ENCLOSURE 4

MONTICELLO NUCLEAR GENERATING PLANT

**SUPPLEMENTAL INFORMATION REGARDING
CYCLE 25 INSERVICE INSPECTION SUMMARY REPORT –
CORE SHROUD SUPPORT FLAW EVALUATION**

**EC-18095
EVALUATION OF THE MONTICELLO SHROUD SUPPORT PLATE UPLIFT LOAD
WITH INDICATIONS IN THE H8 AND H9 WELDS
(NON-PROPRIETARY VERSION)**

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1.0 INTRODUCTION

During the Spring 2011 outage, inspection of the Monticello shroud support plate weld H8 and weld H9 was performed. Visual inspection (EVT1) coverage was obtained from jet pump JP20 to JP1 and JP10 to JP11, as identified in Figure 1 [1]. This accounts for approximately 17% of the H8 and H9 circumference [1]. An additional 64 inches of inspection coverage was acquired with visual inspection VT-3 on the top side of the weld [1] in the area between all the jet jumps. The visual inspection revealed cracking in the shroud support legs but no indications were identified in the welds H8 and H9.

This evaluation is performed to quantify the structural margin retaining the shroud support plate H8 and H9 welds after one cycle of additional operation assuming plastic collapse in shear to be the applicable failure mode because the most significant loading is the uplift load due to the vertical seismic and the pressure difference across the shroud support plate.

2.0 TECHNICAL APPROACH

The technical approach used for this evaluation is based on the BWRVIP-76 [2], limit load approach. The limit load analysis for shear failure is developed based on the approach for determining the limit load for an axial crack in the shroud as presented in [2] and summarized below. Consistent with the BWRVIP methodology in [2], the failure mode of the Alloy 600 and corresponding weld materials is considered to be the net section (plastic) collapse, because of the very high ductility of these materials at reactor operating temperatures. Also, the fluence in this region is not high enough to impact the material ductility.

The limit load for an axial crack assuming tensile failure of the remaining ligament is expressed in Section E.1.2 of [2] as:

[redacted]

By similar approach, the shear failure limit load for a crack in a circular weld can be expressed as:

$$(SF)S = \sigma_{sf} Lt \qquad (2)$$

where: S = shear force due to uplift load
SF = safety factor

σ_{sf} = shear flow stress
L = length of uncracked circumference in circular welds (H8/H9)
t = thickness of shroud support plate.

Using the maximum shear theory or Tresca criteria, the maximum shear stress at yield is half the maximum yield strength. The shear flow stress can be expressed as:

$$\sigma_{sf} = \sigma_f/2$$

There are no plant specific safety factors for the Monticello shroud [1]. Per Section D.5 in Reference 2, required minimum safety factors of 2.77 for normal/upset (Level A/B) conditions and 1.39 for emergency/faulted (Level C/D) conditions are used in this evaluation.

In limit load evaluation, elastic-perfectly plastic material properties are used.

3.0 ASSUMPTIONS

The following assumptions are used:

a. Loading in weld H8 and weld H9 is assumed to be pure shear due to the most significant loads being the vertical seismic and the pressure difference across the shroud support plate.
b. Material properties of Alloy 600 compatible weld metal are assumed to be the same as the Alloy 600 base metal.
c. The shear load is assumed to be evenly distribution between the weld H8 and weld H9.
d. The shear load is assumed to be evenly distributed in the remaining ligament of each weld.
e. For uninspected region, through-wall cracking is assumed. This is conservative since no credit is taken for the uninspected region.
f. For inspected region, surface cracking with depth of 75% of the plate thickness is assumed. This assumption is based on the general evidence provided by the BWR fleet shroud cracking data. The flaws generally arrest at 2/3 of the wall thickness, so the assumption of a 75% wall flaw is conservative.
g. The SSE accelerations are twice as large as the OBE accelerations.
h. The vertical flexural shear from the moment induced by the horizontal acceleration due to the jet pump weight on the support plate is assumed to be negligible. It was estimated that this upward flexural shear is less than 5% of the total uplift shear load.
i. The material is considered to behave in an elastic-plastic manner, which is consistent with BWRVIP methodology for reactor internals in low fluence regions.
j. Crack growth in the depth direction is not considered since the assumed crack depth is based on flaw depths observed from BWR fleet operating experience. Subsequent growth is minimal due to excellent Monticello water chemistry conditions in the lower plenum.
k. Seismic and LOCA are conservatively combined in order to provide added margin to the evaluation and further justify the maximum flaw depth based on BWR fleet operating experience.

