FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT “MATERIALS RELIABILITY PROGRAM (MRP):

TECHNICAL BASIS FOR PREEMPTIVE WELD OVERLAYS FOR

ALLOY 82/182 BUTT WELDS IN PWRS (MRP-169)”

NUCLEAR ENERGY INSTITUTE

ELECTRIC POWER RESEARCH INSTITUTE

PROJECT NUMBER 689

## 1.0 INTRODUCTION

### Background

By letter dated September 7, 2005 (Reference 1), the Nuclear Energy Institute (NEI) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review and approval the Topical Report (TR) “Materials Reliability Program (MRP): Technical Basis for Preemptive Weld Overlays for Alloy 82/182 Butt Welds in PWRs (MRP-169),” Revision 0. In a letter dated August 3, 2006 (Reference 2), the NRC staff issued a request for additional information (RAI) to NEI and requested a response from NEI by September 29, 2006. In a letter to NEI dated April 26, 2007 (Reference 3), the NRC discontinued its review of TR MRP-169, Revision 0, because industry resources had been temporarily diverted to address an emergent technical issue regarding pressurizer nozzle dissimilar metal welds. Therefore, NEI was unable to respond to the NRC staff’s RAI dated August 3, 2006. After an August 23, 2007, public pre-submittal meeting (Reference 4), with the NRC staff, the NEI and the Electric Power Research Institute (EPRI) stated that they would submit the necessary documentation to re-initiate the NRC’s review of TR MRP-169, Revision 0. By letter dated January 9, 2008 (Reference 5), NEI re-submitted for NRC staff review TR MRP-169, Revision 0. The January 9, 2008, letter from NEI contained the responses to the NRC staff’s RAI dated August 3, 2006, along with the proposed changes to MRP-169, Revision 0. By letter dated March 25, 2008 (Reference 6), the NRC staff found that the material presented in TR MRP-169, Revision 0, was sufficient to begin a comprehensive review.

By letter dated April 7, 2008 (Reference 7), the NRC transmitted to NEI a second set of RAI questions. By letter dated May 2, 2008 (Reference 8), NEI responded to the NRC’s RAI dated April 7, 2008, incorporated the response in TR MRP-169, and submitted TR MRP-169, Revision 1.

By letter dated March 2, 2009 (Reference 9), NEI submitted Appendix 1 to TR MRP-169, Revision 1, which contains a set of design and analysis requirements that can be used for cases in which nondestructive examination (NDE) procedures have not been qualified to detect axial flaws in a certain region of the dissimilar metal butt weld (DMW). In the cover memo to this letter, NEI stated that once the safety evaluation (SE) is complete, all relevant information from the SE and Appendix 1 would be incorporated into TR MRP-169, Revision 2, which will be submitted to the NRC as the accepted version of TR MRP-169.

By letter dated November 30, 2009 (Reference 10), NEI responded to the NRC staff’s questions regarding the safety margins of the optimized weld overlay (OWOL) design and the stress level for flaw initiation at the inside surface of the DMW.

By letter dated February 3, 2010 (Reference 11), NEI submitted changes to certain sections of TR MRP-169, Revision 1, to clarify that the weld overlay design is applicable to piping safe ends that are made of Alloy 600 material. All future references to TR MRP-169 in this safety evaluation refer to TR MRP-169, Revision 1, dated February 3, 2010.

By letter dated March 25, 2010, the NRC staff forwarded a draft safety evaluation (SE) for TR MRP-169, Revision 1, to the NEI for comment. By letters dated April 23, 2010 and June 9, 2010, NEI commented on the draft SE. The NRC staff's disposition of NEI's comments on the draft SE is discussed in the attachment to this SE.

Purpose

TR MRP-169, Revision 1, provides the technical basis for the design, analyses, and inspections of the full structural weld overlay (FSWOL) and OWOL in pressurized water reactors (PWR). The weld overlays are used to repair degraded nickel-based Alloy 82/182 DMWs or piping components made of Alloy 600 material by depositing weld metal on the outside surface of the welds and piping components. In addition, the overlays may be used as a preemptive measure to mitigate primary water stress corrosion cracking (PWSCC).

The American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), Section XI, has not yet provided requirements for the installation, design and inspection of the weld overlay as a repair method for degraded piping components. ASME Code Cases N-740-2 (Reference 12) and N-754 (Reference 13) provide requirements for the weld overlay design. However, the NRC staff has not approved either code case in Regulatory Guide 1.147 (Reference 14). Therefore, NEI and EPRI prepared TR MRP-169 as an alternative to the ASME Code, Section XI.

A DMW is a weld that joins two pieces of metal that are not of the same material such as joining a ferritic nozzle to an austenitic stainless steel safe end or piping. The DMW addressed by TR MRP-169, is made of nickel-based Alloy 82/182. Alloy 82 is the weld wire material and Alloy 182 is the weld rod material. In nuclear plants, gas tungsten arc welding and shield metal arc welding have been used to make the DMWs.

The nickel-based Alloy 82/182 DMW weld metal and Alloy 600 base metal have been identified as material susceptible to PWSCC based on the operating experience of PWRs. The weld overlay repair is a process by which nickel-based Alloy 52 or 52M weld metal is deposited on the outside surface of the degraded DMWs and piping components made of Alloy 600 to form a new pressure boundary. In so doing, the safe end and portion of pipe and nozzles that are adjacent to the DMW are also covered with the weld overlay. Alloy 52 or 52M weld metal has been chosen because laboratory testing has shown it to be less susceptible to PWSCC than Alloy 82/182 weld metal.

## 2.0 REGULATORY EVALUATION

Pursuant to Title 10 of *The Code of Federal Regulations* (10 CFR) 50.55a(g)(4), ASME Code Class 1, 2 and 3 components must meet the requirements except the design and access provisions and the preservice examination requirements, set forth in the ASME Code, Section XI, "Rules for Inservice Inspection (ISI) of Nuclear Power Plant Components," to the extent practical within the limitations of design, geometry, and materials of construction of the components. The regulations require that inservice examination of components and system pressure tests conducted during the first 10-year interval and subsequent intervals comply with the requirements in the latest edition and addenda of Section XI of the ASME Code, incorporated by reference in 10 CFR 50.55a(b), 12 months before the start of the 120-month interval, subject to the limitations and modifications listed in 10 CFR 50.55a(b). Pursuant to 10 CFR 50.55a(a)(3), the NRC may authorize alternatives to requirements if the licensee demonstrates that “(i) The proposed alternatives would provide an acceptable level of quality and safety, or (ii) Compliance with the specified requirements of this section would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.”

According to 10 CFR 50.55a(g), nuclear power facility piping and components must meet the applicable requirements of the ASME Code, Section XI. Depending on the edition and addenda of the ASME Code used, article IWA-4000, “Repair/Replacement Activities,” requires that existing flaws in ASME Code Class 1 components either be removed or, if not removed, evaluated in accordance with the appropriate flaw evaluation provisions of the ASME Code, Section XI.

Therefore, if a flaw is to remain in service, an evaluation is required to be performed and subject to review by the NRC, as specified by subarticle IWA-4150(d) of the ASME Code, Section XI, 2004 edition (the latest NRC-approved edition), which requires that the repair/replacement program, plans, and evaluations required by IWA-4160, “Verification of Acceptability,” shall be subject to review by enforcement and regulatory authorities having jurisdiction at the plant site.

In addition, subparagraph IWB-3142.4 of the ASME Code, Section XI, provides acceptance requirements for flaws to be left in service as follows: “A component containing relevant conditions shall be acceptable for continued service if an analytical evaluation demonstrates the component’s acceptability. The evaluation analysis and evaluation acceptance criteria shall be specified by the Owner. A component accepted for continued service based on analytical evaluation shall be subsequently examined in accordance with IWB-2420(b) and (c).” IWB-2420(b) and (c) of the ASME Code, Section XI, provide information on performing successive inspections for flaws left in service and accepted by analytical evaluation.

When a flaw is detected in Class 1 piping components, it is dispositioned in accordance with IWB-3514 (Reference 15) of the ASME Code, Section XI. If the flaw is accepted by the acceptance standards of IWB-3514, the flaw may remain in service. If the flaw exceeds the acceptance standards of IWB-3514, the flaw may be evaluated by the analytical method of IWB-3600, “Analytical Evaluation of Flaws.” If the flaw is accepted by the analytical method, the flaw may remain in service and is required to be inspected in three successive examinations. If the flaw is rejected by IWB-3600, the component containing the flaw must be repaired or replaced.

In summary, the ASME Code, Section XI, requires either that the flaw be repaired (i.e., removed), or that the flaw be dispositioned based on acceptance standards and analytical methods with subsequent examinations. The proposed weld overlay design in TR MRP-169 can be used by licensees in lieu of performing an ASME Code repair or a flaw evaluation with three successive examinations.

TR MRP-169 provides an alternative to the above ASME Code requirements and, thus, an alternative to the regulation in 10 CFR 50.55a, “Codes and Standards.” The NRC staff has evaluated TR MRP-169 in accordance with 10 CFR 50.55a(a)(3)(i).

## 3.0 TECHNICAL EVALUATION

The NRC staff's evaluation of the design, analysis, and nondestructive examinations (NDEs) of the weld overlay application in TR MRP-169 is discussed below.

### 3.1 Design

#### 3.1.1 Weld Overlay Sizing

The weld overlay thickness is designed based on the presence of a postulated flaw (the design basis flaw) in the original pipe, DMW, or nozzle of pressure vessels and pumps. The ASME Code, Section XI, establishes an allowable flaw size for the end-of-evaluation period (the time period during which the flaw is calculated to be acceptable) based on the maximum flaw size that can be sustained in the component without violating the original design safety margins in accordance with the ASME Code, Section III, "Rules for Construction of Nuclear Facility Components Division 1." The maximum allowable flaw size in accordance with the ASME Code, Section XI, IWB-3640, "Evaluation Procedures and Acceptance Criteria for Flaws in Austenitic and Ferritic Piping," is 75 percent of the component nominal wall thickness. The weld overlay sizing requirements can also be found in ASME Code Cases N-740-2, N-754, and N-504-2 (Reference 16). The NRC staff has approved ASME Code Case N-504-3 in Regulatory Guide 1.147, Revision 15; therefore, the NRC staff used ASME Code Case N-504-3 to evaluate TR MRP-169, even though TR MRP-169 refers to N-504-2. The NRC staff notes that the differences between N-504-2 and N-504-3 are not substantial. The ASME Code, Section XI, Appendix Q, "Weld Overlay Repair of Class 1, 2 and 3 Austenitic Stainless Steel Piping Weldments," shall be used when ASME Code Case N-504-3 is used as stated in Regulatory Guide 1.147.

The NRC staff notes that the pipe wall thickness and DMW wall thickness discussed in this safety evaluation are the same thickness. In addition, the wall thickness is the original pipe/weld thickness, not the thickness of the pipe wall plus the weld overlay thickness.

Full Structural Weld Overlay Thickness Design

The FSWOL thickness is designed based on ASME Code, Section XI, IWB-3640 and Appendix C, "Evaluation of Flaws in Piping." A design basis circumferential crack of 100 percent through-wall and 360 degrees around the weld circumference is postulated to be present in the DMW. Once the FSWOL is applied, the design-basis flaw becomes the allowable flaw size for the end-of-evaluation period, and any actual observed or postulated flaws in the DMW must be demonstrated, by a crack growth calculation, not to grow beyond the allowable size before the next scheduled inservice inspection (ISI).

Weld overlay sizing for FSWOLs is governed, in many cases, by the general requirements in the ASME Code, Section XI, that no flaws of depth greater than 75-percent through-wall are acceptable. The minimum FSWOL thickness, regardless of the applied loading, is about one-third the thickness of the original pipe thickness. Thicknesses greater than this may be required if larger applied loadings exist; however, the overlay can never be thinner than this minimum thickness if it is to be classified as a "full structural" weld overlay.
The NRC staff notes that the structural integrity of the FSWOL does not take credit for the underlying DMW because, by design, the FSWOL can support the piping loads without the underlying DMW.

Optimized Weld Overlay Thickness Design

An OWOL is designed for those DMWs that contain flaws with limited size. The OWOL thickness is designed based on a design-basis circumferential flaw of 360 degrees around the DMW circumference in length and a depth equal to 75 percent of the original pipe wall. The OWOL design takes credit for the structural support of the outer 25-percent wall thickness of the DMW thickness. The design-basis flaw size is assumed based on the requirement that the pipe and DMW will be inspected immediately before the OWOL application and no inside surface connected cracks that are greater than 50 percent of the wall thickness is permitted in the original DMW. If a detected flaw has a depth greater than 50-percent through-wall, the OWOL design will not be applicable for the repair.

