Westinghouse Non-Proprietary Class 3

WCAP – 15676

Evaluation of Pressurized Thermal Shock For Beaver Valley Unit 2

Westinghouse Electric Company LLC

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PREFACE

This report has been technically reviewed and verified by:

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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 the propagation of flaws 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 Beaver Valley Unit 2 reactor vessel using the results of the surveillance Capsule W evaluation. Section 2.0 discusses the PTS Rule and its requirements. Section 3.0 provides the methodology for calculating RT_{PTS}. Section 4.0 provides the reactor vessel beltline region material properties for the Beaver Valley Unit 2 reactor vessel. The neutron fluence values used in this analysis are presented in Section 5.0. The results of the RT_{PTS} calculation 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

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, 1995.

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 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 vessel 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 a 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 beltline.

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

$RT_{NDT(U)}$ = 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 form Equation 2.

$$M = 2\sqrt{\sigma^2_u + \sigma^2_\Delta} \qquad (2)$$

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 ΔRT_{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 RT_{NDT}, due to irradiation, and must be calculated using Equation 3.

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

CF (°F) is the chemistry factor, which is a function of copper and nickel content. CF is determined from Table 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 calculated neutron fluence, in units of 10^{19} n/cm^2 (E > 1.0 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 calculation RT_{PTS}.

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

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

To verify that RT_{NDT} for each vessel beltline material is a bounding 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 form 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.

$$CF = \frac{\sum[A_i * f_i^{(0.28-0.10\log f_i)}]}{\sum[f_i^{(0.56-0.20\log f_i)}]} \tag{5}$$

In Equation 5, "A_I" is the measured value of ΔRT_{NDT} and "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 measure values of ΔRT_{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 VERFICATION OF PLANT-SPECIFIC MATERIAL PROPERTIES

Before performing the pressurized thermal shock evaluation, a review of the latest plant-specific material properties for the Beaver Valley Unit 2 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 or 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 Beaver Valley Unit 2 reactor vessel.

Material property values were obtained from material test certifications from the original fabrication. The average copper and nickel values were calculated for the beltline region material using all of the available material chemistry information as shown in Table 1. Initial RT_{NDT} values for Beaver Valley Unit 2 Reactor Vessel Beltline Region Material Properties are shown in Table 2.

