SUPPLEMENTAL INFORMATION
ANALYTICAL EVALUATION OF INSERVICE INSPECTION EXAMINATION RESULTS

Attachment A

Calculation ME-02-98-04, "Fracture Mechanics Evaluation of N1 Safe End," Revision 0

9905130171 990429
PDR ADOCK 05000397
Q PDR

WASHINGTON PUBLIC POWER SUPPLY SYSTEM	CALCULATION COVER SHEET	BDC Page NA

Equipment Piece No.	Project	Page	Cont'd on Page
	WNP-2	1000	100
MS-RPV-3	Discipline: MATERIAL AND WELDING	Calculation No.: ME-02-98-04	
		Quality Class: 1	
	Remarks		

TITLE/SUBJECT/PURPOSE

Title/Subject

FRACTURE MECHANICS EVALUATION OF N1 SAFE END

Purpose

A fracture mechanics evaluation was performed to evaluate a planar indication found during in-service inspection of ISI weld number 24RRC(2)A-1. The indication is on the inside surface of the safe-end and is located at 5:00 o'clock when looking downstream. The indication measures 3.52 inches in length and 0.29 inches deep in a pipe wall that is 2.0 inches thick. The indication exists in SA 336 Class F8 forged type 304 stainless steel safe-end. The size of the defect exceeds the ASME Code Section XI Table IWB 3514-2 allowable and thus requires an evaluation per paragraph IWB 3640 of the Code. The following calculation provides a comprehensive presentation of the fracture mechanics model, applied loads (stresses), and Code evaluations

There are no CMR's against this Calculation

CALCULATION REVISION RECORD

REV NO.	STATUS/ F,P, OR S	REVISION DESCRIPTION	INITIATING DOCUMENTS	TRANSMITTAL NO.
0	F	Initial Issue	PER 298-0600	17710

PERFORMANCE/VERIFICATION RECORD

REV NO.	PERFORMED BY/DATE	VERIFIED BY/DATE	APPROVED BY/DATE
0	Tom Erwin [signature] 5/29/98	[signature] 5/29/98	[signature] 5-31-98

* Study Calculations shall be used only for the purpose of evaluating alternate design options or assisting the engineer in performing assessments.

WASHINGTON PUBLIC POWER SUPPLY SYSTEM

CALCULATION INDEX

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APPENDICES:

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968-25278 R2 (3/98)

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Calculation/CMR ME-02-98-04 Revision 0 was verified using the following methods:

[x] Checklist Below [ ] Alternate Calculations

Checklist Item	Initial
Clear Statement of purpose of analysis	JRJ
Methodology clearly stated and sufficiently detailed and appropriate to proposed application	JRJ
Logical consistency of analysis	JRJ
• Completeness of documenting references	JRJ
• Completeness of documenting and updating output interface documents	JRJ
Completeness of input	JRJ
Accuracy of input data	JRJ
Consistency of input data with approved criteria	
Completeness in stating assumptions	JRJ
Validity of assumptions	JRJ
Calculation sufficiently detailed	JRJ
• Arithmetical accuracy	JRJ
• Physical units specified and correctly used	JRJ
Reasonableness of output conclusion	
Supervisor independency check (if acting as Verifier) - Did not specify analysis approach - Did not rule out specific analysis options - Did not establish analysis inputs	
• If a computer program was used: - Is the program appropriate for the proposed application? - Have the program error notices been reviewed to determine if they pose any limitations for this application? - Is the program name, revision number and date of run inscribed on the output? - Is the program identified on the Calculation Method form? If so, is it listed in chapter 10 of the Engineering Standards Manual?	JRJ
Other Elements Considered	JRJ

• If a separate verifier was used for validating these functions or a portion of these functions, sign and initial below.

Based on the foregoing, the calculation is adequate for the purpose intended.

Verifier Signature(s)/Date: [signature] 5/29/98

Verifier Initials: JRJ

968-25280 R1 (3/98)

WASHINGTON PUBLIC POWER SUPPLY SYSTEM

CALCULATION REFERENCE LIST

PAGE 1.300 CONT'D ON PAGE 1.400

CALCULATION NO. ME-02-98-04

REVISION NO. 0

SEQUENCE NO.	AUTHOR	ISSUE DATE, EDITION, OR REVISION	TITLE	DOCUMENT NO.
1	Failure Analysis Associates	2.23	NASCRAC Manual	-
2	Supply System	5-14-98	Ultrasonic Examination Data Sheet	R-R13-031
3	EPRI	1986	Evaluation of Flaws in Austenitic Steel Piping	NP-4690-SR
4	NRC	1988	Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping	NUREG-0313,Rev.2
5	ASME	1990	ASME Section XI, Nonmandatory Appendix C	Fig C-3210-1
6	Burns & Roe	5/7/76	Hanford II 251" BWR Vessel Stress Report T9,S9,F9 Recirculation Outlet Nozzle	T9,S9,F9
7	ASME	1989	ASME Section XI	IWB-3640
8	S.T. Rolfe J.M. Barsom	1977	Fracture and Fatigue Control in Structures	-
9	ASME	1986	ASME Section III, Appendices	Appendix I Table I-2.2
10	Structural Integrity	March 1998	The Effect of Radiation on the Fracture Toughness of Austenitic Stainless Steel Base and Weld Material	SIR-97_095
11	J.F.Harvey	1985	Theory and Design of Pressure Vessels	pg 61

44-068 (10/89)

WASHINGTON PUBLIC POWER SUPPLY SYSTEM	CALCULATION OUTPUT INTERFACE DOCUMENT REVISION INDEX	Page 1.4000 Cont'd On Page 2.000 Calculation No. ME-02098-04
Prepared By/Date Tom Erwin *Tom Erwin 5/29/98*	Verified by/Date *[signature] 5/29/98*	Revision No. 0

The below listed output interface calculations and/or documents are impacted by the current revision of the subject calculation. The listed output interfaces require revision as a result of this calculation. The documents have been revised, or the revision deferred with Manager approval, as indicated below.

