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Palisades Nuclear Plant
Operated by Nuclear Management Company, LLC

July 30, 2001

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-001

DOCKET 50-255 - LICENSE DPR-20 - PALISADES PLANT
REQUEST FOR APPROVAL TO USE ASME CODE CASE N-504-1 FOR REPAIR OF CONTROL ROD DRIVE MECHANISM UPPER HOUSING ASSEMBLIES

Beginning on about June 9, an increase in Primary Coolant System (PCS) leakage was detected and was monitored until the plant was shutdown on Wednesday, June 20, 2001 (Mode 3). On Thursday, June 21, 2001 a leak was identified in the upper housing assembly for control rod drive mechanism (CRDM) number 21. Observation of a steam plume visually verified the leak as coming from the CRDM-21 upper housing assembly, just above the reactor head CRDM flange. Specifically, the leak was observed near the upper housing assembly pipe to eccentric reducer butt-weld. This weld is identified as 119-33D in the 10-Year Master Inservice Inspection Plan. Upon identifying the pressure boundary leakage, the plant entered Technical Specification Action 3.4.13.B. Following entry into Technical Specification Action 3.4.13.B, the PCS was placed in Mode 5 to effect repairs to the CRDM-21 upper housing assembly.

The CRDM-21 housing is one of forty-five assemblies that include a nominal eight-inch diameter austenitic stainless steel pipe. Each CRDM is located on the reactor head. The upper housing assembly is attached to the Control Rod Drive Mechanism nozzle, which penetrates the reactor vessel head. Control rod drive mechanism upper housing assemblies were constructed in accordance with ASME Section III, Winter 1965 Addenda, as a sub-component supplied with the reactor vessel head. The control rod drive mechanism upper housing assemblies are made up of standard piping components that are assembled and then machined to form the housing assembly.

A047

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Non-destructive examination of the CRDM-21 upper housing assembly revealed that a through-wall axially orientated flaw had propagated from the inside surface of weld 119-33D. The CRDM-21 upper housing assembly was removed for destructive examination to determine the specific root cause. This housing will be replaced. Additional examination by liquid penetrant (PT) and ultrasonic test (UT) methods was performed for several of the remaining forty-four upper housing assemblies. Due to examination limitations associated with the UT method, some of these examinations were supplemented with radiographic tests (RT). Using the RT, additional indications have been discovered in several housings. The RT confirmed all indications identified by the UT results. In addition, RT also discovered indications not visible via UT.

American Society of Mechanical Engineers (ASME) Code Case N-504, "Alternate Rules For Repair of Class 1, 2, and 3 Austenitic Stainless Steel Piping, Section XI, Division 1," was approved by the ASME Boiler and Pressure Vessel Code (B&PV Code), Section XI on April 30,1992, and was revised (N-504-1) on August 9,1993. This Code Case expired on July 1,1995 with the publication of ASME Section XI, 1995 Edition. However this code case remains listed as an acceptable code case in the latest edition of Regulatory Guide 1.147, "Inservice Inspection Code Case Acceptability, ASME Section XI Division 1," Revision 12, dated May 1999. This Code Case is written for application on piping components. While not considered a piping component, the CRDM upper housing assemblies are assembled using standard flanges, eccentric reducers and piping. After assembly the housings are machined to manufacturer's specifications. Materials and methods of welding are consistent with direct application of the code case. Therefore, pursuant to 10 CFR 50.55a(a)(3) and footnote 6 of 10 CFR 50.55a, Nuclear Management Company (NMC) requests approval for the use of Code Case N-504-1 for the repair of any Control Rod Drive Mechanism Upper Housing Assemblies for which the Code Case can be shown to apply, and where such repair is determined to be the appropriate course of action. Code Case N-504-1 provides an acceptable alternative repair to the repair techniques presently approved for use by the NRC.

To comply with the intent of the pre-service inspection requirements of Code Case N-504-1, the weld overlay repair plan has been written to require PT, UT and RT, within their limitations, for pre-service inspection. Enclosure 1 provides the CRDM Upper Housing Assembly Repair Plan that would be applied to any CRDM housings that are repaired with a weld overlay in accordance with Code Case N-504-1. In addition, following completion of any weld overlay repairs made in accordance with this request, NMC will provide the NRC with its plan for future inspections of the repaired housings.

Enclosure 2 provides information to support the applicability of Code Case N-504-1 to trans-granular stress corrosion cracking (TGSCC) as well as to intergranular stress corrosion cracking (IGSCC). It also discusses TGSCC behavior and crack growth considerations, and establishes that the weld overlay repair technique places the internal surface of the pipe into a residual compressive stress condition, reducing the possibility of new crack initiation and/or propagation of existing flaws. Thus, the weld overlay in this application should not be different in this regard from any other application for which the Code Case has already been approved for use.

Enclosure 3 provides the Weld Overlay Design for the control rod drive mechanism upper housing assembly weld overlay repair.

Prompt NRC review and approval are requested.

SUMMARY OF COMMITMENTS

This letter contains one new commitment and no revisions to existing commitments. The new commitment is:

> Following completion of any weld overlay repairs made in accordance with this request, NMC will provide the NRC with its plan for future inspections of the repaired housings.

Paul A. Harden
Director, Engineering

CC Administrator, Region III, USNRC
Project Manager, NRR, USNRC
NRC Resident Inspector – Palisades

Enclosures

ENCLOSURE 1

NUCLEAR MANAGEMENT COMPANY, LLC
PALISADES PLANT
DOCKET 50-255

JULY 30, 2001

REQUEST FOR APPROVAL TO USE ASME CODE CASE N-504-1 FOR REPAIR OF CONTROL ROD DRIVE MECHANISM UPPER HOUSING ASSEMBLIES

CONTROL ROD DRIVE MECHANISM
UPPER HOUSING ASSEMBLY WELD REPAIR PLAN

5 Pages

WELD OVERLAY REPAIR OF AUSTENITIC STAINLESS STEEL CRDM UPPER HOUSINGS

1.0 REPAIR PLAN SCOPE

1.1 The purpose of this repair plan is to define the controls used for the performance of Weld Overlay Repairs (WOR) for the CRDM upper housings. It is currently anticipated that PCI will perform WOR's for CRDM upper housings as identified by the customer (Palisades) and based on results of non-destructive examination.

2.0 ENGINEERING

2.1 The Engineering for this repair is based on a design provided by contract with Structural Integrity Associates of San Jose, California. The overlay is designed to meet the requirements of ASME Section XI, 1989 Edition, with Code Case N-504-1. In addition, the requirements of United States Nuclear Regulatory Commission, Generic Letter 88-01 dated January 25, 1988 with Supplement 1 dated February 4, 1992, and NUREG-0313 Revision 2, published January 1988 were used as a reference.

3.0 REPAIR PLAN DETAILS

3.1 General

3.1.1 The WOR's applied under this plan will be applied by PCI Energy Services under its NR Quality Assurance Program, Second Edition, Revision 1. A repair permit from the State of Michigan will be obtained for each overlay performed. Code symbol stamping is not required for the scope of work addressed by this Repair Plan. A complete data package will be provided to Palisades Nuclear Power Plant.

3.1.2 All welding will be performed using welders and Welding Procedure Specifications (WPS's) qualified to the requirements of ASME Section IX 1995 Edition, 1996 Addenda. Welding controls are provided via use of the weld process travelers in PCI Project Instruction (PI) PI-21807-02.

3.2 Original Construction Code

3.2.1 The pressure housing design and fabrication conform to the requirements of the ASME Pressure Vessel Code, Section III, 1965 edition, for Class A vessels per Paragraph N-131.

3.3 **Current Construction Code**

3.3.1 The design, welder/welding operator, filler metal procurement and weld repair work addressed by this repair plan shall be performed in accordance with ASME Section XI, 1989 Edition. Nondestructive Examination is to be performed by Palisades in accordance with ASME Section V and Section XI, 1989 Edition.

3.3.2 In addition, the weld overlay repairs shall comply with the requirements of ASME Code Case N-504-1.

3.4 **Flaw and NDE Description**

3.4.1 Liquid Penetrant, Ultrasonic and Radiography Examinations have identified indications that metallurgical analysis determined to be Transgranular Stress Corrosion Cracking (TGSCC) in or near the weldments identified in Section 1.0.

3.4.2 Visual inspection of Control Rod Drive number 21 revealed a steam leak with boric acid deposit on the pressure housing. CRD-21 was removed and destructively examined. Results of this examination are described below.

CRD-21 has a total of four cracks that were identified at weld number 3 by dye penetrant examination of the internal surface. As identified above, all of the indications were metallurgically examined and all were determined to be TGSCC. The indications were both circumferential and axial in orientation. There will be no repair made to CRD-21, it will be replaced before returning the plant to service.

