ATTACHMENT A

"ANALYTICAL EVALUATION OF INDICATION IN WELD 32-WD-050 FOR DER 1-97-0877"

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Analytical Evaluation of Indication in Weld 32-WD-050 for DER 1-97-0877 (Recirculation System Loop 12)	Calculation No. S12.9-32M028			
	(Sub)system(s) 32	Building Drywell	Floor Elev. 237'	Index No. S12.9
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MPR
ASSOCIATES INC.
ENGINEERS

Analytical Evaluation of Indication in Weld 32-WD-050 For DER 1-97-0877

Revision 0

April 4, 1997

QUALITY ASSURANCE DOCUMENT
This document has been prepared, reviewed, and approved in accordance with the Quality Assurance requirements of 10CFR50 Appendix B, as specified in the MPR Quality Assurance Manual.

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CONTENTS

Section 1

BACKGROUND AND PURPOSE

DER 1-97-0877 (Reference 1) reports that during refueling outage RFO14 at NMP-1, a non-geometric planar indication was discovered by ultrasonic examination during inservice inspection of weld 32-WD-050. The weld is located in the NMP-1 recirculation system piping, in the suction riser of the Loop 12 recirculation loop. Weld 32-WD-050 is a circumferential weld joining the downstream side of suction side block valve 32-376 to the adjacent pipe spool. The weld was identified during construction as 32-FW-12S-5. Section 3.2 of this report summarizes key information pertaining to the pipe, weld and indication documented in the DER and other references.

The acceptance criteria for flaws in piping are documented in the ASME Code Section XI, 1983 Edition with Summer 1983 addenda (Reference 2), which is the governing code for NMP-1 inservice inspections. NMPC personnel documented in DER 1-97-0877 that the indication observed does not meet the acceptance criteria in Section XI Table IWB-3410-1.

Paragraph IWB-3132 of the 1986 Edition of Section XI states that components whose volumetric examination reveals flaws that do not meet the acceptance criteria of Table IWB-3410-1 shall be corrected either by repair or replacement, or accepted by analytical evaluation for service. (Section 3.1 below provides the basis for using the 1986 Edition of Section XI.) Requirements for acceptance by analytical evaluation are provided in paragraphs IWB-3132.4, IWB-3600, and Appendix C to Section XI.

Appendix C to Section XI rules for analytical evaluation require flaw growth analysis for stress corrosion cracking or fatigue, or both, as appropriate to the flaw under evaluation.

The purpose of this report is to document the analytical evaluation per Section XI of the reported indication. In particular, the report documents the following steps taken to evaluate the indication:

- Section 2 summarizes the results of investigation by NMPC to characterize the flaw and identify its apparent cause.

- Section 3 documents the flaw growth analysis and acceptance evaluation for the flaw based on growth due to stress corrosion cracking and due to fatigue.

A summary is provided in Section 4.

Section 2

APPARENT CAUSE FOR THIS INDICATION

The flaw described in DER 1-97-0877 is circumferentially oriented on the pipe ID and is located in the piping base metal immediately adjacent to a circumferential weld. Flaws of this type may result from an original weld defect or from intergranular stress corrosion cracking (IGSCC) attack.

To characterize the indication and identify its apparent cause, NMPC investigated the history of weld 32-WD-050 and performed additional non-destructive examinations of the area near the indication. Results of these activities are as follows:

- <u>History.</u> Weld 32-WD-050 was installed in 1982-3 when the original recirculation system piping was replaced with stainless steel material with enhanced resistance to intergranular stress corrosion cracking. The weld was made using procedures designed to minimize sensitization of the pipe base metal adjacent to welds. In 1986, Weld 32-WD-050 was stress improved by induction heating.

  Plant records show that a radiographic test performed following the root pass of this weld identified an area of incomplete fusion (Reference 3). The affected area was removed by grinding and rewelded. No indications were observed in a follow-up RT examination after the repair.

  An ultrasonic examination of Weld 32-WD-050 was performed following installation. No indications were reported at that time (Reference 4). There have been no other inservice volumetric examinations of this weld prior to RFO14.

- <u>Additional NDE.</u> Upon discovery of the indication in RFO14, NMPC re-examined the radiographic films from the 1982-3 installation and performed additional ultrasonic and radiographic examinations to characterize the flaw. This effort revealed that the indication reported in DER 1-97-0877 is in the same location as the area of incomplete fusion reported during installation (Reference 5). The indication cannot be seen in the radiographic film taken after the 1983 root pass repair or in the film taken in RFO14.

  After the indication was found, NMPC performed ultrasonic examination of an expanded sample of nine other circumferential welds in Recirculation Loops 11, 12 and 13. No other indications were identified in this expanded sample or in the other 14 recirculation system piping circumferential welds examined in RFO14.

As stated earlier, the cause of the indication could not be positively ascertained by the non-destructive examinations performed to date. The indication may be a remnant of the installation root pass weld repair performed in the same location. However, it is possible that the flaw resulted from IGSCC attack, possibly initiating in the pipe ID at the location of the root pass weld repair.

