NUCLEAR ENERGY INSTITUTE

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SUBJECT: 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"

PROJECT NUMBER: 689

The Nuclear Energy Institute (NEI) is pleased to provide the enclosed responses to the NRC's request for additional information (RAI) on EPRI Topical Report MRP-169 (TR), "Technical Basis for Pre-Emptive Weld Overlays for Alloy 82/182 Butt Welds in Pressurized Water Reactors (PWRs)."

EPRI MRP-169 details the methodology and criteria for using preemptive weld overlays (PWOL) to prevent dissimilar metal welds from cracking in PWR primary coolant pipes and nozzles. The report was first submitted for NRC review on September 7, 2005. NRC issued a request for additional information on August 3, 2006 (ADAMS ML062050337; TAC NO. MC9779). The responses to the RAI questions with proposed MRP-169 changes are contained in the enclosed document. The enclosed document is considered to be non-proprietary.

MRP and NEI representatives last met with the NRC staff on August 23, 2006 to discuss the industry approach to addressing the staff RAIs (meeting minutes documented in ADAMS ML 0724200980). As part of the meeting, the industry requested the Safety Evaluation Report (SER) for this TR be issued in time to support the Fall 2008 refueling outages when this PWOL application may be required. Based on this, the SER would need to be approved and issued by early summer 2008 to support plant outage planning and relief request submittals. The industry is willing to support the Staff to meet this need date.

NRC staff review of the enclosed report is exempt from the fee recovery provision contained in 10 CFR Part 170. A fee waiver was already granted when the TR was first submitted. This approval is documented in an NRC letter dated August 3, 2006 (ADAMS ML060370431). Based on our discussions with the Staff, the approved fee waiver will remain in effect for the re-submittal of the TR and RAI responses since the scope and purpose of the TR have not changed.

We look forward to working with the Staff towards a successful completion of the safety evaluation.

If you have any technical questions regarding this matter, please contact me at 202.739.8137; jhr@nei.org or Mike Melton at 202.739.8049; mam@nei.org.

Sincerely,

James H. Riley

James H. Riley

Enclosure

c: Mr. Edmund T. Sullivan, Senior Level Advisor, NRC
Mr. Timothy R. Lupold, Materials Engineer, NRC

MRP Letter 2007-053

NRC RAI Response

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General Content

General Question 1 *NEI has requested that the Nuclear Regulatory Commission (NRC) staff review and approve only Section 4, Design Requirements, and Section 7.1, Examination Requirements, of MRP-169. However, the NRC staff review and potential approval of these sections has necessitated the review of the entire report. Accordingly, the NRC staff is transmitting questions on various sections beyond 4 and 7.1 and will need responses to those questions in order to proceed with the review.*

Proposed Response Comment acknowledged. No response required.

General Question 2 *The treatment of pre-emptive full structural, design, and optimized weld overlays (WOLs) is confusing because in various sections the discussions of the design and optimized pre-emptive weld overlay (PWOL) are intermingled with the discussion of the full structural PWOL. The NRC staff suggests that the report be clarified to (a) provide an introductory section that defines the differences between full structural, design, and optimized WOLs and (b) more clearly separate out the differences in the design and inspection rules for each category of overlay.*

Proposed Response As suggested, clarification will be added to MRP-169 that defines the function of weld overlays to be either 'repair' or 'mitigation', and that within each function type, a weld overlay may be either an optimized weld overlay (OWOL) or a full structural weld overlay (FSWOL). An OWOL may be used for repair only if an existing flaw can be characterized as less than a prescribed through-wall dimension (i.e., 50% through wall) and justified by design analysis. Table 1 will be included in the revised report to summarize each overlay type with attendant design and inspection requirements from both MRP-139/169 and the ASME draft Code Cases N-740-1 and N-754. The term 'design overlay' will no longer be used in MRP-169.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1) Section 4.1 has been completely rewritten to provide general background information on weld overlay design and its relationship to ASME Section XI flaw evaluation rules. The discussion of FSWOLs and OWOLs is also expanded and clarified. New Figures 4-1 and 4-2 are added to support this background discussion. A new summary Section (4.7) and Table (4-1, which is Table 1 from this response) have been added summarizing the various design and inspection requirements for FSWOLs and OWOLs.

Table 1 – Weld Overlay Design Types and Associated Design and Inspection Requirements

Weld Overlay Type	Pre-WOL Inspection Completed?	Design Basis Flaw for WOL	Crack Growth Design Basis	Post-WOL Exam Volume (PSI and ISI)	Post-WOL Inservice Inspection Schedule (MRP-139/169 vs. ASME Code Cases)
Repair – Full Structural	Yes	100% thru-wall, full circ.	Actual observed flaw shall not exceed design basis flaw size in next inspection interval	WOL + outer 25% of Code DMW Exam Volume	MRP-139/169: (Cat. F) Once in the next 5 years, and then if no growth 100% in subsequent 10 year interval CC N-740-1: Once in the next two RFOs, and then if no growth, a 25% sample population on a 10 year basis
Repair – Full Structural	No	100% thru-wall, full circ.	Assumed 75% flaw shall not exceed design basis flaw size in next inspection interval	WOL + outer 25% of Code DMW Exam Volume	MRP-139/169: (Cat. F) Once in the next 5 years, and then if no growth 100% in subsequent 10 year interval CC N-740-1: Once in the next two RFOs, and then if no growth, a 25% sample population on a 10 year basis
Preemptive – Full Structural	Yes	100% thru-wall, full circ.	Assumed 10% flaw shall not exceed design basis flaw size in next inspection interval	WOL + outer 25% of Code DMW Exam Volume	MRP-139/169: (Cat. B) 100% every interval (10 years) CC N-740-1: A 25% sample population on a 10 year basis
Repair – Optimized	Yes	75% thru-wall, full circ.	Actual observed flaw shall not exceed design basis flaw size in next inspection interval	WOL + outer 50% of Code DMW Exam Volume	*MRP-139/169: (Cat. F) Once in the next 5 years, and then if no growth 100% in subsequent 10 year interval CC N-754: Once in the next two RFOs, and then if no growth, a 25% sample population on a 10 year basis (outer 50%)
Preemptive – Optimized	Yes	75% thru-wall, full circ	Assumed 10% flaw shall not exceed design basis flaw size in next inspection interval	WOL + outer 50% of Code DMW Exam Volume	*MRP-139/169: (Cat. B) 100% every interval (10 years) CC N-754: A 25% sample population on a 10 year basis

* Current MRP-139 requirement is that overlays must be full structural to qualify as Cat. B or F, however, a revision to MRP-139 is planned to support these categories for optimized overlays (similar to MRP-139, Section 6) .

General Question 3 *There may be conflicts between MRP-169 and other MRP reports. Question 3 under "Inspections" illustrates one such example. Sections 4 and 7.1 of MRP-169 contain information that is also in MRP-139, "Primary System Piping Butt Weld Inspection and Evaluation Guideline," which the NRC staff has not been requested to review and approve. Also, MRP-169 may not be consistent with MRP-140, "Leak-Before-Break [LBB] Evaluation for PWR Alloy 82/182 Welds." The NRC staff recommends that additional reviews be performed of these documents for consistency.*

Proposed Response MRP has performed a consistency review of MRP-169 (in its proposed revised form) with respect to MRP-139 and MRP-140.

An inconsistency currently exists regarding classification of OWOLs due to the fact that the OWOL concept was defined after publication of MRP-139, and therefore was not addressed in it. MRP-139 provides categories for FSWOLs (B if the DMW is inspected and found clean, and F if it is inspected and found cracked prior to WOL application) as well as for DMWs treated by stress improvement (C if the DMW is inspected and found clean, and G if it is inspected and found cracked prior to the stress improvement application). The MRP-139 inspection requirements for these categories are summarized in the following table.

Table 2 – MRP-139 Inspection Requirements for FSWOLs and DMWs treated by Stress Improvement

MRP-139 Inspection Category	Applies to:	Examination Extent and Schedule
B	Inspected, uncracked, reinforced by FSWOL	Existing Code Examination Program or Approved Alternative
C	Inspected, uncracked, mitigated by SI	50% within next 6 years; if clean, then Code program or approved alternative
F	Inspected, cracked, reinforced by FSWOL	Once in next 5 years; if no new indications/growth, then Code program or approved alternative
G	Inspected, cracked, mitigated by SI	100% at 2 RFO intervals. If no new indications/growth after 2 exams then Code program or approved alternative

A revision to MRP-139 has been drafted to include the following:

- MRP-139, Category B (not C) is recommended for Alloy 82/182 welds that are inspected in accordance with ASME Section XI, Appendix VIII, prior to OWOL application and found to be free of service-induced defects.
- MRP-139, Category F (not G) is recommended if the weld is found cracked (or a fully qualified inspection is unable to be performed prior to OWOL application) and the OWOL is applied as a repair.

The technical justification for these recommendations is that an OWOL performs not only a stress improvement function, but also provides structural reinforcement with a corrosion resistant material. The assumed design basis flaw size for an OWOL is smaller than for a FSWOL (75% versus 100%), however the post-WOL exam volume and crack growth analysis requirements are adjusted accordingly. The technical justification includes analyses which demonstrate that OWOLs retain structural margin even under the extreme assumption that a PWSCC flaw grows through the entire thickness of the DMW to the overlay (not realistic in view of OWOL design and inspection requirements). This reserve structural margin, which does not exist in the case of stress improvement only, justifies inspection categorization that recognizes both the stress improvement and structural reinforcement attributes of OWOLs.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
No specific changes are required to MRP-169 to address this issue, since changes to MRP-139 have been proposed that will correct the inconsistency. However, the inconsistency and the proposed MRP-139 action are addressed in a footnote to new Table 4-1.

MRP-140 did not specifically address weld overlays, and thus there are no major inconsistencies between it and MRP-169. MRP-169, Rev. 0 provides some specific requirements for LBB to remain applicable to PWSCC susceptible welds that have been mitigated by pre-emptive weld overlays (FSWOLs or OWOLs). However, the current technical basis for regulatory approval of LBB applications does not provide a path for approval of components with active degradation mechanisms such as PWSCC. Efforts are underway within the NRC and EPRI to develop the tools necessary to evaluate the probability of pipe rupture and to define LBB evaluation criteria for welds susceptible to PWSCC. Pending completion of that effort, discussion of LBB requirements and examples in MRP-169, Rev. 1 will be modified to simply state that "plants applying structural weld overlays (FSWOL or OWOL) to current LBB locations should update the original LBB calculations with an evaluation demonstrating that due to the efficacy of the overlay for PWSCC mitigation, concerns for original weld susceptibility to cracking have been resolved."

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
Existing Section 4-5 has been revised to wording that references the joint EPRI /NRC project to develop a more robust technical basis for LBB and provides interim guidance regarding treatment of the LBB analysis associated with DM weld locations to be mitigated by WOL. In addition, the LBB example problem (Section 8.5) will be

eliminated in its entirety. References to LBB analyses were also deleted in several other sections (Abstract, 2.0 Purpose, and 9.0 Conclusions)

General Question 3 *There appears to be a number of differences between MRP-169 and the corresponding draft code case for PWOLs. For example, the draft code case does not provide a maximum residual stress value for the design. Also, the draft code case does not indicate that if a qualified examination cannot be performed immediately prior to the WOL, the WOL should be assumed to be a full structural examination. Please provide a crosswalk of the design and inspection requirements in MRP-169 and the draft code case and discuss any plans to make these two documents consistent, including a revision of MRP-169.*

Proposed Response Table 1 provides a summary of the design basis flaw assumptions and crack growth analysis requirements in MRP-169. These are consistent with Code Case N-740-1 for full structural overlays, and presumably with what the requirements will be for optimized overlays when draft Code Case N-754 is eventually published. Although there are no substantive differences in the design and analysis requirements between MRP-169 and the respective Code Cases, MRP-169 provides additional guidance in areas not addressed by the Code Cases, including residual stress analyses and acceptance criteria, fatigue and fatigue crack growth analyses. There are also differences in the future inservice inspection schedules between MRP-169 and the respective Code Cases which are summarized in the last column of Table 1. These are discussed further under Inspection Question 3 below.

MRP will endeavor to promote consistency between MRP-169 and future drafts of related ASME Code Cases. However, Code Committees are consensus bodies, and the MRP cannot guarantee that the versions of the Code Cases that are eventually issued will be entirely consistent with the MRP guidance in MRP-139/169.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
No specific changes are required to MRP-169 to address the differences in future inspection requirements relative to the Code Cases, since MRP-169 is considered more conservative than the Code Cases in this regard. However, the differences are summarized in the new Table 4-1.

Inspection Questions

Inspection Question 1 *Page 4-2 in Section 4.1 on Weld Overlay Sizing indicates that, "For an optimized structural PWOL,...[t]he pipe will have been inspected, and found to exhibit no evidence of cracking, so there is a high level of assurance that no flaws greater than 10% of the wall thickness exist in the original weld." This wording is not clear as to whether the inspections for an optimized structural PWOL has to be performed immediately prior to the application of the WOL. However, on Pages 7-2 and 7-3 it appears that if a qualified inspection is not performed immediately prior to the application of the PWOL, the weldment must be assumed to be cracked and the WOL repair will be full structural, not optimized structural. Please verify whether the above statement is correct. In other words, please clarify (if possible in both sections of the report) that if a American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code), Section XI, Appendix VIII, inspection is not performed immediately prior to the application of the PWOL, the WOL must be full structural, not optimized structural.*

Proposed Response MRP-169 will be revised to clearly state that a qualified inspection in accordance with ASME Section XI, Appendix VIII, is required immediately prior to application of an OWOL. It will also state that an optimized weld overlay may be used either preemptively or as a repair for observed flaw indications up to 50% through wall, as long as the crack growth analysis demonstrates that the observed flaw would not violate the OWOL design basis in the normal ASME Section XI inspection interval of ten years.

However, there are cases in which the original DMW configuration does not permit full coverage of the pre-overlay exam volume by qualified techniques (i.e. due to cast stainless steel or geometric limitations), or where flaw indications greater than 50% (but less than 75%) through-wall may be detected. MRP-169, Rev. 1 will state that an OWOL may still be applied in such situations, subject to a plant-specific, nozzle-specific technical justification.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
Section 4.1 has been revised to specifically state that for an OWOL: "The pipe will have been inspected immediately prior to the overlay application, using an inspection technique qualified in accordance with ASME Section XI, Appendix VIII" This paragraph is now consistent with Section 7. Section 4.1 also now allows that OWOLs may be used for repairs of flaws up to 50% through the original pipe wall. Finally, a paragraph has been added stating that OWOLs may be used in the event that the original DMW configuration does not permit full coverage of the pre-overlay exam volume by qualified techniques or where flaw indications greater than 50% (but less than 75%) through-wall are detected, subject to a plant-specific, nozzle-specific technical justification.

