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Evaluation of Pressurized Thermal Shock for Vogtle Electric Generating Plant Unit 1

Westinghouse Energy Systems

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WCAP-15069

Evaluation of Pressurized Thermal Shock for Vogtle Electric Generating Plant Unit 1

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PREFACE

This report has been technically reviewed and verified by:

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EXECUTIVE SUMMARY

The purpose of this report is to determine the RT_{PTS} values for the Vogtle Electric Generating Plant Unit 1 reactor vessel beltline based upon the results of the Surveillance Capsule V evaluation. The conclusion of this report is that all the beltline materials in the Vogtle Electric Generating Plant Unit 1 reactor vessel have RT_{PTS} values below the screening criteria of 270°F for plates, forgings or longitudinal welds and 300°F for circumferential welds at EOL (36 EFPY) and life extension (54 EFPY).

1 INTRODUCTION

A Pressurized Thermal Shock (PTS) Event is an event or transient in pressurized water reactors (PWRs) causing severe overcooling (thermal shock) concurrent with or followed by significant pressure in the reactor vessel. A PTS concern arises if one of these transients acts on the beltline region of a reactor vessel where a reduced fracture resistance exists because of neutron irradiation. Such an event may produce a flaw or cause the propagation of a flaw postulated to exist near the inner wall surface, thereby potentially affecting the integrity of the vessel.

The purpose of this report is to determine the RT_{PTS} values for the Vogtle Electric Generating Plant Unit 1 reactor vessel using the results of the surveillance Capsule V evaluation. Section 2.0 discusses the PTS Rule and its requirements. Sections 3.0 provides the methodology for calculating RT_{PTS}. Section 4.0 provides the reactor vessel beltline region material properties for the Vogtle Electric Generating Plant Unit 1 reactor vessel. The neutron fluence values used in this analysis are presented in Section 5.0 and were obtained from Section 6 of WCAP-15067. The results of the RT_{PTS} calculations are presented in Section 6.0. The conclusion and references for the PTS evaluation follow in Sections 7.0 and 8.0, respectively.

2 PRESSURIZED THERMAL SHOCK RULE

The Nuclear Regulatory Commission (NRC) recently amended its regulations for light-water-cooled nuclear power plants to clarify several items related to the fracture toughness requirements for reactor pressure vessels, including pressurized thermal shock requirements. The revised PTS Rule[1], 10 CFR Part 50.61, was published in the Federal Register on December 19, 1995, with an effective date of January 18, 1996.

This amendment to the PTS Rule makes three changes:

1. The rule incorporates in total, and therefore makes binding by rule, the method for determining the reference temperature, RT_{NDT}, including treatment of the unirradiated RT_{NDT} value, the margin term, and the explicit definition of "credible" surveillance data, which is currently described in Regulatory Guide 1.99, Revision 2[2].

2. The rule is restructured to improve clarity, with the requirements section giving only the requirements for the value for the reference temperature for end of life (EOL) fluence, RT_{PTS}.

3. Thermal annealing is identified as a method for mitigating the effects of neutron irradiation, thereby reducing RT_{PTS}.

The PTS Rule requirements consist of the following:

- For each pressurized water nuclear power reactor for which an operating license has been issued, the licensee shall have projected values of RT_{PTS}, accepted by the NRC, for each reactor vessel beltline material for the EOL fluence of the material.

- The assessment of RT_{PTS} must use the calculation procedures given in the PTS Rule, and must specify the bases for the projected value of RT_{PTS} for each beltline material. The report must specify the copper and nickel contents and the fluence values used in the calculation for each beltline material.

- This assessment must be updated whenever there is significant change in projected values of RT_{PTS} or upon the request for a change in the expiration date for operation of the facility. Changes to RT_{PTS} values are significant if either the previous value or the current value, or both values, exceed the screening criterion prior to the expiration of the operating license, including any renewal term, if applicable for the plant.

