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Analysis of Capsule X from FirstEnergy Nuclear Operating Company Beaver Valley Unit 2 Reactor Vessel Radiation Surveillance Program

Westinghouse

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PREFACE

Revision 0 to this report has been technically reviewed and verified by:

F. C. Gift: ***Electronically Approved****

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RECORD OF REVISION

Revision 0: Original Issue

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The purpose of this supplement is to determine the Reference Temperature for Pressurized Thermal Shock (RT_{PTS}) values and Upper Shelf Energy (USE) values for the Beaver Valley Unit No. 2 reactor vessel beltline and extended beltline materials. This analysis will be based upon the results of the latest surveillance capsule X evaluation, sister plant surveillance data, and the implementation of the Extended Power Uprate program. These calculations are performed for End-Of-License-Extended (EOLE) at 54 Effective Full Power Years (EFPY).

The limiting plate material in the Beaver Valley Unit No. 2 reactor vessel is the upper shell plate B9003-2 with a projected EOLE RT_{PTS} value of 160.6°F for 54 EFPY. This value is below the screening criteria of 270°F for forgings/plates in 10 CFR 50 Part 61. The limiting weld material in the Beaver Valley Unit No. 2 reactor vessel is the upper shell longitudinal weld (heat number BOHB (E-8018)) with an EOLE RT_{PTS} value of 128.8°F. This RT_{PTS} value is well below the screening criteria value of 270°F for axial welds at EOLE (54 EFPY). All of the beltline and extended beltline materials maintain USE above 50 ft-lbs at EOLE.

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 predicted decrease in Upper Shelf Energy (USE) is determined as a function of fluence and copper content using either 1) Figure 2 of Regulatory Guide 1.99, Revision 2, Position 1.2, or 2) Surveillance program test results and Figure 2 of Regulatory Guide 1.99, Revision 2, Position 2.2 [Reference 1]. Both methods require the use of the 1/4T vessel fluence.

The purpose of this report is to determine the Reference Temperature for Pressurized Thermal Shock (RT_{PTS}) and USE values for the Beaver Valley Power Station Unit 2 (BVPS-2) reactor vessel using the results of the surveillance Capsule X evaluation, sister plant data, and the implementation of the Extended Power Uprate (EPU) Program. The results presented in this report are for End-Of-License-Extended (EOLE) at 54 Effective Full Power Years (EFPY). Section 2.0 discusses the PTS Rule and its requirements. Section 3.0 provides the methodology for calculating RT_{PTS} and USE. Section 4.0 provides the reactor vessel beltline and extended beltline region material properties for the BVPS-2 reactor vessel. The neutron fluence values used in this analysis are presented in Section 5.0. The results of the RT_{PTS} and USE calculations are presented in Section 6.0. The conclusion and references for the PTS and USE evaluations follow in Sections 7.0 and 8.0, respectively.

2 PRESSURIZED THERMAL SHOCK RULE

The Nuclear Regulatory Commission (NRC) 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, 10 CFR Part 50.61, was published in the Federal Register on December 19, 1995, with an effective date of January 18, 1996 [Reference 2].

This amendment to the PTS Rule makes the following changes:

- 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 [Reference 1].

- 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}.

- 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
  300°F for circumferential weld materials

All available surveillance data must be considered in the evaluation. All credible plant specific surveillance data must also be used in the evaluation.

3 METHODOLOGY FOR CALCULATION OF RT_{PTS} AND USE

RT_{PTS} must be calculated for each vessel beltline material using a fluence value, f, which is the EOL or EOLE 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.

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

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

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

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 irradiation, 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 Table 1 for welds and Table 2 for base metal (plates or forgings) of the PTS Rule. 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 or EOLE fluence is used in calculating RT_{PTS}.

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

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

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 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.

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

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 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.

Per Regulatory Guide 1.99, Revision 2, the Charpy upper-shelf energy is assumed to decrease as a function of fluence and copper content as indicated in Figure 2 of the guide when surveillance data is not used. Linear interpolation is permitted. In addition, if surveillance data is to be used, the decrease in upper-shelf energy may be obtained by plotting the reduced plant surveillance data on Figure 2 of the guide and fitting the data with a line drawn parallel to the existing lines as the upper bound of all the data. This line should be used in preference to the existing graph. The USE can be predicted using the corresponding 1/4T fluence projection, the copper content of the beltline materials and/or the results of the capsules tested to date using Figure 2 in Regulatory Guide 1.99, Revision 2.

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 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 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". In addition to the beltline regions, materials that exceed 1×10^{17} n/cm^2 (E>1.0 MeV) are subject to the guidelines provide in Appendix H of 10 CFR 50 [Reference 3]. In accordance with 10 CFR 50, Appendix H, any materials exceeding 1×10^{17} n/cm^2 (E>1.0 MeV) must be monitored to evaluate the changes in fracture toughness. Reactor vessel materials not traditionally thought of as being plant limiting because of low levels of neutron radiation must now be evaluated to determine the accumulated fluence at 54 EFPY.