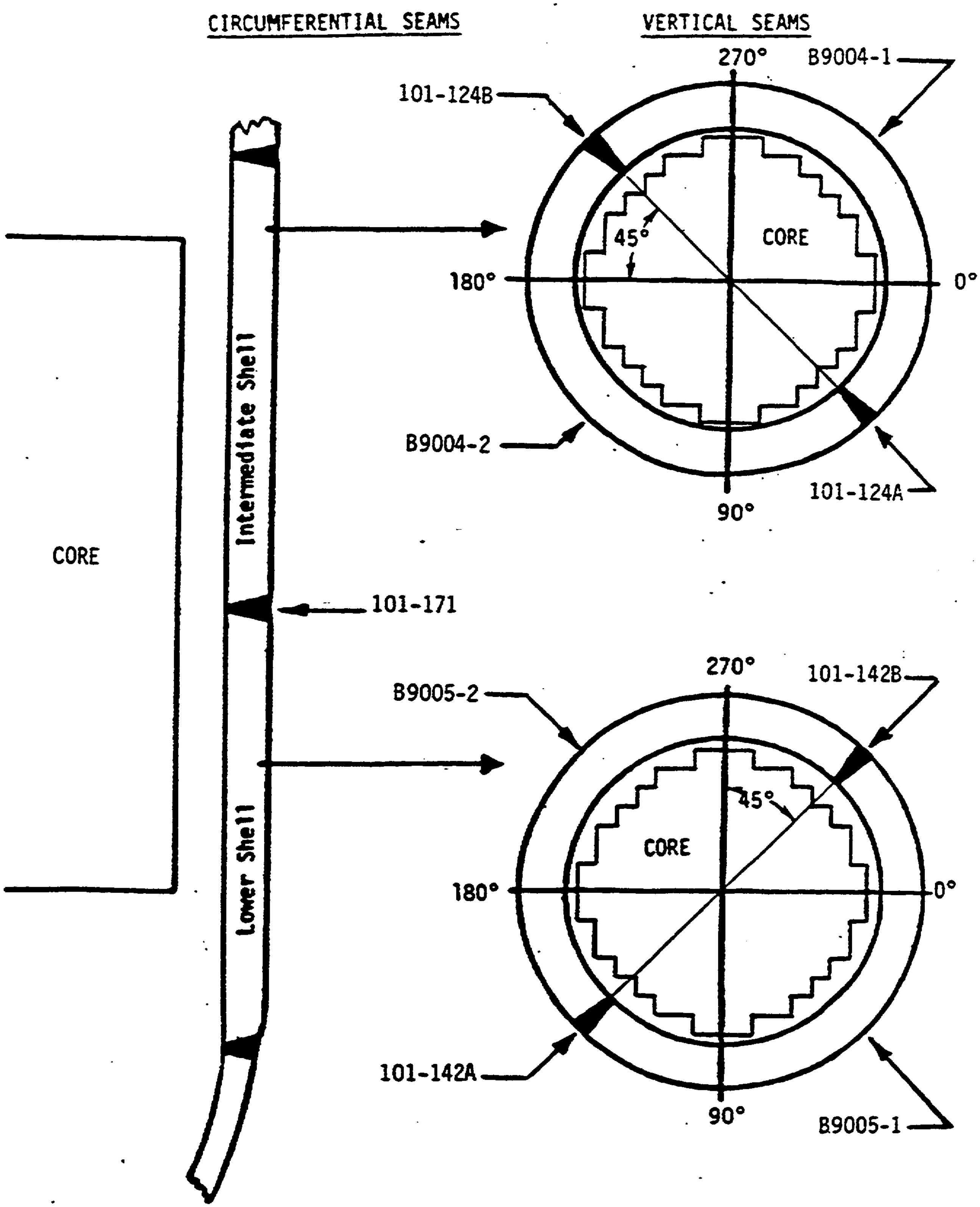

Figure 1: Identification and Location of Beltline Region Material for the Beaver Valley Unit 2 Reactor Vessel

Table 1: Calculation on Average Cu and Ni Weight Percent Values for Beltline Region Materials										
Ref.	Inter. Shell Plate B9004-1		Inter. Shell[a] Plate B9004-2		Lower Shell Plate B9005-1		Lower Shell Plate B9005-2		Weld Metals[b]	
	Cu %	Ni %	Cu %	Ni %	Cu %	Ni %	Cu %	Ni %	Cu %	Ni %
4	0.07	0.53	--	--	--	--	--	--	--	--
6	0.06	0.57	0.06	0.56	0.08	0.57	0.07	0.56	--	--
7	--	--	0.07	0.59	--	--	--	--	--	--
8	--	--	0.05	0.56	--	--	--	--	--	--
9	--	--	--	--	0.08	0.59	--	--	--	--
10	--	--	--	--	--	--	0.07	0.58	--	--
Best Estimate	0.065	0.55	0.06	0.57	0.08	0.58	0.07	0.57	0.046[c]	0.086[c]

Notes:

(a) Surveillance program base metal material.

(b) The surveillance weld specimens were made of the same wire and flux as the intermediate and lower shell vertical seams and the girth weld between the intermediate and lower shell plates (3/16 inch Diameter Wire Type B-4, Heat Number 83642, Linde 0091 Flux, Lot Number 3536).