4.0 DESIGN INPUTS

The following dimensions are used in the evaluation:

Reactor vessel inside diameter (ID):	17.167 ft [1]
Shroud plate thickness:	2.5 inches [3]
Shroud ID:	159.75 inches [4]
Shroud thickness:	1.75 inches [4]
Design ΔP across shroud support plate for Levels A through D	100 psi [1]

Per Reference 1, the vertical earthquake acceleration is 0.06g.

The vessel internal component loads and water loads are obtained from Reference 13 and summarized in Table 1.

The input used to calculate the pressure differential across the shroud support plate for different operating conditions are obtained from Reference 7 and summarized in Table 2. The maximum ΔP for Level A/B is 29.03 psid for the EPU conditions [7]. For Level C/D, the maximum ΔP is 47 psid from the 113% OLTP. Since it is not clear if the Level C/D reactor internal pressure difference (RIPD) considers the decompression of the annulus region following a postulated recirculation line break (RLB) event (typically the Level C/D RIPD is given as the main steam line break pressure difference), a bounding methodology is used in this calculation to calculate an uplift load on the shroud support plate.

Per Reference 1, the Code of Construction is Section III, 1965 with Summer 1966 Addenda [19]. The allowable stress intensity (S_m) is 23.3 ksi [1]. The material yield strength (S_y), ultimate strength (S_u) and allowable stress intensity for Alloy 600 are obtained from Reference 8 at 550 °F for conservatism and summarized in Table 3. As compared to the allowable S_m from Reference 19 stated in Reference 1, the S_m from different Code Editions remains the same.

The input used to calculate the pressure differential across the support plate is summarized in Table 4.

The shroud support plate material is Alloy 600 [15].

The end of evaluation period (EoEP) is 24 months [1].

5.0 CALCULATIONS

5.1 Pressure Difference across Shroud Support Plate

5.1.1 Top of Shroud Support Plate Pressure Calculation

The pressure at the top of the shroud support plate for normal condition, P_{shroud}, is a required input for determination of the pressure difference across the shroud support plate for the postulated Recirculation Outlet Break case. Considering hydrostatic pressure, this may be calculated by:

$$P_{Shroud} = P_0 + \frac{h}{1728 \cdot v_f} \tag{3}$$

where P_0 = pressure at the water surface, psia
h = water height from top of shroud support plate elevation to the water surface, in
v_f = specific volume of the water at the top of the shroud support plate, ft^3/lb = $0.02119 ft^3/lb$ (based on annulus temperature, interpolated from [11]).

Thus, P_{shroud} = 1025 + (512.5 – 99.25)/(1728 x 0.02119)= 1036.3 psia.

The pressure in the lower head is higher than the pressure in the annulus because of the pressure added by the jet pumps. The pressure difference can be estimated from Reference 7 as the maximum differential pressure across the shroud support plate for the Level B condition, which is 29.03 psid.

5.1.2 Shroud Support Plate Pressure Difference Calculation

A conservative lower bound for the pressure above the support plate is the saturation pressure at the annulus temperature. A low pressure above the support plate is conservative because it maximizes lifting force on the plate due to the pressure differential across the plate. If the pressure below the plate is held constant and the pressure above the support plate is lessened, the upward force on the support plate is increased. In normal operation, the lowest pressure in the reactor pressure vessel is the pressure in the steam dome. The saturation pressure at the annulus temperature is slightly less than the steam dome pressure because the annulus liquid is slightly subcooled.

From Reference 7, the maximum Level A/B pressure difference across the shroud support plate is given as 29.03 psid. This pressure differential is expected to exist at the instant of the postulated RLB event.

A conservative lower bound for the pressure above the support plate, following the RLB event, is the saturation pressure at the annulus temperature. Thus the bounding total pressure difference, ΔP, for the Level C/D conditions is given as:

$$\Delta P = P_{shroud} - P_{sat} = (1036.3 + 29.03) - 886.25 = 179.08 \text{ psid}$$

This pressure difference acts to lift the support plate upward.

The pressure differentials across the shroud support plate are summarized in Table 4.

5.2 Postulated Crack Profile

From Reference 1, Welds H8 and H9 were inspected with EVT-1 from JP 20 to JP1 and JP10 to JP11 (about 17% of the circumference), as shown in Figure 1 [4], with an additional 64 inches inspected with VT-3. The regions not inspected by VT-3 are the portion of the welds close to the jet pumps, as illustrated in Figure 1 [1].

Thus, the uninspected regions are considered to be evenly distributed based on the jet pumps pattern, resulting in 10 uninspected regions as illustrated in Figure 1. These regions are conservatively to be cracked through-wall.