IGSCC attack is not expected in this weld for the following reasons:

- The replacement piping material and weld procedures were specified and selected to enhance resistance to IGSCC.
- The weld was stress improved by induction heating stress improvement.
- IGSCC has not been detected elsewhere in the replacement piping installed in 1982-3.

In summary, the cause of the indication has not been determined. It may be an original weld defect, or it may result from IGSCC attack, possibly initiated at the area of the root pass weld repair. Evaluation of the acceptability of this indication will therefore be performed assuming in one case that IGSCC is occurring and in a second case that the flaw is a mechanical defect which could grow due to fatigue.

Section 3

ANALYTICAL EVALUATION

3.1 Section XI Analytical Evaluation Methodology

Paragraph IWB-3132 of the 1986 Edition of Section XI states that components whose volumetric examination reveals flaws that do not meet the acceptance criteria of Table IWB-3410-1 shall be corrected either by repair or replacement, or accepted by analytical evaluation for service. Requirements for acceptance by analytical evaluation are provided in paragraphs IWB-3132.4, IWB-3600, and Appendix C to Section XI.

Appendix C to Section XI provides rules for flaw modeling and evaluation. Flaw growth analysis is based on growth due to stress corrosion cracking or fatigue, or both, as appropriate to the flaw under evaluation.

As described in Section 2 of this report, the cause of the indication reported in DER 1-97-0877 cannot be positively identified. The indication may be a remnant of the installation root pass weld repair performed in the same location, or it may have resulted from IGSCC attack initiated in the pipe ID at the location of the root pass weld repair. Therefore, the analytical evaluation will consider the acceptability of the indication from the standpoint of stress corrosion cracking, and from the standpoint of fatigue.

Note that both NUREG-0313 Revision 2 (Reference 6) and Generic Letter 88-01 (Reference 7) refer to the 1986 Edition of ASME Code Section XI IWB-3600 for evaluation of flaws caused by intergranular stress corrosion cracking (IGSCC). This Code Edition provides detailed requirements for evaluation of IGSCC indications. Therefore, the 1986 Edition of Section XI will be used in this report to evaluate the acceptability of the reported indication for IGSCC. The 1986 Edition will be used for evaluation of fatigue as well.

3.2 Analytical Evaluation of the Indication for Stress Corrosion Cracking

Rules for analytical evaluation of stress corrosion cracking are provided in Section XI, Appendix C. Flaws are evaluated by comparing the maximum flaw dimensions (determined by flaw growth analysis) at the end of a selected evaluation period with the maximum allowable flaw dimensions specified in the Code. Flaw growth due to stress corrosion cracking is computed as a function of material condition, environment, the stress intensity factor due to sustained loading, and the total time that the flaw is exposed to the environment

under sustained loading. The maximum allowable flaw dimensions specified in the code provide a margin of safety for plastic limit load on the pipe section.

In 1988 NMPC obtained computer program SSFLAW, which was developed to evaluate the acceptability of IGSCC flaws in stainless steel piping per the requirements of ASME Section XI. Reference 8 describes the program, its development, and use, and provides a user manual for the program.

The program uses the methodology of the 1986 Edition of Section XI (which is cited in NUREG-0313 Revision 2 as the Code Edition which should be used for these evaluations) to calculate the final flaw length and depth at the end of a service interval, given the initial flaw geometry, applied stresses and pressure loadings, weld characteristics, and key piping geometry and material properties. In brief, the program performs the following steps required by Section XI to evaluate the acceptability of flaws:

- SSFLAW calculates stresses on the pipe section resulting from residual stress due to welding (the major stress affecting flaw growth rate), and combines these stresses with stresses applied from mechanical loads on the pipe cross section. The program then uses these stresses to calculate the instantaneous flaw growth rate. In addition to pressure stress, the applied loadings used to determine the sustained flaw growth rate are thermal expansion and deadweight.

- The flaw size is increased by integrating the calculated instantaneous flaw growth rate with time. The final flaw size at the end of the service interval is then calculated.

- SSFLAW compares the calculated flaw size at the end of the service interval to the allowable depth (from the tables in IWB-3640 of Section XI) for normal plus upset conditions, and for faulted plus emergency conditions. These conditions include pressure, deadweight, and earthquake loads. For high toughness welds like the gas tungsten-arc weld in the subject joint, the loads used for calculating acceptable flaw size do not include the effect of secondary loads (such as thermal expansion loads and residual stresses).

Program SSFLAW was used to determine the final flaw size of the indication reported in DER 1-97-0877 at the end of the upcoming two year run cycle, and to compare that flaw size to the Section XI acceptance criteria. The following sections discuss the program inputs and run results.

3.2.1 Program SSFLAW Inputs

Appendix A to the SSFLAW user's manual (Reference 8) describes the inputs required to run the program. The required inputs are listed below, along with the values to be used in the program.

- Pipe Material. Per the Piping Specification Standard Record Set (Reference 9) for the recirculation system piping (System 32), the large bore recirculation system piping is made from Type 316 stainless steel.