Also, post-overlay ultrasonic examinations and future ISIs will be required to verify the integrity of the applied OWOLs, and the examination volume for these inspections is increased to include the weld overlay plus the outer 50 percent of the original pipe wall.

Since OWOLs take credit for the underlying 25-percent wall thickness of the DMW material, TR MRP-169 requires that the design account for the potentially lower toughness of the DMW material (particularly at the fusion line with the low alloy or carbon steel nozzle) (Reference 17). Reference 17 defines a Z-factor approach to address this concern.

Furthermore, PWSCC in the DMW may also be located near the stainless steel fusion line, and in such cases, tests and analyses have shown (Reference 18) that the limit load for net section collapse is controlled by the lower strength stainless steel material rather than that of the Alloy 82/182 weldment material. An OWOL actually represents a special case in which the piping system loads are carried by a two-layer cylinder. The above considerations of low toughness and low strength apply to the inner layer (i.e., the outer 25 percent of the original DMW), but not to the outer layer (the Alloy 52 weld overlay, which carries the majority of the load). TR MRP-169 provides an analysis technique for addressing this two-layer problem in weld overlay design (Reference 19). In the design of OWOLs, either a two-layer approach such as that described in Reference 19 shall be used, or the lower strength/lower toughness properties shall be used to address potential cracks near the fusion lines of the DMW.

TR MRP-169 states that in some cases, the original DMW configuration does not permit full coverage of the pre-overlay examination volume by qualified techniques because of cast stainless steel or geometric limitations, or where flaw indications greater than 50-percent through-wall, but less than 75-percent through-wall, are detected. An OWOL may still be applied in such situations, subject to a plant-specific, nozzle-specific technical justification demonstrating that the observed or postulated worst-case flaw will not violate the OWOL design basis. TR MRP-169 states that such technical justification shall be subject to NRC review and approval. The NRC staff believes that licensees desiring to apply a weld overlay, utilizing TR MRP-169 as the technical basis to ensure quality and safety, are required to submit a relief request for NRC review and approval.

Weld Overlay Length Design

TR MRP-169 designs the weld overlay length to provide the coverage on both sides of the observed crack in the DMW to allow for adequate transfer of axial loads between the pipe and the weld overlay. The design requirement for the overlay length is the same for both FSWOLs and OWOLs. For axisymmetric loading of a cylinder, local loading effects can be shown to attenuate to a small fraction of their peak value at an axial distance of $0.75\sqrt{Rt}$ (R is the outer radius and t is the nominal wall thickness of the pipe) from the point of loading (Reference 20). Thus, if the weld overlay length is set equal to $0.75\sqrt{Rt}$ on either side of the crack in the DMW, resulting in a total weld overlay length of $1.5\sqrt{Rt}$, the overlay will extend beyond any locally elevated stresses due to the crack. The ASME Code, Section XI, Code Cases N-504-3 and N-740-2 also provide similar guidance for weld overlay length sizing.

When applying FSWOL preemptively, a pre-installation inspection is not required, and it will not be known whether a crack exists in the DMW. For the preemptive weld overlay, the above criterion is conservatively applied such that the minimum weld overlay length must be $0.75\sqrt{Rt}$ beyond either side of the susceptible material (i.e., DMW and buttering or an Alloy 600 safe end). This will result in a total weld overlay length equal to $1.5\sqrt{Rt}$ plus the length of susceptible material on the outside diameter (OD) surface of the original DMW. TR MRP-169 notes that the $0.75\sqrt{Rt}$ distance is a suggested length and that shorter lengths may be used if stress analysis of the specific overlay configuration demonstrates that adequate load transfer and stress attenuation are achieved. However, the NRC staff finds that if a weld overlay is designed with a length less than the $0.75\sqrt{Rt}$ distance on either side of the DMW, the licensee needs to submit its justification for NRC review and approval before weld overlay installation.

Other considerations in the weld overlay design are that the desired residual stress reversal (tensile stresses becomes compressive stresses) occurs over the entire extent of susceptible material on the inside surface of the pipe or nozzle, that the length and other aspects of the weld overlay design result in an inspectable configuration, and that structural discontinuities are acceptable. The overlay tapered transition must satisfy the requirements of article NB-4250 of the ASME Code, Section III, that allow for a maximum 30-degree transition angle between adjacent sections, unless detailed analyses are performed for the specific configuration to establish applicable stress indices for fatigue evaluation.

The NRC staff expects that the life of the weld overlay is designed to be longer than the life of the plant, including the period of license renewal. However, the crack growth calculations, required by TR MRP-169 may show that the postulated or actual flaw may grow to exceed the design-basis flaw size earlier than the expiration of the plant license. In some cases, the postulated flaw in the overlaid DMW may grow to exceed the design-basis flaw in less than the ISI interval of 10 years. In such cases, the inspection interval of the overlaid DMW shall be less than the time period for the flaw to exceed the design-basis flaw (i.e., the overlaid DMW needs to be inspected at an interval less than the time for the analyzed flaw to exceed the design-basis flaw).

In addition, the NRC staff expects that, if applicable, the piping loads for the design of the weld overlay should consider changes in operating conditions (such as increased pressure and temperature) caused by power uprate, steam generator replacements, change of pipe configuration or routing, or any system modifications.

<u>Special Flaw Consideration</u>

The NRC staff notes that the OWOL has less thickness than the FSWOL and is unable, by itself, to satisfy the structural integrity requirements of the ASME Code, Section XI. Instead, the OWOL design requires a portion of the underlying DMW to remain intact and carry a portion of the piping loads. To understand potential limitations of OWOLs, the NRC staff has considered the possibility that either (1) the OWOL design, installation process, or the associated NDE may not perform as expected, or (2) a large preexisting crack may be missed by NDE, or (3) a crack grows in the original DMW after the OWOL is applied. During initial phases of crack growth, bending and residual stress variations and metallurgical inhomogeneity could lead to uneven growth. However, once a portion of a surface crack grows deep enough to encounter the weld overlay material, it would stop growing or grow slowly in the depth direction at that azimuthal location. Other segments of the crack could continue to grow deeper until they also reach the overlay interface. The crack growth could continue until the remaining uncracked ligament of the original DMW is insufficient to adequately reinforce the OWOL material, at which point the mitigated DMW may fail without prior leakage.

In an FSWOL, the overlay material that is less susceptible to PWSCC can be credited with minimizing crack growth into the overlay in the event that a large preexisting crack is missed by NDE, or if design deficiencies or misapplication of the FSWOL results in unanticipated tensile residual stress fields. If large cracks occur in the original DMW under an FSWOL, the FSWOL can withstand full design loading without failing. The overlay material preserves the FSWOL load carrying ability and minimizes the likelihood of pipe rupture. In contrast, if the same deficiency in design or application affects the OWOL, the OWOL material can result in small circumferential cracks in the original DMW growing deeply (e.g.,100-percent through-original wall) around the entire circumference, in which case the OWOL may become unable to withstand its design loading. Therefore, the NRC staff asked NEI to explain why a circumferential flaw of 100-percent through-original wall around the entire pipe circumference was not assumed as the design-basis flaw for the OWOL in TR MRP-169.

In its November 30, 2009 letter, NEI responded that the fundamental design requirement for an OWOL is that it meets all flaw evaluation requirements of the ASME Code, Section XI, IWB-3640, in the presence of a design-basis flaw that is 75-percent through-wall and 360 degrees around the circumference (including full ASME Code margins for all design-basis loading conditions). In addition to this structural requirement, residual stress and crack growth analysis requirements must also be met to demonstrate that any detected flaws (or flaws that could be missed in post-OWOL inspections) will not grow to this size during the operating interval between ISIs.

NEI stated that the combination of residual stress and crack growth analyses performed as part of the OWOL design process, plus process controls during in-plant weld overlay application, provides a high level of assurance that the residual stress improvements predicted for an OWOL will be present. For flaws of the type hypothesized by the NRC staff, the probability of detection is extremely high. Further, in accordance with TR MRP-169, 100 percent of OWOL applications are subject to ISIs each 10-year inspection interval, thus enhancing the likelihood of flaw detection.

NEI performed a sensitivity study to determine the impact of the NRC staff's suggested flaw size on the structural integrity of the OWOL design. NEI used the net section collapse limit method and calculated the structural (i.e., safety) factors using piping loading from three nuclear plants as shown in Table 1 below. Table 2 below shows the allowable structural factors from the ASME Code, Section XI, and NEI-proposed alternative structural factors for the postulated 100-percent through wall circumferential flaw.

As shown in Table 1 below, for Service Level A allowable, only one plant (Plant C) satisfied the ASME Code structural factor. The NRC staff estimated that the other two plants satisfied between 80 and 98 percent of the ASME Code structural factor. For Service Levels B and C, the NRC staff estimated that all three plants satisfied between 75 and 90 percent of the ASME Code structural factor.

The NRC staff understands that the OWOL design intent is to create stress fields such that PWSCC flaw growth is significantly diminished as demonstrated through flaw growth calculations, to examine the outer 50 percent of the original DMW wall thickness after application of the OWOL, and to inspect the DMW once every 10 years. However, uncertainty exists in the calculation of stress fields and crack growth. There is always a potential for flaws to be missed during examinations, although the probability may be small for large flaws. To address these concerns, the NRC staff requested an evaluation of the OWOL, assuming a condition in which a circumferential flaw exists 100 percent through the original DMW thickness and 360 degrees around the weld. The NRC staff acknowledges that several defenses can prevent this worst-case condition and accepts a reduction in the ASME Code allowable safety margin for this beyond-design condition. The NRC staff also acknowledges that the Level D service condition is not applicable because with the assumption that a loss-of-coolant accident (LOCA) has already occurred, the integrity of the primary reactor coolant system (RCS) has already been compromised and further degradation would be inconsequential. Therefore, the NEI-proposed alternative structural factors in Table 2 are appropriate for this special condition.

Table 1
Structural Factors for Three Sample OWOL Designs Assuming the NRC's Suggested Flaw

| Service Level | Plant A | Plant B | Plant C |
|---|---|---|---|
| Level A--Normal Operation | 2.49 | 2.15 | 2.78 |
| Level B--Normal + OBE* | 1.83 | 1.60 | 1.87 |
| Level C--Normal + SSE* | 1.44 | 1.36 | 1.42 |

*Operating Basis Earthquake (OBE)
*Safe-shutdown earthquake (SSE)

Table 2
Structural Factors per ASME Code, Section XI, and
NEI-Proposed Structural Factors for the Special Flaw Assumption

| | ASME Section XI Structural Factor | | NEI-Proposed Structural Factor | |
|---|---|---|---|---|
| Service Level | Membrane Stress | Bending Stress | Membrane Stress | Bending Stress |
| Level A—Normal Operation | 2.7 | 2.3 | 2.4 | 2.0 |
| Level B--Normal + OBE | 2.4 | 2.0 | 1.8 | 1.6 |
| Level C--Normal + SSE | 1.8 | 1.6 | 1.3 | 1.4 |
| Level D--Normal + SSE + LOCA | 1.3 | 1.4 | NA | NA |

The NRC staff notes that the DMW with an OWOL is required to be inspected once during the 10-year inspection interval. This inspection should have a high probability of detecting a large flaw. Generally, the OWOL is designed to generate a zero stress intensity factor at the crack tip so that the flaw will not be likely to grow significantly. However, in the cases where this is not met the acceptability of the OWOL design should be demonstrated through an acceptable crack growth analysis. The OWOL maintains a level of structural integrity by maintaining structural factors greater than 1.0 in the severe case of a large postulated flaw under normal operating and SSE loads. The NRC staff finds that NEI has demonstrated, based on its sensitivity analysis, that the OWOL design provides a reasonable assurance of structural integrity for the overlaid DMW.

## 3.2 Analysis

### 3.2.1 Design Analysis

TR MRP-169 requires the following analyses to be performed for the design of the FSWOL and OWOL:

(a) Weld Overlay Structural Sizing--Analyses are performed to establish the minimum overlay dimensions (length and thickness) required to satisfy ASME Code, Section XI, IWB-3640 requirements in the presence of the maximum observed or assumed defect.

