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Byron Station, Units 1 and 2
Facility Operating License Nos. NPF-37 and NPF-66
NRC Docket Nos. 50-454 and 50-455

Subject: Response to NRC Request for Additional Information to Byron Station Relief Request I3R-08

References: (1) Letter from Dave M. Hoots (Exelon Generation Company, LLC) to U. S. NRC, "3rd 10-Year Inservice Inspection Interval, Relief Request I3R-08, Preventive Weld Overlays on Pressurizer Spray, Relief, Safety and Surge Nozzles and Associated Alternative Repair Techniques," dated April 28, 2006"

(2) Letter from Robert F. Kuntz. (U. S. NRC) to C. M. Crane (Exelon Generation Company, LLC), "Byron Station, Units 1 and 2, Request for Additional Information RE: Relief Request I3R-08 – Alternative To Weld Overlay requirements (TAC Nos. MD1761 and MD1762)," dated August 8, 2006

During the review of the Reference 1 submittal, the NRC determined that additional information was required in order to complete their evaluation of the Byron Station, Units 1 and 2, 3rd 10-Year Inservice Inspection Interval, Relief Request I3R-08, "Preventive Weld Overlays on Pressurizer Spray, Relief, Safety and Surge Nozzles and Associated Alternative Repair Technique." The NRC requested a response to the questions contained in the Reference 2 transmittal. Attachment 1 to this letter provides the Exelon Generation Company, LLC response to these NRC questions.

Should you have any questions concerning this letter, please contact W. Grundmann, Regulatory Assurance Manager, at (815) 406-2800.

Respectfully,

Marseyne Snow for

David M. Hoots
Site Vice President
Byron Station Nuclear Generating Station

Attachments: 1) Response to Request for Additional Information to Inservice Inspection Interval, Relief Request I3R-08
2) White Paper – Relaxation of the 100 Square Inch Size Limitation – Code Case N-638

Response to Request for Additional Information to
Inservice Inspection Interval, Relief Request I3R-08

NRC Question 1:

In your submittal dated April 28, 2006, you state that structural weld overlays are proposed for the welds listed on Table 1, page 6. Only one reference in the submittal is made stating that a full structural overlay will be the design (page 8 of 20). Since this is the only place that the design of the overlay has been referenced, please clarify whether full-structural overlays are to be performed and that no design/optimized overlays will be implemented.

Exelon Generation Company, LLC (EGC) response to Question 1:

Byron Station will install full structural weld overlays of all pressurizer nozzle to safe-end welds. The design documents, CN-CI-06-9, "Byron Units 1 & 2 and Braidwood Units 1 & 2 Pressurizer Spray and Safety/Relief Nozzle Weld Overlay Repair Design," and CN-PAFM-06-25, "Byron/Braidwood Pressurizer Surge Nozzle Weld Overlay Design," establish the required full structural weld thickness and length for overlays for the dissimilar metal safe end welds at the Pressurizer surge, spray, safety and relief nozzles based on plant specific geometry, loadings and ASME Section XI Code Case N-504-2, "Alternative Rules for Repair of Class 1, 2, and 3 Austenitic Stainless Steel Piping," requirements.

The above referenced documents are currently prepared and are under review by EGC and an independent third party reviewer. These documents will be completed and approved for use during the Byron Station Unit 1 Fall 2006 refueling outage (B1R14).

NRC Question 2:

Please indicate what types of nondestructive examinations (NDE) will be performed prior to the weld overlay installation. If pre-welding NDE is not to be performed expand your justification for not performing the NDE prior to welding for your full structural overlays.

EGC response to Question 2:

Byron Station will complete a bare metal visual examination of the Pressurizer Surge, Safety, Relief and Spray Nozzle immediately after the mirror insulation is removed from the nozzle and Dissimilar-Metal weld area. This is to ensure that no through wall cracks exist prior to applying the overlay. Prior to applying the overlay, the entire overlay area will be cleaned, including a distance at least 1.5 times the nozzle end thickness beyond the overlay on the nozzle side and 1.5" beyond the overlay area on the pipe side.

At the completion of the cleaning, a liquid penetrant test (PT) will be performed of the overlay area with an acceptance criteria that no indication greater than 1/16" is permitted. If any indication is found greater than 1/16", the indication will removed and the PT completed again. If any indication(s) do require repair, the repair will be completed and the area will again have a PT completed for final acceptance.

Because of the configuration of the pressurizer nozzle to safe-end welds and the close proximity of the nozzle to safe-end to pipe, a qualified ultrasonic examination of the area, including the existing welds, cannot be performed.

NRC Question 3:

Please discuss your repair strategy as a result of pre-welding NDE. The cover letter indicates that full structural overlays will be performed as a preemptive application, or as a repair application if a flaw is found. If a flaw is detected in the weld by NDE prior to weld overlay, confirm that the weld overlay thickness calculation is based on the worst-case flaw.

EGC response to Question 3:

The design assumption in the previously referenced documents, CN-CI-06-9 and CN-PAFM-06-25, is the presence of a pre-existing flaw that extends the full circumference of the pipe and over the entire original wall thickness. This assumption is consistent with Code Case N-504-2, "Alternative Rules for Repair of Class 1, 2, and 3 Austenitic Stainless Steel Piping," section (f). This design assumption provides for the most restrictive flaw condition that could be considered for the weld overlay thickness.

The above referenced documents are currently prepared and are under review by EGC and an independent third party reviewer. These documents will be completed and approved for use during the Byron Station Unit 1 Fall 2006 refueling outage (B1R14).

NRC Question 4:

For an overlay that extends over an adjacent weld (if it occurs), please discuss in detail your strategy for expansion of examinations if an unacceptable flaw is found by post-welding NDE of the weld overlay that was not scheduled for an inservice examination that outage.

EGC response to Question 4:

Although adjacent welds (i.e., pipe to safe-end welds) will be overlayed, none of these welds are scheduled for Inservice Inspection in the upcoming Fall 2006 Byron Station Unit 1 refueling outage. Any expansion of the examination scope due to unacceptable flaws in the adjacent welds will be based on an evaluation of the unacceptable flaw characteristics. This evaluation will include whether other elements in the segment or segments are subject to the same root cause conditions. No additional examinations will be performed if there are no additional elements identified as being susceptible to the same root cause conditions. If the evaluation does identify a common degradation mechanism, then further examinations would be performed on those elements.

NRC Question 5

Please identify when the flaw evaluations and shrinkage stress effects analyses required under Code Case N-504-2(g), Items 2, and 3, will be performed as they relate to your outage schedule.

EGC response to Question 5:

Flaw evaluations in accordance with Code Case N-504-2(g) Item 2 are covered under Calculations CN-PAFM-06-67, "Byron and Braidwood Units 1 and 2 Pressurizer Surge Nozzle Structural Weld Overlay Fatigue Crack Growth Evaluation," CN-MRCDA-06-8, "Byron and Braidwood Units 1 and 2 Pressurizer Spray Nozzle Fatigue Crack Growth Analysis for Weld Overlay Repairs," and CN-MRCDA-06-16, "Byron and Braidwood Units 1 and 2 Pressurizer Safety and Relief Nozzle Fatigue Crack Growth Analysis for Weld Overlay Repairs."

Shrinkage stress effects analyses in accordance with Code Case N-504-2(g) Item 3 are covered under Calculations, CN-PAFM-06-100, "Byron Unit 1 PSARV Piping Stress Evaluation Due to Shrinkage Weld Over-Lay (SWOL)," CN-PAFM-06-101, "Byron Unit 1 (CAE) Surge Line Analysis for the Shrinkage Effect at Nozzle Weld Over-Lay Location," CN-PAFM-06-102, "Byron Unit 1 (CAE) Spray Line Analysis for the Shrinkage Effect at Nozzle Weld Over-Lay Location," and CN-PAFM-06-109, "Byron Unit 1 Support Evaluation for Surge, Spray and PSARV Line Due to Shrinkage Weld Over-Lay (SWOL)."

The above referenced documents are currently prepared and are under review by EGC and an independent third party reviewer. These documents will be completed and approved for use during the Byron Station Unit 1 Fall 2006 refueling outage (B1R14).

NRC Question 6:

On page 11 of your submittal, you indicate that "The maximum area of an individual weld based on the finished surface over the ferritic material will exceed 100 sq. in. and will be on the order of 300 sq. in." As you note, a portion of your basis for acceptability is the staff's approval of the Susquehanna Steam Electric Station overlay. To support your basis for meeting an acceptable level of quality and safety, identify the similarities and differences in the overlay designs and stresses with Susquehanna that apply to Byron Station Units 1 and 2.

EGC response to Question 6:

The NRC acceptance of the Susquehanna relief request was not based on specific design and stresses but on the industry work demonstrating the acceptability of larger areas of ambient temperature temper bead welding. Because the basis was not specific to Susquehanna, Byron Station referred to that approval. Since the initial submittal of the Byron Station Relief Request I3R-08, the American Society of Mechanical Engineers (ASME) has approved Code Case N-638-3, "Similar and Dissimilar Metal Welding Using

Ambient Temperature Machine GTAW Temper Bead Technique," which increased the 100 square inch limitation to 500 square inches.

The technical basis accompanying that Case revision provides an expanded basis for the change in area limitation. A copy of the technical basis, "White Paper – Relaxation of the 100 Square Inch Size Limitation – Code Case N-638" is included as Attachment 2 to this letter to provide additional basis for justification of the Byron Station relief request. Additionally, in a June 28, 2006 letter to Calvert Cliffs, the NRC approved a relief request for weld overlays based on operational experience and the technical basis included in this same white paper.

