WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-14543

EVALUATION OF PRESSURIZED THERMAL SHOCK FOR THE BEAVER VALLEY UNIT 1 REACTOR VESSEL

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PREFACE

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SECTION 1.0
INTRODUCTION

A limiting condition on reactor vessel integrity known as Pressurized Thermal Shock (PTS) may occur during a severe system transient such as a Loss-Of-Coolant-Accident (LOCA) or a steam line break. Such transients may challenge the integrity of a reactor vessel under the following conditions:

- severe overcooling of the inside surface of the vessel wall followed by high repressurization;

- significant degradation of vessel material toughness caused by radiation embrittlement; and

- the presence of a critical-size defect in the vessel wall.

In 1985, the Nuclear Regulatory Commission (NRC) issued a formal ruling on PTS. It established screening criteria on pressurized water reactor (PWR) vessel embrittlement as measured by the nil-ductility reference temperature, termed RT_{PTS}.[1] RT_{PTS} screening values were set for beltline axial welds, forgings or plates, and beltline circumferential weld seams for the end-of-license plant operation. All PWR vessels in the United States have been required to evaluate vessel embrittlement in accordance with the criteria through end of license. The NRC recently amended its regulations for light water nuclear power plants to change the procedure for calculating radiation embrittlement. The revised PTS Rule was published in the Federal Register, May 15, 1991 with an effective date of June 14, 1991.[2] This amendment makes the procedure for calculating RT_{PTS} values consistent with the methods given in Regulatory Guide 1.99, Revision 2[3].

The purpose of this report is to determine the RT_{PTS} values for the Beaver Valley Unit 1 reactor vessel to address the revised PTS Rule. Section 2.0 discusses the 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 1 reactor vessel. The methodology and resulting neutron fluence values used in this analysis are presented in Section 5.0. The results of the RT_{PTS} calculations are presented in Section 6.0. The conclusions and references for the PTS evaluation follow in Sections 7.0 and 8.0, respectively.

SECTION 2.0

PRESSURIZED THERMAL SHOCK

The PTS Rule requires that the PTS submittal be updated whenever there are changes in core loadings, surveillance measurements or other information that indicates a significant change in projected RT_{PTS} values. The Rule outlines regulations to address the potential for PTS events on pressurized water reactor vessels in nuclear power plants that are operated with a license from the United States Nuclear Regulatory Commission (USNRC). PTS events have been shown from operating experience to be transients that result in a rapid and severe cooldown in the primary system coincident with a high or increasing primary system pressure. The 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 result in the propagation of flaws postulated to exist near the inner wall surface, thereby potentially affecting the integrity of the vessel.

The Rule establishes the following requirements for all domestic, operating PWRs:

* All plants must submit projected values of RT_{PTS} for reactor vessel beltline material by giving values for time of submittal, the expiration date of the operating license, and the projected expiration date if a change in the operating license or renewal has been requested. This assessment must be submitted within six months after the effective date of this Rule if the value of RT_{PTS} for any material is projected to exceed the screening criteria. Otherwise, it must be submitted with the next update of the pressure-temperature limits, or the next reactor vessel surveillance capsule report, or within five years from the effective date of this Rule change, whichever comes first. These values must be calculated based on the methodology specified in this rule. The submittal must include the following:

    1) the bases for the projection (including any assumptions regarding core loading patterns), and

    2) copper and nickel content and fluence values used in the calculations for each beltline material. (If these values differ from those previously submitted to the NRC, justification must be provided.)

* The RT_{PTS} screening criteria for the reactor vessel beltline region is:

  270°F for plates, forgings, axial welds; and

  300°F for circumferential weld material.

* The following equations must be used to calculate the RT_{PTS} values for each weld, plate or forging in the reactor vessel beltline:

  Equation 1: $RT_{PTS} = I + M + \Delta RT_{PTS}$

  Equation 2: $\Delta RT_{PTS} = CF * f^{(0.28 - 0.10 \log f)}$

* All values of RT_{PTS} must be verified to be bounding values for the specific reactor vessel. In doing this each plant should consider plant-specific information that could affect the level of embrittlement.

* Plant-specific PTS safety analyses are required before a plant is within three years of reaching the screening criteria, including analyses of alternatives to minimize the PTS concern.

* NRC approval for operation beyond the screening criteria is required.

SECTION 3.0

METHOD FOR CALCULATION OF RT_{PTS}

In the PTS Rule, the NRC Staff has selected a conservative and uniform method for determining plant-specific values of RT_{PTS} at a given time. For the purpose of comparison with the screening criteria, the value of RT_{PTS} for the reactor vessel must be calculated for each weld and plate or forging in the beltline region as follows.

$$RT_{PTS} = I + M + \Delta RT_{PTS}, \text{ where } \Delta RT_{PTS} = CF * FF$$

I = Initial reference temperature (RT_{NDT}) in °F of the unirradiated material

M = Margin to be added to cover uncertainties in the values of initial RT_{NDT}, copper and nickel contents, fluence, and calculational procedures, per Regulatory Guide 1.99, Revision 2, in °F.

$$M = \text{margin} = 2\sqrt{\sigma_\Delta^2 + \sigma_i^2}, \text{°F}$$

σ_i = 0°F when I is a measured value

σ_i = 17°F when I is a generic value

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 $0.5*\Delta RT_{PTS}$

FF = fluence factor = $f^{(0.28 - 0.10 \log f)}$, where

f = Neutron fluence (10^{19} n/cm^2, E>1.0 MeV) at the clad/base metal interface

CF = Chemistry Factor in °F from the tables[2] for welds and base metals (plates or forgings). If plant-specific surveillance data from two or more surveillance capsules has been deemed credible per Regulatory Guide 1.99, Revision 2, it should be considered in the calculation of the chemistry factor.

SECTION 4.0

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 1 vessel beltline region was performed. The beltline region of a reactor vessel, per ASTM E185-82[4], is "the irradiated region of the reactor vessel (shell material including weld regions and plates or forgings) that directly surrounds the effective height of the active core and adjacent regions that are predicted to experience sufficient neutron damage to warrant consideration in the selection of the surveillance material". Figure 1 identifies and indicates the location of all beltline region material for the Beaver Valley Unit 1 reactor vessel.

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 surveillance capsule testing program[5]. The average copper and nickel values were calculated by the Duquesne Light Company for each of the beltline region materials using all of the available material chemistry information.[6] This data was submitted to the NRC in response to Generic Letter 92-01, Revision 1, Supplement 1, Reactor Vessel Structural Integrity. Table 1 presents these average Cu and Ni weight percent values.

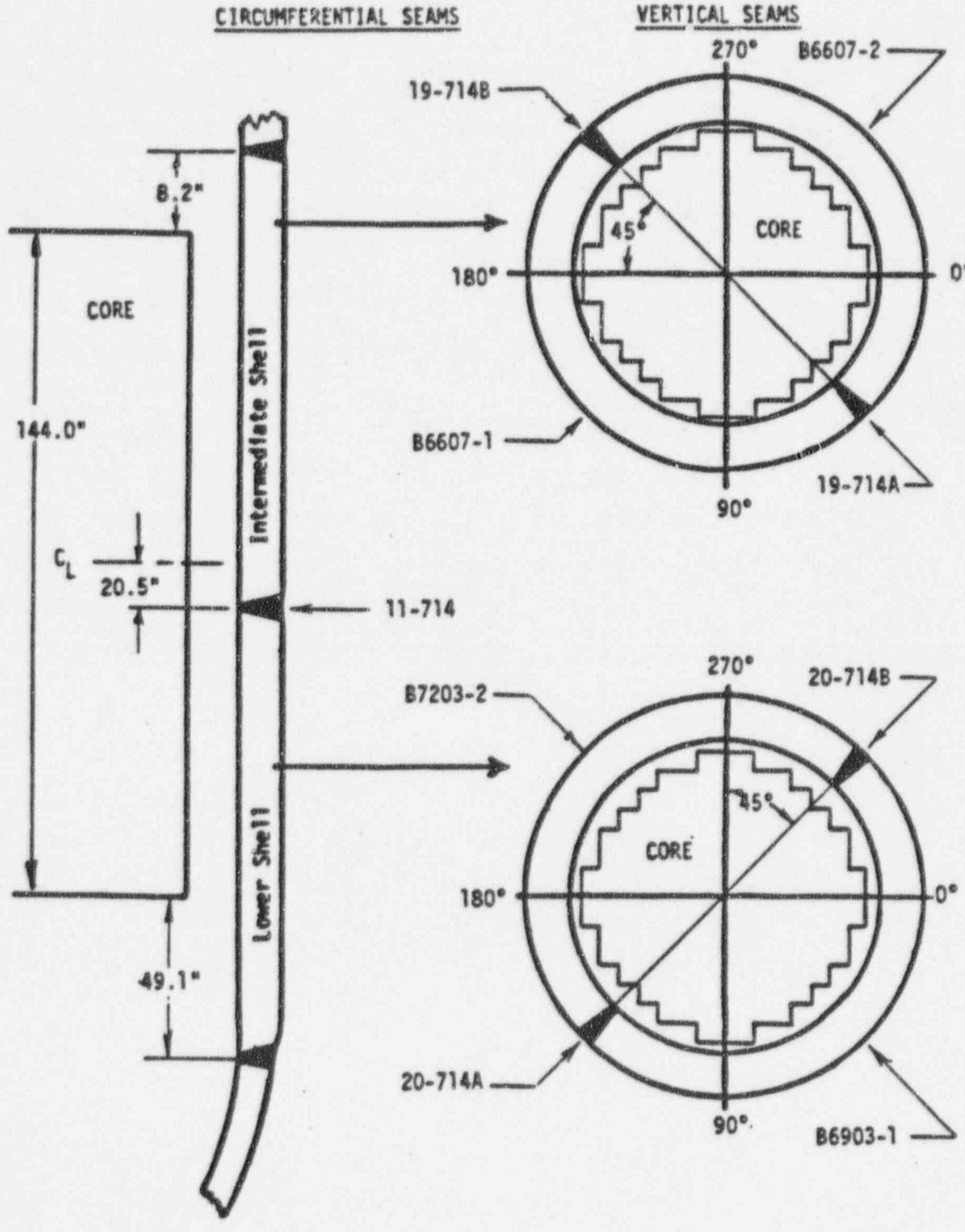


Figure 1 Identification and Location of Beltline Region Materials for the Beaver Valley Unit 1 Reactor Vessel

