Entergy

Entergy Nuclear Operations, Inc.
Palisades Nuclear Plant
27780 Blue Star Memorial Highway
Covert, MI 49043

July 31, 2007

10 CFR 50.55a

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Palisades Nuclear Plant
Docket 50-255
License No. DPR-20

Request for Relief from ASME Section XI Code Requirements for Repair of Service Water System Pipe

Dear Sir or Madam:

Pursuant to 10 CFR 50.55a(a)(3)(i), Entergy Nuclear Operations, Inc. (ENO) is requesting relief from certain sections of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section XI, 2001 Edition with addenda through 2003, for repair of a 16-inch service water pipe with through-wall leakage. The details of the relief request are enclosed.

ENO's proposed alternative to a permanent repair of the service water pipe provides an acceptable level of quality and safety. ENO requests approval by October 1, 2007.

Enclosure 1 contains a request for relief from the ASME Code, Section XI, IWA-4000 "Repair/Replacement Activities." As an alternative, ENO proposes to use ASME Code Case N-513-2, "Evaluation Criteria for Temporary Acceptance of Flaws in Moderate Energy Class 2 or 3 Piping," with a modification to extend the duration of the use of the code case until the end of fuel cycle 20, which is expected to be in 2009. As part of the proposed alternative, ENO would use analysis of the flawed pipe to demonstrate structural integrity until the through-wall leaks are permanently repaired.

Enclosure 2 contains a background discussion of the service water system pipe through-wall leak and actions taken to address the pipe flaw. In a teleconference on July 19, 2007, ENO provided a history of the service water pipe leak and the repair options considered for permanent repair. Enclosure 2 expands on that background information.

Enclosure 3 contains an evaluation of the flaw.

Summary of Commitments

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

Perform repair or replacement in accordance with the applicable code requirements no later than the end of fuel cycle 20, which is expected to be in 2009.

Christopher J. Schwarz
Site Vice President
Palisades Nuclear Plant

Enclosures (3)

CC Administrator, Region III, USNRC
Project Manager, Palisades, USNRC
Resident Inspector, Palisades, USNRC

ENCLOSURE 1
REQUEST FOR RELIEF FROM ASME SECTION XI
INSERVICE INSPECTION PROGRAM

Proposed Alternative in Accordance with 10 CFR 50.55a(a)(3)(i)

1. American Society of Mechanical Engineers (ASME) Code Component Affected

The affected components are the Palisades Nuclear Plant service water Class 3 piping, specifically, HB-23-16", service water from containment (containment penetration MZ-13) and downstream of CV-0824, "Service Water Outlet Containment Isolation Valve."

2. Applicable Code Edition and Addenda

The Palisades Plant Inservice Inspection Program conforms to the requirements of the ASME Boiler and Pressure Vessel Code, Section XI, 2001 edition with addenda through 2003.

3. Applicable Code Requirements

Subparagraph IWB-3522.1, "Visual Examination VT-2," reads: "The following relevant conditions that may be detected during the conduct of system pressure tests shall require corrective action to meet the requirements of IWB-3142 and IWA-5250 prior to continued service:

(a) leakage from non-insulated components (IWA-5241);"

Subsubarticle IWA-5250(a)(3) reads: "Components requiring corrective action shall have repair/replacement activities performed in accordance with IWA-4000 or corrective measures performed where the relevant condition can be corrected without a repair/replacement activity.

4. Reason for Request

In accordance with 10 CFR 50.55a(a)(3)(i), Entergy Nuclear Operations, Inc. (ENO) is requesting to implement an alternative to ASME Section XI, Subarticle IWA-5250(a)(3) to perform a repair or replacement in accordance with IWA-4000.

During July 30, 2006, routine operator rounds in the west engineering safeguards room, a pinhole leak was discovered in a critical service water system (SWS) pipe. The leak is in a 16-inch pipe, approximately one foot downstream of containment isolation valve CV-0824. The leak location is just downstream of a pipe-to-flange weld in a short (approximately one foot) pipe section upstream of a 90° elbow. The containment isolation valve is a flanged-end, 16-inch butterfly valve that is operated in a throttled position to restrict flow to the containment air coolers. The leak is not within the containment penetration boundary. The leak involves the pressure boundary of an ASME Class 3 system and affects the operability of the engineered safeguards system due to potential flooding and the SWS heat removal capability. Figure 1 provides an isometric drawing of piping section containing the flaw.

ENO evaluated several repair options. Details of the options are provided in Enclosure 2, along with information describing licensee actions taken after the leak was discovered. ENO's preferred repair option involves installation of a temporary (non-Code) repair during the 2007 refueling outage, followed by a permanent repair in the subsequent refueling outage. As noted in Enclosure 2, ENO only recently identified this repair option, after discovering that the original repair plan would not meet Code requirements. However, the preferred option would not meet Code Case N-513-1, "Evaluation Criteria for Temporary Acceptance of Flaws in Moderate Energy Class 2 or 3 Piping, Section XI, Division 1," because permanent repair would not be performed until the subsequent refueling outage which is expected to be in 2009. Therefore, relief is needed to implement an alternative to ASME Section XI, Subarticle IWA-5250(a)(3) to perform a repair or replacement in accordance with IWA-4000.

As discussed in Enclosure 2, the option to make a permanent repair in the subsequent refueling outage is preferable because:

- The flaw area is not isolable using system valves from the remainder of the service water system without significant modification.
- A repair or replacement activity cannot be completed within the limitations of plant Technical Specifications.
- Isolating all service water and draining the system when the reactor fuel is in the spent fuel pool would represent a considerable risk to spent fuel pool cooling.

ENO has identified a proposed alternative that would provide an acceptable level of quality and safety.

5. Proposed Alternative and Basis for Use

ENO is requesting to use ASME Code Case N-513-2 "Evaluation Criteria for Temporary Acceptance of Flaws in Moderate Energy Class 2 or 3 Piping Section XI, Division 1," with one modification as an alternative to performing a repair in accordance with ASME Section XI, IWA-4000. The SWS meets the temperature and pressure provisions in Code Case N-513-2 as maximum operating temperature is less than 200°F and maximum operating pressure is less than 275 psig. The Nuclear Regulatory Commission has granted relief for Palisades to use Code Case N-513-2 for the fourth Inservice Inspection Interval in a letter dated May 16, 2007 (Accession number ML071170148). ENO is requesting to use Code Case N-513-2 with the following modification:

The reply section of the Code Case states:

> *It is the opinion of the Committee that the following requirements may be used to accept flaws, including through-wall flaws, in moderate energy Class 2 or 3 piping, without performing a repair/replacement activity for a limited time, not exceeding the time to the next scheduled outage.*

ENO is requesting to extend the duration of the use of this code case to allow the continued use of this code case for an additional fuel cycle (until the end of fuel cycle 20, currently scheduled for 2009)

The modification to Code Case N-513-2 noted above describes an alternative that provides an acceptable level of quality and safety, pursuant to 10 CFR 50.55a(a)(3)(i). The basis for acceptable quality and safety include meeting the conditions of Code Case N-513-2 for continued monitoring and structural integrity. ENO performs routine monitoring in accordance with the code case. A flaw evaluation based upon Code Case N-513-2 shows that the current condition of the piping downstream of control valve CV-0824 in the service water return from containment (HB-23-16) outside of the containment penetration MZ-13 will maintain structural integrity, even in the presence of pinhole leaks. The acceptable minimum wall thickness, t_{min} (i.e. 360°) for this piping is 0.033 inches, and an acceptable flaw size per the subject Code Case is 36.52 inches axially and 35.87 inches circumferentially. The flaw evaluation is provided in Enclosure 3.

Additionally, ENO has completed a flaw growth analysis that demonstrates structural integrity would be assured with margin until the 2009 refueling outage. Regular inspections of the pipe have shown that there has been minimal flaw growth after the leak was first discovered and characterized. Since February 2007, flaw growth has been insignificant. A projection of the flaw extents and depths based on the leak history shows that, while thinning is expected be greater in 2009 than it is today, the predicted flaw should still be significantly smaller than the calculated acceptable flaw size.

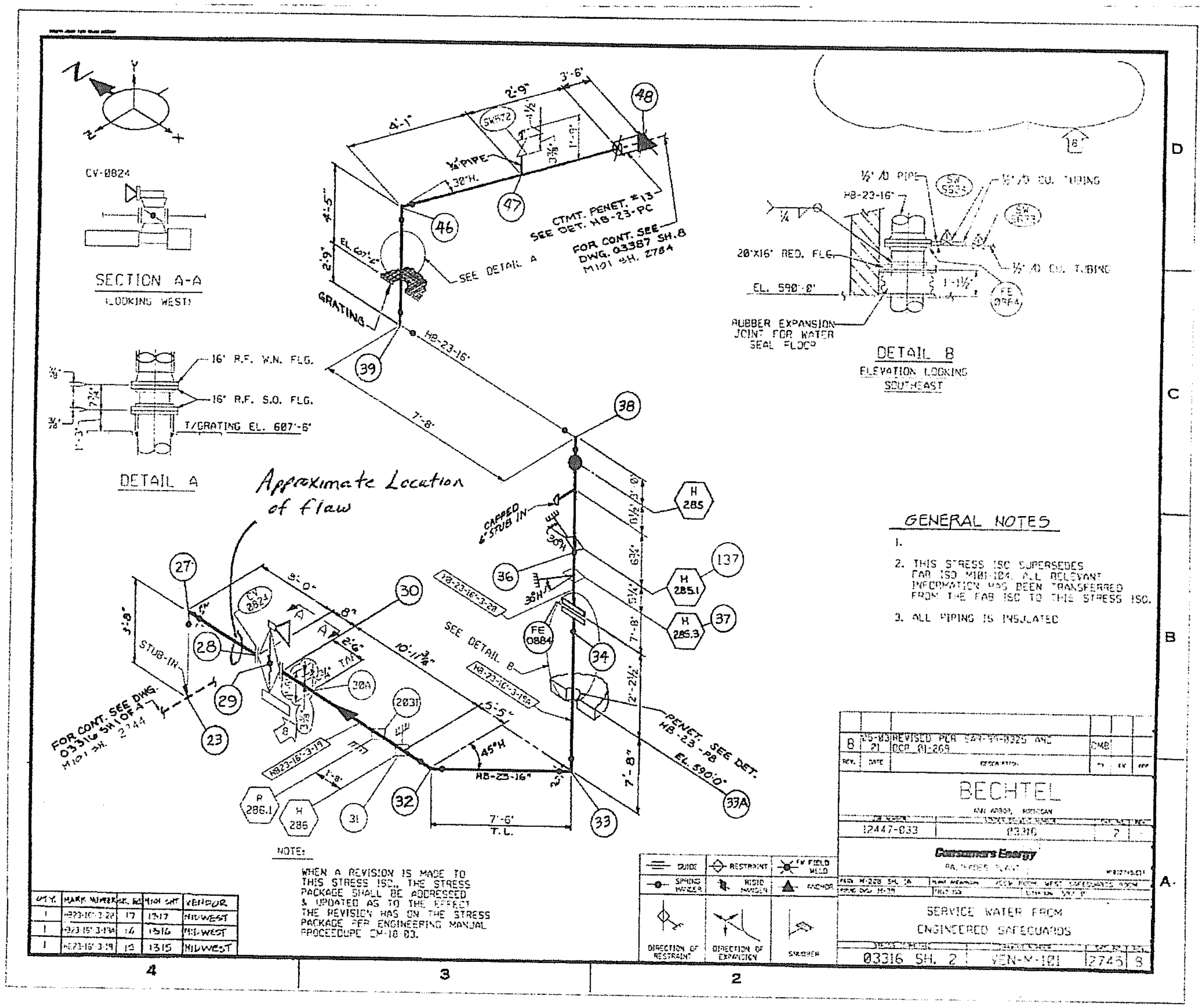
The pinhole leaks do not affect the ability of the SWS to perform its heat removal functions. The leak location is downstream of all heat loads, and it is downstream of all system valves used for SWS flow balancing. Flow balancing is conducted each refueling outage to ensure adequate flow is provided to all critical heat loads. There are no barriers between the leak location and the SWS discharge to the make-up basin and to Lake Michigan. Because of the leak location, there is no effect on the ability of the SWS to perform safety related heat removal functions during all modes of plant operation, and there is no effect on the system flow margin.