Furthermore, it is noted that since the nozzle-to-safe-end welds and the weld overlays are fabricated from austenitic materials with inherent toughness, no cracking in the overlays is expected to occur due to the shrinkage associated with the weld overlay. With respect to the low alloy steel material in the nozzle, many temper bead weld overlays have been applied in the nuclear industry to these nozzle-to-safe end locations. In no instance has there been any reported cracking due to the weld overlay application. The stiffness and high toughness inherent in the low alloy steel nozzle is expected to protect against any cracking and limit any distortion that might occur in the nozzle.

Byron Station will be measuring and evaluating the axial shrinkage to validate that the calculations (i.e., CN-PAFM-06-100, CN-PAFM-06-101, CN-PAFM-06-102 and CN-PAFM-06-109) are in accordance with ASME Code Case N-504-2(g) Item 3. Also, any cracking that might occur will be detected by the final non-destructive examination (NDE) of the weld overlay. Laboratory testing and field experience have documented and qualified the temper bead weld overlay repair for nozzle-to-safe-end welds and these efforts and experience have demonstrated that this technique provides a quality, sound repair that maintains structural integrity, thus demonstrating an acceptable level of quality and safety.

In addition to the technical justification above, the ferritic area of the nozzle to be overlayed is less than 100 square inches on all nozzles except the surge line nozzle. The surge line nozzle is marginally over the 100 square inches.

The following table lists the estimated square inch areas of overlay. This table identifies both the total surface area of weld overlay coverage and the surface area of weld overlay coverage over the ferritic nozzle.

Nozzle ID	Estimated Total Surface Area of Weld Overlay (square inches)	Estimated Surface Area of Weld Overlay on Ferritic Nozzle (square inches)
Spray – PN-02	158	30
Relief – PN-03	219	43
Safety – PN-04	221	43
Safety – PN-05	217	43
Safety – PN-06	217	43
Surge – PN-07	485	108

NRC Question 7:

On page 12 of your submittal, you identified the start time for the 48-hour hold time from ambient temperature for post welding NDE to completion of the third layer welding. On July 17, 2006, the staff submitted a no vote to N-638-X, which dealt with shortening the 48-hour hold time. The 48 hour hold time, from the time when a weld has reached ambient temperature after the completion of welding, is reasonable because it provides defense in depth for repairs on P-3 materials that do not receive preheat or postweld heat treatment as part of the weld repair process. It is the staff's position that the white paper and its referenced EPRI Report (GC-111050) do not provide a technical justification to reduce the current 48-hour hold time requirements. Please provide justification in terms of deterministic evidence and/or actual test data that demonstrates that the time boundary you request is sufficient to identify any hydrogen cracking, or withdraw your request for relief from this requirement.

EGC response to Question 7:

Byron Station recognizes that the NRC does not agree on the justification for starting the 48-hour hold after the third layer is applied, therefore, Byron Station will follow the current requirement in Code Case N-638-1 and start the 48-hour hold time after the last layer is applied and the weld has reached ambient temperature.

NRC Question 8:

On page 2 of your submittal, you identify Regulatory Guide 1.147, Rev. 14 as an applicable requirement. On page 12 of your submittal, you identify Code Case N-638-2 as the basis for not performing the "full UT" of the 1.5T band for structural weld overlays. This Code Case is not approved or conditionally approved for use in Regulatory Guide 1.147, Rev. 14. Since the Code Case you reference has not been approved for use by the staff, please submit an acceptable technical justification for relief from the UT coverage requirements.

EGC response to Question 8:

For clarification, it needs to be identified that Code Case N-638-1 is only being used for welding on and directly adjacent to the P-No. 3 ferritic nozzle materials, since only these locations require ambient temperature Gas Tungsten Arc Welding (GTAW) temper bead welding in lieu of the Code required post-weld heat treatment. Therefore, the N-638-1 ultrasonic examination of a band around the area to be welded of at least 1.5 times the component thickness or 5", whichever is less, is only required on the nozzle side of the weld overlay and does not apply to both sides of the weld overlay as indicated in the NRC request for additional information.

The following information is offered to further demonstrate the acceptability of not performing the ultrasonic examinations of the ferritic nozzle material band around the area to be welded of at least 1.5 times the component thickness or 5", which ever is less.

When the ambient temperature GTAW temper bead Code Case provisions were initially developed in 1997, little experience was available for ambient temperature GTAW temper bead welding. Although developmental testing indicated the acceptability of the process, conservative provisions were added to the Code Case because little actual field experience was available for welding without the temper bead pre-heat and post-bake temperature requirements. One such conservative provision was the requirement to examine a band around the area to be welded of at least 1.5 times the component thickness or 5", which ever is less, using surface and ultrasonic methods. The intent of such examinations was to ensure that no adverse effects impacted the ferritic steel base material as a result of the ambient temperature temper bead welding process.

The adverse effect considered by ASME was the potential for delayed hydrogen cracking. Delayed hydrogen cracking is only a potential concern when welding on ferritic materials or using ferritic filler materials and is not a concern for welding on austenitic materials such as stainless steel safe-ends and stainless steel piping or using austenitic Alloy 52M filler materials. For austenitic weld overlays covered by the Byron Station relief request, the concern is limited to the heat-affected zone in the P-No. 3 nozzle material at the weld overlay to nozzle interface.

For comparison, it is helpful to look at the requirements in ASME Section XI, Subsubarticle IWA-4630, "Temper Bead Welding of Dissimilar Materials," compared to those in Code Case N-638-1. IWA-4630, in ASME Section XI, 2001 Edition through the 2003 Addenda, applicable to the Byron Station 3rd Interval, addresses repairs where a defect is excavated and the resulting cavity is welded using the dissimilar metal temper bead welding process. When using IWA-4630, a volumetric examination of the IWA-4610(a) preheated band is not required by IWA-4634, "Examination," for dissimilar metal temper bead welding. IWA-4634 mandates a surface examination of this pre-heated band and of the weld itself. This surface examination of the pre-heated band was imposed because a surface examination is best suited to identify unlikely but detrimental surface breaking cracking caused by elevated pre-heat and potential hydrogen cracking at the component surface in the heat-affected zone and base metal immediately adjacent to the welded cavity. IWA-4634 also mandates a volumetric examination of the deposited weld metal itself, but imposes no volumetric examination requirement for the pre-heated band. Volumetric examination of the band was not considered necessary.

Based on the experience gained since the initial development of ambient temperature GTAW temper bead provisions, and the experience with temper bead welding performed in accordance with IWA-4600 procedures, and based on a comparison of the examination differences in Case N-638-1 and IWA-4630, ASME began processing a revision to Case N-638-1 in 2004 to eliminate the examination of the adjacent base metal band and required the welded excavation be examined in accordance with the Construction Code. This revision became Code Case N-638-2, as referenced in the basis for the Code Case N-638-1 modification in the Byron Station Relief Request I3R-08.

Furthermore, Code Case N-638-1 and the temper bead welding techniques in IWA-4600 are written to address repair welds where a defect is excavated and the resulting cavity is filled using a temper bead technique. For IWA-4630 dissimilar metal temper bead welding in the 2001 Edition, through 2003 Addenda, surface examination of an extended band around the weld is specified as described above. For Code Case N-638-1, the surface and volumetric examination of a band of equivalent size around the weld was imposed as a conservative measure as described above. However, an excavated cavity configuration differs significantly from the weld overlay configuration addressed in Code Case N-504-2 and Appendix Q, "Weld Overlay Repair of Class 1, 2, and 3 Austenitic Stainless Steel Piping Weldments." For an excavated cavity, the fusion line between the weld and the cavity is more critically oriented for hydrogen cracking than the fusion line between a weld overlay and the underlying base metal and/or original welds. For weld overlays, potential hydrogen cracking associated with the Pressurizer weld overlays would be limited to the heat-affected zone in the P-3 nozzle material at the weld overlay to nozzle interface. Potential hydrogen cracking in the heat-affected zone at the toe of the weld overlay is best identified by a surface examination. Potential hydrogen cracking in the heat-affected zone in the weld overlay to nozzle interface under the weld overlay is best identified by a UT examination of the weld overlay. These potential causes of cracking are addressed by the Byron Station proposed modification to N-638-1, which examines the adjacent band and the weld with a surface examination, as required by N-638-1, and examines the weld overlay by UT examination in accordance with Case N-504-3, Appendix Q and demonstrated PDI UT procedures for examination of weld overlays, but eliminates the UT examination of the adjacent band.

Therefore, based on the above information, the Byron Station proposed modification to N-638-1 adequately examines the appropriate areas and volumes to address the potential types and locations of cracking, thereby assuring an acceptable level of quality and safety. The N-638-1 ultrasonic examination of the band outside of the weld overlay offers no additional benefit in terms of quality or safety.

In addition to the above justification, there are obstructions that limit performance of the N-638-1 ultrasonic examinations. Although this is not the basis for the Byron Station modification to N-638-1 to not perform the ultrasonic examination, it is provided for further information. In the following discussion, the ultrasonic (volumetric) examination requirement for the band is the entire base metal below the band surface. The ultrasonic inspection is to be conducted in accordance with Appendix I of the ASME Code Section XI.

With respect to the weld overlay process on Pressurizer nozzle dissimilar metal welds, the Code Case N-638-1 defined band and examination volume would encompass the nozzle base metal volume in the regions of the outside diameter (OD) nozzle tapered surface and, for some nozzles, a part of the nozzle larger cylindrical diameter. Such surfaces are not conducive for gaining full coverage of the examination volume due to non-coupling of the ultrasonic test probes over the surface. Obstructions causing this non-coupling include the edge of the weld overlay, the transition between the OD nozzle taper and the nozzle larger cylindrical diameter, and the nozzle outer blend area that transitions to the nozzle to shell weld.

