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PROJECT NAME: Point Beach Unit 1 CRDM Top Head Analysis

CLIENT: NMC Point Beach Nuclear Plant

CALCULATION TITLE: PWSCC Crack Growth Correlations and Fatigue Crack Growth Calculations for Point Beach Unit 1

Document Revision	Affected Pages	Revision Description	Project Mgr. Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1-7 A1 – A19	Original Issue	H. L. GUSTIN 2/17/04	H. L. GUSTIN 2/17/04 G. L. STEVENS 2/17/04
1	1-7 A1-A19	Incorporates actual overlap measurements for nozzle 26. Appendix A is not affected.	H. L. GUSTIN H L Gustin 5/12/04	H. L. GUSTIN H L Gustin 5/12/04 MING QIN Minghao Qin 5/12/04
2	1-8 A1-A19	Addresses hypothetical growth in Alloy 82 material, as a conservative representation for Alloy 52	H. L. GUSTIN H L Gustin 5/15/04	H. L. GUSTIN H L Gustin 5/15/04 P. C. RICCARDELLA 5/15/04

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1.0 STATEMENT OF PROBLEM

Point Beach Unit 1 is proceeding with repair of RPV top head CRDM Nozzle 26 during the current, Spring 2004 refueling outage. Because of the steepness of this nozzle, and the relatively small head diameter and thickness, the standard Framatome repair process will result in a portion of the new attachment weld overlapping the original Alloy-82/182 weld over a portion of the circumference (see Figure 1).

In order to evaluate repair options for the Point Beach Unit 1 Top Head CRDM penetrations, this calculation evaluates the growth of hypothetical flaws in the original alloy 82/182 weld through the weld repair fusion line with the low alloy steel base material. Earlier revisions of this calculation assumed a crack growth rate applicable to Alloy-600 base metal. To respond to NRC comments received on the earlier calculation, the calculation is revised herein to incorporate crack growth rates applicable to Alloy 82 weld metal.

Note that the repair weld through which the hypothetical crack is assumed to be propagating is Alloy-52, which has generally been shown to be highly resistant to PWSCC cracking and crack growth. The only potential crack growth region is at the fusion line between the low alloy steel nozzle and the Alloy-52 weld metal, in which some dilution of the weld metal may occur. Both the Alloy-600 and Alloy-82 crack growth curves are believed to be conservative approximations of the expected crack growth rate in this dilution zone.

2.0 METHODOLOGY

Stress intensity factors at the interface of the new, Alloy-52 repair weld and the original, Alloy-82/182 J-groove weld have been computed in Ref [5] assuming the entire original J-groove weld to be cracked. These K-levels are based on operating plus residual stresses resulting from the original J-groove weld plus the new repair weld, at normal operating conditions. The result K-levels are assumed to remain constant for the small amount of crack extension through the interface region, since the cracking will be confined to a narrow region of diluted material.

The resulting K-levels are then inserted into a stress corrosion crack growth law (see section 3.0 below) to determine the rate of crack propagation versus time, and to predict the time necessary for the assumed initial crack to grow through the new repair weld diluted zone and thus cause potential leakage during the upcoming fuel cycle.

3.0 MATERIAL CRACK GROWTH RATE

The industry has established a panel of experts on stress corrosion cracking to review available data on PWSCC growth in components such as the CRDM penetration tubes and associated nickel-based weld metals. The panel is comprised of international experts, including representatives from NRC research and its contractors. This panel has established a recommended crack growth law for Alloy-600 base material [1], and more recently a recommended crack growth curves for Alloy 82 and 182 weld metals [2]. The correlation of available crack growth data from [2] is shown in Figure 2, normalized to a service temperature of 617 °F. The reported top head temperature for Point Beach Unit 1 is 592°F [7]. The crack growth rate is a strong function of temperature, and so to represent the Point Beach condition, it is necessary to adjust the Alloy-82 crack growth correlation for the lower temperature. References 1 and 2 also provide an activation energy equation for temperature adjustment of the crack growth curves.

For Alloy-82 weld material the PWSCC crack growth correlation reported in [2], adjusted to the Point Beach head temperature of 592°F is

$$da/dt = 5.12 \times 10^{-08} (K-K_{th})^{1.6}$$

where:

da/dt = crack growth rate at temperature T in in/hr
K = crack tip stress intensity factor (ksi$\sqrt{in}$)
K_{th} = crack tip stress intensity factor threshold
= 0 (ksi$\sqrt{in}$)

This correlation is applicable to evaluating the growth of ID connected flaws in Alloy 82 GTAW weld material. Since the diluted zone being evaluated in this calculation is Alloy-52, also a GTAW welding process, the Alloy-82 curve is conservatively applied.

