Exelon Nuclear

Exelon Generation
4300 Winfield Road
Warrenville, IL 60555

www.exeloncorp.com

RS-03-206

October 29, 2003

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

Dresden Nuclear Power Station, Unit 2
Facility Operating License No. DPR-19
NRC Docket No. 50-237

Subject: Request for Approval of Pipe Flaw Evaluation

Reference: NRC Generic Letter 88-01, "NRC Position on IGSCC in BWR Austenitic Stainless Steel Piping," dated January 25, 1988

In accordance with Generic Letter (GL) 88-01, "NRC Position on IGSCC in BWR Austenitic Stainless Steel Piping," dated January 25, 1988 (i.e., Reference), Exelon Generation Company, LLC (EGC) requests NRC approval of a pipe flaw evaluation for a weld in the Reactor Recirculation (RR) system piping at Dresden Nuclear Power Station (DNPS), Unit 2 that EGC proposes to leave as-is without repair. The flaws do not meet the acceptance standards of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code) Section XI, 1995 Edition with 1996 Addenda, for continued operation without evaluation.

On October 22, 2003, during the current DNPS Unit 2 refueling outage (i.e., D2R18), EGC identified, using an automated phased array ultrasonic testing (UT) technique, four separate planar flaws on the "B" RR loop suction nozzle, between the safe end and the pipe elbow. The inspections were conducted in accordance with GL 88-01 and Boiling Water Reactor Vessel and Internals Project (BWRVIP) Report 75, "Technical Basis for Revisions to Generic Letter 88-01 Inspection Schedules," as modified by associated NRC Safety Evaluation dated May 14, 2002. The UT examination used Performance Demonstration Initiative (PDI) qualified personnel, equipment, and procedures. The weld, identified as 2/1/0202B-28/PS2/201-1, is a category "D" weld and is located in the 28-inch diameter "B" RR loop suction nozzle between the safe end and pipe elbow. The safe end is constructed of furnace sensitized SA376-TP316 material, with a measured pipe wall thickness of 1.34 inches. The flaws are on the safe end side of the weld, with no axial indication. The through-wall depth, measured from the inside diameter, of each flaw does not exceed 0.24 inches. The lengths of the four flaws are 1.728 inches, 2.788 inches, 3.614 inches, and 17.075 inches (i.e., pipe outside diameter length). The last examination of this weld was performed in October 1999, using manual UT, and no recordable indications were identified.

A001

The original scope of UT examinations of IGSCC susceptible welds for D2R18 was in accordance with our commitments to GL 88-01 and BWRVIP Report 75 and included eight category "D" welds in the RR system. Following the discovery of the flaws in weld 2/1/0202B-28/PS2/201-1, the inspection scope was expanded in accordance with GL 88-01/BWRVIP Report 75 (as modified by associated NRC Safety Evaluation dated May 14, 2002) by adding eight additional category "D" welds in the RR system. No other flaws were identified within the expanded weld inspection population nor within the remaining seven welds of the original population.

An evaluation of the flaws assuming conservative crack growth rates has been performed by General Electric (GE) and is attached to this letter. The evaluation was performed using the methodology and acceptance criteria specified in ASME Code, Section XI, 1995 Edition with 1996 Addenda, subarticle IWB-3640, "Evaluation Procedures and Acceptance Criteria for Austenitic Piping," and the guidance of NUREG-0313, Revision 2, "Technical Report on Material Selection and Process Guidelines for BWR Coolant Pressure Boundary Piping." This flaw evaluation considered a conservative flaw size, expected growth rates assuming both hydrogen and normal water chemistry, and plant chemistry parameters, and demonstrates that substantial structural margin exists for more than one operating cycle considering normal water chemistry since the acceptance criteria of subarticle IWB-3640 are met.

Therefore, EGC has concluded that the flaws are acceptable as-is for continued operation through the next operating cycle. However, based on the D2R18 inspection results discussed above and the weld classifications contained in GL 88-01, weld 2/1/0202B-28/PS2/201-1 will be reclassified from category "D" to "F" (i.e., cracked weld with inadequate or no repair) and will require inspection each refueling outage.

EGC requests NRC review and approval of the attached flaw evaluation report by October 31, 2003, in support of unit startup.

Should you have questions concerning this submittal, please contact Mr. Kenneth M. Nicely at (630) 657-2803.

Respectfully,

Patrick R. Simpson

Patrick R. Simpson
Manager – Licensing

Attachment: General Electric Nuclear Energy Report No. GE-NE-0000-0022-6311-01, "Fracture Mechanics Evaluation of the Indication in the Recirculation Line at the Safe-End to Elbow 2/1/0202B-28/PS2/201-1 Weld at the Dresden Unit 2," dated October 2003

cc: Regional Administrator - NRC Region III
NRC Senior Resident Inspector - Dresden Nuclear Power Station

ATTACHMENT

General Electric Nuclear Energy Report No. GE-NE-0000-0022-6311-01,
"Fracture Mechanics Evaluation of the Indication in the Recirculation Line
at the Safe-End to Elbow 2/1/0202B-28/PS2/201-1 Weld at the Dresden Unit 2,"
dated October 2003

GE Nuclear Energy

ENGINEERING AND TECHNOLOGY
GE Nuclear Energy
175 Curtner Avenue, San Jose, CA, 95125

GE-NE-0000-0022-6311-01
DRF 0000-0022-6311
Class II
October 2003

FRACTURE MECHANICS EVALUATION OF THE INDICATION IN THE RECIRCULATION LINE AT THE SAFE-END TO ELBOW 2/1/0202B-28/PS2/201-1 WELD AT THE DRESDEN UNIT 2

FINAL

Prepared By: Shawn A. Kleinsmith
D. Sommerville, Engineer
S. Kleinsmith, Engineer
Structural Analysis & Hardware Design

Verified By:
B. Branlund, Principal Engineer (Technical Lead)
H. Mehta, Engineering Fellow
Structural Analysis & Hardware Design

Approved By: 10/28/03
for M. Schrag, Manager A. MAHADEVAN
Structural Analysis & Hardware Design

IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT

Please Read Carefully

The only undertakings of the General Electric Company (GE) respecting information in this document are contained in the contract between Exelon and GE, (Dresden Unit 2 "Recirc Line Weld Flaw JCO"), effective (October 27, 2003), as amended to the date of transmittal of this document, and nothing contained in this document shall be construed as changing the contract. The use of this information by anyone other than Exelon, or for any purpose other than that for which it is furnished by GE, is not authorized; and with respect to any unauthorized use, GE makes no representation or warranty, express or implied, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document, or that its use may not infringe privately owned rights.

ABSTRACT

During the D2R18 (October 2003) in-service inspection of the Dresden Unit 2 Recirculation Piping, an indication was found in the heat affected zone (Safe-End Side) of the Safe-End to Elbow weld PS2/201-1 that exceeded the ASME acceptance standards of IWB-3514.3 of the 1995 Edition, including the 1996 addendum (Reference 1). The examination was performed in accordance with the requirements of Generic Letter 88-01 and the Boiling Water Reactor Vessel and Internals Project (BWRVIP) Report 75, "Technical Basis for Revisions to Generic Letter 88-01 Inspection Schedules", as modified by associated NRC Safety Evaluation dated May 14, 2002. The examination was performed using Automated Phased Array Ultrasonic Inspection Technology and showed a total of four (4) circumferential indications on the inside diameter of the pipe, with a total measured cumulative length of approximately 25.2 inches long (approximately 28.3% of circumference) with maximum depth of 0.24 inch (approximately 18.0% of thru-wall thickness). Figure 1 shows a schematic of the observed indications. The flaws were evaluated for continued operation using the criteria of Appendix C, Section XI, ASME Code - 1995 Edition, including the 1996 Addendum (Reference 1). The results of the evaluation for normal water chemistry (NWC) confirm that the required ASME Code structural margins are maintained beyond the next (1) operating cycle, two (2) years in length. The results of the evaluation for Hydrogen Water Chemistry with Noble Chemistry (HWC/NobleChem™) confirm that the required ASME Code structural margins are maintained beyond the next two (2) operating cycles, each two (2) years in length. For both chemistry situations/assumptions (NWC & HWC/ NobleChem™) it is shown that adequate structural margins are maintained considering at least one (1) additional cycle of operation, two (2) years in length. Therefore, continued operation 'as is' for at least one (1) additional operating cycle, two (2) years in length is justified.

TABLE OF CONTENTS

TABLE OF FIGURES

1. INTRODUCTION

During the October 2003 in-service inspection of the Dresden Unit 2 Recirculation Piping, an indication was found in the heat affected zone (Safe end Side) of the Safe-End to Elbow weld PS2/201-1 that exceeded the ASME acceptance standards of IWB-3514.3 in the ASME Code - 1995 Edition, including the 1996 addendum (Reference 1). The examination was performed in accordance with the requirements of Generic Letter 88-01 and the Boiling Water Reactor Vessel and Internals Project (BWRVIP) Report 75, "Technical Basis for Revisions to Generic Letter 88-01 Inspection Schedules", as modified by associated NRC Safety Evaluation dated May 14, 2002. The examination was performed using automated UT and showed four (4) circumferential indications. Reference 2 provides details of the UT examination of the 2/1/0202B-28/PS2/201-1 weld and a description of the Flaws is given in Section 2 of this report.

2. DESIGN INPUTS

The Design Input Request (DIR) responses from Exelon (Reference 7) states that the RPV Nozzle Safe-end is SA-376 TP 316 stainless steel (furnace sensitized) with an outside diameter of 28.375 inches with a wall thickness of 1.34 inches. The Design Stress Intensity (Sm) for the material at 550°F is 17600 psi (Reference 1). The RPV pressure used in the fracture mechanics evaluation is taken from the "Reactor Vessel – Power Uprate – Design Specification" (Reference 6).

3. FLAW DESCRIPTION

Reference 2 provides details of the UT examination of the 2/1/0202B-28/PS2/201-1 weld. The Automated Phased Array Ultrasonic Inspection showed a total of four (4) circumferential flaw indications on the inside surface of the Safe-End on the upstream side of the weld.

Table 1 shows the flaw locations relative to Top Dead Center, the reference point, the flaw lengths, and flaw locations relative to each other. Figure 1 is a Schematic that graphically shows the information for the observed indications.

TABLE 1 – OBSERVED FLAWS, LOCATION, AND LENGTHS

Flaw Number	Flaw Start from TDC (inches)	Flaw Stop from TDC (inches)	Flaw Length* (inches)	Relative Distance Between Flaws in (+) direction (inches)
1	+15.149	+16.877	1.728	0.823
2	+17.700	+20.488	2.788	6.634
3	+27.122	+30.736	3.614	34.303
4	+65.039	+82.114	17.075	22.178

* Flaw length dimensions are relative to the outside of the pipe.

The sum (simple addition) of the flaw lengths is 25.2 inches. Therefore approximately 28.3% of the total circumference is flawed. The Examination Summary Sheet (Reference 2) states that a shear wave, 45° RL and 60° RL were used to size the crack tip depth. The maximum thru-wall depth of 0.24 inch (approximately 18.0% of thru-wall thickness) was calculated/reported for indications 1 thru 4 and used for the fracture mechanics evaluation.

The indications exceed the acceptance standards of IWB-3514.3 and must be evaluated using the procedures outlined in IWB-3600, Section XI, ASME Code. This report describes the methods and results of the evaluation.

4. FLAW GEOMETRY USED FOR CALCULATION

The analyzed flaw geometry is based on the "Multiple and Complex Crack Characterizations (Case 3)" recommendations provided in NUREG-0313 Rev. 2 (Reference 4). The flaw geometry is one (1) fully circumferential flaw with a uniform depth equal to the maximum thru-wall depth determined in the UT examination (0.24 inch). Figure 2 is a Schematic that graphically shows the assumed/analyzed flaw.