AFFECTED DOCUMENT NO.	CHANGED BY (e.g., BDC, SCN, CMR, Rev.)	CHANGED DEFERRED (e.g., RFTS, LETTER NO.)	DEPT. MANAGER *
None			

* Required for deferred changes only.

968-25285 R1 (3/98)

Discussion of Results

Three computer runs were used to evaluate the indication in the N1 nozzle safe-end. The first modeled the indication using the normal operational loads of the system.

The second model used three transients that could possibly occur in one year interval. These transients were the thermal discontinuity stress, OBE and SSE. This model was used to determine the crack growth expected from the fatigue loading at different crack depths allowing determination of when the cracking would become a significant contributor to crack growth. This allowed the determination that the crack growth would only become significant at the end of the interval selected for the next inspection.

The third model used the adjusted crack length (20:1 ratio) as required by NUREG 0313 Rev. 2 for the end of the IGSCC crack growth at R 16 as input. The required fatigue cycles for OBE and SSE were than applied to this crack dimension to determine acceptability for the interval.

The results of the computer runs are as follows:

The indication will grow to a depth of 0.983" by R 16 if IGSCC is active and the fatigue cycles are experienced.

In comparing the results to the 1989 ASME Section XI Code Tables IWB-3641-5 and -6. Indication is acceptable for continued operation until R 16.

The weld will be reinspected prior to R16, see PERA 298-0600 CAP 1 PTL A149503.

Conclusions

Taking into account the following conservatism's:

1. The weld residual stress distribution used is for an as welded component. The stainless steel safe-end to nozzle weld had MSIP performed on it during R 9. The distribution should be compressive at the ID.

2. The stresses are conservatively high due to the use of OBE stresses for steady state thermal. Also the pressure stress used is the hoop stress not the axial pressure stress.

3. No faucet are evident during the weld examination that would indicate IGSCC is active.

It has been determined that WNP-2 may operate until R16 before reexamination of the nozzle to safe-end weld has to occur. The evaluation demonstrates under the worst imposed loading conditions the flaw meets the acceptance criteria of the ASME Section XI IWB-3641-5 and 3641-6. The main fracture mechanism that will propagate the flaw is intergranular stress corrosion cracking. If the IGSCC phenomena is active the indication will increase in depth to 0.983" by R16. which is less than the ASME Code allowable.

WASHINGTON PUBLIC POWER SUPPLY SYSTEM	CALCULATION METHOD	Page 3000 — Cont'd On Page 3001
		Calculation No. ME-02-98-04
Prepared By/Date: T.M.Erwin, Tom Erwin 5/29/98	Verified by/Date: [signature] 5/29/98	Revision No. 0

Analysis Method (Check appropriate boxes)

- [x] Manual (As required, document source of equations in Reference List)
- [x] Computer — [ ] Main Frame — [x] Personal
  - [x] In-House Program
  - [ ] Computer Service Bureau Program
    - [ ] BCS [ ] CDC [ ] PCC [ ] OTHER ______
- [x] Verified Program: Code name/Revision NASCRAC 2.23
- [ ] Unverified Program: Document in Appendix B

Approach/Methodology — REV. BAR

Flaw Evaluation

Problem

During the performance of Inservice Inspection of the reactor vessel RRC A loop an indication was discovered in the heat affected zone of the 24 inch RRC suction nozzle (N1A) to safe-end weld 24RRC(2)A-1. The indication is on the inside surface of the safe-end and is located at 5:00 o'clock when looking downstream. The indication measures 3.52 inches in length and 0.29 inches deep in a pipe wall that is 2.0 inches thick. The indication exists in ductile SA 336 Class F8 forged type 304 stainless steel. The design minimum wall based on faulted pressure is 1.01 inches. The remaining ligament in the safe-end is 1.71 inches.

The indication has existed for some time. Due to changes in the ultrasonic techniques and technology the ability to detect material variations and conditions has increased. An example of this increase in sensitivity is demonstrated in this examination. The same weld was examined during the R9 outage and no indication was detected at that time. However, using the new GE ultrasonic data system the same data tape was reviewed from the R9 outage and it was determined that the same indication existed at that time. The new R13 data output and the R9 data output were compared and the indication shows no change in depth or length that is not within the inaccuracies of the equipment. The indication has been in the system since at least R9 with no change in depth or length.

The indication is required to be evaluated as an IGSCC indication even though it shows no IGSCC charactreistics.

Flaw Evaluation

The linear indication was evaluated using the NASCRAC computer code developed by Failure Analysis Associates. This code uses stress field influence functions as the basis for flaw propagation. The NASCRAC model selected is a shell element containing an elliptically shaped circumferential flaw. The model is identified as 703 in the NASCRAC manual. This particular model includes three crack growth degrees of freedom encompassing the respective circumferential and crack depth coordinates. The evaluation was performed using conservative linear elastic fracture mechanics principles.

All Models The maximum fracture toughness used for the stainless steel material was $150ksi\sqrt{in}$. The value is conservative and is approximately one half of the fracture toughness value that is achievable for this type of stainless steel product form. (BWRVIP Report SIR-97-095) (10)

Load Combinations

The load combinations used in this evaluation are provided in section 5.0 of this calculation. The following provides the combinations used by each of the models.

N1IGSCC.IN The IGSCC calculation for normal operation was performed using 11 node points from the I.D. to O.D. For each point Kmin was calculated by setting the stress value equal to zero. Kmax was determined by conservatively combining the weld residual stresses, circumferential pressure stress, deadweight and the OBE stress that includes thermal (see section 5.0). The number of cycles used is 24 since the Paris equation crack growth law is in in/hour. One load block represents 24 hours or one day.