Based on the information above, the proposed alternative to apply Code Case N-513-2 with a modification in lieu of performing a repair in accordance with ASME Section XI, IWA-4000 provides an acceptable level of quality and safety.

6. Duration of Proposed Alternative

ENO requests approval of the proposed alternative until the end of fuel cycle 20, which is expected to be in 2009.

FIGURE 1


Approximate Location of flaw
SECTION A-A
LOOKING WEST
CV-0824
DETAIL A
16" R.F. W.N. FLG.
16" R.F. S.O. FLG.
T/GRATING EL. 607'-6"
SEE DETAIL A
GRATING
HB-23-16"
CTMT. PENET. #13
SEE DET. HB-23-PC
FOR CONT. SEE DWG. 03387 SH.8
M101 SH. 2784
DETAIL B
ELEVATION LOOKING SOUTHEAST
20"X16" RED. FLG.
EL. 590'-0"
RUBBER EXPANSION JOINT FOR WATER SEAL FLOOR
GENERAL NOTES
1.
2. THIS STRESS ISO SUPERSEDES FAB ISO M101-104. ALL RELEVANT INFORMATION HAS BEEN TRANSFERRED FROM THE FAB ISO TO THIS STRESS ISO.
3. ALL PIPING IS INSULATED
SEE DETAIL B
PENET. SEE DET. HB-23-PB
EL. 590'0"
CAPPED 6" STUB IN
STUB-IN
FOR CONT. SEE DWG. 03316 SH.1 OF 4
M101 SH. 2744
HB-23-16"
7'-6" T.L.
NOTE:
WHEN A REVISION IS MADE TO THIS STRESS ISO., THE STRESS PACKAGE SHALL BE ADDRESSED & UPDATED AS TO THE EFFECT THE REVISION HAS ON THE STRESS PACKAGE PER ENGINEERING MANUAL PROCEDURE EM-18 03.
BECHTEL
Consumers Energy
SERVICE WATER FROM ENGINEERED SAFEGUARDS
12447-033
03316 SH. 2
GUIDE
RESTRAINT
SPRING HANGER
RIGID HANGER
ANCHOR
DIRECTION OF RESTRAINT
DIRECTION OF EXPANSION
SNUBBER
4
3
2
D
C
B
A

ENCLOSURE 2
BACKGROUND INFORMATION ON SERVICE WATER LEAK

Entergy Nuclear Operations, Inc. (ENO) is providing additional background information on the service water system pipe through-wall leak and actions taken to address the pipe flaw. In a teleconference with the Nuclear Regulatory Commission (NRC) on July 19, 2007, ENO provided a brief history of the service water pipe leak and the repair options considered for permanent repair. The information below provides additional details.

1. Discovery of Leak and Initial Repair Plan

During July 30, 2006, routine operator rounds in the west engineering safeguards room, a pinhole leak was discovered in a critical service water system (SWS) pipe a few inches downstream of the containment isolation valve. The leak location is just downstream of a pipe to flange weld in a short (approximately one foot) pipe section upstream of a 90° elbow. The containment isolation valve is a flanged-end, sixteen-inch butterfly valve that is operated in a throttled position to restrict flow to the containment air coolers. The leak rate was measured at approximately 0.0003 gpm. The leak is not within the containment penetration boundary. The leak involves a pressure boundary of an American Society of Mechanical Engineers (ASME) Class 3 system, and affects the operability of the engineered safeguards system due to potential flooding and the SWS heat removal capability.

An initial evaluation of the subject flaw was performed using the criteria prescribed in ASME Code Case N-513-1, "Evaluation Criteria for Temporary Acceptance of Flaws in Moderate Energy Class 2 or 3 Piping Section XI, Division 1." The evaluation determined that the degraded SWS pipe continued to comply with code case criteria. The evaluation concluded that structural integrity would be maintained with a through-wall flaw much larger than the existing flaw. In accordance with code case requirements, periodic monitoring was initiated. The service water pipe was classified as operable but degraded.

Several repair methods were evaluated in 2006. These methods are described below, along with information regarding their disposition.

1. Submit a relief request and use ASME Section XI, IWA-4340 to install a branch connection. This option was discarded due to the prohibition against the use of this code allowance contained in 10 CFR 50.55a, "Codes and Standards."

2. Implement Code Case N-661-1, "Alternate Requirements for Wall Thickness restoration of Classes 2 and 3 Carbon Steel Piping for Raw Water Service Section XI, Division 1," weld overlay and perform a repair or replacement activity during the 2007 refueling outage. This

option was discarded since the code case had not been endorsed by the NRC in Regulatory Guide 1.147, "Inservice Inspection Code Case Acceptability, ASME Section XI, Division 1," would require submittal of a relief request within one year of the need date, and did not offer any advantages over use of Code Case N-661.

3. Replace the flawed pipe during the 2007 refueling outage through the use of system valves, line-stop, bladders or alternate spent fuel pool (SFP) cooling. This option was not fully pursued due to the complex planning, engineering, procurement and implementation.

4. Perform a 360° weld overlay in accordance with Code Case N-661. This option relied on peening to close the through-wall leak path. This option was chosen as the primary path for performance of a Code-compliant repair, as it would allow repairs to be made online and without removing the SWS from service. The repair was scheduled for completion in July 2007.

The 360° weld overlay option was contingent on the ability to meet the NRC conditions for approval of Code Case N-661 in Regulatory Guide 1.147. These conditions are:

a) If the root cause of the degradation has not been determined, the repair area is only acceptable for one cycle,

b) Weld overlay repair of an area can only be performed once in the same location, and

c) When through-wall repairs are made by welding on surfaces that are wet or exposed to water, the weld overlay repair is only acceptable until the next refueling outage.

The weld overlay repair option (Option 4) in accordance with Code Case N-661 was pursued until June 2007. By this time, three additional pinhole leaks, all within a two-inch by two-inch wastage area at the bottom of the SWS pipe developed. This was expected due to the likely cause of the degradation. Historically, similar leaks were caused by erosion due to cavitation from the downstream effect of the throttled butterfly valve. However, the additional pinholes led ENO to question the ability to peen over the through-wall leaks and the ability to weld over the area. Further examination of the repair plan also revealed that the planned reliance of peening to close the through-wall leak path would not meet NRC limitation (c) placed on the use of Code Case N-661. Following this determination, ENO determined that the best course of action would include the installation of a temporary clamp to control leakage and continued monitoring in accordance with Code Case N-513-2. Additionally this course of action would require that a permanent repair be made during the upcoming 2007 refueling outage, otherwise relief from the requirement to complete a permanent repair by the end of the refueling outage would be required.

The pinhole leaks do not affect the ability of the SWS to perform its heat removal functions. The leak location is downstream of all heat loads, and it is downstream of all system valves used for SWS flow balancing. Flow balancing is conducted each refueling outage to ensure adequate flow is provided to all critical heat loads. There are no barriers between the leak location and the SWS discharge to the make-up basin and to Lake Michigan. Because of the leak location, there is no effect on the ability of the SWS to perform safety related heat removal functions during all modes of plant operation, and there is no effect on the system flow margin.

Plant experience with this leak and previous similar leaks indicates flaws of this type, caused by erosion due to cavitation from the downstream effect of the throttled butterfly valve, do not propagate rapidly. There is a large margin between the existing leak rate and the 25-gpm capacity of the sump pumps, so flooding in the west engineering safeguards room is not expected. This margin is sufficient to allow monitoring and trending of any increases in leak rate. Controls have been established so that corrective actions are taken when leak rate trends indicate the 25-gpm limit would be reached within thirty days.

ENO plans to install a clamp to control leakage prior to the 2007 refueling outage. It is not intended to improve structural capability of the piping system.

2. Additional Repair Options Considered

In June 2007, when it became apparent that the original repair plan was not a Code repair, additional repair options were evaluated. ENO recognized that the flaw area is not isolable using system valves from the remainder of the SWS, and that the SWS would have to be shut down and drained to permit a permanent repair. Isolating the repair area requires the following actions:

- Isolation of service water loads from containment
- Isolation of all critical service water loads or the diversion of the discharge water from these sources.
- Installation of pipe plugs in the mixing basin, which is at a higher water level than the repair area, or removal of the mixing basin stop logs to lower the water level.

Based on the current SWS configuration, stopping all service water and draining the system would present a considerable risk to SFP cooling. In order to isolate the repair area, ENO has considered the following methods: installation of a line stop, alternate SFP cooling, and alternate SWS discharge flow path. These three methods are described below.

<u>Line-Stop</u>
Based on the current service water configuration, stopping all service water and draining the system would represent a considerable risk to SFP cooling system because of decay heat from the recently-discharged fuel. ENO considered the use of a line-stop process. This process uses a hot tap method to isolate the service water line and allow repair or replacement of the flawed pipe while the portion of the SWS the supporting component cooling water system (CCW), and ultimately the SFP cooling system, remains in service. The line-stop process requires the installation of a fitting at the plugging location. This process may be feasible for the Palisades leak; however, significant engineering and planning issues exist. They include:

- The seal quality of the installed plug must support SWS operation while sufficiently isolating the flaw area to complete repairs. Seal quality is based upon many factors, which include the internal condition of the pipe system. If the inside of the pipe system is clean, then the plugging head seal would meet requirements. If the pipe inside diameter is not clean, leakage can be expected. Suppliers of line-stop services do not guarantee a 100% seal. Therefore, it may not be possible to isolate flow to the flaw area.

- Installation of tooling necessary to complete a line-stop application requires significant overhead clearances. Tooling diagrams, which have been reviewed for the Palisades application can require up to thirteen feet of clearance without consideration of clearances necessary for tool movement to and from the work location. The existing system and building configuration allow less than seven feet of clearance between the piping system and ceiling of the west safeguards room. Therefore, new tooling would need to be designed to support installation of a line-stop at Palisades. The short duration between when the option was identified and the outage challenge ENO's ability to design and create the needed tooling.

- Installation of the proposed line-stop would be at a non-preferred location. Due to limited straight pipe between the flaw and the downstream junction (approximately one foot), the line-stop installation would be at a 90° elbow. This installation is not preferred and represents a risk to successful installation.

Alternate SFP Cooling

ENO considered installing an alternate SFP cooling system. This system would replace the CCW function for removal of SFP decay heat and keep the temperature of the SFP within limits while the SWS is out of service. Because an alternate SFP cooling system would temporarily be taking the place of the permanent CCW and SFP cooling system, it would need to be installed to a level of quality equal to the replaced systems.