Appendix I of the ASME Code Section XI, 2001 Edition through the 2003 Addenda requires that the ultrasonic examination be conducted in accordance with ASME Code Section V, Article 4 and all supplements of Appendix I except Supplement 9 – Scan Angles. These requirements include straight beam scanning for laminar and planar reflectors and angle beam scanning for planar reflectors. The straight beam scanning will most likely not detect any delayed hydrogen cracking due to mis-orientation of the cracking with respect to the beam and to the anticipated near surface location of such cracking. Essentially the straight beam is a repeat of the nozzle material examination required by the Construction Code. The angle beam examinations will be largely impacted by the outer diameter surface configuration. To maximize angle beam examination coverage would entail a series of special transducers to be applied even though the most effective angle beam transducers would be those configured to detect near surface breaking planar reflectors. However, the most effective NDE method for detection of near surface breaking planar reflectors is not with a volumetric method but with a surface examination method, as discussed above. Therefore, performing a limited UT examination of the adjacent nozzle ferritic material band provides no additional benefit in terms of quality and safety.

In conclusion, based on the above information, the Byron Station proposed modification to Case N-638-1 adequately examines the appropriate areas and volumes to address the potential types and locations of cracking, thereby assuring an acceptable level of quality and safety. The Case N-638-1 ultrasonic examination of the band outside of the weld overlay offers no additional benefit in terms of quality or safety. Because the Case N-638-1 ultrasonic examination of the band outside of the weld overlay offers no additional benefit in terms of quality or safety, performing a limited ultrasonic examination only serves to increase radiological dose for UT examiners.

NRC Question 9:

On page 10 of your submittal, you state that the Byron Station Third Interval ISI Program is based on the ASME 2001 Edition, through 2003 Addendum, which is the basis for relief from the IWA-5000 requirements. Please identify any pertinent Code paragraphs from your ISI Code of record or staff acceptable Code Cases to support your request for relief.

EGC response to Question 9:

The Byron Station request does not petition to use Code Case N-504-2 in its entirety. Code Case N-504-2 was utilized as a basis for designing the structural weld overlays. In addition, the Byron Station request does not ask for relief from the requirements of IWA-5000, "System Pressure Tests,". The modification to N-504-2 addressed in the Byron Station request is to use the provision of IWA-4540, "Pressure Testing of Class 1, 2 and 3 Items," of Section XI 2001 Edition through 2003 Addenda, which does not require a hydrostatic test and that a system leakage test may be used instead.

This system leakage test is performed in accordance with the requirements of IWA-5000. The proposed Byron Station modification to Case N-504-2 simply notes that the provisions in Section XI will be used. Basis for this is further illustrated in that Non-mandatory Appendix Q, required by the NRC to be used along with Case N-504-2, does not take exception to the pressure test requirements of IWA-4540, thereby allowing the use of either a hydrostatic test or a system leakage test.

Attachment 2

White Paper – Relaxation of the 100 Square Inch Size Limitation – Code Case N-638

RRA 00-04, BC 04-1000, Revise Code Case N-638-2 to Address Limitations on Size of Repairs

White Paper-Relaxation of the 100 square inch Size Limitation-Code Case N-638

EXECUTIVE SUMMARY

The restriction on surface area size of 100 square inches for ambient temperature temper bead welding using the machine GTAW welding was arbitrarily established. The restriction was imposed to facilitate acceptance of the original code case. Dissimilar weld overlays have been approved by the NRC and in service on BWR piping since 1985. Many BWR dissimilar metal weld overlay applications have exceeded 100 square inches. In addition a dissimilar metal weld overlay over 100 square inches was installed, approved by the NRC and put in service at Three Mile Island Unit 1 (TMI-1) on a surge line to hot leg nozzle. In addition weld buttering for the reactor coolant pipe to the reactor vessel outlet nozzle weld repair at the VC Summer plant was performed using ambient temperature temper bead welding in accordance with N-638. The surface area that was buttered was about 140 square inches. Further ambient temperature temper bead welding per the case has been used for weld pads on pressurizers to replace heater sleeves. About 120 such pads were welded to the pressurizer lower heads to replace the heater sleeves at Calvert Cliffs with no adverse effects. The pads had a combined surface area greater than 1800 square inches

The results from both analytical and experimental programs discussed in the report show that the residual stress distributions for both cavity repairs and weld overlay repairs of 100 square inches and repairs up to 500 square inches are comparable. This includes comparison of the tensile stresses that result beyond the edges of the cavity type repairs in the base material and at the ends of weld overlay repairs. Thus up to 500 square in welds made in accordance with the requirements of Case N-638 have similar or better residual stress distributions to 100 square in welds and all welds meet the stress allowable requirements of Section III, the Construction Code or Owner's requirements as applicable. Further results from metallurgical evaluations and mechanical testing show that cooling of the heat affected zone is rapid enough to form a martensitic structure that is adequately tempered by the subsequent weld deposited layers.

Performance of the repairs over 100 square inches in service as well as the results of analyses and experimental results for repairs up to 500 square inches demonstrate that the repairs are acceptable and safe.

1) Background

The purpose of this action is to relax an arbitrary limitation that was included in N-638 to restrict the use of the ambient temperature bead welding to a surface area of less then 100 square inches and a depth of less then 50% through wall. Code Case N-432-1, which requires a preheat temperature of 300 F and a post weld soak in the 450 – 550 F for 2 hours. The same rules for temper bead welding by GTAW in IWA – 4630 require the same preheat and post weld soak requirement for temperature but a 2 hour hold is required for P-1 materials and a 4 hour hold for P-3 materials except restrictions on size and depth similar to those in N-638 are required.

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It is not clear what the restriction on surface area for ambient temperature temper bead process was intended to address. The welding in N-638 is done using bare filler wire and welding grade shielding gases. The process is by its nature a low hydrogen process. Further diffusion of hydrogen is very rapid for low alloy steels. Nonetheless the post weld soaks in the Code and Code Case are intended as post hydrogen bake outs permitting NDE after the repair has returned to ambient temperature. N-638, since it does not impose the post bake, requires that a 48 - hour hold time prior to NDE be imposed to verify that the unlikely event of hydrogen induced cold cracking has not occurred. Further it should be pointed out that the post weld soak temperatures are too low to either temper the heat affected zone (HAZ) in the ferritic material or be an effective stress relief.

2) Technical Discussion

The temper bead weld process for excavated cavity and overlay repairs of ferritic and dissimilar metal welds using the automatic GTAW process have been performed at operating nuclear power plants for the past 20 years or longer. They have been performed by both welding at ambient temperature and with a pre-heat and post weld soak as discussed above. In no instance has hydrogen induced cracking occurred. Further qualification tests have demonstrated that fracture toughness of the heat affected zones are as high or higher than repairs using conventional welding and post weld stress relief heat treatments in accordandce with ASME code rules. Further all repairs meet the stress allowables of Section III, the Construction Code or Owner's requirements as applicable. Results from metallurgical evaluations and mechanical testing show that cooling of the HAZ is rapid enough to form a martensitic structure that is adequately tempered by the subsequent weld deposited layers.

a) *Older Qualification Programs*

EPRI conducted a program to evaluate weld overlay repairs of 12" BWR N-2 inlet nozzle to safe end weld joints (1) that was published in January 1991. As a part of the program a mockup of a nozzle to safe end weld was fabricated and destructive tested. The destructive testing included mechanical, hardness and Metallographic testing. The metallography and hardness demonstrated that the temper bead welding resulted in adequate tempering of the P-3 nozzle in the HAZ and reduced hardness in the HAZ to about 300 to 350 Knoop (about R_c 34 - 37) after three layers of weld had been deposited. In addition FEA analysis was performed to demonstrate that the residual stresses after the overlay were compressive on the ID in the region of the weld with the material susceptible to IGSCC. An overlay following the EPRI program was implemented at Vermont Yankee. Results of the qualification program and inspections are included in the report as well. The overlay has been in-service since the 1990's, been inspected several times and showed no evidence of degradation.

EPRI conducted a program to provide a justification for extended overlay design life (2). While most of the program was intended to address overlay repairs for susceptible SS welds, the results of several test programs are included that show experimental results for ID residual stresses before and after application of a weld overlay. Further these programs were conducted on large diameter piping where the overlays would be far in excess of the 100 square inch limitation.

In one test (GPC/SI/WSI) two sections of 28" diameter pipe were welded together in a manner similar to that for the BWR main reactor coolant piping. A baffle was welded axially to divide the pipe segment into 2 halves. Axial and circumferential notches were ground in to the pipe near the girth weld. One half of the pipe ID was exposed to boiling $MgCl_2$ prior to applying the weld overlay. Extensive cracking was seen at the tip of each notch showing the presence of high residual tensile stresses at the notch tip. After weld overlay the other half of the pipe was exposed to boiling $MgCl_2$. No cracking occurred at the similar notch locations in the second half of the pipe showing the residual tensile stress at the notch tips changed from tensile to compressive following application of the overlay. This test confirmed the efficacy of the FEA.

In a second test (EPRI/J.A. Jones 24" mockup) a weld overlay was applied to the pipe and the residual stresses were determined experimentally and by FEA. The results of this residual stress and measurement project have shown that both axial and circumferential residual stresses are compressive at the pipe ID surface following a weld overlay of the thickness applied to the pipe. This also represents an experimental verification of FEA results for a large diameter reasonably thick wall pipe where the overlay would well exceed 100 square inches.