As noted above, the repair material is Alloy 52. Since chromium content has been shown to be a key contributor to nickel-based alloy PWSCC resistance, this material (Alloy 52, with a chromium content of 28-31%) will have significantly higher PWSCC resistance than will Alloy 600 (chromium content 14-17%) or its associated weld materials Alloy 182 (chromium content 13-17%) or Alloy 82 (chromium content 18-22 %). The lower chromium content of the Alloy -82 material is deemed sufficient to account for the potential effects of dilution of the Alloy-52 material in the interface region with the low alloy steel head.

4.0 CRACK GROWTH CALCULATIONS

The objective of the calculation is to determine the time that would be required for a crack at the interface of the Alloy 52 repair material, the low alloy steel head material, and the underlying J-groove material to propagate parallel to the repair weld by a PWSCC mechanism through a distance defined by the repair weld ligament. If the time for such propagation is greater than the remaining service life of the head, no penetration of the pressure boundary due to such a crack would be predicted.

The above crack growth correlation was used with the SI program pc-CRACK [3] to perform PWSCC crack growth calculations. A hypothetical flaw was considered, which represents the bounds on geometries that may be encountered. This hypothetical flaw was a flaw in the axial-radial plane, across the entire remaining J-groove + butter. Such a flaw would be opened by hoop stresses, resulting in a tunnel crack under the repair weld.

PWSCC is driven by both applied and weld residual stresses. Based on analyses performed by Dominion Engineering [3], as summarized in another SI calculation [5], the normal operating stresses plus the weld residual stresses in the hoop direction can reasonably be represented by a constant through-wall stress intensity factor of 57 ksi$\sqrt{in}$, at the junction of the Alloy-52 repair weld and the low alloy steel head material.

The analysis assumed that the entire original J-groove weld material was degraded (cracked), so no credit was taken for any flaw initiation or growth time in the remaining J-groove material. Because a constant applied K is assumed, starting flaw size has no effect on crack growth rate.

The flaw located in the axial-radial plane (opened by hoop stresses) was determined to be the governing flaw case, since the applied plus residual stresses in the hoop direction are greater than those in the radial direction by a factor of two to four at the location of the postulated crack, based upon review of Dominion Engineering results [3] for nodes in this location. As a result, crack growth in a radial-circumferential plane would be slower by a comparable factor.

Nozzle 26 is being repaired during the Spring 2004 outage. The repair of this nozzle has a minimum remaining ligament of 0.5 inch [6]. The repair may also contain a weld root defect of 0.1 inch based on Framatome analyses. Both cases (with and without a postulated root defect) are considered here, with pc-CRACK results contained in Appendix A.

This analysis took no credit for the portion of the repair weld that overlapped the Alloy 182 material, and so as a result the repair weld ligament was considered to be reduced in length from the design value. The repair weld is Alloy 52 weld material applied by a GTAW process.

4.1 Fatigue crack growth

Fatigue crack growth is driven by cyclic stresses. For the present case, the stress state for the assumed flaws is dominated by weld residual stresses (conservatively estimated as a constant 60 ksi) which are steady state secondary stresses. These residual stresses will not vary with heat-up/cooldown and other plant cycles, and will therefore have only a limited effect on fatigue crack growth (that is, they will have some effect on R-ratio, but none on delta K values due to cyclic plant operation. For the limited period of remaining plant operation with the current vessel head (estimated at less than 100 heat-up/cooldown cycles, producing a cyclic stress of 20 ksi), propagation of the hypothetical cracks considered herein by a fatigue mechanism is estimated at approximately 0.0002 inch, and is therefore considered negligible compared to PWSCC propagation discussed above. The pc-CRACK fatigue crack growth results are also included in Appendix A.

5.0 RESULTS

The above analysis produces the following results. These results assume that an initial radial-axial flaw is present in the original J-groove weld, equal to the entire size of that weld. The growth is then calculated for the indicated remaining ligament length of potentially diluted Alloy-52 weld metal in the repair weld..

For the nozzle 26 repair (remaining ligament = 0.5 inch without an assumed root defect, or 0.4 inch with an assumed root defect), the time required for the assumed flaw to propagate through the remaining ligament is 1.73 EFPY (15200 EFPH) for the no root defect case, and 1.39 EFPY (12200 EFPH) for the root defect case. A crack would have to propagate through this remaining ligament before leakage and possible wastage of the vessel head material could occur.

The conclusion of this calculation is that, even with the very conservative assumption of using Alloy 82 crack growth rates for Alloy 52 weld material, a hypothetical remnant weld crack will not grow through the repair weld ligament for essentially all of the remaining cycle of operation before the reactor vessel head is replaced during the next scheduled refueling outage.