Inspection Question 2 *On Page 4-2 in Section 4.1, the ASME Code Case N-504-2 is mentioned. This ASME Code Case lists calculations to be completed under g(1), (2), and (3). Additionally, Page 4-3 states that a joint-specific, overlay-specific weld residual stress analysis is required for each unique PWOL configuration. It has come to the NRC staff's attention that the ASME Code Case N-504-2 analyses are not being completed by the licensees prior to startup. Please discuss what calculations need to be completed for a PWOL prior to startup or provide a technical justification for any calculations not performed until a specified time has elapsed after startup.*

Proposed Response The structural sizing calculations sufficiently define the design of a weld overlay repair for the purposes of structural integrity and thus safety for plant startup and some short period of plant operation. The remaining calculations (residual stress, crack growth and Section III fatigue analysis) are only to substantiate the life of the design. The time needed to complete these calculations should be decided by utility and approved by NRC. Technically, there is no difference between an emergent (repair) overlay versus a planned (preemptive) overlay on this timing issue. Traditionally, these should be completed within one month of return to power for repair overlay. This timing has been regularly accepted by NRC for repair overlays, performed on an emergent basis, of DMWs in which cracks were discovered during an outage.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
No specific changes are proposed to address this question.

Inspection Question 3 *In Section 4.4, the last sentence in the section on Fatigue Crack Growth on Page 4-6 states that, "PWOL examinations may not be eliminated or reduced as a result of Risk-Informed [inservice inspection] ISI considerations." Section 7.2 on Inspection Interval and Sample Size for PWOLs indicates that if qualified examinations are performed prior to application of the PWOL and such ISI demonstrates the weld to be absent of any flaws or crack-like indications, future ISI of the welds shall be performed in accordance with the current requirements of Section XI of the ASME Code. This paragraph goes on to say that, "This requirement is consistent with MRP-139 Category B, except that it is independent of whether the PWOL is a full structural or optimized structural overlay." MRP-139, Category B inspections are the existing ASME Code examination program or approved alternative. The staff understands "approved alternatives" to mean alternatives to ASME Code requirements which the NRC has previously approved. Approved alternatives may include risk-informed ISI programs. Risk-informed ISI may lead to certain dissimilar metal (DM) welds never being inspected after the post-mitigated inspection. Please clarify this potential conflict between MRP-169 and MRP-139.*

Proposed Response As indicated in the response to Inspection Question 1 above, the inspection requirement noted for an optimized weld overlay with a clean pre-inspection is acknowledged as inconsistent with MRP-139 on the subject of subsequent inspection requirements for OWOLs. A revision to MRP-139 has been drafted has been developed to make MRP-139 consistent with MRP-169 in this regard. We understand that there is also an inconsistency here with respect to Code Case N-740-1, which permits overlays, under some circumstances, to "be placed into a population to be examined on a sample basis. Twenty-five percent of this population shall be examined once every 10 years." MRP-169 will require 100% inspection of the population of weld overlays to be inspected every ten years, and is thus more conservative than the Code Case in this regard.

However, upon reconsideration, MRP would like to retain the option of applying an "approved alternative" (i.e. RI-ISI) to weld overlaid PWR DMWs at some time in the future, pending sufficient experience and technical justification. If this option is pursued, it will be documented in a generic technical justification (similar to BWRVIP-75), and individual RI-ISI updates will explicitly identify any reduction in inspections of weld overlaid DMWs.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
The sentence disallowing RI-ISI has been deleted from Section 4.4, and additional guidance on the subject has been added in Section 7.3, stating that, at some future time, after inservice inspections have demonstrated successful operating experience with PWR overlays, additional inspection relief may be provided, as was done for BWR overlays in BWRVIP-75.

Inspection Question 4 *In Section 4-4, the discussion of ASME intervals and "that interval" for allowable flaw sizes on Page 4-6 is confusing. Please provide a few examples for subsequent ISIs using the criteria you discuss.*

Proposed Response The wording of Section 4-4 will be changed for added clarity.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
The wording in Section 4.4 regarding subsequent inspection intervals has been revised for clarity, and an example, based on new Figure 4-1 is discussed.

Inspection Question 5 *The fourth paragraph in Section 7.1 discusses construction examination of a WOL on piping that is normally examined from the inside surface for ISI. The construction examination is the overlay volume. The criterion is silent on examination of the heat affected zone. Provide an explanation for excluding the heat affected zone from the examination of the WOL. The same paragraph is silent on performing examination from the inside surface prior to applying the WOL. If a crack is located on the inside surface, how effective would depth sizing be after applying the WOL. Discuss why an examination prior to applying the WOL is or is not necessary. Discuss the monitoring of an inside surface crack from the inside surface at a location with an outside surface WOL.*

Proposed Response The required exam volume for the acceptance (construction) examination of the overlay includes the entire weld overlay (except for the tapered end regions) and the associated HAZ. This inspection is performed from the OD of the overlay regardless of whether pre-and post-overlay inservice inspections are performed from the ID or OD. Section 7.1 and Figure 7-1 of MRP-169 will be clarified on these points.

If ISI examinations are performed from the inside surface, the application of the overlay will not require changes to previously qualified examination procedures. However, some additional qualification may be required to demonstrate that ID connected flaws are still detectable after application of the overlay and associated compressive stresses. The weld overlay mockups discussed in Inspection Question 6 below will be available for such qualification, and will contain flaws of various depths, installed prior to application of the weld overlays.

It is possible that some very shallow ID flaws may not be able to be detected after they are put in compression by the overlay, but if they grow outside of the compressive region, ID examinations will be able to readily detect and size them. Current sizing procedures for examination of DMWs from the ID are not limited to the inner 1/3 of the DMW thickness, but are qualified for the entire DMW thickness.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
The wording in Sections 7.1 regarding inside surface inspections has been revised to indicate that the WOL acceptance exam must still be performed from the OD and that some additional qualification of the ID technique is required for post-overlay exams. Also, revised Figure 7-1 now indicates that the required exam volume for the overlay acceptance exam includes the HAZ under the WOL.

Inspection Question 6 *The last paragraph in Section 7.1 states that procedures, equipment, and personnel will be qualified for examinations of WOLs in accordance with Appendix VIII of the ASME Code, as amended in Section 50.55a of Title 10 of the Code of Federal Regulations. The ASME Code, Appendix VIII, Supplement 11 qualifications apply to full structural WOL of austenitic piping (WOL thickness plus 25 percent of through-wall (T-W) base metal thickness). For the optimized WOL, the minimum percent T-W inspection volume is the WOL plus base metal necessary for structural integrity including consideration for flaw growth up to the design basis flaw depth plus a 25 percent T-W tolerance. Therefore, the minimum percent T-W inspection volume is a variable and may require inspecting 50 percent T-W of the base metal. For an optimized WOL, discuss the performance demonstration qualifications for similar configurations (same diameter pipe-to-pipe), dissimilar configurations (different diameter pipe-to-flange or nozzle), DM welds, and cast austenitic piping.*

Proposed Response Criteria and mockup samples are being developed in order to qualify procedures and personnel to examine the required expanded volume for optimized overlays (i.e., the overlay plus outer 50% of original weldment). A demonstration mockup currently exists of a typical surge nozzle weld overlay with ID defects installed at depths ranging from 10% to 75% through the original DMW wall thickness. These defects were installed using standard PDI techniques to simulate service induced flaws, prior to application of the weld overlay, so that any crack closure effects that may occur due to weld overlay compressive stresses are present in the mockup.

A large diameter qualification sample (36 inches) is currently being fabricated using similar flaw depths and fabrication procedures, and has a nozzle configuration representative of an RPV hot leg nozzle, (including different diameter pipe-to-nozzle, DM weld, and cast austenitic safe-end). This mockup will be available for PDI qualification of post-overlay inspection procedures and personnel (from either ID or OD) including the expanded exam volume for optimized overlays.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
No changes to MRP-169 are required to address this issue. The requirement to perform PDI-qualified inspections of the expanded OWOL exam volume is clearly stated, and it is incumbent on the industry to have qualification criteria and mockups in place in a timeframe consistent with upcoming OWOL applications.

Inspection Question 7 *Section 7.2.1 states that if an ISI examination immediately prior to a full structural or optimized WOL that is absent of any flaws or crack-like indications, then future ISI of the WOL shall be performed in accordance with requirements of Section XI of the ASME Code. What are the specific ASME Code, Section XI non-destructive examination (NDE) methods and volume and/or surface examination requirements? Do the examination requirements of Section XI, Appendix Q of the ASME Code apply?*

Proposed Response The future ISI coverage requirement include a volume inclusive of ½" from each DM weld toe and from the surface of the weld overlay and to a depth of 25% or 50% (as applicable) of the original base material/weld thickness and the inspections must be qualified in accordance with ASME Section XI, Appendix VIII, as discussed in response to Inspection Question 6 above. A figure will be added to MRP-169 to depict post overlay exam volumes for acceptance examinations as well as PSI/ISI examinations of FSWOLs and OWOLs. ASME Section XI, Appendix Q, as well as Code Case N-460 coverage requirements apply to overlay pre- and inservice inspections.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
Figure 7-1 has been modified to specifically identify the required inspections and exam volumes for post overlay inspection, including the acceptance examination, and pre- and inservice inspections. The wording in Section 7.1 has also been expanded to

specify that ASME Section XI, Appendix Q as well as Code Case N-460 coverage requirements apply to overlay pre- and inservice inspections.

Inspection Question 8 *Section 7.2.2 states that if no ISI examination is performed immediately prior to a full structural WOL, or crack-like indications are detected, then the weld must be assumed cracked. Discuss the application of the requirements of Section XI, Appendix Q of the ASME Code and explain the differences between Appendix Q and the referenced, MRP-139, Category F, examination frequency, examination methods, and examination volume.*

Proposed Response The requirements of Section XI, Appendix Q, regarding examination methods and examination volume are consistent with those included in MRP-139 Category F and thus with MRP-169. MRP-139 (and MRP-169) differ with Appendix Q only on the subject of examination frequency, which as itemized in Table 1, are as follows:

1. The first subsequent inspection for Category F welds in MRP-139/169 is all welds once in the next 5 years, and then if no growth, 100% are inspected in each successive 10 year interval
2. The first subsequent inspection for cracked, overlaid welds in Appendix Q is all welds once within the next two RFOs, and then if no growth, a 25% sample population is inspected on a 10 year basis.

MRP 139/169 are considered more conservative than Appendix Q in this regard, because the difference in the first inspection schedule (5 years versus 2 RFOs (i.e. 3 to 4 years)) is insignificant compared to the subsequent inspection requirement of 100% versus a 25% sample.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
No specific changes are proposed to address this issue.

Leak-Before-Break Questions

LBB Question 1 *Section 4.5 indicates that, "Prior to performing the PWOL, a qualified examination of the weld and adjacent base material must be performed to show that no cracking is present." Not all welds previously approved for LBB by the NRC can be inspected by a qualified examination. For example, qualified procedures have not been developed for examination of DM welds between cast austenitic components and ferritic components. How does MRP-169 address the issues discussed in Section 4.5 for these types of welds?*

Proposed Response We recognize that some DMWs have been approved for LBB that cannot be inspected by a qualified examination and others may inspect and find some cracking. Certainly, applying a WOL to these components (full structural or optimized) and the subsequent NDE can only improve the situation. A key feature of weld overlays is that they improve inspection coverage (relative to the required post-overlay exam volume), in addition to their residual stress improvement and structural reinforcement benefits.

As previously discussed under General Question 2, a new NRC/EPRI program is underway to define LBB criteria for welds susceptible to PWSCC and to develop the tools necessary to evaluate the probability of pipe rupture in systems with active degradation mechanisms. In the interim, pending results of that effort, discussion of LBB requirements in MRP-169, Rev. 1 will be modified to simply state that "plants applying structural weld overlays (FSWOL or OWOL) to current LBB locations should demonstrate the efficacy of the overlay to mitigate PWSCC concerns for original weld susceptibility to cracking."

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
Existing Section 4-5 has been revised to wording that references the joint EPRI /NRC project to develop a more robust technical basis for LBB and provides interim guidance regarding treatment of the LBB analysis associated with DM weld locations to be mitigated by WOL. In addition, the LBB example problem (Section 8.5) will be eliminated in its entirety. References to LBB analyses were also deleted in several other sections (Abstract, 2.0 Purpose, and 9.0 Conclusions)

LBB Question 2 *The application of a PWOL would alter the piping configuration assumed in the LBB critical flaw size and leakage crack size analyses. Section 4.5 is not clear that for PWOLs these LBB analyses need to be performed and verified to satisfy the specified margins in draft Standard Review Plan 3.6.3. Please clarify in both the RAI response and a revision to MRP-169 that these analyses need to be performed for the PWOLs applied to welds in piping systems that were approved for LBB.*

Proposed Response As previously discussed, pending results of the joint NRC/EPRI program on LBB for welds susceptible to PWSCC, the discussion of LBB in MRP-169 will be revised to the above wording.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
Same as for Question LBB 1 above.

Fatigue Questions

Fatigue Question 1 *In Section 4.4, provide the basis for postulating the existing CUF=0.2 as a threshold for not requiring a fatigue analysis per Section III NB-2300 of the ASME Code, since the existing CUF is based on the simplified rules of the ASME Code, Section III NB-3600, which are not applicable to WOL regions. The NRC staff also believes that the appropriate NB-3200 fatigue analysis should be based on the licensing basis design transients, and not on an alternate, less severe, set of design transients.*

Proposed Response The basis for 0.2 was primarily engineering judgment. MRP-169 also imposes the additional restriction (for not performing a fatigue analysis) that there be no severe thermal transients at the location, beyond normal plant startups and shutdowns. As with the license renewal process, overlay fatigue analyses can be performed with a basis less conservative than the original design basis transient set, so long as the assumptions regarding transients to date can be substantiated by plant records, and assumed future transients are tracked as part of the plant's design basis.

MRP-169 will clarify that some aspects of post-overlay fatigue analyses are performed in accordance with NB-3600, i.e., on the piping side of the overlay; while NB-3200 criteria are applicable for the nozzle side of the weld overlay repair.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
Section 4.4 was modified to state specific Code paragraphs applicable to the fatigue usage evaluation.

Fatigue Question 2 *Relative to Section 4.4, the NRC staff notes that for those plants that have been approved for license renewal or are considering license renewal application, the license renewal period extends plant life to 60 years. Discuss the time period considered for end of life of the PWOL as evaluated for fatigue crack growth.*

Proposed Response The required time period for fatigue crack growth (as well as PWSCC crack growth) analysis in MRP-169 is to the end of the next ASME Section XI inspection interval (ten years). A plant may optionally utilize an analysis period to the end of plant life, in which case the license renewal period should be included.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
Section 4.4 was modified to specifically require inclusion of the license renewal period for FCG analyses that utilize an analysis period to the end of plant life.

Weld Overlay Effectiveness Questions

WOL Effectiveness Question 1 *Section 5.1 on Page 5-4 discusses the "MRP/EPRI PWOL Development Program for Alloy 600 [primary water stress corrosion cracking] PWSCC Mitigation." This section indicates that the program is on-going and that the analysis results are preliminary. Please provide the status of this program and the final results.*

Proposed Response The final residual stress analysis and measurement results from the PWOL mock-up are available and will be added to the revision of MRP-169. Additional details of the mockup program are documented in MRP-208 (to be published) which will be referenced. Copies of MRP-208 can be provided to the NRC staff, when published, with appropriate proprietary information caveats by EPRI.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
Section 5.1 (5) was completely re-written and Figures 5-12 thru 5-15 added summarizing the results of the PWOL mockup program.