TABLE 1

Beaver Valley Unit 1 Reactor Vessel Beltline Materials Average Cu and Ni Values

Beltline Region Material	Cu wt %	Ni wt %
Intermediate Shell Plate B6607-1	0.14	0.62
Intermediate Shell Plate B6607-2	0.14	0.62
Lower Shell Plate B6903-1 (surveillance program)	0.20	0.54
Lower Shell Plate B7203-2	0.14	0.57
Intermediate Shell Long. Welds 19-714A/B Heat #305424	0.263	0.632
Lower Shell Long. Welds 20-714A/B Heat #305414	0.338	0.606
Circumferential Weld 11-714 Heat #90136	0.278	0.071

TABLE 2

Interpolation of Chemistry Factors from Regulatory Guide 1.99, Revision 2, Position 1.1

Material	Ni, wt %	Chemistry Factor, °F
Intermediate Shell Plate B6607-1 Given Cu wt % = 0.14	0.60	100
	0.62	**100.5**
	0.80	105
Intermediate Shell Plate B6607-2 Given Cu wt % = 0.14	0.60	100
	0.62	**100.5**
	0.80	105
Lower Shell Plate B6903-1 Given Cu wt % = 0.20	0.40	125
	0.54	**141.8**
	0.60	149
Lower Shell Plate B7203-2 Given Cu wt % = 0.14	0.40	91
	0.57	**98.7**
	0.60	100
Inter. Shell Long. Welds 19-714A/B Given Cu wt% = 0.263	0.60	181.2
	0.632	**186.3**
	0.80	213.2
Lower Shell Long. Welds 20-714A/B Given Cu wt% = 0.338	0.60	208.2
	0.606	**209.1**
	0.80	237.2
Circ. Weld 11-714 Given Cu wt% = 0.278	0.00	121.4
	0.071	**127.0**
	0.20	137.2

TABLE 3

Calculation of Chemistry Factors Using Credible Surveillance Capsule Data

Material	Capsule	Capsule f	FF	ΔRT_{NDT}	$FF*\Delta RT_{NDT}$	FF^2
Lower Shell Plate B6903-1 (Longitudinal)	V	0.316	0.684	128.1	87.6	0.467
	U	0.690	0.896	118.9	106.5	0.803
	W	0.915	0.975	147.7	144.0	0.951
Lower Shell Plate B6903-1 (Transverse)	V	0.316	0.684	137.8	94.2	0.467
	U	0.690	0.896	131.8	118.1	0.803
	W	0.915	0.975	179.9	175.4	0.951
				Sum:	725.9	4.442
						163.4
Weld Metal	V	0.316	0.684	158.0	108.1	0.468
	U	0.690	0.896	164.6	147.5	0.803
	W	0.915	0.975	185.8	181.2	0.951
				Sum:	436.7	2.221
						196.6

NOTES:
f = fluence (10^{19} n/cm^2). Obtained from recent fluence reevaluation presented in Section 5.0 of this report (documented in WCAP-14554[7]).
FF = fluence factor = $f^{(0.28 - 0.1*\log f)}$
ΔRT_{NDT} values obtained from hyperbolic tangent curve-fitted Charpy V-notch curves. See Appendix A of this report.
CF = $\sum(FF * \Delta RT_{NDT}) \div \sum(FF^2)$

A summary of the pertinent chemical and mechanical properties of the beltline region plates and weld materials of the Beaver Valley Unit 1 reactor vessel are given in Table 4. Chemistry Factor (CF) and Initial RT_{NDT} (I) values are also presented in Table 4.

TABLE 4

Beaver Valley Unit 1 Reactor Vessel Beltline Region Material Properties Used in Calculations

Material	Cu wt %	Ni wt %	Chemistry Factor, °F [a]	Initial RT_{NDT}, °F
Intermediate Shell Plate B6607-1	0.14	0.62	100.5	43
Intermediate Shell Plate B6607-2	0.14	0.62	100.5	73
Lower Shell Plate B6903-1	0.20	0.54	141.8	27
Lower Shell Plate B6903-1 Using S/C Data (RG 1.99, Pos. 2.1)	--	--	163.4	27
Lower Shell Plate B7203-2	0.14	0.57	98.7	20
Intermediate Shell Long. Welds 19-714A/B Heat #305424	0.263	0.632	186.3	-56
Intermediate Shell Long. Welds 19-714A/B Using S/C Data (RG 1.99, Pos. 2.1)	--	--	196.6	-56
Lower Shell Long. Welds 20-714A/B Heat #305414	0.338	0.606	209.1	-56
Circumferential Weld 11-714 Heat #90136	0.278	0.071	127.0	-56

NOTE:

(a) Chemistry Factor calculated per Tables 1 and 2 of 10 CFR 50.61 and Regulatory Guide 1.99, Revision 2, Position 2.1.

(b) Initial RT_{NDT} values of the plate materials are measured while the weld materials have generic values.

SECTION 5.0

NEUTRON FLUENCE METHODOLOGY AND RESULTS

This section provides the results of the neutron dosimetry evaluation. Included is an update of the dosimetry evaluation for Capsules V, U, and W. This update is based on current state-of-the-art methodology and nuclear data including recently released neutron transport and dosimetry cross-section libraries derived from the ENDF/B-VI database. This report provides a consistent up-to-date neutron exposure database for use in evaluating the material properties of the Beaver Valley Unit 1 reactor vessel. The complete Beaver Valley Unit 1 fluence reevaluation is documented in WCAP-14554[7]. The results of the updated dosimetry evaluation for each of the surveillance capsules removed to date are presented in the following table.

TABLE 5

Beaver Valley Unit 1 Surveillance Capsule Fluence Reevaluation Results[7]

Capsule	Capsule Lead Factor	Capsule Fluence (10^{19} n/cm^2, E>1.0 MeV)	Uncertainty	EFPY
V	1.65	0.316	8%	1.16
U	1.10	0.690	8%	3.58
W	1.10	0.915	9%	5.92

Additionally, the updated capsule fluence values and lead factors for the capsules remaining in the reactor vessel are presented in Tables 6 and 7, respectively.

TABLE 6

Capsule Neutron Fluence (10^{19} n/cm^2, E > 1.0 MeV) Projections[7]

EFPY	Capsule X	Capsule Y	Capsule T	Capsule Z	Capsule S
10.8 (EOC 10)	2.384	1.589	1.084	1.084	0.8626
12	2.544	1.723	1.217	1.244	0.9441
14	2.822	1.956	1.450	1.522	1.086
16	3.101	2.188	1.683	1.801	1.228
18	3.379	2.421	1.915	2.079	1.369
20	3.658	2.654	2.148	2.358	1.511
22	3.936	2.886	2.381	2.636	1.653
24	4.215	3.119	2.613	2.915	1.795
26	4.493	3.352	2.846	3.193	1.936
27.1 (EOL)	4.646	3.480	2.974	3.346	2.014

TABLE 7

Capsule Lead Factor Projections[7]

EFPY	Capsule X	Capsule Y	Capsule T	Capsule Z	Capsule S
10.8 (EOC 10)	1.73	1.16	0.79	0.79	0.63
12	1.71	1.16	0.82	0.84	0.64
14	1.69	1.17	0.87	0.91	0.65
16	1.66	1.17	0.90	0.97	0.66
18	1.64	1.18	0.93	1.01	0.67
20	1.63	1.18	0.96	1.05	0.67
22	1.62	1.19	0.98	1.08	0.68
24	1.61	1.19	1.00	1.11	0.68
26	1.60	1.19	1.01	1.13	0.69
27.1 (EOL)	1.59	1.19	1.02	1.15	0.69

The calculated peak fast neutron fluence (E > 1.0 MeV) values at the inner surface of the Beaver Valley Unit 1 reactor vessel are presented in Table 8. Fluence values are projected for each of the reactor vessel beltline region materials.

TABLE 8

Best Estimate Maximum Fluence (10^{19} n/cm^2, E > 1.0 MeV) for the Beaver Valley Unit 1 Reactor Vessel Beltline Region Materials[7]

EFPY	Lower Shell Plates	Lower Shell Longitudinal Welds	Circumferential Weld	Intermediate Shell Plates	Intermediate Shell Longitudinal Welds
10.8 (EOC 10)	1.376	0.2726	1.376	1.376	0.2726
12	1.478	0.3009	1.478	1.485	0.3009
14	1.655	0.3500	1.655	1.675	0.3500
16	1.833	0.3991	1.833	1.865	0.3991
18	2.010	0.4482	2.010	2.055	0.4482
20	2.188	0.4973	2.188	2.244	0.4973
22	2.365	0.5464	2.365	2.434	0.5464
24	2.543	0.5955	2.543	2.624	0.5955
26	2.721	0.6446	2.721	2.814	0.6446
27.1 (EOL)	2.818	0.6716	2.818	2.919	0.6716

SECTION 6.0

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 Beaver Valley Unit 1 reactor vessel for fluence values at the present time (10.8 EFPY), and end-of-license. The end-of-license EFPY was calculated to be 27.1 EFPY. The PTS Rule requires that each plant assess the RT_{PTS} values based on plant specific surveillance capsule data whenever:

- Plant-specific surveillance data has been deemed credible as defined in Regulatory Guide 1.99, Revision 2, and

- RT_{PTS} values change significantly. (Changes to RT_{PTS} values are considered significant if the value determined with RT_{PTS} equations (1) and (2), or that using capsule data, or both, exceed the screening criteria prior to the expiration of the operating license, including any renewed term, if applicable, for the plant.)