3.4.3 Subsequent NDE examinations have revealed other indications on other CRDM upper housings which would be Code rejectable. These flaws were also both circumferential and axial in orientation. Any additional locations which may be found through further inspection, and which are in accordance with the N-504-1 code case, may be repaired with a structural weld overlay.

3.5 **Flaw Removal Method**

3.5.1 The surface to be repaired shall be examined using penetrant testing. Indications which are greater than 1/16 inch must be prepared for weld reinforcement by one of two methods as described in section (c1) or (c2) of code case N-504-1. Penetrant testing which has been performed to date has resulted in PT exams free of indications. Any future indications which may be found which do not meet the requirements of Palisades's ISI acceptance criteria and/or Code Case N-504-1 will be prepared as described above to provide a defect free weld and heat affected zone.

3.6 Description of Work

3.6.1 The technique consists of applying the designed weld overlay using low carbon (L grade), high ferrite ≥(10%F), ER309L filler material over Austenitic Stainless Steel piping, using the Machine GTAW process for a specified minimum distance beyond the observed flaws on both sides. Multiple layers of delta ferrite containing weld metal are applied completely around the outside surface of the pressure housing. The system will remain flooded with water during the application of the overlay material to provide cooling of the housing. The manual GTAW and SMAW processes will be used for leak, steam blowout and defect repairs.

3.7 The Design

3.7.1 The WOR is a "Structural Overlay" design meeting the requirements of ASME Section XI, Code Class N-504-1 as detailed in Structural Integrity Associates, Inc. design report "Standard Weld Overlay Design for Palisades CRDM Upper Housing Welds," W-CPC-13Q-304, Rev. 2 [Enclosure 3 of NMC's July 30, 2001 letter to NRC].

3.8 Examination and Test Procedures

3.8.1 In-process and final NDE are Palisades's responsibility. Measurement is discussed in PI-21807-02. WOR's over indications shall receive an In-service or functional test.

3.8.2 The weld overlay examinations shall comply with the requirements of ASME Code Case N-504-1. In addition, all WORs shall be radiographed in accordance with ASME Boiler and Pressure Vessel Code, 1989 Edition, Section V, Article 2 requirements.

3.8.3 Upon completion of all WORs, the seismic support structure for all of the CRDM upper housings shall receive a final VT-3 examination.

3.9 Documentation

3.9.1 The repairs addressed by this Repair Plan shall be documented as outlined in PI-21807-02 and shall be documented by Nuclear Management Company (NMC) on Form NIS-2, "Owners Report of Repair or Replacement," or equivalent form. The following documents shall be permanently maintained by Palisades:

1. CMTR's for all Filler Materials
2. WPS's, PQR's and Welder/Weld Operator Qualifications

3. NDE Procedures and Personnel Qualification Records
4. Section XI Repair Plan (this document)
5. NDE Reports
6. Weld Overlay Design Report
7. Welding Data Sheets
8. Welding Operator Log Sheets
9. Equipment Calibration Records
10. WOR Design Report/Design Calculation Package
11. Process Control Travelers
12. WOR Application and Examination Procedures

4.0 APPLICABLE WORK REQUIREMENTS

4.1 Work Order packages shall be developed for use in implementation of the work scope addressed by this Repair Plan. These packages will, as a minimum, establish requirements for the following:

1. General overlay welding details
2. Welding procedures specifications
3. Welder and welding operator qualifications
4. Weld filler material
5. Overlay layout
6. Welding instructions and techniques
7. Defects and steam blow-out repair
8. Final surface condition
9. In-process and final NDE and measurement
10. Examination personal qualifications and documentation

5.0 PRESSURE TESTS

5.1 In accordance with Code Case N-504-1, completed overlays shall be pressure tested in accordance with ASME B&PVC Section XI, Paragraph IWA-5000. Overlays applied over flaws that penetrate the pressure boundary shall be hydrostatically tested while overlays over indications that do not penetrate the pressure boundary shall receive a system leakage, in-service, or functional test.

ENCLOSURE 2

NUCLEAR MANAGEMENT COMPANY, LLC
PALISADES PLANT
DOCKET 50-255

JULY 30, 2001

REQUEST FOR APPROVAL TO USE ASME CODE CASE N-504-1 FOR REPAIR OF CONTROL ROD DRIVE MECHANISM UPPER HOUSING ASSEMBLIES

WELD OVERLAY APPLICABILITY
TO
CRDM HOUSING WELDS

3 Pages

Weld Overlay Applicability
to
CRDM Housing Welds

The application of weld overlay technology to defective CRDM housing welds at the Palisades Nuclear Station is an appropriate repair to restore the weld to full ASME Code operating margins. Weld overlays have been used extensively in BWR piping systems and also have been applied to many PWR components including CRDM canopy seals. The technology has been successfully applied to mitigate the effects of stress corrosion cracking including both intergranular and transgranular forms. Pertinent information is provided to address potential questions regarding the application of weld overlays for flaws in the weldment joining the housing cylinder to reducer (weld #3).

A leaking defect initially was discovered at the #3 weld of the housing installed for CRDM- 21. All welds on this Type 347 austenitic stainless steel housing were inspected and the housing removed for extended nondestructive and destructive examinations. Axial and circumferential flaws of varying depths were found. Metallurgical samples were removed from the defective weld for evaluation. Optical and SEM testing produced results that identified the cracking in both orientations as transgranular stress corrosion cracking (TGSCC). Thorough inspections were performed on all of the welds in the removed housing, but no additional indications were found. Other housings have been inspected, but no reportable indications have been identified for any welds other than the #3 weld. It is noted that both axial and circumferential indications have been reported at the same #3 weld in other housings. A root cause investigation is underway to understand the reasons for the TGSCC and why the cracking phenomenon has been limited to the #3 weld location.

Evaluations have been provided in Attachments 1 and 2 to this enclosure that conclude the following points justifying the weld overlay application to the CRDM housings. These points are listed as follows:

- TGSCC is a localized form of corrosion that is well known to occur in most specifications of austenitic stainless steels including Type 347.
- TGSCC will be isolated to specific locations in susceptible materials where requisite tensile stress and supporting environment are coincident.
- The tensile stress requirements will be found at welds because of the additive effects of weld residual stress, operation stresses, and installation stresses.
- All housing girth welds were ground during initial fabrication. ID surface examination of weld #3 in housing 21 identified that location as the most heavily ground of weld locations #2 through #5. [Grinding is known to exacerbate surface stress, create surface crack initiation sites, and may alter the material microstructure to create a localized surface more susceptible to TGSCC mechanisms than the rest of the base material.

- A deep machining gouge was found associated with the deep circumferential indication at weld #3. A feature such as this often serves as an initiation site for stress corrosion cracks and is one reason the TGSCC is restricted to a specific weld region.
- The cracking locations can be defined by inspection methods and weld overlays can be designed to restore code design margins.
- Weld overlay will place most of the base material on which it is placed into compressive stress fields – cracks will not grow in compressive stress fields surrounding the crack tip.
- The weld deposit material (Type 309L) designed for overlays at weld #3 will create a 10% to 13% ferrite microstructure known to be highly resistant to TGSCC and will be capable of forming a barrier to crack extension into the overlay deposit.
- Code Case N-504-1 is not specific to any degradation mechanism, including IGSCC, nor is it restricted to any Class 1, 2 or 3 piping system since the analytical approach of ASME Section XI IWB-3600 is not so restricted.
- Analytical tools can be applied to piping components containing flaws to determine if Code Design margins have been maintained and whether or not the component can be returned to service for an additional operating interval.
- The crack growth rate (CGR) of TGSCC in the Type 347 housing materials has been measured from growth rings on crack surfaces to be less than 1×10^{-5} in/hr. This rate is 5 times slower than the accepted stress independent CGR for IGSCC in BWR austenitic components. A rate of 2×10^{-5} in/hr is suggested as a conservative rate with which to predict TGSCC crack extension in CRDM housings for prescribed intervals. This rate is consistent with crack growth rates for similar materials and environments reported in the literature.
- The crack aspect ratio has been measured for both axial and circumferential TGSCC defects found in weld #3. The aspect ratio is shown to be 4 to 1. Aspect ratio is useful to estimate the depth of known ID surface crack lengths. Alternatively, the same ratio is useful to estimate crack lengths from known or assumed crack depths. However, the weld overlay design assumes a 360°, through-wall indication or flaw.