Conceptually, the alternate SFP cooling system would employ a heat exchanger cooled by a chilled water system. Chilled water would be pumped through one side of the heat exchanger, while SFP water would be pumped through the other side, cooled, and returned to the SFP. The heat exchanger and pumps for circulating the SFP water would be located near the SFP, while the water chiller units would be located in the yard area outside of the auxiliary building.

Designing, procuring, and installing the safety-related equipment for the alternate SFP cooling system involves significant resources. Activities would include:

- Calculate SFP heat load with full-core off-load in order to size the alternate SFP cooling system.
- Design and construct seismically-qualified chilled water supply and return piping and pipe supports. Routing chilled water piping from yard area to SFP area cannot impact ability to maintain radiological release path boundary to the environment for a postulated fuel handling accident.
- Design and construct seismically-qualified SFP heat exchanger supply and return piping and pipe supports.
- Design and construct seismic mounting structure/frame for heat exchanger and circulating pumps in SFP area.
- Design connection to safety-related electrical power source for alternate SFP cooling chillers and pumps.
- Procure potentially long lead time components including safety-related heat exchanger, pumps, valves, piping and structural components.
- Address potential for SFP boron dilution in the event of heat exchanger leakage or chilled water pipe leak/failure.

These activities pose a significant challenge to ENO due to the short duration between when the need was identified and the start of the 2007 refueling outage. This affects ENO's ability to align internal or vendor support, and it may not be possible to get all of the needed equipment. Additionally, many of the activities need to be planned in conjunction with other planned outage activities to ensure appropriate equipment lineups are available and there is sufficient workspace to perform field work. Adding a significant complex task that has no corresponding safety benefit shortly before the outage would present a distraction.

Alternate SWS Discharge
ENO also considered installation of an alternate service water discharge flow path for SWS loads in order to allow CCW to remain in service. An alternative discharge flow path could be provided for CCW heat exchangers, diesel generators, engineered safeguards pumps, control room coolers and safeguards. CCW would be able to support SFP decay heat removal while the portion of the SWS containing the flaw is repaired or replaced.

Because the alternate service water discharge flow path would temporarily be taking the place of the permanent system flow paths, as a minimum, the components inside of the auxiliary building would need to be safety-related. This is necessary to avoid room flooding and to continue to provide cooling in the event of a postulated seismic event.

The alternate service water discharge flow path would involve modification to one CCW heat exchanger outlet via connected piping and hoses. Water would be pumped through the heat exchanger as designed, but the discharge would be alternatively routed to the mixing basin through temporary hoses and piping.

Designing, procuring and installing the safety-related equipment for the alternate service water discharge flow path option involves significant resources. Activities include:

- Design and construct seismically qualified discharge piping and pipe supports.
- Procure potentially long lead time components including safety-related valves, piping and structural components.

As stated above, these three additional options pose a significant challenge to ENO. ENO determined that the preferred option is to apply Code Case N-513-2, with a modification.

3. Code Case Applicability

When the service water leak was first identified, Palisades was in its third inservice inspection interval. The code of record was the 1989 edition of ASME Section XI with no addenda. The SWS piping flaw evaluation conducted following the initial discovery of the flaw in July 2006, followed the guidance of Code Case N-513-1, which was applicable to Palisades' code of record and was conditionally accepted in Regulatory Guide 1.147, Revision 14.

In December 2006, Palisades began its fourth inservice inspection interval and updated the code of record to the 2001 edition of ASME Section XI with addenda through 2003. As part of this code update, a relief request was submitted to allow for the use of Code Case N-513-2. Relief was required since Code Case N-513-1 is not applicable to the new code of record and N-513-2 had not yet been approved for use in Regulatory Guide 1.147. The NRC granted the relief request to allow Palisades to use Code Case N-513-2 on May 16, 2007 (Accession number ML071170148).

4. Structural Integrity Analysis Results

Following discovery of the through-wall flaw, the licensee completed a structural integrity analysis in accordance with the requirements of Code Case N-513-1. The through-wall flaw was characterized as a small pinhole leak. The flaw is located in the piping at the lower, approximately 6 o'clock position. Additional areas thinned to less than 0.375 inch nominal have been located at approximately the 4-to-8 o'clock position in the lower pipe section and the 10-to-2 o'clock position in the upper pipe section. The cause has been identified as erosion due to cavitation that is the result of a throttled upstream valve. Analysis demonstrates that criteria based on ASME Section XI and ASME Code Case N-513-1 are satisfied, and continued operation without repair of the flaw is acceptable. Table 1 summarizes the calculated allowable flaw sizes, based on planar flaw evaluations:

Table 1: Allowable Flaw Sizes Calculated

Planar Direction	Allowable Flaw Size (in)	Actual Flaw Size (in)
Axial	32.8	≈ 2
Circumferential	23.4	≈ 2

The initial planar evaluation of the pinhole leak concluded that the leak is within the limits of Code Case N-513-1.

ENO completed an additional structural integrity analysis in accordance with the requirements of Code Case N-513-2 in order to demonstrate that the flawed pipe would meet structural analysis requirements until the 2009 refueling outage. This analysis confirmed the previous results and demonstrated that criteria based on ASME Section XI and ASME Code Case N-513-2 are satisfied, and continued operation without repair of the flaw is acceptable.

Additionally, a flaw growth analysis was completed using existing ultrasonic examination results and operating history. This analysis demonstrates that the pipe flaw would not grow to a critical size before the 2009 refueling outage.

Evaluations concluded that structural integrity would be maintained with a through-wall flaw much larger than the present flaw.

5. Impact on Operability

The existence of pinhole leaks calls into question the ability of the piping system to support continued operability of the equipment located in the west engineered safeguards room. The present leak rate from the one pinhole leak discovered in July 2006 has increased from one pinhole leaking at approximately 0.0003 gpm, to five pinholes leaking at approximately 0.04 gallons per minute. (Two additional pinhole leaks were identified in April 2007; another was identified in June 2007, and another pinhole leak was identified in July 2007.) The pinhole leaks are all located within a two-inch by two-inch area on the SWS pipe. The leakage has no immediate impact on engineered safeguards system operability for the equipment located in the west engineered safeguards room. Monitoring using ultrasonic testing and visual examination provides assurance that degradation would not propagate to the point where the leak rate exceeds the capacity of the west engineered safeguards sump pumps. The sump pumps have a capacity of 25 gallons per minute. Assuming only one of two pumps is available, and provided the margin between the existing leak rate and 25 gpm would allow operation for thirty days, operability of the engineered safeguards equipment in the west engineered safeguards room would be maintained. The maximum post accident mission time for the pipe and safeguards room equipment is thirty days.

ENCLOSURE 3

REQUEST FOR RELIEF FROM ASME SECTION XI CODE REQUIREMENTS
FOR REPAIR OF SERVICE WATER SYSTEM PIPE

FLAW EVALUATION

23 PAGES FOLLOW

Structural Integrity Associates, Inc.

CALCULATION PACKAGE

File No.: PAL-13Q-301

Project No.: PAL-13Q

PROJECT NAME:

Service Water Piping Flaw Evaluation and Flaw Growth Analysis

CONTRACT NO.:

Pending

CLIENT:

Nuclear Management Corp.

PLANT:

Palisades

CALCULATION TITLE:

Flaw Evaluation Using ASME Code Case N-513-2 and Flaw Growth Analysis for Service Water Piping at Palisades Nuclear Plant

Document Revision	Affected Pages	Revision Description	Project Manager Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
A	1 – 18 A1 – A5 Computer Files	Draft	R. O. McGill	G. J. Licina R. O. McGill R. V. Perry (Checker)

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1.0 INTRODUCTION

In July 2006, a pinhole leak was discovered approximately one foot downstream of control valve CV-0824 in the "Service Water Return from Containment" piping (HB-23-16) outside of the containment penetration MZ-13 [1]. This single pinhole is located on the bottom of the 16-inch carbon steel pipe in the 6 o'clock position [1]. The most recent NDE inspection data [2d] indicates that there are now 4 separate pinhole leaks in the same vicinity.

The initial leak was determined to be temporarily acceptable [3] per Code Case N-513-1 [4] at the time the leak was discovered (note the current 4 pinholes in combination would also be temporarily acceptable per the initial analysis); however, Palisades desires to implement repairs during the spring 2009 refueling outage which violates the provisions of the Code Case since repairs are not planned for the next scheduled outage (September 2007). The analysis contained herein is to provide technical justification for a planned relief request by the plant for postponing repair activity.

There are two objectives of the calculation. First, a flaw evaluation is performed to determine an allowable flaw size per Code Case N-513-2 [5], which provides specific guidance for through-wall nonplanar flaws. Second, a flaw growth analysis is performed based on NDE inspection data provided [2] to predict a bounding flaw size at the time of the spring 2009 outage. This flaw size is then compared to the allowable flaw size calculated.

2.0 METHODOLOGY

The flaw evaluation is based on the criteria prescribed in ASME Code Case N-513-2. Use of this Code Case has been authorized by the Nuclear Regulatory Commission (NRC) for use by Palisades through relief request approval [6]. The Code Case allows for the evaluation of nonplanar, through-wall or part-wall flaws in Class 2/3 moderate energy piping. The through-wall, nonplanar flaw is to be evaluated as planar, through-wall flaws in the axial and circumferential directions (as described in Section 3.0(f) of the Code Case). This evaluation is performed using criteria in ASME Section XI [7] as permitted by Code Case N-513-2.

The nonplanar, through-wall flaw evaluation herein was conducted using SI Pipe Eval software [8] developed by Structural Integrity Associates. SI Pipe Eval is an Excel based evaluation tool programmed in Visual Basic for Applications that performs the flaw evaluation procedure described in Code Case N-513-2. SI Pipe Eval has been verified through the SI software QA program by an independent third party.

The flaw growth analysis is based on NDE inspection data of the affected pipe region provided by Palisades. Those inspections results were acquired on October 27, 2006 [2a], February 14, 2007 [2b], May 9, 2007 [2c] and July 2, 2007 [2d]. More specifically, this inspected region is for the full circumference of the pipe for an axial distance of 9 inches downstream from the pipe-to-control valve weld on a one inch-by-one inch grid. Figures 2 - 5 depict the inspection data using contour plots. A trend and statistical analysis is performed to determine the flaw size at the time of the spring 2009 refueling outage, for comparison to the bounding flaw.

3.0 ASSUMPTIONS / DESIGN INPUTS

The following assumptions are made for the analysis:

1. Seismic OBE, seismic DBE, and thermal moments are assumed negligible [9].
2. Service Level A safety factors are conservatively applied per Section 4.0 of Code Case N-513-2 [5].
3. The number of days of operation, from the time of the most recent NDE examination (7/02/07) to the spring 2009 refueling outage, is 630 days (21 months).

The following design inputs are used for the analysis (material properties are taken at the peak operating temperature):

1. Pipe OD = 16 inch [1].
2. Nominal wall thickness = 0.375 inch [1].
3. Maximum operating pressure = 50 psig [10].
4. Maximum operating temperature = 200°F [1].
5. Material toughness (for circumferential flaws)* = 45 lb/in [7, Table H-8321-1].
6. Material toughness (for axial flaws)* = 45 lb/in [7, Table H-8322-1].
7. Primary bending stress (dead weight), P_b = 1.0749 ksi [9].
8. Pipe expansion stress, P_e = 0 [9].
9. Pipe material is A53 Grade A [1].
10. Allowable design stress, S = 12 ksi [11, Appendix III, p.269].
11. Code yield strength, S_y = 30 ksi [12, p. 105].
12. Code tensile strength, S_u = 48 ksi [12, p. 105].
13. Young's modulus, E = 28,600 ksi [11, Appendix I, p. 129].