- Material Design Stress Intensity (S_m) and Yield Strength (S_y). SSFLAW default values for these parameters are used. The program calculates these parameters for Type 316 material at the operating temperature of the system (discussed below).

- Weld Type. The recirculation system piping was replaced in 1983 with IGSCC resistant material. All circumferential welds made during this replacement were gas tungsten-arc welds (GTAW).

- Residual Stress State. Weld 32-WD-050 was stress improved by induction heating stress improvement in 1986 (one full operating cycle following the replacement). However, as discussed in Section 3 of this report, this weld underwent a local weld root pass repair due to incomplete fusion found during welding; consequently, the local pipe ID stress state near this weld may be non-uniform. For conservatism, the residual stress state in the vicinity of the weld will therefore be considered "as-welded" rather than stress improved.

- Operating Temperature. Per the Piping Specification Standard Record Set for the recirculation system piping, the operating temperature is 550°F.

- Operating Pressure. Per Reference 8, the operating pressure of the reactor vessel is 1050 psig. This is slightly higher than the saturation pressure at the operating temperature of 550°F.

- Pipe Outside Diameter and Wall Thickness. The Piping Specification Standard Record Set states that the large bore recirculation system piping is 28-inch OD, 1.05-inch minimum wall. DER 1-97-0877 provides field NDE records which show that the measured wall thickness is 1.1-inch in the vicinity of the indication. For this evaluation, the specified minimum of 1.05-inch will be used.

- Flaw Orientation, Length and Depth. Per the DER, the orientation is circumferential, the flaw length is 1.25-inch, and the depth is 0.25-inch.

- Service Interval. This is the interval between inspections of the indication. Paragraphs IWB-3132.4(b) and IWB-2420(b) of Section XI require that flaws found acceptable for continued service by the evaluation criteria shall be re-examined during the next three inspection periods. NMP-1 performs inspections at each refueling outage; since the run cycles are two years long, the service interval is therefore considered to be two years (730 days).

- Applied Stresses. Stresses are calculated based on the results of stress analyses of the replaced piping performed by Teledyne in 1983 (Reference 10). Appendix A to this

report documents how the applied stresses used as input for SSFLAW were determined from the Teledyne stress results.

- Reference Source for Allowable Flaw Size. SSFLAW permits using either the Section XI Table IWB-3641 allowables for flaw size, or an alternate (less conservative) method based on the equations in Section XI Appendix C. For this evaluation, the more conservative tables will be specified as the reference source.

3.2.2 Calculated Final Flaw Size and Comparison to Acceptance Criteria

Appendix B to this report presents the printout from two SSFLAW runs. The first run shows that under the normal loading condition the flaw reported in the DER is calculated to grow by stress corrosion cracking to about 0.5-inch in depth by the end of the next two year operating cycle. The second run shows that at that depth, the flaw is acceptable for normal plus upset conditions -- that is, normal plus earthquake loads, and for emergency plus faulted conditions. Specifically, the calculated flaw depth is less than the maximum code allowable depth for plastic collapse of 0.787-inch for these loads. Therefore, the flaw reported in DER 1-97-0877 meets the acceptance criteria of IWB-3600 and is acceptable for the next operating cycle, assuming it is growing due to stress corrosion cracking. (Section 3.3 below presents an analysis of the acceptability of the indication assuming it is growing due to fatigue. Fatigue crack growth is less than one mil and is insignificant.)

Note the following conservatisms are included in the analysis method:

- No credit is taken for the 1986 stress improvement.
- The minimum wall thickness of 1.05-inch was used instead of the measured thickness of 1.1-inch.
- Section XI tables of allowable flaw sizes include a factor of safety of 2.77 against net section collapse.

Program SSFLAW was developed and used in accordance with the MPR Associates Quality Assurance Plan.

3.3 Analytical Evaluation of the Indication for Fatigue

Section XI Appendix C provides rules for analytical evaluation of fatigue flaws. As was the case with stress corrosion cracking evaluation, fatigue flaws are evaluated by comparing the maximum flaw dimensions (determined by flaw growth analysis) at the end of a selected evaluation period with the maximum allowable flaw dimensions specified in the Code. Flaw growth rate due to fatigue is computed based on the range of the applied stress intensity factor for cyclic loadings, and on the material properties of the base metal. The maximum allowable

flaw dimensions specified in the code provide a margin of safety for plastic limit load on the pipe section.

The Appendix C method states that a cumulative fatigue flaw growth study should be performed considering design transients. For each transient, the maximum range of stress intensity factor is determined, and the corresponding incremental fatigue flaw growth rate is determined from fatigue flaw growth rate data. The flaw size is then updated by adding the incremental growth calculated in this manner, and the next transient is then considered. The final flaw size calculated after all transients are considered is then compared to the allowable flaw size in the tables in IWB-3640.

Flaw growth due to fatigue for the indication in Weld 32-WD-050 is calculated in Appendix C to this report. This calculation uses the following inputs:

- Cyclic loadings were determined assuming 20 startups and shutdowns, and ten cycles of seismic loads, in the service interval (the next operating cycle). The startup/shutdown cycles included cycling of pressure stress as well as thermal expansion stresses.

