STRUCTURAL FLAW EVALUATION OF HEAD FLANGE WELD AT DRESDEN NUCLEAR POWER STATION, UNIT 2

Prepared By: Guy H. DeBoo **Date:** 10/16/95
Staff Engineer

Reviewed By: Hien Q. Do **Date:** 10/16/95
Staff Engineer

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1.0 Introduction:

This report provides the results of the D2R14 refuel outage ultrasonic examinations (UT) performed on the Reactor Pressure Vessel (RPV) Head-to-Flange weld, which was performed in accordance with the requirements of ASME Section XI, 1989 Edition, Examination Category B-A. It also includes the evaluation and disposition of a flaw that exceeded the ASME Section XI, 1989 Edition acceptance criteria. (Reference 1)

1.1 Examination Scope

Fifty percent of the RPV Head-to-Flange weld was scheduled for examination during D2R14 refuel outage. This examination scope exceeds the minimum percentage required for Examination Category B-A as it applies to the inspection items that cannot be deferred to the end of the inspection interval.

Raytheon Inc. performed the manual UT and Magnetic Particle examination (MT) using Level II and III examiners qualified to SNT-TC-1A, Supplement B, 1980 or 1984 Edition.

2.0 Flaw Description:

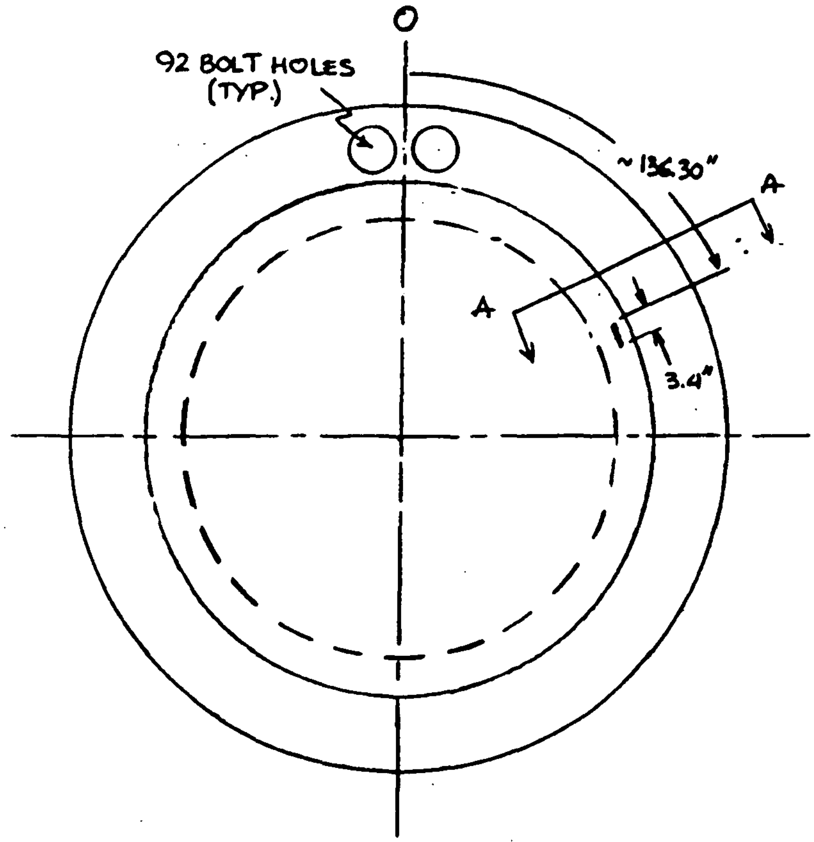
No recordable indications were detected by MT. However, one subsurface flaw exceeding the acceptance criteria delineated in subarticle IWB-3510 of ASME Section XI, 1989 Edition was detected by UT in the RPV Head-to-Flange weld. This flaw exhibits typical characteristics of slag inclusions; such as flaw location in the fusion zone, series of small reflectors, wide and low amplitude signal responses, and signal responses to straight beam examination. Based on these examination results, this flaw is considered to be an original construction flaw which was not service induced. However, because the slag inclusion exceeded the acceptance standards of the Code a flaw evaluation based on the requirements of Reference 2 was performed.