- The RT_{PTS} screening criterion values for the beltline region are:

  270°F for plates, forgings and axial weld materials, and
  300°F for circumferential weld materials.

3 METHOD FOR CALCULATION OF RT_{PTS}

RT_{PTS} must be calculated for each vessel beltline material using a fluence value, f, which is the EOL fluence for the material. Equation 1 must be used to calculate values of RT_{NDT} for each weld and plate or forging in the reactor vessel beltling.

$$RT_{NDT} = RT_{NDT(U)} + M + \Delta RT_{NDT} \quad (1)$$

Where,

$RT_{NDT(U)}$ = Reference Temperature for a reactor vessel material in the pre-service or unirradiated condition

M = Margin to be added to account for uncertainties in the values of $RT_{NDT(U)}$, copper and nickel contents, fluence and calculational procedures. M is evaluated from Equation 2

$$M = \sqrt{\sigma_U^2 + \sigma_\Delta^2} \quad (2)$$

σ_U is the standard deviation for $RT_{NDT(U)}$.

σ_U = 0°F when $RT_{NDT(U)}$ is a measured value.

σ_U = 17°F when $RT_{NDT(U)}$ is a generic value.

σ_Δ is the standard deviation for RT_{NDT}.

For plates and forgings:

σ_Δ = 17°F when surveillance capsule data is not used.

σ_Δ = 8.5°F when surveillance capsule data is used.

For welds:

σ_Δ = 28°F when surveillance capsule data is not used.

σ_Δ = 14°F when surveillance capsule data is used.

σ_Δ not to exceed one half of ΔRT_{NDT}

ΔRT_{NDT} is the mean value of the transition temperature shift, or change in ΔRT_{NDT}, due to irradition, and must be calculated using Equation 3.

$$\Delta RT_{NDT} = (CF) * f^{(0.28 - 0.10 \log f)} \quad (3)$$

CF (°F) is the chemistry factor, which is a function of copper and nickel content. CF is determined from Tables 1 and 2 of the PTS Rule (10 CFR 50.61). Surveillance data deemed credible must be used to determine a material-specific value of CF. A material-specific value of CF is determined in Equation 5.

F is the higher of the best estimate or calculated neutron fluence, in units of 10^{19} n/cm^2 (E > 1.o MeV), at the clad-base-metal interface on the inside surface of the vessel at the location where the material in question receives the highest fluence. The EOL fluence is used in calculating RT_{PTS}.

Equation 4 must be used for determining RT_{PTS} using Equation 3 with EOL fluence values for determining ΔRT_{PTS}

$$RT_{PTS} = RT_{NDT(U)} + M + \Delta RT_{PTS} \qquad (4)$$

To verify that RT_{NDT} for each vessel beltline material is abounding value for the specific reactor vessel, licensees shall consider plant-specific information that could affect the level of embrittlement. This information includes but is not limited to the reactor vessel operating temperature and any related surveillance program results. Results from the plant-specific surveillance program must be integrated into the RT_{NDT} estimate if the plant-specific surveillance data has been deemed credible.

A material-specific value of CF is determined from Equation 5.

$$CF = \frac{\sum[A_i * f_i^{(0.28-0.20\log fi)}]}{\sum[f_i^{(0.56-0.20\log fi)}]} \qquad (5)$$

In Equation 5, "A_i" is the measured value of ΔRT_{NDT} and if "f_i" is the fluence for each surveillance data point. If there is clear evidence that the copper and nickel content of the surveillance weld differs from the vessel weld, i.e., differs from the average for the weld wire heat number associated with the vessel weld and the surveillance weld, the measured values of RT_{NDT} must be adjusted for differences in copper and nickel content by multiplying them by the ratio of the chemistry factor for the vessel material to that for the surveillance weld.