It should be noted that much of the weld shrinkage numerical methods as well the experimental verifications and failure analysis have been performed at government and not-for- profit laboratories (ANL, PNL and Battelle Columbus). Further details on the specific programs are found in the Reference Section in (1) and (2).

b) *More Recent Qualification Programs*

During the development of the code case to relax the limitation on the surface area for ambient temperature Working Group on Welding, after receiving comments from other Code Committees and the NRC, requested that supporting analyses be performed to determine if any significant changes in residual stresses occur if the repair exceeded 100 square inches. It is assumed that the focus on residual stresses was made because past programs have demonstrated that temper bead welding using automatic GTAW provides adequate tempering of the HAZ in P-1 and P-3 materials and does not degrade strength or fracture toughness. Further associated inspections have shown that hydrogen induced cracking has not been a problem with repairs produced by the automatic GTAW temper bead process. The metallurgical aspects discussed appear to be independent of the surface area of the repair but related to input qualified for the welding.

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EPRI sponsored analytical work (3) to evaluate the effects from increases in surface area beyond 100 square inches for both cavity and weld overlay repairs. Three cases were evaluated as a part of the program: a 100 square inch overlay on a nozzle was increased modestly and analyzed, a 500 square inch cavity repair was analyzed and three adjacent 100 square inch cavity repairs were analyzed.

In the first case a weld overlay that was applied to one of the 12 in. diameter Feedwater Nozzles of an operating BWR. The weld overlay was applied in order to restore the structural integrity of the flawed location assuming no credit for any remaining uncracked material in the original safe end. Due to the availability of the information from the utility and a finite element model, this geometry was selected for this initial phase of this work. These residual stress predictions were performed using the ANSYS Rev. 5.3 finite element program. The analysis consists of two parts: a thermal analysis and a stress analysis, to model the welding process in both thermal and mechanical respects. Two axisymmetric finite element models were created, one with a weld overlay of 100 in^2 (Figure 1), the other with the weld overlay extended on the nozzle side until it blends into the nozzle taper surface (Figure 2) (approximately 126 in^2). Figure 3 shows the residual stress on the pipe inside surface. These two figures show that the residual hoop stress is very similar, and in fact the hoop stress for the extended case is even more compressive. The axial stress is less compressive for the extended model, but still with significant compressive stress. This figure also shows that the main area of concern, on the edges of the repair, that stress caused by the 100 sq. in. repair and the larger repair are similar.

In summary results of this evaluation indicate that the combination of the extended overlay and geometric discontinuity of caused by the increased nozzle diameter on the outside surface modify the residual stress. This modified behavior is local to the end where the extension of the overlay was made and the presence of the geometric discontinuity. All other stresses remain essentially the same and the effectiveness of the overlay to provide structural reinforcement at the nozzle-to-safe end weld remains assured. Results of this evaluation indicate that the alternate extended overlay would have been an acceptable overlay from a structural integrity perspective.

In the second case the weld repair configuration selected for evaluation is a cavity of rectangular trough shape, along the longitudinal axis of the reactor vessel, with a depth equal to half of the vessel wall thickness. Two repair sizes, 100 in^2 and 500 in^2 are used. These are the projected areas on the inside surface of the vessel. The actual surface areas in the cavity are much larger, at 328 in^2 and 1894 in^2.

Comparison was made on different paths for the residual stress distribution between the two repair sizes. The stress contours for the two repairs are shown in Figures 4 through 9. In general, the residual stress distributions in the axial and hoop directions are very similar to each other for the two repair sizes. Within the weld repair area, the axial surface residual stress (S_z) for the smaller repair area is lower than the larger repair area. The hoop surface residual stress (S_y) for the smaller repair area is higher than the larger repair cavity. Outside the weld repair cavity, the residual stress for the larger repair area has lower residual stresses on the selected paths, both on the inside surface and through the wall of the reactor vessel.

It is shown that a larger weld repair area does not have a significant adverse effect on the weld residual stress. In some cases, the larger repair area is much more beneficial because of the lower tensile residual stress or higher compressive residual stress. Especially for the case of axial weld repair where an axial crack could exist, the hoop stress is more compressive or less tensile within the weld repair area and outside the repair area. The larger repair area could be less susceptible to the crack growth, due to either stress corrosion or fatigue.

The third case addresses the implementation of a 300 in^2 weld repair on a Reactor Pressure Vessel (RPV) vertical shell weld. The repair is implemented in 3 separate 100 in^2 repair, i.e., a 100 in^2 repair is simulated, then another 100 in^2 repair is simulated immediately adjacent to the first repair, followed by a third 100 in^2 repair immediately adjacent to the second repair. This case was selected to evaluate to ascertain the ramifications of repairs being performed sequentially to stay within the 100 in^2 limitations.

The final weld repair configuration selected for evaluation is a rectangular trough shape, with a depth equal to half of the vessel wall thickness. The final weld repair consists of three temperbead layers, and a weld out of the remaining cavity. Due to the complexity in the modeling, the temperbead layers are present only on the final weld repair volume outside surfaces, or boundaries, that are in contact with the base metal. The temperbead was not modeled in between the two adjacent weld repairs. Also, a half model of the weld repair is used in order to account for the effect of sequence in the weld repairs.

Due to the large volume of the repair cavity and the large number of bead passes, simplifying assumptions, as identified earlier, were used in the weld residual stress analyses. These assumptions should not have a significant impact on the conclusion since the evaluation is made on the comparison of residual stresses among the three individual weld repair areas using similar assumptions and parameters.

The stress contours for the single and three sequential repairs are shown in Figures 10 and 11. Comparison was made for the residual stress distribution on different paths after the completion of each 100 in^2 repair area. In general, each weld repair area induces a similar residual stress distribution within its repair area. In addition, the residual stress in the previously repaired area is reduced due to the subsequent adjacent repairs. This is due to the excavation of base metal in the subsequent weld repair volume that has a relaxation effect of residual stress in the previously repaired area. Also, the welding in the subsequent repair area has an effect similar to PWHT on the previously repair area.

Based on the comparison of the residual stress distributions for the sequential weld repairs, it can be concluded that a subsequent adjacent repair has an overall effect on reducing the residual stress distribution in the previously repair areas. Also, the residual stress in the last repaired area has a very similar residual stress magnitudes compared to an individual repair of 100 in^2.

The current evaluation uses three 100 in^2 repair areas. But the discussions on these results and the conclusions could be applied to any number of weld repair areas in each with an area of 100 in^2.

As a part of a program to evaluate weld overlays as a measure to mitigate PWSCC (4), SI conducted an analysis to determine the residual stress profiles of a 33 in. OD PWR reactor coolant nozzle to a stainless steel pipe. A summary of the dimensions for the finite element mode is shown in Figure 12. The reduced thickness overlay modeled is 0.48 in. thick which is about ½ the thickness of a full structural overlay. The surface area of the overlay on the low alloy steel nozzle was 332 square in. The stress contours before and after the overlaying is shown in Figures 13 and 14. Please note that the overlay is shown in Figure 13 but is not active for analysis purposes since it does not exist at that time. Again it is quite apparent that tensile residual stresses at the ID in the weld location before overlaying become compressive after the overlay is applied. The inside surface axial and hoop stresses are shown in Figure 15. Note that the condition for the pre-WOL at 120 F shown in black curve with diamonds shows the high residual tensile stresses and the post-WOL leakage test curve at 120 F shown in the blue curve with diamonds show that all residual stresses in the weld are compressive where there is any PWSCC susceptible material. Other conditions for residual stresses for the hoop and axial directions are also shown. This evaluation as well as those shown above again demonstrates that acceptable residual stresses to mitigate PWSCC are induced by the shrinkage of the weld overlay. Also it demonstrates that these residual stresses are independent of the surface area of the repair and related to other parameters. The overlay could well have been extended an additional 2 in. up the nozzle to increase the surface area over 500 square in. with similar results for the 332 square in. case analyzed.

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c) Service History

Dissimilar metal overlays have been performed at some BWR units as long as 15 to 20 years ago. Several BWR units recently applied weld overlays to nozzle/safe-end locations and one PWR unit, Three Mile Island Unit 1 applied an overlay on a hot leg-to-surge line nozzle using temperbead welding procedures. Machine GTAW temperbead procedures were used to perform the repairs with the RPVs filled with water to avoid excessive radiation exposure to repair personnel. These BWR plants were Perry, Duane Arnold, Hope Creek, Nine Mile Point Unit 2 (NMP-2), Pilgrim, Susquehanna and two at Hope Creek. The Perry and Nine Mile Point Unit 2 overlays were applied to feedwater nozzles. Duane Arnold applied overlays to two recirculation inlet nozzles, and Hope Creek applied an overlay to a core spray nozzle and a recirculation inlet nozzle. All of these repairs were performed at ambient preheat temperatures except for the Hope Creek core spray nozzle overlay. Further several utilities have planned contingent repairs for nozzle welds that have Alloy 182 butter and Alloy182 filler. The code requirement limiting the application of temperbead procedures to 100 in^2 significantly influenced the design of some of the weld overlays. Further relief from the surface area limitation has been requested and approved by the NRC on a case basis for several of these repairs.

In addition weld buttering for the reactor recirculation pipe to the reactor vessel outlet nozzle weld repair at the VC Summer plant was performed using ambient temperature temper bead welding in accordance with N-638. The surface area that was buttered was about 140 square inches. Further ambient temperature temper bead welding per the case has been used for weld pads on pressurizers to replace heater sleeves. About 120 such pads were welded to the pressurizer lower heads to replace the heater sleeves at Calvert Cliffs with no adverse effects.

Service history with these overlays at dissimilar metal weldments has been excellent. Inspection methods that are qualified in accordance with PDI are available and have been used to conduct the examinations.

Further all repairs meet the stress allowables from Section III, the Construction Code or Owner's requirements as applicable. Further results from metallurgical evaluations and mechanical testing show that cooling of the heat affected zone is rapid enough to form a martensitic structure that is adequately tempered by the subsequent weld deposited layers.