Material property values were obtained from material test certifications from the original fabrication as well as the additional material chemistry tests performed as part of the Beaver Valley Unit 2 surveillance capsule testing program [Reference 4]. The average copper and nickel values were calculated for each beltline and extended beltline region material using all of the available material chemistry information. A summary of the pertinent chemical and mechanical properties of the beltline and extended beltline region forgings/plates and weld material of the Beaver Valley Unit 2 reactor vessel is given in Tables 1 and 2.

Table 1
BVPS-2 Reactor Vessel Beltline Material Properties[a]

Material Description	Wt % Cu	Wt % Ni	Initial RT_{NDT}[b] (°F)	Initial USE (ft-lbs)
Intermediate Shell Plate B9004-1	0.065	0.55	60	83
Intermediate Shell Plate B9004-2	0.06	0.57	40	79
Lower Shell Plate B9005-1	0.08	0.58	28	82
Lower Shell Plate B9005-2	0.07	0.57	33	78
Intermediate to Lower Shell Weld 101-171 (Heat 83642)	0.046	0.086	-30	145
Intermediate Longitudinal Weld 101-124 A&B (Heat 83642)	0.046	0.086	-30	145
Lower Longitudinal Weld 101-142 A&B (Heat 83642)	0.046	0.086	-30	145

NOTE:
(a) Materials information taken from WCAP-16527-NP [Reference 4] and WCAP-16528-NP [Reference 5].
(b) All initial RT_{NDT} values are measured values.

Table 2
BVPS-2 Reactor Vessel Extended Beltline Material Properties[(a)]

Material Description	Material ID	Heat Number	Wt % Cu	Wt % Ni	Initial RT_{NDT}[(b)] (°F)	Initial USE (ft-lbs)
Upper Shell	B9003-1	A9406-1	0.13	0.60	50	98
	B9003-2	B4431-2	0.12	0.60	60	80
	B9003-3	A9406-2	0.13	0.60	50	98
Upper Shell Longitudinal Welds	101-122A 101-122B 101-122C	51912 (3490)	0.156[(c)]	0.059[(c)]	-50	96
		51912 (3536)	0.156[(c)]	0.059[(c)]	-70	114
		EAIB	0.02	0.98	10 (Gen)	118
		IAGA	0.03	0.98	-30	160
		BOHB	0.05	1.00	10 (Gen)	97
		BAOED	0.02	1.00	-50	150
Upper Shell to Intermediate Shell Girth Weld	103-121	4P5174 (1122)	0.09	1.00[(a)]	-50	70
		51922 (3489)	0.05	1.00[(a)]	-56 (Gen)	102
		AAGC	0.03	0.98	-70	111
		KOIB	0.03	0.97	-60	110
Inlet Nozzles	B9011-1	2V2436-01-002	0.11	0.85	60	105 (68.25)[(d)]
	B9011-2	2V2437-02-001	0.13[(e)]	0.88	60 (Gen)	116 (75.4)[(d)]
	B9011-3	2V2445-02-003	0.13[(e)]	0.84	70	122 (79.3)[(d)]
Inlet Nozzle Welds	105-121A 105-121B 105-121C	4P5174 (1122)	0.09	1.00[(f)]	-50	70
		LOHB	0.03	1.03	-60	137
		HABJC	0.02	1.02	-70	162
		BABBD	0.02	1.04	-70	142
		FABGC	0.03	1.02	-80	119
		EOBC	0.02	0.96	-60	127
		FAAFC	0.07	1.04	-60	119
		CCJC	0.02	0.99	-60	109
		FAGB	0.02	1.06	-30	114
		BAOED	0.02	1.00	-50	150
Outlet Nozzles	B9012-1	AV8080-2E9558	0.13[(e)]	0.72	-10	146
	B9012-2	AV8120-2E9560	0.13[(e)]	0.74	-10	128
	B9012-3	AV8097-2E9559	0.13[(e)]	0.70	-10	127
Outlet Nozzle Welds	107-121A 107-121B 107-121C	BABBD	0.02	1.04	-70	142
		FAAFC	0.07	1.04	-60	119
		HAAEC	0.03	1.03	-80	178
		HABJC	0.02	1.02	-70	162
		HAGB	0.02	1.04	-40	194
		GACJC	0.03	1.00	-80	113
		JAHB	0.03	0.97	-40	149

Notes:
(a) All of the materials data is obtained from Combustion Engineering report MISC-PENG-ER-021 [Reference 6] except as noted.
(b) The generic Initial RT_{NDT} values were determined in accordance with NUREG-0800 [Reference 8] and the 10CFR50.61 [Reference 2].
(c) Chemistry obtained from CE Report NPSD-1039, Revision 2 [Reference 7].
(d) Value in parenthesis is the 65% value per Regulatory Guide 1.99, Revision 2.
(e) The Cu wt% was not available from the CMTR so in accordance with Regulatory Guide 1.99, Rev. 2, a standard deviation analysis (average + standard deviation) was done to determine the value based on Westinghouse 508 Class 2 Nozzle Forgings (178 data points).
(f) Default Wt % Ni content per Regulatory Guide 1.99, Revision 2.