5. CRACK GROWTH MITIGATION ASSESSMENT

Dresden Unit 2 has been operating under Hydrogen Water Chemistry (HWC) since 1983. NobleChem™ was implemented during the Fall outage in 1999. Hydrogen availability during the last two (2) year was greater than 90% at temperatures above 200°F. Barring major transients, it is expected that the hydrogen availability will be at least 90% during the coming cycle with an availability goal of greater than 98%.

The historical and expected water chemistry parameters for Dresden Unit 2 are compared to the EPRI BWR Water Chemistry Guidelines (Reference 3) in the evaluation titled "Dresden Unit 2 Water Chemistry Data from Cycle 18 and Expected Water Chemistry Data from Cycles 19 and 20 Comparison to the EPRI BWR Water Chemistry Guidelines", included in this report as Appendix B.

With the reapplication of NobleChem™ at EOC 18, it is currently expected that the Cycle 18 chemistry can be routinely achieved, barring major transients. Provided the reactor water chemistry at Dresden-2 can be maintained in Cycles 19 and 20 at comparable values to those in Cycle 18, the Hydrogen Water Chemistry & Noble Chemistry (HWC/NobleChem™) crack growth rate values from BWRVIP-14 (Reference 5) are valid and can be utilized. For the purposes of this evaluation, a 90% capacity factor for HWC/NobleChem™ and a conservative factor of improvement (FOI) of 2 for crack growth was used.

6. STRUCTURAL MARGIN ASSESSMENT

The limit load method used in the analysis is consistent with the procedures outlined in Appendix C of Section XI of the ASME Code [1]. A brief description of the method is provided next.

Consider a fully circumferential crack of length, $l = 2\pi R$ and constant depth, d. In order to determine the flaw parameters at which limit load is achieved, it is necessary to apply the equations of equilibrium assuming that the cracked section behaves like a plastic hinge. For this condition, the assumed stress state at the cracked section is as shown in Figure 4, where the maximum stress is the flow stress of the material, σ_f. Equilibrium of longitudinal forces and moments about the original neutral axis gives the following equations:

$$\beta = \pi \cdot \frac{\left(1 - \frac{d}{t} - \frac{Pm}{3 \cdot Sm}\right)}{2 - \frac{d}{t}} \qquad (1)$$

$$Pb' = \left(\frac{2 \cdot 3 \cdot Sm}{\pi}\right) \cdot \left(2 - \frac{d}{t}\right) \cdot \sin(\beta) \qquad (2)$$

Where,
t = pipe thickness in inches
d = the flaw depth in inches
β = angle that defines the location of the neutral axis in radians
P_m = Primary membrane stress in psi
Pb' = Failure bending stress in psi

The safety factor, SF, is then incorporated as follows:

$$Pb' = Z \cdot SF \cdot \left(Pm + Pb + \frac{Pe}{SF} \right) - Pm \qquad (3)$$

P_m and P_b are the primary membrane and bending stresses, respectively. P_e is the secondary stress and includes stresses from all displacement-controlled loadings such as thermal expansion and dynamic anchor motion. Pe is applicable for flux welds only. All three quantities are calculated from the analysis of applied loading. The safety factor is 2.77 for normal/upset conditions and 1.39 for emergency/faulted conditions. The Z factor is discussed next.

Z Factor

The test data considered by the ASME Code in developing the flaw evaluation procedure (Appendix C, Section XI) indicated that the welds produced by a process that did not use a flux had fracture toughness as good or better than the base metal. However, flux welds had lower toughness. To account for the reduced toughness of the flux welds (as compared to non-flux welds) the Section XI procedures prescribe a penalty factor, called a 'Z' factor. Examples of flux welds are submerged arc welds (SAW) and shielded metal arc welds (SMAW). Gas metal-arc welds (GMAW) and gas tungsten-arc welds (GTAW) are examples of non-flux welds. Figure IWB-3641-1 of Reference 1 may be used to define the weld-base metal interface. The expressions for the value of the Z factor in Appendix C of Section XI are given as follows:

$$Z = 1.15\,[1 + 0.013(OD-4)] \text{ for SMAW} \qquad (4)$$
$$= 1.30\,[1 + 0.010(OD-4)] \text{ for SAW}$$

where OD is the nominal outside pipe diameter in inches. The weld was conservatively evaluated as a SAW weld (Reference 10). Therefore, the Z factor in the evaluation was calculated using the expression for SAW. For a 28 inch pipe, the Z factor equals 1.62.

7. FLAW EVALUATION ASSESSMENT

Section XI of the ASME Boiler & Pressure Vessel Code (Reference 1) requires that flaw evaluations consider all relevant methods of crack growth and provides recommendations regarding both Fatigue Crack Growth (FCG) and Intergrannular Stress Corrosion Cracking Crack growth (IGSCC).

FCG is typically negligible compared to IGSCC growth. The only stress cycles acting on the recirculation system that influence FCG are the startup shutdown cycles and seismic events. In the fracture mechanics evaluation GE considered; twenty (20) startup/shutdown cycles and ten (10) seismic events with ten (10) load cycles each, two (2) cycles of operation. The FCG calculated was less than 0.0017 inch at the end of two (2) operating cycle, two (2) years in length each. Therefore, the incremental FCG contribution to length for one (1) cycle, two (2) years, is negligible (less than 0.001 inch crack depth).

IGSCC Crack growth evaluations were performed using three different approaches and the structural margin assessment for these cases are provided in the next section.

1. *Bounding crack growth rates for normal water chemistry (NWC) based on the recommendations in NUREG-0313 Rev. 2 (Reference 4)*

   Figure 3, of this report, from Reference 4 shows the typical stress intensity factors for different pipe sizes and typical weld residual stress patterns. The stresses calculated for this weld are below the 7500 psi considered in Figure 3, however the applied stress intensity distribution shown in Reference 4 was conservatively used. For a 28 inch diameter pipe the maximum K value is 21 ksi-√in over the relevant range of allowable crack depths (based on ASME Section XI, IWB-3600 evaluation methods). The associated crack growth rate (CGR) corresponding to NUREG-0313 Rev.2 (Reference 4) is:

   CGR $= 3.59 \times 10^{-8} K^{2.161}$ in/hour, where K is the applied stress intensity factor in ksi-√in.

   Using a K value of 21 ksi-√in, the corresponding CGR is 2.58×10^{-05} in/hour. This takes no credit for HWC/NobleChem™ operation. Additionally, no credit is taken for the predicted decrease in total stress intensity as the flaw grows deeper into the pipe thickness. Considering these two items, this method is extremely conservative. GE assumed one (1) operating cycle, with a capacity factor of 100%, for a two (2) year cycle thus 17532 hours of hot operation, resulting in an incremental crack growth of 0.453 inch. This growth results in a maximum depth of 0.24 + 0.001 + 0.453 = 0.694 inch at the end of one (1) operating cycle two (2) years in length. Using the crack growth rate discussed above, 25092 hours of operation can be justified before the considered indication reaches the limiting depth determined using the ASME Section XI, Appendix C (Reference 1) analysis methodology. This corresponds to approximately 1.43 cycles of operation based on a two (2) year cycle.

The results of this evaluation demonstrate that adequate structural margin can be demonstrated for operation of Dresden Unit 2 considering the flaw described in this report and the NWC crack growth method described in NUREG 0313, Rev. 2 (Reference 4), for one (1) cycle of operation on a two (2) year fuel cycle.

2. *Plateau crack growth rates based on NRC SER for BWRVIP-14 (Reference 5)*

In the SER for BWRVIP-14, the NRC approved a plateau CGR of 2.2×10^{-5} in/hr for the shroud with NWC conditions. Although this was primarily intended for BWR internals, it is conservative to use this for the recirculation piping since the environment is less oxidizing than that for the internals. Additionally, this CGR is only applicable to items with fluences less than 5.0×10^{20} n/cm^2.

The CGR of 2.2×10^{-5} in/hr for the recirculation piping with NWC conditions has been previously approved by the NRC in the Quad Cities Unit 2 Flaw Evaluation SER (Ref 9). For the fracture mechanics evaluation a CGR of 2.2×10^{-5} in/hour for NWC conditions was used. The fluence limitation, mentioned above, is readily met by the low fluence condition at the recirculation pipe weld. This crack growth rate does not take credit for HWC/NobleChem™. Assuming 17532 hours of hot operation for each cycle, the incremental crack growth is 0.386 inch. This growth results in a maximum depth of 0.24 + 0.001 + 0.386 = 0.627 inch at the end of one (1) operating cycle two (2) years in length. Using the crack growth rate discussed above, 29470 hours of operation can be justified before the considered indication reaches the limiting depth determined using the ASME Section XI, Appendix C (Reference 1) analysis methodology. This corresponds to approximately 1.68 cycles of operation.

The results of this evaluation demonstrate that adequate structural margin can be demonstrated for operation of Dresden Unit 2 considering the flaw described in this report and the NWC crack growth rate described in BWRVIP-14 (Reference 5), and reviewed and approved for use in recirculation piping in the fore mentioned SER (Reference 9), for one (1) cycle of operation on a two (2) year fuel cycle.

3. *Plateau crack growth rates taking credit for HWC/NobleChem™*

This approach takes credit for the HWC/NobleChem™ operation during the next cycle. As discussed earlier, assuming a conservative FOI of 2, and the BWRVIP-14 (Reference 5) plateau CGR of 2.2 $\times 10^{-5}$ in/hour for NWC, the CGR for HWC/NobleChem™ is 1.1 $\times 10^{-5}$ in/hour. The CGR of 2.2 $\times 10^{-5}$ in/hour for NWC, the CGR for HWC/NobleChem™ is 1.1 $\times 10^{-5}$ in/hour and FOI of 2 require that ECP values of less than –230 mV and a HWC operation at greater than 80%. The location of the crack also has to have a lower oxidizing environment than the monitored location. Consistent with the plant chemistry discussion provided in Appendix B, of this report, GE assumes a conservative value of 90% for HWC availability and that the average ECP value is less than –230 mV is maintained. A lower oxidizing environment than the monitored location is met by virtue of the location of the crack. The effective CGR for the next cycle is given by:

Effective CGR = $(0.1 \times 2.2 + 0.9 \times 1.1) \times 10^{-5}$ in/hour or 1.21 $\times 10^{-5}$ in/hour.

Using this CGR and Assuming 17532 hours of hot operation for the next cycle, the incremental growth crack depth is 0.212 inch. This results in a maximum depth of 0.24 + 0.001 + 0.212 = 0.453 in. Using the crack growth rate discussed above, 53487 hours of operation can be justified before the considered indication reaches the limiting depth determined using the ASME Section XI, Appendix C (Reference 1) analysis methodology. This corresponds to approximately 3.05 cycles of operation.

The results of this evaluation demonstrate that adequate structural margin can be demonstrated for operation of Dresden Unit 2 considering the flaw described in this report and the HWC/NobleChem™ crack growth rate described in BWRVIP-14 (Reference 5), and reviewed and approved for use in recirculation piping in the fore mentioned SER (Reference 9), for at least one (1) cycle of operation on a two (2) year fuel cycle.

8. CONCLUSIONS

The evaluation presented is based on several conservative assumptions concerning crack growth and follows the procedures of the Appendix C, Section XI, ASME Code - 1995 Edition, including the 1996 addendum (Reference 1), NUREG-0313 Rev. 2 (Reference 4), and BWRVIP-14 (Reference 5) criteria. Table 2 provides a summary of the calculated Flaw depth after 1 cycle of operation for all chemistry assumptions/situations. The results of the evaluation for normal water chemistry (NWC) confirm that the required ASME Code structural factors are maintained beyond the next (1) operating cycle, two (2) years in length. The results of the evaluation for Hydrogen Water Chemistry with Noble Chemistry (HWC/NobleChem™) confirm that the required ASME Code structural factors are maintained beyond the next three (3) operating cycles, each two (2) years in length. In both chemistry situations (NWC & HWC/NobleChem™), it is shown that adequate structural margins are maintained considering at least one (1) additional cycle of operation, two (2) years in length. Therefore continued operation 'as is' for at least one (1) additional operating cycle, two (2) years in length is justified and all required structural margins are maintained.

