

SAFETY EVALUATION (SE) BY THE OFFICE OF NUCLEAR REACTOR REGULATION

BOILING WATER REACTOR (BWR) VESSEL AND INTERNALS PROJECT (BWRVIP)

TOPICAL REPORT (TR)-1013403 (BWRVIP-181): "BWR VESSEL AND INTERNALS

PROJECT, STEAM DRYER REPAIR DESIGN CRITERIA" (TAC NO. MD8325)

BWRVIP

PROJECT NO. 704

1.0 INTRODUCTION

1.1 Background

Recent experience with steam dryers at operating BWRs, particularly those operating at extended power uprate (EPU) conditions associated with increased steam line flow velocities, has shown significant degradation in the dryer caused by acoustic resonance induced loads. Therefore, the BWRVIP embarked on an effort to develop TRs regarding steam dryers, such as inspection and flaw evaluation guidelines (BWRVIP-139) and repair design criteria, which is the focus of BWRVIP-181 "Steam Dryer Repair Design Criteria." As a result of inspections performed on steam dryers, repairs and modifications were required at some plants. In some cases, the observed damage was so extensive that replacement dryers were subsequently installed.

In order to address BWR vessel internal issues, the BWRVIP was formed in 1994 under a utility directed initiative. Under the guidance of the Repair Focus Group of the BWRVIP, this criteria document, BWRVIP-181 was developed. By letter dated December 19, 2007 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML0735511456), the BWRVIP submitted BWRVIP- 181 to the U.S. Nuclear Regulatory Commission (NRC) staff for review.

By letter dated September 10, 2008 (ADAMS Accession No. ML0823211543), the NRC staff sent a request for additional information (RAI) to the BWRVIP. By letter dated March 25, 2009 (ADAMS Accession No. ML0908901830), the BWRVIP submitted responses to the staff's RAIs.

1.2 Purpose and Applicability

The purpose of BWRVIP-181 is to provide general design guidance and acceptance criteria for temporary and permanent repairs of existing steam dryers or steam dryer components and/or replacement steam dryers. These criteria are intended to assist the BWR owners with guidelines and considerations in planning for the design of repairs/replacements of the steam

dryers. The guidance provided in BWRVIP-181 is applicable to the repair of existing damage of steam dryers as well as to preemptive modifications to steam dryers in preparation for operation at higher power levels including EPU conditions. BWRVIP-181 is applicable to nuclear power plants that are designed as General Electric (GE) plant types BWR/2, BWR/3, BWR/4, BWR/5, and BWR/6. While the dryer inspection guidelines in BWRVIP-139 are still valid for routine inspections, the repair design criteria in BWRVIP-181 supersede any repair guidance in BWRVIP-139.

Repairs, replacement, and installation of mitigating devices such as Acoustic Side Branches (ASBs) and Acoustic Vibration Suppressors (AVSs) are some of the approaches discussed in BWRVIP-181 that address cracking and degradation issues associated with steam dryers. The design of repairs/replacements, as discussed in BWRVIP-181, will maintain the structural integrity of the component under normal operation as well as under postulated transient and design basis accident conditions.

2.0 SUMMARY OF THE TOPICAL REPORT

BWRVIP-181 addresses items such as: (1) steam dryer assembly configurations for various BWR plant types, (2) scope of repairs, (3) general design criteria and American Society of Mechanical Engineers (ASME) Code design guidance, (4) structural and design evaluation, and load combinations, (5) system evaluations, (6) materials, fabrication, and installation, (7) inspection and testing, (8) design basis documentation, and (9) general conceptual designs for repairs.

BWRVIP-181 provides general design guidance and acceptance criteria for temporary and permanent repairs of existing steam dryers or steam dryer components and/or replacement of the steam dryers. Steam dryers use commercially available modules of dryer vanes that are enclosed in a housing designed by GE, which make up the steam dryer assembly. The modules or subassemblies of dryer vanes, called dryer units, are arranged in parallel rows called banks. Four to six banks are used depending on the vessel size. Dryer banks are attached to an upper support ring, which is supported by four to six steam dryer support brackets that are welded attachments to the reactor pressure vessel (RPV). The steam dryer assembly does not physically connect to the shroud head and steam separator assembly and it has no direct connection with the core support or shroud. A cylindrical skirt attaches to the upper support ring and projects downward forming a water seal around the array of steam separators. The normal operating water level is approximately at mid-height on the dryer skirt.