3) Conclusions

The restriction on surface area for temper bead welding was arbitrary, is overly restrictive, leads to increased cost and dose for repairs and does not contribute to safety. There is no direct correlation of residual stresses either for cavity or overlay repairs done using temper bead welding. Cases have been analyzed up to 500 square in. that verify that residual stresses for cavity repairs are at an acceptable level and that residual stresses associated with weld overlay repairs remain compressive in the weld region for larger area repairs as well a for smaller area repairs. The implementing ASME Code and Code Case requirements assure that code stress limits and safety factors are maintained for overlay repairs regardless of size. Metallurgical, mechanical, and hardness testing results show that adequate tempering is achieved and that adequate fracture toughness and strength is maintained in the weld and heat affected zone. The restriction on surface area of repairs should be increased to 500 square in. based on the results of analyses and testing performed to date. The Code should provide an option to users to justify repairs beyond 500 square in. by additional analysis and evaluation.

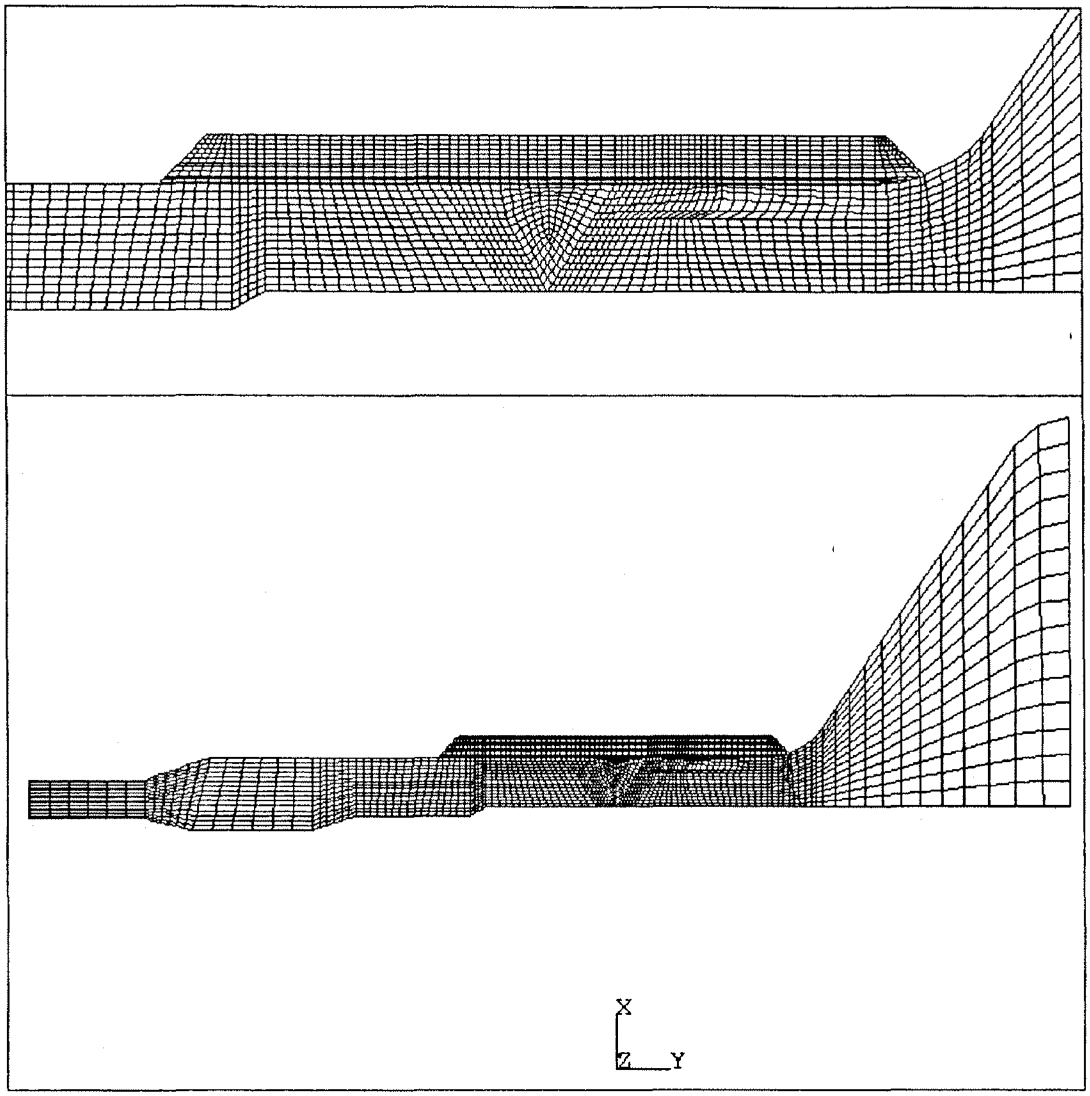


Figure 1. 100 in^2 Finite Element Model

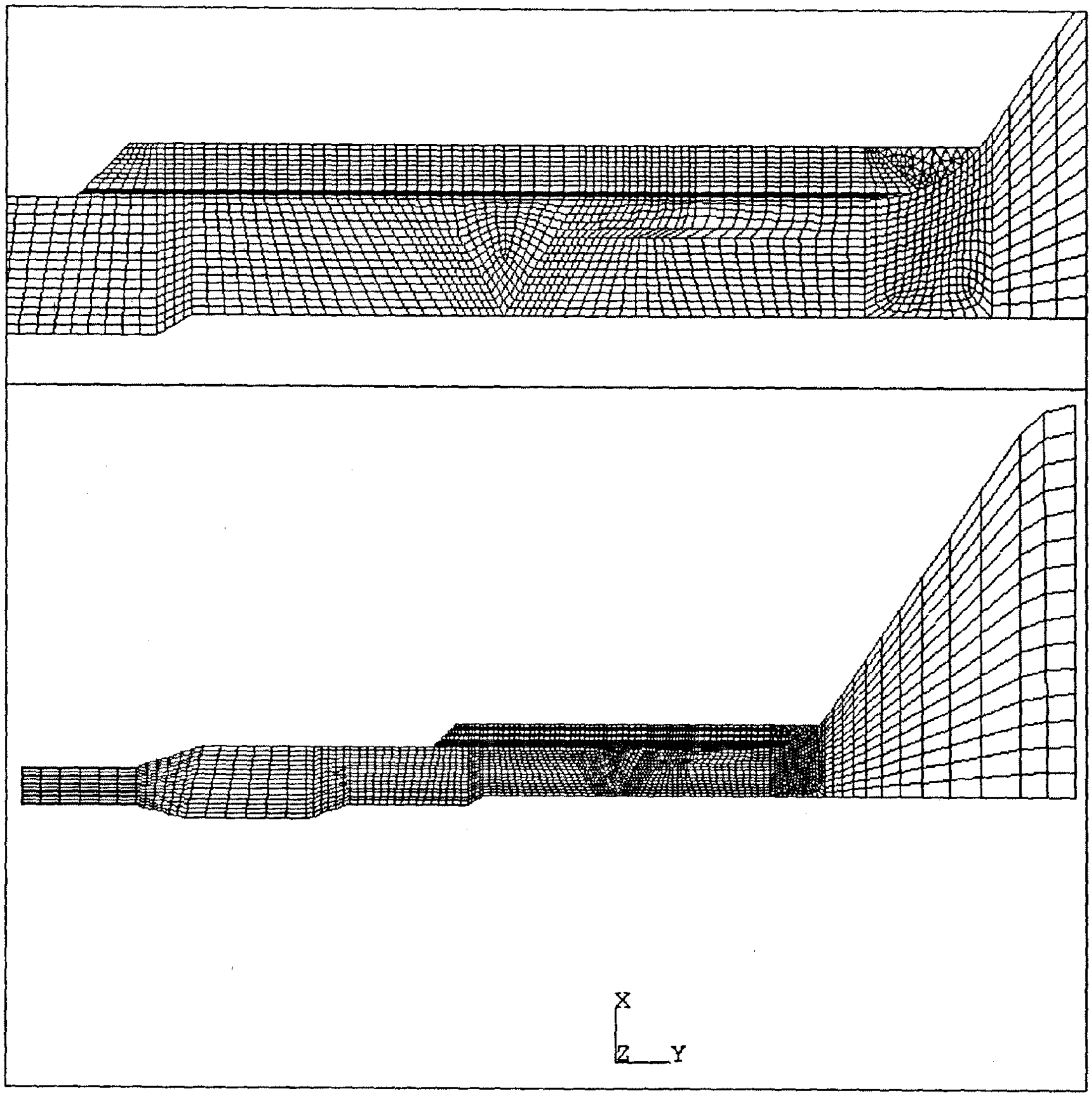
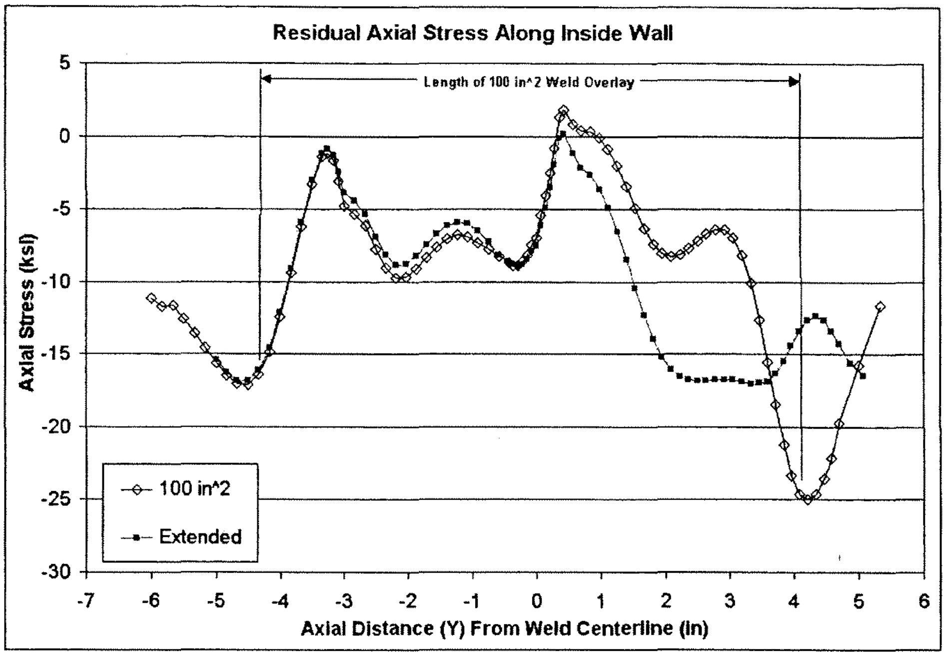