Table 2 - Comparison of Calculated Flaw Depth (After 1 Fuel Cycle) and Structural Allowable Flaw Depth

CGR Assumption	Final Flaw Size after one Cycle (inches)		Structural Allowable Flaw Depth (inches)
	Calculated Depth	Length	Allowable Depth
Normal Water Chemistry (NWC) CGR Based on NUREG-0313 Rev. 2 CGR= 2.58×10^{-5} in/hr	0.694	Fully Circumferential*	0.889
Normal Water Chemistry (NWC) CGR Based on NRC SER for BWRVIP-14 CGR= 2.2×10^{-5} in/hr	0.627	Fully Circumferential*	0.889
Hydrogen Water Chemistry & Noble Chemistry (HWC/NobleChem™) CGR taking credit for HWC/NobleChem™) operation CGR= 1.21×10^{-5} in/hr	0.453	Fully Circumferential*	0.889

* The analyzed flaw geometry is based on the "Multiple and Complex Crack Characterizations (Case 3)" recommendations provided in NUREG-0313 Rev. 2 (Reference 4).

9. REFERENCES

1. American Society of Mechanical Engineers,
   - Boiler & Pressure Vessel Code, Section III (1965) – Nuclear Vessels
   - Section XI, ASME Code 1995 Edition, including the 1996 addendum

2. GE Nuclear Energy, "2R18-052 Examination Report – Examination Summary Sheet for 2/1/0202B-28/PS2/201-1", GE Nuclear Energy, San Jose, CA, October 2003

3. EPRI, "BWR Water Chemistry Guidelines—2000 Revision," EPRI, Palo Alto, California, February 2000, (EPRI Document No. TR-103515-R2.)

4. U.S. Nuclear Regulatory Commission, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping"), U.S Nuclear Regulatory Commission Office of Nuclear Reactor Regulation, (NUREG-0313 Rev.2)

5.
   - BWR Vessel and Internal Projects: Evaluation of Crack Growth in BWR Stainless Steel RPV Internals (BWRVIP-14), EPRI, Palo Alto, CA (EPRI TR-105873), March 1996
   - BWR Vessel and Internal Projects: Evaluation of Crack Growth in BWR Stainless Steel RPV Internals (BWRVIP-14-A), EPRI, Palo Alto, CA (EPRI XXXXXXX), DRAFT August 2003.

6. GE Nuclear Energy, "Reactor Vessel – Power Uprate – Design Specification", GE Nuclear Energy, San Jose, CA (26A5587, Rev. 0)

7. GE Nuclear Energy, "Design Input Request (DIR) - Dresden 2 Recirculation Line Flaw Evaluation, GE Nuclear Energy, San Jose, CA (Contained in DRF# 0000-0022-6311), October 2003

8. Hale, D.A., et al. "Fatigue Crack Growth in Piping and RPV in Simulated BWR Water Environment". GE Nuclear Energy, San Jose, CA, (GEAP-24098), January 1978.

9. SER
   - Letter from Carl F. Lyon, NRC to John L. Skolds, Exelon, "Quad Cities Nuclear Power Station, Unit 2 – Approval of Pipe Flaw Evaluation (TAC No. MB4093)", June 6, 2002. Docket No. 50-265

10. GE Nuclear Energy, "Gen. Require. for Reactor Recirc. Sys. Piping (SS)", GE Nuclear Energy, San Jose, CA, (21A2108, Rev. 0), April 1966.

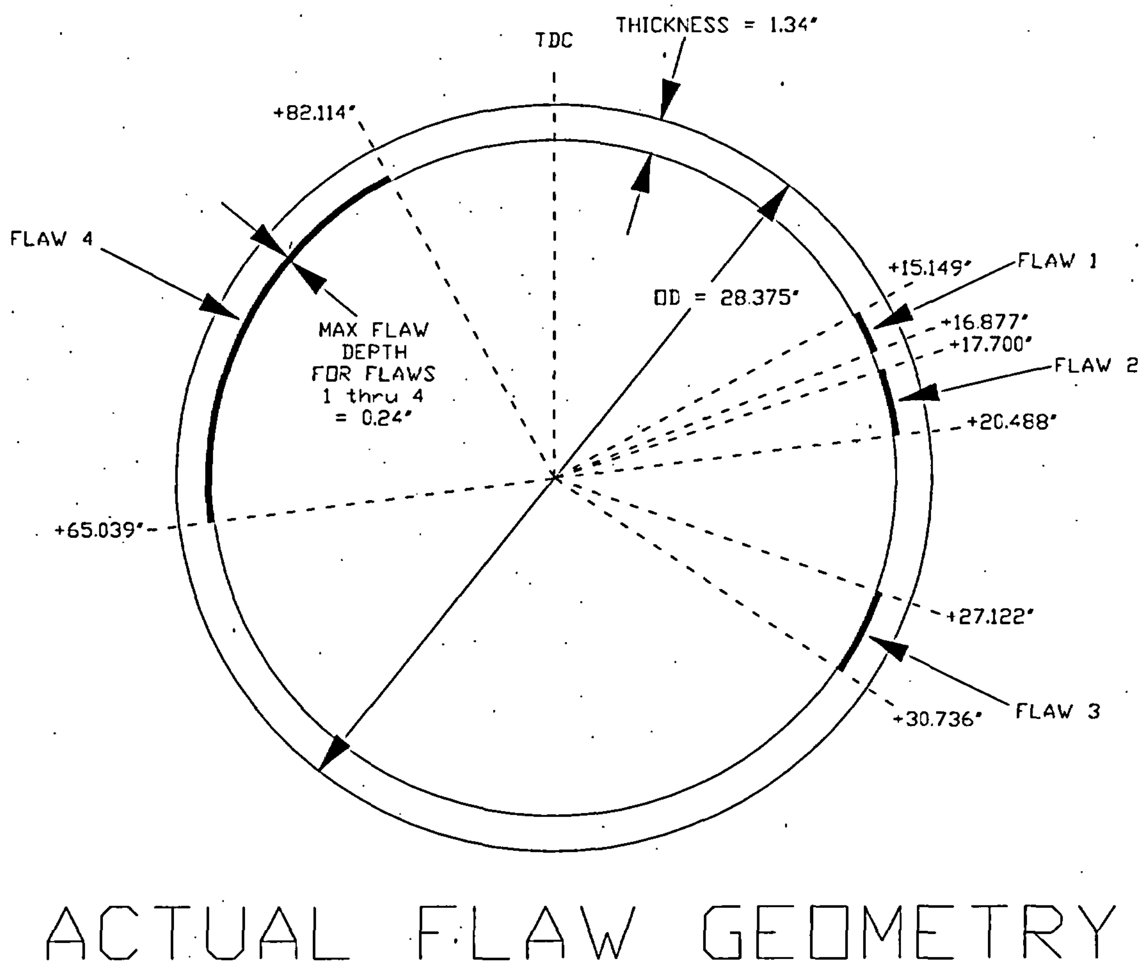

Figure 1 - Schematic of the Indications in Weld 2/1/0202B-28/PS2/201-1 (PS2/201-1)

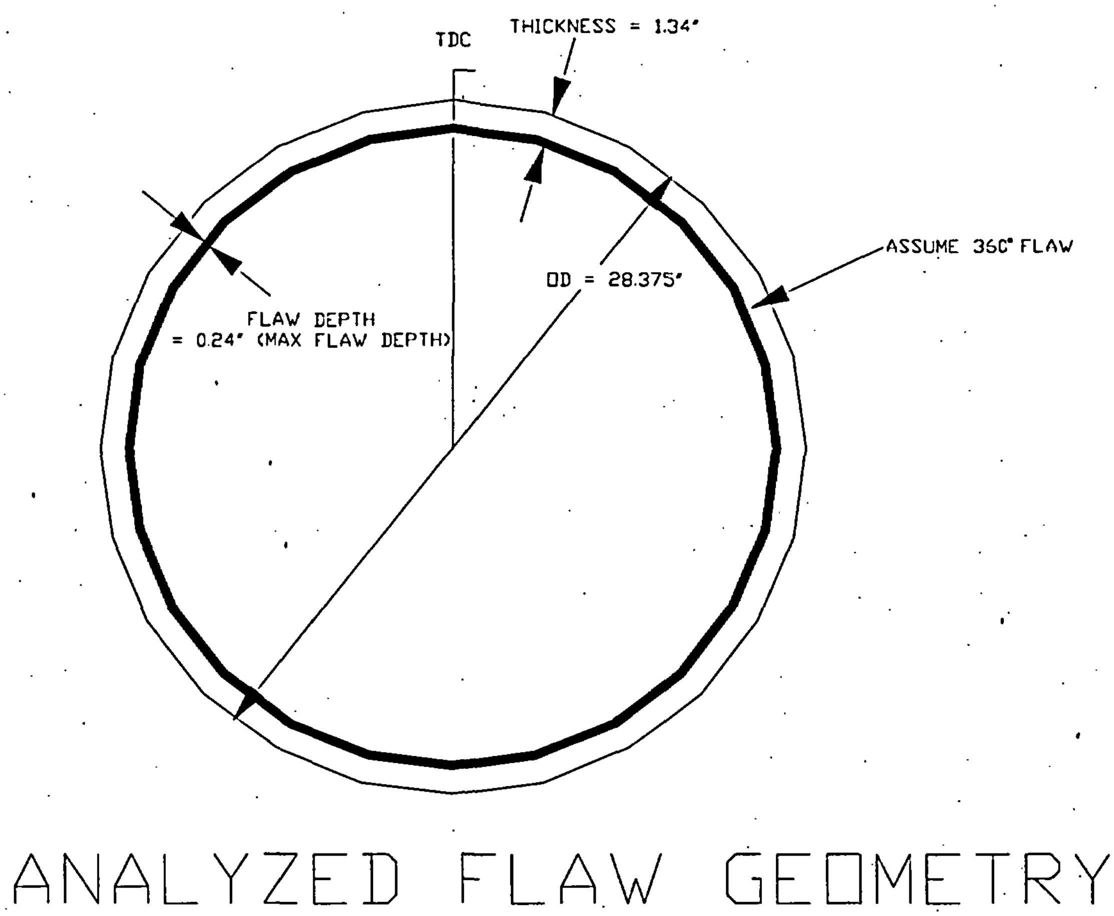

Figure 2 - Schematic of Assumed/Analyzed in Weld 2/1/0202B-28/PS2/201-1 (PS2/201-1)