WOL Effectiveness Question 2 *Section 5.2 on Analytical Programs discusses the effects of WOL without water backing. Given the rapid cooling with relatively thin water backed components, is the temper bead technique always used for WOLs?*

Proposed Response Weld overlays may be applied with or without water backing, and with or without temperbead welding procedures, depending on the specific nozzle location, nozzle geometry and Code PWHT requirements. Whatever procedure is used, MRP-169, Section 4.2 requires a nozzle-specific residual stress analysis that reflects the actual geometry and conditions under which the overlay welding is performed.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
No specific changes are proposed to address this issue

WOL Effectiveness Question 3 *A premise of the PWOL design is that the overlay will induce compressive stress in the inside diameter region of the pipe so that PWSCC flaws will not initiate or a small existing PWSCC flaw would not propagate. Discuss the potential adverse impact of a PWOL on a weld with a subsurface flaw considering that the crack tip may experience the tensile component of the T-W stress gradient.*

Proposed Response Crack growth analysis is required (Section 4.2) for the specific geometry to which the weld overlay is applied with input from the configuration-specific residual stress analysis. The cracktip stress intensity factor (K) is determined, which is a function of the stresses (operational plus residual) integrated over the entire crack face and must be shown to be negative for crack depths up to the applicable overlay design and inspection requirement (i.e. 50% thru-wall for OWOLs, or 75% through-wall for FSWOLs). Then the complementary region (the outer 50% or 25% of the base material, as appropriate) is inspected to demonstrate it to be crack-free. These combined requirements assure that flaws (surface or subsurface) will not grow to a depth that would violate the overlay design basis. In addition the overlays are installed using materials that have been shown to be highly resistant to crack propagation due to PWSCC, adding yet another layer of protection.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
Specific requirements for the PWSCC crack growth analysis have been added to Section 4.2.

Stress Analysis Questions

Stress Analysis Question 1 *Section 4.2 discusses residual stress improvement and indicates that, "the resulting inside surface stresses, after application of operating pressure and loads must be less than 10 ksi tensile. This target stress level has been selected as a conservatively safe value, below which PWSCC initiation, or growth of small initiated cracks, is unlikely." This criterion appears to be based on the presence of only small preexisting cracks. However, if preexisting cracks extend into a tensile stress region of the original weld, crack propagation may continue to occur. Please justify the appropriateness of this criterion given that MRP-169 indicates that PWOLs may be used without performing examinations prior to application of the WOL and given that the probability of detection even for relatively deep flaws is less than 1..*

Proposed Response The 10 ksi maximum tensile stress criterion provides protection against new PWSCC initiation. Laboratory data and field observations have shown that high stresses, on the order of the material yield strength, are necessary to initiate PWSCC. Limiting ID surface stress levels less than 10 ksi ensures a very low probability of initiating new PWSCC cracks after application of the weld overlay.

MRP-169 also imposes crack growth criteria (PWSCC and FCG) which, in conjunction with the required pre- and post-overlay inspections, provide protection against propagation of pre-existing cracks that would violate the overlay design basis. Also note that, because of the nature of the fracture mechanics calculations, in which the cracktip stress intensity factor (K) is a function of the stresses integrated over the entire crack surface, the K for a postulated crack in an overlaid weld typically remains compressive (no crack growth) for cracks that extend into the tensile stress region of the post-overlay stress field. Other safety factors are present in the ASME Section XI flaw evaluation rules to address (among other things) the probability of non-detection of NDE techniques. The effect of a probability of detection less than 1 is no different for weld overlays than for any other Section XI flaw evaluation or for any other PWSCC mitigation approach.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
The requirements for PWSCC crack growth analysis are expanded and clarified in Section 4.2, and together with the 10 ksi surface stress limit, constitute an integral part of the acceptance criteria for post-overly residual stresses.

Stress Analysis Question 2 *Section 4.2 discusses overlay specific weld residual stress analysis and states that these analyses are required for each unique PWOL configuration. This section also notes that most boiling water reactor pipe WOLs did not require weld specific residual stress analyses since the geometric* *configurations were fairly standard. Please provide the criteria that will be used to determine whether or not weld specific residual stress analyses will be performed.*

Proposed Response Criteria will be added to MRP-169 clarifying when overlay specific residual stress analyses are required. The proposed criteria are that, for any significant geometry, material, or welding process differences from a previously analyzed overlay, beyond standard drawing/fabrication tolerances, nozzle specific residual stress analyses should be performed.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
Wording has been added to Section 4.2 defining criteria for when an overlay-specific weld residual stress analysis is required.

Stress Analysis Question 3 *Page 4-4 in Section 4-2 indicates that the resultant stresses on the inner diameter (ID), after the application of operating pressures and loads, must be less than 10 ksi tensile. Page 4-3 indicates that, "to adequately demonstrate the favorable residual stress effects of a WOL, one must start with a highly unfavorable, pre-overlay residual stress." Describe how the pre-overlay residual stress will be determined. How will the repair history (or lack of information on the repair history) be taken into account in the stress analysis used to determine the post-overlay stress profile?*

Proposed Response The example problems in Section 8 of MRP-169 utilize a very conservative starting assumption of a 360° ID repair that is 50% through-wall. This flaw assumption was demonstrated by analysis and measurements on the PWOL mockup (based on a 90° arc repair) to yield very high, tensile residual stresses prior to application of the weld overlay, as discussed above under WOL effectiveness question 1 and new report section 5.1 (5)) . This repair assumption and the resulting residual stresses conservatively bound any repairs that may have been made during plant construction. It is the recommended starting point for residual stress analyses performed in accordance with MRP-169.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
No specific changes are proposed to address this issue.

Stress Analysis Question 4 *Figures 5-11 and 5-12 show the residual hoop and axial stress distributions for the PWOL mockup. After application of the PWOL, the residual hoop and axial stresses in the WOL appear to be mostly compression. In addition, prior to the application of the PWOL, the figures indicate high tensile hoop and axial stresses that may be beyond the ultimate stresses of the materials. After application of the PWOL, the high tensile regions in the nozzles become compressive, but the compressive regions appear to remain compressive. The stresses in the WOL* *are also shown mostly as compressive. Figures 8-8 and 8-9 show the residual stress distribution for a pressurizer spray nozzle, which appears to be similar to the mock-up geometry. The stress distributions are different from those of the mock-up nozzle. Likewise, the T-W stresses shown in Figures 8-11, 8-13 and 8-15 tend to be tensile towards the outer surface, as expected.*

Proposed Response The PWOL mockup stress analysis results presented in MRP-169, Rev. 0 were identified as preliminary. Final analysis results along with residual stress measurements on the mockup are reported in MRP-208, and will be included in MRP-169, Rev. 1. The post-overlay axial residual stresses for the PWOL mockup show the expected pattern of compression on the ID of the original weld, transitioning to tension near the OD of the original weld and in the overlay itself.

4.a) Provide a discussion why the stress distributions in the mock-up PWOL are different from those of the nozzle PWOLs in Section 8.

Proposed Response (4a) The PWOL mockup actually more closely simulates a surge nozzle than a pressurizer spray nozzle. The spray nozzle is smaller in diameter and is relatively thicker (smaller radius to thickness ratio). The post-overlay residual stresses for the mockup in Section 5 and the surge nozzle example in Section 8 do not differ significantly, when compared under like conditions.

Note that the residual stresses for the PWOL mockup in Section 5 were reported at room temperature, since their purpose is a comparison to residual stress measurements which were performed on the mockup at room temperature. The stresses for the example nozzles in Section 8 were reported at operating temperature (650°F) and also included operating stresses (pressure plus thermal expansion). Because of the differential thermal expansion effects of the various materials involved, this can result in differences in the post-overlay stress distributions at different temperatures.

Appendix A to this response provides contour plots of axial and hoop post-overlay residual stresses at 70°F for the surge nozzle example of Section 8 and the PWOL mockup of Section 5. Careful examination of these plots indicates that the residual stress distributions for the two are quite similar, when compared under like conditions.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
No specific changes are proposed to address this issue.

4.b) Provide a table showing the material properties used in the finite element analyses in Section 5 and Section 8.

Proposed Response (4b) Tables of temperature-dependent materials properties used in the residual stress calculations are provided in Appendix B to this response.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
No specific changes are proposed to address this issue.

Stress Analysis Question 5 In Table 8-5, identify the acronyms HLST, HHST, CLST, and CHST.

Proposed Response Acronyms will be spelled out in revision to MRP-169, as follows: HLST = Heatup Low Pressure Stratification, HHST = Heatup High Pressure Stratification, CLST = Cooldown Low Pressure Stratification, CHST = Cooldown High Pressure Stratification.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
Footnote will be added to Table 8-5 defining acronyms.

Stress Analysis Question 6 *Draft ASME Code Cases related to WOLs contain a requirement to evaluate the effects of any changes in applied loads, as a result of weld shrinkage from the entire overlay, on other items in the piping system (e.g., support loads and clearances, nozzle loads, and changes in system flexibility and weight due to the WOL). MRP-169 does not appear to address these conditions. Please address this comment.*

Proposed Response Analysis requirements similar to those contained in the draft ASME Code Cases will be added to the revision to MRP-169.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
New section 4.6 has been added addressing these requirements.

Example Analysis

Example Analysis Question 1 *Page 8-5 indicates that, "The final spray nozzle overlay dimensions that produce these results are a WOL thickness of 0.3" and a WOL length of ~7.2", making this effectively a full structural overlay as defined in Table 8-3, ..." As stated in Section 4.1, PWOL thickness is calculated based on the ASME Code maximum flaw depth considerations, IWB-3641 allowable flaw size considerations, and residual stress considerations. Clarify what aspect(s) of this analysis yielded a full structural WOL versus an optimized WOL result.*

Proposed Response IWB-3641 allowable flaw size evaluations (aka: structural sizing calculations) were performed for each of the example nozzles in Section 8, considering the appropriate design basis flaw size assumption (100% thru-wall for FSWOL and 75% thru-wall for OWOL) and a typical set of applied nozzle loads. This led to the required design thicknesses for full structural and optimized overlays listed in Table 8-3. However, in some cases, residual stress and inspectability considerations interceded, and required greater overlay lengths and thicknesses than the minimums required by the structural sizing calculations. These are tabulated in Table 8-4. For the spray and surge nozzle examples, these considerations produced overlay dimensions that were greater than the minimums required by the structural sizing calculations for OWOLs, and resulted in minimum overlay designs that were essentially the same as those for FSWOLs on these nozzles.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
No specific changes are proposed to address this issue.

Clarifications

1. *Please clarify the word "consider" in the following statement on Page 4-9: "[I]n meeting the leakage rate requirements, one must consider the potential for more flow resistance through a PWSCC crack morphology."*

Proposed Response As previously discussed, a new NRC/MRP program is underway to define LBB criteria for welds susceptible to PWSCC and to develop the tools necessary to evaluate the probability of pipe rupture with active degradation mechanisms. In the interim, pending results of that program, the discussion of LBB has been totally revised, as discussed in LBB Questions 1 and 2.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
Same as for Question LBB 1 above.

2. *The NRC staff has identified the following typographical errors. (a) In the last paragraph in Section 8-1, it appears that Table 8-2 should have been identified as Table 8-3,*

Proposed Response It *will be* Corrected

(b) References to Tables 8-7 through 8-9 on Pages 8-10 and 8-11 may be incorrect.

Proposed Response The LBB Section and associated tables have been deleted.

3. *The last "sentence" on Page 4-5 is not a complete sentence. Please clarify.*

Proposed Response: Corrected

4. *As part of the design requirements, the NRC staff requests clarifications regarding how certain parameters may be limitations or conditions, if any, to the application of the PWOL. For example, the following parameters:*

4.a. applicable pipe sizes
4.b. applicable pipe thicknesses
4.c. applicable configurations, e.g., pipe-to-pipe, pipe-to-safe end, pipe to nozzle
4.d. applicable pipe degradation mechanisms
4.e. maximum WOL thickness
4.f. number of times a PWOL can be applied to a location

Proposed Response: Subject to the design and analysis requirements specified in MRP-169, no limitations are envisioned in the above areas on application of PWOLs.

Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
No specific changes are proposed to address this issue.

Other Change to MRP-169, Rev. 1

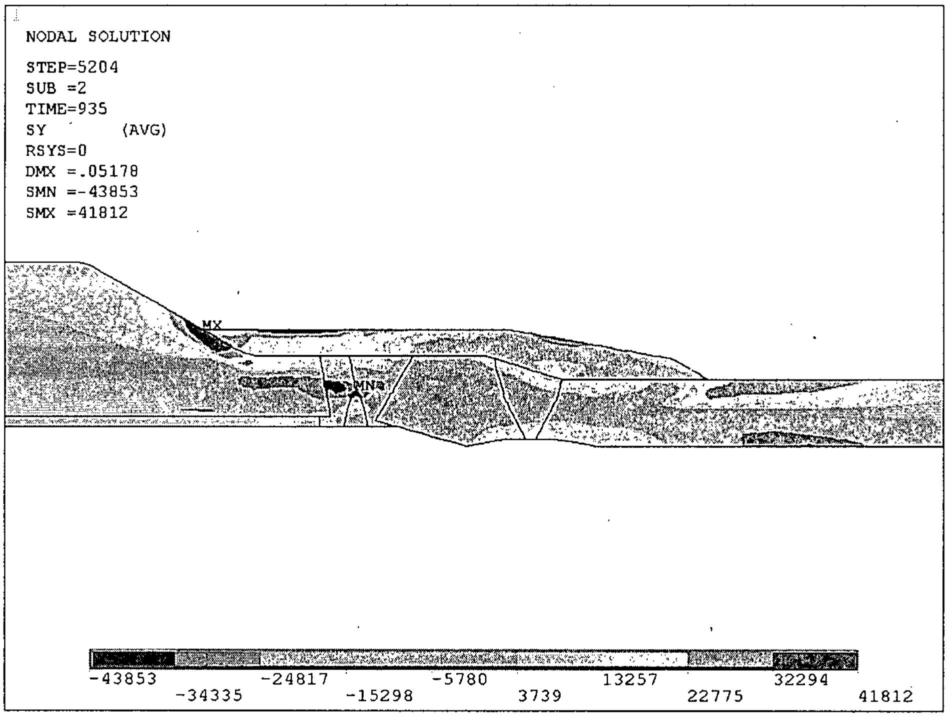
(not related to RAI Questions)

Fatigue Crack Growth Law MRP-169, Rev. 0 contained a very complex and conservative FCG law taken from a 2001 ANL Report (NUREG/CR-6721, "Effects of Alloy Chemistry, Cold Work, and Water Chemistry on Corrosion Fatigue and Stress Corrosion Cracking of Nickel Alloys and Welds," U.S. Nuclear Regulatory Commission (Argonne National Laboratory), April 2001.) A more recent ANL publication (NUREG/CR-6907, "Crack Growth Rates of Nickel Alloy Welds in a PWR Environment," U.S. Nuclear Regulatory Commission (Argonne National Laboratory), May 2006) published after initial issue of MRP-169 recommended instead that "The (fatigue) CGRs of Alloy 182 in the PWR environment are a factor ~ 5 higher than those of Alloy 600 in air under the same loading conditions." The recommended FCG law and examples will be changed to this recommendation.