5 NEUTRON FLUENCE VALUES

The calculated fast neutron fluence (E > 1.0 MeV) values at the inner surface of the BVPS-2 reactor vessel are shown in Tables 3 and 4 for the beltline and extended beltline materials, respectively. These values were projected using ENDF/B-VI cross sections and are based on the results of the Capsule X radiation analysis and comply with Reg. Guide 1.190 [Reference 9]. Note that the details of the fluence projections are discussed in WCAP-16527-NP [Reference 4] (Capsule X analysis report).

These fluence data tabulations include fuel cycle specific calculated neutron exposures at the end of the eleventh fuel cycle as well as future projections for several intervals extending to 54 EFPY. The projections were based on the assumption that the core power distributions and associated plant operating characteristics for Cycle 12 were representative of plant operation to 17 EFPY and that the preliminary Cycle 13 core power distributions were applicable beyond 17 EFPY. The calculations account for a core power uprate from 2689 MWt to 2900 MWt at 17 EFPY.

TABLE 3
Maximum Calculated Fluence (E > 1.0 MeV) on the Pressure Vessel Clad/Base Metal Interface for Beaver Valley Unit 2

Cycle	Cumulative Irradiation Time [EFPY]	Neutron Fluence (E > 1.0 MeV) [n/cm^2]			
		0°	15°	30°	45°
11	13.9	1.52E+19	9.43E+18	7.21E+18	5.08E+18
Future	17.0	1.83E+19	1.12E+19	8.54E+18	6.05E+18
Future	20.0	2.19E+19	1.32E+19	9.90E+18	7.00E+18
Future	25.0	2.79E+19	1.64E+19	1.22E+19	8.59E+18
Future	32.0	3.63E+19	2.09E+19	1.54E+19	1.08E+19
Future	48.0	5.56E+19	3.12E+19	2.26E+19	1.59E+19
Future	54.0	6.29E+19	3.50E+19	2.53E+19	1.78E+19

TABLE 4
Calculated Fluence (E > 1.0 MeV) on the Pressure Vessel Clad/Base Metal Interface for Beaver Valley Unit 2 for the Beltline and Extended Beltline Regions

Material	Neutron Fluence (E > 1.0 MeV) [n/cm^2]		
	13.9 EFPY	48.0 EFPY	54.0 EFPY
Lower Shell to Lower Closure Head Weld	< 1.00E+17	< 1.00E+17	< 1.00E+17
Lower Shell	1.52E+19	5.56E+19	6.29E+19
Lower Shell Longitudinal Welds	5.08E+18	1.59E+19	1.78E+19
Lower Shell to Intermediate Shell Weld	1.51E+19	5.52E+19	6.24E+19
Intermediate Shell	1.50E+19	5.50E+19	6.22E+19
Intermediate Shell Longitudinal Welds	5.00E+18	1.57E+19	1.76E+19
Intermediate Shell to Upper Shell Weld	1.16E+18	5.23E+18	5.95E+18
Upper Shell	9.58E+17	4.32E+18	4.92E+18
RCS Inlet Nozzle to Upper Shell Weld	< 1.00E+17	4.29E+17	4.90E+17
RCS Outlet Nozzle to Upper Shell Weld	< 1.00E+17	2.05E+17	2.34E+17

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

6.1 BVPS-2 RT_{PTS} Calculations for 54 EFPY

Using the prescribed PTS Rule methodology, RT_{PTS} values were generated for all beltline and extended beltline region materials of the BVPS-2 reactor vessel for fluence values at EOLE (54 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 (heat number 83642) is provided and applied as follows:

1) There have been four capsules removed from the BVPS-2 reactor vessel.

2) The data for the surveillance program plate material is deemed credible. The data was used with a σ_Δ margin of 8.5°F.

3) The data for the Unit 2 surveillance program weld material is deemed credible. The data was used with a σ_Δ margin of 14°F.

4) The surveillance capsule materials are representative of the actual vessel plate and intermediate shell longitudinal weld metal (weld heat 83642).

5) The resulting RT_{PTS} values for intermediate shell plate B9004-2 remains below the screening criteria at 54 EFPY based on Positions 1.1 and 2.1 of Regulatory Guide 1.99, Revision 2. The resulting RT_{PTS} values for all other materials remains below the PTS Rule screening criteria at 54 EFPY.

Chemistry factor values for the Beaver Valley Unit 2 beltline region materials based on Position 1.1 and 2.1 from Regulatory Guide 1.99, Revision 2 are presented in Table 5. Additionally, chemistry

factor values for the BVPS-2 extended beltline materials based on Position 1.1 of Regulatory Guide 1.99, Revision 2 are presented in Table 6. Tables 7 and 8 contain the RT_{PTS} calculations for all beltline and extended beltline region materials at 54 EFPY.

6.2 BVPS-2 Upper Shelf Energy Calculations for 54 EFPY

Per Regulatory Guide 1.99, Revision 2, the Charpy upper-shelf energy is assumed to decrease as a function of fluence and copper content as indicated in Figure 2 of the guide when surveillance data is not used. Linear interpolation is permitted. In addition, if surveillance data is to be used, the decrease in upper-shelf energy may be obtained by plotting the reduced plant surveillance data on Figure 2 of the guide and fitting the data with a line drawn parallel to the existing lines as the upper bound of all the data. This line should be used in preference to the existing graph. The USE can be predicted using the corresponding 1/4T fluence projection, the copper content of the beltline materials and/or the results of the capsules tested to date using Figure 2 in Regulatory Guide 1.99, Revision 2.

