August 20, 2001

Carl Terry, BWRVIP Chairman
Niagara Mohawk Power Company
Post Office Box 63
Lycoming, NY 13093

SUBJECT: FINAL SAFETY EVALUATION OF THE "BWR VESSEL AND INTERNALS PROJECT, SHROUD VERTICAL WELD INSPECTION AND EVALUATION GUIDELINES (BWRVIP-63)," (TAC NO. MA6015)

Dear Mr. Terry:

The NRC staff has completed its review of the Electric Power Research Institute (EPRI) proprietary report TR-113170, "BWR Vessel and Internals Project, Shroud Vertical Weld Inspection and Evaluation Guidelines (BWRVIP-63)," dated June 1999. The BWRVIP-63 report was submitted to the U. S. Nuclear Regulatory Commission for staff review by letter dated July 1, 1999. It was supplemented by letter dated May 30, 2001, in response to the open items in the staff's initial safety evaluation (SE), dated April 18, 2000.

The BWRVIP-63 report provides generic guidelines intended to describe appropriate inspection recommendations to assure safety function integrity of the subject safety-related reactor pressure vessel (RPV) internal components. The BWRVIP-63 report presents a formal approach, based upon linear elastic fracture mechanics (LEFM) and limit load analysis, to evaluate the allowable level of cracking in core shroud vertical welds without compromising the safety functions of the core shroud. It also provides a methodology for the use of nondestructive examination (NDE) techniques in addition to inspection locations and frequencies that are predicated upon developing screening criteria as a function of the flaw length and depth.

The NRC staff has reviewed the BWRVIP-63 report and finds, in the enclosed final SE, that the revised guidance of the BWRVIP-63 report, with the modifications as described in the enclosed SE, is acceptable for inspection of the subject safety-related RPV internal components. This finding is based on information submitted by the above cited letters. The staff has concluded that licensee implementation of the guidelines in the BWRVIP-63 report, as modified, will provide an acceptable level of quality for inspection and flaw evaluation of the safety-related components addressed.

The staff requests that you incorporate the staff's recommendations, as well as your responses to other issues raised in the staff's initial SE, into a revised, final BWRVIP-63 report. Please inform the staff within 90 days of the date of this letter as to your proposed actions and schedule for such a revision.

Please contact C. E. (Gene) Carpenter, Jr., of my staff at (301) 415-2169, if you have any further questions regarding this subject.

Sincerely,

/ra/

William H. Bateman, Chief
Materials and Chemical Engineering Branch
Division of Engineering
Office of Nuclear Reactor Regulation

Enclosure: As stated

cc: BWRVIP Service List

The staff requests that you incorporate the staff's recommendations, as well as your responses to other issues raised in the staff's initial SE, into a revised, final BWRVIP-63 report. Please inform the staff within 90 days of the date of this letter as to your proposed actions and schedule for such a revision.

Please contact C. E. (Gene) Carpenter, Jr., of my staff at (301) 415-2169, if you have any further questions regarding this subject.

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William H. Bateman, Chief
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U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
SAFETY EVALUATION OF THE EPRI PROPRIETARY REPORT TR-113170, "BWRVIP VESSEL AND INTERNALS PROJECT, SHROUD VERTICAL WELD INSPECTION AND EVALUATION GUIDELINES (BWRVIP-63)"

1.0 INTRODUCTION

1.1 Background

By letter dated July 1, 1999, the Boiling Water Reactor Vessel and Internals Project (BWRVIP) submitted the Electric Power Research Institute (EPRI) proprietary Report TR-113170, "BWR Vessel and Internals Project, Shroud Vertical Weld Inspection and Evaluation Guidelines (BWRVIP-63)," for NRC staff review. It was supplemented by letter dated May 30, 2001, in response to the open items in the staff's initial safety evaluation (SE), dated April 18, 2000.

The BWRVIP-63 report presents generic guidelines for the inspection and evaluation (I&E) of shroud vertical welds in order to insure structural integrity and margins for safe operations in the presence of a flaw indication. This report provides a formal approach, based upon linear elastic fracture mechanics (LEFM) and limit load analysis, to evaluate the allowable level of cracking in vertical welds without compromising the safety functions of the core shroud. It also recommends a methodology for the use of nondestructive examination (NDE) techniques in addition to inspection locations and frequencies that are predicated upon developing screening criteria as a function of the crack length and depth. The intent of the BWRVIP-63 guidelines is that BWRVIP will adopt the inspection recommendations as a replacement for General Electric (GE) Safety Information Letters (SILs).