* Material toughness conservatively taken at lower shelf temperature.

4.0 CALCULATIONS AND RESULTS

4.1 Flaw Evaluation

The planar flaw characterization approach is illustrated in Figure 1. Planar flaw evaluations are performed to determine allowable flaw sizes for comparison to the predicted flaw sizes (analysis below) using the assumptions and design input listed above. Table 1 summarizes the calculated allowable flaw sizes. SI Pipe Eval input and output are provided in Appendix A.

Table 1: Allowable Flaw Sizes Calculated

Planar Direction	Allowable Flaw Size (in)
Axial	36.52
Circumferential	35.87

4.2 Flaw Growth Analysis

Figures 2 through 5 show that thinning is confined to approximately half of the circumference with the most serious thinning at the edge of the weld. Those same thickness results are shown in 2-dimensional profile representations in Figures 6 through 8. In Figure 8, the axial profile shows there is a dramatic difference between the minimum reported value for a given circumferential position and the average for that circumferential band.

Figure 9 is a statistical plot that shows the cumulative distribution of the measured thickness at each of the four inspections. Figure 10 is also a cumulative distribution plot of the apparent deltas, where delta is determined by the point-to-point difference at each grid between successive inspections. Note that negative delta values indicate that the thickness at that grid has increased.

Figure 9 shows that the cumulative distribution is basically bilinear. The best fit line at the higher thickness show a very small variation in thickness that is near the t_{nom}, and that the measured thickness is greater than t_{nom} for some measurements. The bilinear nature of Figure 9 demonstrates that there are actually two populations; one that is thinning (e.g., the lower half of the circumference), and one that is not. The lower thickness values, essentially all of which are at PHI values of -1 or less (PHI is essentially equivalent to the standard deviation of the observations). The differences between the best fit lines for different examinations provide an estimate of the rate of metal loss; at least since the first data set was collected in October 2006. The different data in Figure 9 show that not much thinning has occurred since February 2007. Best fit lines to the lower curves (i.e., where there is thinning) show that between October 2006 and July 2007 (248 days) that the rate of thinning is essentially 0.0273 inch/year (7.48×10^{-5} inch/day).

Figure 10 shows the same basic data in a different way. Figure 10 shows the same effect observed from Figures 6-8, but more quantitatively, using the apparent deltas as the measure. The advantage of evaluating delta is that effects show up directly and changes can be observed more readily. The primary disadvantage is that the error in measurements (each thickness measurement will have an error associated with it; typically ±0.010 inch for UT thickness measurements) will be magnified with the differences between subsequent individual measurements are compared. The means of all three data sets (i.e., the value at PHI = 0) are very close to zero, implying that the mean metal loss over the three measurements is very near zero. Figure 10 also shows that the vast majority of the metal loss occurred before the initial inspection in October 2006, with a much smaller amount of metal loss at any point between October 2006 and February 2007. Since February 2007, metal loss has been nil. The extremes of the apparent deltas were significant for the second data set, but have been much smaller in the two most recent inspections.

Extrapolating these results to September 2009 indicates the minimum thickness in any grid will be 0 (i.e., a leak is definitely predicted) and the minimum thickness of any circumferential band where thinning is occurring (actually half of a circumference) will be of the order of 0.150 inch. Using the extreme values that the statistical plots permit predicts that the cumulative distribution of thickness in September 2009 will look like the plot in Figure 11. If it is assumed that all thinning occurs in the one inch grid closest to the weld, the band averages for that one inch grid will decrease from 0.292 inch (July 2007) to 0.260 inch.

The UT thickness data have demonstrated that thinning was occurring prior to October 2006, that some thinning persisted between October 2006 and February 2007, but that essentially no thinning has occurred since that time. A key assumption in the projection to September 2009 is that the operative degradation mechanism that produced the thinning will be no more severe in the ensuing 24 months than it has been since October 2006. As such daily walkdowns and continued UT thickness determinations are recommended as discussed in Section 2.0(f) of the Code Case.

5.0 CONCLUSIONS

A flaw evaluation based upon Code Case N-513-2 has shown that the current condition of the piping downstream of control valve CV-0824 in the Service Water Return from Containment piping (HB-23-16) outside of the containment penetration MZ-13 will maintain structural integrity, even in the presence of a pinhole leak. The acceptable t_{min} (i.e., 360°) for this piping is 0.033 inch [3]. An allowable flaw size per Code Case N-513-2 and the loading to which this line is subjected is 36.52 inches (axial) by 35.87 inches (circumferential).

Regular inspections of the pipe have shown that there was minimal flaw growth after the leak was first discovered, then characterized in October 2006. Since February 2007, flaw growth has been nil. A projection of the flaw extent and depths based upon the entire history for which the pipe has been characterized using UT thickness measurements on one inch grids shows that at September 2009 the thinning will be larger than it is today; however, the predicted flaw will still be significantly smaller than the acceptable flaw size as calculated.

As noted above, the vast majority of the thinning occurred prior to October 2006, with some minimal thinning persisting between October 2006 and February 2007, but with essentially no thinning occurred since that time. A key assumption in the projection of these results to September 2009 is that the operative degradation mechanism that produced the thinning will be no more severe in the ensuing 24 months than it has been since October 2006. As such daily walkdowns and continued UT thickness determinations are recommended as discussed in Section 2.0(f) of the Code Case.

6.0 REFERENCES

1. NMC, "Operability Recommendation," CAP: 01041995, Rev. 0, July 30, 2006, SI File Number PAL-11Q-201.

2. Palisades NDE inspection data, SI File Number PAL-13Q-201:
   a. Ultrasonic Erosion Corrosion Examination Report, Work Order Number: 00294169 06, Examination Date: 10/27/06.
   b. Ultrasonic Erosion Corrosion Examination Report, Work Order Number: 00294169 10, Examination Date: 2/14/07.
   c. Ultrasonic Erosion Corrosion Examination Report, Work Order Number: 00294169 13, Examination Date: 5/09/07.
   d. Ultrasonic Erosion Corrosion Examination Report, Work Order Number: 00294169 15, Examination Date: 7/02/07.

3. SI Calculation Package PAL-11Q-301, "Flaw Evaluation for Service Water Piping at Palisades Nuclear Plant Using ASME Code Case N-513-1," Revision 0.

4. ASME Code Case N-513-1, "Evaluation Criteria for Temporary Acceptance of Flaws in Moderate Energy Class 2 or Class 3 Piping Section XI, Division 1," Cases of ASME Boiler and Pressure Vessel Code, March 28, 2001.

5. ASME Code Case N-513-2, "Evaluation Criteria for Temporary Acceptance of Flaws in Moderate Energy Class 2 or Class 3 Piping Section XI, Division 1," Cases of ASME Boiler and Pressure Vessel Code, February 20, 2004.

6. NRC Relief Request Approval Letter, "Safety Evaluation by the Office of Nuclear Regulation Use of ASME Code Case N-513-2," July 3, 2006, SI File Number PAL-13Q-202.

7. ASME Boiler and Pressure Vessel Code, Section XI, Appendix C, 2001 Edition (2002 Addenda).

8. SI Pipe Eval, Version 1.3, Structural Integrity Associates, 2007.

9. Email attached from Michael Acker (NMC) to Bob McGill (Structural Integrity), "Service Water pipe Info.pdf," Dated August 2, 2006, 10:45 AM, SI File Number PAL-11Q-202.

10. Email from George Schrader (NMC) to Bob McGill (Structural Integrity), "RE: Service Water Piping Flaw Evaluation," Dated August 10, 2006, 8:55 AM, SI File Number PAL-11Q-204.