For BVPS-2, there exists surveillance data for plate B9004-2 and weld heat 83642. Each of the measured drops in USE for each of these material heats is plotted on Figure 2 of Regulatory Guide 1.99, Revision 2 with a horizontal line drawn parallel to the existing lines as the upper bound of all data. Figures 1 and 2 were used in the determination of the % decrease in USE for the beltline and extended beltline materials. Tables 9 and 10 document the USE values for all of the materials at 54 EFPY. All of the beltline or extended beltline material USE values maintain 50 ft-lbs or greater at 54 EFPY.

Table 5
Summary of the BVPS-2 Beltline Material Chemistry Factor Values Based on Regulatory Guide 1.99, Revision 2, Position 1.1 and Position 2.1

Material Description	Chemistry Factor	
	Position 1.1	Position 2.1
Intermediate Shell Plate B9004-1	40.5	---
Intermediate Shell Plate B9004-2	37	51.5
Lower Shell Plate B9005-1	51	---
Lower Shell Plate B9005-2	44	---
Lower Longitudinal Weld 101-142 A & B (Heat 83642)	34.4	12.5
Intermediate Longitudinal Weld 101-124 A&B (Heat 83642)	34.4	12.5
Intermediate to Lower Shell Girth Weld 101-171 (Heat 83642)	34.4	12.5
Surveillance Weld Metal (Heat 83642)	38	---

Table 6
BVPS-2 Extended Beltline Material Chemistry Factors

Component	Material ID	Heat	Cu wt%	Ni wt%	Calculated Chemistry Factor (°F)
Upper Shell Plates	B9003-1	A9406-1	0.13	0.60	91.0
	B9003-2	B4431-2	0.12	0.60	83.0
	B9003-3	A9406-2	0.13	0.60	91.0
Upper Shell Longitudinal Welds	101-122A 101-122B 101-122C	51912 (3490)	0.156	0.059	73.71
		51912 (3536)	0.156	0.059	73.71
		EAIB	0.02	0.98	27.0
		IAGA	0.03	0.98	41.0
		BOHB	0.05	1.00	68.0
		BAOED	0.02	1.00	27.0
Upper to Intermediate Shell Girth Weld	103-121	4P5174 (1122)	0.09	1.00	122.0
		51922 (3489)	0.05	1.00	68.0
		AAGC	0.03	0.98	41.0
		KOIB	0.03	0.97	41.0
Inlet Nozzles	B9011-1	2V2436-01-002	0.11	0.85	77.0
	B9011-2	2V2437-02-001	0.13	0.88	96.0
	B9011-3	2V2445-02-003	0.13	0.84	96.0
Inlet Nozzle Welds	105-121A 105-121B 105-121C	4P5174 (1122)	0.09	1.00	122.0
		LOHB	0.03	1.03	41.0
		HABJC	0.02	1.02	27.0
		BABBD	0.02	1.04	27.0
		FABGC	0.03	1.02	41.0
		EOBC	0.02	0.96	27.0
		FAAFC	0.07	1.04	95.0
		CCJC	0.02	0.99	27.0
		FAGB	0.02	1.06	27.0
		BAOED	0.02	1.00	27.0
Outlet Nozzles	B9012-1	AV8080-2E9558	0.13	0.72	94.0
	B9012-2	AV8120-2E9560	0.13	0.74	94.5
	B9012-3	AV8097-2E9559	0.13	0.70	93.5
Outlet Nozzle Welds	107-121A 107-121B 107-121C	BABBD	0.02	1.04	27.0
		FAAFC	0.07	1.04	95.0
		HAAEC	0.03	1.03	41.0
		HABJC	0.02	1.02	27.0
		HAGB	0.02	1.04	27.0
		GACJC	0.03	1.00	41.0
		JAHB	0.03	0.97	41.0

Table 7
RT_{PTS} Values for BVPS-2 Beltline Region Materials at 54 EFPY

Material	RG Pos.	Surf Neutron Fluence ($x10^{19}$ n/cm²)	Fluence Factor, FF(a)	Chemistry Factor (°F)	Initial RT_{NDT}(b) (°F)	ΔRT_{NDT}(c) (°F)	σ_I (°F)	σ_Δ (°F)	Margin(d) (°F)	RT_{PTS}(e) (°F)
Intermediate Shell Plate B9004-1	1.1	6.2200	1.4429	40.50	60.0	58.4	0.0	17.0	34.0	**152.4**
Intermediate Shell Plate B9004-2	1.1	6.2200	1.4429	37.00	40.0	53.4	0.0	17.0	34.0	127.4
	2.1	6.2200	1.4429	51.50	40.0	74.3	0.0	8.5	17.0	131.3
Lower Shell Plate B9005-1	1.1	6.2900	1.4449	51.00	28.0	73.7	0.0	17.0	34.0	135.7
Lower Shell Plate B9005-2	1.1	6.2900	1.4449	44.00	33.0	63.6	0.0	17.0	34.0	130.6
Lower Shell Longitudinal Welds 101-142 A&B (Heat 83642)	1.1	1.7800	1.1584	34.40	-30.0	39.8	0.0	19.9	39.8	49.7
	2.1	1.7800	1.1584	12.50	-30.0	14.5	0.0	7.2	14.5	-1.0
Intermediate Shell Longitudinal Weld 101-124 A&B (Heat 83642)	1.1	1.7600	1.1554	34.40	-30.0	39.7	0.0	19.9	39.7	49.5
	2.1	1.7600	1.1554	12.50	-30.0	14.4	0.0	7.2	14.4	-1.1
Intermediate to Lower Shell Girth Weld 101-171 (Heat 83642)	1.1	6.2400	1.4435	34.40	-30.0	49.7	0.0	24.8	49.7	69.3
	2.1	6.2400	1.4435	12.5	-30.0	18.0	0.0	9.0	18.0	6.1