All of the points identified above support the design and application of weld overlay technology to restore the defective conditions of the CRDM upper housings to ASME Code design margins. The overlay (once applied) will not permit further extension of TGSCC flaws. Analytical tools that characterize flaws and flaw behavior are supported with measured CGR and crack aspect ratio.

ENCLOSURE 2
ATTACHMENT 1

NUCLEAR MANAGEMENT COMPANY, LLC
PALISADES PLANT
DOCKET 50-255

JULY 30, 2001

REQUEST FOR APPROVAL TO USE ASME CODE CASE N-504-1 FOR REPAIR OF CONTROL ROD DRIVE MECHANISM UPPER HOUSING ASSEMBLIES

WELD OVERLAY APPLICATION TO TGSCC IN CRDMs AT PALISADES

9 Pages

Structural Integrity Associates, Inc.

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July 24, 2001
SIR-01-075, Rev. 2
MLH-01-036, Rev. 2

Mr. Robert Van Wagner
Consumers Energy
Palisades Nuclear Plant
27780 Blue Star Memorial Hwy.
Covert, Michigan 49043-9530

Subject: Weld Overlay Application to TGSCC in CRDMs at Palisades

Dear Mr. Van Wagner,

This letter report is a description of the applicability of weld overlay to the Palisades CRDMs.

We thank you for the opportunity to provide this report to Consumers Energy. If you have any questions on the content of this letter report, please do not hesitate to contact Tony or me.

Prepared by: [signature] for A. J. Giannuzzi, PhD. Date: 7-24-01

Reviewed and Approved by: [signature] Marcos L. Herrera, P. E. Date: 7/24/01

bpc
cc: W-CPC-13Q

WELD OVERLAY APPLICATION TO TGSCC IN CRDMS AT PALISADES

The use of the weld overlay repair for intergranular stress corrosion cracking (IGSCC) of austenitic stainless steel piping dates back to 1982 when this repair was used as an interim repair for flawed weld heat affected zones in recirculation system piping in an operating Boiling Water Reactor (BWR). The approach was subsequently endorsed by the U.S. Nuclear Regulatory Commission (NRC) in 1988 with the publication of NUREG-0313 Revision 2, " Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping", and endorsed by the ASME Boiler and Pressure Vessel Code in 1992 with the issue of Section XI Code Case N-504, "Alternative Rules for Repair of Class 1, 2, and 3 Austenitic Stainless Steel Piping". The premise for the use of the weld overlay repair lies within Section XI of the ASME Code and within Reg. Guide 1.147, in which the NRC has endorsed the use of the weld overlay repair in the nuclear industry.

Paragraph IWB-3600 provides an analytical approach for accepting defects in a piping component as provided in ASME Section XI, Paragraph IWB-3600. Alternatively, the defect can be reduced to an acceptable size by either mechanical or thermal means, and then accepted for further service using the rules of IWB-3600. The new feature of the weld overlay approach was that the acceptability of a defect would be established by increasing the wall thickness by deposition of a weld reinforcement material on the outside of the pipe. Further restrictions were placed upon the use of this repair, which included an assumption that the defect extended completely through the pipe wall, for the entire 360-degree circumference of the component. This restriction was not imposed on the analyst when evaluating flaws in existing components.

The Code Case was never intended to be specific to any degradation mechanism, including IGSCC, nor was it restricted to any specific Class 1, 2 or 3 piping system since the approach of analysis per IWB-3600 has never been so restricted. The analytical tools can be applied to piping components containing flaws in order to determine if Code design margins have been maintained and whether or not the component can be returned to service for an additional operating interval.

In practice, the weld overlay repair has been applied to many components where IGSCC was the degradation mechanism. These components have included piping, nozzles, safe-ends, elbows, tees, etc. However, IGSCC has not been the only degradation mechanism for which weld overlays have been completed. For example, ASME Code Cases N-561 and N-562 allow for application of weld overlay repairs to ASME Code Class 2 and 3 carbon steel piping for mitigation against localized corrosion phenomena such as pitting or microbial corrosion. Weld overlay repairs also have been used on PWR pressurizers instrument lines and heater penetrations for temperbead repairs mitigating primary water stress corrosion cracking (PWSCC). For example, weld overlays were applied to the pressurizer heater penetrations at both the ANO and Waterford units. Weld overlays also have been used for thermocouple penetration repairs on PWR reactor vessel heads.

The canopy seals on control rod drive housings in some PWRs also have had weld overlay repairs applied to remedy leaking in these components. The degradation mechanism for these canopy seals was identified as chloride stress corrosion cracking, similar to that observed in the housings/eccentric reducer at Palisades. Canopy seal overlays have been applied at several plants including Zion Units 1 and 2, Byron Units 1 and 2, Prairie Island Units 1 and 2, Diablo Canyon Units 1 and 2, Sequoyah Units 1 and 2, Watts Bar and Point Beach Units 1 and 2.

A key consideration in the application of the weld overlay repair to TGSCC at Palisades is that the expected location of the degradation mechanism can be measured and characterized. For any stress corrosion mechanism (IGSCC or TGSCC), the stress field and the material conditions will uniquely define degradation locations where supporting environmental conditions exist. Both of these conditions typically are found in weld HAZs to support IGSCC in susceptible austenitic stainless steels. It is noted that transgranular stress corrosion cracking is not restricted to a sensitized HAZ. However, the requisite tensile stress field typically will be defined by the shrinkage and distortion attendant to the welding process. For crack initiation, the requisite stresses will be a combination of all sources of stress including other fabrication and installation stresses and pressure stress during operation. The material conditions on the surfaces of welds that have been ground or machined will be cold worked and will help to facilitate crack initiation. These considerations suggest that the locations where TGSCC can be supported primarily will be associated with welds. This means that areas having degradation can be defined and the application of weld overlays provides an appropriate repair tool.

Regardless of cracking mechanism, the presence of a crack driving force is necessary for continued crack growth after application of the weld overlay. Experimental and analytical methods have been used to demonstrate the effectiveness of weld overlays to induce mitigating compressive stress fields beginning on the inside surface and extending across the wall thickness. Compressive stresses will eliminate additional crack propagation as well as the initiation of new flaws. Figure 1 shows the weld overlay induced through-wall residual hoop stress predicted for a 12-inch schedule 80 pipe (thickness = 0.687 inch) [1]. As can be seen, compressive stress exists over the inner 50% of the pipe wall. It should be noted that the driving force for crack growth is the stress intensity factor distribution and not the stress distribution. The stress intensity factor for the stress distribution shown in Figure 1 would be negative well beyond 50% of wall location. The pressure stress induced stress intensity factor would need to be combined with the residual stress contribution to determine the total driving force. The net result would still be expected to be a negative stress intensity factor well beyond 50% of wall location. A negative stress intensity factor implies no crack growth.

Supporting the conclusion that a weld overlay produces a favorable stress state in terms of crack growth mitigation, is the fact that more than one thousand weld overlays have been applied to date without a single incidence of crack growth beyond the weld overlay. The applications have been primarily to mitigate IGSCC, but the stress intensity driving forces will apply equally to TGSCC. Note that overlays have been applied to weld locations containing through-wall flaws.

Figure 2 from Reference 1, shows the results of boiling $MgCl_2$ penetrant testing to demonstrate that compressive stress exist on the surface underneath the weld overlay. The figures show three welds, G, H, and I. Only weld H was weld overlayed. As can be seen, extensive cracking is evident for weld G, and no cracking is seen associated with weld H, which has been overlayed. Since boiling magnesium chloride is a severe chloride environment that produces transgranular SCC at very low stress intensity levels, this testing confirms the effectiveness of weld overlays in producing significant compressive stress on the inside diameter and is consistent with the analytical predictions.

Figure 3 from Reference 2, shows a comparison of the tip of a notch for a deep flaw before and after the weld overlay. This comparison demonstrates that growth of existing flaws is not expected and instead, crack tip blunting is anticipated due to the weld overlay induced stress process. Thus, the application of the weld overlay on the Palisades CRDM is expected to minimize or eliminate any crack extension.

In summary, weld overlay repairs, while originally designed as remedies to IGSCC, have found wide usage in the nuclear power industry as remedial measures to many localized environmental degradation mechanisms including the chloride stress corrosion cracking issue at Palisades. The repair can be used in conjunction with IWB-3600 of Section XI of the Code to restore and demonstrate adequate design margins for defective components. Its use is expanding within the industry. At present, the weld overlay repair is under consideration within Section XI of the Code as a remedy to cracking in socket welds in piping where high cycle fatigue is the mechanism of concern.

References

1. "Assessment of Remedies for Degraded Piping," Electric Power Research Institute, EPRI NP-5881-LD, June 1988.