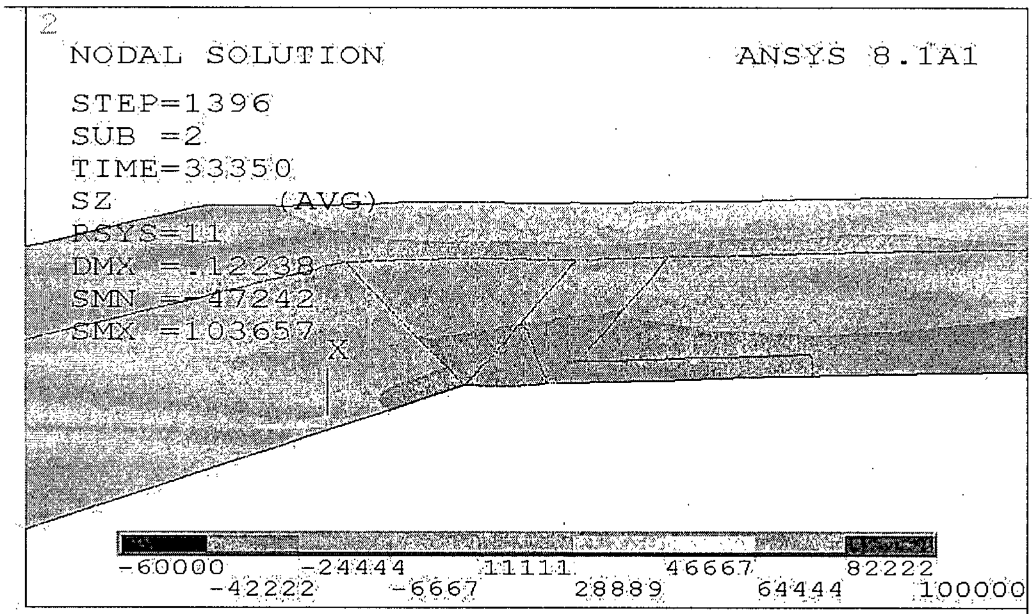
Cross Reference to Appendix C (Selected sections of MRP-169, Rev. 1)
Environmental Fatigue Crack Growth Law in Section 4.4 and Example FCG Analysis in Section 8.3 were revised to reflect the recommendation of the more recent ANL publication.

Appendix A

Comparison of Residual Stress Analyses Results for PWOL Mockup and Surge Nozzle Example in MRP-169

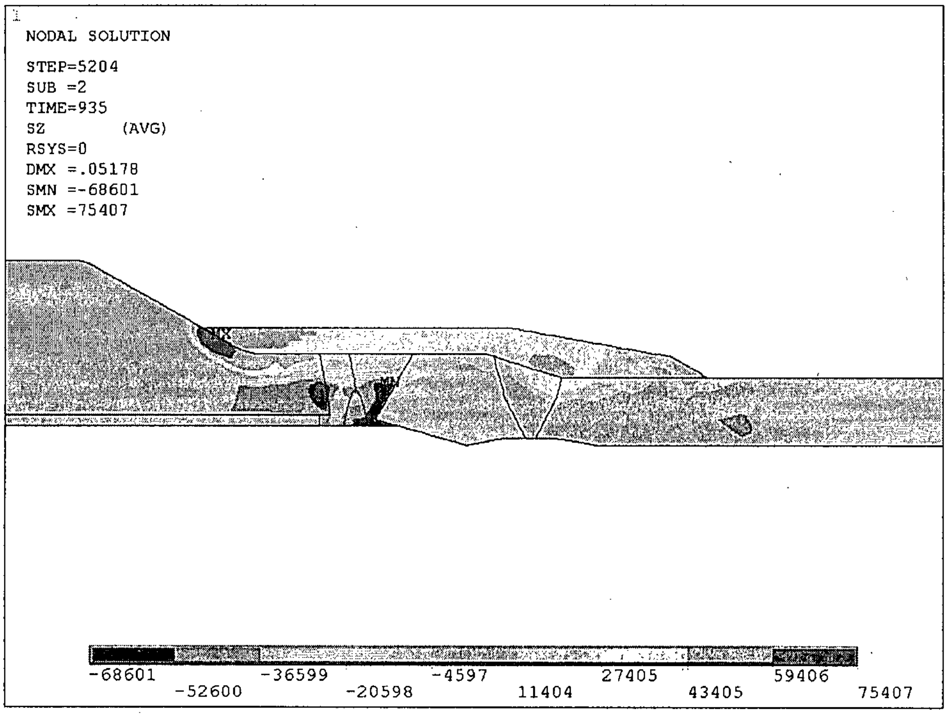


Surge Nozzle Example (Section 8)

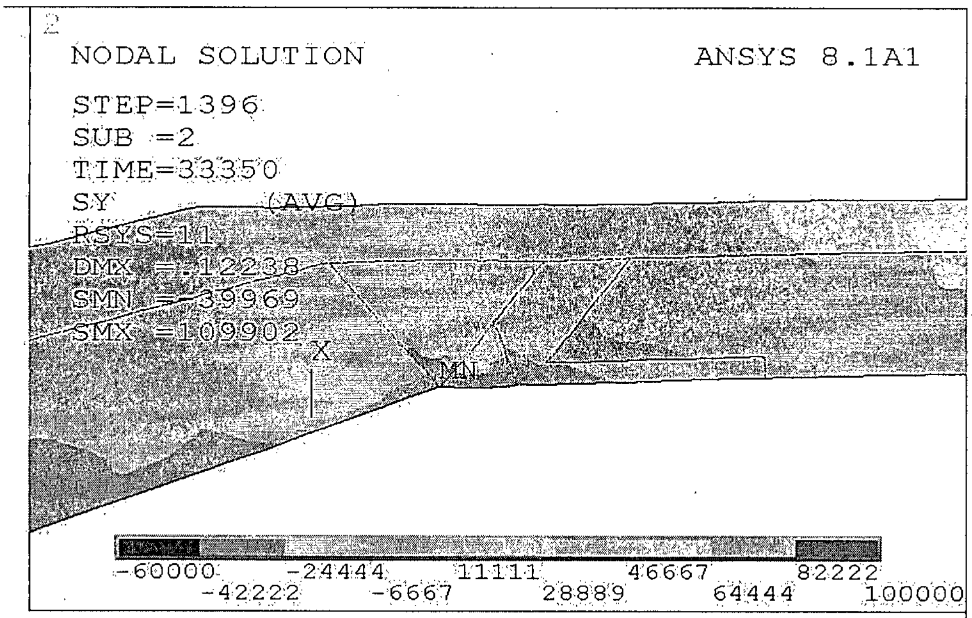


PWOL Mockup (Section 5)

Figure A-1 – Post-Overlay Axial Residual Stress Comparison (Surge Nozzle vs. PWOL Mockup) at 70°F



Surge Nozzle Example (Section 8)



PWOL Mockup (Section 5)

Figure A-2 – Post-Overlay Hoop Residual Stress Comparison (Surge Nozzle vs. PWOL Mockup) at 70°F

Appendix B

Tables of Material Properties Used in Residual Stress Analyses

Table B-1: Material Properties

Material 7 (Nozzle): SA-508, Class 2 (3/4 Ni-1/2 Mo-1/3 Cr-V)

Temperature (°F)	Young's Modulus ($x10^6$ psi)	Thermal Expansion ($x10^{-6}$ in/in/°F)	Thermal Conductivity ($x10^{-4}$ Btu/sec-in-°F)	Specific Heat (Btu/lb-°F)
70	27.8	6.4	5.44	0.105
200	27.1	6.7	5.46	0.114
400	26.1	7.1	5.35	0.125
600	25.2	7.4	5.14	0.135
700	24.6	7.6	5.00	0.140
800	23.9	7.8	4.86	0.147
1000	22.4	8.1	4.56	0.163
1200	20.4	8.3	4.21	0.186
1400	17.7	8.4	3.54	0.406
1600	12.65	8.4	3.50	0.154
1800	7.59	8.4	3.50	0.154
2000	2.54	8.4	3.50	0.154
2100	0.01	8.4	3.50	0.154
2500	0.01	8.4	3.50	0.154
3000	0.01	8.4	3.50	0.154

Materials 5, 6, 9 (Original Nozzle Weld, Weld Butter, Weld Repair): Alloy 82/182/600 (N06600)

Temperature (°F)	Young's Modulus ($x10^6$ psi)	Thermal Expansion ($x10^{-6}$ in/in/°F)	Thermal Conductivity ($x10^{-4}$ Btu/sec-in-°F)	Specific Heat (Btu/lb-°F)
70	31.0	6.8	1.99	0.107
200	30.2	7.1	2.11	0.112
400	29.5	7.5	2.34	0.118
600	28.7	7.8	2.57	0.123
700	28.2	7.9	2.69	0.125
800	27.6	8.1	2.80	0.128
1000	26.4	8.3	3.06	0.134
1200	25.3	8.6	3.31	0.141
1400	23.9	8.9	3.59	0.146
1600	19.3	9.0	3.70	0.148
1800	11.6	9.0	3.70	0.148
2000	3.9	9.0	3.70	0.148
2100	0.01	9.0	3.70	0.148
2500	0.01	9.0	3.70	0.148
3000	0.01	9.0	3.70	0.148

Table B-1 Material Properties (cont'd)

Materials 1, 3, 8 (Cladding, Safe-end Weld, Piping): SA-376 Type 304 (18 Cr-8 Ni)

Temperature (°F)	Young's Modulus ($x10^6$ psi)	Thermal Expansion ($x10^{-6}$ in/in/°F)	Thermal Conductivity ($x10^{-4}$ Btu/sec-in-°F)	Specific Heat (Btu/lb-°F)
70	28.3	8.5	1.99	0.116
200	27.6	8.9	2.15	0.122
400	26.5	9.5	2.41	0.129
600	25.3	9.8	2.62	0.133
700	24.8	10.0	2.73	0.135
800	24.1	10.1	2.82	0.136
1000	22.8	10.3	3.06	0.139
1200	21.2	10.6	3.24	0.141
1400	19.2	10.8	3.45	0.144
1600	15.1	10.8	3.54	0.145
1800	9.1	10.8	3.54	0.145
2000	3.0	10.8	3.54	0.145
2100	0.01	10.8	3.54	0.145
2500	0.01	10.8	3.54	0.145
3000	0.01	10.8	3.54	0.145

Material 4 (Safe-end): SA-182 Type F-316L (16 Cr-12 Ni-2 Mo)

Temperature (°F)	Young's Modulus ($x10^6$ psi)	Thermal Expansion ($x10^{-6}$ in/in/°F)	Thermal Conductivity ($x10^{-4}$ Btu/sec-in-°F)	Specific Heat (Btu/lb-°F)
70	28.3	8.5	1.90	0.121
200	27.6	8.9	2.04	0.124
400	26.5	9.5	2.27	0.129
600	25.3	9.8	2.48	0.133
700	24.8	10.0	2.59	0.135
800	24.1	10.1	2.69	0.136
1000	22.8	10.3	2.89	0.139
1200	21.2	10.6	3.10	0.141
1400	19.2	10.8	3.31	0.145
1600	15.1	10.8	3.40	0.145
1800	9.10	10.8	3.40	0.145
2000	3.00	10.8	3.40	0.145
2100	0.01	10.8	3.40	0.145
2500	0.01	10.8	3.40	0.145
3000	0.01	10.8	3.40	0.145

Table B-1 Material Properties (cont'd)

Material 2 (Weld Overlay): Alloy 52/152/690 (N06690)

Temperature (°F)	Young's Modulus ($x10^6$ psi)	Thermal Expansion ($x10^{-6}$ in/in/°F)	Thermal Conductivity ($x10^{-4}$ Btu/sec-in-°F)	Specific Heat (Btu/lb-°F)
70	30.3	7.7	1.57	0.105
200	29.5	7.9	1.76	0.109
400	28.8	8.0	2.04	0.115
600	28.1	8.2	2.31	0.119
700	27.6	8.3	2.45	0.122
800	27.0	8.3	2.59	0.124
1000	25.8	8.3	2.89	0.129
1200	24.7	8.3	3.17	0.134
1400	23.3	8.3	3.45	0.140
1600	18.8	8.3	3.59	0.143
1800	11.3	8.3	3.59	0.143
2000	3.8	8.3	3.59	0.143
2100	0.01	8.3	3.59	0.143
2500	0.01	8.3	3.59	0.143
3000	0.01	8.3	3.59	0.143

Table B-2: Material Yield Stresses (YS) and Tangent Moduli (TM)

Temperature (°F)	SA 508 Class 2		Alloy 82/182/600		SA-182, Type F-316L		SA 376 Type 304		Alloy 52/152/690	
	YS (ksi)	TM (ksi)	YS (ksi)	TM (ksi)	YS (ksi)	TM (ksi)	YS (ksi)	TM (ksi)	YS (ksi)	TM (ksi)
70	63.6	191.9	53.9	531.1	40.2	680.1	35.8	531.1	49.2	531.1
550	56.3	132.3	50.0	361.5	24.8	415.0	26.5	361.5	36.4	361.5
1000	47.2	79.5	45.7	216.1	20.9	357.1	19.1	216.1	32.7	216.1
1300	36.5	49.6	41.6	138.6	19.3	333.0	15.5	138.6	30.5	138.6
1600	24.2	30.2	24.7	80.5	14.6	247.1	10.5	80.5	27.0	80.5
≥2500	2.0	5.0	2.0	5.0	2.0	5.0	2.0	5.0	2.0	5.0

Appendix C

Selected Sections of MRP 169 with Proposed Changes to Address RAI Questions

Materials Reliability Program:

Technical Basis for Preemptive Weld Overlays for Alloy 82/182 Butt Welds in PWRs (MRP-169)

Revision 1, November 2007

(Selected sections with proposed changes to address RAI questions)

4.0 Design Requirements

4.1 Weld Overlay Sizing

The fundamental assumption of structural weld overlay sizing is that a crack is present in the original pipe or nozzle weld, which must be evaluated in accordance with ASME Section XI flaw evaluation rules [35, 36]. These rules establish an end-of-evaluation-period allowable flaw size based on the maximum size flaw that can be sustained in the component without violating original design margins (typically ASME Section III for primary system components). The end-of period allowable flaw size is illustrated by the horizontal dashed line in Figure 4-1. Section XI also includes a general restriction that in no case shall this flaw size be greater than 75% of the component nominal wall thickness.

Weld overlay sizing requirements are further defined in Code Cases N-504-2 and N-740-1 [3, 4] for Full Structural Weld Overlays (FSWOLs). Full structural weld overlays may be used for any application in which cracking has been detected in a pipe or safe-end weld. ASME Code Section XI allowable flaw size criteria (IWB-3640 and Appendix C) are used for sizing the weld overlay, based on the assumption that a circumferential crack is present completely through-wall and 360° around the original pipe or nozzle cross section. Once the FSWOL is applied, this becomes the allowable end-of-period flaw size, and any actual observed flaws must be demonstrated not to grow to this size before the next scheduled in-service inspection (generally each period, per Section XI successive inspection requirements, IWB-2420-b). Subsequent work [2] has justified extending the successive inspection interval for weld-overly repaired locations in BWR piping back to the original ten-year Section XI interval. A typical crack growth analysis justifying an inspection interval of ten years is illustrated by the solid curve in Figure 4-1.

Weld overlay sizing for FSWOLs is governed, in many cases, by the general Section XI requirement that no flaws of depth greater than 75% through-wall are acceptable. For cases in which applied piping loads are not large, the equation for full structural WOL thickness (t_{WOL}) often reduces to:

$$\text{crack depth} / (t_{\text{orig pipe}} + t_{WOL}) = 0.75$$

But, if the assumed crack depth for WOL sizing is equal to the original pipe wall thickness ($t_{\text{orig pipe}}$):

$$t_{\text{orig pipe}} / (t_{\text{orig pipe}} + t_{WOL}) = 0.75$$
$$t_{WOL} = t_{\text{orig pipe}} / 3$$

The above equation defines a minimum WOL thickness for full structural overlays, regardless of the applied loading. Thicknesses greater than this may be required if larger applied loadings exist, but the overlay can never be thinner than this minimum thickness if it is to be classified as a "full structural" weld overlay.