- Stresses for each cycle were determined using the Teledyne stress analysis report results for thermal expansion and seismic loads, and from longitudinal stress resulting from the system design pressure (1200 psig per the PSRS).

- Stress intensity factors were determined for cyclic loads using the method of Article A-3000 of Appendix A of Section XI. Correction factors for stresses and the flaw shape parameter were determined based on the flaw geometry and the applied stresses.

- The fatigue crack growth rate (da/dN) was determined using the high stress ratio curve for alloy steel wetted surface flaws in Section XI. This provides a worst case flaw growth rate for stainless steel.

The flaw growth due to fatigue for these conditions is less than 0.001-inch over the service interval, as presented in Appendix C of this report. This growth is negligible compared to the flaw size assuming growth by IGSCC. As described in Section 3.2, the allowable flaw size per Section XI is 0.787-inches deep in this material. Therefore, the 0.25-inch deep indication reported in DER 1-97-0877 is acceptable for fatigue growth over the two year service interval.

Section 4

SUMMARY

The cause of the indication has not been determined. It may be an original weld defect, or it may result from IGSCC attack, possibly initiated at the area of the root pass weld repair. Evaluation of the acceptability of this indication was therefore performed assuming in one case that IGSCC is occurring and in a second case that the flaw is a mechanical defect which could grow due to fatigue.

Analytical evaluation of the indication reported in DER 1-97-0877 shows that the indication meets the Section XI acceptance criteria for flaw size for at least the next two year operating cycle, assuming it could grow by either a stress corrosion cracking mechanism or a fatigue mechanism. Therefore, the indication need not be removed or repaired at this time.

Section 5

REFERENCES

1. DER 1-97-0877, "Unacceptable Section XI Indication."

2. ASME Code Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components."
   -- 1983 Edition with Summer 1983 addenda.
   -- 1986 Edition.

3. Newport News Industrial Corporation Weld History Record for Weld Joint Number FW-12S-5, released 2/2/83 (Access Number 00789-0802).

4. NES Data Sheet for Pre-Service Ultrasonic Examination of Weld 32-FW-12S-5 taken after IHSI (dated 2/21/83).

5. NMPC Memorandum from J. Swenszkowski to J. Wadsworth dated April 1, 1997, "32-WD-050," File Code QA97128.

6. NUREG-0313, Revision 2, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping -- Final Report," published January 1988.

7. Generic Letter 88-01, NRC Position on IGSCC in BWR Austenitic Stainless Steel Piping, January 25, 1988.

8. MPR Report MPR-1037, Revision 1, "SSFLAW -- A Computer Program to Evaluate Cracks in Stainless Steel Piping (Version 1.1)," April 1988.

9. Piping Specification Standard Record Set for System 32, Revision 4.

10. Teledyne Engineering Services Technical Report TR-5828-1, "Reactor Recirculation Piping Replacement Analysis," 5/25/83.

11. ASM International, "Atlas of Stress-Corrosion and Corrosion Fatigue Curves," 1990.

Section 6

APPENDICES

Appendix A

Computation of Stresses For Input to SSFLAW

The following spreadsheet pages show the calculation of the applied primary axial stress, primary bending stress and secondary (thermal) stress for normal plus upset conditions, and for emergency plus faulted conditions, for the NMP-1 recirculation piping at the location of the 32-WD-050 weld.

The method used is as follows:

- The Teledyne stress analysis (Reference 10) of Recirculation Loop Number 12 was reviewed to determine which node in the finite element model corresponds to the location of Weld 32-WD-050. This node was determined to be node 140.

- Forces and moments at this node were determined from the Teledyne computer run HX3SBIV (4/12/83), included in Volume 2 of the Teledyne report, for the load cases considered by Teledyne in their analysis. These included:

  - Deadweight
  - Thermal expansion of the entire system from 70°F to 550°F.
  - Thermal expansion with the reactor at 550°F and the piping at a lower temperature
  - Seismic inertia loading in the X, Y and Z global directions
  - Seismic end effect loading in the X, Y and Z global directions

  (The seismic inertia cases were run with varying stiffness for sway struts; only the most conservative case results are considered in this appendix.)

- Forces and moments from these load cases were used to calculate the stresses for input to SSFLAW. Specifically, the following types of stress were calculated from the Teledyne results:

  - <u>Primary Axial And Primary Bending Stress for Normal Conditions</u>. SSFLAW uses these stresses to find the normal stress state sustained at the weld location. These stresses contribute to crack growth throughout the service interval. The only sustained stress of this type is due to deadweight (stress due to internal pressure is considered separately as described below).

    SSFLAW also uses these stresses, plus upset stresses, to determine whether the crack size at the end of the service interval meets the Section XI Table

IWB-3641-1 allowable flaw depth for normal plus upset conditions. The code allowable crack sizes are selected to prevent plastic collapse of the cracked section. Note that in order to accurately represent the normal plus upset case, the crack size at the end of the interval is first calculated using only the normal (deadweight) applied loads; next, a separate SSFLAW run is made in which the stress includes the seismic load (same as the emergency case). The crack size is evaluated separately for normal plus upset alone for that case.