Figure 2. Extended (126 in^2) Overlay Finite Element Model



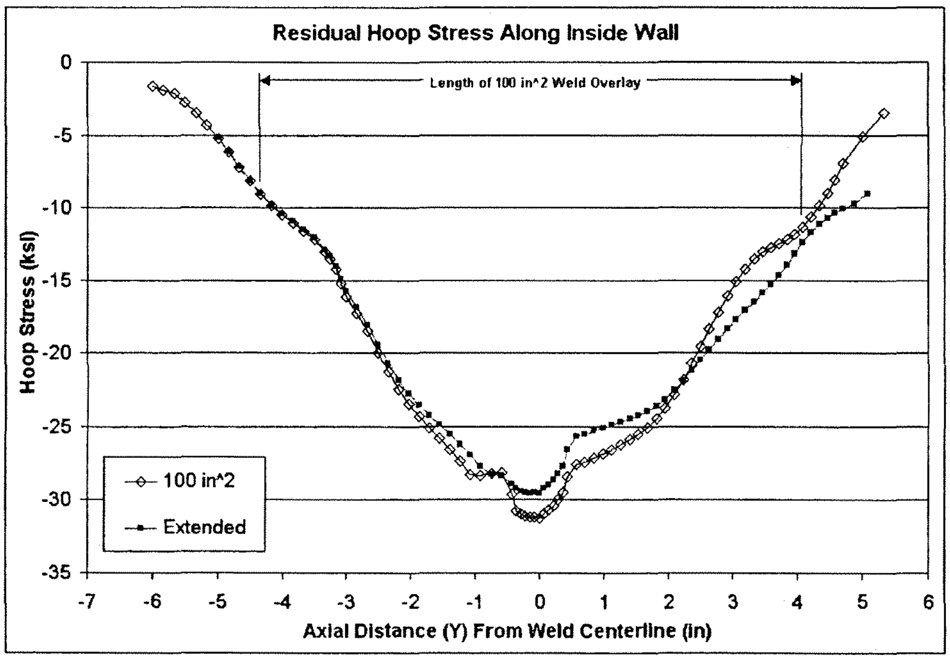


Figure 3. Residual Stresses Along Inside Wall of Pipe

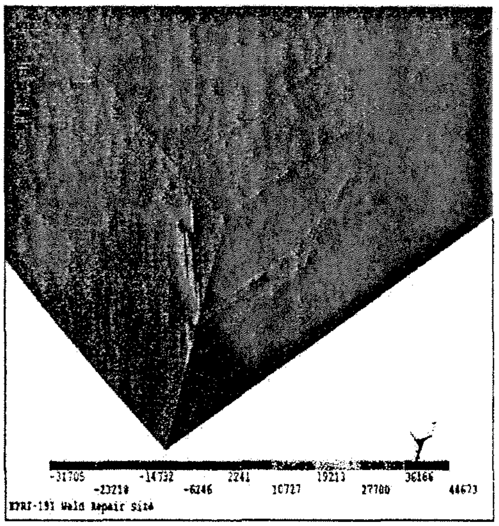


Figure 4 Stress Contour, Sx, at 50 °F After 100 in^2 Repair

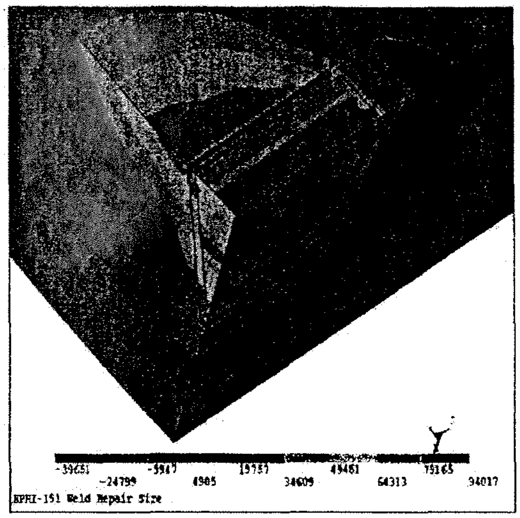


Figure 5 Stress Contour, Sy, at 50 °F After 100 in^2 Repair

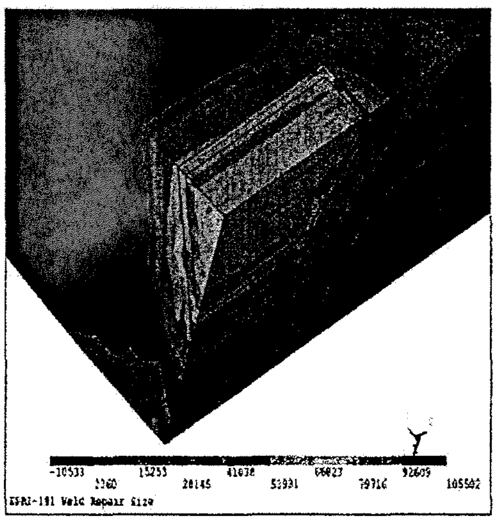


Figure 6 Stress Contour, Sz, at 50 °F After 100 in^2 Repair

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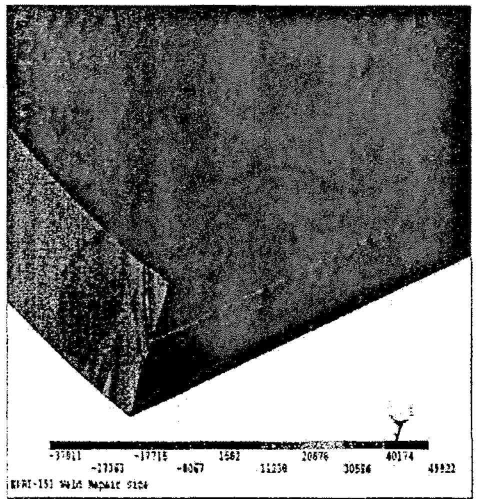


Figure 7 Stress Contour, Sx, at 50 °F After 500 in^2 Repair

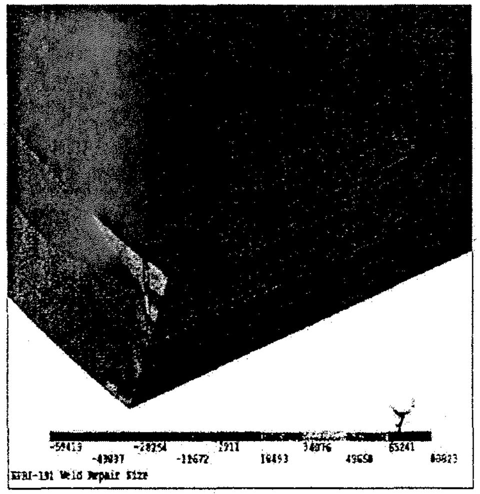


Figure 8 Stress Contour, Sy, at 50 °F After 500 in^2 Repair

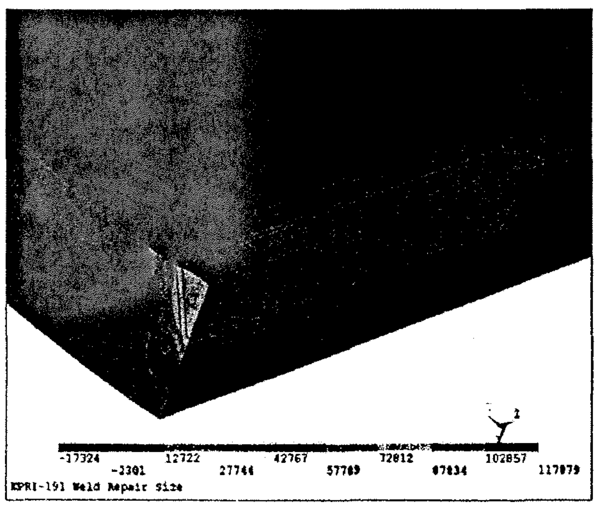
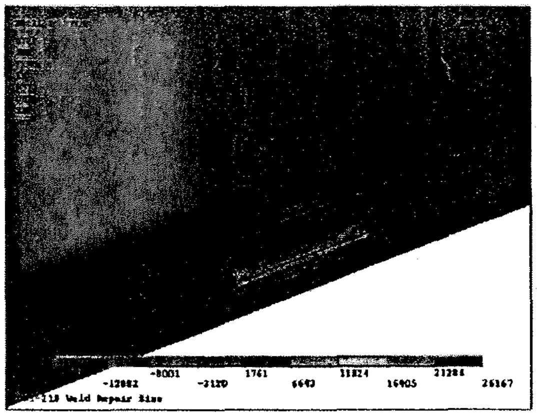
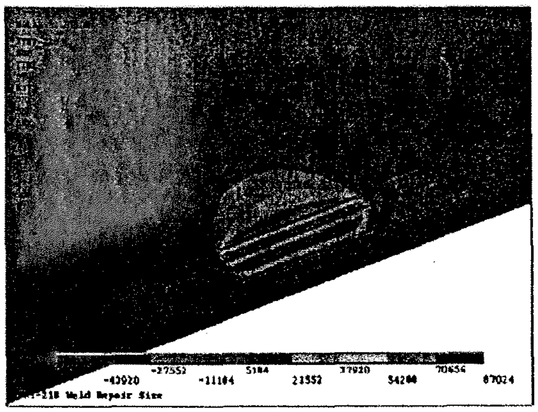