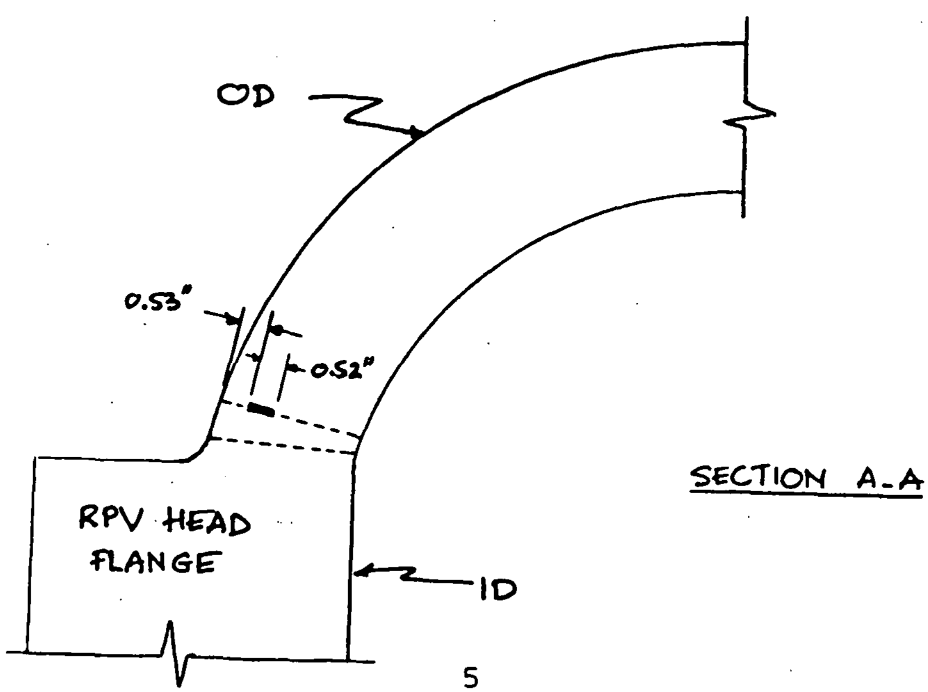
The flaw was characterized as follow:

Planar depth (2a for subsurface flaw):	0.52"
Distance from OD surface (S):	0.53"
Length:	3.40"

See Figure 2.1 for a graphical presentation of this flaw.

Figure 2.1 Flaw Location in the Head - Flange Weld





3.0 Load Definition:

The structural evaluation is performed in accordance with ASME Code Section XI (Ref. 2), to determine the allowable flaw size. Stresses in the region of the circumferential head flange weld are: (i) pressure stress, (ii) bolt preload and (iii) weld residual stress. Since the hydrotest case was determined to be the most limiting plant operation by the 1990 analysis (Ref. 3), only the hydrostatic pressure test case of plant operation is considered here. The pressure membrane stress for the RPV head corresponds to PR/2t or about 18.4 ksi. The bending stress at the RPV head and flange junction due to the bolt preload was taken from the original design report (Ref. 4). Since the head flange weld is about 3 inches away from the junction, an attenuation correction factor of 0.73 was applied to the bending stress. The factor was established by the finite element analysis provided in the 1990 analysis, which determined the bending stress attenuation factor at the inside surface of the head flange weld. A typical bolt-up preload stress distribution was also provided in the 1990 analysis, which shows that maximum longitudinal stress attenuates by the same ratio at the inside and outside surfaces near the head flange junction. Therefore same bending attenuation factor of 0.73 is applied to the outside surface of the head flange weld and the resulting bending stress is 18.5 ksi. Weld residual stress, assumed to be 8 ksi , was treated as a bending stress. All these stresses at the detected flaw location are in tension.