-- <u>Secondary Stresses For Normal Conditions</u>. These stresses are due to thermal expansion and are assumed to be constant throughout the service interval. These stresses also contribute to crack growth rate, but per the Section XI methodology need not be considered in the plastic collapse evaluation for welds made using GTAW, as is the case for Weld 32-WD-050. (GTAW provides a high toughness joint, which permits the weld to yield in a ductile manner in the presence of defects. Section XI methodology recognizes that thermal stresses will be relieved by yielding and will not contribute to plastic collapse for GTAW welds.)

-- <u>Primary Axial And Primary Bending Stress for Upset, Emergency and Faulted Conditions</u>. These stresses are not sustained stresses and so are not considered in the crack growth. SSFLAW uses these stresses to determine if a given crack size at the end of the service interval (i.e., after the crack has grown to its maximum size) meets the Section XI allowables from Tables IWB-3641-1 through 6. For the recirculation system, upset, emergency and faulted conditions are considered here to include seismic loads.

-- <u>Secondary Stresses For Faulted Conditions</u>. As described above, these stresses are not used for high toughness GTAW welds since the stresses are relieved when the pipe section yields. The values input into SSFLAW are equal to the normal thermal stresses.

None of these stresses include pressure-induced stresses; SSFLAW separately calculates the pressure stress and its effect on both crack growth rate and acceptability of the end-of-service interval crack size.

- Axial stress was determined by dividing the applied forces on the weld by the pipe cross sectional area. Bending stress was determined by dividing the applied moment by the pipe section modulus.

- Thermal stresses were determined by dividing the maximum (worst case) thermal expansion moment by the section modulus, and summing this quantity with the corresponding axial tensile force divided by the pipe metal area.

Loop 12
Node 140 Stress Pass Summary
Forces and Geometry Data From TeleDyne Computer Run HX3SBIV

CASE		FX	FY	FZ	MX	MY	MZ
		(pounds)	(pounds)	(pounds)	(inch-pounds)	(inch-pounds)	(inch-pounds)
STATIC	DW	10.0	-9,440.0	-100.0	43,120.0	3,770.0	-18,350.0
	TH-1	-270.0	2,650.0	-160.0	-110,640.0	7,000.0	154,450.0
	TH-2	880.0	-6,710.0	860.0	314,230.0	-40,360.0	-405,160.0
SEISMIC INERTIA	X	-3,150.0	4,510.0	-50.0	-42,110.0	-55,860.0	-468,460.0
	Y	270.0	-100.0	110.0	8,830.0	110.0	18,390.0
	Z	130.0	2,970.0	-3,180.0	507,030.0	-62,840.0	15,590.0
SRSS		3,164.2	5,401.0	3,182.3	508,852.3	84,078.6	469,080.0
SEISMIC END EFFECTS	X	3,590.0	4,880.0	3,450.0	507,200.0	74,650.0	500,270.0
	Y	340.0	450.0	400.0	66,140.0	7,850.0	53,610.0
	Z	3,520.0	4,170.0	3,610.0	543,480.0	65,410.0	491,100.0
SRSS		5,039.3	6,434.7	5,009.5	746,322.2	99,562.6	703,081.3
TOTAL SEISMIC		8,203.5	11,835.8	8,191.7	1,255,174.5	183,641.2	1,172,161.3

SRSS FORCES	SRSS MOMENTS
(pounds)	(inch-pounds)
9,440.5	47,013.5
2,668.5	190,118.4
6,821.9	514,319.0
16,567.6	1,727,179.5

Ma =	Sustained (DW) Moments	SRSS =	47,013.5 inch-pounds
Fa =	Sustained (DW) Forces	SRSS =	9,440.5 pounds
Mb =	Occasional (EQ) Moments	SRSS =	1,727,179.5 inch-pounds
Fb =	Occasional (EQ) Forces	SRSS =	16,567.6 pounds

Pressure and Geometry Data Used in Teledyne Report:

Pressure:	1,200.0 psi
Section Modulus (Z):	598.95847 in^3
Outside Diameter (Do):	28.0 in
Nominal Thickness (tn):	1.05 in
Pipe Metal Area:	88.90 in^2
Stress Intensification Factor (sif):	1.00 --

Calculation of Stresses for SSFLAW

Primary Stress Calculation

Summary of Contributors to Primary Stresses

Case	Axial Force	Moment
DW	9,440.5	47,013.5
EQ	16,567.6	1,727,179.5
Sum	26,008.2	1,774,193.0
Units:	pounds	inch-pounds

Note: The forces and moments shown are SRSSed values. For conservatism, they are assumed to equal the applied axial force and overturning moment.