(b) Design Loads for Weld Overlay--A calculation that documents the specific design loads and transients that will be used for the overlay design.

(c) Finite Element Model of Nozzle with Weld Overlay--A calculation that documents the geometric details of the nozzle and associated components (e.g., DMW, safe end, and pipe) to be used in the overlay analyses.

(d) Thermal and Mechanical Stress Analyses of Nozzle with Weld Overlay--Stresses are calculated in the nozzle plus weld overlay due to design loads and thermal transients for use in ASME Code, Section III, and crack growth evaluations.

(e) Residual Stress Analysis of Weld Overlaid Nozzle--Nozzle-specific elastic-plastic stress analyses of the nozzle are performed to establish the residual stress distribution after application of the overlay. Severe inside diameter (ID) weld repairs are assumed in these analyses that effectively bound any actual weld repairs that may have occurred in the nozzles. The analyses then simulate application of the weld overlays to determine the final residual stress profile. The detailed analyses are discussed in Section 3.2.2, below.

(f) ASME Code, Section III Evaluation of Weld Overlaid Nozzle--Stress and fatigue analyses are performed to demonstrate that installation of the weld overlays does not affect the conclusions of the existing nozzle stress analysis per the ASME Code, Section III. Also, stress and fatigue criteria of Section III will be satisfied for regions of the overlays remote from the observed (or assumed) cracks.

(g) Crack Growth Evaluation of Weld Overlaid Nozzle--Fracture mechanics analyses are performed to predict crack growth, assuming that cracks exist that are equal to or greater than the detected flaw sizes (or the detection thresholds of the applicable NDE, if no flaws are detected). Crack growth attributable to PWSCC is evaluated as well as fatigue crack growth in the original DMW.

(h) Evaluation of Effects of Weld Overlay on Piping System--Shrinkage stresses occurring at other locations in the piping systems arising from the weld overlays, are demonstrated not to have an adverse effect on the piping systems. Clearances of affected pipe supports and restraints are checked after the overlay installation and reset within the design ranges as required. The total added weight on the piping systems resulting from the overlays is evaluated for potential impact on piping system stresses and dynamic characteristics.

The NRC staff finds that the above series of analyses are needed, as they form the technical basis to demonstrate the effectiveness of the weld overlay in maintaining the structural integrity of the DMW and to analyze the potential impact of the overlay on the piping system. For plant-specific weld overlay relief requests, the NRC staff will require the above analyses to be either submitted or available for NRC staff review.

3.2.2 Residual Stress Analysis of Overlaid Dissimilar Metal Welds

One of the technical bases of the weld overlay design is that it will generally generate favorable residual stress reversal (tensile stresses become compressive stresses) at the inner region of the DMW, such that the compressive stresses can mitigate PWSCC initiation and growth. Section 5.0 of TR MRP-169 discusses analytical and experimental work on weld-overlaid boiling water reactor (BWR) pipe-to-pipe welds of various pipe sizes to demonstrate that favorable residual stresses result for FSWOLs. A recent weld overlay test program (Reference 21) also demonstrated that measured residual stresses in a typical PWR mid-sized DMW weld overlay were highly favorable when applied to a DMW with a severe inside surface repair.

The residual stresses for nozzle-to-pipe DMWs are unique in that each nozzle and safe-end design is somewhat unique, often with significant diameter and thickness differences among the nozzle, safe-end, and attached piping. TR MRP-169 requires that a weld joint-specific, overlay-specific weld residual stress analysis be performed for each unique weld overlay configuration in which there is a significant geometry, material, or welding process difference from a previously analyzed overlay (beyond standard drawing/fabrication tolerances). The residual stress analysis must be performed with appropriate methods, including transient thermal analysis capability, nonlinear elastic-plastic modeling capability, and temperature-dependent material properties. The residual stress analysis must be demonstrated to produce residual stress results that are in agreement with (or conservatively bound) experimental measurements. The residual stress analysis should consider actual welding parameters to be used in applying the weld overlay, including bead sequence, welding direction, heat input, thermal boundary conditions (wet or dry) and interpass temperature limits.

The initial residual stress condition of the DMW joint has a significant bearing on DMW susceptibility to PWSCC, especially as influenced by in-process repairs performed during plant construction. In all cases of PWSCC discovered in PWR butt welds, evidence of significant in-process repairs during construction has been found. The residual stress analysis assumes a highly unfavorable, pre-overlay residual stress condition which would result from an inside diameter surface weld repair during construction. If the nozzle-specific weld overlay design is shown to produce favorable residual stresses in this severe case, it is likely that the weld overlay will effectively mitigate against future PWSCC in the DMW. After application of the weld overlay, acceptable residual stresses on the inside surface of the nozzle and DMW at operating temperature, operating pressure, and loads, should be less than 10 kilopounds per square inch (ksi) tensile along the length of the DMW. TR MRP-169 states that laboratory data and field observations have shown that high stresses, on the order of the material yield strength, are necessary to initiate PWSCC. The NRC staff believes that stresses on the order of the yield strength significantly increase the probability of crack initiation, but low stress values alone may not limit PWSCC initiation. Thus, limiting the inside diameter surface stresses under sustained steady-state conditions to less than 10 ksi significantly decreases the probability of new PWSCC-initiated cracks after application of the weld overlay.

The NRC staff asked NEI to provide an additional basis, including supporting data, analyses, and operational experience, to support allowing an inside surface stress threshold of 10 ksi. By letter dated November 30, 2009, NEI responded that since there is no generally accepted PWSCC crack growth threshold for Alloy 82/182 weld metals, satisfying this criterion generally requires that the crack tip stress intensity factor, due to residual stresses, operating pressure and sustained, steady-state loads, be compressive up to the greater of the maximum flaw size (either pre- or post-overlay) or the maximum flaw size in PWSCC-susceptible material that could be missed by the applicable inspections. The NRC staff finds the NEI response acceptable that the inside surface residual stress will be less than 10 ksi and a crack growth analysis of a flaw that is the greater of the maximum flaw size (either pre- or post-overlay) or the maximum flaw size in PWSCC-susceptible material that could be missed by the applicable inspections, shall show that the flaw does not grow to an unacceptable size during the design life of the overlay.

NEI stated that substantial data exist that justify the concept of a threshold for PWSCC initiation in Alloy 600 and its weld metals Alloy 82, 132, and 182. NEI stated further that laboratory data have shown that stress corrosion cracking initiation is difficult when temperature and impurity concentration in the coolant and stress are below certain limits. NEI alluded to a stress threshold below which PWSCC initiation may not occur. The NRC staff believes that PWSCC initiation is a function of stress level, material chemistry, water chemistry, and material surface conditions; therefore, stress alone cannot be used to limit crack initiation but can be used to demonstrate a low probability of crack initiation.

In its November 30, 2009 letter, NEI discussed crack growth rate data for microcracks initiated in two different types of crack initiation specimens. Although reported as crack growth data, the experiments were actually crack initiation tests, since the crack growth rate was computed based on failure time divided into thickness of the thin-walled specimens tested under uniform stress conditions. Samples were tested at stress levels down to 325 megapascals (MPa) (approximately 47 ksi), and at that stress level, the crack growth rates were so slow as to be of little engineering significance (0.03 millimeters per year). The 10-ksi limit is thus 18 to 22 percent of the minimum measured stresses at which PWSCC initiation has been observed in Alloy 132 and 182 weld metals in these laboratory experiments. Therefore, this limit ensures a very low probability of initiating new PWSCC cracks after weld overlay application with significant margin to allow for uncertainties that may occur in attempting to precisely model the magnitude of tensile stress on the wetted surface of in-service DMWs.

TR MRP-169 states that the weld overlay designer must demonstrate that any cracks in PWSCC-susceptible material that are not within the pre- and post-overlay examination volumes would not grow to the point that they would violate the overlay design basis. The NRC staff notes that several laboratory programs have verified the analytical method to design weld overlays and to predict residual stress effects as described in Section 5.0 of TR MRP-169.

Battelle Memorial Institute (Battelle), under contract to the NRC, performed an independent analysis to evaluate the effect of the FSWOL and OWOL on the DMW in a reactor coolant pump discharge nozzle and compared the results with those of the TR MRP-169 analysis. Battelle calculated the welding residual stresses in the overlaid DMW using nozzle and material data from the Davis Besse Nuclear Power Station. By letter dated July 13, 2009 (Reference 22), as part of its weld overlay relief request, Davis Besse provided plant-specific data on the DMW at its reactor coolant pump discharge nozzle and the weld overlay.
Battelle performed a sensitivity study assuming no repair, 25-percent, and 50-percent through-wall, inside diameter, and preservice repairs of the DMW to document the applicability of the OWOL for several repair conditions. The Battelle analysis shows that the OWOL is predicted to reduce the inside diameter axial stresses to compressive stresses in the DMW area. The OWOL will also reduce high inside diameter tensile hoop stresses to uniformly compressive hoop stresses. The Battelle analysis verifies that the weld overlay will produce

compressive stresses at the inside diameter region of the pipe to mitigate crack initiation and growth.

In addition, the NRC staff, acting cooperatively with EPRI under a Memorandum of Understanding, is completing a detailed weld residual stress validation program aimed at both refining computational procedures for residual stress simulations in DMWs, and developing and categorizing the uncertainties in the resulting residual stress predictions. As part of this program, the DMW residual stresses in a large-bore reactor coolant system cold leg nozzle from a cancelled pressurized water reactor plant were analyzed and measured with surface and volumetric techniques. To generate conservative conditions, a prototypic 25-percent-thickness partial arc weld repair was placed on the inner diameter of the DMW. The stresses were reliably measured using the incremental hole drilling technique for surface stresses and deep hole drilling for the through-thickness stress distribution. These measurements were performed before and after application of an OWOL. Incremental hole drilling has been shown to provide reasonably accurate surface residual stress measurements. Deep hole drilling can provide reasonably accurate through-thickness stress measurements but unreliable near-surface measurements. The measurement results indicate that, in their respective regions of applicability, the weld residual stresses were reduced in magnitude due to the application of the OWOL. On the inner diameter, existing tensile hoop stresses (on the order of 5 ksi) became compressive (on the order of 20 ksi), and existing compressive axial stresses (on the order of 20 ksi) became more compressive (on the order of 40 ksi).

To provide additional assurance of the reduction in weld residual stresses following OWOL application, four separate engineering organizations performed independent finite element simulations of the large bore cold leg nozzle. These analyses were performed blind (i.e., without prior knowledge of the measurement results). The analytical results were consistent with the measured results described above. These analyses confirm the reduction in both axial and hoop weld residual stresses due to OWOL application. The reduction magnitudes were consistent with those observed in the measurements as described above.

The Battelle's analysis and the NRC-EPRI validation program verified that the weld overlay (FSWOL and OWOL) will provide favorable compressive residual stresses to minimize the likelihood of PWSCC initiation and growth. Therefore, the NRC staff finds that the TR MRP-169 residual stress acceptance criteria will limit not only the probability of crack initiation based on inside surface stress, but also crack growth. The residual stress analysis is needed to demonstrate that the installed weld overlay will result in favorable stresses in the inner region of the DMW to reduce the probability of crack initiation and growth. The residual stress analysis should model the welding steps to mimic the welding in the field. The NRC believes that a separate PWSCC-growth criterion must be satisfied to demonstrate acceptability of the post-overlay residual stress distribution, not just for observed cracks, but also for conservatively postulated cracks that might escape detection. To satisfy the PWSCC-growth criterion, TR MRP-169 requires that a crack growth calculation be performed to ascertain that a potential crack will not grow to an unacceptable size, the stress intensity factor at the crack tip should be zero or compressive for the steady state condition, and each overlaid DMW with an OWOL will be inspected every 10 years. The NRC staff finds that TR MRP-169 has adequately addressed the issue regarding the adequacy of the 10-ksi limit on the residual stresses.

The combination of inside diameter surface stress and acceptable flaw growth analysis, in conjunction with required post-overlay inspections, provides preemptive mitigation of PWSCC after application of the weld overlay and provides assurance that propagation of pre-existing cracks will not violate the overlay design basis.