4 VERIFICATION OF PLANT SPECIFIC MATERIAL PROPERTIES

Before performing the pressurized thermal shock evaluation, a review of the latest plant-specific material properties for the Vogtle Electric Generating Plant Unit 1 vessel was performed. The beltline region of a reactor vessel, per the PTS Rule, is defined as "the region of the reactor vessel (shell material including welds, heat-affected zones and plates and forgings) that directly surrounds the effective height of the active core and adjacent regions of the reactor vessel that are predicted to experience sufficient neutron radiation damage to be considered in the selection of the most limiting material with regard to radiation damage". Figure 1 identifies and indicates the location of all beltline region materials for the Vogtle Electric Generating Plant Unit 1 reactor vessel.

The best estimate copper and nickel contents of the beltline materials were obtained from WCAP-13931, Rev. 1[4] and CE Report NPSD-1039, Rev. 2[6]. The best estimate copper and nickel content is documented in Table 1 herein. The average values were calculated using all of the available material chemistry information. Initial RT_{NDT} values for Vogtle Electric Generating Plant Unit 1 reactor vessel beltline material properties are also shown in Table 1.

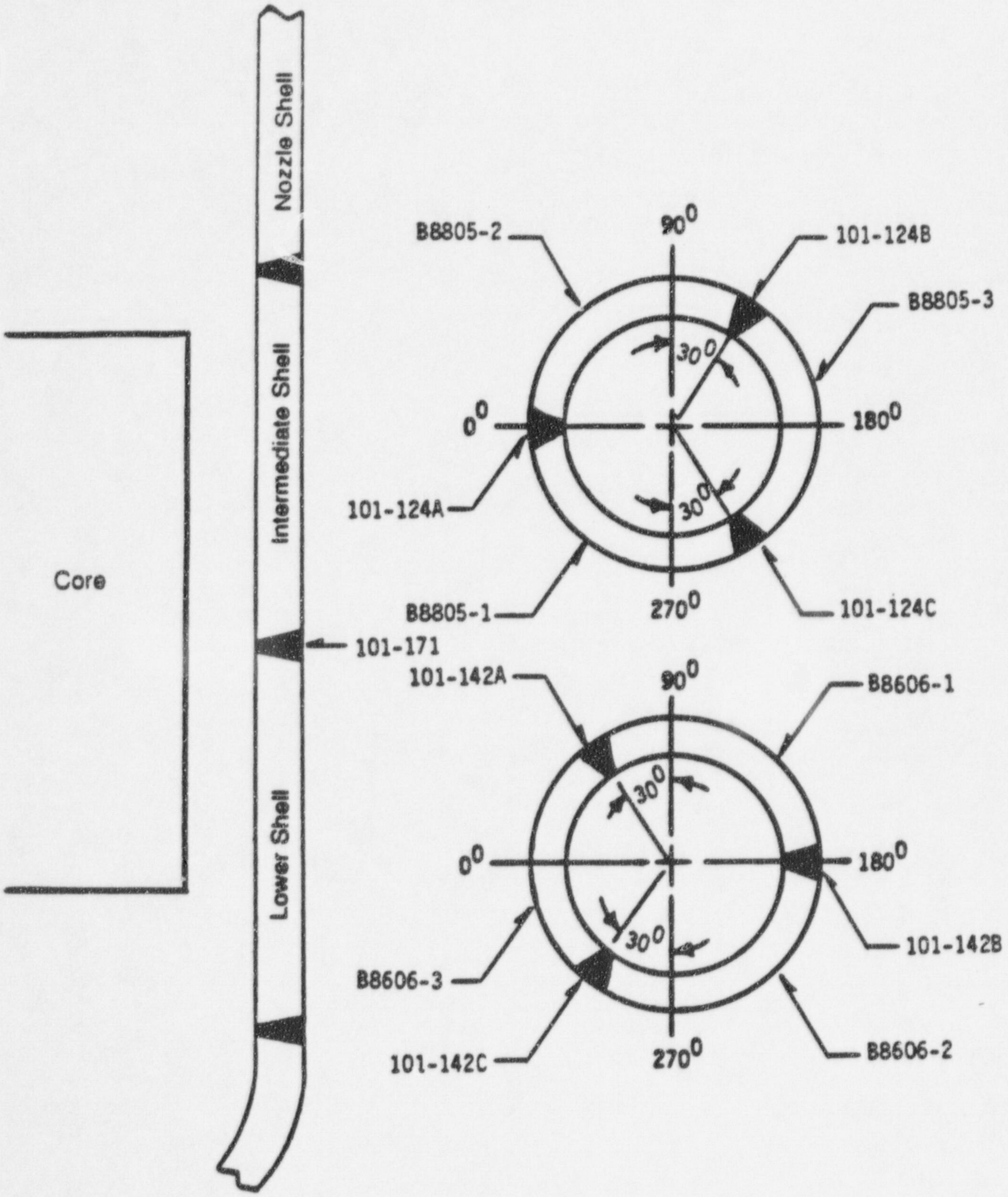

Figure 1: Identification and Location of Beltline Region Materials for the Vogtle Unit 1 Reactor Vessel

Table 1

Vogtle Unit 1 Reactor Vessel Beltline Unirradiated Material Properties[4 & 6]

Material Description	Cu (%)	Ni(%)	Initial RT_{NDT}[(a)]
Intermediate Shell Plate B8805-1	0.083	0.597	0°F
Intermediate Shell Plate B8805-2	0.083	0.61	20°F