N1FAT.IN
N1FAT1.IN The fatigue models also used 11 nodes from I.D. to O.D. The models were set up using stresses in psi instead of ksi. The Paris equation (fatigue) was established using psi instead of ksi. The Kmin for the fatigue models was calculated using the normal operational stresses used in the IGSCC model. The cyclic stresses were made up of cycles from three transients that represent the potential cyclic loading the nozzle could experience in one year. These transients were: One cycle of thermal discontinuity, 300 cycles OBE (contains SRV) and ten cycles SSE.

The modeling applies the requirements identified in NRC Generic Letter 88-01. The flaw was evaluated as an intergranular stress corrosion crack using the crack growth rate equation provided in the generic letter. The weld residual stress distribution provided in the letter was also used even though the weld in question had Mechanical Stress Improvement (MSIP) performed on it in 1994. The weld residual stresses are developed from room temperature yield for 304 material (30 ksi) as the normalization stress outlined in the generic letter. The flaw aspect ratio was reviewed and compared to the requirements of NUREG-0313, Rev. 2. The aspect ratio was determined to be 12:1 which requires correction in length as the crack grows until an aspect ratio of 20:1 is exceeded. Therefore, the final crack growth aspect ratio was corrected manually to comply with the requirements of NUREG-0313, Rev. 2. The correction for aspect ratio was performed at each Refueling outage time period based upon the computer output for the IGSCC model. These intervals were determined as follows: R 14 will occur in approximately 290 days, with two subsequent 290 day intervals until R 16. The flaw length and depth from the R16 corrected value was then used as input into the fatigue model. The fatigue model used one year of expected upset and faulted conditions as required by the Code to assure that the crack will remain within the Code allowable limits and NRC requirements.

Three input files were used to perform the IGSCC and fatigue evaluations. These files were:

N1IGSCC.IN IGSCC for normal operations
N1FAT.IN Fatigue including one year of thermal discontinuity (1cycle), OBE (300 cycles), SSE (10 cycles)
N1FAT1.IN Fatigue incorporating R16 corrected crack length for NRC 20:1 ratio and the same fatigue cycles for N1FAT.IN

The following assumptions and inputs were used in developing each of the models.

All Models: The flaw model used was 703 for a semi-elliptical (circumferential) surface crack in a cylinder. (1)

Flaw Dimensions

N1IGSCC.IN
N1FAT.IN The crack used was 3.52" long and 0.29" deep. The half crack was calculated taking 3.52" and dividing it by 2 to yield 1.76". (2)

N1FAT1.IN The crack length for this model was the results of the 20:1 aspect ratio required by the NRC for IGSCC cracks. The value used is from the crack depth for 870 days of IGSCC growth that would occur by R16. The values used in the model were a length of 17.8" and a depth of 0.89". The half crack was determined by dividing the length by 2 that results in a value of 8.9".

Crack Growth Laws

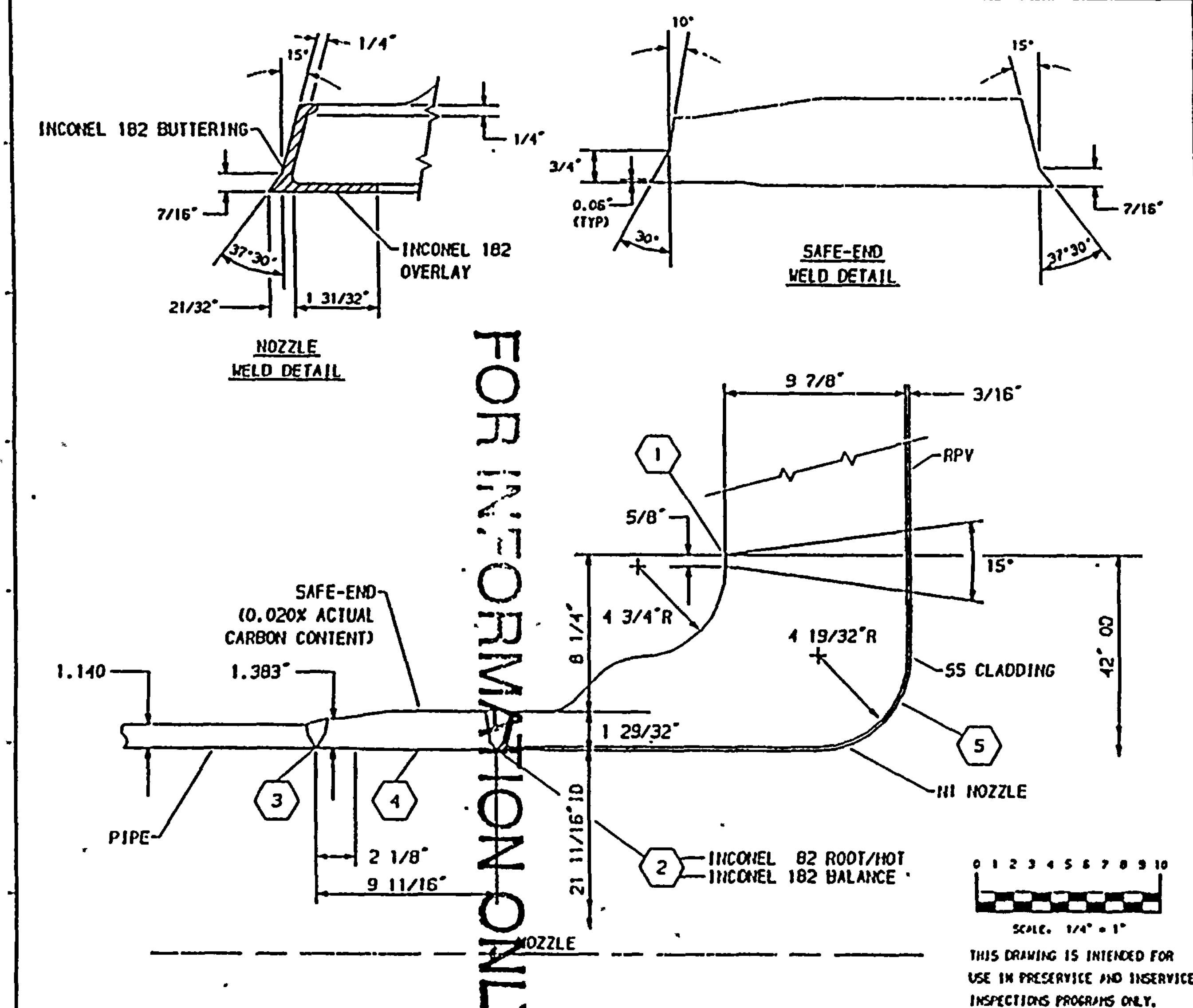
N1IGSCC.IN The Paris equation used for IGSCC growth was that provided in NUREG-0313 Rev. 2. The equation used : (4)