1.2. Purpose

The NRC staff reviewed the BWRVIP-63 report, as supplemented, to determine whether its revised guidance addressed the open items in the staff's initial SE, and if it would provide acceptable levels of quality for inspection and flaw evaluation (I&E) of the subject safety-related RPV internal components. The review considered the consequences of component failures, potential degradation mechanisms and past service experience, the validity of the structural analyses models used based upon a mechanistic understanding of stress corrosion cracking (SCC), the ability of the proposed inspections to detect degradation in a timely manner and whether the given flaw evaluation and inspection criteria meet Code and BWRVIP established criteria.

1.3. Organization of this Report

Because the BWRVIP report is proprietary, this SE was written not to repeat information contained in the report. The staff does not discuss in any detail the provisions of the guidelines nor the parts of the guidelines it finds acceptable. A brief summary of the contents of the BWRVIP-63 report is given in Section 2 of this SE, with the evaluation presented in Section 3.

ENCLOSURE

The conclusions are summarized in Section 4. The presentation of the evaluation is structured according to the organization of the BWRVIP-63 report.

2.0 SUMMARY OF BWRVIP-63 REPORT

The BWRVIP-63 report addresses the following topics:

- Background & Overview - A synopsis of the inspection strategy and nondestructive evaluation (NDE) methodology is provided. Core shrouds, fabricated from both Type 304 and Type 304L, are susceptible to degradation induced by intergranular stress corrosion cracking (IGSCC) in the heat-affected zone (HAZ) of the affected welds. In order to detect such flaws, an inspection approach was developed which "screens" each vertical weld based on the condition of adjacent circumferential welds. A qualitative description of the screening criteria is given along with a sample end of interval (EOI) determination that is necessary to produce a suitable reinspection timetable. Elucidating the degree of uncracked metal requires using either a volumetric exam or a two-sided (inner diameter (ID) and outer diameter (OD)) visual exam.

- Inspection Recommendations - The strategies for inspecting vertical welds, lying between horizontal welds H1 and H7, in Category C repaired and unrepaired BWR core shrouds, are presented along with radial ring weld inspections in repaired shrouds.

- Evaluation of Vertical Weld Indications - Suggested procedures for the evaluation and dispositioning of flaws are described for those vertical welds whose acceptance criteria are not met. A detailed structural analysis, incorporating both linear elastic fracture mechanics (LEFM) and limit load margins, is proposed for varying degrees of cleavage covering a broad range of cracking scenarios. A plant-specific appraisal is to be conducted for those cases which do not correspond to the scenarios discussed in the BWRVIP-63 report. This may entail the use of more detailed calculations or finite element analysis. Leakage from vertical weld cracking is also discussed in case of detection of through-wall cracks in vertical welds during inspection. The report provides the methodology for calculating the leakage through a longitudinal crack.

- Generic Analyses of Inspection Strategies - Appendix A outlines the generic analyses which were performed in order to determine standard guidelines for inspection requirements. For each case, several different core shroud geometries were evaluated in accordance with limit load analysis and LEFM techniques.

- Plant Specific Flaw Evaluation Methodology - Appendix B provides additional guidelines and fundamental criteria for plant specific flaw evaluation which fulfills the BWRVIP-01 LEFM and limit load criteria.

3.0 STAFF EVALUATION

The staff's April 18, 2000, initial SE provided nine open items. The BWRVIP, in its letter of May 30, 2001, addressed these items, which are discussed below.

Issue 1:

The Staff's April 18, 2000, Initial SE Stated:

> The BWRVIP-63 report uses the "*average* crack depth" as a parameter for both the inspection and flaw evaluations. The use of average crack depth in the flaw evaluation does not provide adequate conservatism and it is also not consistent with the guidance provided in the BWRVIP-07 report. As approved by the NRC staff, the *maximum* crack depth should be assumed to ensure a conservative result.