11. ASME Boiler and Pressure Vessel Code, Section III Appendices, 1989 Edition.

12. ASME Boiler and Pressure Vessel Code, Section II, Part A, 1989 Edition.

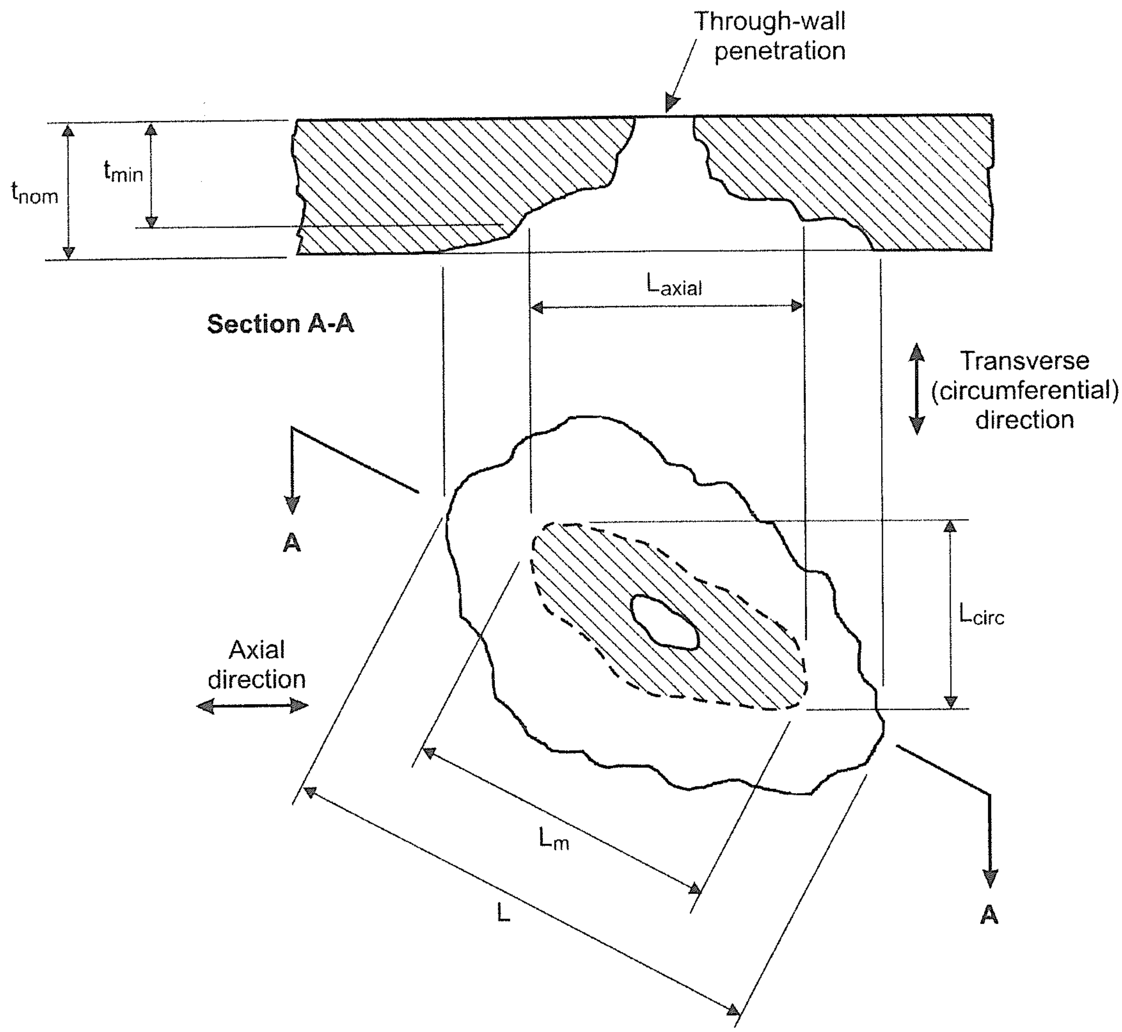

Figure 1. Planar Characterization of Through-wall, Nonplanar Flaw

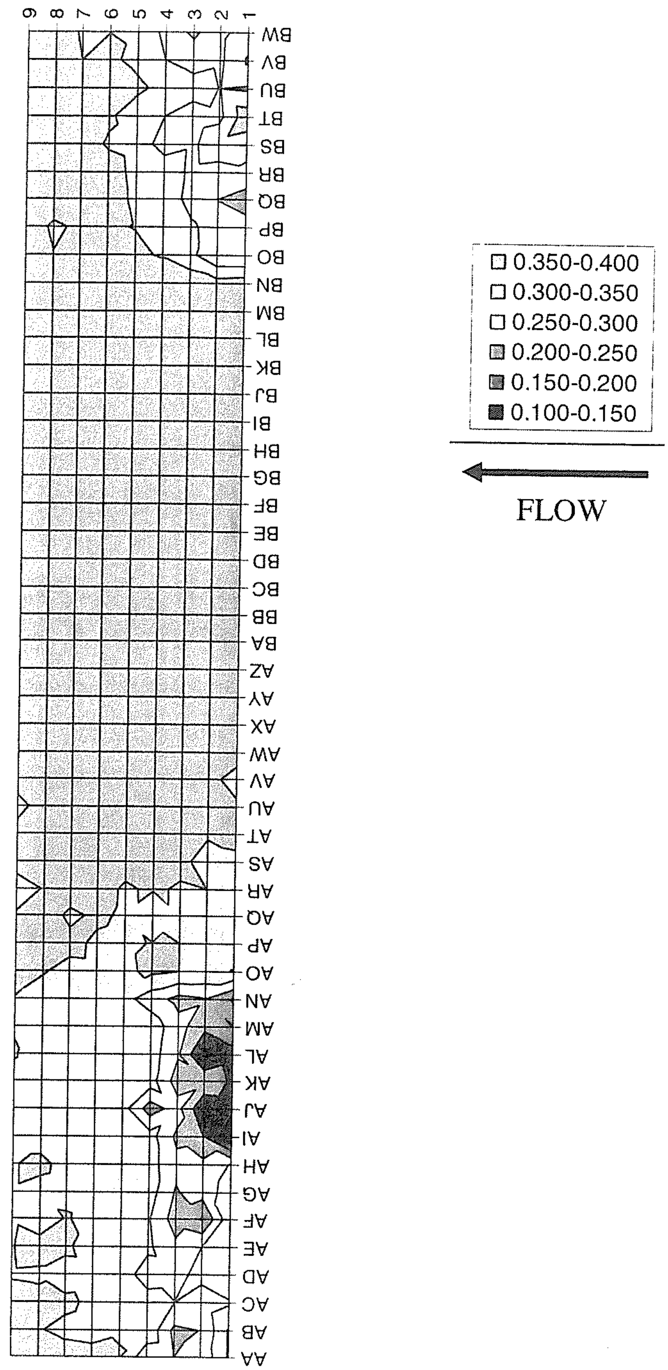

Figure 2. NDE Inspection Data of Effected Pipe Region from 10/27/06

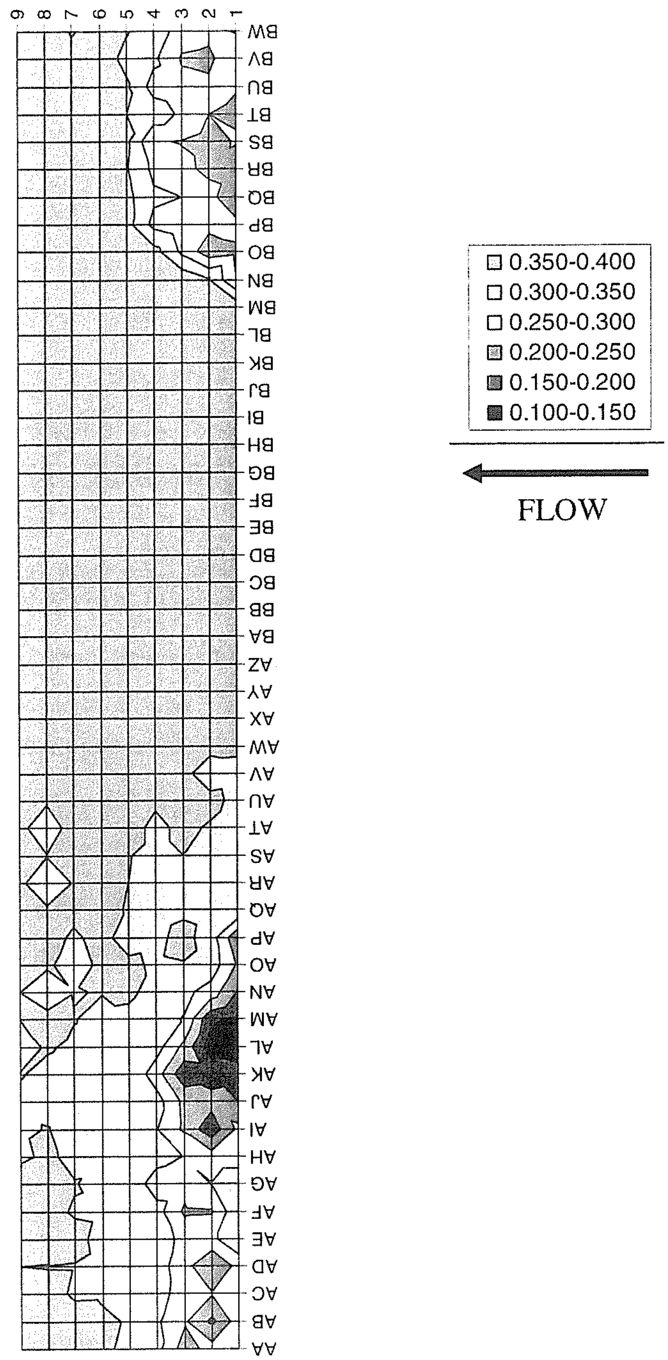

Figure 3. NDE Inspection Data of Effected Pipe Region from 2/14/07

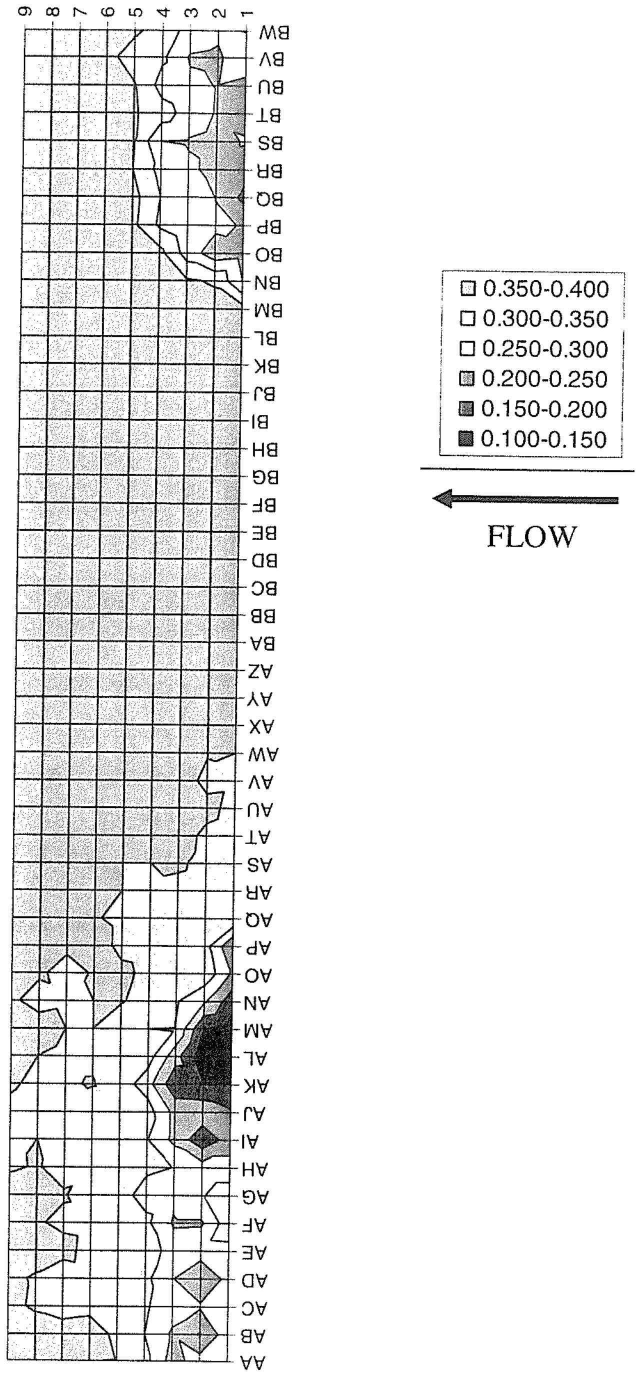

Figure 4. NDE Inspection Data of Effected Pipe Region from 5/09/07

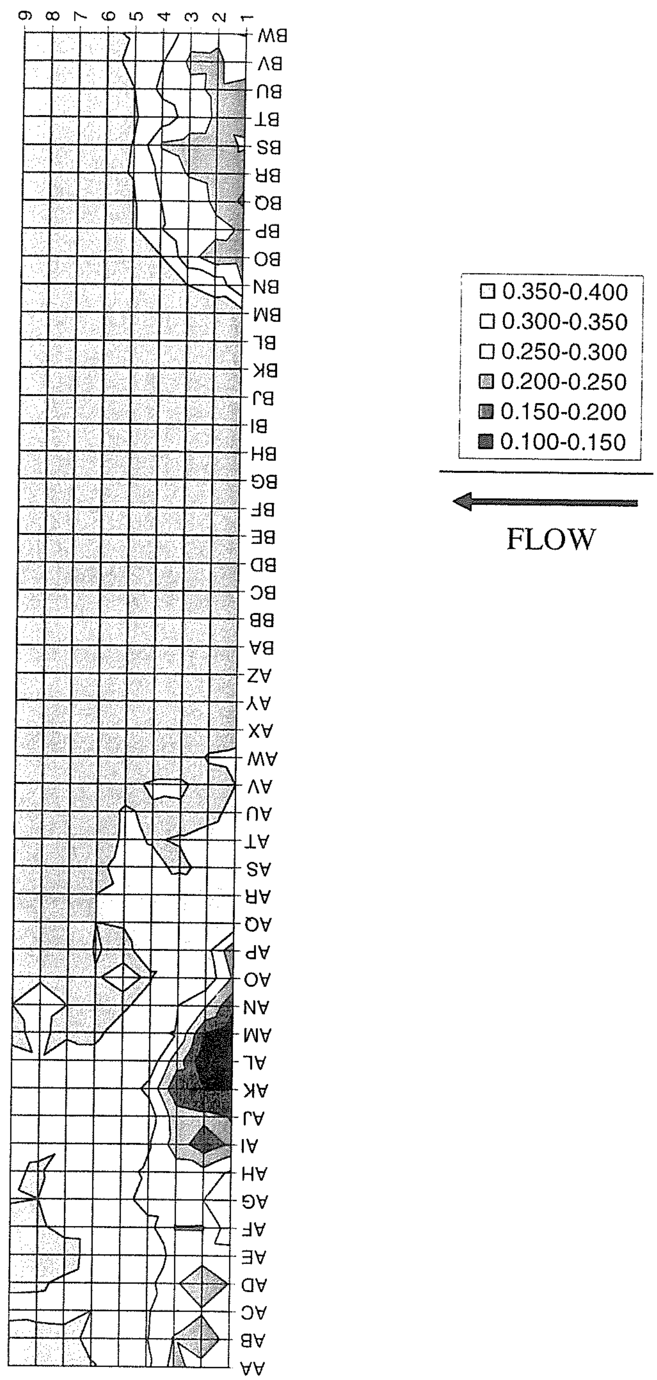

Figure 5. NDE Inspection Data of Effected Pipe Region from 7/02/07

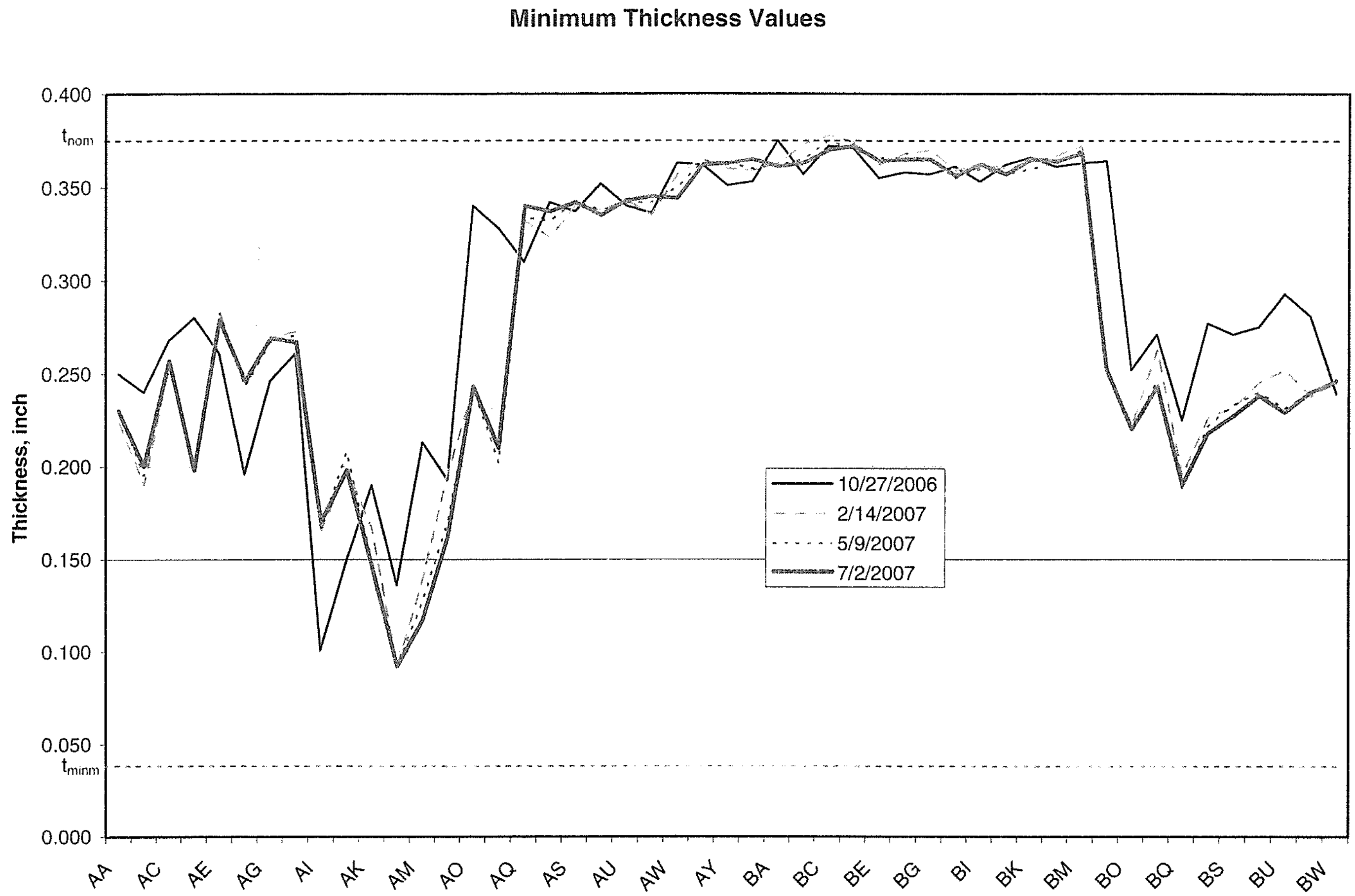

Figure 6. Circumferential Profile – Minimum Values