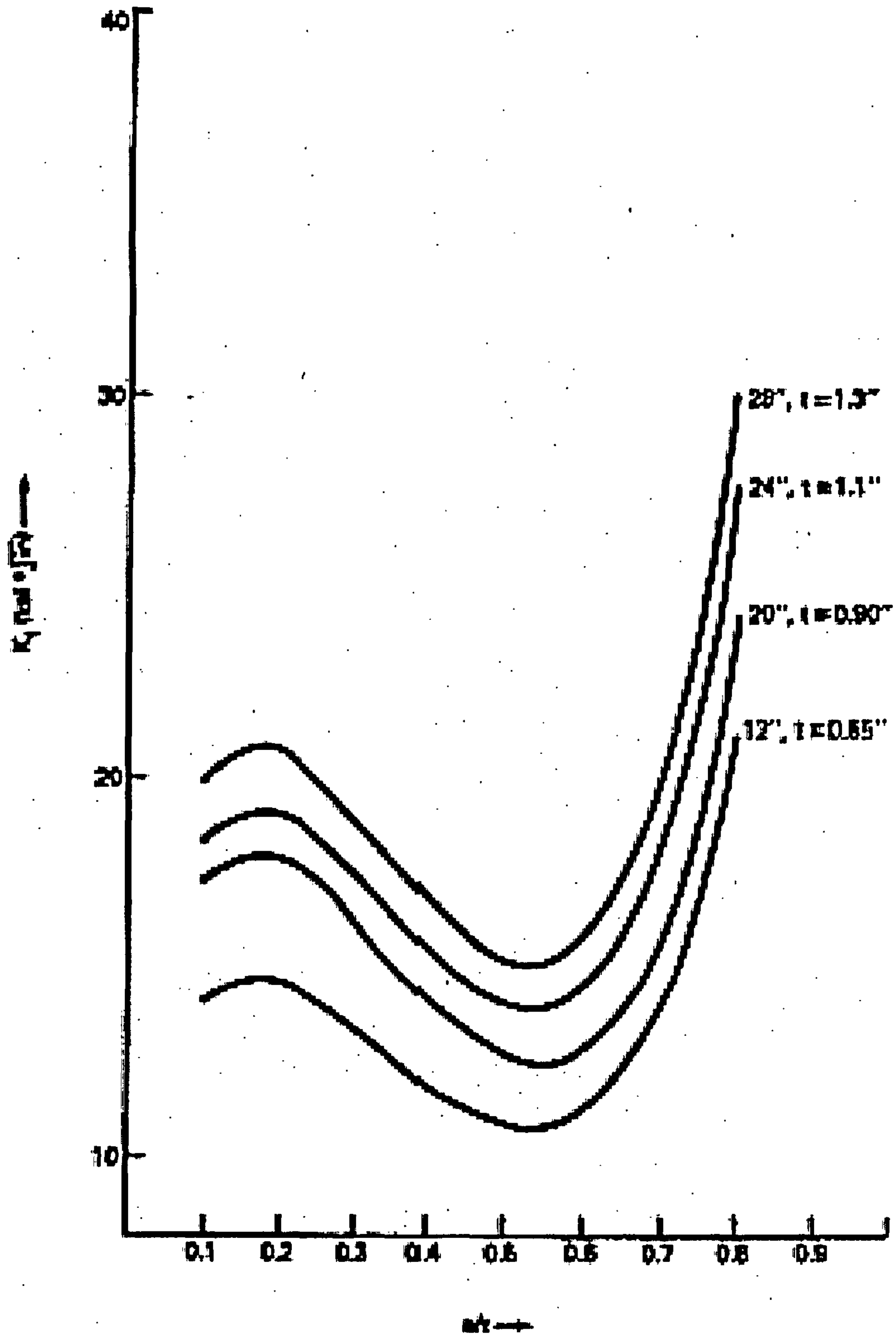

Figure 3 - Through-wall Distribution K_I With Applied Stress of 7500 PSI Stress Intensity Factors for different pipe sizes (From NUREG-0313)

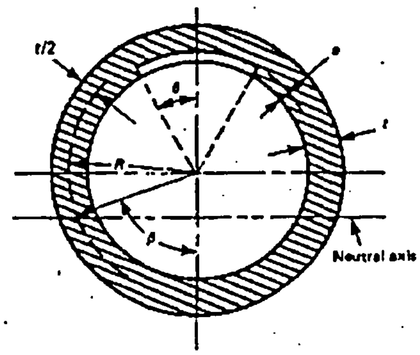

FIG. C-3320-1 CROSS SECTION OF FLAWED PIPE

(c) For shielded metal-arc welds (SMAW) and submerged arc welds (SAW), the results in Tables IWB-3641-5 and IWB-3641-6 can be closely approximated by taking

$$P_b' = Z_1 (SF)(P_m + P_b + P_e/SF) - P_m \qquad (6)$$

where

$$Z_1 = 1.449$$

and for normal operating conditions

$$P_m = 0.5S_m$$

$$(P_m + P_b + P_e/SF) = \text{table ordinate value} \times S_m$$

$$SF = 2.77$$

or for emergency and faulted conditions

$$P_m = 1.0S_m$$

$$(P_m + P_b + P_e/SF) = \text{table ordinate value} \times S_m$$

$$SF = 1.39$$

When using the actual piping stresses to determine an allowable flaw size, the values in Eq. (6) are given by

P_m = piping membrane stress
P_b = piping bending stress
P_e = piping expansion stress
SF = 2.77 for normal operating conditions
= 1.39 for emergency and faulted conditions
Z_1 = 1.15 [1 + 0.013 (OD-4)] for SMAW
= 1.30 [1 + 0.010 (OD-4)] for SAW

OD is the nominal pipe size, NPS, and for NPS ≤ 24 in., use O.D. = 24. Weld material is defined in Fig. IWB-3641-1.

(a) The formulas for obtaining the allowable flaw depths a_n and a_e listed in Tables IWB-3641-1, IWB-3641-2, IWB-3641-5 and IWB-3641-6 are given here.

For circumferential flaws not penetrating the compressive side of the pipe such that $(\theta + \beta) \leq \pi$ (see Fig. C-3320-1), the relation between the applied loads and flaw depth at incipient plastic collapse is given by

$$P_b' = \frac{6S_m}{\pi}\left(2 \sin\beta - \frac{a}{t}\sin\theta\right) \qquad (3)$$

where

$$\beta = \frac{1}{2}\left(\pi - \frac{a}{t}\theta - \pi\frac{P_m}{3S_m}\right)$$

θ = half flaw angle

P_b' is the failure bending stress as defined in paragraphs (b) and (c) below.

For longer flaws penetrating the compressive bending region where $(\theta + \beta) > \pi$ (see Fig. C-3320-1), the relation between the applied loads and the flaw depth at incipient plastic collapse is given by

$$P_b' = \frac{6S_m}{\pi}\left(2 - \frac{a}{t}\right)\sin\beta \qquad (4)$$

where

$$\beta = \frac{\pi}{2 - \frac{a}{t}}\left(1 - \frac{a}{t} - \frac{P_m}{3S_m}\right)$$

θ = half flaw angle

Figure 4 - Appendix C Equations used in the Structural Margin Assessment

APPENDIX A

LOAD & STRESS INPUTS USED IN THE STRUCTURAL MARGIN EVALUATIONS

TABLE A-1 – INPUT LOADS

Load Case	FA* (lbs)	FB* (lbs)	FC* (lbs)	MA* (ft-lbs)	MB* (ft-lbs)	MC* (ft-lbs)
Dead Weight	-88	67	411	-18872	-17916	422
THERMAL 1	-406	130	4735	-37947	-14690	-14640
THERMAL 2	-189	215	4237	-37948	-7129	-11809
THERMAL 3	84	367	3807	-40751	2812	-7728
Seismic OBE	3007	3956	4317	22347	17671	19891
Seismic SSE	6014	7912	8634	44694	35342	39782

* See Figure A-1 for Orientation.

Thermal – 1 Normal operating conditions with shrinkage stress from previous weld overlay repairs and additional shrinkage from three contingent weld overlay repairs

Thermal – 2 Shutdown cooling conditions with shrinkage stress from previous weld overlay repairs and additional shrinkages from three contingent weld overlay repairs

Thermal – 3 Cold operating conditions with shrinkage stress from previous weld overlay repairs and additional shrinkage from three contingent weld overlay repairs.

TABLE A-2: SUMMARY OF LOAD COMBINATIONS

Load Category	Load Combination
Normal / Upset	DW + TH1 + OBE + P
Emergency / Faulted	DW + TH1 + SSE + P

1. Normal / Upset load combination is bounding in this analysis.
2. DW = Deadweight
   TH1 = Normal operating conditions with previous and three contingency weld overlay shrinkage stresses
   OBE = Operational Basis Earthquake
   SSE = Safe Shutdown Earthquake
   P = Axial load created by internal pressure

TABLE A-3: SUMMARY OF STRESSES FOR LIMITING LOAD COMBINATION, NORMAL/UPSET

Primary Membrane Stress, Pm	Primary Bending Stress, Pb	Expansion Stress, Pe
5257 psi	948 psi	716 psi

1. Stresses were calculated using the SRSS magnitude of all forces and moments

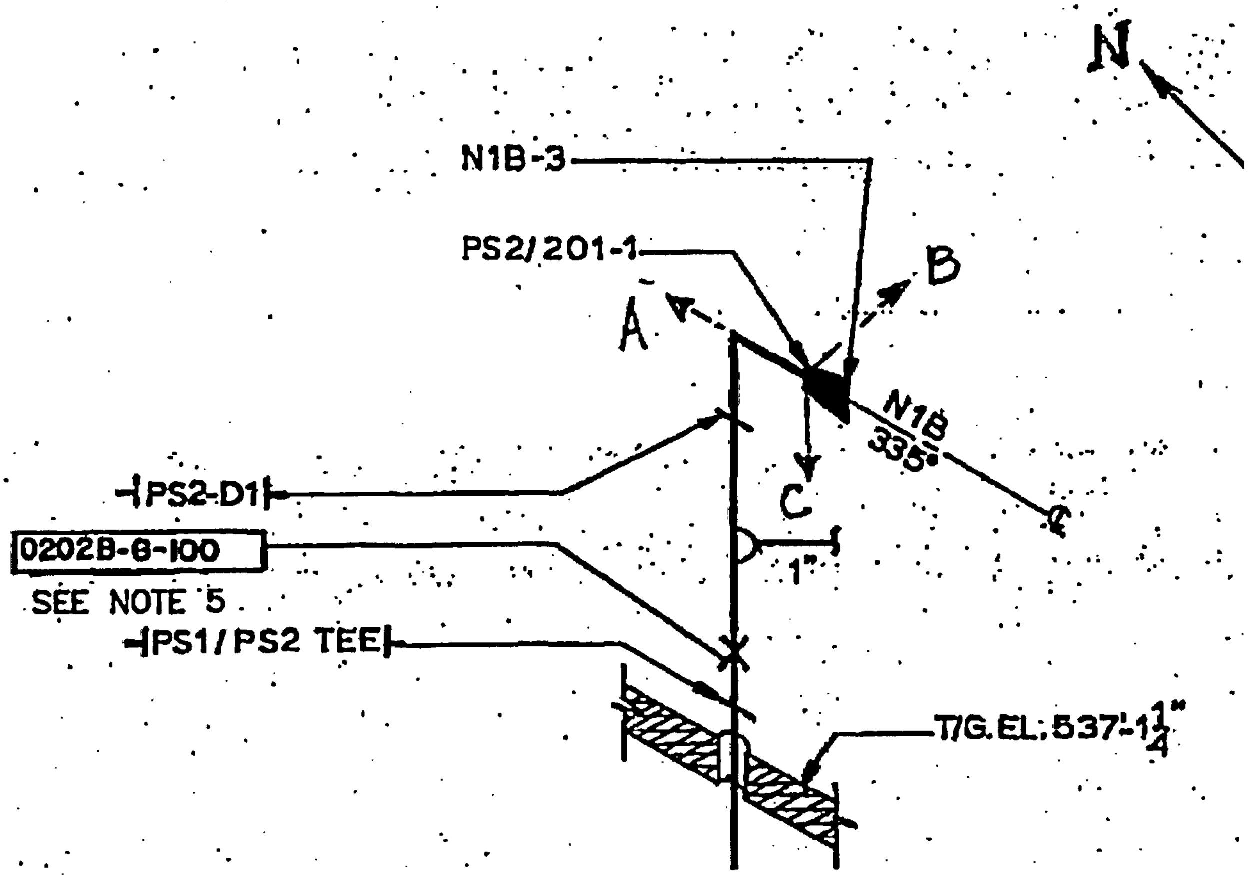

Figure A-1. Forces & Moments Orientation

APPENDIX B

DRESDEN UNIT 2 WATER CHEMISTRY DATA FROM CYCLE 18 AND EXPECTED WATER CHEMISTRY DATA FROM CYCLES 19 AND 20 COMPARISON TO THE EPRI BWR WATER CHEMISTRY GUIDELINES

BACKGROUND

Dresden-2 is the lead domestic plant in terms of operation with Hydrogen Water Chemistry (HWC). Initial testing was performed in 1982, and permanent operation with HWC commenced in 1983, during Fuel Cycle 9. Prior to 1999, typical feedwater hydrogen concentrations were maintained in the range of 1.3 to 1.5 ppm. HWC system availability at Dresden-2 from 1983 to 1999 was 89-93%, one of the better availabilities in the industry for operation at these feedwater hydrogen concentrations.