NOTES:
(a) FF = fluence factor = $f^{(0.28 - 0.1 \log (f))}$.
(b) Initial RT_{NDT} values are measured values.
(c) ΔRT_{PTS} = CF * FF.
(d) $M = 2 * (\sigma_i^2 + \sigma_\Delta^2)^{1/2}$.
(e) RT_{PTS} = Initial RT_{NDT} + ΔRT_{PTS} + Margin.

Table 8
RT_{PTS} Values for BVPS-2 Extended Beltline Region Materials at 54 EFPY

Material	RG Pos.	Surf Neutron Fluence ($x10^{19}$ n/cm^2)	Fluence Factor, FF(a)	Chemistry Factor (°F)	Initial RT_{NDT}(b) (°F)	ΔRT_{NDT}(c) (°F)	σ_I (°F)	σ_Δ (°F)	Margin(d) (°F)	RT_{PTS}(e) (°F)
Upper Shell Plate B9003-1	1.1	0.4920	0.8022	91.00	50.0	73.0	0.0	17.0	34.0	157.0
Upper Shell Plate B9003-2	1.1	0.4920	0.8022	83.00	60.0	66.6	0.0	17.0	34.0	**160.6**
Upper Shell Plate B9003-3	1.1	0.4920	0.8022	91.00	50.0	73.0	0.0	17.0	34.0	157.0
Upper Shell Long Weld 51912-3490	1.1	0.4920	0.8022	73.71	-50.0	59.1	0.0	28.0	56.0	65.1
Upper Shell Long Weld 51912-3536	1.1	0.4920	0.8022	73.71	-70.0	59.1	0.0	28.0	56.0	45.1
Upper Shell Long Weld EAIB	1.1	0.4920	0.8022	27.00	10.0	21.7	17.0	10.8	40.3	72.0
Upper Shell Long Weld IAGA	1.1	0.4920	0.8022	41.00	-30.0	32.9	0.0	16.4	32.9	35.8
Upper Shell Long Weld BOHB	1.1	0.4920	0.8022	68.00	10	54.5	17.0	27.3	64.3	128.8
Upper Shell Long Weld BAOED	1.1	0.4920	0.8022	27.00	-50.0	21.7	0.0	10.8	21.7	-6.7
Upper to Inter Girth Weld 4P5174	1.1	0.5950	0.8546	122.00	-50.0	104.3	0.0	28.0	56.0	110.3
Upper to Inter Girth Weld 51922	1.1	0.5950	0.8546	68.00	-56.0	58.1	17.0	28.0	65.5	67.6
Upper to Inter Girth Weld AAGC	1.1	0.5950	0.8546	41.00	-70.0	35.0	0.0	17.5	35.0	0.1
Upper to Inter Girth Weld KOIB	1.1	0.5950	0.8546	41.00	-60.0	35.0	0.0	17.5	35.0	10.1
Inlet Nozzle B9011-1	1.1	0.0490	0.2895	77.00	60.0	22.3	0.0	11.1	22.3	104.6
Inlet Nozzle B9011-2	1.1	0.0490	0.2895	96.00	60.0	27.8	17.0	13.9	43.9	131.7
Inlet Nozzle B9011-3	1.1	0.0490	0.2895	96.00	70.0	27.8	0.0	13.9	27.8	125.6
Inlet Nozzle Welds 4P5174	1.1	0.0490	0.2895	122.00	-50.0	35.3	0.0	17.7	35.3	20.6
Inlet Nozzle Welds LOHB	1.1	0.0490	0.2895	41.00	-60.0	11.9	0.0	5.9	11.9	-36.3
Inlet Nozzle Welds HABJC	1.1	0.0490	0.2895	27.00	-70.0	7.8	0.0	3.9	7.8	-54.4
Inlet Nozzle Welds BABBD	1.1	0.0490	0.2895	27.00	-70.0	7.8	0.0	3.9	7.8	-54.4
Inlet Nozzle Welds FABGC	1.1	0.0490	0.2895	41.00	-80.0	11.9	0.0	5.9	11.9	-56.3
Inlet Nozzle Welds EOBC	1.1	0.0490	0.2895	27.00	-60.0	7.8	0.0	3.9	7.8	-44.4
Inlet Nozzle Welds FAAFC	1.1	0.0490	0.2895	95.00	-60.0	27.5	0.0	13.8	27.5	-5.0

