dark mark or between two known objects to simulate a crack[1]. After taking a number of measurements of the same simulated crack, the data is statistically analyzed for tool positioning error and expressed as a root mean square (RMS) value. If the crack is representative of those found in the specific component and the true crack size is not known before the demonstration, the tool positioning error values have application usefulness. If the crack is not representative, or the true simulated crack length is known ahead of the demonstration, the tool positioning error becomes biased and the demonstration becomes a measure of the best results that can be expected from the specific tool positioning system making the measurements. The number of measurements performed on any given crack improves the error accuracy. BWRVIP-03, Revision 6, calculates the RMS error using the RMS error equation found in the ASME Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," Mandatory Appendix VIII, "Performance Demonstration for Ultrasonic Examination Systems," Paragraph VIII-3120(d), "Sizing."

Non-blind demonstrations used to develop length-sizing errors are biased because of prior crack knowledge. Simulated cracks (dark marks, saw cuts, and electric discharge machined notches) are normally straight lines with well defined corners that produce non-representative crack images and responses for different NDE methods. The BWRVIP program demonstrations are performed non-blind on simulated and fatigue cracks. The vessel internals are so crack-tolerant that crack measurement accuracy is not considered critical except for the jet pump beams. The underlying premise is that pressure boundary leakage is not a factor on internal welds and any degradation that may occur will be detected before structural integrity (loose parts) becomes compromised. Thus, a substantial error factor can be added to the measured crack size, giving acceptable results.

For UT and ET, the accuracy in crack detection and length sizing is different between non-blind demonstrations and blind performance demonstrations. Non-blind demonstrations have an advantage over blind demonstrations for detection and length sizing because the UT and ET examinations are supplemented with visual observations. The accuracy for depth sizing is normally derived from a limited number of cracks being measured repeatedly. Unless sizing information is shared prior to the demonstration, depth sizing error should be similar (depending on qualification process) for blind and non-blind UT demonstrations.

In 1996, when the NRC staff reviewed BWRVIP-03 (initial issuance), the use of non-blind UT demonstrations were an improvement over the NRC staff-endorsed 1989 Edition of Section XI of the ASME Code. Later editions of ASME Code, Section XI, contained Appendix VIII, "Performance Demonstration for Ultrasonic Examination Systems," which is based on blind performance demonstrations to validate UT procedure effectiveness and UT personnel proficiency. The NRC staff endorsed the supplements to Appendix VIII on a staggered schedule starting in May of 1999. The procedures and personnel qualified to the selected supplements of Appendix VIII provided a level of confidence and reliability that cracks within the

[1] Simulated cracks are assumed to generate responses similar to true cracks for the NDE method selected for the examination.

acceptance ranges of ASME Code, Section XI, Subsection IWB, "Requirements for Class 1 Components of Light-Water Cooled Plants," IWB-3500, "Acceptance Standards" would be detected and accurately sized. The acceptable IWB-3500 cracks are smaller than the cracks that the BWRVIP deems acceptable for non-ASME Code applications.

BWRVIP-03, Revision 6, has identified jet pump beams as a component that is not as tolerant of large flaw measurement errors as the other internal components. However, the guidance for sizing cracks in jet pump beams is similar to the guidance provided for other components in BWRVIP-03, Revision 6.

BWRVIP-03, Revision 6, has vendor-specific UT and ET procedures with crack length and depth sizing RMS values. Because these RMS values were developed using non-blind examinations, the reliability of the RMS values is considered less than the reliability of RMS values developed from blind performance demonstrations developed per ASME Code, Section XI, Appendix VIII. By letter dated May 25, 2004 (ADAMS Accession No. ML041530019), the BWRVIP provided a discussion on crack sizing uncertainty to the NRC staff. This review does not include the information contained in the BWRVIP letter of May 25, 2004. Examination experience shows that the NDE described in BWRVIP-03, Revision 6, can detect the crack sizes of interest. The BWRVIP program leaves to the licensees the responsibility of determining the effects a detected crack has on structural integrity.

3.2 Blind Versus Non-Blind Demonstration

The BWRVIP judged that the cost for blind (procedures and personnel) demonstrations would not provide a commensurate increase in the level of quality and safety because of the robust design of reactor pressure vessel (RPV) internals and the plants' ability to conduct safe shutdowns. The applicability of the BWRVIP's judgment must be evaluated against the safety significance associated with specific I & E BWRVIP reports.