Length of weld H8 = $2\pi R_i$=2*π(159.75/2+1.75)= 2*π(81.625) = 512.865 in
Length of weld H9 = $2\pi R_o$=2*π(17.167*12/2)= 2*π(103.002) = 647.18 in

To simplify, an average length for welds H8 and H9 is used for evaluation.

Average weld length for welds H8 and H9 = (512.865+647.18)/2 =580.02 inch

The inspection length inspected by VT-3 for each weld is approximately 64/2 = 32 inches.

Using the average weld length, the following are obtained for each weld:

Total inspected length = 0.17*580.02+32 = 130.60 inches
Total uninspected length = 580.02 -130.63 inches = 449.42 inches

This corresponds to 449.42/10=44.94 inches for each uninspected region.

5.3 Limit Load for Shear

5.3.1 Applied Loads

5.3.1.1 Uplift Load

The uplift load is due to the pressure difference across the shroud support plate. The ΔP uplift area (UA) is calculated as:

$$UA = \pi(R_o^2-R_i^2)=\pi(103.002^2-81.625^2) = 12399.15\ in^2$$

The uplift loads due to the pressure difference for Level A/B and C/D are calculated and shown in Table 5.

5.3.1.2 Vertical Seismic Load

In Table 1, it is shown that the total weight of the jet pumps is 10 kips. Also, the maximum water weight of 1080 kips from Table 1(b) is selected. Thus the total weight due to internal structure & periphery fuel, jet pumps and water weight is:

Wt = 189 + 10 + 1080 =1279 kips

The vertical seismic acceleration is 0.06g. This is assumed to be for OBE.

The total vertical seismic load for OBE and SSE is summarized in Table 6.

The total upward shear force is summarized in Table 7.

5.4 Crack Growth

Crack growth in the depth direction is not included since the depth used in the evaluation is consistent with the depths based on BWR fleet operating experience. In addition, due to Monticello's excellent water chemistry in the lower plenum, subsequent crack growth will not be significant.

5.4.1 Crack growth in circumferential direction

Per Reference 2, the crack growth rate is $5x10^{-5}$ in/hr. This is used for conservatism regardless of plant specific water chemistry. For 10 uninspected regions, with 2 crack fronts for each region since a through-wall crack is used, the total crack growth Δl for 24 months is:

$$\Delta l = 10*2*5x10^{-5}*2*365*24 = 17.52 \text{ inches}$$

Therefore, the remaining length of un-cracked circumference at the EoEP is

$$L = 130.60 - 17.52 = 113.08 \text{ inches}$$

5.5 Evaluation Cases

Two crack profiles are used to evaluate the structural margin retaining the shroud support plate weld H8 and weld H9. Each of these contains significant conservatisms, which compensate for any uncertainty in the flaw depths. It is important to note that BWR shroud cracking history, of which there is a significant amount, has shown that typically cracks in shroud welds grow to approximately two-thirds of the shroud wall and then appear to become essentially inactive. This is particularly expected for Monticello's case because of the excellent water chemistry experienced in the vicinity of the indications on the lower side of H8 and H9. These two crack profiles are:

(a) Multiple Cracks: A through-wall crack is postulated in the uninspected regions and a remaining ligament of 1/3 of the plate thickness in the inspected region is postulated since inspection was performed on the top side only. The 1/3 wall remaining ligament is based on field experience for BWR shroud welds.

(b) Full Circumferential Surface Crack: A surface crack at the bottom plate surface extending along the circumferential length of Weld H8 and H9 with a crack depth at 75% of the support plate thickness is postulated. This corresponds to a remaining ligament of 0.625 inches in the support plate.

6.0 RESULTS OF ANALYSIS

The limiting shear force due to limit load failure criteria can be calculated using Eq. (2). The flow stress is taken as $3S_m$ per Reference 9 as used in Reference 20.

The analysis results are summarized in Tables 8 and 9 for the two crack profiles described in Section 5.5. It is shown that the safety factors are 14.96 and 2.77 for Levels A/B and C/D, respectively for the multiple crack case. For the surface crack case, the safety factors are 57.58 and 10.67 for Levels A/B and CD, respectively. These are higher than the required safety factors of 2.77 and 1.39 per Reference 2.

7.0 CONCLUSIONS AND DISCUSSIONS

An analysis was performed to evaluate the capacity of the remaining length in the Welds H8 and H9 to prevent the up lift of the core shroud. It is shown that, for an EoEP of 24 months, the calculated safety factors of for Levels A/B and C/D conditions in Weld H8 and H9 are significantly above the required safety factors of 2.77 and 1.39, respectively, for both conservative flaw configurations analyzed.