2. "Justification of Extended Weld-Overlay Design Life," Electric Power Research Institute, EPRI NP-7103-D, January 1991.

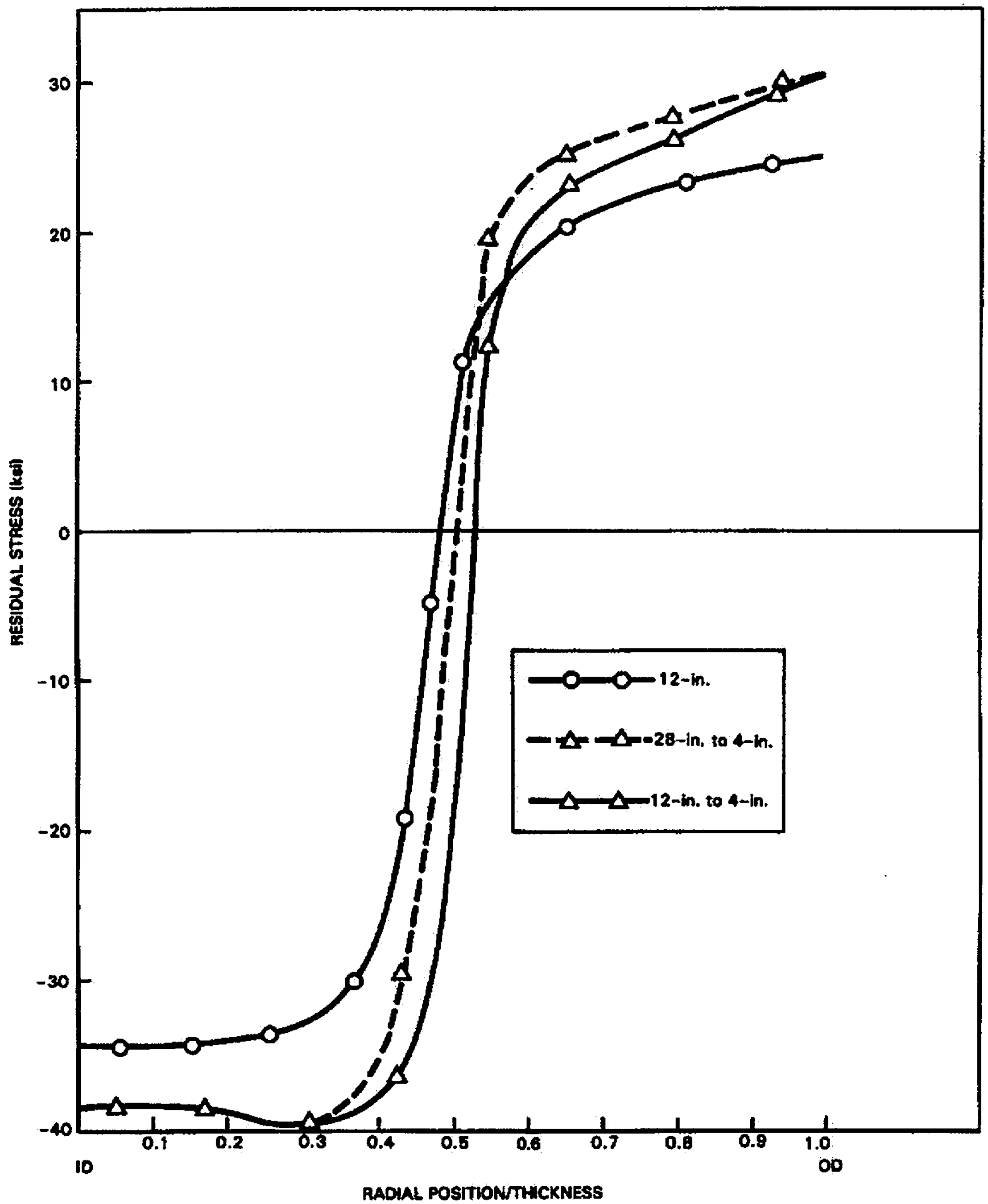
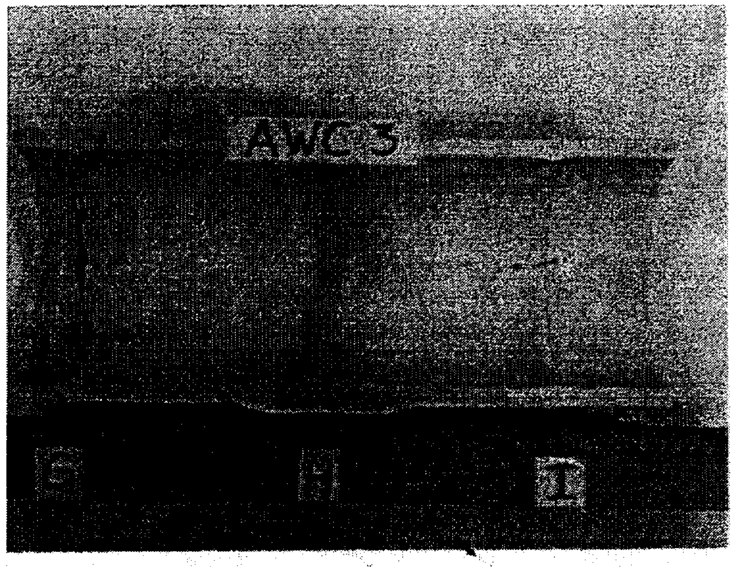
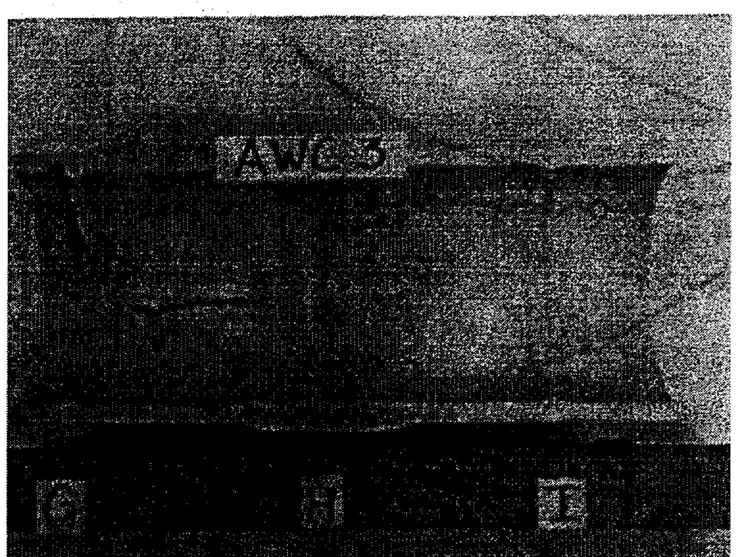


Figure 1: Through-Wall Residual Stress Due to Weld Overlay for 12-inch Diameter Schedule 80 Pipe



0° TO 180°



180° TO 360°

Figure 2: Boiling $MgCl_2$ Test Results

a) Notch Tested Before Weld Overlay   b) Notch Tested After Weld Overlay

Figure 3: Notch Before and After Weld Overlay

ENCLOSURE 2
ATTACHMENT 2

NUCLEAR MANAGEMENT COMPANY, LLC
PALISADES PLANT
DOCKET 50-255

JULY 30, 2001

REQUEST FOR APPROVAL TO USE ASME CODE CASE N-504-1 FOR REPAIR OF CONTROL ROD DRIVE MECHANISM UPPER HOUSING ASSEMBLIES

CRACK GROWTH RATE FOR TGSCC IN CRDM UPPER HOUSINGS

7 Pages

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July 25, 2001
SIR-01-078
MLH-01-40

Mr. Bob V. VanWagner
Consumers Energy
Palisades Nuclear Plant
27780 Blue Star Memorial Hwy.
Covert, Michigan 49043-9530

Subject: Crack Growth Rate for TGSCC in CRDM Housings

Reference:

Dear Mr. VanWagner:

The purpose of this letter is to report measured transgranular stress corrosion (TGSCC) crack growth rates (CGR) for the Palisades CRDM housing weldments. In addition, a conservative CGR is suggested for use in evaluating potential crack propagation in these housings resulting from TGSC in the near neutral aqueous environments containing dilute chloride/oxygen concentrations.

Four pertinent sources of information are identified below:

1. Estimated crack growth rates at Palisades based upon visible growth rings measured on photographs taken of the leaking axial crack fracture surface sectioned from CRDM housing (CRD-21). The duration of cycle operation for each growth ring was determined from plant operation records. The estimated CGR is 0.078 in/year (8.8×10^{-6} in/hr). The data used in the estimate are shown in Attachment 1.