Material	RG Pos.	Surf Neutron Fluence ($x10^{19}$ n/cm^2)	Fluence Factor, FF[(a)]	Chemistry Factor (°F)	Initial RT_{NDT}[(b)] (°F)	ΔRT_{NDT}[(c)] (°F)	σ_I (°F)	σ_Δ (°F)	Margin[(d)] (°F)	RT_{PTS}[(e)] (°F)
Inlet Nozzle Welds CCJC	1.1	0.0490	0.2895	27.00	-60.0	7.8	0.0	3.9	7.8	-44.4
Inlet Nozzle Welds FAGB	1.1	0.0490	0.2895	27.00	-30.0	7.8	0.0	3.9	7.8	-14.4
Inlet Nozzle Welds BAOED	1.1	0.0490	0.2895	27.00	-50.0	7.8	0.0	3.9	7.8	-34.4
Outlet Nozzle B9012-1	1.1	0.0234	0.1894	94.00	-10.0	17.8	0.0	8.9	17.8	25.6
Outlet Nozzle B9012-2	1.1	0.0234	0.1894	94.50	-10.0	17.9	0.0	9.0	17.9	25.8
Outlet Nozzle B9012-3	1.1	0.0234	0.1894	93.50	-10.0	17.7	0.0	8.9	17.7	25.4
Outlet Nozzle Weld BABBD	1.1	0.0234	0.1894	27.00	-70.0	5.1	0.0	2.6	5.1	-59.8
Outlet Nozzle Weld FAAFC	1.1	0.0234	0.1894	95.00	-60.0	18.0	0.0	9.0	18.0	-24.0
Outlet Nozzle Weld HAAEC	1.1	0.0234	0.1894	41.00	-80.0	7.8	0.0	3.9	7.8	-64.5
Outlet Nozzle Weld HABJC	1.1	0.0234	0.1894	27.00	-70.0	5.1	0.0	2.6	5.1	-59.8
Outlet Nozzle Weld HAGB	1.1	0.0234	0.1894	27.00	-40.0	5.1	0.0	2.6	5.1	-29.8
Outlet Nozzle Weld GACJC	1.1	0.0234	0.1894	41.00	-80.0	7.8	0.0	3.9	7.8	-64.5
Outlet Nozzle Weld JAHB	1.1	0.0234	0.1894	41.0	-40.0	7.8	0.0	3.9	7.8	-24.5

NOTES:
(a) FF = fluence factor = $f^{(0.28 - 0.1 \log (f))}$.
(b) Initial RT_{NDT} value for the upper shell forging is a measured value. All other values are generic.
(c) ΔRT_{PTS} = CF * FF.
(d) $M = 2 * (\sigma_I^2 + \sigma_\Delta^2)^{1/2}$.
(e) RT_{PTS} = Initial RT_{NDT} + ΔRT_{PTS} + Margin.

Table 9
BVPS-2 Beltline Materials Projected USE Values at 54 EFPY

Material Description	Wt % Cu[(a)]	1/4T EOLE Fluence (10^{19} n/cm^2)	Initial USE (ft-lbs)	Projected USE Decrease (%)	Projected EOLE USE (ft-lbs)
Intermediate Shell Plate B9004-1	0.065	3.8778	83	26	61.4
Intermediate Shell Plate B9004-2	0.06	3.8778	79	14[(b)]	67.9
Lower Shell Plate B9005-1	0.08	3.9214	82	26	60.7
Lower Shell Plate B9005-2	0.07	3.9214	78	26	57.7
Intermediate to Lower Shell Weld 101-171 (Heat 83642)	0.046	3.8903	145	6.2[(c)]	136.0
Intermediate Longitudinal Weld 101-124 A&B (Heat 83642)	0.046	1.0973	145	4.6[(c)]	138.3
Lower Longitudinal Weld 101-142 A&B (Heat 83642)	0.046	1.1097	145	4.6[(c)]	138.3

NOTES
- (a) The lower line in Figure 2 of Regulatory Guide 1.99, Revision 2, was used as the bounding value when Wt % Cu values were below this limit for plates and/or welds.
- (b) Based on BVPS-2 Surveillance Plate results for B9004-2.
- (c) Based on BVPS-2 Surveillance Weld results for heat 83642.