The BWRVIP's May 30, 2001 Response Stated:

> There are two approaches for the application of average crack depth in BWRVIP-63 (and BWRVIP-76). One approach applies to the screening and acceptance criteria and the second approach applies when performing plant-specific flaw evaluations. These are described in more detail as follows.
>
> The screening and acceptance criteria, presented in Section 3.0 of BWRVIP-63, uses an average crack depth based on the total inspected length. This is appropriate because the models used to develop the screening and acceptance criteria (Section 4.0) are based on conservative LEFM and limit load solutions. The LEFM models assume a uniform depth flaw which is best represented by the average depth. The limit load models are based on the stress condition of the net section remaining, which is also best represented by the average depth. Additional factors of safety, consistent with existing BWRVIP inspection and flaw guidelines, are also included.
>
> The flaw evaluation criteria, presented in Appendices D and F, uses a slightly different approach for determining average crack depth based on only the cracked length, not the total inspected length. However, the guidance provided in BWRVIP-63 (and BWRVIP-76) is stated incorrectly. The BWRVIP intends to clarify only BWRVIP-76 (because BWRVIP-76 supersedes BWRVIP-63) as follows:
>
> Appendix D (page D-1) and Appendix F (page F-11) of BWRVIP-76 presently states "The assumed crack depth in the uninspected region should be set equal to the average crack depth in the inspected region."
>
> BWRVIP-76 should have stated "The assumed crack depth in the uninspected region should be set equal to the average depth of the observed cracks in the inspected region." In other words, the average crack depth should be based on only that portion of the weld that was inspected and found to be cracked. The average crack depth should not be computed based on inspected lengths where no cracking is detected.
>
> The corrected pages of BWRVIP-76 are attached. Note that the example on page F-11 uses the correct crack depth.

Based on the above discussion, the BWRVIP believes that the use of maximum crack depth is excessively conservative whereas the use and application of average crack depth is technically justified and has an adequate level of conservatism.

Staff's Evaluation of BWRVIP Response:

Based on discussions the staff has had with the BWRVIP on crack growth rate, the staff finds that, for plants utilizing effective HWC or NMCA, as defined in the staff's SE for the BWRVIP-62 report, the BWRVIP's proposed usage of assumed crack depth in the uninspected region as equal to the average depth of the observed cracks in the inspected region is acceptable. Plants with NWC should use the more conservative maximum crack depth for the uninspected regions. With this revision, the staff considers this item resolved.

Issue 2:

The Staff's April 18, 2000, Initial SE Stated:

The BWRVIP-63 report states on page 4-1 (Section 4, "Evaluation of Vertical Weld Indications") that "if through-wall cracks in vertical welds were observed during the inspection, leakage from vertical weld cracking must also be evaluated." However, the *potential* leakage at EOI should also be quantitatively assessed using a conservative evaluation methodology even though through-wall cracks were not detected during the inspection. Therefore, if the cracking is *projected* to grow through-wall, a leakage assessment should be provided. A similar statement on page 3-4 (Section 3.1.3, "Acceptance Standards for Vertical Welds") should also be revised.

The BWRVIP's May 30, 2001 Response Stated:

The BWRVIP recognizes that there is a possibility of through-wall cracking in core shrouds, however, the inspections performed to date have not revealed any through-wall cracking. Furthermore, the issue of leakage through a vertical weld has previously been evaluated. BWRVIP-01, which has been reviewed and approved by the NRC, states that "leakage through a fully cracked vertical weld has also been shown to be acceptably small." Therefore, *potential* leakage has been evaluated for *projected* or assumed through-wall flaws and is considered acceptable.

The BWRVIP does believe it is necessary to quantitatively determine the leakage from an actual through-wall flaw as this may have a direct impact on core performance and on the ability to maintain reflood capability.

Therefore, in summary, the BWRVIP believes that only actual through-wall cracks should be evaluated for leakage.

Staff's Evaluation of BWRVIP Response:

The staff agrees that actual through-wall cracks should be evaluated for leakage. In addition, if the cracking is not repaired prior to the next operating cycle and the crack is *projected* to grow through-wall, a leakage assessment should also be performed. A

similar statement on page 3-4 (Section 3.1.3, "Acceptance Standards for Vertical Welds") should also be revised. With this revision, the staff considers this item closed.

Issue 3:

The Staff's April 18, 2000, Initial SE Stated:

> The BWRVIP-63 report states on page 4-2 (Section 4, "Evaluation of Vertical Weld Indications") that "K_{IC} = 150 ksi$\sqrt{}$in based on BWRVIP-01." Elevated fluences on core shroud welds may effect the mechanical properties of the constituent structural materials. Therefore, the material toughness value may vary under high irradiated conditions. Upon availability of relevant data, a fluence threshold should be established for use of this figure in LEFM. When the fluence limit is exceeded, the use of this value should be justified and discussed with the NRC staff.