$$3.59E-8(\Delta K)^{2.161} \text{ in ksi}\sqrt{in}$$

N1FAT.IN
N1FAT1.IN The crack growth rate for fatigue in BWR water environment was determined using the following Paris equation: (3)

$$6.155E-18(\Delta K)^{3.302} \text{ in psi}\sqrt{in}$$

N1IGSCC.IN
N1FAT.IN
N1FAT1.IN The ΔK_{th} value used was 10.0 or 10000 for the fatigue



FOR INFORMATION ONLY

THIS DRAWING IS INTENDED FOR USE IN PRESERVICE AND INSERVICE INSPECTIONS PROGRAMS ONLY.

WELDS

1. N1A 180° LOOP A; N1B 0° LOOP B
2. 24RRC(2)A-1 180° LOOP A; 24RRC(2)B-1 0° LOOP B
3. 24RRC(2)A-2 180° LOOP A; 24RRC(2)B-2 0° LOOP B

NOTES

CAL BLOCK		EXAMINATION
1	UT-119	NOZZLE TO SHELL WELD
2	UT-101	NOZZLE TO SAFE-END WELD
3	UT-7	SAFE-END TO PIPE WELD
4	UT-101	SAFE-END FORGING (IF EXAMINED)
5	UT-119	NOZZLE INNER RADIUS

REFERENCES:

CBI NUCLEAR CO. 205 AE 023
SHT 46 REV 4 N1 NOZZLE FORGING
SHT 47 REV 3 N1 SAFE-END FORGING
SHT 48 REV 4 N1 NOZZLE ASSEMBLY

ISI ISOMETRICS
RRC-101-1 REV 4
RRC-102-1 REV 3

PIPING SYSTEM	NOM DIA INCH	SCH	NOM WALL THICKNESS	MATERIAL SPEC	MATL TYPE	CAL BLOCK NUMBER
24"RRC(2)-4S	24	XXX	1.140	SA 358 GR 304 CL 1	SS	SEE NOTES
SAFE-END	—	—	—	SA 336 CL F8	SS	SEE NOTES
N1 NOZZLE	—	—	—	SA 508 CL 2	CS	SEE NOTES
RPV	—	—	5 7/8	SA 533 GR B CL 1	CS	SEE NOTES

NO	DATE	REVISION	BY	CHKD	APVD
1	[illegible]	UPDATED TO DOCUMENT THE SAFE-END AND INCONEL INFORMATION FOR AS-BUILT CONDITION. MODIFIED [illegible]	[illegible]	[illegible]	DPR
0	7-31-79	ISSUED FOR USE	K-McA	[illegible]	LFB

QUALITY CLASS: 1 | ASME CODE CLASS: 1
ENGR: T HOYLE | DRWN: K-McA | DATE: 5-10-79

WASHINGTON PUBLIC POWER
SUPPLY SYSTEM
RICHLAND, WASHINGTON 99352

WNP-2
WELD & COMPONENT
IDENTIFICATION DIAGRAM

TITLE:
RECIRC SUCTION
N1 NOZZLE AT 0° & 180°

DWG NO. RPV-105 | REV 1

WASHINGTON PUBLIC POWER SUPPLY SYSTEM
CALC: ME-02-88-04 REV: 0
PAGE: 4.001 CONT. ON 4.002
BY: [illegible] DATE: 5/23/90

5.1.26 Semi-Elliptical (Circumferential) Surface Crack in a Cylinder

Model Feature	FORTRAN Variable	Option Featured
Model Index Number	KRKTYP	703
Number of Degrees of Freedom	KRKDOF	3
Crack Front Shape	—	Semi-Elliptical
Finite Width Effects	—	Yes
Influence Function	—	Yes
Variable Thickness Effects	IVTHIC	No
J-Integral Solutions	—	No

Data Input Description

Input Description		FORTRAN Variable	Input Format	Remarks
Variable Thickness		IVTHIC	Tabular	Not Applicable
Initial Crack Size	$a1$	AINITL(1)	Constant	
	$a2$	AINITL(2)	Constant	
	$a3$	AINITL(3)	Constant	
Body Widths	t	WIDTHS(1)	Constant	
	W_2	WIDTHS(2)	Constant	) Terminate
	W_3	WIDTHS(3)	Constant	) Analysis Only
	r	WIDTHS(4)	Constant	
Crack Position	Xc	CENTER(1)	Constant	
	Yc	CENTER(2)	Constant	
Crack Orientation	ϕ	CRKANG	Constant	
Stress Input	$\sigma_{zz}(x)$		Equational Tabular	
	$\sigma_{zz}(x,y)$		Equational Tabular	