### 3.2.3 Crack Growth Calculations

TR MRP-169 requires the assessment of crack growth attributable to fatigue and PWSCC per the ASME Code, Section XI. The fatigue crack growth calculation assesses the potential growth of cracks resulting from cyclic loadings at the overlay location. The fatigue crack growth calculation is performed for the overlaid DMWs to obtain an appropriate inspection interval. TR MRP-169 requires that the following steps be included for the fatigue crack growth calculations:

(a) Determine the loading conditions that must be considered. The loadings considered in the original plant design, including any later changes, must be determined. The loadings are (1) pressure, (2) bending moments due to dead weight, piping thermal expansion, nozzle anchor movement effects, operating basis earthquake (OBE), and stratification, as applicable, (3) local thermal stratification, if applicable, (4) thermal transient through-wall stresses, and (5) residual stresses. For purposes of crack growth analysis, the number of cycles per heatup/cooldown is established.

(b) Determine the applied stresses, including through-wall and circumferential distribution, at the weld overlay location for each loading condition. Stresses in both the hoop and axial direction must be quantified.

(c) Characterize the initial flaw depth and aspect ratio. If the DMW is inspected and no flaws are detected before application of the weld overlay, an initial circumferential flaw depth greater than or equal to 10 percent of the nominal pipe or nozzle thickness shall be assumed, with a length equal to the wall thickness (a/l = 0.1, where “a” is the flaw depth and “l” is the flaw length). An initial axial flaw greater than or equal to 10 percent of the pipe wall thickness with an aspect ratio (l/a) equal to the length (axial width) of the DMW at the outside surface divided by the pipe wall thickness shall also be assumed.

If pre-installation examination of the DMW is not performed before application of the weld overlay, a larger initial flaw size shall be assumed, consistent with the post-overlay examination requirement (50 and 75 percent of the original wall thickness for circumferential and axial flaws, respectively). The fatigue crack growth equation will be based on that for Alloy 600 in the PWR environment, as reported in References 23 and 24. Reference 24 indicates that the fatigue crack growth rate of Alloy 182 in the PWR environment is a factor of about 5 higher than that of Alloy 600 in air under the same loading conditions. Crack growth analysis is then conducted on a cycle-by-cycle basis for a period equal to the standard ASME Code, Section XI inspection interval (10 years) or to end of life, including the license renewal period where applicable. The NRC staff is still investigating the fatigue crack growth rate to ensure that the fatigue crack growth rate in the PWR water environment encompasses more laboratory data. Licensees should use a conservative fatigue crack growth rate in their crack growth calculation to support their plant-specific weld overlay relief requests. The NRC staff will update the fatigue crack growth rate in the PWR water environment for Alloy 82/182 welds via a safety evaluation of plant-specific relief requests or through NRC generic communications.

In its November 30, 2009 letter, NEI states that a PWSCC crack growth criterion should be satisfied to demonstrate the acceptability of the post-weld overlay residual stress distribution.

This criterion requires that any cracks detected in the pre- or post-overlay inspections, or that are not within the examination volumes in the PWSCC-susceptible material, would not grow because of PWSCC to the point that they will violate the overlay design basis (75-percent through-wall for OWOLs or 100-percent through-wall for FSWOLs). Since there is no generally accepted PWSCC crack growth threshold for Alloy 82/182 weld metals, satisfying this criterion generally requires that the crack tip stress intensity factor (resulting from residual stresses, operating pressure and steady-state loads) be compressive up to the greater of the maximum flaw size (either pre- or post-overlay) or the maximum flaw size in PWSCC-susceptible material that could be missed by the applicable inspections. Again, the NRC staff finds acceptable that the inside surface residual stress will be less than 10 ksi and a crack growth analysis of a flaw that is the greater of the maximum flaw size (either pre-or post-overlay) or the maximum flaw size in PWSCC-susceptible material that could be missed by the applicable inspections, shall show that the flaw does not grow to an unacceptable size during the design life of the overlay.

TR MRP-169 states that the allowable flaw size at the end-of-evaluation period is the design-basis flaw for structural sizing of the FSWOL or OWOL (i.e. 75 or 100 percent of the original wall thickness, as applicable). If the crack growth analysis shows that a flaw will not grow to the design-basis flaw size during the 10-year ASME Code, Section XI inspection interval or longer, the 10-year inspection interval is justified for subsequent ISIs (after any intermediate inspections imposed by MRP-139 (Reference 25)). If the crack growth analysis shows that the flaw will grow to the design-basis flaw size, then the inspection interval must be based on the time to reach that size, except that the inspection interval cannot be greater than the 10-year interval specified in the ASME Code, Section XI.

The NRC staff has not approved MRP-139. However, the NRC staff notes that if a flaw is detected in the pre-installation examination of a DMW, the overlaid DMW needs to be reexamined during the first or second refueling outage following the overlay installation. The NRC staff also notes that the inspection interval of the overlaid DMW will depend upon the requirements of 10 CFR 50.55a or an NRC-approved plant-specific relief request for the weld overlay. In addition to the 10-year ASME Code inspection interval, the NRC staff notes that the inspection interval cannot be greater than the inspection interval requirements of 10 CFR 50.55a or NRC-approved plant-specific relief request for the weld overlay.

For the FSWOL design in which the original DMW is not ultrasonically examined before overlay installation but a flaw is detected in the outer 25 percent of the overlaid DMW thickness, the NRC staff notes that the postulated initial flaw depth for the crack growth calculation needs to be the detected flaw depth into the outer 25 percent of the original wall plus the inner 75 percent of the DMW thickness. This assumes that the detected flaw in the outer 25 percent of the DMW thickness is connected to the inside surface of the pipe. The worst-case flaw size should be assumed because the current ultrasonic testing (UT) method has not yet been qualified to inspect flaws in the inner 75 percent of pipe wall thickness after weld overlay installation.

### 3.2.4 Cumulative Fatigue Usage Factor Calculations

The cumulative fatigue usage factor calculation is performed to demonstrate that the fatigue usage factor satisfies the allowable cumulative usage factor of 1.0 as required by the ASME Code, Section III, articles NB-3200 and NB-3600, in the region where the overlay is being applied. The cumulative fatigue usage factor at an overlaid DMW may be increased due to addition of the weld overlay because the through-wall thermal stresses may be increased at the overlaid DMW (greater thickness). There will be structural discontinuities at the weld overlay to piping and nozzle transitions. The fatigue usage factor at the location without the weld overlay is an indicator of the severity of loads at the location. If the fatigue usage factor at the weld location, or adjacent locations, is less than 0.2 and the location is not subject to thermal transients more severe than those associated with normal and upset reactor coolant hot leg, or cold leg transients, TR MRP-169 suggests that fatigue usage factor calculations due to application of the weld overlay do not need to be considered further. The NRC staff does not object to the aforementioned criteria; however, the NRC staff notes that licensees must demonstrate that the cumulative fatigue usage factor at all pipe locations must satisfy the requirements of the ASME Code, Section III, articles NB-3200 and NB-3600.

Locations that experience cycling because of more severe thermal transients (e.g., those associated with charging nozzles, pressurizer spray nozzles, or surge lines with stratification) may be adversely affected from the standpoint of fatigue. For these locations, a fatigue reevaluation shall be conducted at the transitions between the weld overlay and the adjacent pipe or nozzle locations. TR MRP-169 states that the fatigue evaluation shall consider the plant design transients, or an alternate less severe set of transients (as allowed by the ASME Code, Section XI, Appendix L, "Operating Plant Fatigue Assessment"). The effect of the actual plant operating transients at the weld overlay locations may be considered if such data are available.

TR MRP-169 states that the fatigue usage factor calculations shall be conducted using the applicable rules of the ASME Code, Section III, for Class 1 components (NB-3600, "Piping Design," for piping and NB-3200, "Design by Analysis," for vessel nozzles). Code editions and addenda later than the original construction Code may be used, as allowed by ASME Code, Section XI, Appendix L.

The NRC staff finds that the fatigue usage factor calculation follows the requirements of the ASME Code, Section III; therefore, it is acceptable. However, the NRC staff notes that at present, the NRC has not yet approved Appendix L in the context of 10 CFR 50.55a. Therefore, before weld overlay installation, licensees who use Appendix L need to submit a justification for

NRC review and approval, demonstrating that Appendix L is applicable to the cumulative fatigue usage factor calculations.

### 3.2.5 Evaluation of Effects of Weld Overlay on Piping System

Stresses may develop in other locations of a piping system because of weld shrinkage as a result of the weld overlay installation. The level of stresses resulting from the weld overlay shrinkage depends on the amount of shrinkage that occurs and the piping system geometry (i.e., its stiffness). Overlay weld shrinkage may also produce displacements at locations in the system, such as pipe hangers and pipe whip restraints that need to be checked against design tolerances. The added mass and stiffness produced by the weld overlay may have an effect on the dynamic response characteristics of the system. To address these effects, TR MRP-169 recommends the following actions after a weld overlay is installed:

1. Measurement of Weld Overlay Shrinkage - Common practice is to apply punch marks at several azimuthal locations on the piping and/or nozzles, beyond the ends of the overlays, and to measure the distance between those punch marks before and after application of the overlays.

2. Evaluation of Shrinkage Stresses - The stresses due to the measured shrinkage are evaluated via a piping model, or other evaluation means. Although no ASME Code, Section III stress limits are directly applicable to such sustained secondary stresses, a guideline is to compare them to the primary plus secondary stress limit (3 Sm). Such stresses may also affect PWSCC crack growth evaluations of other susceptible welds in the system (with or without weld overlays).

3. System Walkdowns - Because of displacements produced by weld overlay shrinkage in the piping system, after application of the overlay, a walkdown is required to check hanger setpoints and clearances at any pipe whip restraints to ensure that they are within tolerance.

4. Evaluation of Mass and Stiffness Effects - The mass added to the piping systems by the weld overlay and the effect of the overlay on piping system stiffness should also be evaluated, based on as-built dimensions, to determine if they have any significant effects on dynamic analyses of the system.

Although TR MRP-169 recommends these evaluations, the NRC staff believes that the above evaluations must be performed as part of the weld overlay application to verify that the weld overlay of a DMW will not affect the entire piping system. The remaining calculations (residual stress, crack growth and Section III fatigue analysis) are performed to substantiate the life of the design. TR MRP-169 does not specify a deadline for submitting these evaluations to the NRC after weld overlay installation. The NRC staff expects that the NDE results of the overlaid DMW will be submitted 14 days after the completion of the overlay examination. In addition, the NRC staff expects to receive a summary of the ASME Code, Section III stress analysis and crack growth calculations before Mode 4 of plant operation. The final report on these stress analyses should be submitted 60 days after plant restart (i.e., after the generator output breaker is closed).

The NRC staff finds that the above evaluations are consistent with ASME Code Case N-504-3 and are acceptable because the evaluations will ensure that the piping system after weld overlay will satisfy the piping design requirements of the ASME Code, Section III. Although it is not discussed in TR MRP-169, the NRC staff notes that a system leakage test must be performed after the weld overlay installation. The NRC staff notes that a FSWOL and OWOL cannot be installed onto an existing weld overlay that is degraded.

#### 3.2.6 Leak-Before-Break Considerations

General Design Criterion 4 (GDC 4), “Environmental and Dynamic Effects Design Bases,” of Appendix A, “General Design Criteria for Nuclear Power Plants,” to 10 CFR Part 50, “Domestic Licensing of Production and Utilization Facilities,” allows the concept of leak before break (LBB) to be applied to RCS piping. The LBB concept postulates that the plant’s leakage monitoring systems would detect small through-wall flaws in a piping system long before the flaws could grow to unstable sizes. Leakage exceeding the limit specified in plant technical specifications requires operator action or plant shutdown.

Larger diameter RCS piping in many PWRs have been evaluated following regulatory guidance in NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition” (hereafter referred to as the SRP), Section 3.6.3, “Leak-Before-Break Evaluation Procedures,” to justify that the dynamic effects associated with pipe rupture can be excluded from the design bases. The NRC staff has approved some LBB evaluations. As a result, licensees have been allowed to remove pipe whip restraints and other protective barriers that would otherwise be required to protect against the local effects of a high-energy line break.

SRP Section 3.6.3 does not recommend the LBB application for a piping system that experiences active degradation mechanisms such as PWSCC; however, PWSCC has occurred in DMWs of LBB piping. Therefore, the NRC and industry are working to develop a more robust technical basis for determining that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping. Until this effort is complete, plants applying FSWOL or OWOL to current LBB piping must update the original LBB evaluation to demonstrate that, due to the efficacy of the overlay for PWSCC mitigation, concerns for original weld susceptibility to PWSCC have been adequately addressed and that the safety margins as specified in SRP Section 3.6.3 are still satisfied.