2. W. J. Shack reports the CGR for TGSCC as 1.4×10^{-5} in/hr (10^{-7} mm/sec) in Reference 1.

3. A CGR for TGSCC also was estimated from growth rings measured on the surface of a crack in a CRDM housing at Fort Calhoun (Reference 2). The cracking at Fort Calhoun was verified by metallography to be TGSCC due to chlorides. The estimated CGR was reported to be consistent with Reference 2 above.

4. A bounding CGR for IGSCC in BWR environments generally is accepted as 5×10^{-5} in/hr. (Reference 3)

Description of Cracking

A leaking defect was discovered in CRDM housing Number 21 (CRD-21). All of the weldments in this housing assembly were inspected by ultrasonic examination and the leaking indication was identified as axial, but no additional indications were identified in this housing. Other accessible housings were inspected with manual ultrasonic techniques, and one axial linear indication was identified in each of two additional housings (CRD-25 and CRD-40) in the same weld. No other indications were identified in any other weld. The leaking housing was removed and further inspections were conducted (VT, PT and RT). Three additional defects were discovered in the same weld of the CRD-21 housing. This weld is identified as weld # 3. Again no other defects were identified in any other weld in the housing. A decision was made to conduct a detailed destructive metallurgical examination of weld #3 to ascertain the nature and extent of the indications.

It was noted that the seal housing welds at the top of the CRDM assemblies had a history of service degradation. The apparent cause was TGSCC in every case resulting from exposure to an aqueous environment containing both chlorides and oxygen, and localized tensile stresses were reported to have been induced during installation. Since the material was austenitic stainless steel, all of the requisite conditions for transgranular stress corrosion cracking were present. A similar form of transgranular stress corrosion cracking was identified at a sister plant (Fort Calhoun) but in weld #5 (An inside surface weld buildup just above weld #3 used to form a guide for the internal assembly.

Metallurgical Examination of CRD-21

The metallurgical examination confirmed all four indications (2 large and 2 small). All indications were separated mechanically, and a metallurgical examination was conducted of the fracture surfaces. The examinations of the fracture surface features by optical and SEM techniques clearly showed the presence of multidirectional surface striations on grain faces, and numerous secondary cracks were identified running out of the main fracture plane. These features are classical indications of TGSCC.

Other features were apparent on the fracture surfaces of the two larger defects (deeper and longer). The first feature observed is the presence of large beach marks (crack growth rings). Such rings are typical of stress corrosion cracking where the cracking cycle is interrupted. The growth rings are believed to be the result of oxidization of the fracture surface and the different colors are manifestations of different oxide thicknesses. The result is a set of multicolored rings suggesting growth rings. Ten to twelve rings were recorded on the large axial crack (seamless pipe side). The rings were less distinct in the weld material and on the forged elliptical reducer portions. This less distinct appearance of the growth rings is a result of the larger sizes of the reducer grains and the weld deposit dendrites. By measuring the spacing of the growth rings and identifying the last dozen operational cycles, it was possible to estimate a growth rate for the TGSCC. Only three visible growth rings were identified on the large circumferential crack surface and these also were measured and related to the last three operational cycles. Results were averaged for each crack face separately and compared. These results indicated a consistent crack growth rate for both cracks. Measurements and computations are shown in Attachment 1.

Another feature observed was the geometry of the crack front. The small circumferential defects were located in or at the weld root. The crack front was irregular. It is suggested that this is a result of a crack front driven primarily by weld residual stresses, and had not grown sufficiently deep for the driving force to be dominated by pressure stresses. The two deeper cracks were very consistent and uniform suggesting that the driving force is dominated by pressure stresses. The driving force is an important consideration in terms of being uniform through-wall so that the crack would penetrate the wall and leak while retaining a consistent aspect ratio. This seems to be the case for the two deep cracks.

Finally, the crack aspect ratios were measured for the two deep cracks (one leaking axial crack and one part-through circumferential). Both cracks measured a 4 to 1 aspect ratio, and were quite consistent. It was noted that the growth of the axial crack appeared to be somewhat restricted on the lower side due to a rapid increase in wall thickness at the reducer. This may have minimized the growth of the crack on the reducer side and restricted the measured aspect ratio. However, a careful examination of the growth rings indicated that this effect was only operative in the later stages of crack growth and would have had minimal effect on aspect ratio.

Crack Growth Rates

The housing material at Palisades is stabilized Type 347 stainless steel. The alloy contains columbium that ties up the carbon available to precipitate carbides in grain boundaries and thus minimizes sensitization of weld heat affected zones (HAZ). IGSCC is not likely to be the stress corrosion mechanism because the grain boundaries will not be depleted in chromium. Instead, the cracking mechanism will be TGSCC and will not be restricted to heat affected volumes adjacent to welds. TGSCC will have a slower crack growth rate (References 1 and 4) than IGSCC. Crack growth ring measurements for both the deep axial and the deep circumferential defects indicate an average growth rate of 8.8×10^{-6} in/hr and 9.6×10^{-6} in/hr, respectively. This is more than 5 times lower than the overall bounding value approved for IGSCC (Reference 3). The good chemistry value for TGSCC is suggested at 2.2×10^{-5} in/hr (Reference 2). This value is more than twice the growth rate measured for the TGSCC at Palisades. The lower rate also is consistent with the growth rate estimated for the cracked CRDM housing at Ft. Calhoun (Reference 2). It should be noted that the cracking observed at Fort Calhoun was verified by Metallography as TGSCC due to chlorides. The growth rings observed at the CRD-21 housing are consistent with those observed at Fort Calhoun. It is believed that the cracking at Palisades and at Fort Calhoun are due to the same mechanism operating in a similar environment.

CGR for IGSCC is compared because IGSCC in dilute chloride/oxygen aqueous environments would be expected to be greater than that for TGSCC because of the higher strain energies found in grain boundaries as compared to the grain matrix material. (Attachment 2) The information cited in items 1 and 2 above support the notion that the growth rate reviewed and approved by the NRC for IGSCC in BWR environments will be conservative (Reference 3). These IGSCC rates could be used as conservative estimates for the TGSCC CGR.

The IGSCC CGR cited in Reference 3 is supported by extensive laboratory test data and characterizes the crack growth rates for different environmental conditions in BWRs. The values given bound the measured CGR for TGSCC at Palisades.

Recommendation

Based upon these considerations it is recommended that a crack growth rate of 2.2×10^{-5} in/hr be used as a conservative estimate for the growth rate of the TGSCC that may occur in CRDM housings. This value is approximately twice as large as the measured CGR for TGSCC at the CRD-21 housing and at Fort Calhoun and would represent a conservative approach to account for crack size variations.

Attachment 1: Estimated Crack Growth Rate for TGSCC in CRDM 21

Large Axial Crack at Weld No. 3

Growth Ring ID	Spacing (in.)		Cycle Duration (yrs)	CGR (in/yr)	
	A	B		A	B
1 to 2	0.015	0.015	0.131	0.115	0.115
2 to 3	0.015	0.021	0.542	0.028	0.039
3 to 4	0.012	0.012	0.175	0.069	0.069
4 to 5	0.027	0.027	0.348	0.078	0.078
5 to 6	0.03	0.024	0.175	0.171	0.137
6 to 7	0.021	0.027	0.422	0.050	0.064
7 to 8	0.035	0.038	0.347	0.101	0.110
8 to 9	0.024	0.027	0.545	0.044	0.050
9 to 10	0.038	0.035	0.534	0.071	0.066
10 to 11	0.033	0.038	0.722	0.046	0.053

Aspect Ratio for Axial Crack - 4 to 1

Avg.CGR (in/yr)	0.077	0.078
Avg.CGR (in/hr)	8.80E-06	8.88E-06

Large Circumferential Crack at Weld No. 3

Growth Ring ID	Spacing (in.)		Cycle Duration (yrs)	CGR (in/yr)	
	A	B		A	B
1 to 2	0.018	0.018	0.131	0.137	0.137
2 to 3	0.014	0.014	0.542	0.026	0.026
3 to 4	0.015	0.016	0.175	0.086	0.091

Avg.CGR (in/yr)	0.083	0.085
Avg.CGR (in/hr)	9.47E-06	9.69E-06

Aspect Ratio for Circumferential Crack - 4 to 1

References

1. W. J Shack, "Environmentally Assisted Cracking in Light Water Reactors", Semi-annual Report, Argonne National Laboratory, October 1987 – March 1988.
2. B. Lisowyj, "Evaluation of Cracking in Type 348 Stainless Steel Control Element Drive Mechanism Housings", Sixth International Symposium on Environmental Degradation of Materials in Nuclear Power Systems – Water Reactors, Edited by R. E. Gold and E. P. Simonen, The Minerals, Metals & Materials Society, 1993.
3. Letter, NRC Jack R. Stroschneider to Carl Terry (BWR VIP Chairman) December 3, 1999 - Final Safety Evaluation of Proprietary Report EPRI TR-105873 – "BWRVIP Evaluation of Crack Growth Rate in BWR Stainless Steel Internals –BWRVIP-14".