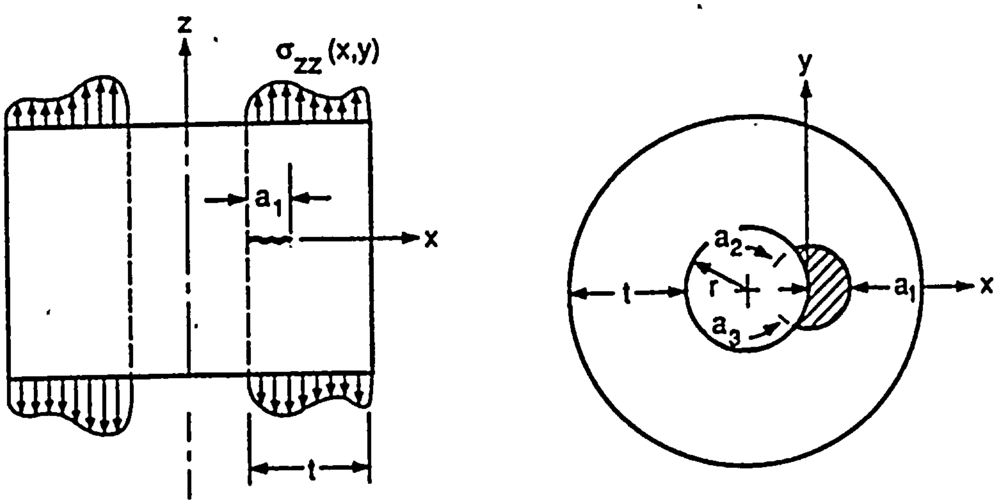
K-Solutions:

Limits : $1 \leq a_2 + a_3/a_1 \leq 20$; $0.0 \leq a_1/t \leq 1.0$

Accuracy : approximately 10% for $0.0 \leq a_1/t \leq 0.8$ and $1 \leq a_2 + a_3/a_1 \leq 12$

WASHINGTON PUBLIC POWER SUPPLY SYSTEM
CALC: ME-02-98-04 REV: 0
PAGE: NASCRAC User's Manual CONT. ON 7.003
BY: [signature] DATE: 5/23/98
VERIFIED: [signature] DATE: 5/25/98

703



WASHINGTON PUBLIC POWER SUPPLY SYSTEM
CALC. ME-02-98-04 REV. 0
PAGE 4.003 CONT. ON 5.006
BY: DATE 5/23/98
VERIFIED: DATE: 5/25/98

The purpose of the calculation is to determine the bounding stress in the Recirculation outlet nozzle N1 at safe end to nozzle weld.

Actual loads at the nozzle due to the pipe are lower than the allowable loads provided in the reference documents listed below. Actual pipe loads are available in calculation 8.14.107.

References:
1. Hanford II -251 " BWR Vessel Stress Report Sections T9,S9,F9 Recirculation Outlet Nozzle.

2. Drawing 732E143, Purchase part Reactor Vessel, MPL item No. B13-D003

3. Drawing 761E716, Reactor Vessel Loadings

Recirculation Outlet:
Maximum Allowable Nozzle Loads for Evaluation:

	H (kips)	M (inch kips)
Design Mech. Load	0.0	5850
Dead Wt.	58.50	1580
Seismic Pri	164	2950
Seismic RFE	164	2950
Thermal RFE	292	7020

The above moments are applied at the end of the safe end. The weld of concern is the safe end to nozzle weld which is 9.75 inches +/- 1/16 inch from the load application point.

Nozzle Design Pressure: 1250 psi
Nozzle Faulted Pressure: 1375 psi

Nozzle Loads for Recirculation Outlet Nozzle from Calculation 8.14.107 which includes power uprate and snubber optimization of the recirculation piping.

Condition	Force - lbs	Moment - inch kips
Primary	5552	167.408
Secondary	34431	1805.391
Primary (Faulted)	25481	1066.453

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		Calculation No. ME-02-98-04
Prepared By/Date JR Cole 5/25/98	Verified By/Date A. Rafer 5/26/98	Revision No. 0 REV. BAR

Safe end material is SA-336 F8

$Sm := 16.65$ ksi @ 575 F

$Z := 9.75$ inch   Z is the offset distance from the application point of the loads.

$Pd := 1250$ psi $OD := 25.5$ inch

$Pf := 1375$ psi $ID := 21.6876$ inch

$I_{mom} := 9896$ in^4 $A_{noz} := 141.292$ in^2

Calculate tangential Pressure Stresses using the thickwall formula from Theory and Design of Pressure Vessels, J.F. Harvey, 1985 pg 61

$a := \frac{ID}{2}$ $b := \frac{OD}{2}$ $r := 10.84, 11.2 .. 12.75$ inch

$$\sigma_p(r) := \frac{a^2 \cdot Pd}{b^2 - a^2}\left(1 + \frac{b^2}{r^2}\right)$$

Pressure Stress Variation with radius from ID to OD is shown below.

r	$\sigma_p(r)$ psi
10.84	$7.79 \cdot 10^3$
11.2	$7.504 \cdot 10^3$
11.56	$7.244 \cdot 10^3$
11.92	$7.007 \cdot 10^3$
12.28	$6.791 \cdot 10^3$
12.64	$6.594 \cdot 10^3$

Since the range variable for r did not exactly match the outside diameter the following equation adjusts to the exact outside radius.

$r := 12.75$

$$\sigma_p(r) := \frac{a^2 \cdot Pd}{b^2 - a^2}\left(1 + \frac{b^2}{r^2}\right)$$

$\sigma_p(r) = 6.536 \cdot 10^3$ psi.

Thus the tangential pressure stress varies from 7800 psi to 6530 psi. This stress is tensile around the circumference of the shell. Based on the orientation of the flaw the tangential stress would not be a tensile stress for a flaw in the tangential direction.

Reset the radius to vary from ID to OD and recalculate the radial pressure stress.