4.0 Stress Intensity Factor Results:

The stress intensity factor K_I for the detected flaw geometry is calculated based on the flat plate model provided in Article A-3000 of the ASME code (Ref. 2). The radius to thickness (R/t) ratio for the head flange region is about 30, therefore the effect of RPV head curvature is negligible. The total stress intensity at the flaw location is 35.7 ksi-$\sqrt{in}$, which is less than the allowable K_I of 46.0 ksi$\sqrt{in}$ provided in the 1990 analysis. The allowable K_I was based on: (i) the top head RT_{NDT} of 20°F and the required test temperature of 175°F at 1171 psi, and (ii) a safety factor of $\sqrt{10}$ for normal conditions (including upset and test conditions). It should be pointed out here that this allowable K_I is conservative for the flaw evaluation. Since the top head experiences little irradiation embrittlement effects, the fracture toughness requirement of the vessel is largely determined by the K_I value of the vessel in the active fuel region (beltline). As fluence accumulation in the beltline increases, the shift in fracture toughness would require increasing test pressure temperature above 175°F. This, in turn, increases the allowable K_I value used for the evaluation in accordance with Figure A-4200-1 of the Code. Table 4.1 shows the stress intensity factors for other flaw sizes which are calculated based on the following assumptions: (i) same aspect ratio as the detected flaw, i.e. a/l = 0.076; (ii) the growth direction of the flaw depth is radially outward towards the O.D. surface where the bending stress is highest. In the table, the flaw depth of 0.87 inch is the maximum depth that the flaw can reach and still be classified as subsurface flaw according to ASME code Section IWB-3600. These results are plotted in Figure 4.1 and the maximum allowable flaw depth is 0.715 inch.

Flaw Depth (2a), in	K_I, ksi-√in
0.52	35.7
0.61	41.1
0.70	45.3
0.87	55.3

TABLE 4.1 Stress Intensity Factors

5.0 Crack Growth Evaluation:

Since the flaw is assumed to remain subsurface and given in its proximity to the outside surface, it is reasonable to assume that the crack growth takes place in air. Therefore only fatigue crack growth will be considered. The growth was calculated using the curves in ASME Section XI Division 1 Appendix A Figure A-4300-1. The worst case curve was used for conservatism. The stress intensity factor range, ΔK, was based on the range of stress between a free stress state and bolt-up and the pressure test condition at the current detected crack depth of 0.52 inch. The growth value given by the curve is $3.5x10^{-5}$ in/cycle. Assuming a very conservative crack growth rate of 0.0035 inch per fuel cycle (a reduction factor of 100) would allow 10 heatup-cooldown cycles combined with top head bolt-up and 90 other occurrences of lesser events such as scrams etc per fuel cycle. Any contribution from thermal transients to the fatigue crack growth is conservatively accounted for by this factor. It should also be noted that, the effect of thermal transients in the head flange region is not a bounding condition because the allowable K_I value will increase when the RPV head temperature is raised beyond the hydrotest requirement of 175°F.