During refueling, the steam dryer is supported from the floor of the equipment pool by the lower support ring that is located at the bottom edge of the skirt. Wet steam flows upward from the steam separators into an inlet header, horizontally through the perforated plates (if applicable) and dryer vanes, vertically in an outlet header and into the RPV dome. Steam then exits the RPV through the steam outlet nozzles. Moisture is separated from the steam by vanes and the hooks that are attached to the vanes. The captured moisture flows downward by gravity to a collection trough that carries the flow of liquid to drain pipes and vertical drain channels. The liquid flows by gravity through the vertical drain channels to the lower end of the skirt, where the flow exits below normal water level.

GE BWR steam dryer technology has evolved over many years and several product lines. The addition of perforated plates in certain designs results in a more uniform velocity over the height of the vanes. BWRVIP-181 describes eleven BWR steam dryer designs. While the design of

various types of the steam dryers is similar, the main differences that impact the structural integrity of the steam dryer are the design of hoods (using square, slanted, or curved hood type), and the stiffening of the hoods (using gussets, inner braces, or tie rods).

BWR 2/3/4/5/6 steam dryers are welded assemblies constructed with stainless steel type 304 with 0.08-percent maximum carbon content. The material in the weld heat affected zone is likely to be sensitized. [

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the steam dryer is located in the steam space, but the lower half of the skirt is below normal water level. These environments are highly oxidizing. [

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The steam dryer does not perform a safety function and is not required to prevent or mitigate the consequences of accidents. However, the steam dryer contributes to the thermal efficiency, and thus power output of the plant by removing moisture (liquid) from the flow as it passes through the steam dryer assembly. Although the steam dryer is not a safety-related component, it is designed to withstand design basis events. Table 6-1 of the BWRVIP-181 topical report provides recommended ASME design and fabrication guidance for use in steam dryer repair/replacement activities. The structural integrity is considered to be adequate if the degraded steam dryer in the cracked condition does not continue to experience significant crack propagation and if the safety consequences of any loose parts that may be generated have been previously analyzed and proven acceptable. The ability to shut down the reactor (control rod insertion), provide adequate core cooling, and the ability to isolate the main steam lines must be assured even when a credible loose part is postulated.

The BWRVIP-181 topical report provides design criteria for repairs/replacement of degraded steam dryer assemblies. Section 4 of the topical report categorizes repairs and replacements into three categories, namely Category A, B, and C which require different levels of evaluation and implementation.

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The repair design considers loads associated with normal operation, upset condition loads from anticipated operational occurrences, and emergency/faulted condition loads from design basis accidents.

The topical report addresses steam dryer assembly repairs caused by cracking from IGSCC and fatigue loading and discusses different options: such as (i) leaving the flaw in place, but structurally replacing the flawed area, or (ii) removal of the flaw by a qualified machining process with subsequent weld repair, if required.

The repairs should be such that they will not adversely impact the design performance of the steam dryer. When multiple repairs are performed on a steam dryer, evaluation for the interacting effect must also be performed.

3.0 STAFF EVALUATION

The staff has reviewed BWRVIP-181 regarding steam dryer repair design criteria from the design and structural adequacy perspective. The topical report provides general design guidance and acceptance criteria for temporary and permanent repairs of existing steam dryers or steam dryer components and/or replacement of the steam dryers. Based on a review of the topical report and the responses to the staff's RAls provided by the BWRVIP, the staff finds that the steam dryer repair design criteria are useful in assisting the BWR owners with guidelines and considerations in planning for the design of repairs or replacements of steam dryers. The guidance provided in BWRVIP-181 is applicable to the repair of existing damage as well as to preemptive modifications to steam dryers in preparation for operation at higher power levels including EPU conditions. The topical report also provides some conceptual designs for repairs that were successfully utilized in the past and for use in current and future repairs. The staff finds the recommendations in the TR for steam dryer repairs reasonable because they are based on substantial past operating experience data. The staff finds that the topical report adequately addresses the appropriate analysis and design basis documentation requirements as applicable for the A, B, and C Categories for steam dryer repairs and replacements to ensure that the repairs will adequately meet the plant's current licensing basis. The staff also finds that the topical report adequately addressed the need for loose parts evaluation and adequately considered this as a key item with regards to steam dryer repairs.

Section 1 of the topical report provides an introduction to steam dryers and includes a table of BWR plant types and their corresponding plant names, and Section 2 contains definitions of the terms: replacement, repair, steam dryer assembly, and safety analysis report. The staff finds

the introduction acceptable because it includes a table that accurately associates the BWR plant type with the corresponding plant. The staff finds the definitions acceptable because the major terms such as repair, replacement, and steam dryer assembly are correctly defined.

The steam dryer assembly configuration and safety function are addressed in Section 3 of the topical report. The staff reviewed Section 3 of the topical report and requested additional information as discussed below.