The BWRVIP's May 30, 2001 Response Stated:

> The BWRVIP is presently evaluating fracture toughness properties of highly irradiated stainless steel. The BWRVIP expects to submit the results of this work to the NRC in early 2001. The results may indicate that some changes are required to existing BWRVIP guidelines for shroud inspection and flaw evaluation for highly irradiated welds. However, in the interim, we believe the approach provided in BWRVIP-76, Section D.1.1 is acceptable for evaluating these conditions. If a different method is used by the utility, we agree that it should be justified and discussed with the NRC staff.

Staff's Evaluation of BWRVIP Response:

> Based on the above, this item remains open and will be addressed in the staff's review of the BWRVIP-76 report.

Issue 4:

The Staff's April 18, 2000, Initial SE Stated:

> The BWRVIP-63 report states on page B-1 (Appendix B, "Plant Specific Flaw Evaluation Methodology") that "plant-specific analysis may be required if acceptance criteria "c" of Section 3.2 .... cannot be satisfied." Section 3.1.3, "Acceptance Standards for Vertical Welds," should be the correct citation not Section 3.2, "Vertical Welds in Repaired Shrouds."

The BWRVIP's May 30, 2001 Response Stated:

> The BWRVIP agrees that the citation of Section 3.2 should be corrected to Section 3.1.3.

Staff's Evaluation of BWRVIP Response:

> The staff finds that these actions adequately addresses this open item.

Issue 5:

The Staff's April 18, 2000, Initial SE Stated:

> The BWRVIP-63 report states on page B-2 (Appendix B, "Plant Specific Flaw Evaluation Methodology") that "submittal to the NRC of these analyses along with the inspection results is required within *90 days* of the inspection." The reporting requirements for plant- specific flaw analysis should be consistent with those expressed in the BWRVIP-76 report, which states on page 4-1 (Section 4.3, "Analytical Evaluations of Inspection Results") that the analytical results "shall be reported to the NRC within *30 days* after completion of the inspection."

The BWRVIP's May 30, 2001 Response Stated:

> The BWRVIP will provide a response to Item 5 at a later date.

Staff's Evaluation of BWRVIP Response:

> Based on the above, this item remains open and will be addressed in the staff's review of the BWRVIP-76 report.

Issue 6:

The Staff's April 18, 2000, Initial SE Stated:

> The effect of neutron fluence level on the crack growth rate should be consistent with that discussed in the BWRVIP-07 report. When the fluence level exceeds $5x10^{20}n/cm^2$, the appropriate crack growth rate to be used in the flaw evaluation should be discussed with and approved by the NRC staff.

The BWRVIP's May 30, 2001 Response Stated:

> Until such time as the BWRVIP submits a crack growth evaluation for highly irradiated stainless steel, we agree that when the fluence level exceeds $5x10^{20}n/cm^2$, the appropriate crack growth rate to be used in plant-specific flaw evaluations will be provided to NRC for concurrence.

Staff's Evaluation of BWRVIP Response:

> The staff finds that this response adequately addresses this open item.

Issue 7:

The Staff's April 18, 2000, Initial SE Stated:

> The BWRVIP-63 report states on page 3-1(Section 3, "Inspection Recommendations") that "NDE uncertainty does *not* need to be considered since it is adequately covered by conservatisms in the flaw evaluation methods." BWRVIP-member utilities must determine the measurement uncertainty associated with NDE techniques to be used for

inspection of the reactor vessel components consistent with the methodology specified in the BWRVIP-03 report (Section 2.3 “Guidelines for Determining NDE Technique Uncertainty”) as approved by the NRC staff, and include the measurement uncertainties in the flaw evaluation consistent with guidance in the BWRVIP-07 report.

The BWRVIP’s May 30, 2001 Response Stated:

The BWRVIP will provide a response to Item 7 at a later date.

Staff’s Evaluation of BWRVIP Response:

Based on the above, this item remains open and will be addressed in the staff’s review of the BWRVIP-76 report.