As presented in Table 2, chemistry factor values for the Beaver Valley Unit 1 beltline region materials based on average copper and nickel weight percent were calculated using Tables 1 and 2 from 10 CFR 50.61. Additionally, chemistry factor values based on credible surveillance capsule data were calculated per Regulatory Guide 1.99, Revision 2, Position 2.1 (Table 3). Table 4 presents all of the chemistry factor and initial RT_{NDT} values used in the PTS calculations. Table 9 provides a summary of the RT_{PTS} values for all beltline region material for 10.8 and 27.1 EFPY.

TABLE 9

RT_{PTS} Calculations for the Beaver Valley Unit 1 Beltline Region Materials

Material	CF	f	FF	I	M	ΔRT_{PTS}	RT_{PTS}
Current Time 10.8 EFPY							
Inter. Shell Plate B6607-1	100.5	1.376	1.089	43	34	109.4	186.4
Inter. Shell Plate B6607-2	100.5	1.376	1.089	73	34	109.4	216.4
Lower Shell Plate B6903-1	141.8	1.376	1.089	27	34	154.4	215.4
using S/C data (RG Pos. 2.1)	163.4	1.376	1.089	27	29.1*	177.9	234.0
Lower Shell Plate B7203-2	98.7	1.376	1.089	20	34	107.5	161.5
Inter. Shell Long. Welds 19-714A/B	186.3	0.2726	0.646	-56	65.5	120.3	129.8
using S/C data (RG Pos. 2.1)	196.6	0.2726	0.646	-56	44	127.0	115.0
Lower Shell Long. Welds 20-714A/B	209.1	0.2726	0.646	-56	65.5	135.0	144.5
Circumferential Weld 11-714	127.0	1.376	1.089	-56	65.5	138.3	147.8
End-of Life (27.1 EFPY)							
Inter. Shell Plate B6607-1	100.5	2.919	1.284	43	34	129.1	206.1
Inter. Shell Plate B6607-2	100.5	2.919	1.284	73	34	129.1	236.1
Lower Shell Plate B6903-1	141.8	2.818	1.276	27	34	180.9	241.9
using S/C data (RG Pos. 2.1)	163.4	2.818	1.276	27	29.1*	208.4	**264.5**
Lower Shell Plate B7203-2	98.7	2.818	1.276	20	34	125.9	179.9
Inter. Shell Long. Welds 19-714A/B	186.3	0.6716	0.888	-56	65.5	165.5	175.0
using S/C data (RG Pos. 2.1)	196.6	0.6716	0.888	-56	44	174.7	162.7
Lower Shell Long. Welds 20-714A/B	209.1	0.6716	0.888	-56	65.5	185.8	195.3
Circumferential Weld 11-714	127.0	2.818	1.276	-56	65.5	162.0	171.5

* Determined to be 29.1°F from 1σ band of industry data scatter[8]. See Appendix B.

SECTION 7.0
CONCLUSIONS

As shown in Table 9, all RT_{PTS} values remain below the NRC PTS screening criteria values using fluence values for the present time (10.8 EFPY) and end-of-license (27.1 EFPY). A plot of RT_{PTS} values versus EFPY of Operation, shown in Figure 2, illustrates the available margin for the Beaver Valley Unit 1 reactor vessel beltline region materials. Lower Shell Plate B6903-1 is the limiting Beaver Valley Unit 1 reactor vessel beltline region material.

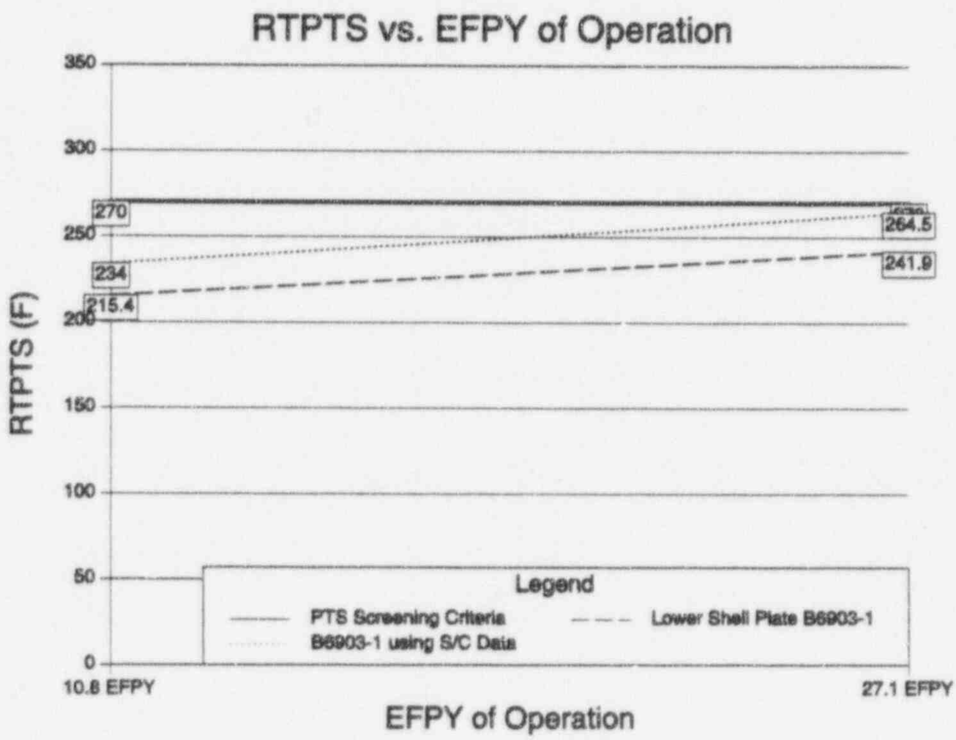


Figure 2 RT_{PTS} versus EFPY of Operation for Beaver Valley Unit 1 Limiting Material - Lower Shell Plate B6903-1

SECTION 8.0
REFERENCES

1. 10 CFR Part 50.61, "Analysis of Potential Pressurized Thermal Shock Events," July 23, 1985.

2. 10 CFR Part 50.61, "Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events," May 15, 1991. (PTS Rule)

3. Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials," U.S. Nuclear Regulatory Commission, May 1988.

4. ASTM E185-82, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels", E706 (1F).

5. WCAP-8457, "Duquesne Light Company Beaver Valley Unit No. 1 Reactor Vessel Radiation Surveillance Program", J. A. Davidson, et al., October 1974.

6. "Beaver Valley Power Station Reactor Vessel Data, Unit 1", RVDATA3.XLS, Ted Huminski, Duquesne Light Company, 11/9/95.

7. WCAP-14554, Beaver Valley Unit 1 Fluence Reevaluation, S. L. Anderson, dated June 1996.

8. "Beaver Valley 1 Reactor Vessel PTS Analysis", prepared by Timothy J. Griesbach, reviewed by Brian F. Beaudoin, ATI Consulting, dated 12/12/95.

APPENDIX A

Reevaluation of the Charpy V-Notch Transition Temperature Shifts (ΔRT_{NDT}) using Hyperbolic Tangent Curve Fitting Methods [A-1]

The limiting material of interest in the Beaver Valley Unit 1 reactor vessel is lower shell plate B6903-1, heat number C6317-1. This plate is also the Beaver Valley Unit 1 surveillance program base material. Both longitudinal (LT) and transverse (TL) orientated specimens from this plate material were tested in the unirradiated and irradiated conditions. The irradiated data was obtained from specimens removed and tested from Capsules U, V, and W (References A-2 through A-5).

Position 2.1 of Regulatory Guide 1.99, Revision 2[A-6], has been used to evaluate the projected level of embrittlement in this plate from a best-fit of the measured Charpy V-notch test data. A reevaluation of the Charpy test data was performed using the CVGRAPH program[A-7], which calculated a hyperbolic tangent (TANH) curve-fit of the data. The hyperbolic tangent function is commonly used to mathematically describe the Charpy test results according to the following equation. (See Figure 1 of this Appendix.)

$$CVN = A + B \tanh [(T - T_0 / C] \qquad (1)$$

where CVN is the Charpy V-notch energy,

(A - B) is the asymptotic lower shelf energy,

(A + B) is the asymptotic upper shelf energy,

T_0 is the mid-transition temperature corresponding to A, and

C is the measure of the slope of the transition region.

Eight sets of data were considered. The impact energy versus temperature values were obtained and tanh coefficients determined for curve-fits to each of the data sets. The fitted results for the base material are shown in Figures 2 through 5 for the transverse data and Figures 6 through 9 for the longitudinal data. The calculated T_{30} and ΔT_{30} temperatures are given in Table A-1.

TABLE A-1

Calculated T_{30} and ΔT_{30} Values from the TANH Curve-Fits

Capsule	Orientation	T_{30} (°F)	Calculated ΔT_{30} (°F)
Unirradiated	TL	18.1	--
V	TL	155.9	137.8
U	TL	149.8	131.7
W	TL	198.0	179.9
Unirradiated	LT	-3.4	--
V	LT	124.8	128.[illegible]
U	LT	115.4	118.9
W	LT	144.[illegible]	147.8

The Beaver Valley Unit 1 surveillance weld is heat number 305424, which is same material as the intermediate shell axial welds in the reactor vessel. The weld material was tested in the unirradiated and irradiated conditions. The irradiated data was obtained from specimens removed and tested from Capsules U, V, and W (References A-2 through A-5). The impact energy versus temperature values were obtained and tanh coefficients determined for curve-fits to the data. The results for the Beaver Valley Unit 1 surveillance weld are shown in Figures 10 through 13 of this appendix. The calculated T_{30} and ΔT_{30} values are presented in the following table.