3.3 BWRVIP-03, Revision 6: Uncertainty Versus ASME Code Tolerance

ASME Code Class 1, 2, and 3 BWR pressure boundary welds are examined, as a minimum, according to ASME Code requirements. Therefore, BWRVIP-03, Revision 6, measurement errors associated with pressure boundary UT examinations are the same as those of the ASME Code. The pressure boundary measurement errors are the maximum acceptable RMS values satisfying the qualification screening criteria of ASME Code Section XI, Appendix VIII and associated supplements. The ASME Code has not established measurement errors for NDE tool placement or Section XI, Appendix III, examinations.

For BWR non-pressure boundary welds, the measurement errors shown in BWRVIP-03, Revision 6, were developed from data gathered during demonstrations using specific component procedures. These component procedures are not sufficiently detailed to ensure reproducibility of results. Thus the measurement errors in BWRVIP-03, Revision 6, are only an indication of achievable RMS values. The measurement errors developed from non-blind demonstrations are considered less accurate in flaw characterization than measurement errors developed from ASME Code, Section XI, Appendix VIII performance demonstrations.

Although the BWRVIP-03, Revision 6, discussed the probability of detection (POD) for a flaw of a particular size, the accuracy of this information is questionable because data from non-blind demonstrations were used as input. The accuracy presented by the POD can be misleading unless the non-blind bias is removed. The application of measurement error and POD

referenced in BWRVIP-03, Revision 6, are the responsibility of the licensee. A relative comparison of the error values between pressure boundary (Appendix VIII) and non-pressure boundaries (BWRVIP) is presented in Tables 1, 2 and 3 of this SE.

Table 1: Summary of BWRVIP-03 Requirements for non-ASME Code UT Examinations

UT Application for Components	UT Personnel Qualifications	UT Procedure Qualifications Non-Appendix VIII	Notes
Outer Diameter examinations of internal attachments and shroud support-to-vessel welds	Appendix VIII, Supplement 4	Non-blind demonstration according to BWRVIP-03 were used to determine RMS error	5, 6
Dissimilar Metal Weld in standby liquid control piping	Appendix VIII, Supplement 10	Non-blind demonstration according to BWRVIP-03 were used to determine RMS error	5, 6
Jet Pump Beams Core Plate Bolts Shroud Support H8 & H9	Generic Level II, Non-blind Application-Specific Training	Non-blind demonstration according to BWRVIP-03 were used to determine RMS error	2, 5, 6
The remaining components and systems	Appendix VIII, Supplement 2, Intergranular Stress Corrosion Cracking (IGSCC)	Non-blind demonstration according to BWRVIP-03 were used to determine RMS error	1, 3, 4, 5

Notes to Table 1:

1. The BWRVIP considers any IGSCC limitations that are placed on ASME Code, Section XI, Appendix VIII, Supplement 2, personnel qualifications as not applicable to BWRVIP applications because the training described in the tables above are considered sufficient to perform reliable examinations.

2. Vendors and utilities are responsible for ensuring that the content and quality of application-specific training are appropriate, that the examiner is competent, and that the mockups are representative for their vessel internals. They also provide the personnel for monitoring, verifying, and documenting the non-blind demonstrations.

3. The BWRVIP relies on vendors and utilities to document the ET and UT technique, equipment, technical content, and key parameters. The details of the selected technique are in the site-specific procedures and not in BWRVIP-03, Revision 6, or the BWRVIP I & E topical reports.

4. The BWRVIP considers that IGSCC personnel qualifications are applicable.

5. BWRVIP-03, Revision 6, RMS error determinations are the product of demonstrations that are less rigorous than demonstrations based on ASME Code, Section XI, Appendix VIII, RMS error determinations. The crack RMS error tolerance for individual components is in the component specific BWRVIP inspection and evaluation documents (i.e., BWRVIP-47, etc.).

6. The BWRVIP considers that IGSCC personnel qualifications are not required.

Table 2: Summary of BWRVIP-03 Requirements for non-ASME Code VT Examinations

VT Personnel Qualification	VT Demonstration	VT Application	Remarks
VT-1, VT-3 Generic Level II + 4 Hours of Component Specific Training + 10 Hours of work time with a Qualified Level II	Fixture measuring accuracy is from a black line.	RPV Internals, Components, and Associated Repairs	BWRVIP mockups have not been used for visual demonstrations
	Detect ½ mil wire for EVT-1		Camera uses a minimum of 450 horizontal lines

Table 3: Summary of BWRVIP-03 Requirements for non-ASME Code ET Examinations

ET Personnel Qualification	ET Procedure Qualification	ET Application	Remarks
ET Generic Level II	Non-blind	Used to supplement UT examinations	Not used as a stand alone examination

3.4 Procedure Qualification

In BWRVIP-03, Revision 6, component procedures only contain a few of the essential variables listed in ASME Code, Section XI, Appendix VIII. There is nothing in the BWRVIP-03, Revision 6, guidance that joins key parameters (a term similar to essential variables, but less inclusive) and component procedures to BWRVIP-03, Revision 6, demonstrations and to site examination procedures. The licensee is responsible for referencing the BWRVIP-03, Revision 6, component procedure in the site examination procedure.