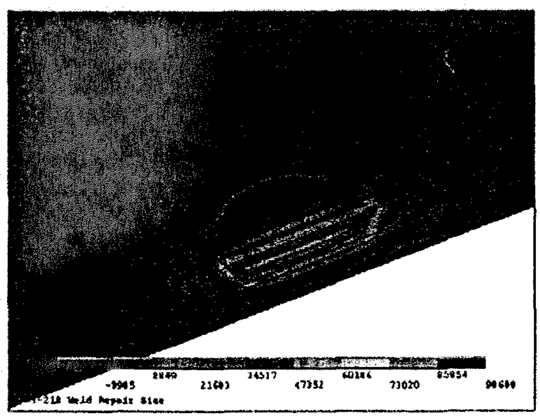
Figure 9 Stress Contour, Sz, at 50 °F After 500 in^2 Repair



a. Radial Stress (S_x)

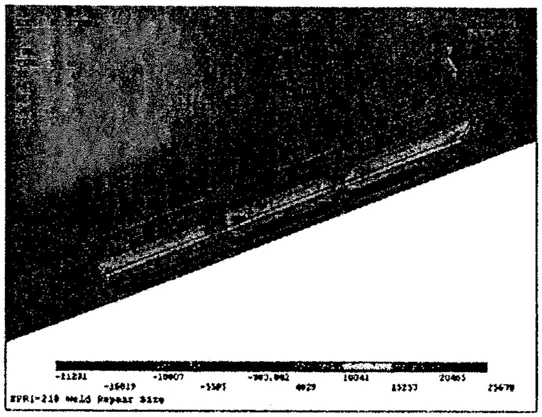


b. Hoop Stress (S_y)

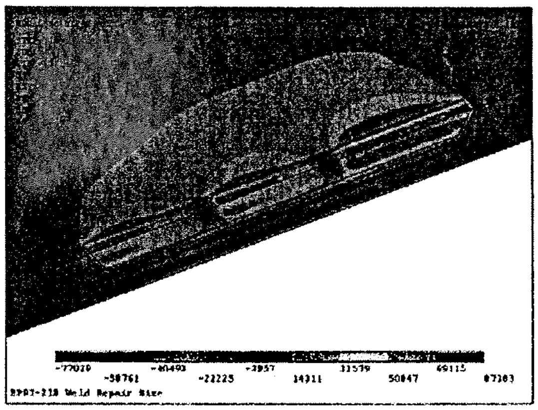


c. Axial Stress (S_z)

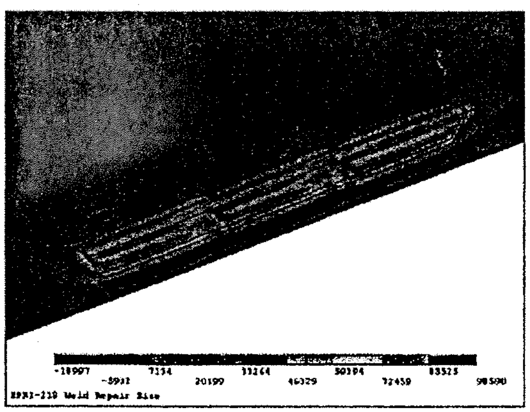
Fig.10 Stress Contour, at 70°F After 1st 100 in^2 Repair



a. Radial Stress (S_x)



b. Hoop Stress (S_y)



c. Axial Stress (S_z)

Fig. 11 Stress Contour, at 70 °F After 3rd 100 in^2 Repair

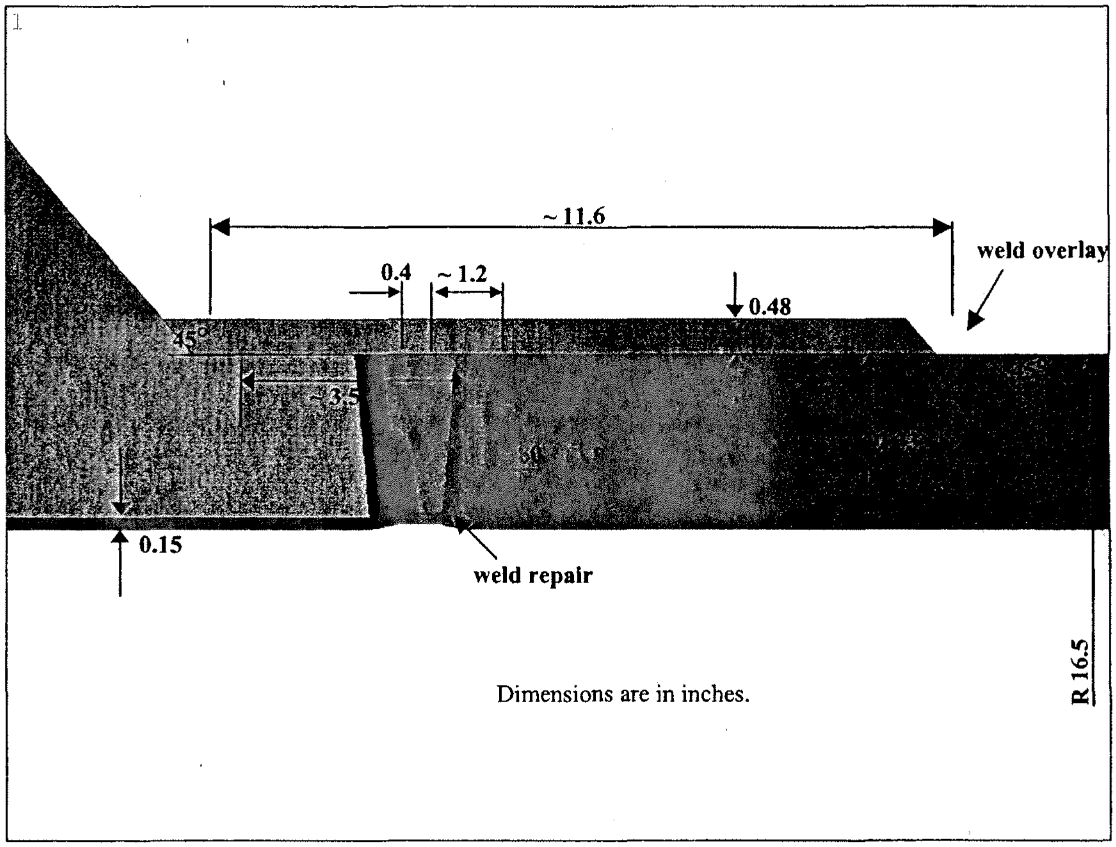
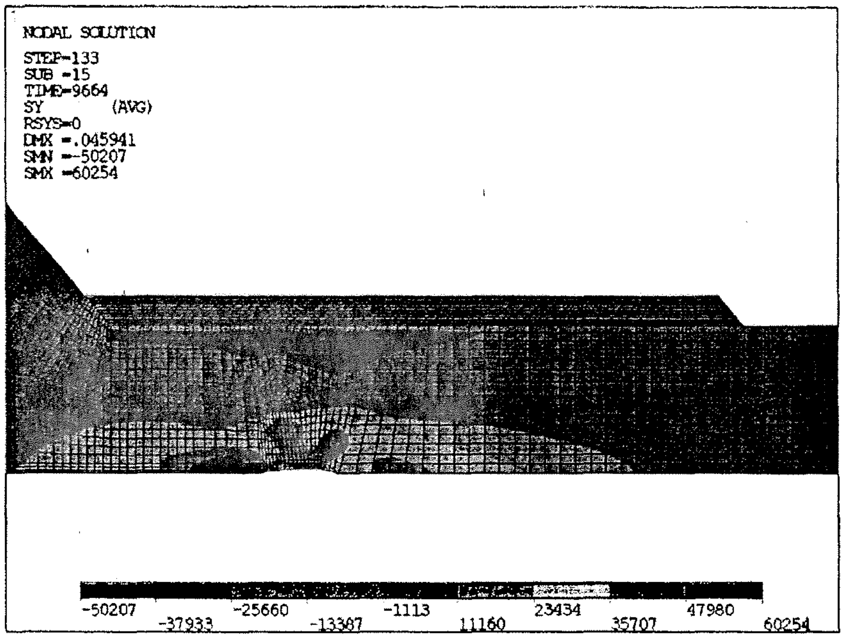
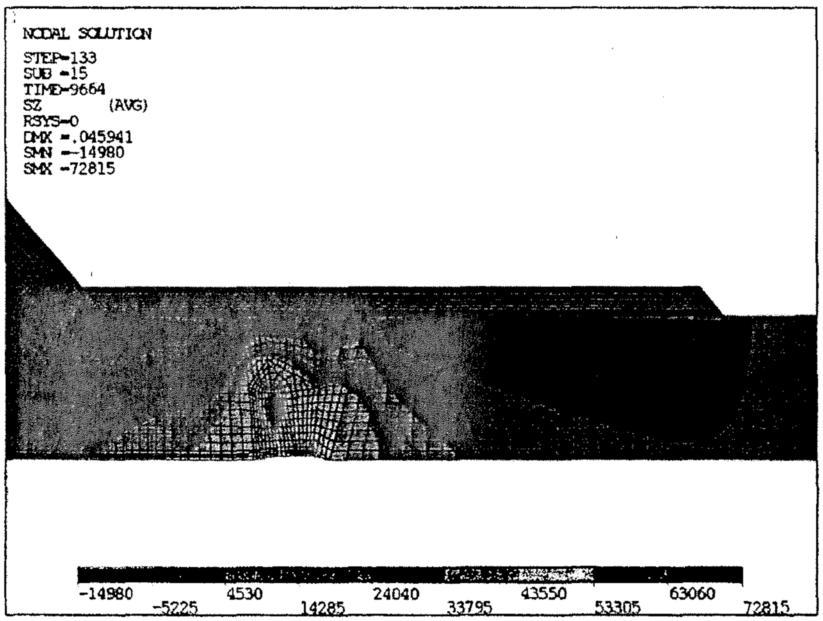