Intermediate Shell Plate B8805-3	0.062	0.598	30°F
Lower Shell Plate B8606-1	0.053	0.593	20°F
Lower Shell Plate B8606-2	0.057	0.60	20°F
Lower Shell Plate B8606-3	0.067	0.623	10°F
Intermediate Shell Longitudinal Welds, 101-124A, B & C[(b)]	0.042[(c)]	0.102	-80°F
Lower Shell Longitudinal Welds, 101-142A, B & C[(b)]	0.042[(c)]	0.102	-80°F
Circumferential Weld 101-171[(b)]	0.042[(c)]	0.102	-80°F
Surveillance Program Weld Metal	0.040	0.102	- -

Notes:

(a) The initial RT_{NDT} values for the plates and welds are based on measured data.

(b) All welds, including the surveillance weld, were fabricated with weld wire heat number 83653, Linde 0091 Flux, Lot No. 3536. Per Regulatory Guide 1.99, Revision 2, "weight percent copper " and "weight percent nickel" are the best-estimate values for the material, which will normally be the mean of the measured values for a plate or forging or for weld samples made with the weld wire heat number that matches the critical vessel weld."

(c) The copper weight percent of 0.042 was obtained using all available data for that heat of weld wire per reference 6. This value is more conservative than that documented (0.039) in Vogtle Electric Generating Plant's "Pressure and Temperature Limits Report".

5 NEUTRON FLUENCE VALUES

The calculated fast neutron fluence (E > 1.0 MeV) values at the inner surface of the Vogtle Electric Generating Plant Unit 1 reactor vessel for 36 and 54 EFPY are shown in Table 2. These values were projected using the results of the Capsule V radiation analysis. See Section 6.0 of the Capsule V analysis report, WCAP-15067[5].

TABLE 2
Fluence (E > 1.0 MeV) on the Pressure Vessel Clad/Base Interface for Vogtle Unit 1 at 36 (EOL) and 54 (Life Extension) EFPY