For preemptive weld overlays on dissimilar metal welds, an "optimized" structural weld overlay is also defined in this document as an acceptable alternative to full structural overlays when there are no flaws present in the weld or any observed flaws are limited in size. For an optimized weld overlay, the design basis flaw assumption is still 360° around the weld, but with a depth equal to

75% of the original pipe wall. An illustration of the design basis flaw size differences for full structural and optimized overlays is provided in Figure 4-2.

The OWOL flaw size assumption is a reasonable and conservative design basis for preemptive overlays, since:

1. The pipe will have been inspected immediately prior to the overlay application, using an inspection technique qualified in accordance with ASME Section XI, Appendix VIII [27] and found to exhibit no evidence of cracking greater than 50% of the wall thickness in the original weld.
2. Post-overlay ultrasonic examinations (and future inservice inspections) will be required to verify the integrity of the applied weld overlay, and the examination volume for these inspections is increased to include the weld overlay plus the outer 50% of the original pipe wall (see Section 4.3 - Inspectability Considerations).

There are cases in which the original DMW configuration does not permit full coverage of the pre-overlay exam volume by qualified techniques (i.e. due to cast stainless steel or geometric limitations), or where flaw indications greater than 50% (but less than 75%) 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.

With a design basis crack depth assumption for OWOL sizing that is 75% of original wall thickness, the assumed flaw already meets the general Section XI 75% criterion without an overlay. Thus, the resulting OWOL thickness will not be controlled by this somewhat arbitrary limit, but will instead be based on the actual internal pressure and pipe loads at the location of the DMW being overlaid, and the ASME Code, Section XI IWB-3641 allowable flaw size criteria. In some cases, the minimum thickness required to provide compressive residual stresses may govern the overlay size (See Section 4.2 – Residual Stress Improvement) .

Code Cases N-504-2 and N-740-1 [3, 4] also provide guidance for weld overlay length sizing, and these are the same for both FSWOLs and OWOLs. The underlying requirement is that sufficient weld overlay length be provided on either side of the observed crack to allow for adequate transfer of axial loads between the pipe and the weld overlay. 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 $0.75\sqrt{Rt}$ from the point of loading [10] (where R is the outer radius and t is the nominal wall thickness of the cylinder). Thus, if the weld overlay length is set equal to $0.75\sqrt{Rt}$ on either side of the crack, 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. In application of weld overlays preemptively, however, no crack will have been detected, so 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. This will result in a total weld overlay length equal to $1.5\sqrt{Rt}$ plus the length of susceptible material (Alloy 82 or 182 weld metal and buttering) on the OD surface of the original DMW. It is noted that the $0.75\sqrt{Rt}$ recommendation is only a rule of thumb, and that shorter lengths may be used if justified by stress analysis of the specific PWOL configuration, to demonstrate that adequate load transfer and stress attenuation are achieved.

Other considerations also factor into weld overlay design. These include that PWOLs be of sufficient length and thickness to achieve the desired residual stress reversal over the entire extent of susceptible material on the inside surface of the pipe or nozzle (see Section 4.2), that the length and other aspects of the weld overlay design result in an inspectable configuration (see Section 4.3), and that no unacceptable structural discontinuities are created. For PWOLs that overlay a tapered transition (or create one), the design must satisfy the ASME Code, Section III requirements of NB-4250 that allow for a maximum 30° transition angle between adjacent sections, unless detailed analyses are performed of the specific configuration to establish applicable stress indices for fatigue evaluation.

4.2 Residual Stress Improvement

A key aspect of the weld overlay design process is to demonstrate that favorable residual stress reversal occurs such that PWSCC initiation and growth is mitigated. Extensive analytical and experimental work was performed on weld-overlaid BWR pipe-to-pipe welds of various pipe sizes to demonstrate that favorable residual stresses result for full-structural weld overlays (summary provided in Section 5 below). A recent PWOL test program also demonstrated that measured residual stresses in a typical PWR mid-sized DMW weld overlay were highly favorable when applied to a weld with a severe inside surface repair (also summarized in Section 5). Since the geometric configuration of BWR pipe-to-pipe joints and the associated weld overlays are fairly standard, most BWR pipe weld overlays did not require weld specific residual stress analyses. The designs relied on the large body of residual stress work that already existed.

The residual stress story for nozzle-to-pipe DMWs is not as straightforward for several reasons.

- Each nozzle / safe-end design is somewhat unique, often with significant diameter and thickness differences between the nozzle, the safe-end and the attached piping.
- Many design configurations involve two welds in relatively close proximity, which can interact with one another.
- As discussed above, an optimized structural overlay concept is being introduced for preemptive applications, and in some cases, the WOL length and thickness required to produce favorable residual stresses may govern the overlay design, rather than structural considerations.

For these reasons, a joint specific, overlay specific weld residual stress analysis is required for each unique PWOL configuration in which there is a significant geometry, material, or welding process difference from a previously analyzed overlay, beyond standard drawing/fabrication tolerances. These must be performed with analysis methods and tools that are appropriate for this type of analysis, including transient thermal analysis capability, non-linear elastic-plastic modeling capability, and temperature dependent material properties. Several such tools exist and have been demonstrated to produce residual stress results that are in agreement with experimental measurements (see Section 5).

Finally, it has been shown that the initial residual stress condition of the DMW joint has a significant bearing on its susceptibility to PWSCC, especially as influenced by in-process repairs performed during plant construction. In fact, in essentially all cases in which PWSCC has been discovered in PWR butt welds, evidence of significant in-process repairs during construction has been found. Thus to adequately demonstrate the favorable residual stress effects of a weld overlay, one must start with a highly unfavorable, pre-overlay residual stress condition such as that which would result from an ID surface weld repair during construction. If the nozzle-specific weld overlay design is shown to produce favorable residual stresses in this severe case, one can be assured that it will effectively mitigate against future PWSCC in the DMW. Acceptable residual stresses for purposes of satisfying this requirement are those which, after application of the weld overlay, are compressive on the inside surface of the nozzle, over the entire length of PWSCC susceptible material on the inside surface, at operating temperature, but prior to applying operating pressure and loads. After application of operating pressure and loads, the resulting inside surface stresses must be less than 10 ksi tensile. As documented in Reference [44], laboratory data and field observations have shown that high stresses, on the order of the material yield strength, are necessary to initiate PWSCC. Thus limiting ID surface stresses under sustained steady state conditions to less than 10 ksi ensures a very low probability of initiating new PWSCC cracks after application of the weld overlay.

A separate PWSCC crack growth criterion must also be satisfied to demonstrate the acceptability of the post-weld overlay residual stress distribution. This criterion requires that any cracks detected in the pre-overlay inspection, or that are not within the pre- or post-overlay examination volumes in the PWSCC susceptible material, would not grow by PWSCC to the point that they would violate the overlay design basis (75% through-wall for OWOLs or 100% through-wall for FSWOLs). Since there is no generally accepted PWSCC crack growth threshold for Alloy 82/182 weld metals [45], satisfying this criteria generally requires that the cracktip stress intensity factor, due to residual stresses, operating pressure and sustained, steady-state loads, be compressive up to the maximum flaw size detected, or the maximum flaw size that could be missed by the applicable inspections.

The above combination of ID surface stress and crack growth criteria, in conjunction with required post-overlay inspections, provides protection against initiating new PWSCC cracks after application of the weld overlay and/or propagation of pre-existing cracks that would violate the overlay design basis.

4.3 Inspectability Considerations

One additional aspect of WOL design is that it must be inspectable. As discussed previously, post overlay examination requirements include the weld overlay itself, plus the outer 25% of the original pipe wall thickness. This examination requirement applies to FSWOLs, which use as their design basis a crack completely through the original pipe wall thickness. The 25% of original pipe wall thickness examination requirement is seen as providing added margin by verifying the arrest of an existing flaw and advanced warning in the unlikely case that the crack is not arrested before propagating into the WOL. In the case of optimized weld overlays, a flaw would violate the design basis if it extended into the outer 25% of the pipe wall. Thus the examination must provide additional coverage to preserve a similar "advanced warning" examination volume. Thus, since the OWOL design basis flaw is 75% of the original pipe wall, then the post WOL examination (and subsequent inservice inspections) must cover the WOL material plus the outer 50% of the original wall thickness in the PWSCC susceptible material.

A summary of the required examination volumes for post overlay inspections is provided in Figure 7-1. Two separate exam volumes are illustrated, one for the overlay acceptance examination (Figure 7-1(a)), and a second for the overlay pre- and inservice inspections (Figure 7-1(b)).

ASME Code, Section XI, 1995 Edition and later includes NRC accepted rules for inspection of welds in piping that require the procedures, equipment, and personnel to be qualified by a performance demonstration in accordance with Appendix VIII, Supplement 11 [26]. The utilities sponsored a performance demonstration initiative (PDI), implemented at the EPRI NDE Center, which satisfies these requirements, as amended for weld overlay repairs, and a number of organizations have successfully qualified personnel and techniques to inspect weld overlays under that program. Therefore, as has been the case for weld overlay repairs, ASME Section XI, Appendix VIII, Supplement 11 shall be implemented for PWOLs. The PWOL design, including surface preparation specifications, should be reviewed to confirm that a PDI qualified examination can be performed.

4.4 Fatigue Considerations

There are two issues that must be addressed from a fatigue viewpoint relative to installation of a weld overlay on an existing weld. The first involves evaluation of potential growth of cracks due to cyclic loadings at the overlay location. The second involves assuring that additional stresses are not created by the application of the overlay that would contribute to an unacceptable end-of-life fatigue usage factor in the region where the overlay is being applied.

The sensitivity to fatigue effects depends upon whether or not there are significant cyclic loadings at the overlay location and if there are structural discontinuities in addition to the overlay that result in stress concentrations. The most severe cyclic loading effects are generally due to thermal transients. The effects of pressure cycles are generally not significant since the applied stresses must meet primary stress limits in the design process. Piping thermal expansion moments are generally not significant, unless there are a significant number of thermal transients or if there are stratification effects in the associated piping. By performing fatigue evaluations for the overlaid locations, the potential for adverse fatigue effects is evaluated and an appropriate inspection interval determined.

Fatigue Crack Growth

The potential for growing a flaw from an initial flaw size to the allowable size for the overlay is evaluated by performing a crack growth analysis. The following steps are included:

- Determine the loading conditions that must be considered. The loadings considered in the original plant design, including any later changes, must be determined. For purposes of crack growth analysis, the number of cycles per heatup/cooldown cycle is established.
- 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. This may include loads due to:
    - Pressure

- Bending moments due to dead weight, piping thermal expansion, nozzle anchor movement effects, seismic OBE, and stratification, as applicable
  - Local thermal stratification, if applicable
  - Thermal transient through-wall stresses
  - Residual stresses
- Characterize the initial flaw depth and aspect ratio. If the location is inspected and no flaws are detected prior to application of the weld overlay, an initial circumferential flaw depth greater than or equal to 10% of the nominal pipe or nozzle thickness shall be assumed, with a length equal to the wall thickness (a/l = 0.1 aspect ratio flaw). An initial axial flawgreater than or equal to 10 percent of the pipe wall thickness with an aspect ratio (l/a) equal to the length of the Alloy 600 weld at the outside surface divided by the pipe wall thickness shall also be assumed.
- If PDI qualified examination of the PWOL location is not performed prior to application of the PWOL, then a larger initial flaw size shall be assumed, consistent with the post-PWOL examination requirement (50% or 75% of the original wall thickness).
- The fatigue crack growth law will be based on that for Alloy 600 in the PWR environment, as reported in [6 and 47]. Reference 47 indicates that the fatigue crack growth rate (FCGR) of Alloy 182 in the PWR environment is a factor ~ 5 higher than that of Alloy 600 in air under the same loading conditions. The FCGR for Alloy 600 in air obtained from Reference 6 is given by:

$$(da/dN)_{air} = C_{A600}\,(1\text{-}0.82R)^{-2.2}\,(\Delta K)^{4.1}\text{, units of m/cycle} \quad (2)$$

where:

C_{A600} = $4.835\text{x}10^{-14} + 1.622\text{x}10^{-16}T - 1.49\ \text{x}10^{-18}T^2 + 4.355\ \text{x}10^{-21}T^3$
T = temperature inside pipe, °C (taken as the maximum during the transient)
R = R-ratio = (K_{min}/K_{max})
ΔK = $K_{max} - K_{min}$ = range of stress intensity factor, Mpa-$m^{0.5}$

Note that a factor of 5 should be applied to Equation (2) to account for the PWR environment [47]. Also, note that Equation (2) in accordance with Reference 47 is independent of rise time of the transient. Alternate crack growth laws may be used if justified on a case-by-case basis (e.g. as further data become available).

- Crack growth analysis is then conducted on a cycle-by-cycle basis for a period equal to standard ASME Section XI inspection interval (ten years) or to end of life, including license renewal period where applicable.
- Several locations around the circumference of the component shall be considered to assure that the critical location is evaluated

The allowable end-of-evaluation period flaw size is that considered in the design basis for structural sizing of the weld overlay (i.e. 75% or 100% of the original wall thickness, as applicable). If the crack growth analysis shows that fatigue crack growth will not grow a flaw to the design basis depth for the normal ASME Code, Section XI inspection interval or greater, then the Section XI ten-year interval is justified for subsequent inservice inspections (after any intermediate inspections imposed by MRP-139, as discussed in Section 7). If the crack growth analysis shows that the crack will grow to the allowable 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 ASME Section XI ten-year interval. For example, referring to the illustration in Figure 4-1, the crack growth curve reaches the allowable flaw size at exactly ten years, which justifies a ten year inspection cycle exactly. If the intersection of the two curves occurred to the left, at say six years, then the inspection interval would have to be reduced to six years. If, however, the intersection moved to the right, then the inspection interval would still be truncated at ten years.

Fatigue Usage Evaluation

The fatigue usage at a PWOL location may be increased due to addition of the weld overlay since the through-wall thermal stresses may be increased (greater thickness) and there will be structural discontinuities at the weld overlay to piping and nozzle transitions. To assess this potential, the usage factor at the location without the weld overlay is an indicator of the severity of loads at the location. If the 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 that that associated with normal and upset reactor coolant hot leg/cold leg transients, then no further consideration need be given to fatigue due to application of the weld overlay.

Locations that experience cycling due to more severe thermal transients (e.g., 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 re-evaluation shall be conducted at the transitions between the weld overlay and the adjacent pipe or nozzle locations. The fatigue evaluation shall consider the plant design transients, or an alternate less severe set of transients (as allowed by ASME Code, Section XI, Appendix L). Consideration may be given to the effect of the actual plant operating transients at the PWOL locations if such data are available.

The fatigue analysis shall be conducted using the applicable rules of ASME Code, Section III for Class 1 components (NB-3600 for piping and NB-3200 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.

4.5 Leak Before Break

The original plant design basis included the postulation of high energy line breaks to ensure the dynamic effects of such an event could be mitigated, the plant could be safely shut down, and the health and safety of the public would be protected. In many instances this led to engineered solutions to prevent or diminish the effects of the postulated ruptures. However, over time NRC research showed that the probability of failure of some piping systems was low enough in certain specific circumstances that such measures taken to protect against failure did not contribute significantly to overall plant safety and 10CFR50, Appendix A, General Design Criterion (GDC) 4 was revised to include the following statement:

"However, dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping."