In October 1999, at EOC 16, the initial NobleChem™ application was performed at Dresden-2. The NobleChem™ application performed during hot shutdown incorporates platinum and rhodium on all wetted surfaces. During subsequent power operation, the noble metals on the surface catalyze the recombination of hydrogen and oxidants at significantly reduced feedwater hydrogen concentrations, while still achieving Electrochemical Corrosion Potential (ECP) readings appreciably below –230 mV(SHE), the industry-accepted threshold for mitigation (initiation and propagation) of Intergranular Stress Corrosion Cracking (IGSCC). Following noble metal applications, typical ECP readings are less than –400 mV(SHE) with feedwater hydrogen concentrations of 0.20-0.35 ppm. Following the initial NobleChem™ application, feedwater hydrogen has been maintained at concentrations between 0.20-0.40 ppm. Overall HWC system availability for Cycles 17 and 18 has been 91.3 and 98.8%, respectively.

Durability of the noble metal treated surfaces in the system was to be tracked with stainless steel coupons that were treated with noble metals in the initial application. These coupons were placed in the plant durability monitoring system during operation in Cycles 17 and 18. The durability monitor is designed to have continuous flow of reactor water, at operating temperature, taken upstream of the RWCU heat exchangers. Periodic removal and analysis of coupons would provide guidance for the timing of subsequent noble metal applications. GE had previously made recommendations that a NobleChem™ reapplication should be performed before the projected noble metal surface concentration on the durability coupons decreased below 0.1 $\mu g/cm^2$. The threshold surface concentration to maintain catalytic recombination under low flow conditions is about 0.03 $\mu g/cm^2$, based on laboratory evaluations.

Due to various issues, the availability of the Dresden-2 durability monitor during Cycles 17 and 18 was limited. A coupon removed after one month of operation indicated a noble metal surface concentration of 1.38 $\mu g/cm^2$. A second coupon removed after 4.8 months of operation indicated a surface concentration of 1.33 $\mu g/cm^2$. No other durability coupon retrievals were performed at

Dresden-2. Based on similar coupon data from other BWRs that have received NobleChem™ applications, the loss of noble metals from coupon surfaces with time is an exponential function whose y-intercept is the initial surface concentration (Figure 1). While exponential projections indicated the noble metal surface concentration on the durability coupons would still be greater than 0.1 μg/cm² after 72 months of operation (3 fuel cycles), the conservative decision was made to reapply NobleChem™ after two cycles of operation (EOC 18). This second application was performed during October 14-16, 2003.

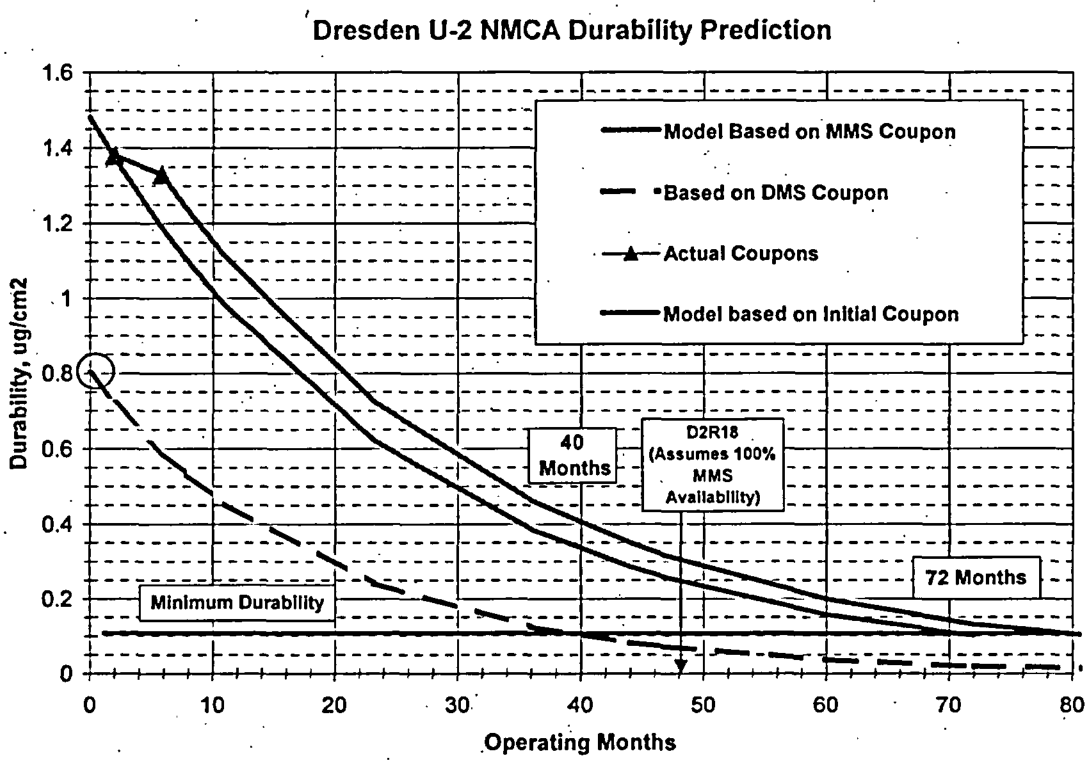

Figure B-1. Projected Noble Metal Durability at Dresden-2

CYCLE 17 AND 18 DATA THAT INFLUENCES THE EFFICACY OF HWC

Monthly average values for key chemistry parameters following NobleChem™ applications are shown in Figure 2 and Figure 3 for Dresden-2 Cycle 17 and Cycle 18, respectively. Daily and monthly average values for reactor water conductivity, sulfate and chloride for Dresden-2 Cycle 18 are shown in Figures 4-6.

- **Influence of ECP**

No ECP data are available for Cycle 17. During Fuel Cycle 18, the Dresden-2 ECP readings, measured in the plant durability monitor system, ranged between –475 and –500 mV(SHE) when the HWC system was in operation. Based on comparable feedwater hydrogen concentrations between the two cycles, there is no reason to believe that the potentials during Cycle 17 would have been significantly higher than those observed in Cycle 18. All measured values are more negative than the GE recommended value of –400 mV(SHE) for plants that have received NobleChem™ applications.

- **Influence of Feedwater Hydrogen Concentration and Molar Ratio**

For NobleChem™ plants, the typical break point, where small increases in feedwater hydrogen concentration produce a rapid decrease in ECP response, occurs at a concentration of approximately 0.12 ppm. At this feedwater hydrogen concentration, potentials typically will decrease from +100 mV(SHE) to -350 mV(SHE). At this feedwater hydrogen concentration, the molar ratio of hydrogen to oxidants (oxygen and peroxides) is 2:1 at all locations in the vessel. GE has recommended that BWRs operate with a feedwater hydrogen concentration that produces a molar ratio of greater than 3:1 at the limiting location for mitigation. Typically, this 3:1 ratio is achieved with feedwater hydrogen concentrations in the range of 0.2-0.4 ppm. Operation in this range avoids significant ECP changes with small changes in feedwater hydrogen concentration that could cycle the system in and out of mitigation. The available data in Figures 2 and 3 indicate that Dresden-2 has operated with significant margin for feedwater hydrogen concentration that results in a molar ratio significantly above 4:1, the current NRC position. In these figures, the molar ratio values were calculated based on the ratio of dissolved hydrogen to dissolved oxygen in reactor water samples. Note that the calculated H_2/Oxidant molar ratios could be biased high, because of low reactor water dissolved oxygen measured in the sample line. Measured dissolved oxygen concentrations below 2 ppb were assumed to be 2 ppb for these calculations, providing additional conservatism to the molar ratios.

- **Influence of HWC Availability**

GE has always maintained the position that HWC system availability, based on operating time of the reactor at a temperature greater than 200°F, should be maximized, and that HWC system interruptions be treated with urgency. The current GE recommendation for HWC system availability in plants that have received a NobleChem™ application is > 98%, which is significantly higher than other industry guidelines. As indicated earlier, the HWC system availability at Dresden-2 has been quite good during Cycles 17 and 18. Much of the time when HWC has been unavailable has been during periods of startup, where there are limitations on the power level when hydrogen flow can be initiated.

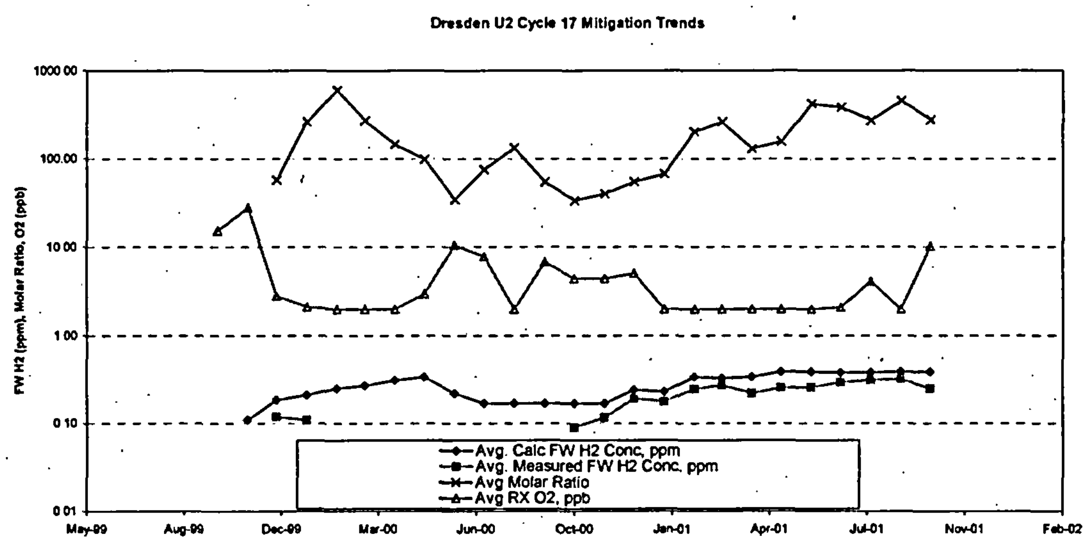

Figure B-2. NobleChem™ Parameters for Dresden-2 Cycle 17

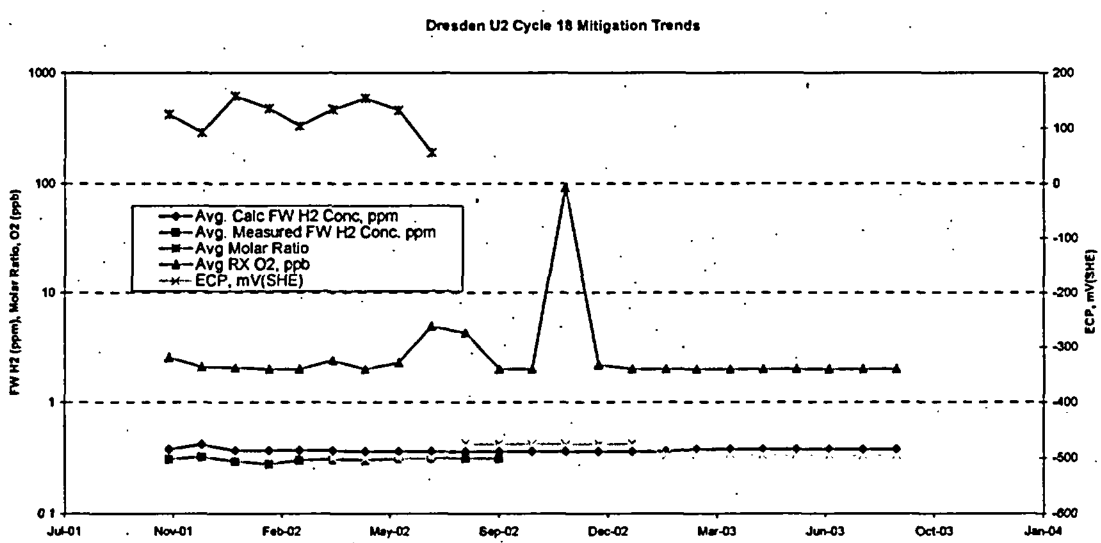

Figure B-3. NobleChem™ Parameters for Dresden-2 Cycle 18

- **Influence of Conductivity and Zinc**

Dresden-2 Reactor water conductivity has consistently been maintained below current industry standards. Nominal daily and monthly average values at Dresden-2 were less than 0.1 µS/cm. For operation above 10% power, the EPRI BWR Water Chemistry Guidelines [1] recommends that engineering evaluations be performed when reactor water conductivity exceeds 0.30 µS/cm, the current Action Level 1 value. The most significant perturbations to conductivity in Cycle 18 were the result of a resin intrusion during BOC 18 startup, a reactor scram on 10/1/2003, and the NobleChem™ reapplication at EOC 18. The resin intrusion event, and the elevated conductivity and sulfate concentrations, have been previously been dispositioned. The elevated conductivity from the scram was mostly attributable to soluble iron and zinc, which are benign to IGSCC issues. No significant chloride or sulfate concentration increases were observed following the scram. Conductivity increases from the NobleChem™ reapplication were anticipated, owing to elevated concentrations of sodium and nitrate ions, neither of which have been implicated with IGSCC issues. Chloride and sulfate concentrations were never greater than 5 ppb during the reapplication period. BWRVIP-14 [2] provides a more restrictive conductivity value, with the recommendation that conductivity should be maintained below 0.15 µS/cm. Only in a few instances was this more restrictive value exceed during Cycle 18, and the duration of the excursions was typically no more than 24 hours during power operation.

