SUPPLEMENTAL INFORMATION
ANALYTICAL EVALUATION OF INSERVICE INSPECTION
EXAMINATION RESULTS

Attachment B

CMR-98-0243, "Fracture Mechanics Evaluation of N1A Nozzle Safe End."

WASHINGTON PUBLIC POWER SUPPLY SYSTEM

CALCULATION MODIFICATION RECORD

ORIGINAL

BDC Page: N/A

CMR Page: 1

Cont'd On Page: 2

INITIATION

Calc. Modification No.	Applies to: Calculation No.	Rev.
CMR-98-0243	ME-02-98-04	0

This CMR has been filed against the current revision of the identified calculation, and must be closed out at a future date. All technical data needed to actually update the calculation has been included in this CMR package.

1. Purpose of CMR

This CMR provides the new fracture mechanics calculations and computer runs required to adjust the examination schedule for the N1 nozzle indication to 970 days versus 870 days evaluated in the initial calculation. The change to the examination time interval was required because of the change in the outage date.

2. Input Data Summary (Use additional sheets if necessary)

The data inputs were the same as those used in the original calculations for the IGSCC and Fatigue evaluations. The change was made to the initial crack length used in the fatigue evaluation for the OBE and SSE computer run. The initial crack depth was taken from the IGSCC computer output for 970 days of operation. The initial length was determined as in the original calculation by multiplying the depth by 20 as required by NUREG 0313 Rev 2. The applied cycles required for OBE and SSE were then applied to this crack size and the resulting final crack depth compared to the ASME Code tables as in the original calculation to determine acceptability. It was determined that the 970 days of operation is acceptable base on the results of this CMR.

3. Predicted Result or conclusion

When this CMR is incorporated into the calculation, the results/conclusions will be:

It has been determined that WNP-2 may operate for 970 days 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 1.05" (including OBE and SSE) by the end of 970 days of operation, which is less than the ASME Code allowable.

There are No other CMR's against Calc ME-02-98-04.
There are No interfacing Calculations effected by this CMR.

Prepared by / Date	Verified by / Date
Tom Erwin 10/5/98 — Tom Erwin 10/5/98	[signature] 10/6/98

CLOSEOUT

This CMR has been incorporated into Revision ____ of the identified calculation

Signature ____________ Date ____________

968-19954 R2 (3/98)

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VERIFICATION CHECKLIST FOR CALCULATIONS AND CMRs

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Calculation/CMR CMR-98-0243 Revision 0 was verified using the following methods:

☒ Checklist Below ☐ Alternate Calculations

Checklist Item	Initial
Clear Statement of purpose of analysis	JRL
Methodology clearly stated and sufficiently detailed and appropriate to proposed application	JRL
Logical consistency of analysis	JRL
• Completeness of documenting references	JRL
• Completeness of documenting and updating output interface documents	JRL
Completeness of input	JRL
Accuracy of input data	JRL
Consistency of input data with approved criteria	JRL
Completeness in stating assumptions	JRL
Validity of assumptions	JRL
Calculation sufficiently detailed	JRL
• Arithmetical accuracy	JRL
• Physical units specified and correctly used	JRL
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?	JRL
Other Elements Considered	JRL

• 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: John R LaSalle 10/6/98

Verifier Initials: JRL

968-25280 R1 (3/98)

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CALCULATION OUTPUT SUMMARY

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1.4	1.4001

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Revision No. 0

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Discussion of Results

Four 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 and fourth models used the adjusted crack length (20:1 ratio) as required by NUREG 0313 Rev. 2. The third model used 870 days for the end of the IGSCC crack growth and the fourth used 970 days of operation for the end of IGSCC crack growth as input. The required fatigue cycles for OBE and SSE were then 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 1.05" by the end of 970 days 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 for 970 days of operation.

The weld will be reinspected prior to 970 days of operation, 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 facets are evident during the weld examination that would indicate IGSCC is active.

It has been determined that WNP-2 may operate for 970 days before reexamination of the nozzle to safe-end weld is required. The evaluation demonstrates that 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 1.05" by the end of 970 days of operation which is less than the ASME Code allowable.

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 determined. 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 time period based upon the computer output for the IGSCC model. These intervals were determined as follows: 290 day intervals were used until final interval of an additional 100 days for a total of 970 days. The flaw length and depth of 970 day 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 870 days corrected crack length for NRC 20:1 ratio and the same fatigue cycles for N1FAT.IN
N1FAT2.IN Fatigue model for 970 days of operation.

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 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".

N1FAT2.IN For 970 days a 0.935" depth and half crack of 9.35".

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 N1FAT2.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&2.IN The ΔK_{th} value used was 10.0 or 10000 for the fatigue

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Prepared By/Date: T.M. Erwin	Verified by/Date: [illegible signature] 10/6/98	Revision No.: 0

As identified on the summary sheet this CMR is to evaluate the indication found in the N1A nozzle of the RPV for 970 days of operation. The following provides the calculations in support of this evaluation.

From ME-02-98-04 computer output for the IGSCC evaluation (pages 22 and 23 of file N1IGSCC.OUT) the following numbers were used to determine the crack depth for 970 days of operation.

Duration (days)	976.3	955.2	delta of 21.1 days
Crack Depth	0.9382531	0.9289635	delta of 0.0092896 inches

To determine the crack growth/day delta in inches /21.1 days = 0.00044026 inches/day

976.3 days - 970 days = 6.3 days

6.3 days x 0.00044026 inches/day = 0.0027736 inches

for 970 days 0.9382531- 0.0027736 = .9354824 inches

Therefore the crack depth for 970 days is 0.935 inches that was used for input into the OBE and SSE model for the fatigue evaluation to determine the flaw size after the event.

The crack length used was determined by multiplying the flaw depth by 20 to maintain the aspect ratio as required by NUREG 0313 Rev. 2. The new input for the flaw depth and half crack for the input file for OBE and SSE is 0.935 inches deep and a half crack of 9.35 inches (file N1FAT2.IN). All other inputs stay the same as those identified in the calculation.

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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 intervals and by reviewing the output data for the IGSCC crack growth depth for estimated operational days between outages. The maximum length and depth used to complete the fatigue evaluation was determined after 970 days of operation, these values are 0.935" deep and 18.7" in length.

Table 5

Days	Depth=in.	New Crack Length=in.
0	0.29	5.8
290	0.544	10.88
580	0.746	14.92
870	0.89	17.8
970	0.935	18.7

The Input file for N1FAT1.IN contains the flaw length of 18.7" and depth of 0.935". 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 18.712" and 1.05" deep.

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

$$l_f = 18.71''$$

$$a_f = 1.05''$$

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 = 1.05 / 2.0" = .525

l_f / Circumference ratio = 18.7" / 75.36" = .248

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 1.05" < 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 0.54 using linear interpolation as allowed by the table.

Therefore tha maximum flaw = 2.0 * 0.54 = 1.08"

since 1.05" < 1.08" 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 for 970 days of operation.