The NRC staff has asked licensees that propose to apply the weld overlay on the LBB-approved piping to submit, as appropriate, for NRC review and approval a license amendment request with an updated LBB evaluation to demonstrate that the LBB piping with the weld overlay satisfies the recommended safety margins of SRP Section 3.6.3. Once the NRC completes its study of the technical basis for LBB application in light of PWSCC, the agency will issue additional regulatory guidance for the LBB evaluation.

## 3.3 Inspection Requirements

### 3.3.1 Types of Examinations

After the weld overlay is installed on a DMW, TR MRP-169 requires acceptance, pre-service inspection (PSI), and ISI examinations to be performed as discussed in Section 7 of TR MRP-169. TR MRP-169 states that the ASME Code, Section XI, Appendix Q, and ASME Code Cases N-504-2 and N-740-2 define the requirements for the type of examinations and associated examination volumes for FSWOLs. These requirements are consistent with current Performance Demonstration Initiative (PDI) techniques and were originally developed for weld overlay repairs of intergranular stress corrosion cracking in boiling water reactor stainless steel welds, where the initiating flaws are fully characterized with respect to length and depth. Since the FSWOL design assumes that the original flaw is completely through the original pipe wall, inspection of the outer 25 percent of the original pipe wall and the weld overlay is specified for pre-service and subsequent inservice examinations, such that the examination would provide some advance warning if the flaw were to unexpectedly propagate into the outer 25 percent of the region of the pipe. Also, the UT examination technology available when Code Case N-504-2 was issued could reliably support examinations of the outer 25 percent of the original pipe wall. The NRC staff notes that for the DMW that contains a 100-percent through-wall flaw, the advanced warning is moot; however, the FSWOL is designed to support a pipe with a 100-percent through-wall flaw.

For OWOLs, where the weld overlay design assumes the existence of a flaw 75 percent through the original wall thickness, a similar “advance warning” examination volume is needed for the unlikely event that a flaw initiates and begins propagating after application of the OWOL. For this design assumption, examination coverage for weld overlay PSI and subsequent ISIs is increased to include the thickness of the weld overlay plus the outer 50 percent of the original pipe wall thickness.

TR MRP-169 states that for the overlay acceptance examination, 100 percent of the required UT examination volume and penetrant testing (PT) surface examination in Figure 7-1(a) of TR MRP-169 shall be conducted. For PSI and ISIs of overlaid DMWs, essentially 100 percent (i.e., greater than 90 percent) of the required examination volume in Figure 7-1(b) of TR MRP-169 shall be examined, but shall include no less than 100 percent of any PWSCC-susceptible material (i.e., Alloy 82/182 DMW and Alloy 600 components) within the examination volume. Weld overlay examinations must conform to the rules in the ASME Code, Section XI, for welds in piping that require the procedures, equipment, and personnel to be qualified by a performance demonstration in accordance with Appendix VIII, "Performance Demonstration for Ultrasonic Examination Systems," to the ASME Code, Section XI, as amended in 10 CFR 50.55a. Currently, licensees use the PDI qualification process to satisfy these requirements. The NRC staff notes that PSI of the overlaid DMW needs to achieve 100 percent examination coverage of the required examination volume unless the original DMW or associated component configuration prevents a100-percent examination coverage. In such cases, the NRC staff would permit the "essentially 100 percent" examination coverage for PSI.

The NRC staff and its contractor, Pacific Northwest National Laboratory, reviewed the PDI qualification protocols for detecting circumferential flaws in the outer 50 percent of thickness of the DMW with the OWOL at the EPRI NDE Center in Charlottesville, NC, in February 2009. The NRC staff notes that the PDI program for examining the axial flaws in the OWOL is the same as that for the FSWOL which has been qualified. The NRC staff finds that the PDI program is acceptable for examination of the overlaid DMWs with the OWOL design.
TR MRP-169 states that as an alternative to the above requirements, for cases in which current ISI requirements are satisfied by inspecting the inner one-third of the original DMW from the inside surface of the nozzle, licensees may continue to perform such examinations, in lieu of the outside surface weld overlay examinations specified above. In such cases, the acceptance examination of the weld overlay plus the underlying heat-affected zone (Figure 7-1(a) of TR MRP-169) is still required from the outside surface. Existing inside surface examination procedures may continue to be adequate for such inspections but will require additional demonstration or qualification on weld overlay mockups to demonstrate that inside diameter connected flaws are still detectable after application of the overlay and the associated compressive stresses.

The NRC staff has not yet approved any plant-specific weld overlay relief requests that specify examinations of the overlaid DMW from the inside surface of the pipe. However, a volumetric examination using qualified UT is permitted to be performed from the inside surface of the DMW. If cracking is detected extending beyond the required weld examination volume (i.e., inner one-third of the DMW thickness), a qualified UT examination must also be performed from the outside surface of the DMW for the examination volume specified in Figure 7-1(b) of TR MRP-169. If the volumetric examination from the inside surface of the DMW is performed by an unqualified UT, a qualified UT examination must also be performed from the outside surface of the pipe and the examination volume must satisfy Figure 7-1(b) of TR MRP-169. However, licensees may forgo the UT examination from the outside surface of the DMW if an alternative in a relief request is submitted for the NRC review and approval which specifies actions required when the ASME-required root mean square error cannot be met for personnel depth sizing qualification. Regardless of the type of examination, before licensees install the weld overlay, they must submit a plant-specific relief request, including the details of the examinations, for NRC staff review and approval.

The inspection frequency for the DMW overlaid with the FSWOL is that if overlaid DMW has no flaw demonstrated by the pre-installation inspection and PSI, the overlaid DMW may be placed in the 25 percent sample population for future inspection in the 10-year inspection interval. If the overlaid DMW contains a flaw in service or a flaw is assumed in the DMW because a pre-installation inspection was not performed, the overlaid DMW is required to be examined during the first or second refueling outage after the installation. If the overlaid DMW is found with no flaw growth or no additional flaw during the ISI, the overlaid DMW may be placed in the 25 percent sample population. If flaw growth or new flaw is found during the ISI, the overlaid DMW is required to be reexamined in the subsequent first or second refueling outage.
The inspection frequency for the DMW overlaid with the OWOL has the similar inspection strategy as that of the FSWOL. The major difference is that the OWOL is not allowed to be placed in a 25 percent sample population. All DMWs overlaid with the OWOL are required to be inspected once during every 10-year inspection interval. Because of the limited reliability of UT of cast austenitic stainless steel (CASS) components, the NRC staff noted that licensees that have CASS components that are welded to an overlaid DMW should provide additional inspection and/or design requirements in their relief request as described below.

For application of an FSWOL to a DMW that joins a CASS component, the NRC staff requires the following inspection strategy. If preservice and inservice examinations in accordance with the ASME Code, Section XI, Appendix VIII, Supplement 11, cannot be performed for the entire weld overlay examination volume because of CASS components associated with the overlaid DMW, licensees have two options: (1) postulate a 100-percent initial flaw in the DMW in the crack growth evaluation, or (2) postulate a 75-percent through-wall depth in the crack growth calculation, provided that the DMW with its required examination volume is examined at a higher frequency than is required for the DMW that does not join CASS components. The subject DMW will be ultrasonically examined during the first or second refueling outage following the weld overlay installation. The ultrasonic examination during the first or second refueling outage is not required if ultrasonic examination is performed before weld overlay installation and after installation without detecting any planar flaws in the original DMW or the weld overlay. After the first inservice examination, the required examination volume shall be ultrasonically examined within 10 years from installation until the ultrasonic examination is qualified to examine the CASS portion of the required inspection volume in accordance with the performance demonstration requirements of the ASME Code, Section XI, Appendix VIII. The inspection of the overlaid weld shall not be credited with satisfying the requirement of the 25-percent inspection sample every 10 years of overlaid welds without CASS materials. After the required examination volume undergoes qualified ultrasonic examination for the CASS material and no planar flaws are detected, the weld may be placed in the 25-percent inspection sample population.

When applying an OWOL to a DMW that joins a CASS component, licensees have two options: (1) postulate a 75-percent initial flaw in the DMW in the crack growth evaluation, or (2) postulate a 50-percent through-wall depth for a circumferential flaw and 75-percent through-wall depth for an axial flaw in the crack growth calculation, provided that the DMW with its required examination volume is examined at a higher frequency than is required for the DMW that does not join CASS components. The subject DMW will be ultrasonically examined during the first or second refueling outage following the weld overlay installation. The ultrasonic examination during the first or second refueling outage is not required if the ultrasonic examination performed before the weld overlay installation and after the installation detects no planar flaws in the original DMW or the weld overlay. After the first inservice examination, the required examination volume shall be ultrasonically examined every 10 years from the date of the OWOL installation.

### 3.3.2 Inspection Interval and Sample Size

Section 7.2 of TR MRP-169 states that PWSCC-susceptible weldments with no known cracks (based on examination) that have been reinforced by an FSWOL made of material less susceptible to PWSCC are designated Category B per MRP-139. PWSCC-susceptible weldments that contain known cracks that have been repaired by an FSWOL are designated Category F per MRP-139. Section 7.2 of TR MRP-169 requires the ISI intervals described below for the overlaid DMWs:

Case 1. If a UT is performed on the DMW before application of the overlay, and the DMW is shown to be without flaws or crack-like indications, future ISI of the DMW shall be performed in accordance with current ASME Code, Section XI, requirements. TR MRP-169 states that this requirement is consistent with MRP-139 Category B, except that it is independent of whether the weld overlay is an FSWOL or an OWOL.

Case 2. If the DMW was not ultrasonically inspected immediately before application of the weld overlay, or if flaws or crack-like indications were detected during post-installation examinations, future ISIs shall be performed consistent with requirements for cracked, weld overlay repaired weldments (MRP-139 Category F). After the weld overlay and initial post-overlay examination, such weldments shall be inspected once in the next five years. If no new indications are detected or if existing indications have not propagated, the inspection interval shall revert to the existing ASME Code, Section XI, ISI program.

Case 3. If a post-overlay ISI detects a planar flaw in the weld overlay examination volume, crack growth analyses shall address the flaw. If the flaw is found acceptable, the weld overlay examination volume shall be reexamined during the first or second refueling outage following discovery of the flaw.

The NRC staff finds that the above inspection requirements for the FSWOL and OWOL differ slightly from the inspection requirements of Appendix Q to the ASME Code, Section XI, Code Cases N-740-2 and N-770 (Reference 26), and the NRC-approved plant-specific weld overlay relief requests. In light of the differences, Table 4-1 of TR MRP-169 presents a comparison of the inspection requirements in ASME Code Cases N-740-1 and N-754 to the inspection requirements of MRP-139. In addition, the NRC staff noted that TR MRP-169 did not require additional examinations of the overlaid DMW population if an examination revealed crack growth or a new crack occurring in an overlaid DMW.

However, these inconsistencies are understandable because the inspection strategy for the weld overlay has evolved since EPRI's issuance of MRP-139. The ASME Code has prepared several code cases (N-740, N-754, and N-770). Code Case N-770 provides inspection requirements for the FSWOL and OWOL. The NRC staff is incorporating Code Case N-770 into 10 CFR 50.55a with conditions via rulemaking. Once, the final rule for the current 10 CFR 50.55a rulemaking is published, licensees must follow the inspection requirements of 10 CFR 50.55a for weld overlays. In the meantime, the NRC staff requests that licensees planning to apply weld overlays submit a plant-specific relief request based on inspection requirements that are consistent with the inspection requirements of the latest version of Code Cases N-754, N-740-2, and N-770 and the latest NRC-approved weld overlay relief requests.

TR MRP-169 states that for overlaid DMWs, either preemptively or as repairs, risk-informed ISI programs should be modified to include inspections consistent with the requirements of MRP-139 and TR MRP-169. The NRC staff has not yet formulated a position regarding inspection of the overlaid DMWs in terms of a risk-informed ISI program. Therefore, any licensee plans to either include or exclude the overlaid DMWs from the risk-informed ISI program should include the proposed inspection plan in the plant-specific relief request for NRC staff review and approval.