In its response to the staff's request for clarification on steam flow velocities in Section 3.1.2 of the topical report, the BWRVIP proposed a revision to state that local regions in the dome near the nozzle entries might be continuously exposed to steam flow significantly in excess of 100 fps, and even higher velocities may be experienced under power uprate conditions. This is acceptable to the staff because the statement addresses the significance with respect to the steam velocity for local regions of the steam dryer and for EPU conditions.

In Section 3.2, the topical report states that the limiting design basis event for steam dryer structural integrity is the main steam line (MSL) break outside the containment. The staff requested the BWRVIP to address fluctuating pressure loads on the steam dryer induced by acoustic excitation in MSL safety relief valve stand pipes, as those could be severe based on the recent operating experience with steam dryer failures at EPU operation. The BWRVIP, in its response, proposed two changes to Section 3.2. These included the following: (1) clarification to a statement to read that the limiting event for steam dryer structural integrity is the MSL break outside containment from the allowable stress perspective, and (2) addition of a sentence to state that the acoustic loads have also been shown to be significant in certain cases, and the fluctuating pressure loads on the steam dryer induced by acoustic excitation in the main steam line safety relief valve inlet stand pipes have the potential to create an alternating stress that can exceed fatigue limits during normal operation. The staff agrees that these loads must be given consideration in the design of a repair. These changes to Section 3.2 of the topical report adequately address the staff's comment on the acoustic loads and therefore the staff finds the proposed changes acceptable.

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The staff reviewed Section 4 regarding the scope of repairs. The staff sought clarification on the replacement steam dryers that can be evaluated as Category A, if the decision to replace the steam dryers is for reasons other than an increase in loading. In its response, the BWRVIP proposed to add a sentence in Sections 4 and 7.4 of the topical report to reflect that the design shall include consideration of flow induced vibration (FIV) loads as in the case of a Category C dryer, if the dryer is expected to be subjected to increased loading due to EPU operation. Based on a review of the proposed clarification, as stated above, the staff considers this issue to be adequately addressed.

The design objectives, addressed in Section 5 of the topical report, were reviewed by the staff. The topical report initially did not address installation interference problems and damages during dryer replacements. The staff requested the BWRVIP address steam dryer repair design criteria to be used during installation to avoid interference problems and component damages during the installation of new steam dryers, as experienced during recent installations at some plants. In response, the BWRVIP agreed to revise the report by adding a paragraph to Section 5.8. The paragraph will state that industry experience has shown that total reliance on design drawings of original steam dryers and nearby reactor components for the design of a repair or replacement involves some risk. Modifications to the design dimensions may have been necessary to accommodate installation. In at least one instance, a newly-fabricated dryer was damaged during installation due to interference with existing reactor components. When possible, in-vessel measurements to verify that adequate installation clearances exist, for a given replacement dryer design, should be made during an outage of opportunity prior to fabrication of the replacement dryer. In the event that damage occurs during installation, its repair shall be treated as any other Category A, B or C repair (as appropriate to the dryer) and the applicable repair design criteria are to be applied in its entirety. The staff reviewed the proposed change to the topical report and finds it acceptable because it adequately addresses interference problems and repair design criteria that can be applied to the repair of any damages occurring during the installation of replacement dryers. Section 5 of the report also provides a discussion on loose parts consideration. The staff finds that the topical report adequately addresses the significance of loose parts as addressed in detail in the BWRVIP-06-A report.

Section 6 provides guidelines for compliance with the ASME Code, Section III, with respect to the design of repairs to, or the replacement of, steam dryers. This section provides, in sufficient detail, the general design criteria that are to be implemented for repair/replacement of Category A, B and C steam dryers. The staff specifically reviewed the non-destructive examination requirements specified in Section 6. The BWRVIP referenced the inspection requirements specified in ASME Code, Section III, Subsections NB/NC/ND. The staff noted that since the repair/replacement steam dryers are designed per ASME Code, Section III, Subsection NG, the inspection requirements specified in ASME Code, Section III, Subsection NG are relevant for the steam dryers. In this context, the staff requested that the BWRVIP confirm that the ASME Code, Section III, Subsection NG inspection requirements would be used in lieu of the ASME Code, Section III, Subsection NB/NC/ND inspection requirements. By letter dated March 25, 2009, the BWRVIP provided a response in which it stated that it would revise Table 6-1 to indicate that the inspection requirements specified in ASME Code, Section III, Subsection NG would be used for steam dryers. The staff accepted the BWRVIP's response because compliance with the inspection requirements specified in ASME Code Section III, Subsection NG is appropriate for the steam dryers and it would ensure adequate weld quality in steam dryer welds. With the aforementioned modification, the staff concluded that Table 6-1 provides an adequate summary of the selection of the materials, welding, inspections and design criteria.