Under this revised rule, larger diameter RCS piping in many plants has been evaluated following regulatory guidance in U.S. NRC Standard Review Plan 3.6.3, "Leak-Before-Break Evaluation Procedures," to justify that the dynamic effects associated with pipe rupture can be excluded form the design bases. These evaluations have been reviewed and, in general, approved by the NRC staff. As a result utilities have been allowed to remove pipe whip restraints and other protective barriers that would otherwise be required to protect against the local effects of high-energy line break. Leak-before-break (LBB) has also been used to eliminate the dynamic effects of pipe break for other situations (e.g., reduction of reactor internals loadings as a result of pipe break).

However, the current technical basis for regulatory approval of LBB applications does not provide for evaluation of active degradation mechanisms other than fatigue and thus is at odds with recent operating experience with PWSCC and the actions being taken to mitigate and manage its effects. Consequently, efforts are underway within the NRC and EPRI 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 structural weld overlays (FSWOL or OWOL) to current LBB locations should update the original LBB calculations with an evaluation demonstrating that due to the efficacy of the overlay for PWSCC mitigation, concerns for original weld susceptibility to cracking have been resolved. Once additional regulatory guidance is provided, the licensee should review this evaluation to determine if additional analysis is needed.

4.6 Evaluation of Weld Overlay Effects on Piping system

Stresses may develop in other locations of a piping system due to the weld shrinkage at the overlays. These stresses are system wide, and similar in nature to restrained free end thermal expansion or contraction stresses. The level of stresses resulting from weld overlay shrinkage depends upon 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. Finally, 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, the following actions are recommended following application of a weld overlay:

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 then evaluated via a piping model, or other evaluation means. Although there are no directly applicable ASME Section III stress limits that apply 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 Walk Downs* - Due to displacements produced by weld overlay shrinkage in the piping system, it is also required that, after application of the overlay, a walk-down be performed to check hanger set points 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.

4.7 Summary

In summary, weld overlays can be applied either preemptively or as repairs to observed PWSCC indications, and overlays performing either function may be either full structural (FSWOLs) or optimized (OWOLs), subject to specific design, analysis and inspection requirements defined in this section. Table 4-1 provides a summary of the applicable design and inspection requirements (pre- and post-overlay) for all categories of weld overlays, including FSWOLs and OWOLs applied either preemptively or as repairs. It also cross references requirements from other applicable documents (i.e. MRP-139 and ASME Code Cases).

Table 4-1 – Summary of Weld Overlay Design Types and Associated Design and Inspection Requirements

Weld Overlay Type	Pre-WOL Inspection Completed?	Design Basis Flaw for WOL	Crack Growth Design Basis	Post-WOL Exam Volume (PSI and ISI)	Post-WOL Inservice Inspection Schedule (MRP-139/169 vs. ASME Code Cases)
Repair – Full Structural	Yes	100% thru-wall, full circ.	Actual observed flaw shall not exceed design basis flaw size in next inspection interval	WOL + outer 25% of Code DMW Exam Volume	MRP-139/169: (Cat. F) Once in the next 5 years, and then if no growth 100% in subsequent 10 year interval CC N-740-1: Once in the next two RFOs, and then if no growth, a 25% sample population on a 10 year basis
Repair – Full Structural	No	100% thru-wall, full circ.	Assumed 75% flaw shall not exceed design basis flaw size in next inspection interval	WOL + outer 25% of Code DMW Exam Volume	MRP-139/169: (Cat. F) Once in the next 5 years, and then if no growth 100% in subsequent 10 year interval CC N-740-1: Once in the next two RFOs, and then if no growth, a 25% sample population on a 10 year basis
Preemptive – Full Structural	Yes	100% thru-wall, full circ.	Assumed 10% flaw shall not exceed design basis flaw size in next inspection interval	WOL + outer 25% of Code DMW Exam Volume	MRP-139/169: (Cat. B) 100% every interval (10 years) CC N-740-1: A 25% sample population on a 10 year basis
Repair – Optimized	Yes	75% thru-wall, full circ.	Actual observed flaw shall not exceed design basis flaw size in next inspection interval	WOL + outer 50% of Code DMW Exam Volume	*MRP-139/169: (Cat. F) Once in the next 5 years, and then if no growth 100% in subsequent 10 year interval CC N-754: Once in the next two RFOs, and then if no growth, a 25% sample population on a 10 year basis (outer 50%)
Preemptive – Optimized	Yes	75% thru-wall, full circ	Assumed 10% flaw shall not exceed design basis flaw size in next inspection interval	WOL + outer 50% of Code DMW Exam Volume	*MRP-139/169: (Cat. B) 100% every interval (10 years) CC N-754: A 25% sample population on a 10 year basis

* - MRP-139, Rev. 0 states that a weld overlay must be full structural to qualify as Category B or F, however a revision to MRP-139 has been prepared justifying these categories for OWOLs subject to them meeting the specific requirements of this section.

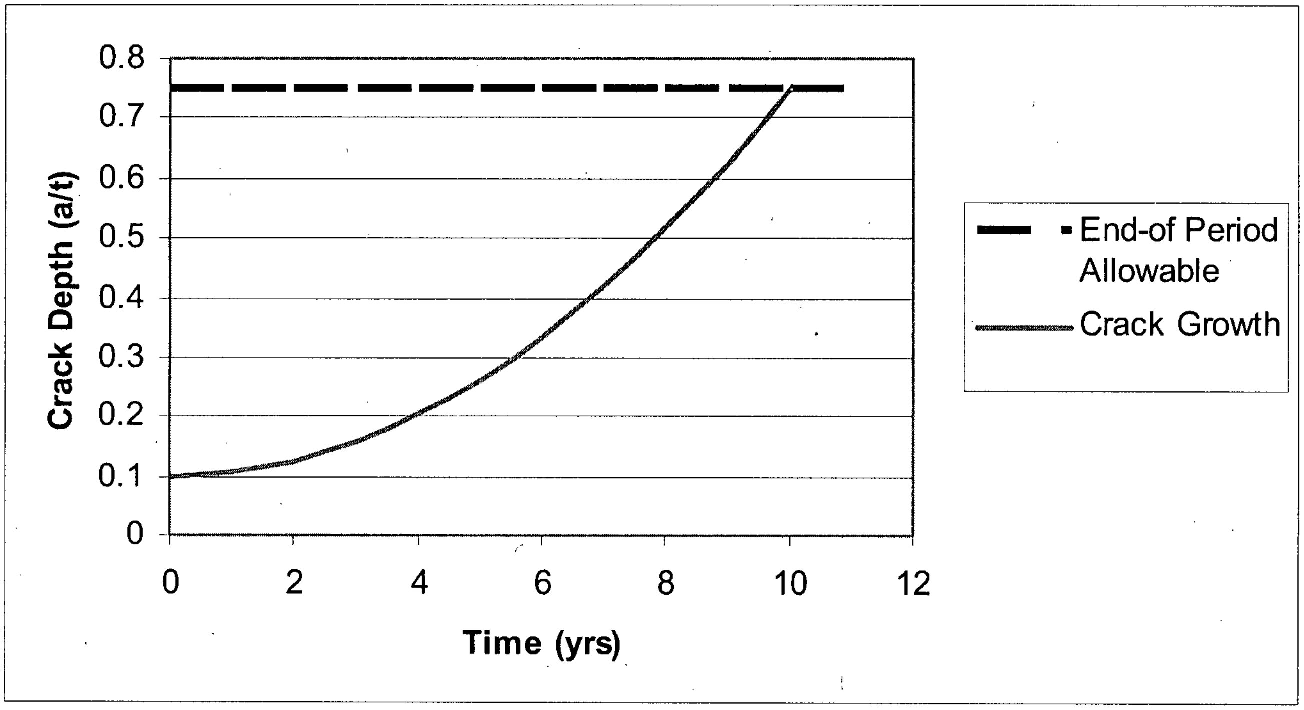
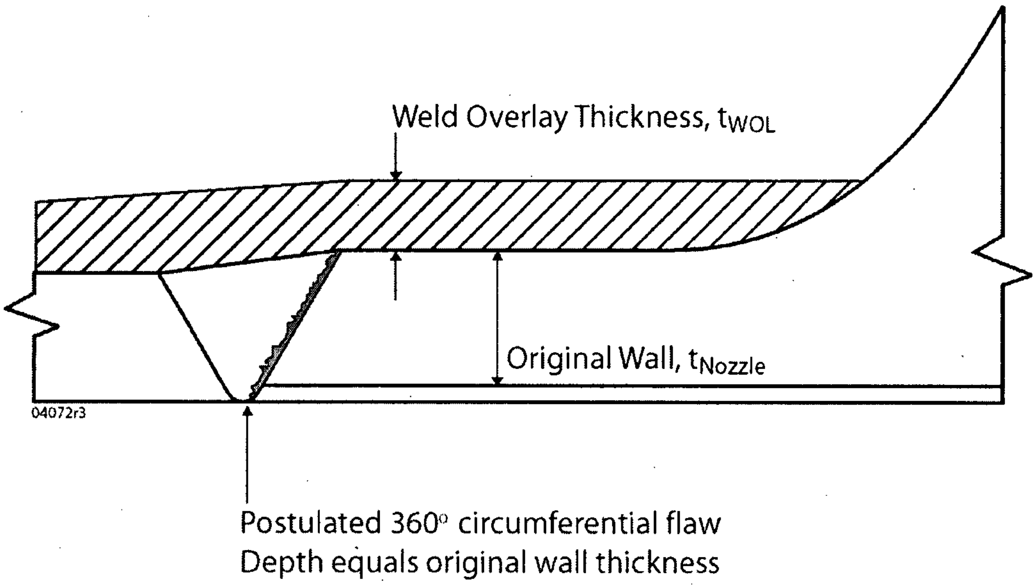
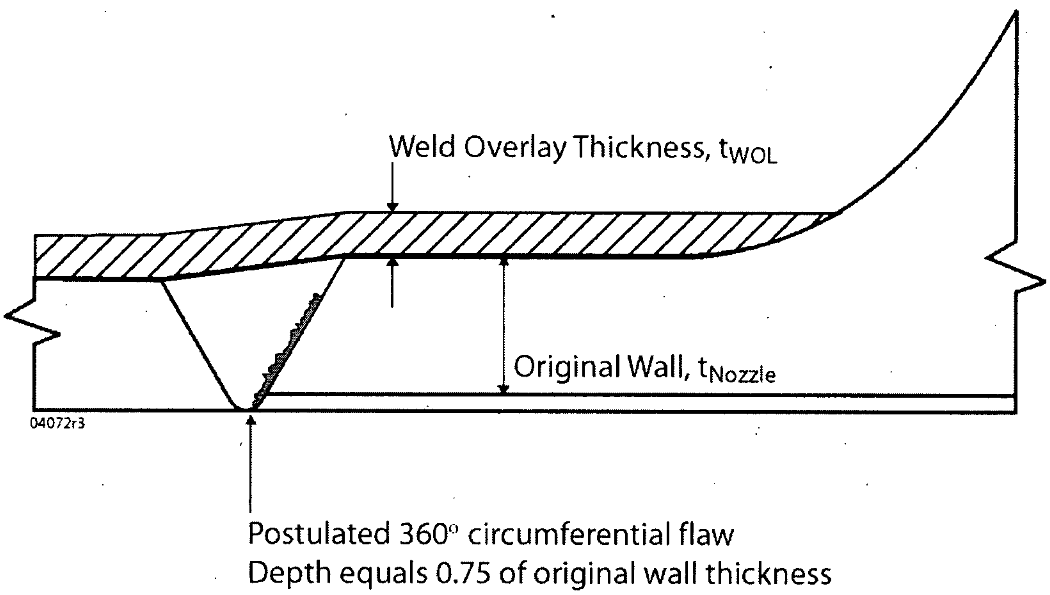


Figure 4-1 – Schematic Illustration of ASME Section XI Flaw Evaluation Basic Concept



a) **Full Structural Weld Overlay (FSWOL)**



b) **Optimized WOL (OWOL)**

Figure 4-2 – Illustration of Full Structural and Optimized Weld Overlay Design Basis Flaw Size Assumptions

5.0 Verification of weld overlay effectiveness

5.1 Experimental Programs

Since the initial use on BWR piping, weld overlays have been demonstrated analytically to produce beneficial residual stresses in a variety of pipe sizes and joint configurations. In addition to the analytical work, a number of laboratory programs have been undertaken to verify experimentally the effectiveness of the weld overlays in arresting the growth of pre-existing cracks under BWR conditions. The following paragraphs summarize some of the experimental studies performed to demonstrate the residual stress crack arrest and structural capabilities of the weld overlay repair.

(5) MRP/EPRI PWOL Development Program for Alloy 600 PWSCC Mitigation

A PWOL development program was sponsored by the MRP/EPRI to validate analytical finite element residual stress analysis (FEA) techniques with experimental residual stress, microstructures, hardness and chemistry measurements. A detailed description of the program and results is contained in MRP-208 [48] and a brief summary is provided below.

Structural Integrity Associates (SI) with the aid of Welding Services Inc. (WSI) designed and fabricated a mockup representing a steel pressurizer nozzle welded to a stainless steel pipe with Alloy 82/182 filler material containing a significant weld repair on the ID (Figure 5-10). SI performed finite element analyses to determine residual stress distribution in the mockup, pre- and post-overlay (Figures 5-11 – 5-13). The mockup was examined by surface and UT examinations and residual stresses in the mockup were characterized non-destructively by the x-ray diffraction method prior to application of the weld overlay. Subsequently a weld overlay was applied and the overlaid mockup was again examined by surface and UT methods and residual stresses measured by x-ray diffraction on the OD and ID surfaces. Post overlay residual stress meaurements were also taken at one ID location using the hole-drilling method. The mockup was then cut up and examined metallographically.

Figures 5-14 and 5-15 present a comparison of measured versus analytical residual stresses on the ID surface of the nozzle, both pre- and post-overlay. It can be seen from these figures that the analytical predictions are in reasonable agreement with the measurements as are the results from the two different measurement techniques (XRD and hole drilling). Both analyses and measurements show that application of the overlay changed the ID surface stresses from very highly tensile at some locations, in both the hoop and axial directions, to uniformly high compression. The results of this program:

1. Add confidence in the analytical procedures used to predict weld overlay residual stresses (per Section 4.2), and
2. Demonstrate the residual stress benefits of a PWOL on a prototypical PWR nozzle safe-end geometry with a severe ID surface repair.