Conductivity by itself is not sufficient to characterize the aggressiveness of the reactor coolant. A considerable fraction of the Dresden-2 reactor water conductivity is attributable to soluble zinc from the plant feedwater zinc injection program. Dresden-2 routinely has maintained a reactor water soluble zinc concentration in the range of 5-10 ppb. Zinc has never been implicated with IGSCC issues, and there is some information that indicates the presence of soluble zinc can actually reduce crack growth rates.

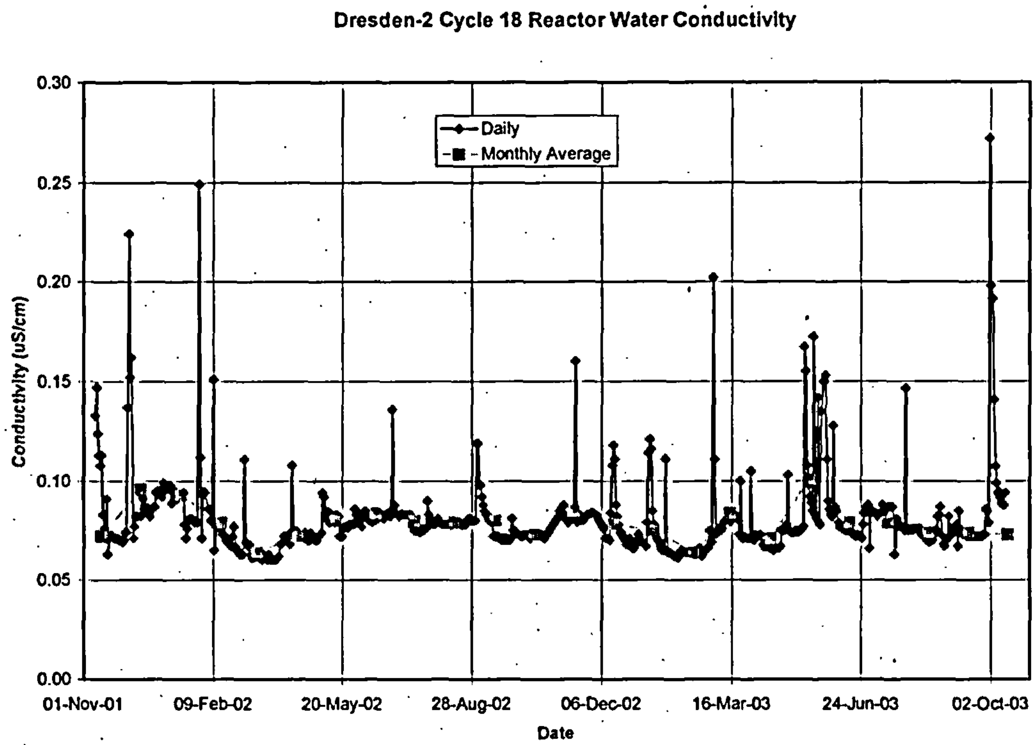

Figure B-4. Dresden-2 Reactor Water Conductivity in Cycle 18

- **Influence of Chloride and Sulfate Ions**

Chloride and sulfate ions, which are also constituents of conductivity, are closely monitored in all BWRs, due to their known participation in several documented IGSCC events. For operation above 10% power, the EPRI Guidelines Action Level 1 value for chloride and sulfate concentration is 5 ppb. Figure 5 indicates that the Action Level 1 concentration for chloride was never exceeded during Mode 1 operation in Cycle 18. Nominal values were consistently less than 1 ppb. For sulfate (Figure 6), a few excursions above 5 ppb were reported for Cycle 18, and except for the BOC18 startup transient, the duration of each Action Level 1 excursion was less than 24 hours. Nominal values were less than 3 ppb.

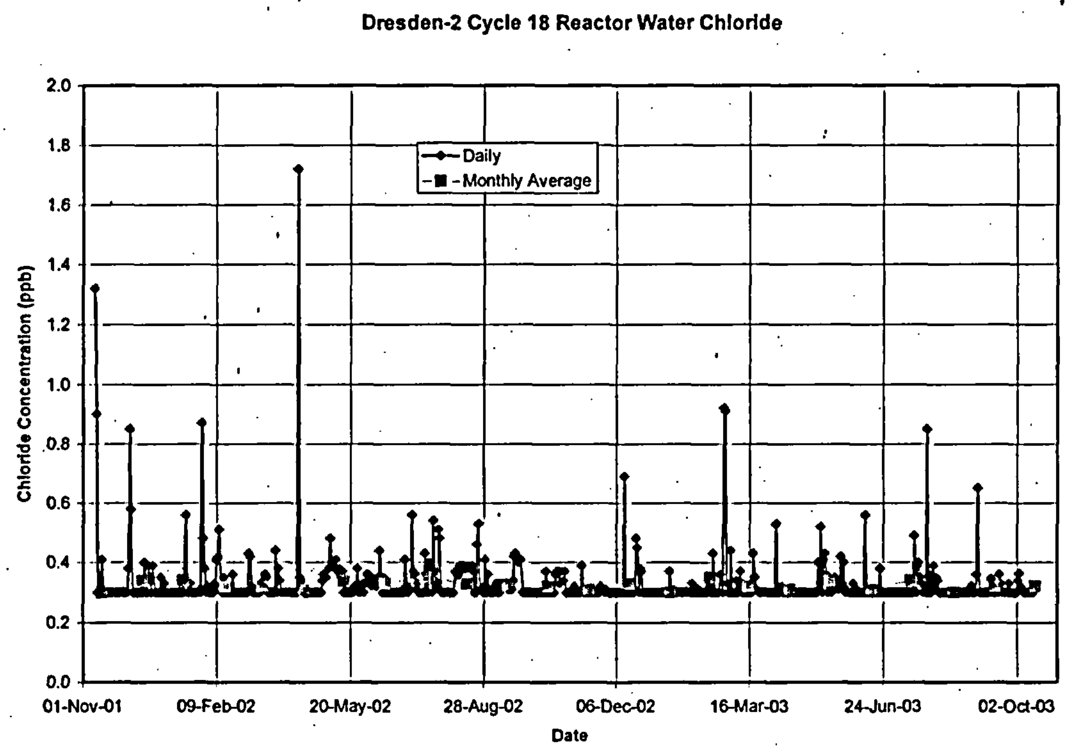

Figure B-5. Dresden-2 Reactor Water Chloride in Cycle 18.

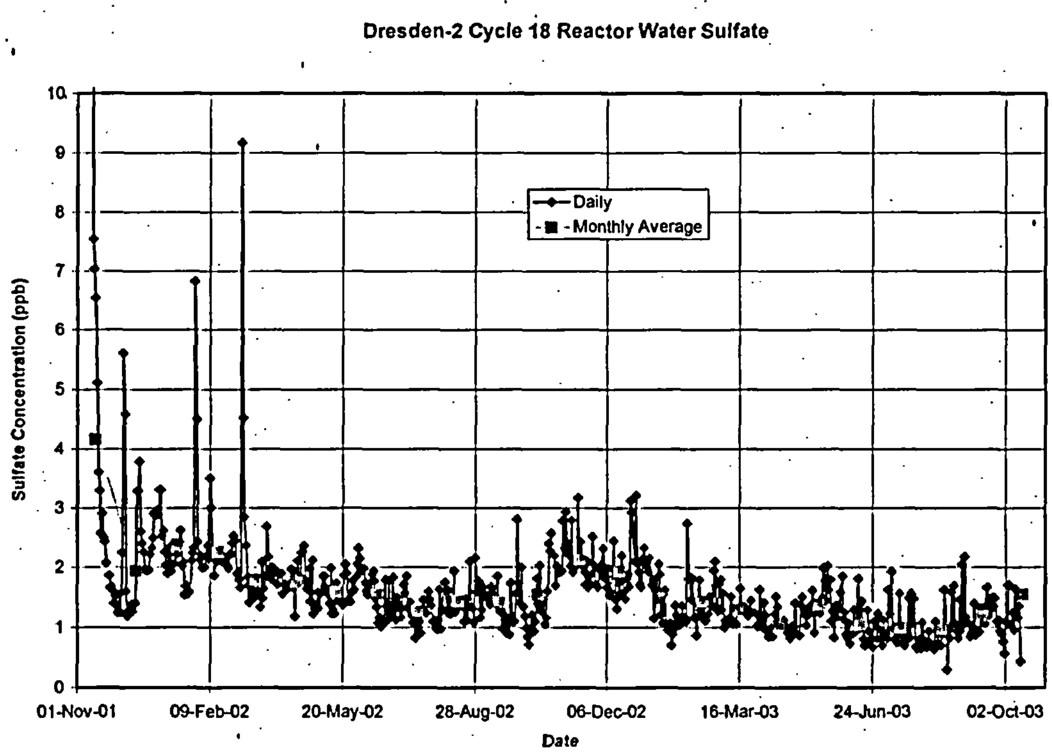

Figure B-6. Dresden-2 Reactor Water Sulfate in Cycle 18.

CONCLUSIONS AND RECOMMENDATIONS

Provided the reactor water chemistry at Dresden-2 can be maintained in Cycles 19 and 20 at comparable values to those in Cycle 18, the HWC crack growth rate values in the current flaw assessment can be utilized. With the reapplication of NobleChem™ at EOC 18, it is currently expected that the Cycle 18 chemistry can be routinely achieved, barring major transients. Specifically the attributes of importance are:

- ECP readings < -230 mV(SHE), with recommended operation below –400 mV(SHE)
- Hydrogen:Oxidant Molar Ratio > 4:1, which will require a feedwater hydrogen concentration of 0.35-0.40 ppm
- Hydrogen Water Chemistry system operation with an availability goal of greater than 98% at temperatures above 200°F
- Reactor water conductivity < 0.15 μS/cm
- Reactor water chloride and sulfate concentrations less than 5 ppb, with goals of less than 1 ppb chloride and less than 2 ppb sulfate

REFERENCES

[1]. "BWR Water Chemistry Guidelines—2000 Revision," EPRI, Palo Alto, California, February 2000, EPRI Document No. TR-103515-R2.

[2]. "BWR Vessel and Internals Project—Evaluation of Crack Growth in BWR Stainless Steel RPV Internals (BWRVIP-14)," EPRI, Palo Alto, California, March 1996, EPRI Document No. TR-105873.