Very truly yours,

Performed by: for
R. Smith

Reviewed by:
A. J. Giannuzzi

Approved by:
M. L. Herrera

ENCLOSURE 3

NUCLEAR MANAGEMENT COMPANY, LLC
PALISADES PLANT
DOCKET 50-255

JULY 30, 2001

REQUEST FOR APPROVAL TO USE ASME CODE CASE N-504-1 FOR REPAIR OF CONTROL ROD DRIVE MECHANISM UPPER HOUSING ASSEMBLIES

STANDARD WELD OVERLAY DESIGN FOR PALISADES CRDM UPPER HOUSING WELDS

21 Pages

STRUCTURAL INTEGRITY Associates, Inc.	CALCULATION PACKAGE	FILE No.: W-CPC-13Q-304 PROJECT No.: W-CPC-13Q

PROJECT NAME: Safety Assessment and Evaluation of the Palisades CRDM Upper Housing Flaw and Proposed Weld Overlay

CLIENT: Consumers Energy

CALCULATION TITLE: Standard Weld Overlay Design for Palisades CRDM Upper Housing Welds

PROBLEM STATEMENT OR OBJECTIVE OF THE CALCULATION:

Determine the standard weld overlay dimensions for the Palisades CRDM Upper Housing Weld.

Document Revision	Affected Pages	Revision Description	Project Mgr. Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1 – 13 A-1 – A-2 B-1 – B2	Original Issue	MLH 7/12/01	MLH 7/12/01 SST 7/12/01
1	1 – 13 A0 – A2 B0 – B2 C0-C2	Incorporate Customer Comments	MLH 7/14/01	MLH 7/14/01 SST 7/14/01
2	1 – 12 A0 – A1 B0 – B2 C0 – C2	Incorporate Customer Comments and Length Calculation Results	[signature] 7/18/01	[signature] 7/18/01 [signature] 7/18/01

1.0 OBJECTIVE

Consumers Energy is preparing a standard weld overlay design for the upper housing to eccentric reducer weld in the CRDMs at the Palisades Nuclear Plant. This calculation package documents the results of the weld overlay design. A weld overlay repair meeting the requirements of the NUREG-0313, Revision 2 [1] "Standard Weld Overlay", and ASME Code Case N-504-1 [2] will be prepared.

2.0 APPROACH

The overlay was designed as a full structural overlay in accordance with the requirements of NUREG-0313, Revision 2 [1] (which was implemented by Generic Letter 88-01 (Reference 3)), ASME Code Case N-504-1 [2], Section XI of the ASME Boiler and Pressure Vessel Code, Paragraph IWB-3640 [4]. The overlay will extend around the full circumference of the CRDM for the required lengths on both sides of the upper housing to eccentric reducer weld. It was designed by assuming the weld to be completely cracked through the original pipe wall. The thickness of the overlay was determined by comparing the weld overlay strength for a combination of internal pressure and seismic stresses with the criteria contained in Paragraph IWB-3641 [4]. Both normal operating and emergency/faulted conditions were considered in the evaluation. Per Code Case N-504-1, the overlay design must also meet the ASME Code, Section III stress limits for primary local and bending stress and secondary peak stress.

Specifically, Tables IWB 3641-1 and IWB 3641-2 for circumferential cracks or the equations in Appendix C of ASME Code Section XI can be used to initially size the overlay. These tables and the appropriate equations will be used for the gas tungsten arc welding (GTAW) process, which will be used to apply the overlay. The overlay material will be Type 309L Stainless Steel and will be deposited using the GTAW process. The results of this calculation must be compared against the other requirements to finalize the weld overlay thickness.

3.0 WELD OVERLAY THICKNESS AND LENGTH

This section contains the discussion on the determination of the weld overlay thickness. Three approaches were considered in the determination of the weld overlay thickness. These three approaches are:

- Use of the source equations in Appendix C, Section XI of the ASME Code.
- Use of 75% maximum allowable flaw criteria (per IWB-3640 of ASME Code Section XI).
- Use of ASME Code Section III stress limits (per Code Case N-504-1).

The bounding thickness (maximum) of these three approaches will be taken as the overlay thickness. Each of these approaches is summarized below.

3.1 Use of Equations in Appendix C, Section XI of the ASME Code

The weld overlay thickness, per ASME Code Case N-504-1, is designed using the equations provided in Appendix C of the ASME Code, Section XI. These equations are based on net-section plastic collapse. At the point of collapse, the equations, which describe the equilibrium condition, are (from Reference 4 for $\alpha+\beta>\pi$):

$$\beta = [(1\text{-}d/t\text{-}P_m/\sigma_f)\pi]/(2\text{-}d/t) \quad (3\text{-}1)$$

$$P_b' = (2*\sigma_f/\pi)*[(2\text{-}d/t)\sin(\beta)] \quad (3\text{-}2)$$

where:

	β	=	angle of neutral axis
	P_m	=	primary membrane stress
	σ_f	=	flow stress of material = $3S_m$
	S_m	=	design stress intensity

α	=	half angle of crack = 180° for fully circumferential flaw
d	=	crack depth
t	=	thickness
P_b	=	primary bending stress
P_b'	=	primary bending stress at collapse

P_m and P_b are determined from the applied primary loads at the location of the crack for the original uncracked condition. The condition based on equilibrium, which must be satisfied, is:

$$P_m + P_b' = SF\,(P_m + P_b) \qquad (3\text{-}3)$$

where SF = safety factor = 2.77 for normal or upset condition
1.39 for emergency or faulted condition

Stress Calculation

Only the primary stresses are required in the design of the weld overlay since the weld will be applied using GTAW [4]. The discussion presents the normal case calculations since it is the limiting condition. The normal condition governs because the stresses due to normal condition are more than one-half of the emergency and faulted conditions. Since the required safety factor for the normal condition is twice that for emergency and faulted conditions, and the emergency and faulted loads are less than twice that of the normal condition, the normal condition governs. The primary membrane and bending stresses can be calculated as follows:

Primary membrane = P_m = membrane stress due to pressure and axial loads from other primary loads.

$$P_m = P(OD)/(4t) + (F_{x,deadweight} + F_{x,seismic})/A \qquad (3\text{-}4)$$

where P = internal pressure = 2100 psi (normal pressure)

OD = outside diameter of original upper pipe = 8.625 inch [7]

ID = inside diameter of original upper pipe = 7.189 inch

A = cross sectional area of original pipe = 17.84 in^2

F_x = axial load (from deadweight or seismic) = assumed zero

Primary bending = P_b = bending stress due to seismic and other loads.

$$P_b = (DW+SEISMIC)/Z \quad (3\text{-}5)$$

where DW = moment due to deadweight = assumed zero

SEISMIC= moment due to seismic and other loading = 112 in-kips [5]

I= 142.6 in^4 [5]

Z= I/c (of original pipe) = section modulus = 33.1 in^3

=142.6/4.3125

The seismic moment was determined from [5]. The moments are provided in [5] for the top of the lower flange and the seismic block. The distance between these two locations is approximately 45 inches. The weld of interest is approximately 15 inches above the top of the lower flange. The moment at the top of the lower flange is 25 in-kips. The moment at the seismic block is 286 in-kips. Interpolating between these two locations gives a moment of 112 in-kips at the weld of interest.

$$(286-25)(15/45)+25 = 112 \text{ in-kips}$$

Substituting the geometry and loads into equations 3-4 and 3-5 results in a primary membrane stress of 6.3 ksi and a primary bending stress of 3.4 ksi. Note that shear loads do not contribute to any normal stress and are therefore not considered.

Weld Overlay Thickness Calculation

The **pc-CRACK** computer program (see Appendix A), Reference 6, was used to determine the weld overlay thickness. Since the normal case was limiting, only the normal case was evaluated with the following inputs:

t	=	0.718 inch
S_m	=	19.0 ksi (conservatively at 650°F design temperature)
$3S_m$	=	57.0 ksi
P_m	=	6.3 ksi
P_b	=	3.4 ksi
SF	=	2.77 (for the normal condition)

The design stress intensity, S_m, for the Type 309L weld overlay material is taken as the limiting S_m for the underlying base materials (Type 347 stainless steel).

Results of the **pc-CRACK** analysis give a required weld overlay thickness of approximately 0.21 inch, which is based on the equations of Appendix C of Reference 4.