$r := 10.84, 11.2 .. 12.75$ inch

$$\sigma_{pr}(r) := \frac{a^2 \cdot Pd}{b^2 - a^2}\left(1 - \frac{b^2}{r^2}\right)$$

$a = 10.844$

$b = 12.75$

$\sigma_{pr}(r)$ psi	r inches
$-1.253 \cdot 10^3$	10.84
-967.181	11.2
-707.494	11.56
-470.979	11.92
-254.958	12.28
-57.13	12.64

Calculate nozzle bending stresses at the safe end to nozzle weld by applying the moment plus the force times the offset to give a maximum bending moment

Deadweight Loads:

$Mdwt := 167.5 + 5.552 \cdot Z$ in - kips $c := 12.75$

$Mdwt = 221.632$

WASHINGTON PUBLIC POWER SUPPLY SYSTEM	MANUAL CALCULATION	Page 5.004 — Cont'd On Page 5.005
		Calculation No. ME-02-98-04
Prepared By/Date: J R Yale 5/25/98	Verified By/Date: A. Rafer 5/26/98	Revision No. 0 — REV. BAR

$\sigma_{dwt} := \frac{Mdwt \cdot c}{I_{mom}}$ $\qquad$ $\sigma_{dwt} = 0.286$ ksi

Upset Loads including Thermal

The GE load combination for RPV nozzles takes the maximum of eight different combinations which include thermal, obe, obe displacements, turbine stop valve closure, srv, and srv inertia.

$M_{obe} := 1806 + 34.5 \cdot Z$

$M_{obe} = 2.142 \cdot 10^{3}$ in - kips

$\sigma_{obe} := \frac{M_{obe} \cdot c}{I_{mom}}$ $\qquad$ $\sigma_{obe} = 2.76$ ksi

Faulted Loads:

The GE faulted loads combination does not include thermal bending on the nozzle. Since the upset load combination includes thermal, it is conservatively added to the faulted loading without removal of the dynamic upset loads.

$M_{sse} := 1067 + 25.5 \cdot Z + M_{obe}$

$M_{sse} = 3.458 \cdot 10^{3}$ in - kip

$\sigma_{sse} := \frac{M_{sse} \cdot c}{I_{mom}}$ $\qquad$ $\sigma_{sse} = 4.455$ ksi

WASHINGTON PUBLIC POWER SUPPLY SYSTEM	MANUAL CALCULATION	Page 5.005 Cont's On Page 5.006
		Calculation No. ME-02-98-04
Prepared By/Date [signature] 5/25/98	Verified By/Date [signature] 5/26/98	Revision No. 0 — REV. BAR

Determine the discontinuity stresses due to the attachment of the stainless steel safe end to the carbon steel vessel nozzle. The vessel nozzle has a 3/8 in inconel butter on the surface and then is jointed to the safe end with an inconel weld. Thus there are three different materials to be evaluated for thermal growth.

Nozzle Forging - SA-508 CL 2 (3/4NI-1/2Mo-CR-V)
Coeffiecient of Thermal Expansion - Group A Materials at 550 F
7.34X10^-6in/in/F
Modulus of Elasticity - 27.0X10^6 psi

Safe End - SA-336 F8 - (18CR - 8Ni) Group G
Coefficient of Thermal Expansion - Group 9.45X10^-6 in/in/F
Modulus of Elasticity - 25.55X10^6 psi.

Inconel Weld Metal: SB-167 N06690 (58 Ni - 29Cr - 9Fe)
Coeffiecient of Thermal Expansion - 8.13X10^-6in/in/F
Modulus of Elasticity - 28.2X10^6psi

Check nozzle to inconel thermal discontinuity.

$$E_{ab} := \frac{27.0\cdot 10^6 + 28.2\cdot 10^6}{2} \qquad E_{ab} = 2.76\cdot 10^7 \quad \text{psi}$$

$$\alpha_a := 7.34\cdot 10^{-6} \qquad \alpha_b := 8.13\cdot 10^{-6}$$

$$T_a := 550 - 70 \qquad T_b := 550 - 70$$

$$\sigma_{tdis} := E_{ab}\cdot\left|\alpha_a\cdot T_a - \alpha_b\cdot T_b\right|$$

$$\sigma_{tdis} = 1.047\cdot 10^4 \quad \text{psi}$$ Nozzle to safe end

Check the inconel weld to safe end discontinuity.

$$E_{ab} := \frac{25.5\cdot 10^6 + 28.2\cdot 10^6}{2} \qquad E_{ab} = 2.685\cdot 10^7$$

$$\alpha_a := 9.45\cdot 10^{-6} \qquad \alpha_b := 8.13\cdot 10^{-6}$$

$T_a := 550 - 70$ $\qquad$ $T_b := 550 - 70$

$\sigma_{tdis} := E_{ab} \cdot \left| \alpha_a \cdot T_a - \alpha_b \cdot T_b \right|$

$\sigma_{tdis} = 1.701 \cdot 10^4$ Safe end to inconel weld.

Thus the maximum discontinuity stress is between the stainless steel safe end and the inconel weld metal.

The original vessel stress report provided calculation of the stress concentration factors at the locations of tapered transitions in the nozzle. There was no stress concentration listed for the joint that we are evaluating. Since the weld joint between the safe end and the nozzle is a flush weld between two equivalent diameter cylinders, we can use the stress indices from a flush weld in table NB-3683.2-1.The table lists C3 as 1.0 and K3 as 1.1. Thus for determining peak stress at the material discontinuity, the C3 and K3 indices are applied.