Material	Location	36 EFPY Fluence	54 EFPY Fluence
Intermediate Shell Plate B8805-1	30°	2.09×10^{19} n/cm^2	3.10×10^{19} n/cm^2
Intermediate Shell Plate B8805-2	30°	2.09×10^{19} n/cm^2	3.10×10^{19} n/cm^2
Intermediate Shell Plate B8805-3	30°	2.09×10^{19} n/cm^2	3.10×10^{19} n/cm^2
Lower Shell Plate B8806-1	30°	2.09×10^{19} n/cm^2	3.10×10^{19} n/cm^2
Lower Shell Plate B8806-2	30°	2.09×10^{19} n/cm^2	3.10×10^{19} n/cm^2
Lower Shell Plate B8806-3	30°	2.09×10^{19} n/cm^2	3.10×10^{19} n/cm^2
Intermediate Shell Longitudinal Weld Seam 101-124A (0° Azimuth)	0°	1.17×10^{19} n/cm^2	1.74×10^{19} n/cm^2
Intermediate Shell Longitudinal Weld Seam 101-124B & C (120° & 240°Azimuth)	30°	2.09×10^{19} n/cm^2	3.10×10^{19} n/cm^2
Intermediate to Lower Shell Cirumferential Weld Seam 101-171	30°	2.09×10^{19} n/cm^2	3.10×10^{19} n/cm^2
Lower Shell Longitudinal Weld Seams 101-142A & C (60° & 300° Azimuth)	30°	2.09×10^{19} n/cm^2	3.10×10^{19} n/cm^2
Lower Shell Longitudinal Weld Seam 101-142B (180° Azimuth)	0°	1.17×10^{19} n/cm^2	1.74×10^{19} n/cm^2

6 DETERMINATION OF RT_{PTS} VALUES FOR ALL BELTLINE REGION MATERIALS

Using the prescribed PTS Rule methodology, RT_{PTS} values were generated for all beltline region materials of the Vogtle Electric Generating Plant Unit 1 reactor vessel for fluence values at the EOL (36 EFPY) and life extension (54 EFPY).

Each plant shall assess the RT_{PTS} values based on plant-specific surveillance capsule data. For Vogtle Electric Generating Plant Unit 1, the related surveillance program results have been included in this PTS evaluation.

As presented in Table 3, chemistry factor values for Vogtle Electric Generating Plant Unit 1 based on average copper and nickel weight percent were calculated using Tables 1 and 2 from 10 CFR 50.61[1]. Additionally, chemistry factor values based on credible surveillance capsule data are calculated in Table 4. Tables 5 and 6 contain the RT_{PTS} calculations for all beltline region materials at EOL (36 EFPY) and life extension (54 EFPY).

TABLE 3

Interpolation of Chemistry Factors Using Tables 1 and 2 of 10 CFR Part 50.61

Material	Ni, wt %	Chemistry Factor, °F
Intermediate Shell Plate B8805-1 Given Cu wt% = 0.083	0.597	53.1°F
Intermediate Shell Plate B8805-2 Given Cu wt% = 0.083	0.61	53.1°F
Intermediate Shell Plate B8805-3 Given Cu wt% = 0.062	0.598	38.4°F
Lower Shell Plate B8606-1 Given Cu wt% = 0.053	0.593	32.8°F
Lower Shell Plate B8606-2 Given Cu wt% = 0.057	0.60	35.2°F
Lower Shell Plate B8606-3 Given Cu wt% = 0.067	0.623	41.9°F
Intermediate Shell Longitudinal Welds, 101-124A, B & C Given Cu wt% = 0.042	0.102	34.5°F
Lower Shell Longitudinal Welds,101-142A, B & C Given Cu wt% = 0.042	0.102	34.5°F
Circumferential Weld 101-171 Given Cu wt% = 0.042	0.102	34.5°F
Surveillance Program Weld Metal Given Cu wt% = 0.040	0.102	33.7°F

TABLE 4

Calculation of Chemistry Factors using Surveillance Capsule Data Per Regulatory Guide 1.99, Revision 2, Position 2.1