Table 10
BVPS-2 Extended Beltline Materials Projected USE Values at 54 EFPY

Component	Heat	Wt % Cu[(a)]	1/4T EOLE Fluence (10^{19} n/cm^2)	Initial USE (ft-lbs)	Projected USE Decrease (%)	Projected EOLE USE (ft-lbs)
Upper Shell Plates	A9406-1	0.13	0.3067	98	17	81.3
	B4431-2	0.12	0.3067	80	15.5	67.6
	A9406-2	0.13	0.3067	98	17	81.3
Upper Shell Longitudinal Welds	51912 (3490)	0.156	0.3067	96	23	73.9
	51912 (3536)	0.156	0.3067	114	23	87.8
	EAIB	0.02	0.3067	118	14.5	100.9
	IAGA	0.03	0.3067	160	14.5	136.8
	BOHB	0.05	0.3067	97	14.5	82.9
	BAOED	0.02	0.3067	150	14.5	128.3
Upper to Intermediate Shell Girth Weld	4P5174 (1122)	0.09	0.3709	70	18.5	57.1
	51922 (3489)	0.05	0.3709	102	15	86.7
	AAGC	0.03	0.3709	111	15	94.4
	KOIB	0.03	0.3709	110	15	93.5
Inlet Nozzles	2V2436	0.11	0.0305	105 (68.25)[(b)]	9	95.6 (62.1)[(b)]
	2V2437	0.13	0.0305	116 (75.4)[(b)]	10	104.4 (67.9)[(b)]
	2V2445	0.13	0.0305	123 (79.3)[(b)]	10	110.7 (71.4)[(b)]
Inlet Nozzle Welds	4P5174 (1122)	0.09	0.0305	70	10	63.0
	LOHB	0.03	0.0305	137	8.5	125.4
	HABJC	0.02	0.0305	162	8.5	148.2
	BABBD	0.02	0.0305	142	8.5	129.9
	FABGC	0.03	0.0305	119	8.5	108.9
	EOBC	0.02	0.0305	127	8.5	116.2
	FAAFC	0.07	0.0305	119	9	108.3
	CCJC	0.02	0.0305	109	8.5	99.7
	FAGB	0.02	0.0305	114	8.5	104.3
	BAOED	0.02	0.0305	150	8.5	137.3
Outlet Nozzles	AV8080	0.13	0.0146	146	9	132.9
	AV8120	0.13	0.0146	128	9	116.5
	AV8097	0.13	0.0146	127	9	115.6
Outlet Nozzle Welds	BABBD	0.02	0.0146	142	7.5	131.4
	FAAFC	0.07	0.0146	119	8.5	108.9
	HAAEC	0.03	0.0146	178	7.5	164.7
	HABJC	0.02	0.0146	162	7.5	149.9
	HAGB	0.02	0.0146	194	7.5	179.5
	GACJC	0.03	0.0146	113	7.5	104.5
	JAHB	0.03	0.0146	149	7.5	137.8

NOTES
(a) The lower line in Figure 2 of Regulatory Guide 1.99, Revision 2, was used as the bounding value when Wt % Cu values were below this limit for plates and/or welds.
(b) Values in the parenthesis are the 65% value.