TABLE A-2

Calculated T_{30} and ΔT_{30} Values from the TANH Curve-Fits

Capsule	T_{30} (°F)	Calculated ΔT_{30} (°F)
Unirradiated	-66.0	--
V	91.8	157.8
U	98.4	164.4
W	119.6	185.6

REFERENCES:

A-1. "Beaver Valley 1 Reactor Vessel PTS Analysis", prepared by Timothy J. Griesbach, reviewed by Brian F. Beaudoin, ATI Consulting, dated 12/12/95.

A-2. WCAP-8457, "Duquesne Light Company Beaver Valley Unit No. 1 Reactor Vessel Radiation Surveillance Program", J. A. Davidson, et al., October 1974.

A-3. WCAP-9860, "Analysis of Capsule V from the Duquesne Light Company Beaver Valley Unit 1 Reactor Vessel Radiation Surveillance Program", S. E. Yanichko, et al., January 1981.

A-4. WCAP-10867, "Analysis of Capsule U from the Duquesne Light Company Beaver Valley Unit 1 Reactor Vessel Radiation Surveillance Program", R. S. Boggs, et al., September 1985.

A-5. WCAP-12005, "Analysis of Capsule W from the Duquesne Light Company Beaver Valley Unit 1 Reactor Vessel Radiation Surveillance Program", S. E. Yanichko, et al., November 1988.

A-6. Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials", May 1988.

A-7. CVGRAPH, Charpy V-Notch Curve-Fitting Routine, Version 4.0, developed by ATI Consulting, March 1995.

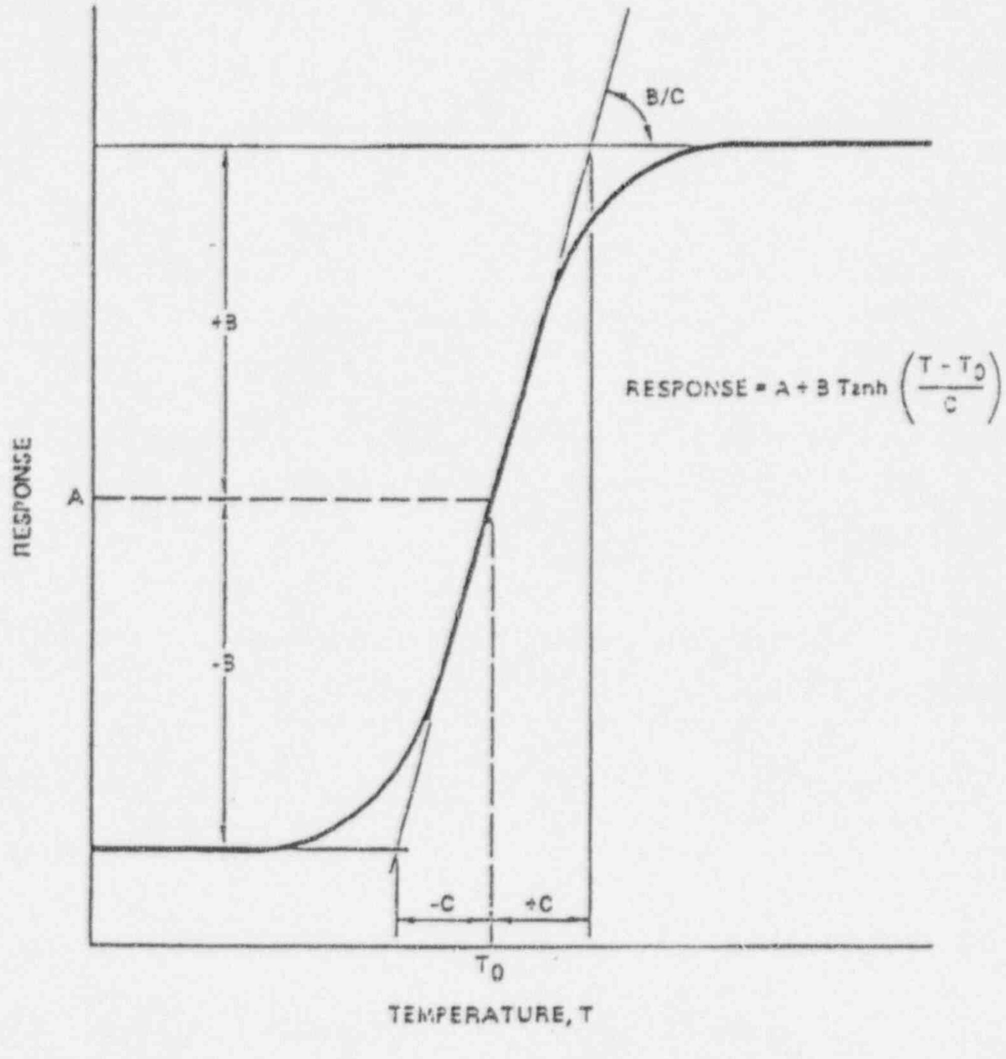


Figure 1. Hyperbolic Tangent (TANH) CVN Curve

Beaver Valley Unit 1 – Base Metal/TL (Unirr)

CVGRAPH 4.0 Hyperbolic Tangent Curve Printed at 16:35:09 on 12-12-1995

Page 1

Coefficients of Curve 1

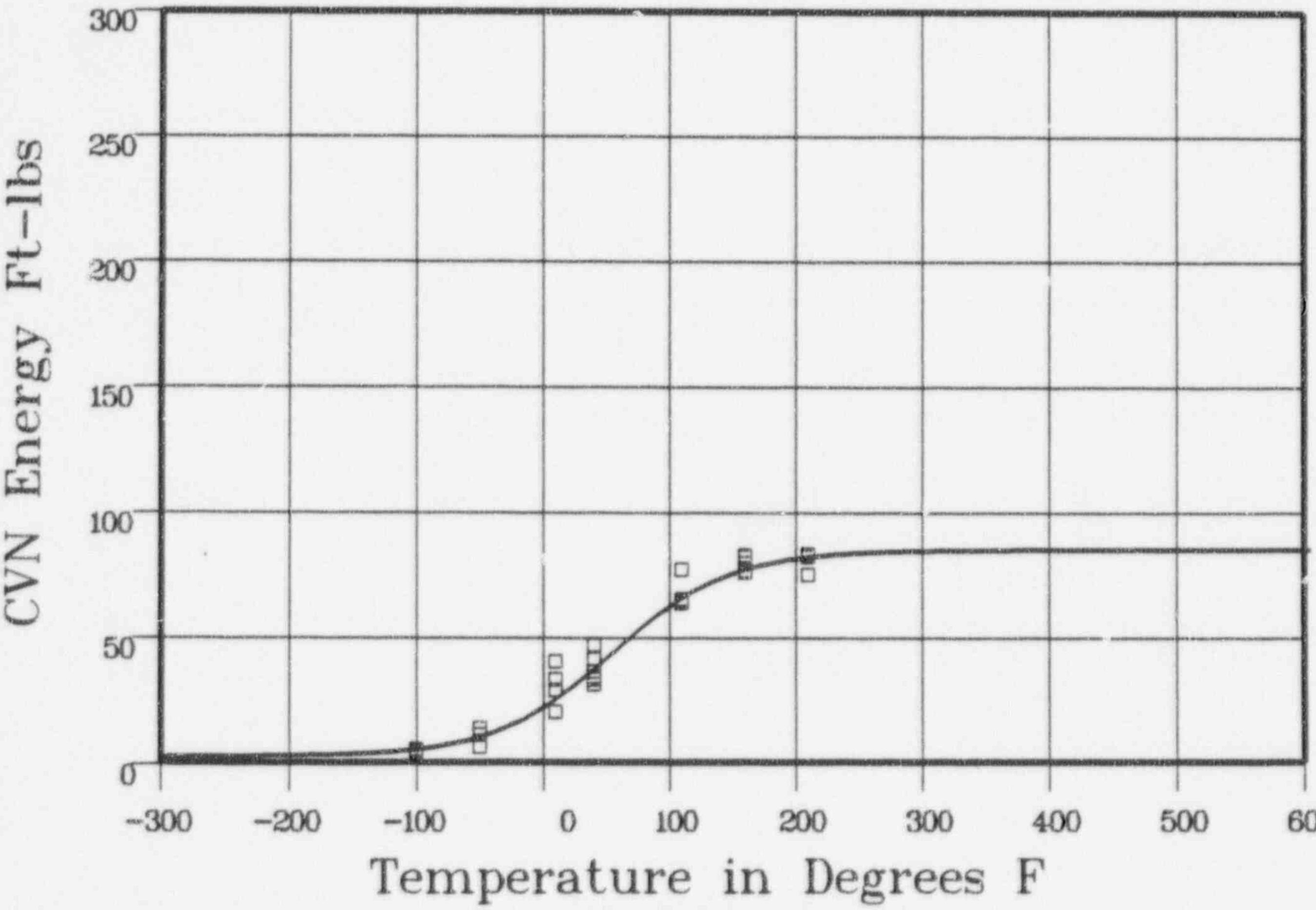
A = 43.49	B = 41.29	C = 93.07	T0 = 49.68

Equation is: CVN = A + B * [tanh((T - T0)/C)]

Upper Shelf Energy: 84.78 Temp. at 30 ft-lbs: 18.1 Temp. at 50 ft-lbs: 64.4 Lower Shelf Energy: 2.2 Fixed