Material	Capsule	Capsule f[a]	FF[b]	ΔRT_{NDT}[c]	$FF*\Delta RT_{NDT}$	FF^2
Intermediate Shell	U	0.3691	0.725	13.6	9.9	0.526
Plate B8805-3	Y	1.276	1.068	31.9	34.1	1.141
(Longitudinal)	V	2.178	1.211	42.7	51.7	1.467
Intermediate Shell	U	0.3691	0.725	0[e]	0.0	0.526
Plate B8805-3	Y	1.276	1.068	15.2	16.2	1.141
(Transverse)	V	2.178	1.211	33.8	40.9	1.467
				SUM	152.8	6.268
	$CF_{B8805\text{-}3} = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (152.8) \div (6.268) = 24.4°F$					
Surveillance Weld	U	0.3691	0.725	25.5[d]	18.5	0.526
Metal	Y	1.276	1.068	7.9[d]	8.4	1.141
	V	2.178	1.211	0[e]	0.0	1.467
				SUM	26.9	3.134
	$CF_{Weld} = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (26.9) \div (3.134) = 8.6°F$					

Notes:

(a) f = Calculated fluence from capsule V dosimetry analysis results(5), (x 10^{19} n/cm^2, E > 1.0 MeV).

(b) FF = fluence factor = $f^{(0.28 - 0.1*\log f)}$

(c) ΔRT_{NDT} values are the measured 30 ft-lb shift values.

(d) The surveillance weld metal ΔRT_{NDT} values have been adjusted by a ratio factor of 1.02.

(e) Actual values for ΔRT_{NDT} are -9.58 (Plate) and -1.34 (Weld). This physically should not occur, therefore for conservatism a value of zero will be used for this calculation.

TABLE 5

RT_{PTS} Calculation for Vogtle Unit 1 Beltline Region Materials at EOL (36 EFPY)

Material	RG 1.99 R2 Method	CF (°F)	FF	$IRT_{NDT(U)}$ [(a)]	ΔRT_{PTS} [(c)]	MΔrgin	RT_{PTS} [(b)]
Intermediate Shell Plate B8805-1	Position 1.1	53.1	1.20	0	63.7	34	98
Intermediate Shell Plate B8805-2	Position 1.1	53.1	1.20	20	63.7	34	118
Intermediate Shell Plate B8805-3	Position 1.1	38.4	1.20	30	46.1	34	110
	Position 2.1	24.4	1.20	30	29.4	17	76
Lower Shell Plate B8606-1	Position 1.1	32.8	1.20	20	39.4	34	93
Lower Shell Plate B8606-2	Position 1.1	35.2	1.20	20	42.2	34	96
Lower Shell Plate B8606-3	Position 1.1	41.9	1.20	10	50.3	34	94
Inter. Shell Longitudinal Weld Seam 101-124A(0° Azimuth)	Position 1.1	34.5	1.04	-80	35.9	35.9	-8
	Position 2.1	8.6	1.04	-80	8.9	8.9	-62
Inter. Shell Long. Weld Seams 101-124B,C (120°, 240° Azimuth)	Position 1.1	34.5	1.20	-80	41.4	41.4	3
	Position 2.1	8.6	1.20	-80	10.3	10.3	-59
Intermediate to Lower Shell Girth Weld Seam 101-171	Position 1.1	34.5	1.20	-80	41.4	41.4	3
	Position 2.1	8.6	1.20	-80	10.3	10.3	-59
Lower Shell Long. Weld Seams 101-142A,C (60°, 300° Azimuth)	Position 1.1	34.5	1.20	-80	41.4	41.4	3
	Position 2.1	8.6	1.20	-80	10.3	10.3	-59
Lower Shell Long. Weld Seam 101-142B (180° Azimuth)	Position 1.1	34.5	1.04	-80	35.9	35.9	-8
	Position 2.1	8.6	1.04	-80	8.9	8.9	-62

Notes:

(a) Initial RT_{NDT} values are measured values.