APPENDIX C

FRACTURE MECHANICS CALCULATION

Subject: D2 Weld PS2/201-1 Indication Evaluation
Date: 10-28-03 2:00 pm
DRF: 0000-0022-6311

Purpose:

This evaluation is being performed to justify continued operation of Dresden Unit 2 considering the IGSCC indications identified in the Recirculation Line Weld PS2/201-1.

Methods:

The flaw evaluation methods used in this analysis are consistent with those described in the ASME B&PV Code Section XI, 1995 edition through the 1996 Addenda, Reference 6.

The IGSCC crack growth methods are consistent with those described in NUREG-0313, Rev. 2 (Reference 5), BWRVIP-14 (Reference 7), and the NRC safety evaluations prepared for Quad Cities Units 2 Recirculation Line flaw evaluations (Reference 8).

The fatigue crack growth rate & method used in this evaluation was extracted from Reference 4.

A number of conservative methodological assumptions were made in this evaluation; they are documented below:

1. Consistent with NUREG-0313, Rev. 2, the flaw is characterized as a 360 degree part through wall flaw even though it is predicted to be approximately 30% of the pipe circumference in length after two cycles of operation.

2. All forces and moments were combined using SRSS to determine the applied stresses. Typically only the axial forces and lateral moments are considered.

3. 50 feet of static head was added to the operating pressure to determine the normal operating pressure in the recirculation line.

4. A bounding constant total applied KI of 21 ksi*in^0.5 was used for the NUREG-0313, Rev. 2 IGSCC crack growth calculation. Crack growth could be calculated incrementally using the actual predicted K at each a/t; however, the maximum KI is used throughout the entire pipe thickness.

5. HWC IGSCC crack growth rates are determined assuming 90% of operation at 1.1E-5 in/hr and 10% of operation at 2.2E-5 in/hr. This predicts a HWC crack growth rate of 1.21E-5 in/hr using BWRVIP-14

6. The FCG is determined using a conservative 120 cycles for the next two fuel cycles.

7. The weld is conservatively assumed to be SAW; this bounds all possible cases.

References:

1. GE Nuclear Energy, "Design Input Request (DIR) - Dresden 2 Recirculation Line Flaw Evaluation, GE Nuclear Energy, San Jose, CA (Contained in DRF# 0000-0022-6311), October 2003 (Attached to this package)

2. American Society of Mechanical Engineers Code,
   * Boiler & Pressure Vessel Code, Section III (1965) Nuclear Vessels

3. GE Nuclear Energy, "Reactor Vessel Power Uprate Design Specification", GENuclear Energy, San Jose, CA (26A5587, Rev. 0)

4. Hale, D.A., et al. "Fatigue Crack Growth in Piping and RPV in Simulated BWR Water Environment". GE Nuclear Energy, San Jose, CA, (GEAP-24098), January 1978.

5. U.S. Nuclear Regulatory Commission, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping"), U.S Nuclear Regulatory Commission Office of Nuclear Reactor Regulation, (NUREG-0313 Rev.2)

6. American Society of Mechanical Engineers Code
   * Section XI, ASME Code 1995 Edition, including the 1996 addendum

7. BWRVIP
   * BWR Vessel and Internal Projects: Evaluation of Crack Growth in BWR Stainless Steel RPV Internals (BWRVIP-14), EPRI, Palo Alto, CA (EPRI TR-105873), March 1996
   * BWR Vessel and Internal Projects: Evaluation of Crack Growth in BWR Stainless Steel RPV Internals (BWRVIP-14-A), EPRI, Palo Alto, CA (EPRI XXXXXXX), DRAFT August 2003.

8. SER
   * Letter from Carl F. Lyon, NRC to John L. Skolds, Exelon, "Quad Cities Nuclear Power Station, Unit 2 Approval of Pipe Flaw Evaluation (TAC No. MB4093)", June 6, 2002. Docket No. 50-265

Inputs:

$D := 28.375 \cdot in$	Nominal pipe OD (Reference 1)
$t := 1.34 \cdot in$	Nominal wall thickness (Reference 1)
$Sm := 17600 \cdot psi$	Design stress intensity of SA-376 TYPE 316 pipe material at 550 F (Reference 2)

Flaw Characterization Assumptions:

$d := 0.24 \cdot in$	$d = 0.24\,in$	Initial depth of IGSCC indication (Reference 1)
$L := 2 \cdot \pi \cdot \frac{D - t}{2}$	$L = 84.933\,in$	Initial length of IGSCC indication, fully circumferential This is consistent with NUREG 0313, Rev. 2 reccomendations for crack characterization.

Area and Section Modulus Ratios using mean radius:

$$Z := \pi \cdot \left[\frac{(D - t)}{2}\right]^2 \cdot t \qquad Z = 769.214\,in^3$$

$$A := 2 \cdot \pi \cdot \frac{(D - t)}{2} \cdot t \qquad A = 113.81\,in^2$$

I. Stress Calculations:

From DIR (Reference 1), the following input loads are considered:

Forces:

Fa_DW := −88·lb	Fb_DW := 67·lb	Fc_DW := 411·lb
Fa_TH1 := −406·lb	Fb_TH1 := 130·lb	Fc_TH1 := 4735·lb
Fa_TH2 := −189·lb	Fb_TH2 := 215·lb	Fc_TH2 := 4237·lb
Fa_TH3 := 84·lb	Fb_TH3 := 367·lb	Fc_TH3 := 3807·lb
Fa_OBE := 3007·lb	Fb_OBE := 3956·lb	Fc_OBE := 4317·lb
Fa_SSE := 6014·lb	Fb_SSE := 7912·lb	Fc_SSE := 8634·lb

Moments:

Ma_DW := −18872·ft·lb	Mb_DW := −17916·ft·lb	Mc_DW := 422·ft·lb
Ma_TH1 := −37947·ft·lb	Mb_TH1 := −14690·ft·lb	Mc_TH1 := −14640·ft·lb
Ma_TH2 := −37948·ft·lb	Mb_TH2 := −7129·ft·lb	Mc_TH2 := −11809ft·lb
Ma_TH3 := −40751ft·lb	Mb_TH3 := 2812·ft·lb	Mc_TH3 := −7728·ft·lb
Ma_OBE := 22347·ft·lb	Mb_OBE := 17671·ft·lb	Mc_OBE := 19891·ft·lb
Ma_SSE := 44694·ft·lb	Mb_SSE := 35342·ft·lb	Mc_SSE := 39782·ft·lb

For conservatism, the SRSS magnitude of the forces and moments shall be considered in this analysis. Note that typically, GENE uses only the axial force and the lateral moments. The method used here is very conservative.

Forces:

$F\_DW := \left(Fa\_DW^2 + Fb\_DW^2 + Fc\_DW^2\right)^{0.5}$ $F\_DW = 425.622\,lb$

$F\_TH1 := \left(Fa\_TH1^2 + Fb\_TH1^2 + Fc\_TH1^2\right)^{0.5}$ $F\_TH1 = 4.754 \times 10^3\,lb$

$F\_TH2 := \left(Fa\_TH2^2 + Fb\_TH2^2 + Fc\_TH2^2\right)^{0.5}$ $F\_TH2 = 4.247 \times 10^3\,lb$

$F\_TH3 := \left(Fa\_TH3^2 + Fb\_TH3^2 + Fc\_TH3^2\right)^{0.5}$ $F\_TH3 = 3.826 \times 10^3\,lb$

$F\_OBE := \left(Fa\_OBE^2 + Fb\_OBE^2 + Fc\_OBE^2\right)^{0.5}$ $F\_OBE = 6.582 \times 10^3\,lb$

$F\_SSE := \left(Fa\_SSE^2 + Fb\_SSE^2 + Fc\_SSE^2\right)^{0.5}$ $F\_SSE = 1.316 \times 10^4\,lb$

Moments:

$M\_DW := \left(Ma\_DW^2 + Mb\_DW^2 + Mc\_DW^2\right)^{0.5}$ $M\_DW = 2.603 \times 10^4\,ft\,lb$

$M\_TH1 := \left(Ma\_TH1^2 + Mb\_TH1^2 + Mc\_TH1^2\right)^{0.5}$ $M\_TH1 = 4.324 \times 10^4\,ft\,lb$

$M\_TH2 := \left(Ma\_TH2^2 + Mb\_TH2^2 + Mc\_TH2^2\right)^{0.5}$ $M\_TH2 = 4.038 \times 10^4\,ft\,lb$

$M\_TH3 := \left(Ma\_TH3^2 + Mb\_TH3^2 + Mc\_TH3^2\right)^{0.5}$ $M\_TH3 = 4.157 \times 10^4\,ft\,lb$

$M\_OBE := \left(Ma\_OBE^2 + Mb\_OBE^2 + Mc\_OBE^2\right)^{0.5}$ $M\_OBE = 3.475 \times 10^4\,ft\,lb$

$M\_SSE := \left(Ma\_SSE^2 + Mb\_SSE^2 + Mc\_SSE^2\right)^{0.5}$ $M\_SSE = 6.949 \times 10^4\,ft\,lb$

The stresses associated with the above loads are:

$$Pm\_DW := \frac{F\_DW \cdot g}{A} \qquad Pm\_DW = 4\,psi$$

$$Pm\_TH1 := \frac{F\_TH1 \cdot g}{A} \qquad Pm\_TH1 = 42\,psi$$

$$Pm\_TH2 := \frac{F\_TH2 \cdot g}{A} \qquad Pm\_TH2 = 37\,psi$$

$$Pm\_TH3 := \frac{F\_TH3 \cdot g}{A} \qquad Pm\_TH3 = 34\,psi$$

$$Pm\_OBE := \frac{F\_OBE \cdot g}{A} \qquad Pm\_OBE = 58\,psi$$

$$Pm\_SSE := \frac{F\_SSE \cdot g}{A} \qquad Pm\_SSE = 116\,psi$$

$$Pb\_DW := \frac{M\_DW \cdot g}{Z} \qquad Pb\_DW = 406\,psi$$

$$Pb\_TH1 := \frac{M\_TH1 \cdot g}{Z} \qquad Pb\_TH1 = 675\,psi$$

$$Pb\_TH2 := \frac{M\_TH2 \cdot g}{Z} \qquad Pb\_TH2 = 630\,psi$$

$$Pb\_TH3 := \frac{M\_TH3 \cdot g}{Z} \qquad Pb\_TH3 = 649\,psi$$

$$Pb\_OBE := \frac{M\_OBE \cdot g}{Z} \qquad Pb\_OBE = 542\,psi$$

$$Pb\_SSE := \frac{M\_SSE \cdot g}{Z} \qquad Pb\_SSE = 1084\,psi$$

The internal pressure stress may be calculated assuming an internal pressure (Reference 3) of 1005 psig plus a static head conservatively assumed as 50 feet; therefore the pressure associated with this head is:

$$62.4\cdot\frac{lb}{ft^3}\cdot 50\cdot ft\cdot 32\cdot\frac{ft}{sec^2} = 21.549\,psi$$

For this evaluation, 25 psig will be conservatively used.