Material: PLATE SA533B1 Heat Number: C6317-1 Orientation: TL

Capsule: Unirr Total Fluence: 0.0



Data Set(s) Plotted

Plant: BV1 Cap.: Unirr Material: PLATE SA533B1 Ori.: TL Heat #: C6317-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	4	5.38	-1.38
-100	2.5	5.38	-2.88
-100	4.5	5.38	-.88
-100	5	5.38	-.38
-50	13.5	10.87	2.62
-50	6	10.87	-4.87
-50	11	10.87	.12

**** Data continued on next page ****

Figure 2. Unirradiated Charpy V-Notch Data (TL Orientation)

Beaver Valley Unit 1 - Base Metal/TL (Unirr)

Material: PLATE SA533B1 Heat Number: C6317-1 Orientation: TL

Capsule: Unirr Total Fluence: 0.0

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	11	10.87	.12
-50	11	10.87	.12
10	33	26.88	6.11
10	40	26.88	13.11
10	28.5	26.88	1.61
10	28.5	26.88	1.61
10	20	26.88	-6.88
40	46.5	39.21	7.28
40	34	39.21	-5.21
40	36	39.21	-3.21
40	33	39.21	-6.21
40	41	39.21	1.78
40	31	39.21	-8.21
110	65	67.04	-2.04
110	64	67.04	-3.04
110	63.5	67.04	-3.54
110	77	67.04	9.95
160	76.5	77.73	-1.23
160	76	77.73	-1.73
160	82.5	77.73	4.76
160	82	77.73	4.26
160	79.5	77.73	1.76
210	83	82.23	.76
210	82.5	82.23	.26
210	75	82.23	-7.23
210	82	82.23	-.23

SUM of RESIDUALS = -2.86

Beaver Valley Unit 1 – Base Metal/TL (V)

CVGRAPH 4.0 Hyperbolic Tangent Curve Printed at 16:35:09 on 12-12-1995

Page 1

Coefficients of Curve 2

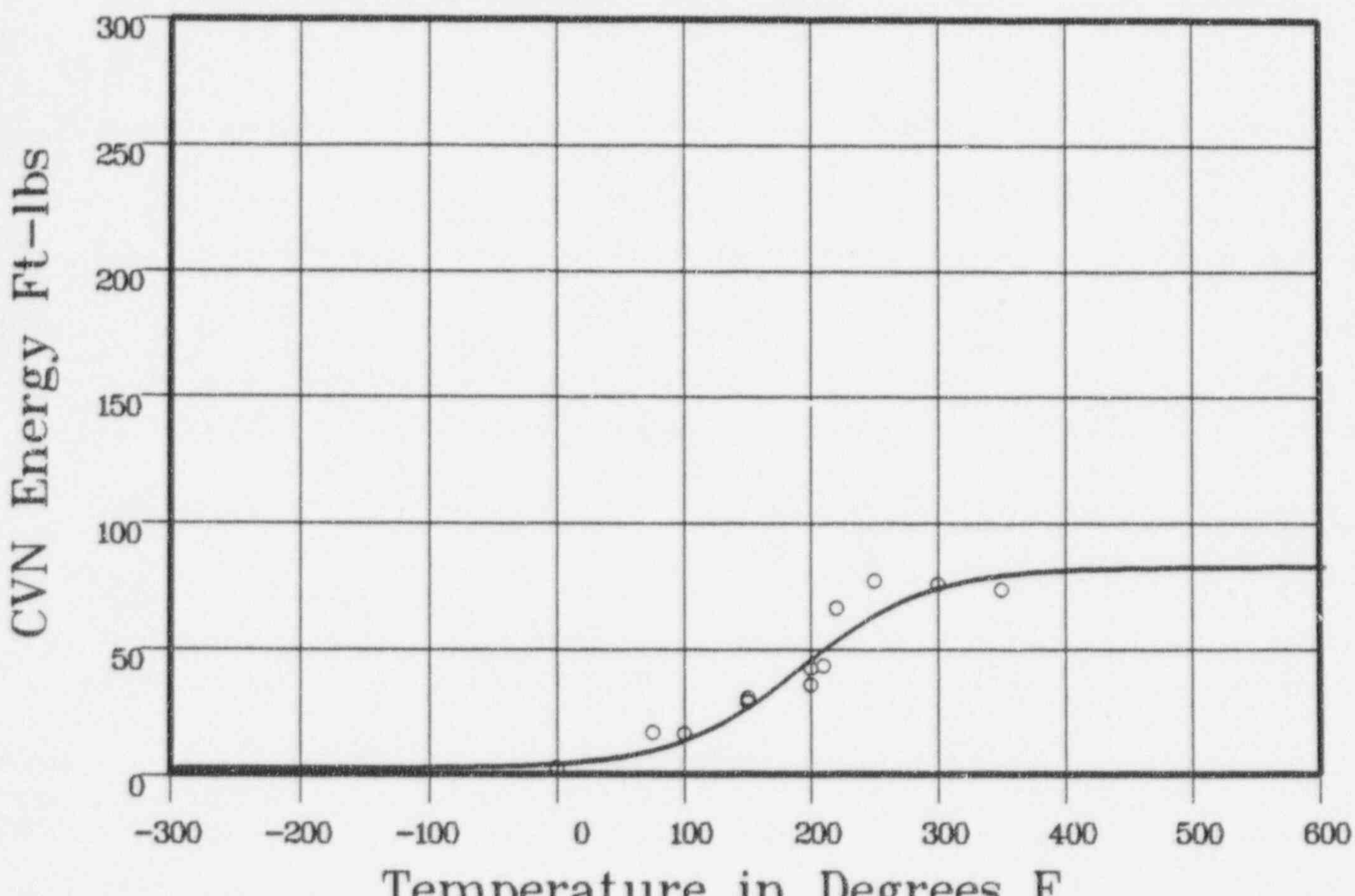
A = 42.2	B = 40	C = 100.33	T0 = 187.5

Equation is: CVN = A + B * [tanh((T – T0)/C)]

Upper Shelf Energy: 82.21 Temp. at 30 ft-lbs: 155.8 Temp. at 50 ft-lbs: 207.2 Lower Shelf Energy: 2.2 Fixed

Material: PLATE SA533B1 Heat Number: C6317-1 Orientation: TL

Capsule: V Total Fluence: 3.16E18



Data Set(s) Plotted

Plant: BV1 Cap.: V Material: PLATE SA533B1 Ori.: TL Heat #: C6317-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	2.5	4.06	-1.56
75	16.5	9.88	6.61
100	16	14.1	1.89
150	30	27.91	2.08
150	28.5	27.91	.58
200	35.5	47.16	-11.66
200	42	47.16	-5.16

**** Data continued on next page ****

Figure 3. Capsule V Charpy V-Notch Data (TL Orientation)

Beaver Valley Unit 1 – Base Metal/TL (V)

Material: PLATE SA533B1 Heat Number: C6317-1 Orientation: TL

Capsule: V Total Fluence: 3.16E18

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
210	43	51.03	-8.03
220	66	54.73	11.26
250	77	64.33	12.66
300	75.5	74.53	.96
350	73.5	79.19	-5.69

SUM of RESIDUALS = 3.97

Beaver Valley Unit 1 - Base Metal/TL (U)

CVGRAPH 4.0 Hyperbolic Tangent Curve Printed at 16:35:09 on 12-12-1995

Page 1

Coefficients of Curve 3

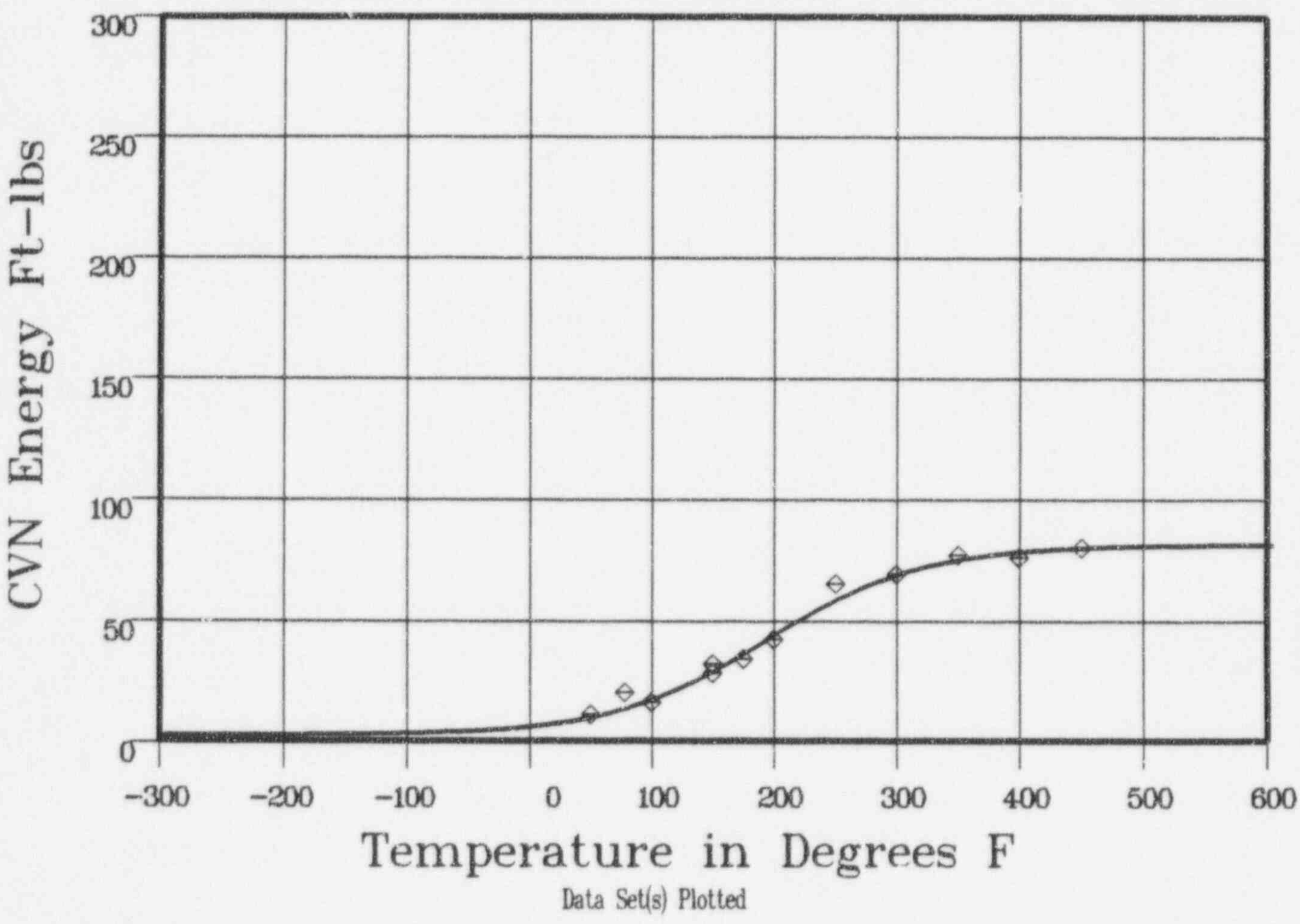
A = 41.69	B = 39.49	C = 127.2	T0 = 188.67