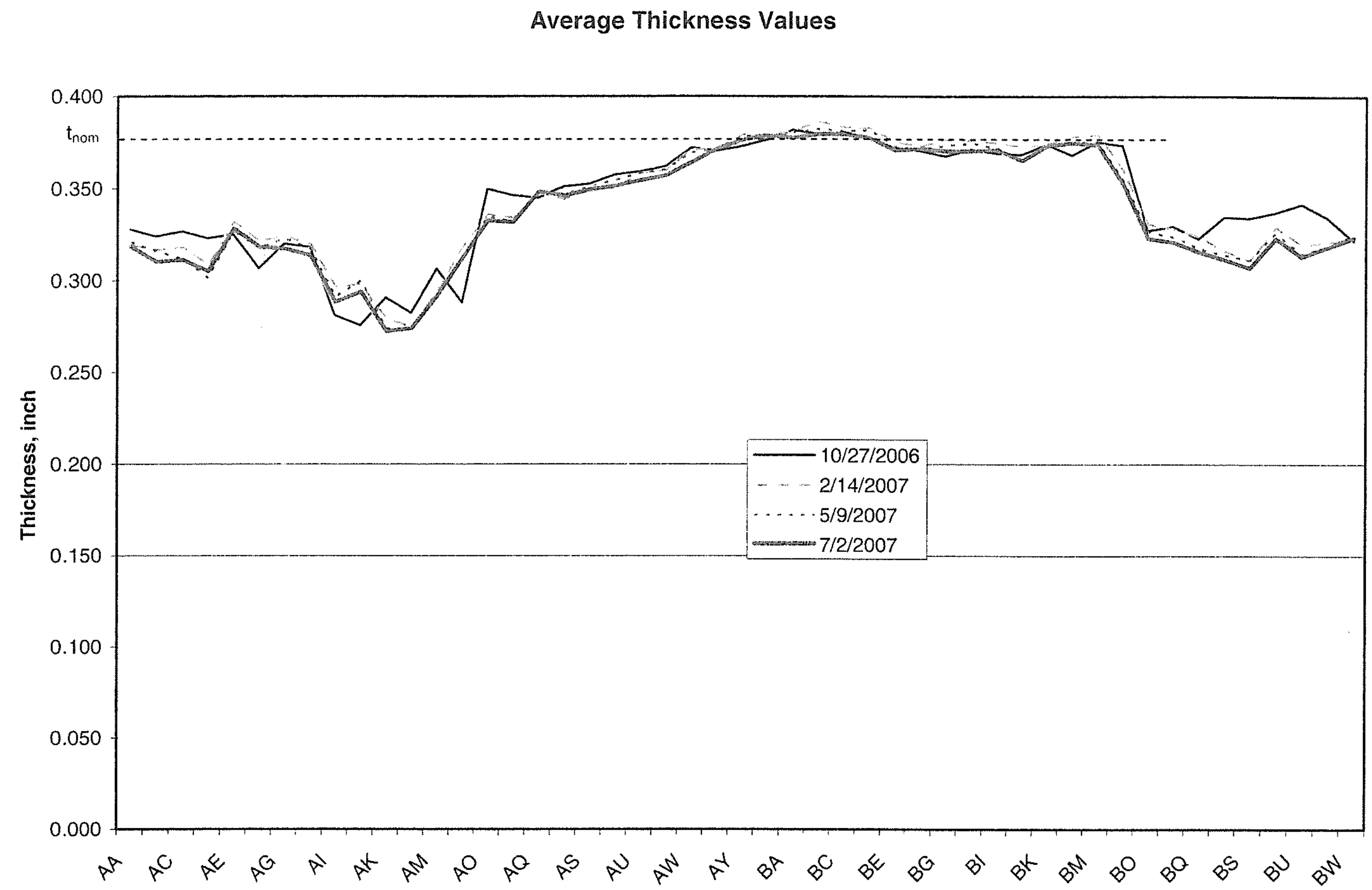

Figure 7. Circumferential Profile – Averages

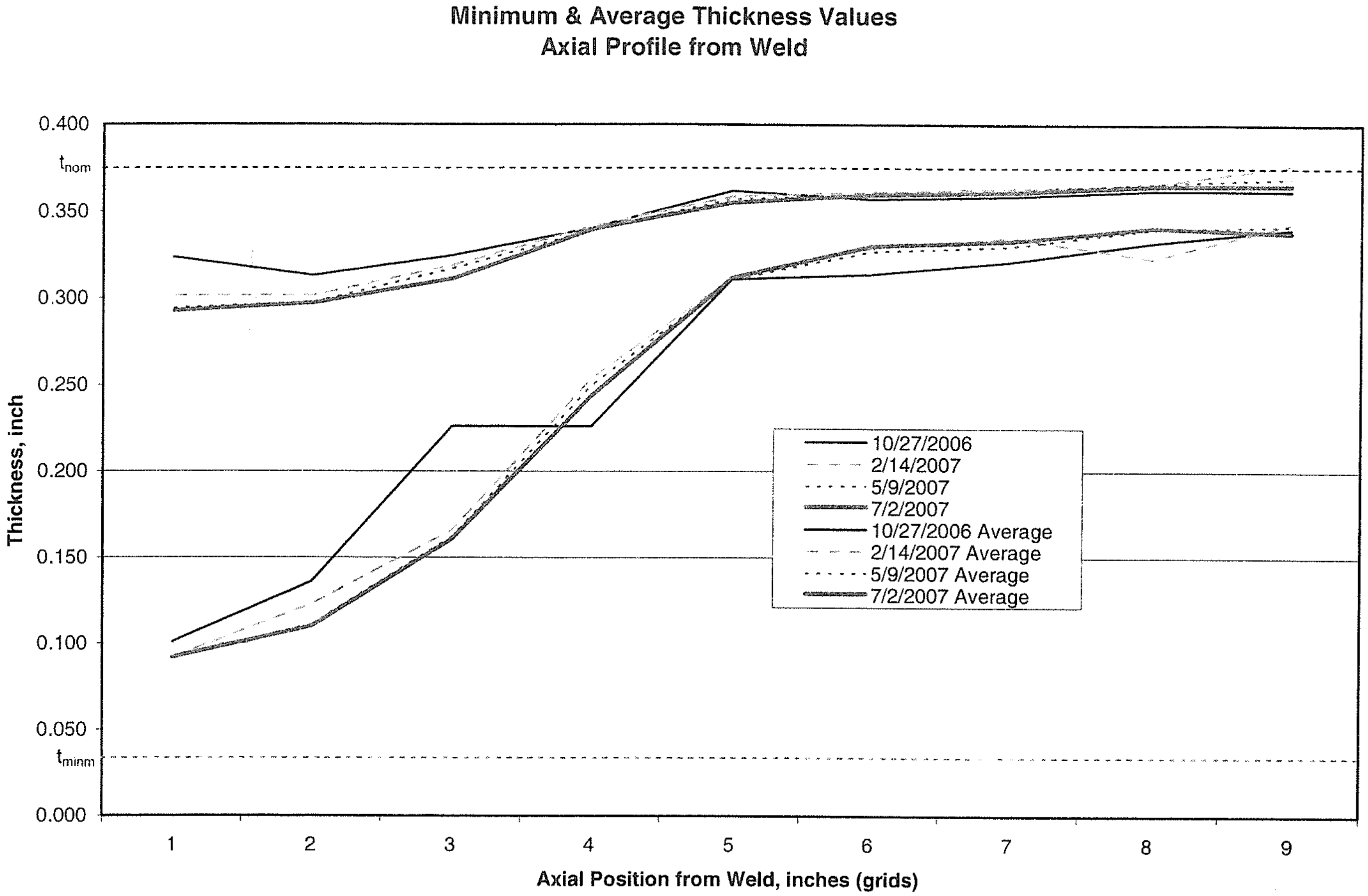

Figure 8. Axial Profiles

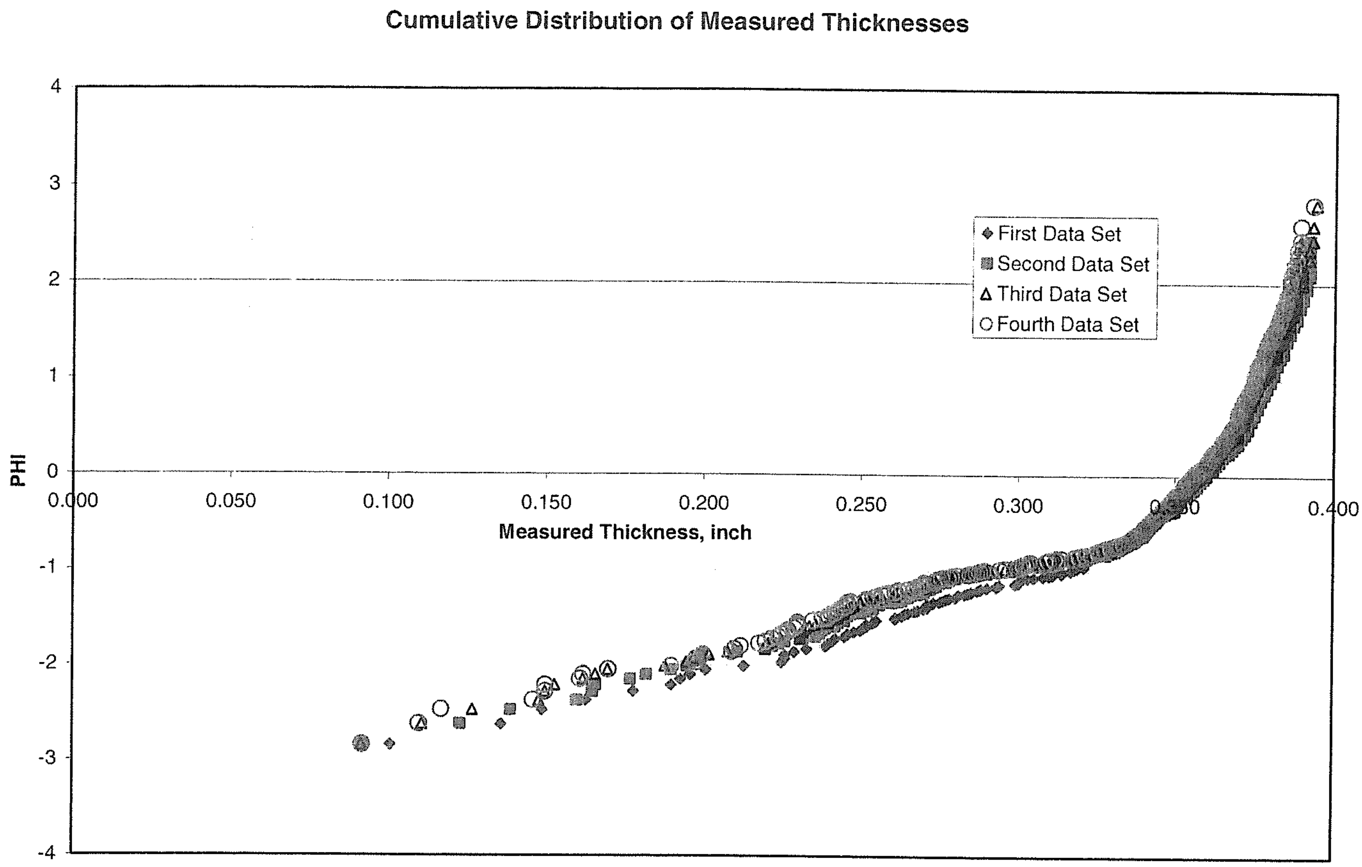

Figure 9. Cumulative Distribution of Measured Thickness

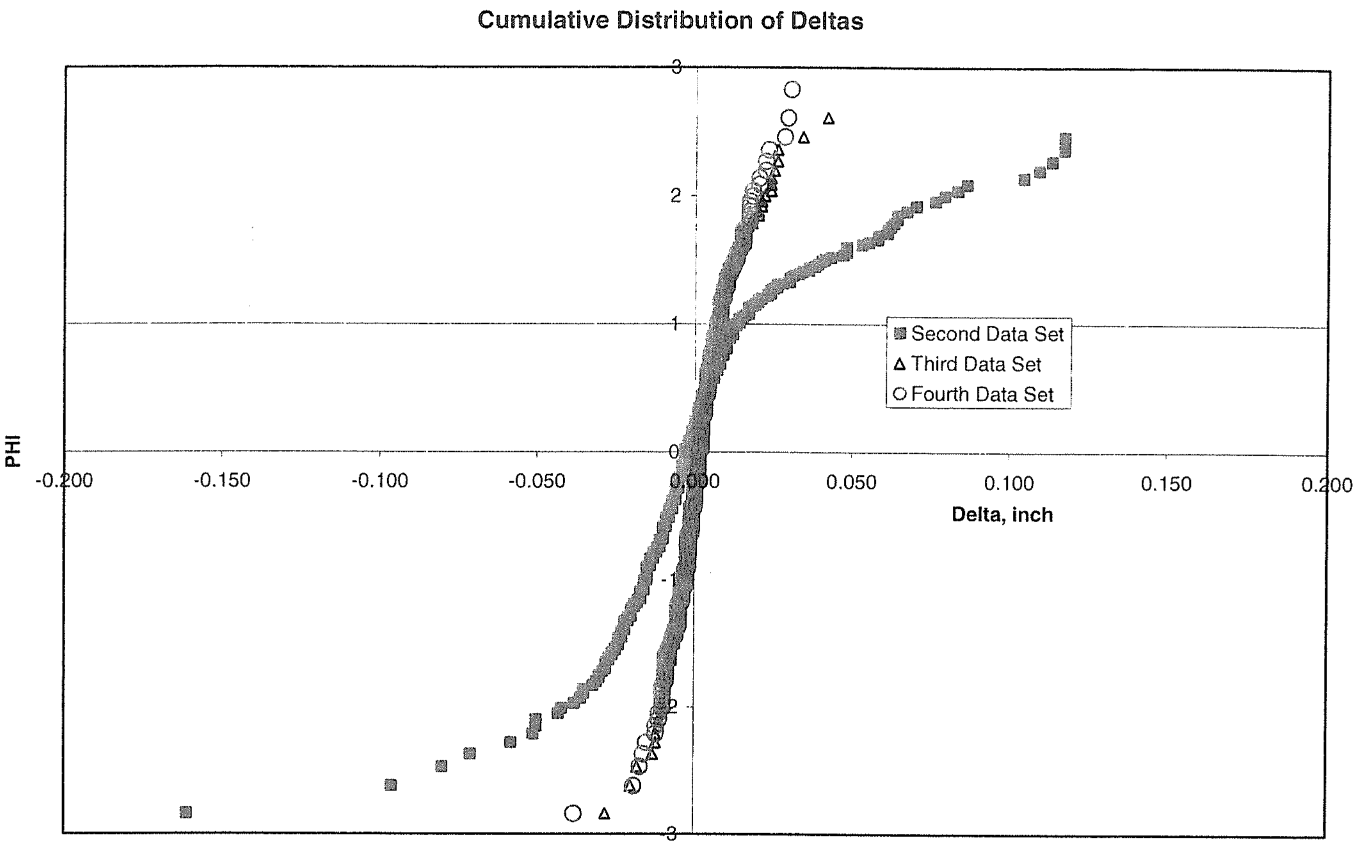

Figure 10. Cumulative Distribution of Deltas (point-to-point thickness differences from one examination to the next)

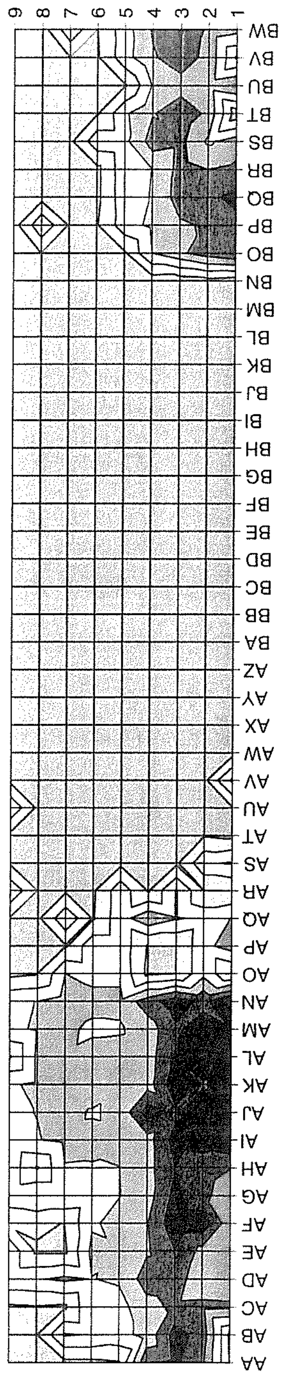

Figure 11. Predicted UT Thickness Map, September 2009

APPENDIX A

SI Pipe Eval Input and Output

Table A-1: SI Pipe Eval Input

Structural Integrity Associates, Inc.

Best Viewed with 1024 x 768 Screen Resolution

SI PIPE EVAL

Evaluation Criteria for Temporary Acceptance of Flaws in Moderate Energy Class 2 or 3 Piping Section XI, Division 1

INPUT

OUTPUT

Pipe & Loading Input

Pipe OD =	16 in
Pipe Thickness =	0.375 in
Pipe Pressure =	50 psig
Operating Temperature =	200 °F
Resultant DW Moment =	75,523 in-lbs
Resultant Seismic OBE Moment =	0 in-lbs
Resultant Seismic DBE Moment =	0 in-lbs
Resultant Thermal Moment =	0 in-lbs
Select Service Level	A

Flaw Description

Axial Nonplanar

Flaw Length =	4 in
Flaw to Thickness Ratio (a/t) =	1.00

Through-wall Flaws (a/t = 1)

Evaluate Flaw

Allowable Flaw: 36.52 in

Code Case Evaluation: PASS

Material Properties

Austenitic

Ferritic

Allowable Design Stress, S =	12.0 ksi
Code Yield Strength, S_y =	30.0 ksi
Code Tensile Strength, S_u =	48.0 ksi
Young's Modulus =	28,600 ksi

NOTE: Results must be cleared prior to new run.