Issue 8:

The Staff’s April 18, 2000, Initial SE Stated:

The BWRVIP-63 report states on page 3-3 (Section 3.1.3, “Acceptance Standards for Vertical Welds”) that “if the weld has been inspected using a *one-sided* technique and no cracking was detected then the weld is acceptable for 6 *EFPY*.” In order to verify the weld integrity, the inspection should consist of a *two-sided* (ID and OD) visual examination. Whenever one-sided visual inspection was performed, the use of its results to determine the reinspection interval should be justified and discussed with the NRC staff. Also, the use of effective full power years (EFPY) as a basis to establish the reinspection interval does not correspond with NRC-approved guidelines. Determination of the acceptable operating time, wherever applicable in the subject report, should be in terms of operating hours or years, not EFPY.

The BWRVIP’s May 30, 2001 Response Stated:

Section 2.2 of BWRVIP-63 specifies that volumetric or two-sided (ID and OD) visual exams are the only acceptable methods for satisfying the acceptance criteria contained in Section 3. This is consistent with the examination guidelines for horizontal welds contained in BWRVIP-76. The beltline region is approximately 75% of the shroud vertical welds and represents a significant two sided or volumetric examination sample. This is considered an adequate sampling to determine if any ID vertical weld cracking exists. However, in some cases a volumetric exam or two-sided visual exam is not possible due to access limitation (obstructions due to hardware, etc.) For these situations, BWRVIP-63 allows for a one-sided exam and states that a maximum EOI of 6 years is acceptable provided that no cracking is detected. If cracks are detected, a plant specific [evaluation] must be performed. Therefore, based on the fact that the bulk of the inspections will be volumetric or visual from both the ID and OD, a substantial amount of weld volume will be examined using this criteria. In general, the regions where one-sided visual exams will be employed will be small compared to those examined by volumetric methods. Furthermore, if cracks are detected using one-sided visual exams, analyses must be performed to determine both the structural integrity and future inspection frequency of the vertical weld. If the evaluation performed differs from the acceptable methods described in the report, the evaluation must be submitted to the

NRC for approval. Therefore, the BWRVIP believes that one-sided visual examinations are acceptable for certain situations provided that Section 2.2 of the BWRVIP-63 is followed.

The BWRVIP agrees with the NRC that the reinspection intervals should be based on operating years, not EFPY. In fact, this is reflected in the BWRVIP-76 report.

Staff's Evaluation of BWRVIP Response:

The staff finds that, with a revision to the BWRVIP-63 report stating that a qualified two-sided EVT-1 type visual exam should encompass *essentially 100 percent* (as defined in 10 CFR 50.55a) of the inspection area, then the EOI criteria, as proposed to be modified, established in Section 2.2 of the BWRVIP-63 report is acceptable. If a licensee cannot achieve essentially 100 percent coverage utilizing a qualified two-sided EVT-1 type visual exam, or if the licensee utilizes a one-sided EVT-1 type visual exam, then the licensee shall provide a technical justification of the proposed reinspection interval to the NRC staff. With these revisions, and the BWRVIP's agreement regarding operating years vice EFPY, the staff considers this item resolved.

Issue 9:

The Staff's April 18, 2000, Initial SE Stated:

The BWRVIP-63 report states on page 3-5 (Section 3.1.3, "Radial Ring Welds") that "if the location of the welds is known (e.g., from plant drawings), then those specific locations shall be inspected from the OD of the ring." To assure complete integrity of the weld, the inspection should extend the entire length of the weld and not just the outer surface. In addition, the particular NDE technique used to detect any discontinuities within this component should be given (e.g., UT or 2-sided VT).

The BWRVIP's May 30, 2001 Response Stated:

Inspection of radial ring welds to date has not revealed any significant cracking or structural integrity concerns. The BWRVIP is recommending that the inspection begin at the OD of the rings. If cracking is detected it is expected that additional surfaces will be examined, on an as-needed basis, as input to plant-specific structural evaluations.

Staff's Evaluation of BWRVIP Response:

As stated in the staff findings for Issue 8, above, and the staff's April 18, 2000, initial SE, if the licensee is utilizing a visual exam, it should be a qualified two-sided (OD and ID) EVT-1 type visual exam which encompasses *essentially 100 percent* (as defined in 10 CFR 50.55a) of the inspection area. With this revision, the staff considers this item resolved.

4.0 CONCLUSION

The staff has reviewed the BWRVIP-63 report, as revised, and finds that the revised guidance of the BWRVIP-63 report, with the modifications as described above, is acceptable for inspection of the subject safety-related internal components. The staff has concluded that licensee implementation of the guidelines in the BWRVIP-63 report will provide an acceptable level of quality for examination of the safety-related components addressed in the BWRVIP-63 report.