$\sigma_{dis} := 1.0 \cdot 1.1 \cdot \sigma_{tdis} \cdot \frac{1}{1000}$ $\qquad$ $\sigma_{dis} = 18.713$ ksi

Summary of Safe end to nozzle stresses:

Design Pressure Stress = 7.790 ksi

Deadweight Bending Stress $\sigma_{dwt} = 0.286$ ksi

Upset Primary plus Sec. Bending Stress $\sigma_{obe} = 2.76$ ksi

Faulted Bending Stress, includes thermal, deadweight, obe and sse.:

$\sigma_{sse} = 4.455$ ksi

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.Thermal Discontinuity Stress at the Carbon.To Stainless Steel Intersection:

$$\sigma_{dis} = 18.713 \quad \text{ksi}$$

Stresses classified as bending stresses above are based on the outer fiber stress to maximize the magnitude. Bending stress on the inner wall is obtained by factoring the stress by 10.84/12.75. Stresses though the wall thickness are linear between the minimum on the inner wall to a maximum at the outer wall.

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FATIGUE CRACK GROWTH RATE BWR ENVIRONMENT (3)

$da/dn = C * E * S * (\Delta K)^n$

C,n = Material constants, C =2.0 E-19,n = 3.302

S = R-ratio correction factor = $(1.0 - 0.5\ R^2)^{-4}$

E = Environmental factor (1.0, 2.0 and 10.0 for air,PWR, and BWR environments, respectively).

ΔK = Kmax - Kmin, psi in

Assume R-ratio = .7

$C * E * S = 2.0\ E\text{-}19 * 10.0\ [\ 1.0 - 0.5\ (.7)^2]^{-4}$

$= 2.0\ E\text{-}18 * [1.0 - 0.5(.49)]^{-4}$

$= 2.0\ E\text{-}18 * [.755]^{-4}$

$= 2.0\ E\text{-}18 * 3.07$

$= 6.155\ E\text{-}18$

THEREFORE $da/dn = 6.155\ E\text{-}18\ (\Delta K)^{3.302}$ for $psi\sqrt{in}$

Weld Residual Stress Calculation for through wall thickness based on NuReg 0313 Rev 2 methodology. (4)

Definition of terms:

S = polynomial coefficients
ε = percent of through wall thickness x/t
R = ratio of residual stress to room temperature yield of 30 ksi for stainless steel. (9)
x = Point measured through wall from ID to OD.
t = Thickness of 2.00"
σ_i = The room temperature yield strength of stainless steel 30 ksi.
σ = The calculated residual stress at location x through wall $\sigma_i * R = \sigma$.

$$S := \begin{bmatrix} 1.0 \\ -6.910 \\ 8.687 \\ -.480 \\ -2.027 \end{bmatrix} \quad i := 0...4 \quad j := 0...10 \quad \varepsilon := \begin{bmatrix} 0.0 \\ 0.1 \\ 0.2 \\ 0.3 \\ 0.4 \\ 0.5 \\ 0.6 \\ 0.7 \\ 0.8 \\ 0.9 \\ 1.0 \end{bmatrix}$$

$$R_j := \sum_i S_i \cdot \varepsilon_j^{\,i}$$

$R = \sigma / \sigma_i$ at the % thickness, ref ε above and σ_i =30 ksi.

$$R = \begin{bmatrix} 1.0 \\ 0.395 \\ -0.042 \\ -0.321 \\ -0.457 \\ -0.47 \\ -0.385 \\ -0.232 \\ -0.044 \\ 0.138 \\ 0.27 \end{bmatrix}$$

RES := R * 30 ksi   RES is the weld residual stress

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Using the information developed on the previous pages the following table identifies the stresses used in performing the evaluations. The last column in Table 1 identifies the stresses used in the IGSCC calculation.

Table 1

x = in.	R	30 * R = ksi	pres.=ksi	DWT= ksi	OBE= ksi	SSE = ksi	30*R+pressure+DWT+OBE=ksi
0	1	30	7.79	0.286	2.76	4.455	40.83
0.2	0.395	11.85	7.79	0.286	2.76	4.455	22.68
0.4	-0.042	-1.26	7.79	0.286	2.76	4.455	9.57
0.6	-0.321	-9.63	7.79	0.286	2.76	4.455	1.2
0.8	-0.457	-13.71	7.79	0.286	2.76	4.455	-2.87
1	-0.47	-14.1	7.79	0.286	2.76	4.455	-3.26
1.2	-0.385	-11.55	7.79	0.286	2.76	4.455	-0.71
1.4	-0.232	-6.96	7.79	0.286	2.76	4.455	3.87
1.6	-0.044	-1.32	7.79	0.286	2.76	4.455	9.51
1.8	0.138	4.14	7.79	0.286	2.76	4.455	14.97
2	0.27	8.1	7.79	0.286	2.76	4.455	18.93

* SSE was used as input to table 4 and is a one time event of safe shutdown earthquake.
**The computer Code rounds these numbers up to the nearest third decimal in scientific notation.

Table 2 contains the stresses used in developing the fatigue cycle for the thermal discontinuity stress. This occurs one time as the RRC system heats up. The minimum stress values used are the same for the IGSCC crack growth calculation for normal operation. The maximum stress is developed by conservatively adding the thermal discontinuity stress equally through wall to the normal operational stresses.

Table 2

x = in. ID-OD	Thermal Discontinuity Stress ksi***	Stress (Min) Thermal (dis)ksi	Stress (Max) Thermal (dis)ksi
0	18.73	40.836	59.566
0.2	18.73	22.686	41.416
0.4	18.73	9.576	28.306
0.6	18.73	1.206	19.936
0.8	18.73	-2.874	15.856
1	18.73	-3.264	15.466
1.2	18.73	-0.714	18.016
1.4	18.73	3.876	22.606
1.6	18.73	9.516	28.246
1.8	18.73	14.976	33.706
2	18.73	18.936	37.666

*** The number 18.73 ksi was conservatively used instead of 18.713 ksi.

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Table 3 contains the stresses used in the fatigue evaluation for the upset loading (OBE). The stresses for OBE were conservatively cycled on top of the normal operating stresses that also contained the OBE stresses. For full stress reversal the minimum stresses used were calculated using the normal stresses and subtracting the OBE stress (Table 1). The maximum stress was developed using the normal stresses and adding the OBE stress. The number of cycles used in the fatigue evaluation was 300/year.