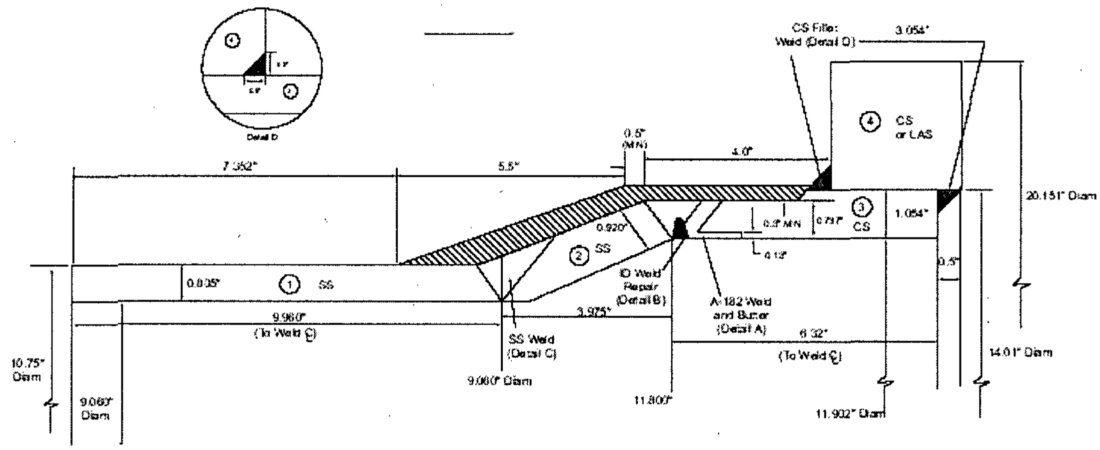


Figure 5-10
Drawing of MRP/EPRI PWOL Mockup

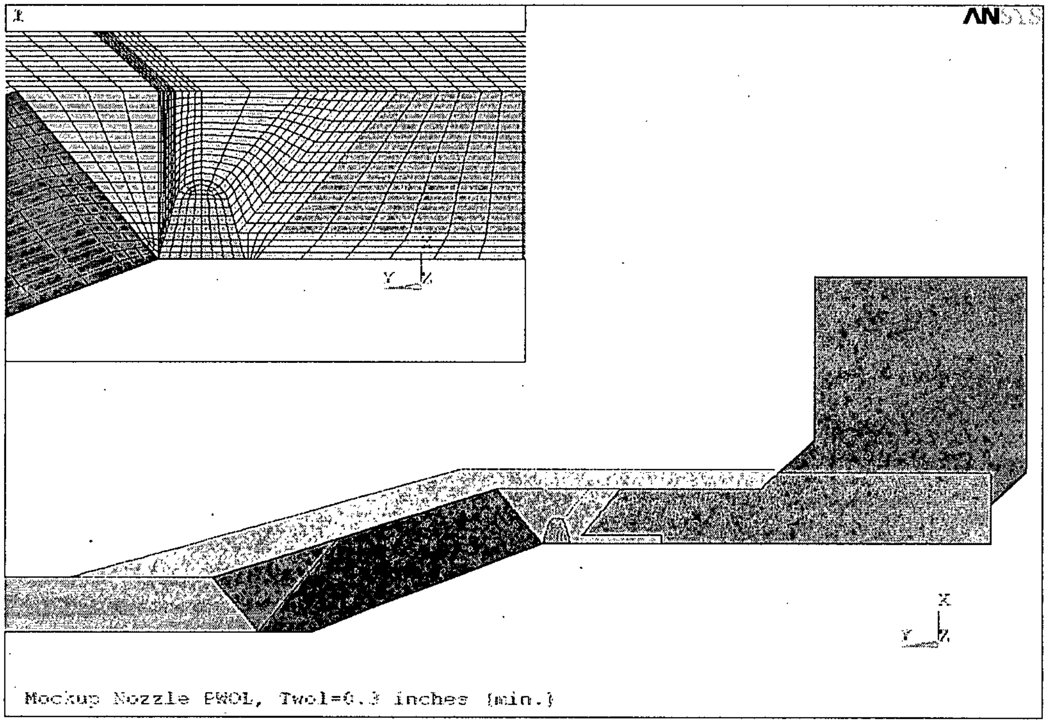
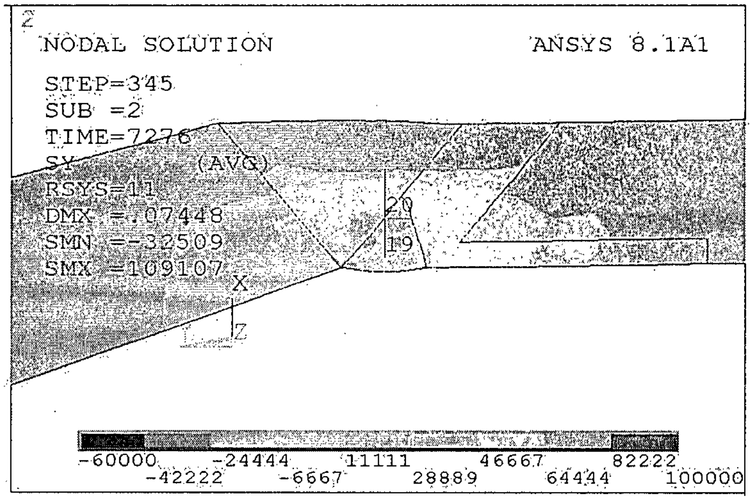
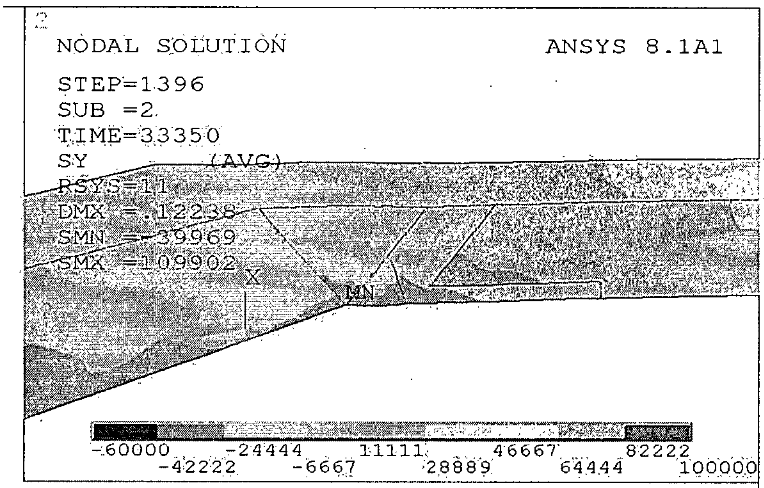


Figure 5-11
FEA Model for the PWOL Mockup

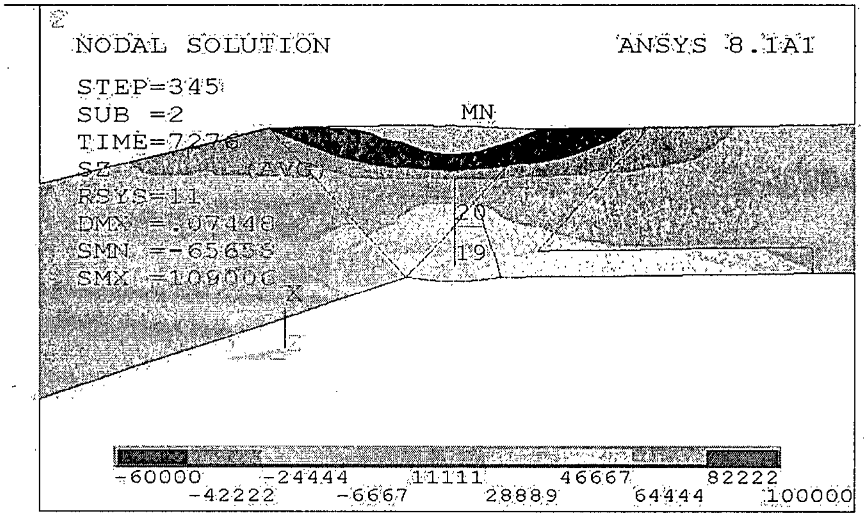


Pre-overlay

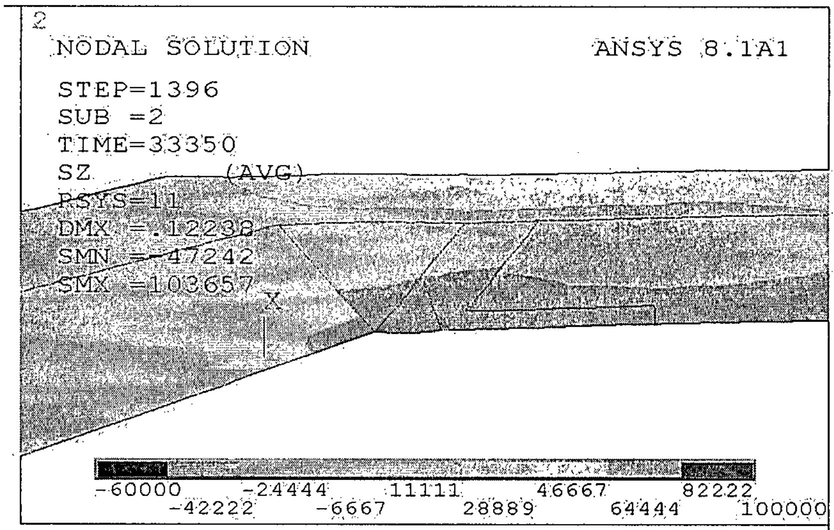


Post-overlay

Figure 5-12
Analytical (FEA) Hoop Stress Results for the PWOL Mockup

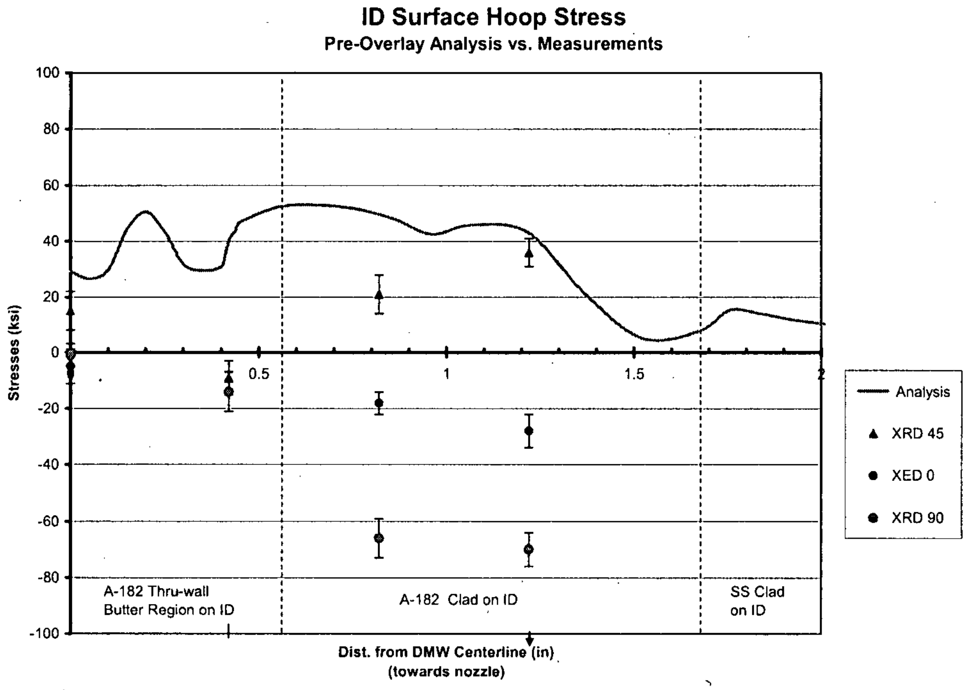


Pre-overlay



Post-overlay

Figure 5-13
Analytical (FEA) Axial Stress Results for the PWOL Mockup



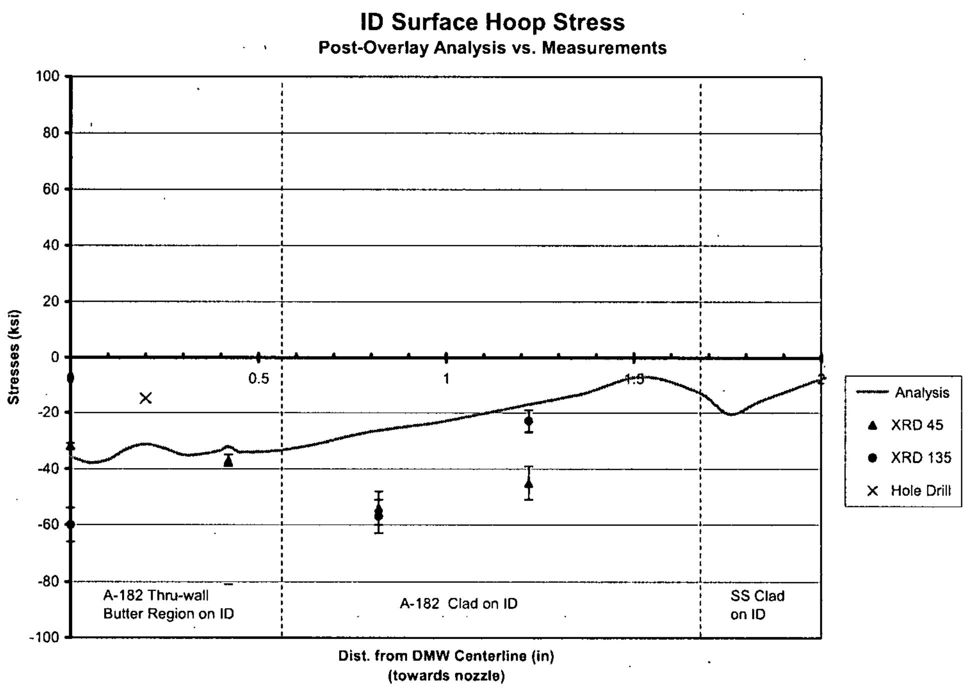
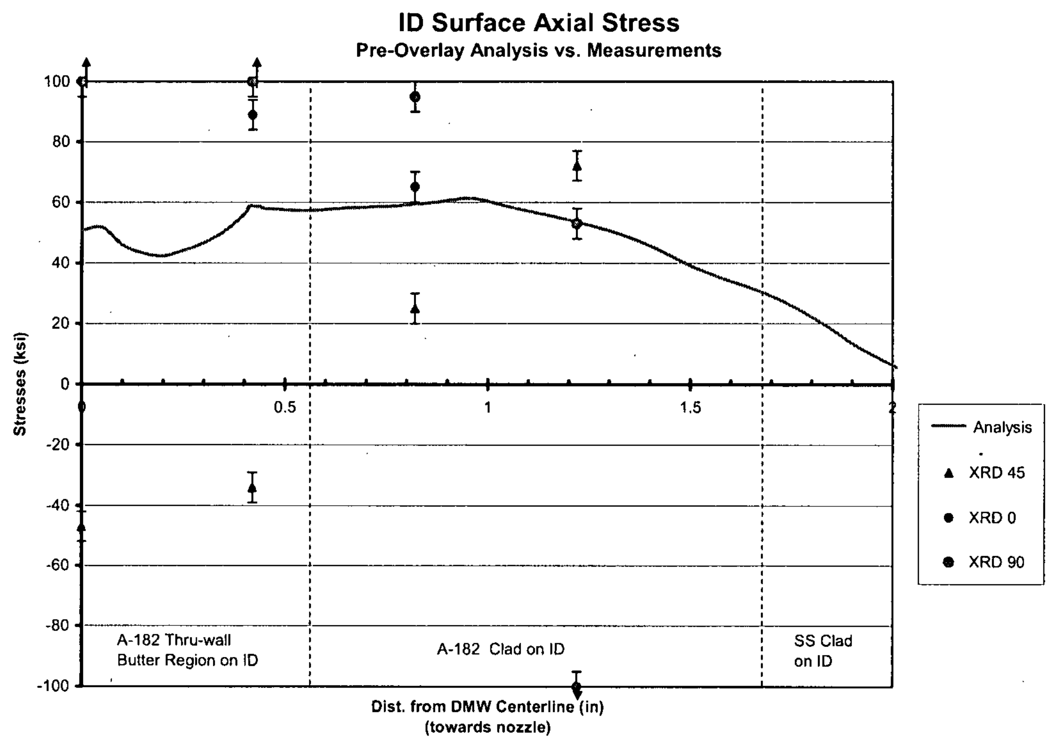