### 3.3.3 Alternative Design and Analysis Requirements for Optimized Weld Overlay

NEI stated that for the OWOL, the post-installation examination (and subsequent ISIs) must cover the OWOL material plus the outer 50 percent of the original wall thickness in the underlying PWSCC-susceptible material. Current attempts to qualify UT procedures for the OWOL examination volume have indicated that, while qualification is possible for inspections for circumferential flaws down to the outer 50 percent of the original wall thickness, some difficulties have been encountered in qualifying examination procedures for the outer 50 percent of the original wall thickness for axial flaws. Appendix 1 to TR MRP-169 provides the following set of design and analysis alternatives that can be used for cases in which procedures cannot be qualified for the extended OWOL examination volume for axial flaws in the overlaid DMWs.

1. OWOL structural sizing shall be performed using a design-basis circumferential flaw assumption of 360 degrees around the PWSCC-susceptible weld with a depth equal to 75 percent of the original pipe wall. The overlaid pipe shall be shown to meet the allowable flaw size criteria in IWB-3641, “Evaluation Procedures,” of the ASME Code, Section XI, in the presence of such an assumed circumferential flaw, including the additional considerations for potential lower toughness in the material of the original weldment and at the fusion line between the original DMW and the weld overlay.

2. The OWOL design shall be evaluated for an assumed axial flaw that is 100 percent through the original pipe wall, with a length equal to 1.5 inches or the total axial length of PWSCC susceptible material under the overlay, whichever is greater. The overlaid pipe shall be shown to meet the allowable axial flaw size limit of the ASME Code, Section XI, Appendix C, Equations seven and eight, but excluding the 75-percent upper-bound limit of applicability.

3. Residual stress, fatigue, and PWSCC crack growth calculations shall be performed. These calculations shall assume a 50-percent through-wall initial circumferential flaw and a 75-percent through-wall axial flaw. The calculations shall show that the predicted crack growth resulting from PWSCC, due to residual stress plus steady-state thermal and pressure (operating condition) loading and fatigue (under normal plant operating conditions) will not violate the overlay design-basis flaws (i.e. 75-percent through wall for circumferential flaws and 100-percent through-wall for axial flaws) until the next scheduled ISI.

4. Post-OWOL NDE (PSI and ISI) shall be conducted with UT procedures, equipment and personnel that are PDI qualified for the expanded OWOL examination volume as shown in Figure 7-1(b) of TR MRP-169 for circumferential flaws only.

5. Post-OWOL NDE (PSI and ISI) shall be conducted with UT procedures, equipment and personnel that are PDI qualified for the FSWOL examination volume as shown in Figure 7-1(b) of MRP-169 for axial flaws. The NRC staff notes that the required UT examination volume for detecting axial flaws in a DMW overlaid with the OWOL is the same as the required UT examination volume for the DMW overlaid with FSWOL.

6. The weld overlay acceptance examination as shown in Figure 7-1(a) of TR MRP-169 shall remain the same as specified in Section 4.3 of TR MRP-169.

TR MRP-169 requires that if the OWOL does not meet these rigorous requirements as originally designed, resizing and additional analyses must be performed until the requirements are satisfied. TR MRP-169 requires that before application of an OWOL, the original DMW is to be inspected ultrasonically and no cracking greater than 50 percent of the wall thickness of the original weld shall exist.

TR MRP-169 notes that axial flaws are less critical than circumferential flaws from the standpoint of structural integrity. Axial flaws attributable to PWSCC in DMWs cannot lead to a pipe rupture or significant loss of coolant because their length is limited to the axial length of the DMW and susceptible material. Laboratory and field experience has shown that active PWSCC flaws blunt and arrest upon reaching nonsusceptible material on either side of the DMW and safe end. In the case of a weld overlaid axial flaw, even if the residual stress and crack growth calculations were in error, and the flaw continued to grow in the original DMW, it would arrest upon reaching weld overlay material. MRP-169 concludes that even in this scenario, the axial flaw would be completely contained and would not lead to either pressure boundary leakage or violation of ASME Code margins.

Because the current UT technology cannot be qualified to detect axial flaws in the entire inspection volume in the overlaid DMW with OWOL, TR MRP-169 proposes alternative requirements for the design, flaw assumptions, and examinations for the axial flaw in the OWOL design as specified in Appendix 1 to TR MRP-169. The NRC staff finds that the alternative requirements are appropriate because the design and inspection requirements are consistent in addressing the UT deficiency in the inspection of the axial flaw. Therefore, the requirements in Appendix 1 are acceptable.

## 3.4 Welding

The weld overlay will be installed on DMWs using Alloy 52 and 152, Alloy 52M, or Alloy 52MS because these weld metals have been shown to be less susceptible to PWSCC than Alloy 82/182. Licensees will use gas tungsten arc welding (GTAW) to apply the weld overlay on the DMW in accordance with the ASME Code. ASME Code Case N-638-1 (Reference 27) which the NRC has approved, provides requirements for welding on low-alloy steel nozzle material to ensure that sufficient fracture toughness and ductility are maintained. TR MRP-169 discusses specific chromium contents in the weld filler material to ensure that the weld overlay will be less susceptible to PWSCC.

TR MRP-169 identifies welding issues with Alloy 52/152 such as formation of oxides, solidification (hot) cracking, and ductility dip cracking. In addition, the NRC staff noted that cracking during overlay installation can also be caused by improper welding procedures (e.g., weld head speed and direction along the pipe circumference) and contaminants surrounding the welding area. Also, the industry has experienced cracking when Alloy 52 weld material is applied to stainless steel piping that contains relatively high sulfur content. In their weld overlay relief requests, licensees should address these welding issues and how they will be managed to minimize the potential for cracking during the weld overlay installation.

Some Alloy 82/182 welds in the primary system of PWRs join ferritic or stainless components with safe ends that are made of Alloy 600 material. Application of a weld overlay that terminates on an Alloy 600 safe end may result in an increase in tensile stresses in the safe end. Since pressure boundary components made of Alloy 600 are known to be susceptible to PWSCC, a weld overlay that terminates on the safe-end may increase the likelihood of safe-end cracking. The NRC staff questioned whether TR MRP-169 is applicable to Alloy 600 safe ends. By letter dated February 3, 2010, NEI responded that the weld overlay design is applicable to safe ends that are made of Alloy 600 material. NEI changed several sections of TR MRP-169 to reflect that the technical basis of the weld overlay design considers Alloy 600 components. Based on the revised pages, the NRC staff finds that TR MRP-169 is applicable to Alloy 600 safe ends. However, the NRC staff expects that if the Alloy 600 safe end is covered with a weld overlay, the residual stresses at the inside diameter region of the safe end needs to be less than 10 ksi. Also, a crack growth analysis of a flaw that is the greater of the maximum flaw size (either pre- or post-weld overlay) or the maximum flaw size in PWSCC-susceptible material that could be missed by the applicable inspections shall show that the flaw does not grow to an unacceptable size during the design life of the overlay.

### 3.5 Summary

The NRC staff considers a weld overlay design to be acceptable when it satisfies the general criteria described below. Specific criteria such as treatment of CASS components and reporting requirements that are discussed in the SE, and subject to the limitations and conditions described in Section 4.0 of this SE, shall also be satisfied.

#### FSWOL Design

Design-Basis Flaws

Postulate in the original DMW a circumferential flaw with a depth of 100-percent through-wall for the entire pipe circumference and an axial flaw with a depth of 100-percent through-wall with a length equal to the width of the susceptible material or 1.5 inches, whichever is greater.

Crack Growth Calculation Flaws

(a) If the DMW is not examined by UT before overlay installation, postulate an inside-surface connected flaw in the circumferential and axial directions with a depth of 75-percent through-wall. The length of the circumferential and axial flaws will be the same as the length of the design-basis flaw discussed above.

(b) If pre-installation UT is performed and a flaw is detected in the DMW, use the detected flaw size.

(c) If pre-installation inspection is performed and no flaw is detected, postulate an inside-surface connected flaw of 10-percent through-wall depth in the circumferential and axial directions. The circumferential and axial length will be the same as the length of the design-basis flaw discussed above.

(d) If the original DMW was not UT inspected before overlay installation, but a flaw is detected in the required overlay inspection volume of the DMW after overlay installation, the postulated flaw size shall be the detected flaw depth plus 75-percent through-wall depth of item (a) above.

(e) After weld overlay installation, if a flaw is detected in the weld overlay during PSI or ISIs, the detected flaw shall be evaluated for crack growth. A flaw detected in the weld overlay during PSI may be accepted by IWB-3514, but not IWB-3600 of the ASME Code, Section XI, because the NRC staff believes that weld overlay should not contain large size flaws. A flaw detected in the weld overlay during ISI may be accepted by IWB-3500 and IWB-3600 if it is caused by fatigue. The PWSCC flaw is not permitted to remain in service in the weld overlay.

Examination Requirements

Follow the latest NRC-approved plant-specific weld overlay relief request. The latest versions of ASME Code Cases N-740-2 and N-770 may be used as references. The inspection requirements of 10 CFR 50.55a are applicable once Code Case N-770 is incorporated by reference in 10 CFR 50.55a. The NRC staff will evaluate examination requirements on a plant-specific basis via weld overlay relief requests.

Stresses and Stress Intensity Factor

The inside diameter stresses shall be less than 10 ksi. Also, a crack growth analysis of a flaw that is the greater of the maximum flaw size (either pre- or post-weld overlay) or the maximum flaw size in PWSCC-susceptible material that could be missed by the applicable inspections shall show that the flaw does not grow to an unacceptable size during the design life of the overlay.

<u>OWOL Design</u>

Design-Basis Flaws

Postulate in the original DMW a circumferential flaw with a depth of 75-percent through wall for the entire pipe circumference and an axial flaw with a depth of 100-percent through-wall with a length equal to the width of the susceptible material or 1.5 inches, whichever is greater. The 100-percent through-wall axial flaw may be reduced to 75-percent through-wall after UT is qualified to detect axial flaws in the outer 50-percent wall thickness region of the DMW. However, licensees need to submit document(s) for NRC review and approval to demonstrate the NDE qualification before assuming a design-basis axial flaw of 75-percent through-wall.

Crack Growth Calculations

(a) The OWOL design requires that DMW be ultrasonically examined before overlay installation. If a flaw is detected in the DMW, use the detected flaw size to perform crack growth calculations.

(b) If no flaw is detected during the pre-installation inspection, postulate an inside-surface connected flaw with a depth of 10-percent through-wall in the DMW in the circumferential and axial directions. The circumferential and axial length will be the same as the length of the design-basis flaw discussed above.

(c) If a flaw is detected in the weld overlay during PSI or ISIs, the detected flaw shall be evaluated for crack growth. A flaw detected in the weld overlay during PSI may be accepted by IWB-3514, but not IWB-3600 of the ASME Code, Section XI, because the NRC staff believes that weld overlay should not contain large size flaws. A flaw detected in the weld overlay during ISI may be accepted by IWB-3500 and IWB-3600 if it is caused by fatigue. The PWSCC flaw is not permitted to remain in service in the weld overlay.

Examination Requirements

All OWOLs must be inspected ultrasonically at least once every 10 years. The latest versions of ASME Code Cases N-754 and N-770 may be used as references. The inspection requirements of 10 CFR 50.55a will be applicable once Code Case N-770 is incorporated by reference in 10 CFR 50.55a. The NRC staff will evaluate examination requirements on a plant-specific basis through weld overlay relief requests.

Stresses and Stress Intensity Factor

The inside diameter stress shall be less than 10 ksi. Also, a crack growth analysis of a flaw that is the greater of the maximum flaw size (either pre- or post-weld overlay) or the maximum flaw size in PWSCC-susceptible material that could be missed by the applicable inspections shall show that the flaw does not grow to an unacceptable size during the design life of the overlay.

## 4.0 LIMITATIONS AND CONDITIONS

Licensees desiring to apply a weld overlay, utilizing TR MRP-169 as the technical basis to ensure quality and safety, are required to submit a relief request for NRC review and approval.

1. The NRC staff will require the analysis described in Section 3.2.1, “Design Analysis,” of this SE to be submitted to the NRC or available for NRC staff review.

2. The NRC staff is still investigating the fatigue crack growth rate to ensure that the fatigue crack growth rate in the PWR water environment encompasses more laboratory data. Licensees should use a conservative fatigue crack growth rate in their crack growth calculation to support their plant-specific weld overlay relief requests. (Additional detail provided in Section 3.2.3 of this SE, “Crack Growth Calculations”).