Fig. 12 Summary of Dimensions for the Weld Overlay Finite Element Model

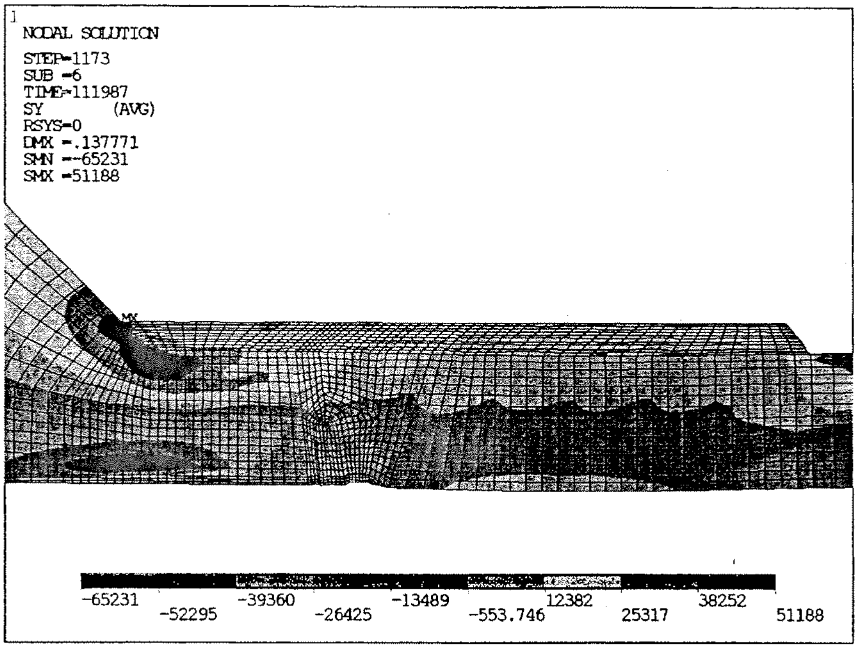


a. Axial

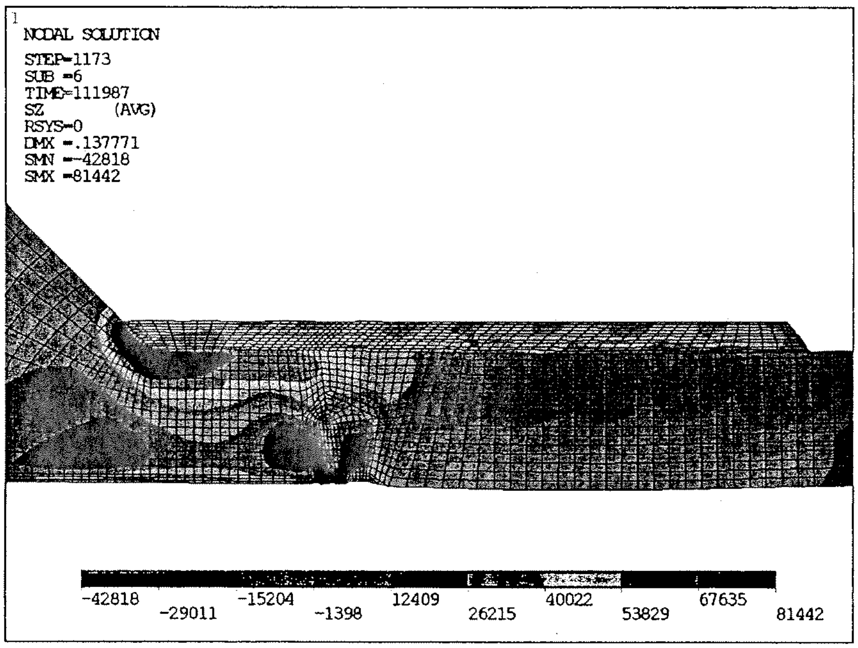


b. Hoop

Fig. 13 Pre-WOL Stress Contours, 70°

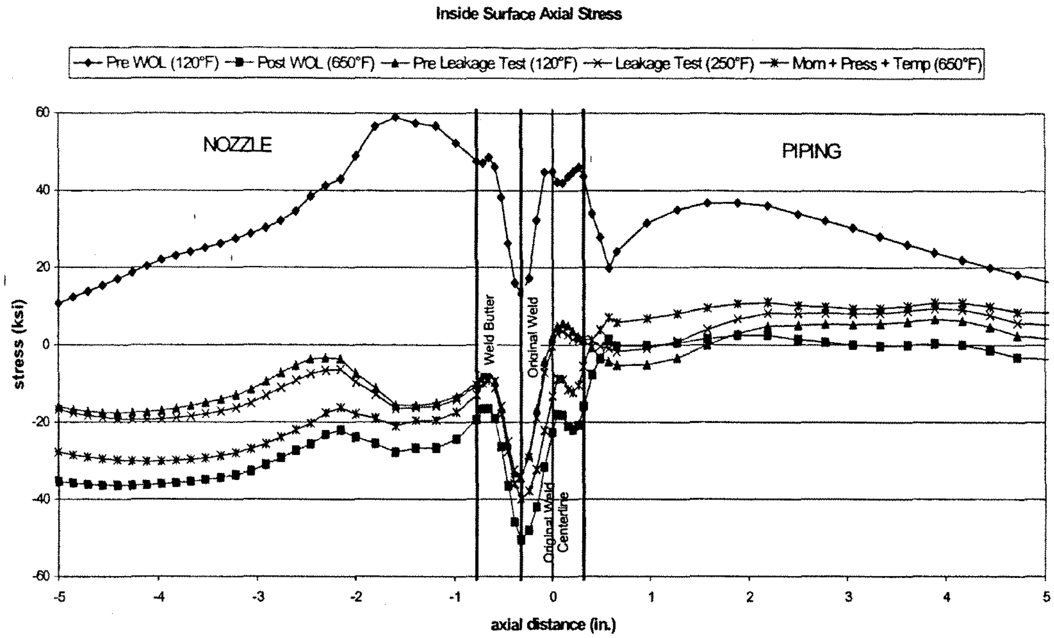


a. Axial



b. Hoop

Fig. 14 Post WOL Hoop Stress Contour, 70 F°



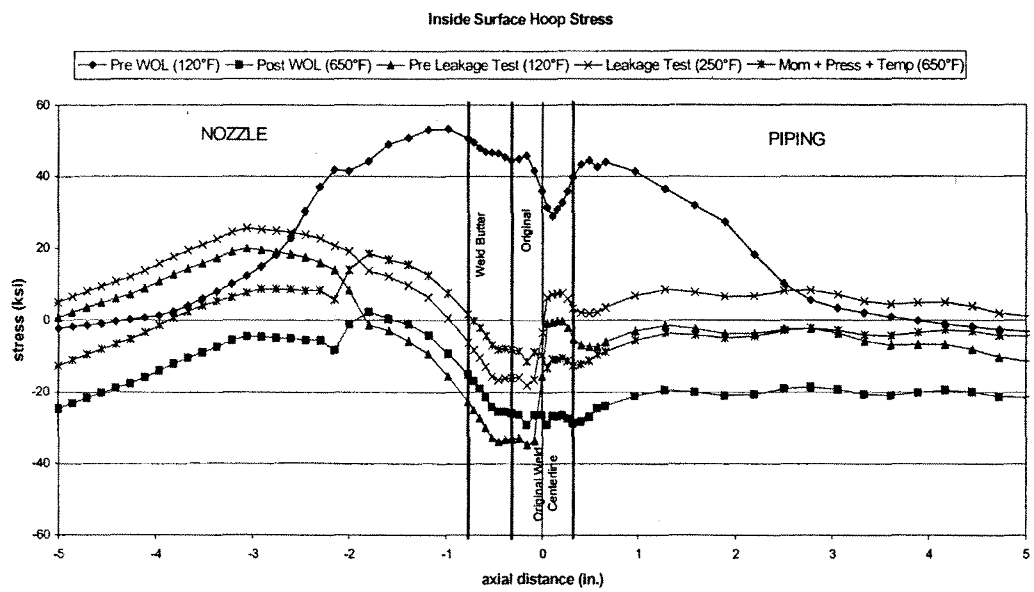


Fig. 15 Inside Surface Stresses at Different Conditions, 5 Layers, Long Overlay, Water Inside Pipe

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4) References

1. "Inconel Weld-Overlay Repair for Low-Alloy Steel Nozzle to Safe-End Joint", EPRI NP-7085-D, January 1991.
2. "Justification for Extended Weld-Overlay Design Life", EPRI-NP-7103-D, January 1991.
3. "Justification for the Removal of the 100 Square Inch Limitation for Ambient Temperature Temper Bead Welding on P-3 Material", EPRI-NP-XXXX, February 2005.
4. "Calculation Package, Preemptive Weld Overlay Residual Stress Analysis", DEV-03-3xx, Structural Integrity Associates, Inc., San Jose, CA, January 2005.