Table 3

x =in	30*R+pressure+DWT+OBE=ksi	Stress (Min) Fatigue OBE=ksi	Stress (Max) Fatigue OBE= ksi
0	40.836	38.076	43.596
0.2	22.686	19.926	25.446
0.4	9.576	6.816	12.336
0.6	1.206	-1.554	3.966
0.8	-2.874	-5.634	-0.114
1	-3.264	-6.024	-0.504
1.2	-0.714	-3.474	2.046
1.4	3.876	1.116	6.636
1.6	9.516	6.756	12.276
1.8	14.976	12.216	17.736
2	18.936	16.176	21.696

Table 4 contains the stresses used in the fatigue evaluation for the faulted loading (SSE). The stresses for SSE were conservatively cycled on top of the normal operating stresses that also contained the OBE stresses. For full stress reversal the minimum stresses used were calculated using the normal stresses and subtracting the SSE stress (Table 1). The maximum stress was developed using the normal stresses and adding the SSE stress. The number of cycles used in the fatigue evaluation was 10/lifetime.

Table 4

x from I	30*R+pressure+DWT+OBE=ksi	Stress (Min) Fatigue SSE=ksi	Stress (Max) Fatigue SSE=ksi
0	40.836	36.381	45.291
0.2	22.686	18.231	27.141
0.4	9.576	5.121	14.031
0.6	1.206	-3.249	5.661
0.8	-2.874	-7.329	1.581
1	-3.264	-7.719	1.191
1.2	-0.714	-5.169	3.741
1.4	3.876	-0.579	8.331
1.6	9.516	5.061	13.971
1.8	14.976	10.521	19.431
2	18.936	14.481	23.391

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Table 5 contains the crack growth adjustments made to the computer calculated values as required by NUREG 0310 Rev. 2. For IGSCC crack growth the NRC requires an aspect ratio (crack length to depth) to be a minimum of 20:1. To calculate this new length the initial value as found during R13 was first multiplied by 20 to obtain the new crack length. This was repeated for subsequent outages and by reviewing the output data for the IGSCC crack growth depth for estimated operational days between outages. R 16 was the last interval prior to R 17 when the flaw length to depth ratio would exceed 33% of the circumference. This length would require the assumption that the flaw was the entire circumference of the pipe in accordance with NUREG 0313 Rev. 2. Therefore, the maximum length and depth used to complete the fatigue evaluation was the R 16 value of 0.89" deep and 17.8 in length.

Table 5

Outage	Days	Depth=in.	New Crack Length=in.
13	0	0.29	5.8
14	290	0.544	10.88
15	580	0.746	14.92
16	870	0.89	17.8

The Input file for N1FAT1.IN contains the flaw length of 17.8" and depth of 0.89". This flaw depth and length was then ran for one year of fatigue cycles due to discontinuity, OBE and SSE in accordance with ASME Code 1989 Section XI Rules. The final length was determined to be 17.81" and 0.983" deep.

These values for Section XI Table IWB-3641-5 and IWB-3641-6 are:

$$l_f = 17.81''$$

$$a_f = 0.983''$$

To determine the Code acceptability of the flaws Tables IWB-3641-5 and -6 are used to determine a_n and a_o. These are the maximum flaw depths for normal and faulted loading conditions. Acceptability is based on a_f being less than these two values. The following calculations are used in conjunction with the referenced Section XI Tables to determined a_n and a_f.

The indication falls into what is classified as weld zone per Fig. IWB-3641-1. This requires the flaw to be evaluated using Tables IWB 3641-5 and -6. The use of these Tables requires the calculation of the defined stress ratio and the flaw length to circumference ratio to determine the allowable depth to thickness ratio. This value is used to determine the maximum flaw depth.

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Circumference of the nozzle is equal to 24*3.14 = 75.36" (based on a nominal diameter of 24")

Depth / Thickness ratio = 0.983" / 2.0" = .492

l_f / Circumference ratio = 17.81" / 75.36" = .236

NORMAL OPERATING (INCLUDING UPSET AND TEST) CONDITIONS

For Table IWB-3641-5 the stress ratio is determined by the following equation: (7)

Stress Ratio = $M(P_m + P_b + P_e) / 2.77 / S_m$ (From the referenced Table)

Using the previous define stresses and an M value of 1.0 (for shielded metal arc welds when OD<24")the above equation for normal operating and upset conditions is equal to :

DWT+OBE+Pressure +OBE+Thermal Discontinuity

0.286+2.76+7.79+2.76+18.73 = 32.326 ksi

NOTE: OBE is added twice conservatively to bound the normal operating and thermal stresses.

Stress Ratio = 32.326 / 2.77 / 16.65 = .701

Using the Stress Ratio and the Circumferential Ratio the allowable Depth to thickness ratio from Table IWB-3641-5 is 0.6.

Therefore the maximum flaw = 2.0 * .6 = 1.2" deep

since 0.983" < 1.2" The flaw is acceptable per Table IWB-3641-5

EMERGENCY AND FAULTED CONDITIONS

For Table IWB-3641-6 the stress ratio is determined using a similar equation as above with the exception of the SSE stress being substituted for one of the OBE and 2.77 being replace with 1.39. (7)

Stress Ratio = $M(P_m + P_b + P_e) / 1.39 / S_m$ (From the referenced Table)

Therefore : 34.021 / 1.39 / 16.65 = 1.47

Using the Stress Ratio and the Circumferential Ratio the allowable Depth to thickness ratio from Table IWB-3641-5 is 0.538

Therefore tha maximum flaw = 2.0 * 0.538 = 1.076"

since 0.983" < 1.076" The flaw is acceptable per Table IWB-3641-6

Conclusion

The flaw meets all the Code Section XI requirements and the N1 nozzle safe-end is acceptable for use without examination until R 16.