Weld Overlay Length

Code Case N-504-1 gives guidance on the weld overlay length. Ideally for a standard "full structural" overlay, the length of the overlay on each side from the location of the flaw is recommended to be:

$$l = 0.75*\sqrt{(Rt)} \quad (3\text{-}6)$$

where R= pipe outer radius

t= pipe nominal wall thickness

Note that this length is not a requirement, but provided as a guide to determine the length that avoids end effects and provide a smooth transition of the load path from the original pipe to the overlay. Substitution of the joint geometry into equation 3-6 results in a length of 1.32 inches on the housing side and a slightly longer length on the eccentric reducer side due to the thicker wall. Note that these lengths apply to the full thickness portion of the weld overlay. This length should be measured from any possible location of the indication assuming it to grow through-wall (either axial or circumferential). Based on the presence of the indication on the housing side, the length should be measured from the furthest axial extent of the axial flaw on the housing side of the weld. On the eccentric reducer side of the weld, the length should be measured from the weld fusion line or from the furthest axial extent of the axial flaw on the eccentric reducer side of the weld, whichever provides the longest total overlay length.

Since Code Case N-504-1 provides guidance only, smaller lengths can be used if technically justified. It is desirable to make the length of the weld overlay on the eccentric reducer side as short as possible in order to avoid welding on the tapered portion of the component. This alternate length is described in Section 3.5.

3.2 Use of 75% Maximum Allowable Flaw Criteria

In a previous section, the thickness of the weld overlay was determined based on meeting the safety margins against collapse included in the source equations of Appendix C of Section XI of the ASME Code. In addition to meeting the appropriate safety factors, the ASME Code in Section XI has also included another requirement, which is that no crack deeper than 75% of wall is allowed.

Since the weld overlay is being performed as a standard (full structural) weld overlay, any flaw or postulated flaw must be assumed to be a through-wall flaw (through original pipe wall). This assumption results in taking no credit for any remaining ligament in the original pipe wall. If this postulated through-wall flaw is taken as 75% of the total wall (total wall thickness = ($a+t_{wo}$) = original pipe thickness (0.718") plus weld overlay thickness for structural reinforcement (t_{wo}). The required overlay thickness can be expressed as:

$$a/(a + t_{wo}) = 0.75 \qquad (2\text{-}6)$$

Substituting in the appropriate values gives,

$$(0.718)/[0.718 + t_{wo}] = 0.75$$

Solving for t_{wo} gives the weld overlay thickness of 0.24 inch. Since this overlay thickness is the minimum acceptable per ASME Code Section XI in order to meet the requirement that no flaw greater than 75% of wall is allowed, the overlay thickness must be at least 0.24 inch.

3.3 Use of ASME Code Section III Stress Limits

Code Case N-504-1 requires that the weld overlay be able to meet the ASME Code Section III stress limits on primary local and primary bending stress and secondary peak stresses. Note that primary local and primary bending stress limits are intended for design conditions, but in this case will be used for the normal and upset conditions. These stress limits are checked only for normal or upset conditions (Level A & B) since significantly higher margins are allowed for emergency and faulted (Level C & D) conditions. This requirement can be expressed as follows:

$$P_L + P_b < 1.5S_m \qquad (3\text{-}7)$$

where P_L = local primary membrane stress

P_b = primary bending stress

Note that a fatigue initiation evaluation, which is impacted by the secondary peak stresses, is not necessary since a flaw is already present. However, fatigue crack growth must be considered per Code Case N-504-1 and is addressed later in this report.

For purposes of this calculation, the hoop stress will be used to calculate the primary local stress intensity since the axial bending stress is small indicating that the hoop direction will govern for the stress intensity check. Note that for the hoop stress calculation, there are no other applied loads, thus, P_b is zero. The required thickness to assure compliance with the primary local plus bending stress is given by:

$$P(OD/2)/t = 1.5S_m$$

Note that for a standard weld overlay, no credit is taken for the original component so the outside diameter (OD) of the original pipe is used in the hoop pressure stress calculation of the weld overlay. Also, the S_m for 600°F is used (19.3 ksi) instead of the conservative value at 19.6 ksi used earlier in the sizing calculation using the ASME Code Section XI source equations. Solving for the thickness, t, gives a weld overlay thickness of 0.313 inches.

3.4 Required Thickness

The required thickness is the maximum of the three different methods used to determine the overlay thickness. Since the 0.313 inch thickness, which was based on the Section III primary local plus bending stress intensity, is the maximum of the three, this is the required thickness.

3.4.1 Fatigue Crack Growth

ASME Code Case N-504-1 requires that fatigue crack growth and growth due to the active mechanism be considered. As discussed in [8], the weld overlay material, Type 309L stainless steel, is essentially immune to stress corrosion cracking as long as ferrite content is 10% or greater. However, fatigue crack growth must still be considered.

For purposes of this calculation, a factor will be applied to the fatigue crack growth rate for stainless steel in the air environment. Reference [4] contains reference fatigue crack growth curves for austenitic steel in an air environment. The ΔK for a circumferential crack (with depth equal to original pipe thickness) subjected to the normal operating pressure and the seismic bending moment was calculated using the pc-CRACK computer program. Results of this unit stress (1 ksi) calculation are shown in Appendix B. At this weld location, the pressure stress is 6.3 ksi and the bending stress is 3.4 ksi. Conservatively assuming the bending stress to be pure membrane results in a total axial membrane stress of 9.7 ksi. From Appendix B, for 1 ksi at 75% of wall (crack depth = 0.718 inch), the stress intensity factor is approximately 3.4 ksi$\sqrt{in}$. Multiplying this by the stress of 9.7 ksi results in an applied stress intensity factor of 34 ksi$\sqrt{in}$. The R-ratio is expected to be low since there is likely significant compressive stress under the overlay. Using the stress intensity factor calculated above of 34 ksi$\sqrt{in}$ and a low R-ratio, results in a crack growth rate of $3x10^{-5}$ in/cycle from Reference 4 (Figure C-3210-1).

Reference 9 gives an environmental factor of 4 for fatigue in the PWR environment. It should be noted that the ASME is considering a Code Case regarding austenitic stainless steel fatigue behavior. Applying the factor of 4 to the air environment fatigue crack growth rate results in a crack growth rate of $1.2x10^{-4}$ in/cycle.

The primary source of loading at this location is startup/shutdown cycles. Reference 10 states that over the 30 years of operation, Palisades has experienced 130 startup/shutdown cycles. The number of cycles during the remaining 10 years plus 20 years of license renewal are estimated as 30(130/30) = 130 cycles. Based on this conservative assumption, the resulting fatigue crack growth is estimated to be:

$$\Delta a = (130)(3x10^{-5} in/cycle)(4) = 0.016 \text{ inch}$$

This confirms that the expected fatigue crack growth is small. To compensate for this, the weld overlay thickness will be increased from 0.313 inches to 0.33 inches.

3.5 Alternate Weld Overlay Length on Eccentric Reducer Side of Weld

As mentioned earlier, it is desirable to limit the length of the overlay on the eccentric reducer side of the weld in order to avoid welding on the tapered portion of the reducer. Typically, the weld overlay length guidance provided in ASME Code Case N-504-1 is conservative and it has been shown that the length of the overlay can be shorter than the guidance provided. This has been demonstrated on Boiling Water Reactor Nozzles where the weld overlay could not be applied to the low alloy steel nozzle material and observed cracked were significantly closer to the edge of the overlay than length guidance provided in ASME Code Case N-504-1.

A finite element analysis was performed in Reference [11] to justify an overlay length shorter than the guidance in Code Case N-504-1. Reference [11] focused on the primary stress intensity limits requirements in Code Case N-504-1. Results of the Reference [11] analysis showed that a length of 0.55 inch was acceptable measured from the weld fusion line on the pipe outside diameter or the furthest axial extent of the axial flaw as indicated by inspection. For purposes of this calculation, the recommended length is 0.6 inches. Note this is the length of the full thickness portion of the overlay measured from the weld fusion line on the pipe outside diameter or from the furthest axial extent of the axial flaw as indicated by inspection. The weld overlay must be blended into the eccentric reducer at a 45 degrees angle. The final standard weld overlay design is shown in Appendix C.