Calculation of Primary Stresses Contributing to Crack Growth (Deadweight Only)

Axial Force Due to Deadweight:	9,440.5	pounds
Pipe Area = pi * (Ro^2 - Ri^2):	88.90	in^2
Axial Stress (= F / Area):	106.2	psi
Bending Moment Due to Deadweight:	47,013.5	inch-pounds
Section Modulus (Z):	598.96	in^3
Bending Stress (= M / Z):	78.5	psi

Calculation of Maximum Primary Stresses (DW + EQ)

Axial Force Due to Deadweight + EQ:	26,008.2	pounds
Pipe Area = pi * (Ro^2 - Ri^2):	88.90	in^2
Axial Stress (= F / Area):	292.6	psi
Bending Moment Due to Deadweight:	1,774,193.0	inch-pounds
Section Modulus (Z):	598.96	in^3
Bending Stress (= M / Z):	2962.1	psi

Calculation of Stresses for SSFLAW (continued)

Secondary (Thermal) Stress Calculation

Thermal Forces and Moments:

Case	Axial Force	Moment
TH-1	2,668.5	190,118.4
TH-2	6,821.9	514,319.0
Units:	pounds	inch-pounds

Note: The forces and moments shown are SRSSed values. For conservatism, they are assumed to equal the applied axial force and overturning moment.

Normal Operating Thermal Stresses:

Axial Force Due to Worst Thermal Case:	6,821.9	pounds
Pipe Area = pi * (Ro^2 - Ri^2):	88.90	in^2
Axial Stress (= F / Area):	$\boxed{76.7}$	psi
Bending Moment Due to Worst Thermal Case:	514,319.0	inch-pounds
Section Modulus (Z):	598.96	in^3
Bending Stress (= M / Z):	$\boxed{858.7}$	psi
Total Secondary Stress (= Axial Plus Bending):	$\boxed{935.4}$	psi

Faulted Condition

Use Normal Operating Secondary Stresses

Overall Summary of Stresses for Input to SSFLAW

			Stress	
Condition	Type	Direction	(psi)	(ksi)
Normal and Upset	Primary	Axial	106.2	0.11
	Primary	Bending	78.5	0.08
	Secondary	Total	935.4	0.94
Faulted and Emergency	Primary	Axial	292.6	0.29
	Primary	Bending	2,962.1	2.96
	Secondary	Total	935.4	0.94

Appendix B

SSFLAW Computer Output

Note: Program SSFLAW was developed and used in accordance with the MPR Associates Quality Assurance Plan.

SSFLAW
Version 1.1
(April 5, 1988)

IGSCC Crack Growth Calculation Results

32-WD-050: Flaw Size at End of Two Years

Pipe Material: Type 316 Stainless Steel
Sm= 17.50 ksi
Sy= 19.35 ksi
Weld Type: GTAW

Pipe Geometry:
Outside Diameter= 28.000 in
Wall Thickness= 1.050 in

System Operating Conditions:
Pressure= 1050.0 psig
Temperature= 550.0 F

Initial Flaw Geometry:
Orientation- Circumferential
Depth= 0.250 in
Length= 1.250 in

Crack Growth Rate Parameters:
C= 0.359D-07 in/hr
n= 2.161
Kth= 8.00 ksi«in

Final Flaw Geometry:
Service Interval= 730 days
Depth= 0.485 in
Length= 4.702 in

ASME Code Section XI (1986 Edition), Section IWB-3640 Analysis
(Using IWB-3641 Tables)

	Normal Conditions	Faulted Conditions
Tensile Stress (ksi)	0.11	0.29
Bending Stress (ksi)	0.08	2.96
Thermal Stress (ksi)	0.94	0.94
Pressure Stress (ksi)	6.47	6.47
Stress Ratio	0.38	0.56
Flaw Length Ratio	0.05	0.05
Final Flaw Depth (in)	0.485	0.485
Allowable Flaw Depth (in)	0.787	0.787
	Flaw Allowable	Flaw Allowable

SSFLAW
Version 1.1
(April 5, 1988)

IGSCC Crack Growth Calculation Results

32-WD-050: Comparison to Normal + Upset Allowable

Pipe Material: Type 316 Stainless Steel
Sm= 17.50 ksi
Sy= 19.35 ksi
Weld Type: GTAW

Pipe Geometry:
Outside Diameter= 28.000 in
Wall Thickness= 1.050 in

System Operating Conditions:
Pressure= 1050.0 psig
Temperature= 550.0 F

Initial Flaw Geometry:
Orientation- Circumferential
Depth= 0.485 in
Length= 4.700 in

Crack Growth Rate Parameters:
C= 0.359D-07 in/hr
n= 2.161
Kth= 8.00 ksi«in

Final Flaw Geometry:
Service Interval= 1 days
Depth= 0.486 in
Length= 4.727 in

ASME Code Section XI (1986 Edition), Section IWB-3640 Analysis
(Using IWB-3641 Tables)

	Normal Conditions	Faulted Conditions
Tensile Stress (ksi)	0.29	0.29
Bending Stress (ksi)	2.96	2.96
Thermal Stress (ksi)	0.94	0.94
Pressure Stress (ksi)	6.47	6.47
Stress Ratio	0.56	0.56
Flaw Length Ratio	0.05	0.05
Final Flaw Depth (in)	0.486	0.486
Allowable Flaw Depth (in)	0.787	0.787
	Flaw Allowable	Flaw Allowable

Appendix C

Calculation of Flaw Growth Due to Fatigue

Appendix C of the 1986 Edition of ASME Code Section XI provides a method for determining the acceptability for continued service of piping containing flaws. This method requires that flaw growth due to fatigue be determined. The method of Section XI Appendix C will be used herein to perform a flaw growth analysis for fatigue for the indication reported in DER 1-97-0877.