The BWRVIP-03, Revision 6, component procedures depend on site examination procedures for the necessary detail to achieve repeatability of the results referenced in the component procedures. The BWRVIP identified key UT parameters for procedure demonstrations, such as size, shape, and frequency of the sound beam, as those parameters expected to have a significant impact on sizing accuracy. The BWRVIP did not consider sensitivity-related parameters as key parameters because they did not alter the position at which a crack tip response appears and they did not alter the crack endpoint position at which the response decays into the ambient noise level. The number of key parameters addressed by BWRVIP-03, Revision 6, is less than the number of essential variables required for Appendix VIII procedure qualifications. The BWRVIP stated that they published enough technical detail (key

parameters) in BWRVIP-03, Revision 6, for utilities to make informed decisions on procedure selection and to ensure that vendors performed the examinations as performed during the demonstrations.

The BWRVIP-03, Revision 6, component procedures are not superseded because they have satisfied the demonstration criteria which have not changed with later BWRVIP-03 revisions. If improvements are developed by a vendor, a new component procedure is created to capture the improvement. The new component procedure is added to the existing accumulation of previously qualified component procedures. The licensee is free to select any BWRVIP-03, Revision 6, component procedure as a guideline for developing site-specific examination procedures. The absence of retiring old component procedures when newer component procedures are demonstrated successfully can negate the potential benefits from NDE improvements. However, all of the component procedures have satisfied the component demonstration criteria.

The BWRVIP has made no changes to its visual demonstration. The BWRVIP is studying NUREG/CR-6860 and NUREG/CR-6943 for future revisions as needed.

3.5 UT Personnel Qualification

BWRVIP-03, Revision 6, stipulates the minimum UT personnel qualification for selected component examinations per ASME Code, Section XI, including an Appendix VII, “Qualification of Nondestructive Examination Personnel for Ultrasonic Examination” (generic) qualification, an Appendix VIII qualification, or an Appendix VIII with IGSCC qualification. An Appendix VII qualification is applicable to all non-Appendix VIII UT examinations and is a prerequisite for Appendix VIII qualifications. Compared to Appendix VII qualifications, Appendix VIII qualifications require more rigorous performance demonstrations and have limited scope.

Experience with Appendix VIII qualifications has shown that general UT knowledge does not translate to an effective application of UT under all circumstances. Because of the uniqueness of application, Appendix VIII has separate qualifications for different material, configuration, equipment, and procedures. Therefore, personnel normally have multiple Appendix VIII qualifications that apply to different combinations of material, configuration, equipment, and procedures. Personnel with Appendix VIII qualifications using Appendix VIII-qualified procedures provide a high degree of reliability and accuracy in detecting and sizing cracks. The Appendix VIII performance demonstration acceptance criterion is considered the examination tolerance for characterizing cracks. An Appendix VIII-qualified person performing an examination with a non-Appendix VIII qualified procedure should be able to detect and determine the size of cracks. However, without the Appendix VIII performance demonstration rigor, the procedure’s effectiveness and reliability is undetermined and considered less reliable than an Appendix VIII-qualified procedure.

BWRVIP-03, Revision 6, uses the same ET and VT generic qualification for personnel and procedures that apply ASME Code, Section XI applications.

4.0 CONCLUSION

The evaluation contained in Section 3.0 of this SE provides a relative comparison of ASME Code-required NDE that became mandatory since the issuance of BWRVIP-03 (initial issuance). The most significant ASME Code, Section XI, change in NDE was the inclusion of Appendix VIII. BWRVIP-03, Revision 6, uses a less rigorous demonstration process than the Appendix VIII performance demonstration requirements.

The BWRVIP-03, Revision 6, component procedures do not account for improvements in NDE technology or ASME Code, Section XI, Appendix VIII. Although BWRVIP-03, Revision 6, is referenced in many I & E component-specific BWRVIP reports, the NDE acceptance criteria and demonstrations have not changed since BWRVIP-03 was first issued. Consequently, the crack tolerance and NDE methods have not changed either. Nevertheless, the NRC staff still considers the guidance in BWRVIP-03, Revision 6, as supplemented by the I & E component-specific BWRVIP reports, capable of detecting the cracks of concern associated with non-pressure boundary RPV internals.

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