These results demonstrate that, even with the postulated flaws in welds H8 and H9, the structural integrity of the shroud support plate is assured.

8.0 REFERENCES

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4. General Electric Drawing 886D487, "Reactor Vessel," No. NX7831-7-2, SI File 1100626.201.
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6. Not used.
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8. ASME Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition with no Addenda.
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13. Monticello Drawing No. NX7831-7-7 (GE Drawing No. 886D482, Revision 10), "Reactor Vessel," SI File No. 1100626.201.
14. Not used.
15. Xcel Energy DIT No. EC 18095, "Shroud Support Plate Uplift Evaluation," Rev.1, SI File 1100626.206.
16. Not used.
17. BWR Vessel and Internals Project: Evaluation of Crack Growth in BWR Stainless Steel RPV Internals (BWRVIP-14A), EPRI, Palo Alto, CA, BWRVIP, 2003, TR-105873.
18. Not used
19. ASME, Boiler and Pressure Vessel Code, Section III, 1965 Edition with Addenda to and including Summer 1966 Addenda.
20. SI Calculation, "Evaluation of the Monticello Shroud with Indications at Welds H8 and H9," SI File 1100560.301, Rev. 0.

Table 1: Load Summary

(a) Loads Supported by Internal Shroud Support [13]

Component	Weight (kips)
Internal Structure & Periphery Fuel	189
Guide loads (all fuel, drives, control rods, guide tubes) for horizontal earthquake loads only	397
Jet Pumps	10

(b) Water Loads [13]

Operating Conditions	Water Weight (kips)
Normal Full Power	353.1
Hot, Stand By	381.4
Cold Vessel, Full	729.2
Refueling (water level 927")	1080
Refueling (water level 655")	651

Table 2: Design Input for Shroud Support Plate Pressure Difference Calculation

Design Variable	Value	Units	Reference
Normal water level elevation, above vessel zero	512.5	in.	12
Recirculation Nozzle centerline elevation, above vessel zero	150	in.	12
Top of the shroud support plate elevation, above vessel zero (1)	98.75	in.	13
Annulus Temperature	530.2	^{o}F	1
Annulus Saturation Pressure	886.25	psia	11
Dome Pressure	1025	psia	1

Note : (1) Calculation based on 108.5" -11.75"+2" from Reference 13.

Table 3: Material Properties at 550 °F

	Alloy 600 Base Metal
Yield Strength (ksi)	30.1
Ultimate Strength (ksi)	80
Stress Intensity S_m (ksi)	23.3

Table 4: Pressure Differential across the Shroud Support Plate

Level	Pressure Differential (psid)
A/B	29.03 [7]
C/D	179.08

Table 5: Uplift Load on Shroud Support Plate

Level	Area (in^2)	Pressure Differential (psid)	Up Force (lbs)
A/B	12399.15	29.3	363295
C/D	12399.15	179.08	2220440

Table 6: Vertical Seismic Load

Level	Coefficient	Total Wt (kips)	Up Force (kips)
A/B	0.06	1279	76.74
C/D	0.12	1279	153.48

Table 7: Total Upward Shear Force

Level	Pressure Differential (kips)	Vertical Seismic Load (kips)	Total (kips)
A/B	363.295	76.74	440.04
C/D	2220.44	153.48	2373.92

Table 8: Limit Load Evaluation Results for Compound Crack Profile

		Level A/B	Level C/D
(1)	EoEP uncracked length (in)	113.08	113.08
(2)	Support plate thickness (in)	2.5	2.5
(3)	Remaining ligament (in)	0.833	0.833
(4)	Available shear area (in^2) (=(1)*(3))	94.20	94.20
(5)	Total applied shear load (kips)	440.04	2373.92
(6)	Applied shear in each weld (kips) (=(5)/2)	220.02	1186.96
(7)	Tensile Flow Stress (ksi)	69.9	69.9
(8)	Shear Flow Stress (ksi)	34.95	34.95
(9)	Shear limited load (kips) (=(8)*(4))	3292.29	3292.29
(10)	Safety Factor (=(9)/(6)	14.96	2.77
(11)	Required Safety Factor	2.77	1.39