APPROACH

Discussion

Paragraph C-3210 of Appendix C states that fatigue flaw growth in austenitic piping can be characterized in terms of the applied stress intensity factor, K_I. This characteristic is of the form:

$$\frac{da}{dN} = C_o(\Delta K_I)^n$$

where *da/dN* is the increase in flaw depth per cycle, *n* and C_o are constants dependent on the material and environmental conditions, and ΔK_I is the maximum range of stress intensity factor associated with the transient.

The stress intensity factor at a flaw of depth *a* (measured in inches) is generally defined as:

$$K_I = \sigma_m M_m \sqrt{\pi}\sqrt{a/Q} + \sigma_b M_b \sqrt{\pi}\sqrt{a/Q}$$

where σ_m and σ_b represent the membrane and throughwall bending stresses (in psi) applied at the flaw location, M_m and M_b, are unitless correction factors for membrane and bending stress, respectively, and Q is the flaw shape parameter. M_m and M_b are dependent on the ratio of flaw depth to the section thickness and the flaw aspect ratio (the ratio of flaw depth to length). Values for these correction factors are given in Figures A-3300-3 and A-3300-5 for surface

flaws. Q is dependent on the flaw aspect ratio and applied stresses at the flaw and is given in Figure A-3300-1.

Procedure for Calculating Flaw Growth for the Indication

In order to determine the growth by fatigue of the indication reported in DER 1-97-0877, a cumulative fatigue flaw growth study is performed as follows:

- A number of fatigue cycles is determined. Based on engineering judgment and past experience, NMP-1 will likely experience no more than ten startups and shut downs in the upcoming service interval. For conservatism, 20 such startup/shutdown cycles are considered, each cycling the recirculation system pressure from 0 psi to the system design pressure of 1200 psi (per the PSRS for the recirculation system), and cycling the system temperature from 70°F to the system design temperature of 550°F. In addition, ten full seismic cycles are considered.

- The maximum range of stress intensity factor, ΔK_I, associated with each transient will be determined using the formula above. Values for membrane and bending stresses for the startup/shutdown cycles, and for the seismic cycles, are calculated from the Teledyne stress analysis results in Appendix A to this report. Membrane stress for pressure loading are determined using $\sigma_m = P D_o / 4 t_n$.

- The incremental flaw growth da/dN corresponding to ΔK_I for each cycle is then determined. The flaw depth a is updated and the process repeated for each later cycle, to yield the final flaw size.

Simplifying Assumptions and Bases

Preliminary analysis showed that the overall flaw growth due to fatigue in the upcoming service interval is minimal. Therefore, use of bounding values and conservative assumptions is appropriate where such use will simplify the analysis. Conservatisms used herein to simplify the analysis are as follows:

- The correction factors M_m and M_b and flaw shape parameter Q are considered to be constant at bounding values for each cycle (i.e., they are set at constant values which do not vary with flaw depth or length).

- The throughwall bending stress is set equal to the overall cross section bending stress, and then added absolutely with the axial membrane stress, to yield the total membrane stress. The bending stress is then set to zero. This is conservative because the membrane correction factor M_m is in all geometries greater than the bending correction factor M_b. Further, this is appropriate because the throughwall bending stresses due to

the moments applied to the pipe are small in comparison to the peak axial stress on the wall due to these moments.

- Constants n and C_o are obtained from the most bounding case shown in Figure A-4300-1 of Section XI:

$$\frac{da}{dN} = 1.20 x 10^{-5} (\Delta K_I)^{5.95}$$

where da/dN is expressed in micro-inches per cycle and ΔK_I is in ksi-root inches. This relationship uses the high stress ratio curve for alloy steel wetted surface flaws in Section XI. This provides a worst case flaw growth rate for stainless steel, which exhibits less crack growth per cycle than does the material shown in Figure A-4300-1 of Section XI (see for example page 232 of Reference 11).

CALCULATION AND RESULTS

The flaw size following each cycle considered is shown on the following spreadsheet. The final flaw size is within one mil (0.001 inch) of the initial flaw size. Therefore, the flaw growth due to fatigue is considered to be negligible over the service interval.