Section 7 of the topical report provides a discussion on structural and design evaluation for Category A repairs, and Category B and C repairs and replacements along with the load combinations. The staff reviewed and requested additional information regarding the discussion on load combinations on Section 7. In response to the staff's comment regarding load combinations (Tables 7-1 and 7-2 in Section 7.3 of the topical report), pertaining to contribution of FIV loads from higher frequencies (above 33 Hz) due to turbulent flow excited acoustic resonances to steam dryer stresses, the BWRVIP agreed that higher frequency loads are often significant in dryer design. As a result, the BWRVIP developed a revised set of loads and load

combinations that appropriately consider high frequencies. The BWRVIP's response also included revised load combination tables, namely Table 7-1 that is applicable for Mark I plants, and Table 7-2 that is applicable for Mark II and Mark III plants. These revised tables show significant changes that appropriately represent the FIV loads included in the applicable load combinations associated with the normal, upset, emergency, and faulted service conditions. The staff finds the BWRVIP's response acceptable because the revised load combination tables properly include and consider FIV in the applicable load combinations for the various service conditions.

The staff reviewed Section 8 which briefly addresses leakage, pressure drop, flow distribution, and power uprate under system evaluation and the staff found this section acceptable because the significance of the potential for acoustic resonance loads in the main steam line and attachments was adequately highlighted based on past experience.

Section 9 addresses material selection, fabrication and installation requirements for the steam dryer components. The BWRVIP invokes the BWRVIP-84 report requirements, which were previously approved by the staff. This section provides details regarding the fabrication and installation requirements for steam dryers for which licensees are expected to comply. Since IGSCC is affected by the presence of crevices and cold work, this section adequately provides guidance with respect to controlling the crevices and surface conditions of the steam dryer components. In addition, welding requirements, including underwater welding (when required), and the ASME Code, Section IX weld qualification requirements are specified in this section. The staff's review found that this section provides sound guidelines for selection of materials and fabrication requirements for the steam dryers, and the licensee's compliance with these requirements is essential to ensure that adequate quality will be achieved for steam dryer components.

The staff sought clarification regarding Section 9.2.10, and requested examples of welds in the steam dryer that have compressive residual stresses requiring no augmented examinations. In its response, the BWRVIP proposed to eliminate this caveat and revise the report to require augmented inspections, if solution annealing can not be performed. This is acceptable to the staff because the caveat on compressive stress will be eliminated.

Section 10 describes pre- and post-installation inspection requirements for repaired steam dryers (i.e., Categories A and B) which licensees must comply with to ensure that adequate quality will be achieved for the repair. This section, however, does not address the final inspection criteria for the repair/replacement welds. Therefore, the staff requested the BWRVIP confirm that the ASME Code, Section III, Subsection NG inspection requirements would be used. In a letter dated March 25, 2009, the BWRVIP provided a response in which it stated it would revise paragraph 10.2 to indicate that the scope and frequency of all inspections of Category A, B, and C steam dryers, which are repaired or fabricated to ASME Code, Section III, Subsection NG requirements shall be inspected in accordance with the Subsection NG criteria. The staff accepted the BWRVIP response because compliance with the inspection requirements, as specified in ASME Code Section III, Subsection NG for the steam dryers is consistent with the ASME Code requirements and, therefore, the staff finds that adequate weld quality will be achieved for the steam dryers.

The staff noted that Section 10 did not clearly identify the criteria regarding inspection frequency for Category A and B steam dryers. Therefore, the staff requested the BWRVIP confirm that the inspection frequency of Category A and B steam dryer welds shall be consistent with the intent of the BWRVIP-139, "BWR Vessel and Internals Project, Steam Dryer Inspection and Flaw Evaluation

Guidelines.” In its response dated March 25, 2009, the BWRVIP stated that for Category A and B steam dryers, the requirements regarding frequency of inspections, as specified in the BWRVIP-139 report shall be met. The staff found the BWRVIP’s response acceptable because the inspection criterion in the BWRVIP-139 report were already approved by the staff and the criterion would ensure that adequate quality will be achieved for steam dryer welds.