Table 9: Limit Load Evaluation Results for Surface Crack Profile

		Level A/B	Level C/D
(1)	EoEP uncracked length (in)	580.02	580.02
(2)	Support plate thickness (in)	2.5	2.5
(3)	Remaining ligament (in)	0.625	0.625
(4)	Available shear area (in^2) (=(1)*(3))	362.51	362.51
(5)	Total applied shear load (kips)	440.04	2373.92
(6)	Applied shear in each weld (kips) (=(5)/2)	220.02	1186.96
(7)	Tensile Flow Stress (ksi)	69.9	69.9
(8)	Shear Flow Stress (ksi)	34.95	34.95
(9)	Shear limited load (kips) (=(8)*(4))	12669.7	12669.7
(10)	Safety Factor (=(9)/(6)	57.58	10.67
(11)	Required Safety Factor	2.77	1.39

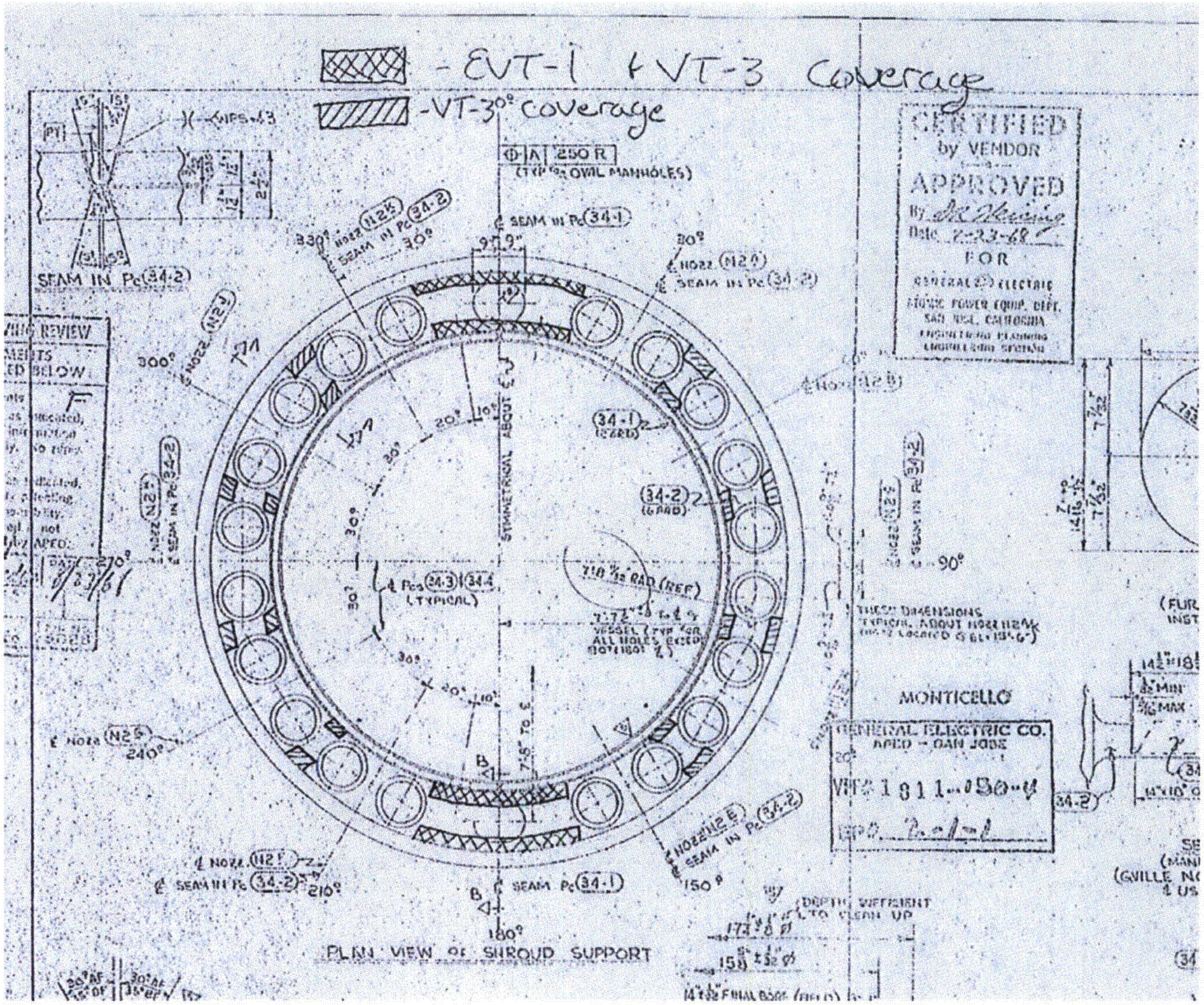

Figure 1. Jet Pumps Inspection Illustration