Clear Results

Help

Version 1.3

Execution Date: 7/21/2007

Notes:

1. Resultant DW moment = $\frac{P_b I}{R}$, where I = moment of inertia and R = outside pipe radius.
2. Flaw length is arbitrarily chosen.

Table A-2: SI Pipe Eval Axial Evaluation Output

SI PIPE EVAL, SOLUTION SUMMARY: Axial Nonplanar, Ferritic
(Note: flaw is treated as an axial ***and*** circumferential planar flaw. Flaw must pass both conditions.)

Description of Solution Methodology:
A screening criteria [ASME Section XI Appendix C (2001), Section C-4300] must first be performed to determine the fracture analysis method. If the screening criteria calls for an EPFM or Limit Load analysis, then the inputs provided are used with the hoop stress and material flow stress calculated from Equations 2 and 3 of Code Case N-513-2 for use in Equation 1 to determine the allowable flaw length. If the screen criteria calls for an LEFM analysis, then the inputs provided are used with the evaluations procedures described in Section C-7200. An iterative process is used to determine the allowable flaw length.

SCREEN CRITERIA DETERMINATION

Screening Criteria = 1.73 $SC = K_r^{'} / S_r^{'}$ Section XI Appendix C, Figure C-4220-1

$\frac{SC < 0.2}{\text{Limit Load}}$	$\frac{0.2 \le SC < 1.8}{\text{EPFM}}$	$\frac{SC \ge 1.8}{\text{LEFM}}$

$K_r^{'} =$ 0.067 $K_r^{'} = \left[1000K_I^2 / E'J_{Ic}\right]^{0.5}$ Section XI Appendix C, Section C-4310

$S_r^{'} =$ 0.038 $S_r^{'} = (pR_m / t) / \sigma_y$ Section XI Appendix C, Section C-4310 (Note: sigma y used instead of sigma I for through-wall flaw.)

Variables Used In Above Equations:

$K_I =$ 2.502 psi-in$^{1/2}$ $K_I = (pR_m / t)(\pi a / Q)^{0.5} F$ Section XI Appendix C, Section C-4312

$R_m =$ 7.8125 in $R_m = \frac{D_o - t}{2}$ $Q =$ 1.09 $Q = 1 + 4.593(a/l)^{1.65}$ Section XI Appendix C, Section C-4312

$F =$ 2.31 $F = 1.12 + 0.053\alpha + 0.0055\alpha^2 + (1.0 + 0.02\alpha + 0.0191\alpha^2)(20 - R_m/t)^2 / 1400$ Section XI Appendix C, Section C-4312

$\sigma_y =$ 27,100 psi Section XI Appendix C, Figure C-4220-1

$E' =$ 3.1E+07 psi $E' = E / (1 - \upsilon^2)$ Section XI Appendix C, Section C-1300 $J_{Ic} =$ 45 in-lb/in^2

LIMIT LOAD & EPFM ANALYSIS ***THIS ANAYSIS IS USED***

Flow Stress = 39,000 psi $\sigma_f = (S_y + S_u)/2$ Code Case N-513-2 Equation 3

Hoop Stress = 1,067 psi $\sigma_h = pD_o / 2t$ Code Case N-513-2 Equation 2

Structural Factor, Membrane = 2.7 Section XI Appendix C, Section C-2622

Allowable Flaw Length = 36.52 in $l_{all} = 1.58\sqrt{Rt}\left[\left(\frac{\sigma_f}{SF_m \sigma_h}\right)^2 - 1\right]^{\frac{1}{2}}$ Code Case N-513-2 Equation 1

Table A-3: SI Pipe Eval Circumferential Evaluation Output

SI PIPE EVAL, SOLUTION SUMMARY: Circumferential Nonplanar, Ferritic
(Note: flaw is treated as an axial ***and*** circumferential planar flaw. Flaw must pass both conditions.)

Description of Solution Methodology:
A screening criteria [ASME Section XI Appendix C (2001), Section C-4300] must first be performed to determine the fracture analysis method. If the screening criteria calls for a Limit Load analysis, then inputs provided are used with ASME Section XI Appendix C (2001), Section C-5320. An iterative approach is used on theta (half crack angle) to determine the allowable flaw size conforming to the allowable pipe bending stress ***and*** allowable pipe membrane stress. If the screening criteria calls for an EPFM analysis, then the inputs provided are used with Section C-6320. The analysis is identical to the Limit Load analysis except that a Z adjustment factor is used in determining the allowable pipe bending and membrane stresses. If the screen criteria calls for an LEFM analysis, then the inputs provided are used with the evaluations procedures described in Section C-7200. An iterative process is used to determine the allowable flaw length.

$\frac{R_m}{t} =$ 20.83 **The ratio of mean radius to thickness is greater than 20, thus the analysis will be conservative.** $R_m =$ 7.81 in $R_m = \frac{D_o - t}{2}$

SCREEN CRITERIA DETERMINATION

Screening Criteria = 2.45 $SC = K_r' / S_r'$ Section XI Appendix C, Figure C-4220-1

$\frac{SC < 0.2}{\text{Limit Load}}$ $\frac{0.2 \le SC < 1.8}{\text{EPFM}}$ $\frac{SC \ge 1.8}{\text{LEFM}}$

$K_r' =$ 0.088 $K_r' = \left[1000K_I^2 / E'J_{Ic}\right]^{0.5}$ Section XI Appendix C, Section C-4310

$S_r' =$ 0.036 $S_r' = (\sigma_b + \sigma_e)/\sigma_b'$ when $(\sigma_b + \sigma_e) \ge \sigma_m$ else $S_r' = \sigma_m / \sigma_m'$ Section XI Appendix C, Section C-4310

Variables Used in Above Equations:

$K_I =$ 37,371 psi-in$^{1/2}$ $K_I = K_{Im} + K_{Ib}$ Section XI Appendix C, Section C-4311

$K_{Im} =$ 18,635 psi-in$^{1/2}$ $K_{Im} = \left[P/(2\pi R_m t)\right](\pi a)^{0.5} F_m$ Section XI Appendix C, Section C-4311, where: $P =$ 9,133 lbs

$K_{Ib} =$ 18,736 psi-in$^{1/2}$ $K_{Ib} = \left[M/(\pi R_m^2 t)\right](\pi a)^{0.5} F_b$ Section XI Appendix C, Section C-4311, where: $M =$ 75,523 in-lbs

$F_m =$ 11.92 $F_m = 1.10 + x\left[0.15241 + 16.772(x\theta/\pi)^{0.855} - 14.944(x\theta/\pi)\right]$ Section XI Appendix C, Section C-4312

$F_b =$ 6.98 $F_b = 1.10 + x\left[-0.09967 + 5.0057(x\theta/\pi)^{0.565} - 2.8329(x\theta/\pi)\right]$ Section XI Appendix C, Section C-4312

$E' =$ 3.1E+07 psi $E' = E/(1-\upsilon^2)$ Section XI Appendix C, Section C-1300 $J_{Ic} =$ 45 in-lb/in^2

$\sigma_b =$ 1,075 psi $\sigma_e =$ 0 psi $\sigma_m =$ 533 psi

$\sigma_b = D_o M_b / 2I$ $\sigma_e = D_o M_e / 2I$ $\sigma_m = pD_o / 4t$ Section XI Appendix C, Section C-2500

$\sigma_b' =$ 29,878 psi $\sigma_b' = \frac{2\sigma_y}{\pi}\left[2\sin\beta - \frac{a}{t}\sin\theta\right]$ where $\beta = \frac{1}{2}\left[\pi - \frac{a}{t}\theta - \pi\frac{\sigma_m}{43.4}\right]$ when $(\theta+\beta) \le \pi$ Section XI Appendix C, Section C-4311

$\sigma_b' = \frac{2\sigma_y}{\pi}\left[\left(2 - \frac{a}{t}\right)\sin\beta\right]$ where $\beta = \pi\left(1 - \frac{a}{t} - \frac{\sigma_m}{43.4}\right)/\left(2 - \frac{a}{t}\right)$ when $(\theta+\beta) > \pi$

$\sigma_y =$ 27,100 psi Section XI Appendix C, Figure C-4220-1

$\sigma_m' =$ 22,804 psi $\sigma_m' = \sigma_y\left[1 - \frac{a}{t}\frac{\theta}{\pi} - \frac{2\varphi}{\pi}\right]$ where $\varphi = \arcsin\left[0.5\frac{a}{t}\sin\theta\right]$ Section XI Appendix C, Section C-4311

Table A-3: SI Pipe Eval Circumferential Evaluation Output (cont.)

SI PIPE EVAL, SOLUTION SUMMARY: Circumferential Nonplanar, Ferritic (continued)

LEFM ANALYSIS

Structural Factor, Membrane = 2.7 Structural Factor, Bending = 2.3 Section XI Appendix C, Section C-2621

$\sigma_b =$ 1,075 psi $\sigma_e =$ 0 psi $\sigma_m =$ 533 psi

$\sigma_b = D_o M_b / 2I$ $\sigma_e = D_o M_e / 2I$ $\sigma_m = pD_o / 4t$ Section XI Appendix C, Section C-2500

$F_m =$ 11.92 $F_m = 1 + A_m(\theta/\pi)^{1.5} + B_m(\theta/\pi)^{2.5} + C_m(\theta/\pi)^{3.5}$ Code Case N-513-2 Appendix I-2.0

where:

$A_m = -2.02917 + 1.67763(R_m/t) - 0.07987(R_m/t)^2 + 0.00176(R_m/t)^3$

$B_m = 7.09987 - 4.42394(R_m/t) + 0.21036(R_m/t)^2 - 0.00463(R_m/t)^3$

$C_m = 7.79661 + 5.16676(R_m/t) - 0.24577(R_m/t)^2 + 0.00541(R_m/t)^3$

$F_b =$ 6.98 $F_b = 1 + A_b(\theta/\pi)^{1.5} + B_b(\theta/\pi)^{2.5} + C_b(\theta/\pi)^{3.5}$ Code Case N-513-2 Appendix I-2.0

where:

$A_b = -3.26543 + 1.52784(R_m/t) - 0.072698(R_m/t)^2 + 0.0016011(R_m/t)^3$

$B_b = 11.36322 - 3.91412(R_m/t) + 0.18619(R_m/t)^2 - 0.004099(R_m/t)^3$

$C_b = -3.18609 + 3.84763(R_m/t) - 0.18304(R_m/t)^2 + 0.00403(R_m/t)^3$

$K_{Im} =$ 18,635 $K_{Im} = (SF_m)F_m\sigma_m(\pi a)^{0.5}$ Section XI Appendix C, Section C-7300

$K_{Ib} =$ 18,736 $K_{Ib} = \left[(SF_b)\sigma_b + \sigma_e\right]F_b(\pi a)^{0.5}$ Section XI Appendix C, Section C-7300

$K_{Ir} =$ 0 K_I from residual stresses at the flaw location, Section XI Appendix C, Section C-7300

$K_I =$ 37,371 psi-in$^{1/2}$ $K_I = K_{Im} + K_{Ib} + K_{Ir}$ Section XI Appendix C, Section C-7300

$K_c =$ 37,607 psi-in$^{1/2}$ $K_c = (J_{Ic}E'/1000)^{0.5}$ Section XI Appendix C, Section C-7200

Allowable Flaw Length = 35.87 in Entered Flaw Length = 4.0 in

The half flaw length is incrementally increased up to the stability condition limit: $K_I \le K_c$