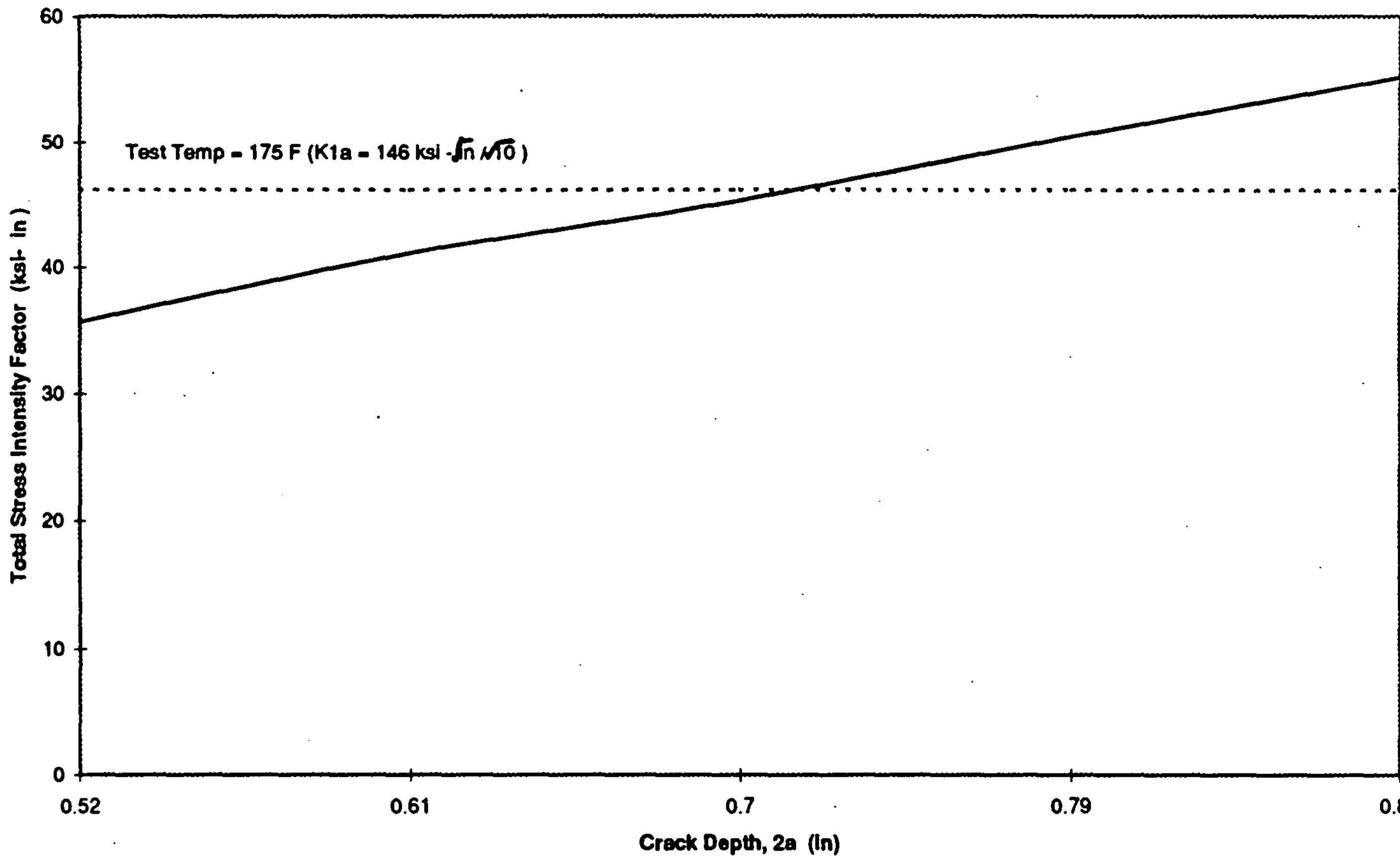


Figure 4.1 K vs. 2a for Pressure Test Condition

6.0 Allowable Flaw Size For Continued Operation:

By subtracting the crack growth from the maximum allowable flaw size of 0.715 inch, the allowable detected flaw depth for the next fuel cycle is 0.712 inch. The allowable detected flaw depth for the next 10 fuel cycles is 0.68 inch. Both values are considerably greater than current detected flaw depth of 0.52 inch. This evaluation concludes that the acceptance criteria of the ASME code Section IWB-3600 for both normal/upset and emergency/faulted conditions has been met for 10 fuel cycles. These conclusions are also applicable to similar flaws that may be found in the remaining (50%) of the head flange weld provided the flaw remains subsurface as defined in ASME Code Section IWB-3610 and is not subjected to the reactor environment.

7.0 Conclusion:

The evaluation of this subsurface flaw, 0.52" in depth and 3.4" in length, has determined it to be acceptable for 10 boltup cycles of the RPV head flange. This conclusion was reached using the methodology of Appendix A and the acceptance criteria of IWB -3600 of Reference 2.

The remaining fifty percent (50%) of the RPV Head-to-Flange weld has been scheduled for UT during the current D2R14 refuel outage to satisfy the additional examination requirement of ASME Section XI, subarticle IWB-2430. In accordance with ASME Section XI, subarticle IWB-2420, the weld area containing the aforementioned flaw will be scheduled for reexamination during the next three (3) inspection periods. Inspection period is defined by ASME Section XI, Table IWB-2412-1. If the reexaminations reveal that the flaw remains essentially unchanged for three successive inspection periods, the component examination schedule will revert to the original schedule of successive examination.

8.0 REFERENCES:

1. G. DeBoo to C. Chu, ComEd FAX, *UT Test Report - Dresden U2 RPV Head*, September 29, 1995.

2. ASME Boiler and Pressure Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Component, 1989 Edition.

3. T. Swift, Structural Evaluation of Head Flange Weld, Vessel Flange Weld and Upper Shell Weld at Dresden Nuclear Power Station Unit 2, GE Report SASR 90-77, October, 1990.

4. E. Winslow, *Stress Analysis of Closure. Vol. 2*, Babcock & Wilcox Company, June 1967, GE VPF #1248-436-1.

5. "Structural Evaluation of Head Flange Weld At Dresden Nuclear Power Station, Unit 2", GENE-523-A107-1095, DRF 137-0010-8, October 13, 1995.

ATTACHMENT B