Equation is: CVN = A + B * [tanh((T - T0)/C)]

Upper Shelf Energy: 81.19 Temp. at 30 ft-lbs: 149.8 Temp. at 50 ft-lbs: 215.8 Lower Shelf Energy: 2.2 Fixed

Material: PLATE SA533B1 Heat Number: C6317-1 Orientation: TL

Capsule: U Total Fluence: 6.90E18



Data Set(s) Plotted

Plant: BV1 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: C6317-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	11	10.22	.77
78	20	13.99	6
100	16	17.89	-1.89
150	28	30.04	-2.04
150	32	30.04	1.95
175	34	37.46	-3.46
200	42	45.2	-3.2

**** Data continued on next page ****

Figure 4. Capsule U Charpy V-Notch Data (TL Orientation)

Beaver Valley Unit 1 - Base Metal/TL (U)

Material: PLATE SA533B1 Heat Number: C6317-1 Orientation: TL

Capsule: U Total Fluence: 6.90E18

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
250	65	59.39	5.6
300	69	69.5	-.5
350	77	75.4	1.59
400	76	78.44	-2.44
450	80	79.91	.08

SUM of RESIDUALS = 2.45

Beaver Valley Unit 1 – Base Metal/TL (W)

CVGRAPH 4.0 Hyperbolic Tangent Curve Printed at 16:35:09 on 12-12-1995

Page 1

Coefficients of Curve 4

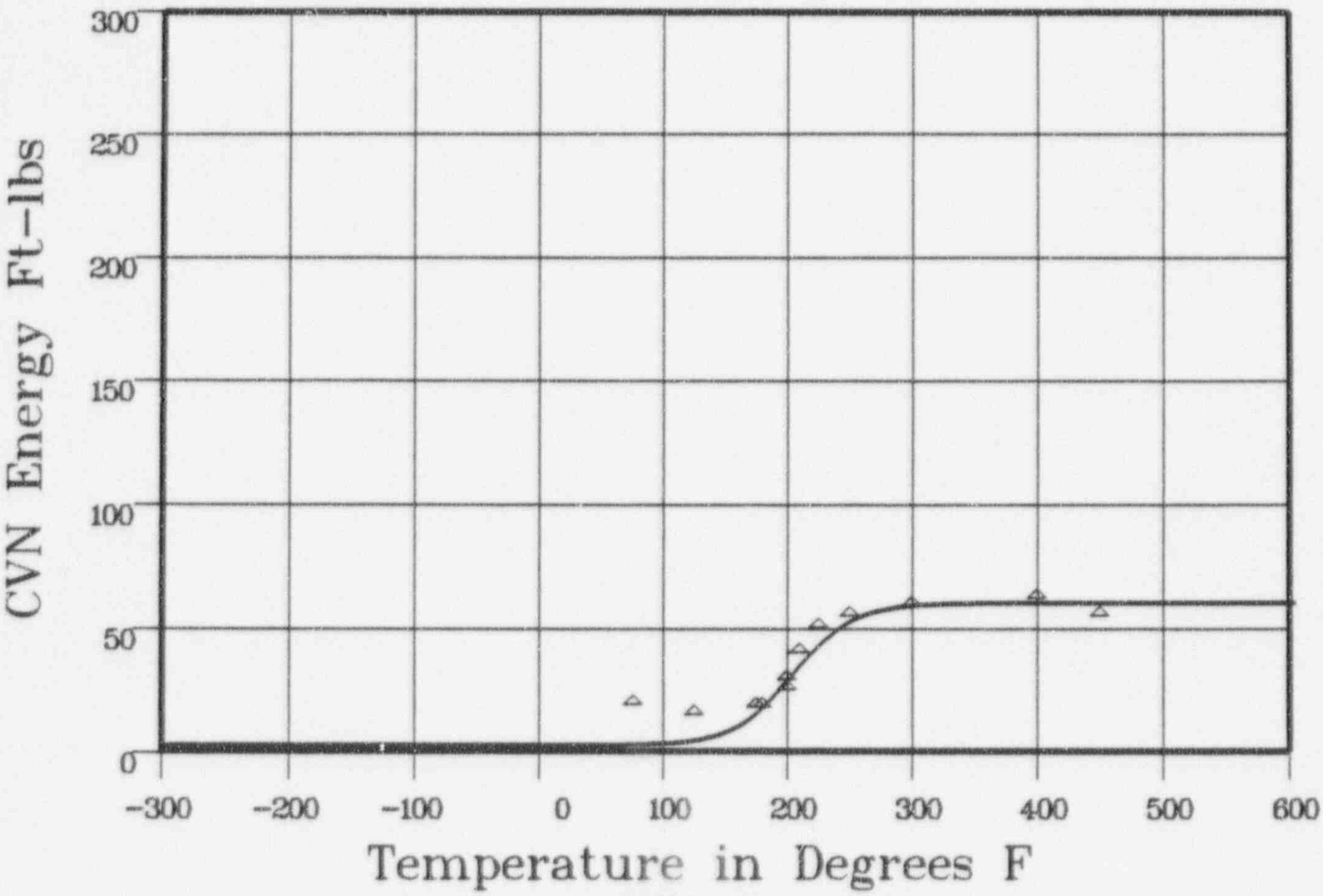
A = 31.12	B = 28.92	C = 48.2	T0 = 199.9

Equation is: CVN = A + B * [tanh((T - T0)/C)]

Upper Shelf Energy: 60.04 Temp. at 30 ft-lbs: 198 Temp. at 50 ft-lbs: 237.4 Lower Shelf Energy: 2.2 Fixed

Material: PLATE SA533B1 Heat Number: C6317-1 Orientation: TL

Capsule: W Total Fluence: 9.15E18



Data Set(s) Plotted

Plant: BV1 Cap.: W Material: PLATE SA533B1 Ori.: TL Heat #: C6317-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
76	19	2.53	16.46
125	15	4.67	10.32
175	18	17.38	.61
180	18	19.81	-1.81
200	29	31.18	-2.18
200	25	31.18	-6.18
210	40	37.09	2.9

**** Data continued on next page ****

Figure 5. Capsule W Charpy V-Notch Data (TL Orientation)

Beaver Valley Unit 1 – Base Metal/TL (W)

Material: PLATE SA533B1   Heat Number: C6317-1   Orientation: TL

Capsule: W   Total Fluence: 9.15E18

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
225	50	44.95	5.04
250	55	53.61	1.38
300	59	59.15	-.15
400	62	60.03	1.96
450	55	60.04	-5.04

SUM of RESIDUALS = 23.34

Beaver Valley Unit 1 - Base Metal/LT (Unirr)