The pressure membrane stress is:

$$P\_m := \frac{1030\cdot psi\cdot(D-t)}{4\cdot t} \qquad P\_m = 5195\,psi$$

The load combinations used for this analysis considering the load descriptions provided in the DIR (Reference 1) are:

Condition:	Normal/Upset:	DW+TH1+OBE+P
	Emergency/Faulted:	DW+TH1+SSE+P

It is evident from reviewing the stresses above that the Normal/Upset condition will be governing in the fracture mechanics evaluation.

$$Pm\_nu := Pm\_DW + Pm\_OBE + P\_m \qquad Pm\_nu = 5257\,psi$$

$$Pb\_nu := Pb\_DW + Pb\_OBE \qquad Pb\_nu = 948\,psi$$

$$Pe\_nu := Pm\_TH1 + Pb\_TH1 \qquad Pe\_nu = 716\,psi$$

II. Limit Load Evaluation:

$SF := 2.77$ — ASME (Reference 6) required Safety Factors

$Z := \frac{1.3}{in} \cdot [1 \cdot in + 0.01 \cdot (D - 4 \cdot in)]$ $\quad Z = 1.617$ — Flux weld factor for SAW weld

For a fully circumferential crack the allowable flaw size is determined below:

$$Pb1 := Z \cdot SF \cdot \left(Pm\_nu + Pb\_nu + \frac{Pe\_nu}{SF} \right) - Pm\_nu$$

Applied stress at crack

$Pb1 = 23691\,psi$

$dot := 0.5 \qquad \beta := 1$ — Initial Guess values for dot and β

Given

$$\beta = \pi \cdot \frac{\left(1 - dot - \frac{Pm\_nu}{3 \cdot Sm} \right)}{2 - dot} \qquad Pb1 = \left(\frac{2 \cdot 3 \cdot Sm}{\pi} \right) \cdot (2 - dot) \cdot \sin(\beta)$$

$$\begin{pmatrix} dot \\ \beta \end{pmatrix} := Find(dot, \beta)$$

$dot = 0.664$ — Allowable crack depth to thickness ratio

III. Fatigue Crack Growth Evaluation

Fatigue crack growth is typically negligible compared to IGSCC crack growth. This evaluation is performed for two cycles of operation; therefore, the following conservative assumptions shall be made for the FCG calculation:

1. ΔK=21 ksi*in^0.5
2. R=0.0
3. During the next two cycles 20 startup shutdown cycles will occur
4. During the next two cycles 10 seismic events with 10 load cycles each will occur

A ΔK = 21 ksi*in^0.5 is very conservative because this value is extracted from Figure 4-1 of NUREG 0313, Rev. 2 (Reference 5) using an applied stress of 7500 psi and considering the weld residual stress. The weld residual stress is 30 ksi (Reference 5) at the inside surface and contributes significantly to the total KI predicted for the IGSCC crack growth; however, it is a steady state load and does not contribute to ΔK (it is not cyclic).

The R ratio will change as the crack grows deeper into the material. This is observed from reviewing the residual stress distribution through the pipe thickness. For startup-shutdown cycles, the R ratio will change from close to 1 for shallow flaws to 0 for deeper flaws. For the seismic cycles, the R ratio will be close to 1. The ΔK considered here is significantly larger than is expected because we have considered the contribution from the weld residual stress which is not cyclic and not necessary for inclusion in ΔK.

The evaluation performed here is extremely conservative and the predicted FCG for the few cycles expected (even considering the very conservative assumptions regarding number of expected events) will not increase if a different R ratio is used. therefore, it is

In calculating the Effective Stress Intensity Factor an R ratio of 0 was used as it produces the most conservative result. For the correlation curves from the attached figure (Figure 4-4) the most conservative curve was used to determine the crack growth rate.

Twenty startup shutdown cycles during the next two fuel cycles is obviously conservative as is the use of 10 seismic events during the next two fuel cycles.

From Figure 4-4 of GEAP-24098 (Reference 4), Fatigue Crack Growth in Piping and RPV Steel in a Simulated BWR Water Environment, a FCG for the conditions shown above is selected.

$CGR\_FCG\_2 := 14 \cdot 10^{-6} \ \frac{in}{cycle}$ Fatigue crack growth rate

The total FCG expected for the conditions considered (2 Cycles) is:

$CG\_FCG\_2 := CGR\_FCG\_2 \cdot 120$ $CG\_FCG\_2 = 0.0017\ in$

The total FCG expected for the conditions considered (1 Cycle) is:

$CG\_FCG\_1 := \frac{CG\_FCG\_2 \cdot (in)}{2}$ $CG\_FCG\_1 = 0.001\ in$

It is evident that the FCG contribution to the final crack size is negligible for 1 cycle of operation.

IV. IGSCC Crack Growth Calculations:

For conservatism a KI=21 ksi*in^0.5 taken from NUREG-0313, Rev. 2 Figure 4 shall be used. This value corresponds to the maximum KI over the range of a/t allowed by ASME Section XI and an applied stress of 7500 psi.

$CGR := 3.59 \cdot 10^{-8} \cdot 21^{2.161} \left(\frac{in}{hr}\right)$ — Crack growth rate equation using a ΔK=21 ksi*in^0.5

$CGR = 2.585 \times 10^{-5} \frac{in}{hr}$

$H := 2 \cdot 365.25 \cdot 24 \cdot hr$ $\quad H = 17532 hr$ — Total hours of operation during 1 two year cycle

$CG := CGR\,H + CG\_FCG\_1$ — Total crack growth for one cycle

$CG = 0.454 in$

$df := d + CG$ $\quad df = 0.694 in$ — Total depth of crack after one cycle

$ddot := \frac{df}{t}$ $\quad ddot = 0.518$ — Crack depth to pipe thickness ratio after one cycle

$df := d + 2CG$ $\quad df = 1.148 in$ — Total depth of crack after two cycles

$ddot := \frac{df}{t}$ $\quad ddot = 0.857$ — Crack depth to pipe thickness ratio after two cycles

$cycle := 1$ $\quad Hallow := 20000 \cdot (hr)$ — Initial Guess values for cycle and Hallow

Given

$$Hallow = \frac{(0.664t - d - CG\_FCG\_1 \cdot cycle)}{CGR} \qquad cycle = \frac{Hallow}{H}$$

$$\begin{pmatrix} cycle \\ Hallow \end{pmatrix} := Find(cycle, Hallow)$$

$Hallow = 25092 hr$

$cycle = 1.431$ Allowable crack depth to thickness ratio

B. BWRVIP-14 Methodology - Depth CGR = 2.2E-5 in/hr

$CGR := 2.2 \cdot 10^{-5} \cdot \frac{in}{hr}$

$CG := CGR \cdot H + CG\_FCG\_1$ — Crack growth after one cycle of operation

$CG = 0.387\,in$

$df := d + CG$ — $df = 0.627\,in$ — Crack depth after one cycle of operation

$dbot := \frac{d + CG}{t}$ — $dbot = 0.468$ — Crack depth to pipe thickness ratio after one cycle

$df2 := d + 2 \cdot CG$ — $df2 = 1.013\,in$ — Crack depth after two cycles of operation

$dbot := \frac{d + 2 \cdot CG}{t}$ — $dbot = 0.756$ — Crack depth to pipe thickness ratio after two cycles

$cycle := 1$ — $Hallow := 20000 \cdot (hr)$ — Initial Guess values for cycle and Hallow

Given

$$Hallow = \frac{(0.664t - d - CG\_FCG\_1 \cdot cycle)}{CGR} \qquad cycle = \frac{Hallow}{H}$$

$$\begin{pmatrix} cycle \\ Hallow \end{pmatrix} := Find(cycle, Hallow)$$

$Hallow = 29470\,hr$

$cycle = 1.681$ Allowable crack depth to thickness ratio

C. BWRVIP-14 Methodology using FOI=2 for HWC/Noble Chem - Depth CGR = 1.1E-5 in/hr

Assuming that HWC is 90% available, the effective crack growth rate is:

$CGR := 1.21 \cdot 10^{-5} \cdot \frac{in}{hr}$

$CG := CGR \cdot H + CG\_FCG\_1$ Crack growth after one cycle of operation

$CG = 0.213\,in$

$df := d + CG$ $df = 0.453\,in$ Crack depth after one cycle of operation

$dbot := \frac{d + CG}{t}$ $dbot = 0.338$ Crack depth to pipe thickness ratio after one cycle

$df2 := d + 2 \cdot CG$ $df2 = 0.666\,in$ Crack depth after two cycles of operation

$dbot := \frac{d + 2 \cdot CG}{t}$ $dbot = 0.497$ Crack depth to pipe thickness ratio after two cycles

$cycle := 1$ $Hallow := 20000 \cdot (hr)$ Initial Guess values for cycle and Hallow

Given

$Hallow = \frac{(0.664t - d - CG\_FCG\_1 \cdot cycle)}{CGR}$ $cycle = \frac{Hallow}{H}$

$\begin{pmatrix} cycle \\ Hallow \end{pmatrix} := Find(cycle, Hallow)$

$Hallow = 53487\,hr$

$cycle = 3.051$ Allowable crack depth to thickness ratio

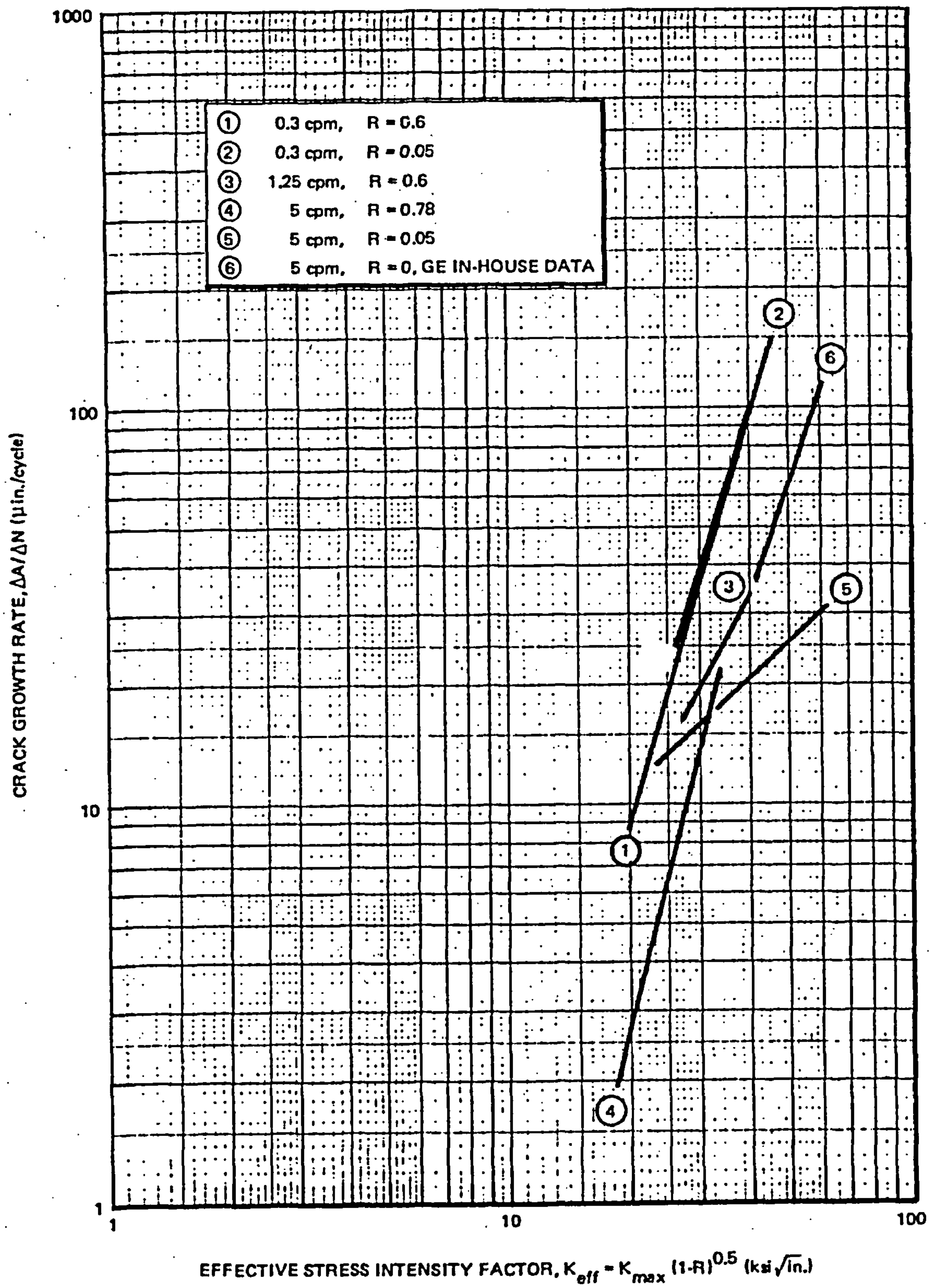

Figure 4-4. Types 304 and 304L Stainless Steel Crack Growth Data - Simulated BWR Water Environment