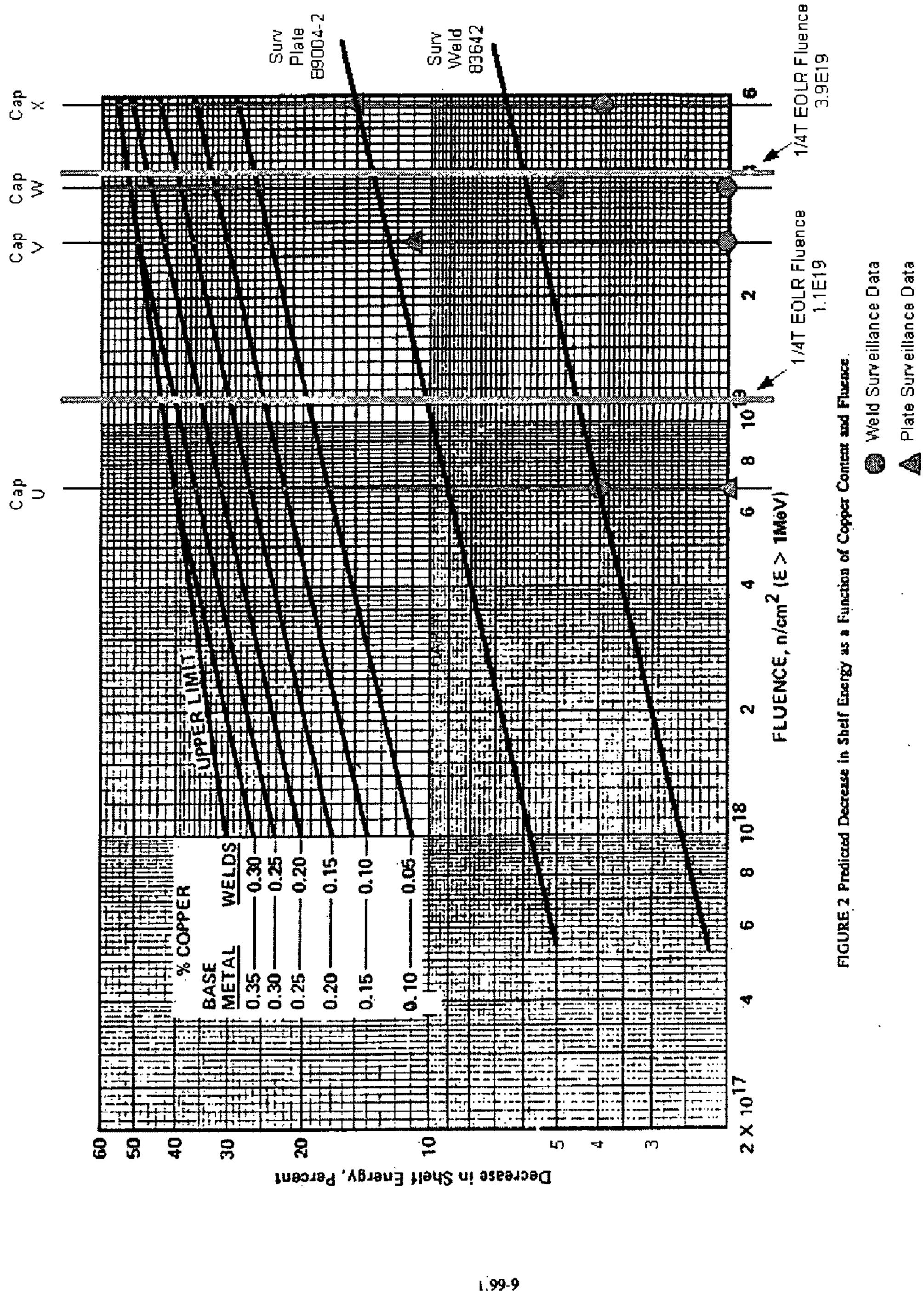

Figure 1 USE % Drop for BVPS-2 Beltline Materials for 54 EFPY

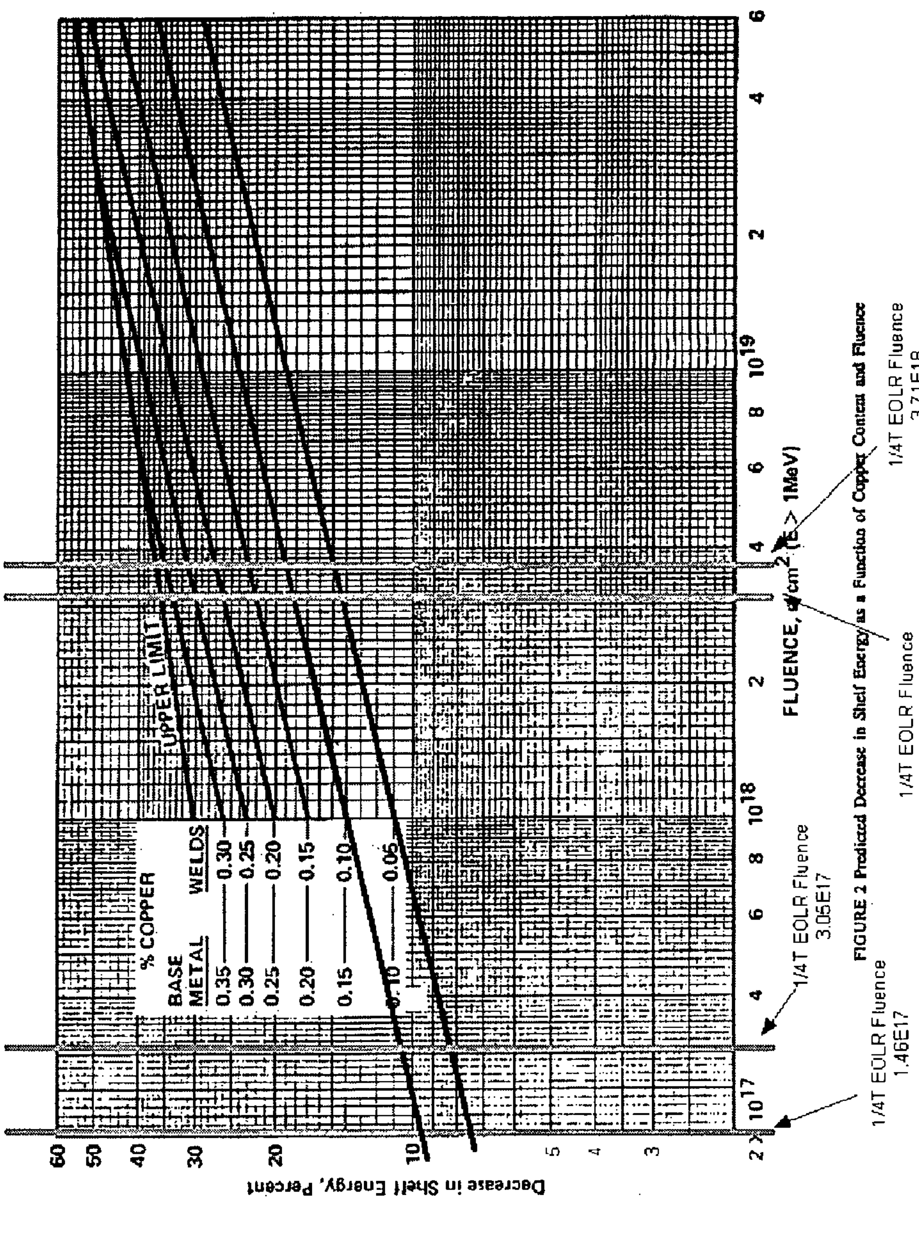

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Figure 2 USE % Drop for BVPS-2 Extended Beltline Materials for 54 EFPY

7 CONCLUSION

All of the beltline and extended beltline region materials in the Beaver Valley Unit 2 reactor vessel have EOLE RT_{PTS} values well below the screening criteria values of 270°F for forgings/plates and 300°F for circumferential welds at EOLE (54 EFPY).

All of the USE values for the beltline and extended beltline materials are greater than 50 ft-lbs at EOLE (54 EFPY).

8 REFERENCES

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