CVGRAPH 4.0 Hyperbolic Tangent Curve Printed at 16:55:24 on 12-12-1995

Page 1

Coefficients of Curve 1

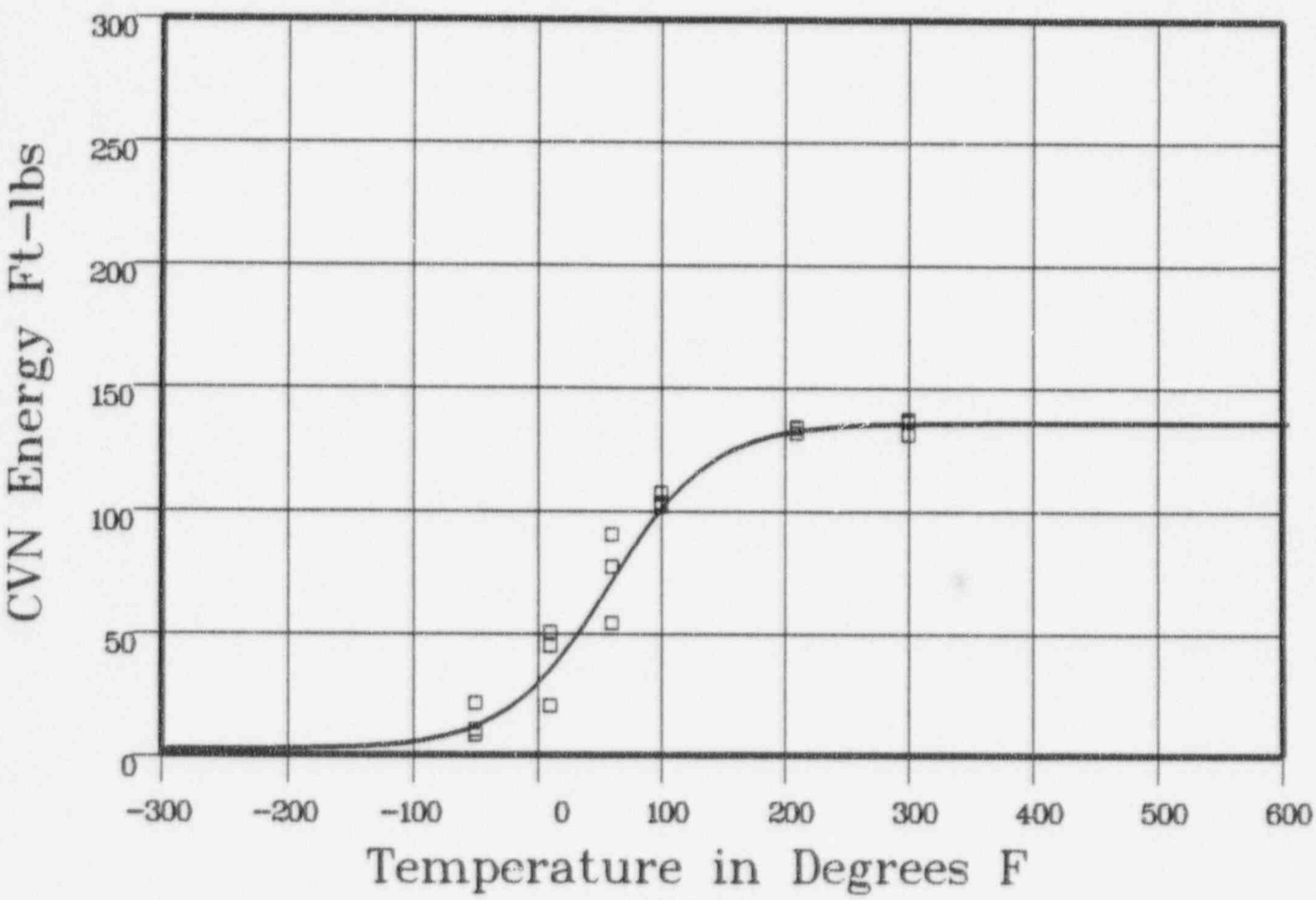
A = 68.93	B = 66.73	C = 83.76	T0 = 52.5

Equation is: CVN = A + B * [tanh((T - T0)/C)]

Upper Shelf Energy: 135.67 Temp. at 30 ft-lbs: -3.4 Temp. at 50 ft-lbs: 28 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C6317-1 Orientation: LT

Capsule: Unirr Total Fluence: 0.0



Data Set(s) Plotted

Plant: BV1 Cap.: Unirr Material: PLATE SA533B1 Ori.: LT Heat #: C6317-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	10	12.82	-2.82
-50	8	12.82	-4.82
-50	21	12.82	8.17
10	44.5	37.71	6.78
10	50	37.71	12.28
10	20	37.71	-17.71
60	77	74.89	2.1

**** Data continued on next page ****

Figure 6. Unirradiated Charpy V-Notch Data (LT Orientation)

Beaver Valley Unit 1 - Base Metal/LT (Unirr)

Material: PLATE SA533B1   Heat Number: C6317-1   Orientation: LT

Capsule: Unirr   Total Fluence: 0.0

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
60	90	74.89	15.1
60	54	74.89	-20.89
100	101.5	103.18	-1.68
100	103	103.18	-.18
100	107	103.18	3.81
210	134	132.63	1.36
210	133.5	132.63	.86
210	131.5	132.63	-1.13
300	131	135.31	-4.31
300	137	135.31	1.68
300	136	135.31	.68

SUM of RESIDUALS = -.72

Beaver Valley Unit 1 - Base Metal/LT (V)

CVGRAPH 4.0 Hyperbolic Tangent Curve Printed at 16:55:24 on 12-12-1995

Page 1

Coefficients of Curve 2

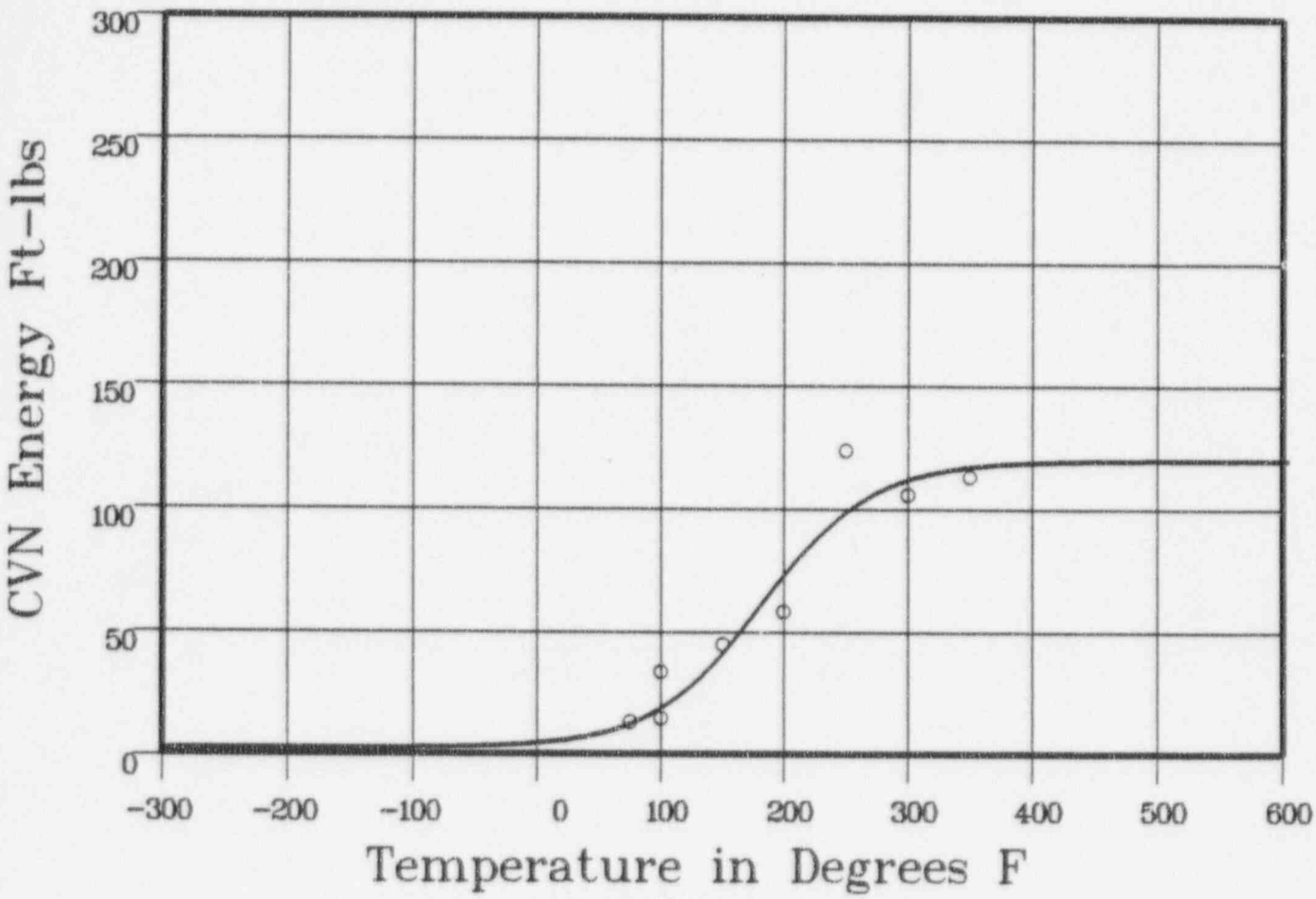
A = 60.85	B = 58.65	C = 89.99	T0 = 177.42

Equation is: CVN = A + B * [tanh((T - T0)/C)]

Upper Shelf Energy: 119.5 Temp. at 30 ft-lbs: 124.8 Temp. at 50 ft-lbs: 160.5 Lower Shelf Energy: 2.2 Fixed

Material: PLATE SA533B1 Heat Number: C6317-1 Orientation: LT

Capsule: V Total Fluence: 3.16E18



Data Set(s) Plotted

Plant: BV1 Cap: V Material: PLATE SA533B1 Ori: LT Heat #: C6317-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
75	13	13.12	-.12
100	14.5	20	-5.5
100	33.5	20	13.49
150	44.5	43.5	.99
200	58	75.25	-17.25
250	123.5	100	23.49
300	105.5	112.27	-6.77

**** Data continued on next page ****

Figure 7. Capsule V Charpy V-Notch Data (LT Orientation)

Beaver Valley Unit 1 - Base Metal/LT (V)

Material: PLATE SA533B1 Heat Number: C6317-1 Orientation: LT

Capsule: V Total Fluence: 3.16E18

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
350	113	117.02	-4.02

SUM of RESIDUALS = 4.29

Beaver Valley Unit 1 – Base Metal/LT (U)