(c) Best Estimate Cu and Ni obtained from CE NPSD-1119 Revision 1[13]

TABLE 2
Reactor Vessel Beltline Material Unirradiated Toughness Properties

Material Description		**Cu (%)**	**Ni (%)**	**Initial RT_{NDT}***
Closure Head Flange[12]	B9002-1	- - -	0.74	-10
Vessel Flange[12]	B9001-1	- - -	0.73	0
Intermediate Shell Plate	B9004-1	0.065	0.55	60
Intermediate Shell Plate	B9004-2	0.06	0.57	40
Lower Shell Plate	B9005-1	0.08	0.58	28
Lower Shell Plate	B9005-2	0.07	0.57	33
Intermediate to Lower Shell Weld (Heat 83642)	101-171	0.046	0.086	-30
Intermediate Longitudinal Weld (Heat 83642)	101-124 A & B	0.046	0.086	-30
Lower Longitudinal Weld (Heat 83642)	101-142 A & B	0.046	0.086	-30
Surveillance Weld (Heat 83642)	- -	0.065**	0.065**	- -

*The Initial RT_{NDT} values for the plates are based on measured data while the weld values are generic.
** Average of Tag "a" in CE NPSD-1039, Rev. 2, CEOG 1054(14)

5 NEUTRON FLUENCE VALUES

The calculated fast neutron fluence (E > 1.0 MeV) values at the inner surface of the Beaver Valley Unit 2 reactor vessel are shown in Table 3. These values were projected using the results of the Capsule W radiation analysis. See Section 6.0 of the Capsule W analysis report, WCAP-15675[5].

Table 3 Calculated Fast Neutron Fluence (E>1.0 MeV) for the Beltline Region of the Beaver Valley Unit 2 Reactor Vessel

Operating Time (EFPY)	Azimuthal Location			
	0°	15°	30°	45°
9.77	1.103×10^{19}	6.875×10^{18}	5.270×10^{18}	3.668×10^{18}
25	2.976×10^{19}	1.854×10^{19}	1.420×10^{19}	9.884×10^{18}
32	3.847×10^{19}	2.396×10^{19}	1.835×10^{19}	1.277×10^{19}
48	5.837×10^{19}	3.635×10^{19}	2.783×10^{19}	1.938×10^{19}
54	6.584×10^{19}	4.100×10^{19}	3.139×10^{19}	2.186×10^{19}

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

Using the prescribed PTS Rule methodology, RT_{PTS} values were generated for all beltline region materials of the Beaver Valley Unit 2 reactor vessel for fluence values at the EOL (32 EFPY) and EOLE (48 EFPY).

Each plant shall assess the RT_{PTS} values based on plant-specific surveillance capsule data. For Beaver Valley Unit 2, the related surveillance program results have been included in this PTS evaluation. Specifically, the Beaver Valley Unit 2 plant-specific surveillance capsule data for the intermediate shell plate B9004-2 and weld metal is provided for the following reasons:

1) There have been three capsules removed from the reactor vessel, and the data is deemed credible per Regulatory Guide 1.99, Revision 2.

2) The surveillance capsule program is credible (See Appendix A).

As presented in Table 4, chemistry factor values for Beaver Valley Unit 2 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 5. Table 6 contains the RT_{PTS} calculations for all beltline region materials at 32 and 48 EFPY.

Table 4 Interpolation of Chemistry Factors Using Tables 1 and 2 of 10 CFR 50.61

Material	Ni, wt %	Chemistry Factor, °F
Intermediate Shell Plate B9004-1 Given Cu wt % = 0.065	0.55	40.5
Intermediate Shell Plate B9004-2 Given Cu wt % = 0.06	0.57	37
Lower Shell Plate B9005-1 Given Cu wt % = 0.08	0.58	51
Lower Shell Plate B9005-2 Given Cu wt % = 0.07	0.57	44
Vessel Welds Given Cu wt % = 0.046	0.086	34.4