3. TR MRP-169 notes that the $0.75\sqrt{Rt}$ distance is a suggested length and that shorter lengths may be used if stress analysis of the specific overlay configuration demonstrates that adequate load transfer and stress attenuation are achieved. However, the NRC staff finds that if a weld overlay is designed with a length less than the $0.75\sqrt{Rt}$ distance on either side of the DMW, the licensee needs to submit its justification for NRC review and approval before weld overlay installation. (Additional detail provided in Section 3.1.1 of this SE, “Weld Overlay Length Design”).

4. The NRC staff expects that the life of the weld overlay is designed to be longer than the life of the plant, including the period of license renewal. However, the crack growth calculations, required by TR MRP-169 may show that the postulated or actual flaw may grow to exceed the design-basis flaw size earlier than the expiration of the plant license. In some cases, the postulated flaw in the overlaid DMW may grow to exceed the design-basis flaw in less than the ISI interval of 10 years. In such cases, the inspection interval of the overlaid DMW shall be less than the time period for the flaw to exceed the design-basis flaw (i.e., the overlaid DMW needs to be inspected at an interval less than the time for the analyzed flaw to exceed the design-basis flaw). (Additional detail provided in Section 3.1.1 of this SE, “Weld Overlay Length Design”).

5. If applicable, the piping loads for the design of the weld overlay should consider changes in operating conditions (such as increased pressure and temperature) caused by power uprate, steam generator replacements, change of pipe configuration or routing, or any system modifications. (Additional detail provided in Section 3.1.1 of this SE, “Weld Overlay Length Design”).

6. The NRC staff has not approved MRP-139. However, if a flaw is detected in the pre-installation examination of a DMW, the overlaid DMW needs to be reexamined during the first or second refueling outage following the overlay installation. The NRC staff also notes that the inspection interval of the overlaid DMW will depend upon the requirements of 10 CFR 50.55a or an NRC-approved plant-specific relief request for the weld overlay. In addition to the 10-year ASME Code inspection interval, the inspection interval cannot be greater than the inspection interval requirements of 10 CFR 50.55a or NRC-approved plant-specific relief request for the weld overlay. (Additional detail provided in Section 3.2.3 of this SE, “Crack Growth Calculations”).

7. For the FSWOL design in which the original DMW is not ultrasonically examined before overlay installation but a flaw is detected in the outer 25 percent of the overlaid DMW thickness, the postulated initial flaw depth for the crack growth calculation needs to be the detected flaw depth into the outer 25 percent of the original wall plus the inner 75 percent of the DMW thickness. (Additional detail provided in Section 3.2.3 of this SE, “Crack Growth Calculations”).

8. If the fatigue usage factor at the weld location, or adjacent locations, is less than 0.2 and the location is not subject to thermal transients more severe than those associated with normal and upset reactor coolant hot leg, or cold leg transients, TR MRP-169 suggests that fatigue usage factor calculations due to application of the weld overlay do not need to be considered further. The NRC staff does not object to the aforementioned criteria; however, the NRC staff notes that licensees must demonstrate that the cumulative fatigue usage factor at all pipe locations must satisfy the requirements of the ASME Code, Section III, articles NB-3200 and NB-3600. (Additional detail provided in Section 3.2.4 of this SE, “Cumulative Fatigue Usage Factor Calculations”).

9. The NRC staff finds that the fatigue usage factor calculation follows the requirements of the ASME Code, Section III; therefore, it is acceptable. However, the NRC has not yet approved Appendix L in the context of 10 CFR 50.55a. Therefore, before weld overlay installation, licensees who use Appendix L need to submit a justification for NRC review and approval, demonstrating that Appendix L is applicable to the cumulative fatigue usage factor calculations. (Additional detail provided in Section 3.2.4 of this SE, “Cumulative Fatigue Usage Factor Calculations”).

10. As described in Section 3.2.5 of this SE, (“Evaluation of Effects of Weld Overlay on Piping System”) TR MRP-169 recommends that several evaluations be performed after a weld overlay is installed. Although TR MRP-169 recommends these evaluations, the NRC staff believe that the evaluations described in Section 3.2.5 of this SE must be performed as part of the weld overlay application to verify that the weld overlay of a DMW will not affect the entire piping system. TR MRP-169 does not specify a deadline for submitting these evaluations to the NRC after weld overlay installation. The NRC staff requests that the NDE results of the overlaid DMW will be submitted 14 days after

the completion of the overlay examination. In addition, the NRC staff expects to receive a summary of the ASME Code, Section III stress analysis and crack growth calculations before Mode 4 of plant operation. The final report on these stress analyses should be submitted 60 days after plant restart (i.e., after the generator output breaker is closed).

11. Although it is not discussed in TR MRP-169, the NRC staff notes that a system leakage test must be performed after the weld overlay installation. A FSWOL and OWOL cannot be installed onto an existing weld overlay that is degraded.

12. The NRC and industry are working to develop a more robust technical basis for determining that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping. Until this effort is complete, plants applying FSWOL or OWOL to current LBB piping must update the original LBB evaluation to demonstrate that, due to the efficacy of the overlay for PWSCC mitigation, concerns for original weld susceptibility to PWSCC have been adequately addressed and that the safety margins as specified in SRP Section 3.6.3 are still satisfied. The NRC staff has asked licensees that propose to apply the weld overlay on the LBB-approved piping to submit for NRC review and approval a license amendment request with an updated LBB evaluation to demonstrate that the LBB piping with the weld overlay satisfies the recommended safety margins of SRP Section 3.6.3. (Additional detail provided in Section 3.2.6 of this SE, “Leak-Before-Break Considerations”).

13. The NRC staff notes that PSI of the overlaid DMW needs to achieve 100 percent examination coverage of the required examination volume unless the original DMW or associated component configuration prevents a 100-percent examination coverage. In such cases, the NRC staff would allow the “essentially 100 percent” examination coverage for the PSI. (Additional detail provided in Section 3.3.1 of this SE, “Types of Examinations”).

14. The NRC staff has not yet approved any plant-specific weld overlay relief requests that specify examinations of the overlaid DMW from the inside surface of the pipe. However, a volumetric examination using qualified UT is permitted to be performed from the inside surface of the DMW. If cracking is detected extending beyond the required weld examination volume (i.e., inner one-third of the DMW thickness), a qualified UT examination must also be performed from the outside surface of the DMW for the examination volume specified in Figure 7-1(b) of TR MRP-169. If the volumetric examination from the inside surface of the DMW is performed by an unqualified UT, a qualified UT examination must also be performed from the outside surface of the pipe and the examination volume must satisfy Figure 7-1(b) of TR MRP-169. Regardless of the type of examination, before licensees install the weld overlay, they must submit a plant-specific relief request, including the details of the examinations, for NRC staff review and approval. (Additional detail provided in Section 3.3.1 of this SE, “Types of Examinations”).

15. Because of the limited reliability of UT of CASS components, licensees that have CASS components that are welded to an overlaid DMW should provide additional inspection and/or design requirements in their relief request as described in Section 3.3.1 of this SE, “Types of Examinations”).

16. The NRC staff is incorporating Code Case N-770 into 10 CFR 50.55a with conditions via rulemaking. Once, the final rule for the current 10 CFR 50.55a rulemaking is published, licensees must follow the inspection requirements of 10 CFR 50.55a for weld overlays. In the meantime, the NRC staff requests that licensees planning to apply weld overlays submit a plant-specific relief request based on inspection requirements that are consistent with the inspection requirements of the latest version of Code Cases N-754, N-740-2, and N-770 and the latest NRC-approved weld overlay relief requests. (Additional detail provided in Section 3.3.2 of this SE, “Inspection Interval and Sample Size”).

17. The NRC staff has not yet formulated a position regarding inspection of the overlaid DMWs in terms of a risk-informed ISI program. Therefore, any licensee plans to either include or exclude the overlaid DMWs from the risk-informed ISI program should include the proposed inspection plan in the plant-specific relief request for NRC staff review and approval. (Additional detail provided in Section 3.3.2 of this SE, “Inspection Interval and Sample Size”).

18. TR MRP-169 identifies welding issues with Alloy 52/152 such as formation of oxides, solidification (hot) cracking, and ductility dip cracking. In addition, the NRC staff noted that cracking during overlay installation can also be caused by improper welding procedures (e.g., weld head speed and direction along the pipe circumference) and contaminants surrounding the welding area. Also, the industry has experienced cracking when Alloy 52 weld material is applied to stainless steel piping that contains relatively high sulfur content. In their weld overlay relief requests, licensees should address these welding issues and how they will be managed to minimize the potential for cracking during the weld overlay installation. (Additional detail provided in Section 3.4 of this SE, “Welding”).

## 5.0 CONCLUSION

The NRC staff finds that TR MRP-169, Revision 1, as revised by letter dated February 3, 2010, adequately describes the methods for the weld overlay design, the supporting analyses of the design, the experiments that verified the analyses, and the inspection requirements of the overlaid DMWs. The design of the FSWOL and OWOL follows the intent of the acceptance standards of the ASME Code, Sections III and XI. The effect of the weld overlay on the residual stress benefits has been demonstrated by the analysis and verified by the laboratory experiments with mockups.

The ASME Code, Section XI has not yet included requirements for the weld overlay application, and the NRC staff has not yet approved ASME weld overlay code cases N-740-2 and N-754 in 10 CFR 50.55a via Regulatory Guide 1.147. Therefore, licensees planning to install an FSWOL or an OWOL on DMWs need to request relief from the ASME Code requirements before overlay installation. Licensees may reference TR MRP-169 in their weld overlay relief request as the technical basis for the weld overlay design. When TR MRP-169 is used in a weld overlay relief request, the NRC staff expects that the technical issues discussed in this safety evaluation, as summarized in Section 3.5 of this SE, the limitation and conditions as summarized in Section 4.0 of this SE, and the issues raised in the NRC staff’s RAIs will be adequately addressed. The plant-specific relief request should discuss any deviations from MRP-169 as approved.

The NRC staff expects that the weld overlay relief request will specify plant-specific inspection requirements which should be consistent with the latest ASME Code development, such as ASME Code Cases N-740-2, N-754, and N-770, and the NRC's regulations in10 CFR 50.55a.

The NRC staff concludes that TR MRP-169 has provided an adequate technical basis to demonstrate that the DMW overlaid with either the FSWOL or the OWOL will provide reasonable assurance that the structural integrity of the piping system will be maintained to perform its intended function. Therefore, the NRC staff approves the use of TR MRP-169.

## 6.0 REFERENCES

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2. Letter from M. Honcharik (NRC) to J. Riley (NEI), "Request for Additional Information (RAI) Regarding Materials Reliability Program (MRP-169), Technical Basis For Preemptive Weld Overlays For Alloy 82/182 Butt Welds In PWRS," August 3, 2006 (ADAMS Accession No. ML062050337)

3. Letter from J. Golder (NRC) to J. Riley (NEI), "Closeout For Review of Materials Reliability Program (MRP): Technical Basis For Preemptive Weld Overlays For Alloy 82/182 Butt Welds in Pressurized Water Reactors (MRP-169)," April 26, 2007 (ADAMS Accession No. ML071130113).

4. Letter from T. Mensah (NRC) to S. Rosenberg (NRC), "Summary of the August 23, 2007, Category 2 Public Meeting With the Nuclear Energy Institute (NEI): Pre-Submittal Meeting For Review of Material Reliability Program (MRP): Technical Basis For Preemptive Weld Overlays for Alloy 82/182 Butt Welds In Pressurized Water Reactors (MRP-169)," September 10, 2007 (ADAMS Package No. ML072490281).

5. Letter from J. Riley (NEI) to NRC Document Control Desk, "Response to NRC Request for Additional Information (RAI) Regarding Materials Reliability Program (MRP-169), "Technical Basis For Preemptive Weld Overlays for Alloy 82/182 Butt Welds in PWRS," January 9, 2008 (ADAMS Package No. ML080780312).

6. Letter from S. Rosenberg (NRC) to J. Riley (NEI), "Acceptance for Review of Nuclear Energy Institute Topical Report Material Reliability Program (MRP): Technical Basis For Preemptive Weld Overlays For Alloy 82/182 Butt Welds in Pressurized Water Reactors (MRP-169)," March 25, 2008 (ADAMS Accession No. ML080780600).

7. Letter from T. Mensah (NRC) to J. Riley (NEI), "Request for Additional Information RE: Nuclear Energy Institute Topical Report Material Reliability Program (MRP): Technical Basis For Preemptive Weld Overlays For Alloy 82/182 Butt Welds in Pressurized Water Reactors (MRP-169)," April 7, 2008 (ADAMS Accession No. ML080940280).