Figure 5-14
Comparison of Analytical vs. Measured Hoop Residual Stress Results for PWOL Mockup



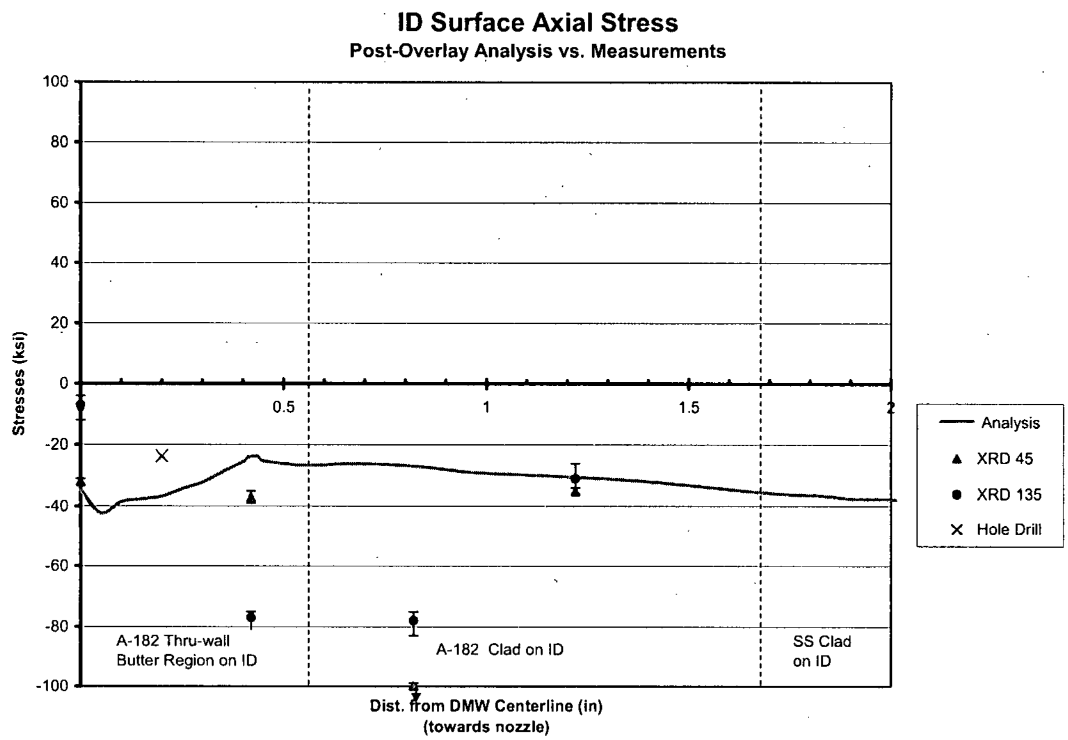


Figure 5-15
Comparison of Analytical vs. Measured Axial Residual Stress Results for PWOL Mockup

7.0 EXAMINATION REQUIREMENTS

Examination requirements for weld overlays of PWR system butt welds involve two aspects. One is the type of examination and the other is the required interval. Fortunately, both of these aspects of examination requirements are well defined for BWR system weld overlays due to significant experimental, analytical and field experience, such that a reasonable adaptation can be developed for preemptive weld overlays of PWR system butt welds.

7.1 Requirements for Types of Examination for Weld Overlays

The requirements for the type of examinations and associated examination volumes for full structural weld overlays are defined in Section XI Appendix Q and ASME Code Cases N-460, N-504-2 and N-740-1.

These requirements are consistent with current PDI techniques and were originally developed for weld overlay repairs of IGSCC in BWR stainless steel welds, where the initiating flaws are fully characterized with respect to length and depth. Since the full structural weld overlay designs for these repairs assumed that the original flaw is completely through the original pipe wall, inspection of the outer 25% of the original pipe wall along with the weld overlay is specified for pre-service and subsequent inservice examinations, such that it provides some advance warning if flaw were to unexpectedly propagate into that region, before they violate the overlay design basis. Also, the ultrasonic examination technology available at the time Code Case N-504-2 was issued could reliably support examinations of the outer 25% of the original pipe wall.

For optimized overlays (OWOLs), where the weld overlay design assumes the existence of a flaw 75% through the original wall thickness, it is desired to provide a similar "advance warning" examination volume for the unlikely event that a flaw would initiate and begin propagating after application of the PWOL. For this design assumption, examination coverage for weld overlay preservice inspections and subsequent inservice inspections is increased to include the thickness of the weld overlay plus the outer 50% of the original pipe wall thickness. This will provide additional margin to account for the uncertainty regarding the pre-weld overlay status of the original weld and is well within current ultrasonic examination capabilities. For full structural preemptive weld overlays, where the weld overlay design assumes the existence of a flaw 100% through the original pipe wall, inspection of the outer 25% of the original pipe wall along with the weld overlay will continue to be the requirement. Details of the examination requirements and exam volumes for both FSWOLs and OWOLs are provided in Figure 7-1. These are consistent with the current requirements for FSWOLs (Section XI Appendix Q and ASME Code Cases N-460, N-504-2 and N-740-1) and the expanded exam volume requirement for OWOLs described above).

As discussed in Section 4, weld overlays 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, as amended in 10CFR50.55a. Currently, the utilities use the PDI qualification process to satisfy these requirements. Procedures, equipment, and personnel used for examination of preemptive weld overlays shall be qualified in accordance with these rules [27, 42].

As an alternative to the above requirements, for cases in which current inservice inspection requirements are satisfied by inspecting the inner 1/3 of the original DMW from the inside surface of the nozzle, the utility may continue to perform such examinations, in lieu of the outside surface WOL examinations specified above. In such cases, the acceptance examination of the WOL plus the underlying HAZ (Figure 7-1(a)) 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 ID connected flaws are still detectable after application of the overlay and the associated compressive stresses.

7.2 Inspection Interval and Sample Size for Preemptive Weld Overlays

The inspection interval and sample size for IGSCC mitigating weld overlays in BWR weldments are defined in NUREG-0313. NUREG-0313 defines examination requirements in terms of the category of IGSCC susceptible weldment. The categories of weldments are based on 1) the IGSCC resistance of the materials in the original weldment, 2) whether or not stress improvement (or overlay) has been performed on the original weldment, 3) whether or not a post stress improvement UT examination has been performed, 4) the existence (or not) of cracking in the original weldment, and 5) the likelihood of undetected cracking in the original weldment prior to the application of the overlay. The categories range from A through G, with the higher letter categories requiring augmented inspection intervals and/or sample size. Category A is the lowest category, consisting of piping that has been replaced (or originally fabricated) with IGSCC resistant material.

The MRP Primary System Piping Butt Welds Inspection and Evaluation Guidelines (MRP-139) utilize a similar classification scheme [1]. Specifically, in accordance with MRP-139, PWSCC susceptible weldments with no known cracks (based on examination) that have been reinforced by a full structural weld overlay made of PWSCC resistant material are designated Category B. PWSCC susceptible weldments that contain known cracks that have been repaired by a full structural weld overlay are designated Category F.

For PWOL applications in which a pre-overlay examination is performed and no PWSCC-like indications are detected, the absence of cracking in the original weldment, the structural reinforcement and resistant material supplied by the overlay, the residual stress improvement provided by the PWOL, and the requirement to do a PDI qualified examination immediately following application of the PWOL are deemed to be consistent with MRP-139 Category B for either full structural or optimized structural overlays. Therefore the following requirements for subsequent inservice inspections shall be satisfied:

1. For PWSCC susceptible weldments for which an inservice inspection is performed in accordance with ASME Code, Section XI, Appendix VIII, Supplement 2, 3 or 10 [26] immediately prior to application of the PWOL, and such inservice inspection demonstrates the weld to be absent of any flaws or crack-like indications, future ISI of the welds shall be performed in accordance with current ASME Section XI Code requirements. This requirement is consistent with MRP-139 Category B, except that it is independent of whether the PWOL is a full structural or optimized structural overlay.

2. For PWSCC susceptible weldments for which an inservice inspection in accordance with ASME Code, Section XI, Appendix VIII, Supplement 2, 3, or 10 [26] is not performed immediately prior to application of the PWOL, or in which flaws or crack-like indications are detected, the weldment must be assumed to be cracked. In such cases, future inservice inspections shall be performed consistent with requirements for cracked, WOL-repaired weldments (MRP-139 Category F). After the weld overlay and initial post-overlay examination, such weldments shall be inspected once in the next 5 years. If no new indications are seen or if no growth of existing indications is observed in the examination volume, the inspection interval shall revert to the existing ASME Code program.

7.3 Dissimilar Metal Weld Examination Requirements

The current requirements for inservice inspection of dissimilar metal welds (> 4 Inch NPS) are defined in ASME Code, Section XI and summarized as follows:

Initial Preservice and Subsequent Inservice Inspections:
Surface: Liquid penetrant examination of weld and heat affected zone surfaces
Volumetric: Ultrasonic examination of inner 33% of original weld and heat affected zone

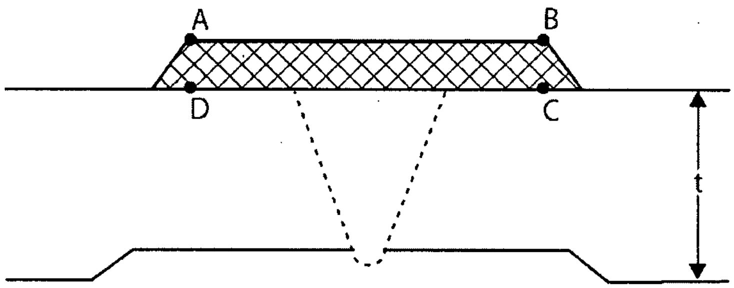
Requirements for the inspection interval and sample size for dissimilar metal welds are defined in ASME Code, Section XI as 100% of welds inspected every 10 years (Category B-F).

As noted above, the Materials Reliability Program (MRP), sponsored by EPRI, has recently issued guidelines requiring augmented examinations for PWSCC susceptible butt welds [1] that are similar in concept to the NUREG-0313 requirements for BWR IGSCC susceptible welds. These guidelines will not be repeated here, but involve inspections as often as once every inspection period (3 1/3 years) for unmitigated welds in higher temperature locations of the reactor coolant system (e.g. pressurizer and hot leg nozzles).

In recent years, building on industry experience, many utilities have implemented risk-informed inspection approaches, consistent with ASME Code, Section XI Code Cases 560-2, 577-1 and 578-1. Some of these applications have resulted in elimination or reduction of examination of Alloy 82/182 locations. However, risk-informed ISI programs are required to be living programs. As such, recent industry experience with Alloy 82/182 cracking, including MRP-139 inspection guidance, must be incorporated as these programs are updated. For weld overlays performed on PWSCC-susceptible locations, either preemptively or as repairs, RI-ISI programs should be modified to include inspections consistent with this document. However, it is anticipated that, at some future time, after inservice inspections have demonstrated successful operating experience with PWR overlays, additional inspection relief may be provided, as was done for BWR overlays in BWRVIP-75 [2].

Initial Acceptance Examination

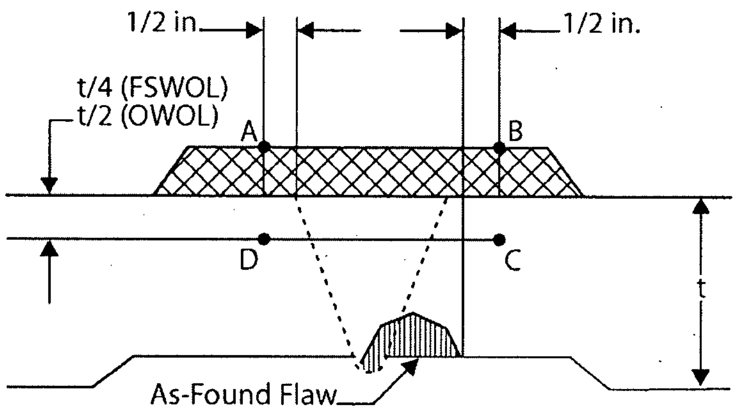
Surface:	Liquid penetrant examination of overlay material surface + ½ inch of base metal on either side of overlay
Volumetric:	Ultrasonic examination of overlay material (A-B-C-D) plus underlying HAZ (C-D) for fabrication welding defects



WOL Acceptance Examination Volume A-B-C-D

Preservice and Subsequent Inservice Inspections

Surface:	Liquid penetrant examination of overlay material surface
Volumetric:	Overlay directly over original weld and heat affected zone for PWSCC propagation to a depth of the outer 25% (FSWOL) or 50% (OWOL) of underlying nozzle/pipe/DMW. (A-B-C-D)



Preservice and Inservice Examination Volume A-B-C-D

Figure 7-3
Preservice and Inservice Inspection Requirements for Weld Overlays

9.0 Conclusions

A comprehensive discussion of weld overlay (WOL) repair technology used in U.S. nuclear power plants is presented, and a set of criteria and benefits are presented for application of this technology preemptively, as a mitigation procedure for uncracked locations in Alloy-82/182 dissimilar metal butt welds (PWOLs). Two types of preemptive overlays are defined, full structural weld overlays (FSWOL) and optimized weld overlays (OWOL) and detailed design, analysis and inspection requirements are specified for each in Section 4. The design criteria include sufficient thickness of resistant material (Alloy 52, 52M or 52MS weld metal) to provide new structural reinforcement of the original pipe weld sufficient to sustain design basis loads within ASME Code margins, under a set of design basis flaw assumptions. The PWOL must also supply sufficient thickness and length to effectively reverse the highly tensile residual stresses from the original DMW, including the potential detrimental effects of an assumed, in-process repair weld during plant construction, and must be designed to permit UT coverage of the applicable examination volume for each overlay type.

Data from prior experimental programs that support WOL residual stress and structural integrity benefits are presented, and a review of over fifteen years of operating experience with WOLs in BWRs is cited to support the theoretical work in this report. A recent EPRI/MRP PWOL program, which included fabrication of a PWOL mockup for residual stress confirmation, is also described. The results of that program confirmed the beneficial residual stress effects of the overlay, and validated the residual stress analytical procedures used in the overlay design process. In addition, a review of materials and welding considerations essential to producing PWSCC resistant weld overlays is presented, and detailed discussion of post-PWOL inspection requirements is presented.

Finally, structural and residual stress calculations are presented for three example cases representative of typical nozzle geometries in a PWR ranging from small to large diameter (a pressurizer top head nozzle, a pressurizer surge nozzle, and a reactor vessel hot leg nozzle). The example calculations demonstrate application of the criteria defined in the report and the resulting weld overlay designs for these nozzles. Analyses are also presented to demonstrate acceptable fatigue life in the fatigue sensitive surge nozzle.

Based on these studies and results, NRC approval of the following position is requested. Namely, if a PWOL is applied that meets the design requirements of Section 4 of this report, plus the metallurgical and welding conditions described in Section 6, then the inspection program described in Section 7 shall apply, and credit may continue to be taken for Leak Before Break of the PWOL-treated weld in the licensing basis for the plant.

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