Table 5 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*ΔRT_{NDT}	FF^2
Intermediate Shell Plate B9004-2 (Longitudinal)	U	0.608	0.86	24.26	20.86	0.74
	V	2.63	1.26	55.93	70.47	1.59
	W	3.625	1.335	71.04	94.83	1.78
Intermediate Shell Plate B9004-2 (Transverse)	U	0.608	0.86	17.56	15.10	0.74
	V	2.63	1.26	46.27	58.30	1.59
	W	3.625	1.335	63.39	84.63	1.78
				SUM:	344.19	8.22
$CF = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (344.19) \div (8.22) =$ **41.9 °F**						
Beaver Valley Surveillance Weld Metal 83642	U	0.608	0.86	3.64	3.13	0.74
	V	2.64	1.26	25.47	32.09	1.59
	W	3.625	1.335	6.21	8.29	1.78
				SUM:	43.51	4.11
$CF = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (43.51) \div (4.11) =$ **10.6°F**						

Notes:
(a) f = Calculated fluence from the Beaver Valley Unit 2 capsule W 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 for Beaver Valley Unit 2 taken from Capsule W analysis[5].
(d) The surveillance weld metal ΔRT_{NDT} values have been adjusted by a ratio factor of 1.0.

Table 6 RT_{PTS} Calculations for Beaver Valley Unit 2 Beltline Region Materials at 32 EFPY

Material	Fluence (n/cm^2, E>1.0 MeV)	FF	CF (°F)	ΔRT_{PTS}[c] (°F)	Margin (°F)	$RT_{NDT(U)}$[a] (°F)	RT_{PTS}[b] (°F)
Intermediate Shell Plate B9004-1	3.847	1.348	40.5	54.6	34	60	149
Intermediate Shell Plate B9004-2	3.847	1.348	37	49.9	34	40	124
→ Using S/C Data	3.847	1.348	41.9	56.5	17	40	114
Lower Shell Plate B9005-1	3.847	1.348	51	68.7	34	28	131
Lower Shell Plate B9005-2	3.847	1.348	44	59.3	34	33	126
Vessel Beltline Welds [d]	3.847	1.348	34.4	46.4	46.4	-30	63
Vessel Beltline Welds using s/c Data	3.847	1.348	10.6	14.3	14.3	-30	-1

Notes:
(a) Initial RT_{NDT} values are measured values
(b) $RT_{PTS} = RT_{NDT(U)} + \Delta RT_{PTS} + Margin$ (°F)
(c) $\Delta RT_{PTS} = CF * FF$
(d) All vessel beltline Welds are from Heat # 83642, Linde 0091, Flux Lot #3536

Table 7 RT_{PTS} Calculations for Beaver Valley Unit 2 Beltline Region Materials at 48 EFPY

Material	Fluence (n/cm^2, E>1.0 MeV)	FF	CF (°F)	ΔRT_{PTS}[c] (°F)	Margin (°F)	$RT_{NDT(U)}$[a] (°F)	RT_{PTS}[b] (°F)
Intermediate Shell Plate B9004-1	5.837	1.432	40.5	58.0	34	60	152
Intermediate Shell Plate B9004-2	5.837	1.432	37	53.0	34	40	127
→ Using S/C Data[e]	5.837	1.432	41.9	60.0	17	40	117
Lower Shell Plate B9005-1	5.837	1.432	51	73.0	34	28	135
Lower Shell Plate B9005-2	5.837	1.432	44	63	34	33	130
Vessel Beltline Welds [d]	5.837	1.432	34.4	49.3	49.3	-30	69
Vessel Beltline Welds using s/c Data	5.837	1.432	10.6	15.2	15.2	-30	0

Notes:
(a) Initial RT_{NDT} values are measured values
(b) $RT_{PTS} = RT_{NDT(U)} + \Delta RT_{PTS} + Margin$ (°F)
(c) $\Delta RT_{PTS} = CF * FF$
(d) All vessel beltline Welds are from Heat # 83642, Linde 0091, Flux Lot #3536

7 CONCLUSIONS

As shown in Tables 6 and 7, all of the beltline region materials in the Beaver Valley Unit 2 reactor vessel have RT_{PTS} values well below the screening criteria of 270°F for plates or forgings and longitudinal welds and 300°F for circumferential welds at EOL (32 EFPY) and EOLE (48EFPY).

8 REFERENCES

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