8. Letter from J. Riley (NEI) to T. Mensah (NRC),"Response to NRC Request for Additional Information (RAI) Regarding Materials Reliability Program (MRP) -169, Technical Basis For Preemptive Weld Overlays For Alloy 82/182 Butt Welds in PWRS," May 2, 2008 (ADAMS Package No. ML082610258).

9. Letter from J. Riley (NEI) to NRC Document Control Desk, "Materials Reliability Program (MRP) – 169, Revision 1 Appendix – Alternative Design/Analysis Requirements for Optimized Weld Overlays (OWOL) Subject to Performance Demonstration Initiative (PDI) Limitations," March 2, 2009 (ADAMS Package No. ML090690630).

10. Letter from J. Riley (NEI) to NRC Document Control Desk, "Materials Reliability Program Technical Basis for Preemptive Weld Overlays for Alloy [82/182] Butt Welds, MRP-169 Revision 1," November 30, 2009 (ADAMS Accession No. ML093430269).

11. Letter from J. Riley (NEI) to T. Mensah (NRC), "Changes to Materials Reliability Program (MRP-169 Rev. 1), Technical Basis for Preemptive Weld Overlays for Alloy 82/182 Butt Welds in PWRs," February 3, 2010 (ADAMS Package No. ML100360487).

12. American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) Case, N-740-2, "Full Structural Dissimilar Metal Weld Overlay for Repair or Mitigation of Class 1, 2, and 3 Items, Section XI, Division 1," Draft, November 15, 2007.

13. American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code) Case,N-754, "Optimized Structural Dissimilar Metal Weld Overlay for Mitigation of Class 1, 2, and 3 Items, Section XI, Division 1," Draft, July 21, 2009.

14. U.S. NRC Regulatory Guide 1.147, "Inservice Inspection Code Case Acceptability, ASME Code, Section XI, Division 1," October 2007.

15. American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME Code), IWB-3514, "Standards for Examination Category B-F, Pressure Retaining Dissimilar Metal Welds in Vessel Nozzles, and Examination Category B-J, Pressure Retaining Welds in Piping," 2004 Edition.

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Date:

NRC RESOLUTION OF NUCLEAR ENERGY INSTITUTE (NEI) COMMENTS ON DRAFT SAFETY EVALUATION FOR TOPICAL REPORT MATERIALS RELIABILITY PROGRAM (MRP): TECHNICAL BASIS FOR PREEMPTIVE WELD OVERLAYS FOR ALLOY 82/182 BUTT WELDS IN PRESSURIZED WATER REACTORS (MRP-169)

PROJECT NO. 689

By letter dated March 25, 2010, an NRC draft safety evaluation (SE) regarding the U.S. Nuclear Regulatory Commission's (NRC's) approval of Topical Report MRP-169, was provided for NEI review and comment. By letters dated April 23, 2010, and June 9, 2010, NEI commented on the draft SE. The NRC staff's dispositions of the NEI comments on the draft SE are provided below.

**NEI Comments dated April 23, 2010**

1. NEI Technical Comment No. 1

*On p 19, lines 5-7, the SER states, "The NRC staff notes that PSI of the overlaid DMW needs to achieve 100 percent examination coverage of the required examination volume. The NRC staff would allow the "essentially 100 percent" examination coverage for the ISI, but not for the PSI. This position is reiterated in item 13 of Section 4.0, Limitations and Conditions (p26, lines 29-32).*

The industry does not understand the logic for requiring different examination coverage requirements for PSI versus ISI. The same examination volume applies to both of these exams (Figure 7-1b) in MRP-169, Rev. 1, reproduced below), and if there are physical restrictions that limit the ability to achieve 100 percent examination coverage (rather than "essentially 100 percent"), then those restrictions will affect both PSI and ISI. However, if this statement applies to the weld overlay acceptance examination, for which the applicable examination volume is AB-C-D in Figure 7-1a), then this is consistent with the coverage requirements of Section 7.1 of MRP-169-1: "For the overlay acceptance examination, 100% of the required UT and PT exam volumes in Figure 7-1a) shall be examined. For post-overlay pre- and inservice inspections, essentially 100% (>90%) of the required exam volume in Figure 7-1b) shall be examined, but shall include no less than 100% of any PWSCC susceptible material within the exam volume."

Also pertinent to this topic are the examination coverage requirements currently contained in Code Case N-770, Article -2500 (c). These are as follows:

> (c) For axial and circumferential flaws, examination shall be performed to the maximum extent practical using qualified personnel and procedures. If 100% coverage of the required volume for axial and circumferential flaws cannot be met, but essentially 100% coverage for circumferential flaws (100% of the susceptible material volume) can be

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achieved, the examination for axial flaws shall be completed to achieve the maximum coverage practical, with any limitations noted in the examination report. The examination coverage requirements shall be considered to be satisfied.

In accordance with Article -2220 of that Code Case, these requirements apply to pre-service examinations of mitigated locations, prior to return to service, including "mitigation by weld overlay, stress improvement with welding, inlay, or onlay, or by mitigation using non-welded stress improvement methods". *Page 21, Lines 35-38 of the SER states "In the meantime, the NRC staff requests that licensees planning to apply weld overlays submit a plant-specific relief request based on inspection requirements that are consistent with the inspection requirements of the latest version of Code Cases N-754, N-740-2, and N-770 and the latest NRC-approved weld overlay relief requests."* Since the above-stated examination coverage requirements of MRP-169-1 are consistent with (actually more conservative than) those contained in N-770, it appears that the SER is inconsistent on this point.

<u>NRC Response to NEI Technical Comment No. 1</u>

NEI Technical Comment No. 1 addresses lines 5 to 7 on page 19 and lines 29 to 32 on page 28 of the draft safety evaluation.

The NRC staff believes that the preservice inspection (PSI) of the overlaid dissimilar metal weld (DMW) needs to achieve 100-percent volumetric examination coverage of the required examination volume because the weld overlay should be designed so as to achieve a 100-percent examination coverage. In addition, PSI provides a baseline examination to comprehensively determine the condition of the repaired DMW and weld overlay. However, the NRC staff understands that there may be cases where the original DMW or associated component configuration prevents a 100-percent coverage. In such cases, the NRC staff would allow the "essentially 100 percent" examination coverage for PSI.

The NRC has revised the affected paragraphs on pages 19 and 28 as follows:

> *The NRC staff notes that PSI of the overlaid DMW needs to achieve 100-percent examination coverage of the required examination volume unless the original DMW or associated component configuration prevents a100-percent examination coverage. In such cases, the NRC staff would permit the "essentially 100 percent" examination coverage for PSI.*

2. <u>NEI Technical Comment No. 2</u>

*On p 19, lines 5-7 the SER states "The NRC staff finds that if the examination is performed from the inside surface of the DMW, a UT examination must also be performed from the outside surface of the pipe and the examination volume must satisfy Figure 7-1(b) of TR MRP-169."*

The logic for this additional requirement is also unclear. There would be no benefit to performing an examination of the standard ASME Section XI ISI examination volume (i.e. inner 1/3 of the DMW wall thickness) from the inside surface if there is also a requirement to perform an examination from the outside surface of the Figure 7-1b) examination volume. Performing the inside surface examination, as specified in MRP-169-1, with additional demonstration or qualification on weld overlay mockups to demonstrate that ID connected flaws are still detectable after application of the overlay, will ensure that there are no ID connected flaws in the PWSCC susceptible material that could propagate to the point that they would violate the overlay design basis.

This additional requirement is also inconsistent with the current requirements of Code Case N-770. Footnote 8 to Table 1 in that Code Case (Inservice Inspection of Full Structural Weld Overlays), paragraph (c) states that, “As an alternative to (a) for inservice inspection, the weld examination volume in Figure 1 (i.e. the standard ASME Section XI inner 1/3 ISI examination volume) may be ultrasonically examined. If cracking is detected extending beyond the weld examination volume, the weld examinations of (a) and (b) above shall be performed (i.e. the weld overlay exam volume, outer 25% of DMW wall thickness) to determine the acceptability of the weld overlay.” So N-770 only requires additional inspections from the outside surface to be performed if the inside surface exams detect cracking that extends beyond the inside surface exam volume. The current version of N-770 also contains similar wording in Footnote 13(c) for optimized weld overlays (denoted “stress improvement by weld overlay” in that document).

<u>NRC Response to NEI Technical Comment No. 2</u>

NEI Technical Comment No.2 addresses lines 26 to 33 on page 19 and lines 34 to 43 on page 28 of the draft safety evaluation.

The NRC staff notes that the UT examination from the inside surface of a DMW in a thick pipe has not been qualified for depth sizing by the Performance Demonstration Initiative or the ASME Code, Section XI, Appendix VIII. Therefore, the NRC requires that if a licensee uses an unqualified ultrasonic testing (UT) to examine the overlaid DMW from the inside surface, a qualified UT needs to be performed from the outside surface of the overlaid DMW as well. In light of the NEI comment, the NRC has revised the affected paragraphs on pages 19 and 28 as follows:

> *The NRC staff has not yet approved any plant-specific weld overlay relief requests that specify examinations of the overlaid DMW from the inside surface of the pipe. A volumetric examination using qualified UT is permitted to be performed from the inside surface of the DMW. If cracking is detected extending beyond the required examination volume (i.e., inner one-third of the DMW thickness), a qualified UT examination must also be performed from the outside surface of the DMW for the examination volume specified in Figure 7-1(b) of TR MRP-169. If the volumetric examination from the inside surface of the DMW is performed by an unqualified UT, a qualified UT examination must also be performed from the outside surface of the pipe and the examination volume must satisfy Figure 7-1(b) of TR MRP-169. However, licensees may forgo the UT examination from the outside surface of the DMW if an alternative in a relief request is submitted for the NRC review and approval which specifies actions required when the ASME-required root mean square error cannot be met for personnel depth sizing qualification. Regardless of the type of examination, before licensees install the weld overlay, they must submit a plant-specific relief request, including the details of the examinations, for NRC staff review and approval. (Additional detail provided in Section 3.3.1 of this SE, “Types of Examinations”).*

3. <u>NEI Editorial Comments (1) through (7)</u>

<u>NRC Response to NEI Editorial Comments</u>

The NRC agrees with all seven editorial comments and has changed the draft safety evaluation accordingly.

**NEI Comments dated June 9, 2010**

1. NEI Technical Comment

The industry commented on a sentence in the safety evaluation on page 11 and a similar sentence on page 14. The staff stated that "…The NRC staff asked NEI to provide an additional basis, including supporting data, analyses, and operational experience, to support allowing an inside surface stress threshold of 10 ksi. By letter dated November 30, 2009, NEI responded that since there is no generally accepted PWSCC crack growth threshold for Alloy 82/182 weld metals, satisfying this criterion generally requires that the crack tip stress intensity factor, due to residual stresses, operating pressure and sustained, steady-state loads, be compressive up to the greater of the maximum flaw size (either pre- or post-overlay) or the maximum flaw size in PWSCC-susceptible material that could be missed by the applicable inspections. The NRC staff believes that the crack tip stress intensity factor shall be compressive up to the greater of the maximum flaw size detected (both pre- and post-overlay) or the maximum flaw size that the NDE procedure is not performance demonstration initiative (PDI) qualified to detect…"

The industry disagrees with the staff's position that the crack tip stress intensity factor must be compressive. The industry believes that the staff took a general recommendation in MRP-169 and made it a firm requirement.

NRC Response to NEI Technical Comment

The staff agrees with the industry's viewpoint that the stress intensity factor at the crack tip is a design goal rather than a requirement. The staff believes that the crack growth calculation will provide reasonable assurance that the crack in the original dissimilar metal weld will not grow to an unacceptable size. In addition, periodic examinations of the overlaid welds will be performed in accordance with the design requirements of the weld overlay to monitor the crack growth. The staff has revised the underlined portion of the above paragraph on pages 11 and 14 of the safety evaluation to read as follows:

> *The NRC staff finds the NEI response acceptable that the inside surface residual stress will be less than 10 ksi and a crack growth analysis of a flaw that is the greater of the maximum flaw size (either pre- or post-overlay) or the maximum flaw size in PWSCC-susceptible material that could be missed by the applicable inspections, shall show that the flaw does not grow to an unacceptable size during the design life of the overlay.*