Calculation of Flaw Growth Due to Fatigue

Initial Conditions:

Flaw Depth	a	0.25 inch
Flaw Length	L	1.25 inch
Wall Thickness	tn	1.05 inch
Pipe OD	Do	28.0 inch

Applied Stresses:

Design Pressure	Pmax	1200 psig

Axial Membrane Stress Due to Pressure:

= Pmax * Do / (4 tn) 8000.0 psi

Stress Due to Thermal Cycles (Reference: Appendix A)

Axial Stress:	76.7 psi
Gross Section Bending Stress:	858.7 psi
Peak Membrane Stress:	935.4 psi

Combined Pressure and Thermal Stresses (for Startup/Shutdown Cycles)

= 8000.0 psi + 935.4 psi = 8935.4 psi

8.94 ksi

Stress Due to Seismic Cycles (Reference: Appendix A)

Axial Stress:	292.6 psi	
Gross Section Bending Stress:	2962.1 psi	
Peak Membrane Stress:	3254.7 psi	= 3.25 ksi

Flaw Size Increment for Each Cycle

Case I: Startup and Shutdown Cycles

Cycle Number	Flaw Size at Start of Cycle (inch)		Correction Factors (unitless)			Applied Stresses (ksi)		Delta K (ksi - root inch)	da/dN (inch per cycle)	End of Cycle Flaw Depth (inch)
	Depth	Length	Mm	Mb	Q	Membrane	Bending			
Initial	0.2500000	1.25	1.3	--	1.1	8.94	--	9.82	9.57E-06	0.2500096
1	0.2500096	1.25	1.3	--	1.1	8.94	--	9.82	9.57E-06	0.2500191
2	0.2500191	1.25	1.3	--	1.1	8.94	--	9.82	9.57E-06	0.2500287
3	0.2500287	1.25	1.3	--	1.1	8.94	--	9.82	9.58E-06	0.2500383
4	0.2500383	1.25	1.3	--	1.1	8.94	--	9.82	9.58E-06	0.2500479
5	0.2500479	1.25	1.3	--	1.1	8.94	--	9.82	9.58E-06	0.2500575
6	0.2500575	1.25	1.3	--	1.1	8.94	--	9.82	9.58E-06	0.2500670
7	0.2500670	1.25	1.3	--	1.1	8.94	--	9.82	9.58E-06	0.2500766
8	0.2500766	1.25	1.3	--	1.1	8.94	--	9.82	9.58E-06	0.2500862
9	0.2500862	1.25	1.3	--	1.1	8.94	--	9.82	9.58E-06	0.2500958
10	0.2500958	1.25	1.3	--	1.1	8.94	--	9.82	9.58E-06	0.2501054
11	0.2501054	1.25	1.3	--	1.1	8.94	--	9.82	9.58E-06	0.2501149
12	0.2501149	1.25	1.3	--	1.1	8.94	--	9.82	9.59E-06	0.2501245
13	0.2501245	1.25	1.3	--	1.1	8.94	--	9.82	9.59E-06	0.2501341
14	0.2501341	1.25	1.3	--	1.1	8.94	--	9.82	9.59E-06	0.2501437
15	0.2501437	1.25	1.3	--	1.1	8.94	--	9.82	9.59E-06	0.2501533
16	0.2501533	1.25	1.3	--	1.1	8.94	--	9.82	9.59E-06	0.2501629
17	0.2501629	1.25	1.3	--	1.1	8.94	--	9.82	9.59E-06	0.2501725
18	0.2501725	1.25	1.3	--	1.1	8.94	--	9.82	9.59E-06	0.2501821
19	0.2501821	1.25	1.3	--	1.1	8.94	--	9.82	9.59E-06	0.2501917
20	0.2501917	1.25	1.3	--	1.1	8.94	--	9.82	9.59E-06	0.2502013

Flaw Size Increment for Each Cycle (Continued)

Case II: Seismic Cycles (Following 20 Startup/Shutdown Cycles)

Cycle Number	Flaw Size at Start of Cycle (inch)		Correction Factors (unitless)			Applied Stresses (ksi)		Delta K (ksi - root inch)	da/dN (inch per cycle)	End of Cycle Flaw Depth (inch)
	Depth	Length	Mm	Mb	Q	Membrane	Bending			
Initial	0.25020125	1.25	1.3	--	1.1	3.25	--	3.58	2.36E-08	0.25020128
1	0.25020128	1.25	1.3	--	1.1	3.25	--	3.58	2.36E-08	0.25020130
2	0.25020130	1.25	1.3	--	1.1	3.25	--	3.58	2.36E-08	0.25020132
3	0.25020132	1.25	1.3	--	1.1	3.25	--	3.58	2.36E-08	0.25020135
4	0.25020135	1.25	1.3	--	1.1	3.25	--	3.58	2.36E-08	0.25020137
5	0.25020137	1.25	1.3	--	1.1	3.25	--	3.58	2.36E-08	0.25020139
6	0.25020139	1.25	1.3	--	1.1	3.25	--	3.58	2.36E-08	0.25020142
7	0.25020142	1.25	1.3	--	1.1	3.25	--	3.58	2.36E-08	0.25020144
8	0.25020144	1.25	1.3	--	1.1	3.25	--	3.58	2.36E-08	0.25020147
9	0.25020147	1.25	1.3	--	1.1	3.25	--	3.58	2.36E-08	0.25020149
10	0.25020149	1.25	1.3	--	1.1	3.25	--	3.58	2.36E-08	0.25020151

Final Flaw Depth: 0.25020 inches

[illegible]