Also, in Section 10, the BWRVIP stated that the pre and post-installation inspections for repaired Category C welds are specified by the designer. With respect to this issue, the staff requested the BWRVIP confirm whether: (1) the inspection criteria specified in ASME Code, Section III, Subsection NG apply for repaired Category C steam dryers and (2) the frequency of inspections for the repaired Category C steam dryers is consistent with the BWRVIP-139 report. In its response dated March 25, 2009, the BWRVIP stated Category C steam dryer repair welds would be inspected per the ASME Code, Section III, Subsection NG, after the repair was completed. However, the subsequent in-service examinations of the steam dryers would comply with the intent of the BWRVIP-139 report. The staff found the BWRVIP’s response acceptable because the inspection criteria in the BWRVIP-139 report were already approved by the staff and the criteria would ensure adequate quality will be achieved for the steam dryer welds. Additionally, compliance with inspection criteria specified in the ASME Code, Section III, Subsection NG would ensure adequate quality will be achieved for Category C steam dryer welds.

In Section 11, the BWRVIP addressed the Quality Assurance (QA) program, which is acceptable to the staff because the design and fabrication of repairs are to be conducted under an augmented QA program meeting the intent of the design and fabrication requirements of 10 CFR Part 21 or 10 CFR Part 50, Appendix B, as the steam dryer is not a safety related component. Section 12 discusses adequately the design basis documentation requirements for Categories A, B, and C repairs. The staff found these design basis documentation requirements acceptable.

Section 13 presents general conceptual designs for steam dryer repairs. The topical report correctly notes that the restoration of the original safety margin may not be adequate, if operation at higher power levels, such as when EPU is anticipated. Common repairs mentioned in the topical report include stop drilling techniques to retard crack propagation, weld reinforcement, structural reinforcement, removal of cracked components if they are redundant and not serving any structural function, leaving benign flaws as-is, grinding out the fatigue crack, and re-welded to restore the design margin. Section 14 lists the applicable references cited in the body of the topical report.

The staff sought clarification regarding the applicability of the leave-as-is approach to IGSCC and/or certain fatigue cracks. In its response, the BWRVIP proposed to add a paragraph to Section 13.1.5 to explain leave-as-is flaws. The leave-as-is approach is most easily applied to flaws whose growth has been confirmed to have been arrested and/or are growing slowly due to IGSCC alone. Also, some relatively small flaws that are growing due to fatigue cracking may also be left in place, provided it can be demonstrated that the fatigue growth will not result in an unacceptable flaw size, before a subsequent inspection and re-characterization of the flaw can be performed. The proposed explanation by the BWRVIP, as described above, is acceptable to the staff because it adequately addresses the applicability of the leave-as-is approach to IGSCC as well as relatively small fatigue cracks with slow growth rates, not resulting in an unacceptable flaw size and not affecting the structural integrity of the dryer.

In response to the staff’s request on acoustic load mitigation devices to eliminate load sources if they are significant, the BWRVIP proposed to include paragraphs briefly describing two devices,

namely, ASBs and AVSs in Section 13.2 of the topical report. The staff found the BWRVIP's proposed change acceptable because it adequately addresses the acoustic load mitigation devices.

Based on a review of the topical report and the responses to staff's request for additional information provided by the BWRVIP, the staff concludes that the steam dryer repair design criteria are useful in assisting the BWR owners with guidelines and considerations in planning for the design of repairs or replacements of the steam dryers. The staff finds the guidance provided in BWRVIP-181 to be applicable to the repair of existing damage as well as to preemptive modifications to steam dryers in preparation for operation at higher power levels, including EPU's. The staff finds the recommendations in the topical report for steam dryer repairs to be reasonable because they are based on substantial past operating experience data. The staff finds that the topical report adequately addresses the appropriate analysis and design basis documentation requirements for the Categories A, B, and C, steam dryer repairs/replacements to ensure that the repairs are safe in meeting the plant's current licensing basis. The staff also finds that the topical report adequately addresses the need for loose parts evaluation and considers this to be a key item for steam dryer repairs.

4.0 CONCLUSION

The staff has reviewed BWRVIP-181 that was transmitted to the NRC by the BWRVIP's letter dated December 19, 2007, and the additional information provided in the RAI responses, included in the BWRVIP's letter dated March 25, 2009, and finds that the topical report, as modified and clarified, is acceptable for providing guidance on the design criteria for steam dryer repairs/replacements, for the selection of the materials that are to be used for steam dryers, and for establishing fabrication, installation, and inspection requirements for steam dryers. Therefore, the staff has concluded that implementation of the guidelines in BWRVIP-181, as modified to incorporate the resolution of RAIs as discussed in this SE, shall be included in the "-A" version of this topical report and will provide an acceptable technical basis for the design criteria for use in the structural and design evaluation of steam dryer repairs and replacements, applied loads and load combinations, recommended ASME Code design guidance, fabrication and installation, and inspection of the steam dryers.

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