(b) RT_{PTS} = Initial $RT_{NDT(U)}$ + ΔRT_{PTS} + Margin (°F)

(c) $\Delta RT_{PTS} = CF * FF$

TABLE 6

RT_{PTS} Calculation for Vogtle Unit 1 Beltline Region Materials at Life Extension (54 EFPY)

Material	RG 1.99 R2 Method	CF (°F)	FF	$IRT_{NDT(U)}$ [a]	ΔRT_{PTS} [c]	Margin	RT_{PTS} [b]
Intermediate Shell Plate B8805-1	Position 1.1	53.1	1.30	0	69.0	34	103
Intermediate Shell Plate B8805-2	Position 1.1	53.1	1.30	20	69.0	34	123
Intermediate Shell Plate B8805-3	Position 1.1	38.4	1.30	30	49.9	34	114
	Position 2.1	24.4	1.30	30	31.7	17	79
Lower Shell Plate B8606-1	Position 1.1	32.8	1.30	20	42.6	34	97
Lower Shell Plate B8606-2	Position 1.1	35.2	1.30	20	45.8	34	100
Lower Shell Plate B8606-3	Position 1.1	41.9	1.30	10	54.5	34	99
Inter. Shell Longitudinal Weld Seam 101-124A(0° Azimuth)	Position 1.1	34.5	1.15	-80	39.7	39.7	0
	Position 2.1	8.6	1.15	-80	9.9	9.9	-60
Inter. Shell Long. Weld Seams 101-124B,C (120°, 240° Azimuth)	Position 1.1	34.5	1.30	-80	44.9	44.9	10
	Position 2.1	8.6	1.30	-80	11.2	11.2	-58
Intermediate to Lower Shell Girth Weld Seam 101-171	Position 1.1	34.5	1.30	-80	44.9	44.9	10
	Position 2.1	8.6	1.30	-80	11.2	11.2	-58
Lower Shell Long. Weld Seams 101-142A,C (60°, 300° Azimuth)	Position 1.1	34.5	1.30	-80	44.9	44.9	10
	Position 2.1	8.6	1.30	-80	11.2	11.2	-58
Lower Shell Long. Weld Seam 101-142B (180° Azimuth)	Position 1.1	34.5	1.15	-80	39.7	39.7	0
	Position 2.1	8.6	1.15	-80	9.9	9.9	-60

Notes:

(a) Initial RT_{NDT} values are measured values.

(b) RT_{PTS} = Initial $RT_{NDT(U)}$ + ΔRT_{PTS} + Margin (°F)

(c) ΔRT_{PTS} = CF * FF

7 CONCLUSIONS

As shown in Tables 5 and 6, all of the beltline region materials in the Vogtle Electric Generating Plant Unit 1 reactor vessel have EOL (36 EFPY) RT_{PTS} and Life Extension (54 EFPY) RT_{PTS} values below the screening criteria values of 270°F for plates, forgings and longitudinal welds and 300°F for circumferential welds.

8 REFERENCES

1 10 CFR Part 50.61, "Fracture Toughness Requirements For Protection Against Presuurized Thermal Shock Events", Federal Register, Volume 60, No. 243, dated December 19, 1995.

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3 WCAP-11011, "Georgia Power Company Alvin W. Vogtle Unit No. 1 Reactor Vessel Radiation Surveillance Program", L.R. Singer, February 1986.

4 WCAP-13931, Rev. 1, "Analysis of Capsule Y from the Georgia Power Company Vogtle Unit 1 Reactor Vessel Radiation Surveillance Program", M.J. Malone, et al., August 1995.

5 WCAP-15067, "Analysis of Capsule V from the Georgia Power Vogtle Electric Generating Plant Unit 1 Reactor Vessel Radiation Surveillance Program", T. J. Laubham, et al., September 1998.

6 CE NPSD-1039, Rev. 2, "Best Estimate Copper and Nickel Values in CE Fabricated Reactor Vessel Welds, Appendix A, CE Reactor Vessel Weld Properties Database, Volume 1," CEOG Task 902, June 1997.