6.0 REFERENCES

1. Materials Reliability Program, "Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Thick-Wall Alloy 600 Material," MRP-55, Revision 1, November 2002. EPRI Proprietary

2. Minutes of EPRI-MRP PWSCC Crack Growth Expert Panel Meeting, October 3, 2003 – Gaithersburg, Maryland, EPRI Letter PWR-MRP 2003-38 by John Hickling, October 20, 2003. MRP Proprietary.

3. Dominion Engineering, "Point Beach Unit 1 CRDM Nozzle Repair Weld Analysis" Calculation C-4430-00-2, Revision 1, SI File PBCH-09Q-204.

4. Structural Integrity Associates, **pc-CRACK**[tm] **for Windows**, version 3.1-98348.

5. Calculation, "Fracture Mechanics Evaluation of Point Beach Unit 1 Top Head CRDM 43.5 Degree Azimuth Penetration Weld Repair," PBCH-09Q-301, Revision 0.

6. E-mail from Brian Kemp (NMC) to Hal Gustin (SI) 5/12/04

7. Materials Reliability Program, "Interim Alloy 600 Safety Assessments for US PWR Plants, Part 2: Reactor Vessel Top Head penetrations," MRP-44, EPRI Report No. TP-1001491, Part 2, May 2001

Figure 1 – Illustration of Nozzle 26 Repair and Associated Overlap Region

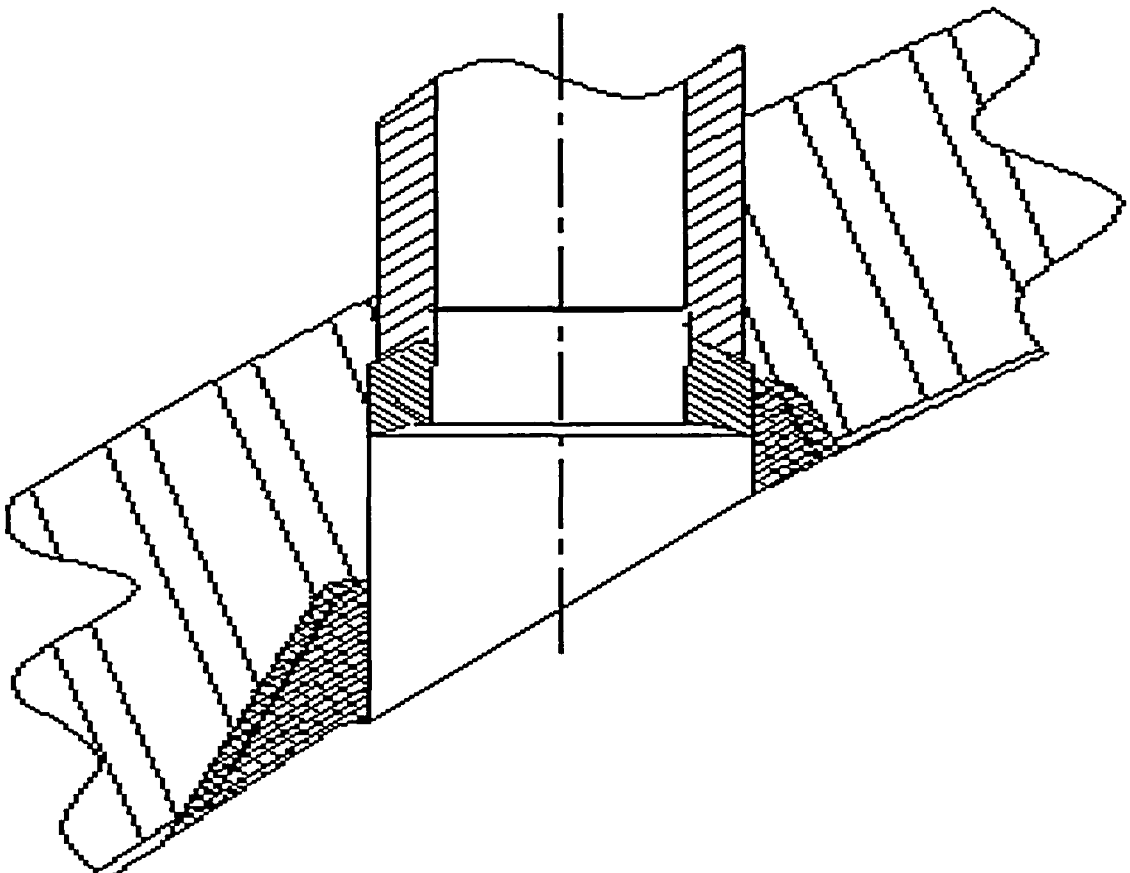

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Figure 2 – Alloy-82 and -182 Crack Growth Rate Correlations at 617 °F, from Reference [2]