4.0 REFERENCES

1. NUREG-0313, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping," Revision 2, June 1986.

2. American Society of Mechanical Engineers (ASME) Code Case N-504-1.

3. USNRC, Generic Letter 88-01, 1988.

4. American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code, Section XI, 1989 Edition.

5. Letter, Thomas Nelson to William Russel (NRC), November 24, 1981, SI File W-CPC-13Q-206

6. Structural Integrity Associates, "**pc-CRACK** User's Manual," Version 3.1-98348, December 1998.

7. Drawing CND SE-2175, SI File No. W-CPC-13Q-203.

8. Structural Integrity Report, SIR-01-066, Rev.1, "Safety Assessment Report for the Palisades Nuclear Plant Control Rod Drive Mechanism Weld Overlay," July 2001.

9. Transactions of the ASME, Journal of Pressure Vessel Technology, Pressure Vessel and Piping Codes, Evaluation of Flaws in Austenitic Piping, Section XI Task Group for Piping Flaw Evaluation, ASME Code, Volume 108, August 1986.

10. E-mail, Hubert Stacks to Anthony Giannuzzi, "Number of Heatup Cycles at Palisades," July 12, 2001.

11. Structural Integrity Calculation Package, "Determination of the Minimum Weld Overlay Length for CRDM Housing Eccentric Reducer, Weld # 3 ," SI Calculation Package W-CPC-307, July 18, 2001.

APPENDIX A

Weld Overlay Thickness
Calculations using **pc-CRACK**

tm
pc-CRACK for Windows
Version 3.1-98348

Structural Integrity Associates, Inc.
3315 Almaden Expressway, Suite 24
San Jose, CA 95118-1557
Voice: 408-978-8200
Fax: 408-978-8964
E-mail: pccrack@structint.com

Structural Reinforcement Sizing Evaluation

Date: Wed Jul 11 17:18:37 2001
Input Data and Results File: STAND.CNS

Title: Palisades Standard Overlay Design

Wall thickness =	0.7180		
Membrane stress =	6.3000	Safety factor =	2.7700
Bending stress =	3.4000	Safety factor =	2.7700
Stress Ratio =	1.4142		
Allowable stress =	19.0000		
Flow stress =	57.0000		

L/Circum

	0.00	0.10	0.20	0.30	0.40	0.50	0.60
Final a/t	1.0000	1.0000	1.0000	1.0000	0.9521	0.8643	0.8115
Reinforcement thickness	0.0000	0.0000	0.0000	0.0000	0.0361	0.1128	0.1668

	0.70	0.80	0.90	1.00
Final a/t	0.7861	0.7744	0.7725	0.7725
Reinforcement thickness	0.1953	0.2092	0.2115	0.2115

End of pc-CRACK Output

APPENDIX B

Stress Intensity Factor for Circumferential Flaw
using **pc-CRACK**

Structural Integrity Associates, Inc.
3315 Almaden Expressway, Suite 24
San Jose, CA 95118-1557
Voice: 408-978-8200
Fax: 408-978-8964
E-mail: pccrack@structint.com

Linear Elastic Fracture Mechanics

Date: Thu Jul 12 09:16:29 2001
Input Data and Results File: CIRCRK.LFM

Title: Palisades Overlay Evaluation, CPC-13Q

Load Cases:

Case ID	Stress Coefficients C0	C1	C2	C3	Type
Unit Load (1ksi	1	0	0	0	Coeff

------Through Wall Stresses for Load Cases With Stress Coeff-------

Wall Depth	Case Unit Load
0.0000	1
0.0838	1
0.1677	1
0.2515	1
0.3354	1
0.4192	1
0.5030	1
0.5869	1
0.6707	1
0.7546	1
0.8384	1

Crack Model: Circumferential Crack in Cylinder (t/R=0.1)

Crack Parameters:
Wall thickness: 1.0480
Max. crack size: 0.8384

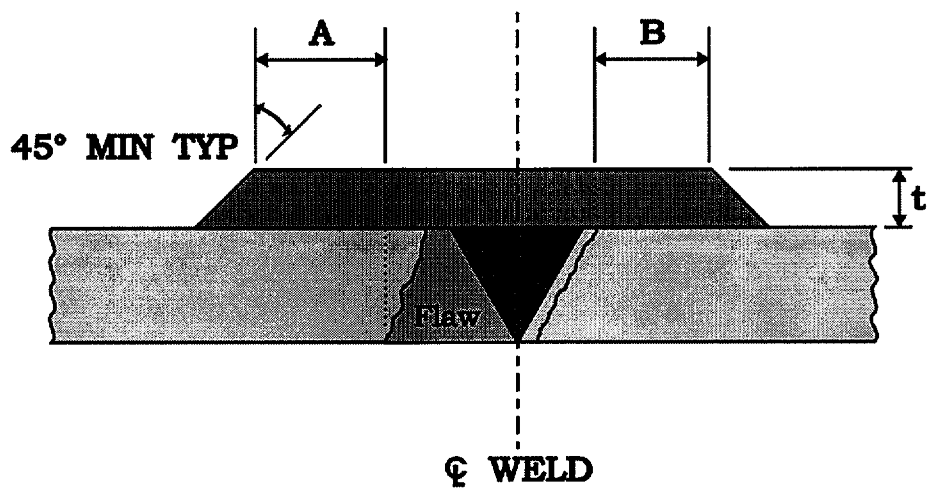
--------------------Stress Intensity Factor--------------------

Crack Size	Case Unit Load
0.0168	0.254579
0.0335	0.361649
0.0503	0.444912
0.0671	0.516032
0.0838	0.579504
0.1006	0.637621
0.1174	0.695537
0.1341	0.752213
0.1509	0.807019
0.1677	0.860346
0.1844	0.912484
0.2012	0.963655
0.2180	1.01679
0.2348	1.07235
0.2515	1.12777
0.2683	1.18312
0.2851	1.23845
0.3018	1.29383
0.3186	1.35222
0.3354	1.41986
0.3521	1.48825
0.3689	1.55738
0.3857	1.62725
0.4024	1.69787
0.4192	1.76923
0.4360	1.84522
0.4527	1.92211
0.4695	1.99987
0.4863	2.07852
0.5030	2.15805
0.5198	2.23843
0.5366	2.32456
0.5533	2.41334
0.5701	2.50317
0.5869	2.59402
0.6036	2.6859
0.6204	2.7788
0.6372	2.87623
0.6540	2.97834
0.6707	3.08162
0.6875	3.18605
0.7043	3.29161
0.7210	3.39831
0.7378	3.50865
0.7546	3.62784
0.7713	3.74836
0.7881	3.87017
0.8049	3.99328
0.8216	4.11767
0.8384	4.24332

End of pc-CRACK Output

Appendix C

Standard Weld Overlay Design



WELD NUMBER	FLAW CHARACTERIZATION	DESIGN DIMENSIONS			COMMENTS
		t	A	B	
CRD #____	Axial and Circumferential	0.33" (min)	0.6" (min)	0.6" (min)	A is measured from the edge of the flaw. B is measured from the toe of the weld or the edge of the flaw (whichever provides longest weld overlay length).

Revision	Prepared by/ Date	Checked by/ Date	Approved by/ Date	COMMENTS
1	MLH 7/18/01	SST 7/18/01	MLH 7/18/01	Modify Length
0	MLH 7/12/01	SST 7/12/01	MLH 7/12/01	

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Job No: W-CPC-13Q	Plant/Unit: Palisades	STRUCTURAL INTEGRITY ASSOCIATES, INC.
File No: W-CPC-13Q-502		
Drawing No: W-CPC-13Q-502	Title: CRDM Standard Weld Overlay Design	Sheet 1 of 2

NOTES

1. Blend weld overlay into component with a gentle radius.

2. Weld wire material is to be type ER309L, with as-deposited delta ferrite content greater than 10%.

3. Component surface is to be examined by the dye penetrant method and accepted as clean prior to overlay application in order to include the entire deposited overlay thickness in meeting the design requirement, per NUREG-0313, Revision 2. If local repair required to seal existing defect, seal weld can be made manually using E308L or E309L electrode.

4. In the event that the original component surface does not pass the Note 3 requirements, the first deposited weld layer is to be examined by the dye penetrant method and accepted as clean before proceeding with subsequent layers.

5. Minimum of two weld overlay layers to be applied after the surface has passed examination by dye penetrant method.

6. The first acceptable weld layer is to have a measured delta ferrite content greater than 10% ferrite.

7. Minimum thickness includes no allowance for surface conditioning operations to facilitate UT inspections.

8. Design length is as shown in figure W-CPC-13Q-502, Sheet 1 of 2; greater length may be required for effective UT inspection. This is to be determined in the field.

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Job No: W-CPC-13Q	Plant/Unit Palisades	STRUCTURAL INTEGRITY ASSOCIATES, INC.
File No: W-CPC-13Q-502		
Drawing No: W-CPC-13Q-502	Title: CRDM Standard Weld Overlay Design	Sheet 2 of 2