CVGRAPH 4.0 Hyperbolic Tangent Curve Printed at 16:55:24 on 12-12-1995

Page 1

Coefficients of Curve 3

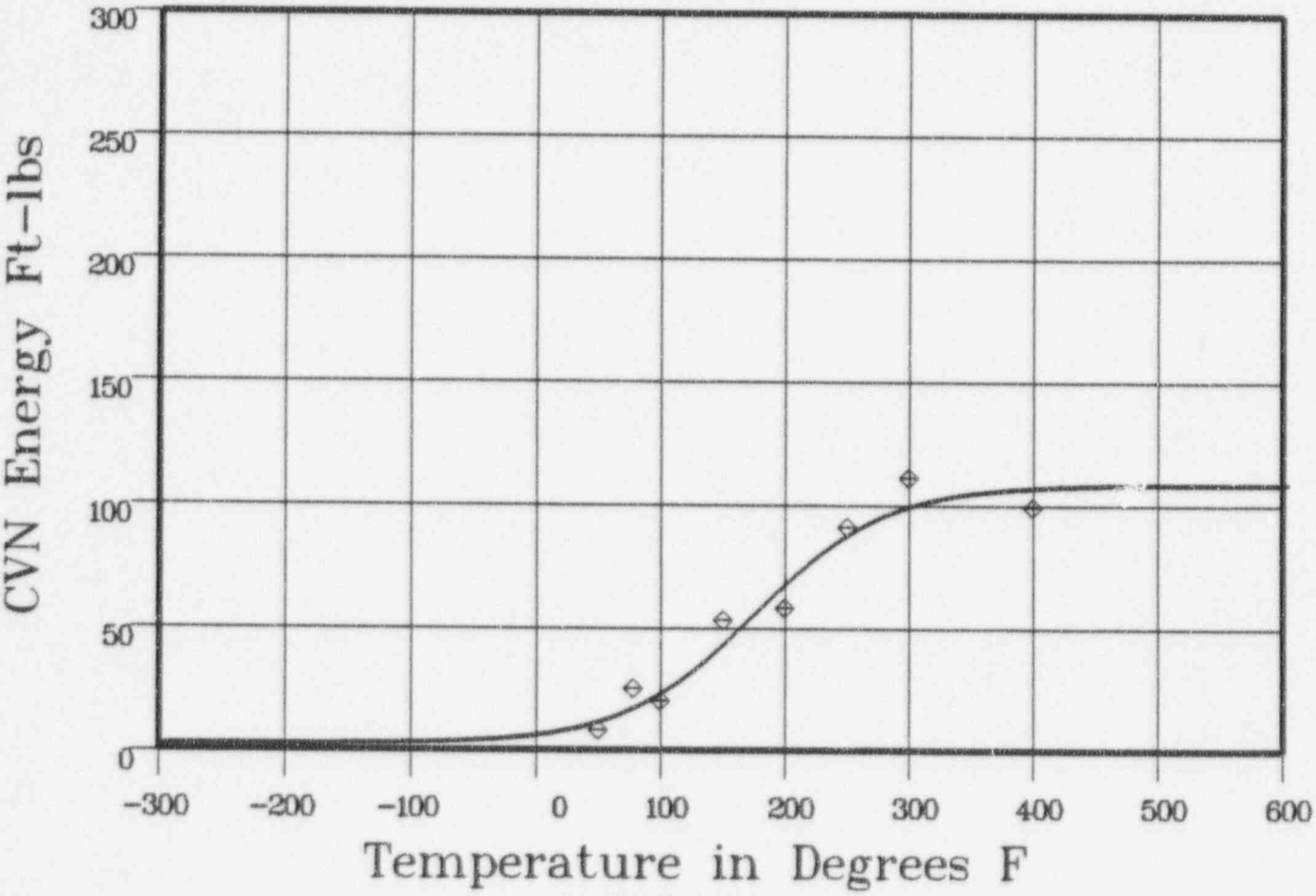
A = 55.23	B = 53.03	C = 106.02	T0 = 170.32

Equation is: $CVN = A + B * [\tanh((T - T0)/C)]$

Upper Shelf Energy: 108.26 Temp. at 30 ft-lbs: 115.4 Temp. at 50 ft-lbs: 159.8 Lower Shelf Energy: 2.2 Fixed

Material: PLATE SA533B1 Heat Number: C6317-1 Orientation: LT

Capsule: U Total Fluence: 6.90E18



Data Set(s) Plotted

Plant: BV1 Cap.: U Material: PLATE SA533B1 Ori.: LT Heat #: C6317-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	8	12.13	-4.13
78	25	18.01	6.98
100	20	24.44	-4.44
150	53	45.18	7.81
200	58	69.69	-11.69
250	91	88.96	2.03
300	111	99.81	11.18

**** Data continued on next page ****

Figure 8. Capsule U Charpy V-Notch Data (LT Orientation)

Beaver Valley Unit 1 - Base Metal/LT (U)

Material: PLATE SA533B1 Heat Number: C6317-1 Orientation: LT

Capsule: U Total Fluence: 6.90E18

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
400	99	106.89	-7.89

SUM of RESIDUALS = -.14

Beaver Valley Unit 1 – Base Metal/LT (W)

CVGRAPH 4.0 Hyperbolic Tangent Curve Printed at 16:55:24 on 12-12-1995

Page 1

Coefficients of Curve 4

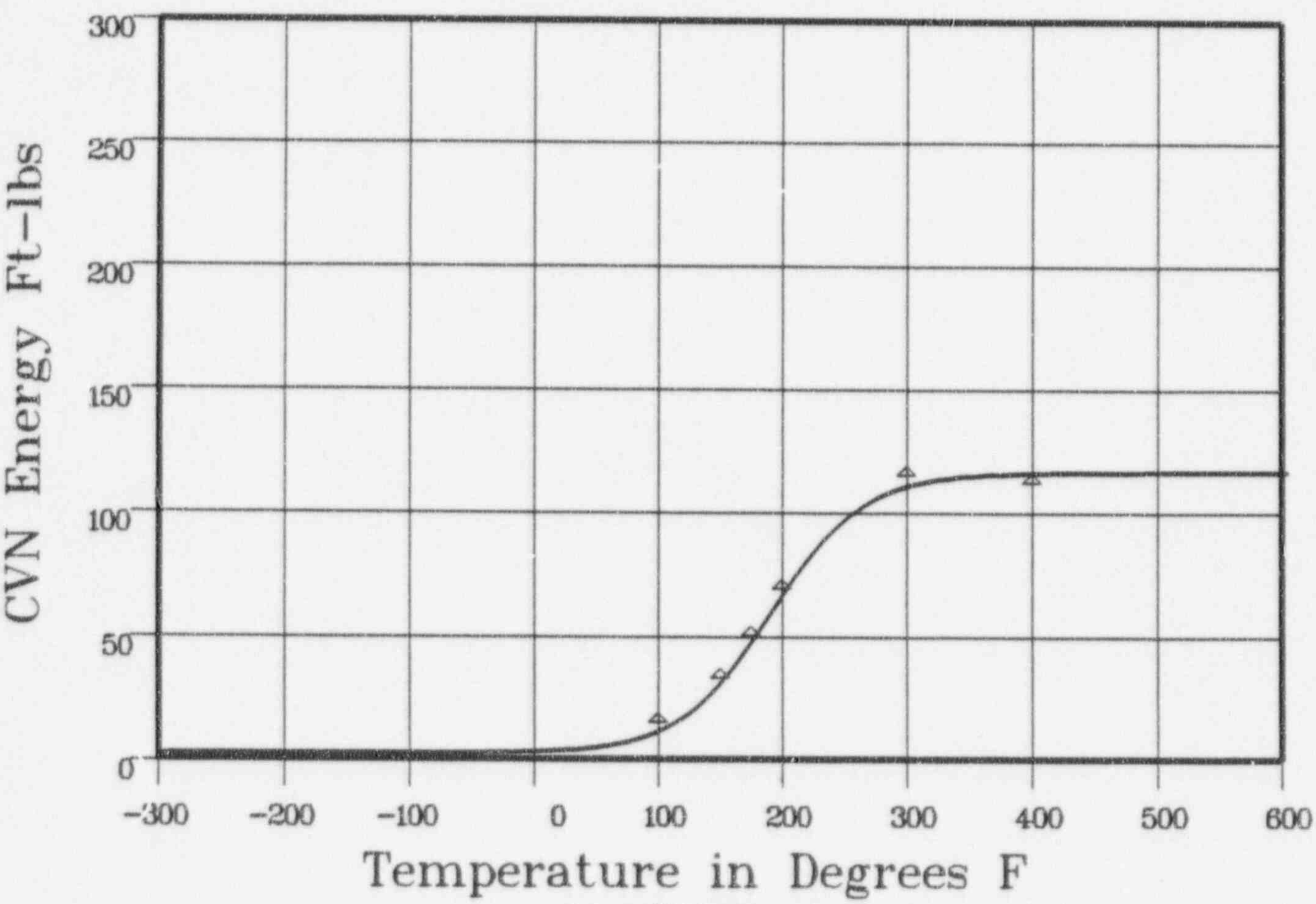
A = 59.15	B = 56.95	C = 74.27	T0 = 186.32

Equation is: CVN = A + B * [tanh((T - T0)/C)]

Upper Shelf Energy: 116.11 Temp. at 30 ft-lbs: 144.3 Temp. at 50 ft-lbs: 174.2 Lower Shelf Energy: 2.2 Fixed

Material: PLATE SA533B1 Heat Number: C6317-1 Orientation: LT

Capsule: W Total Fluence: 9.15E18



Data Set(s) Plotted

Plant: BV1 Cap.: W Material: PLATE SA533B1 Ori.: LT Heat #: C6317-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
100	15	12.35	2.64
150	33	33.32	-.32
175	50	50.53	-.53
200	69	69.52	-.52
300	115	111.01	3.98
400	112	115.75	-3.75

SUM of RESIDUALS = 1.48

Figure 9. Capsule W Charpy V-Notch Data (LT Orientation)

Beaver Valley Unit 1 - Weld Metal (Unirr)

CVGRAPH 4.0 Hyperbolic Tangent Curve Printed at 17:16:33 on 12-12-1995

Page 1

Coefficients of Curve 1

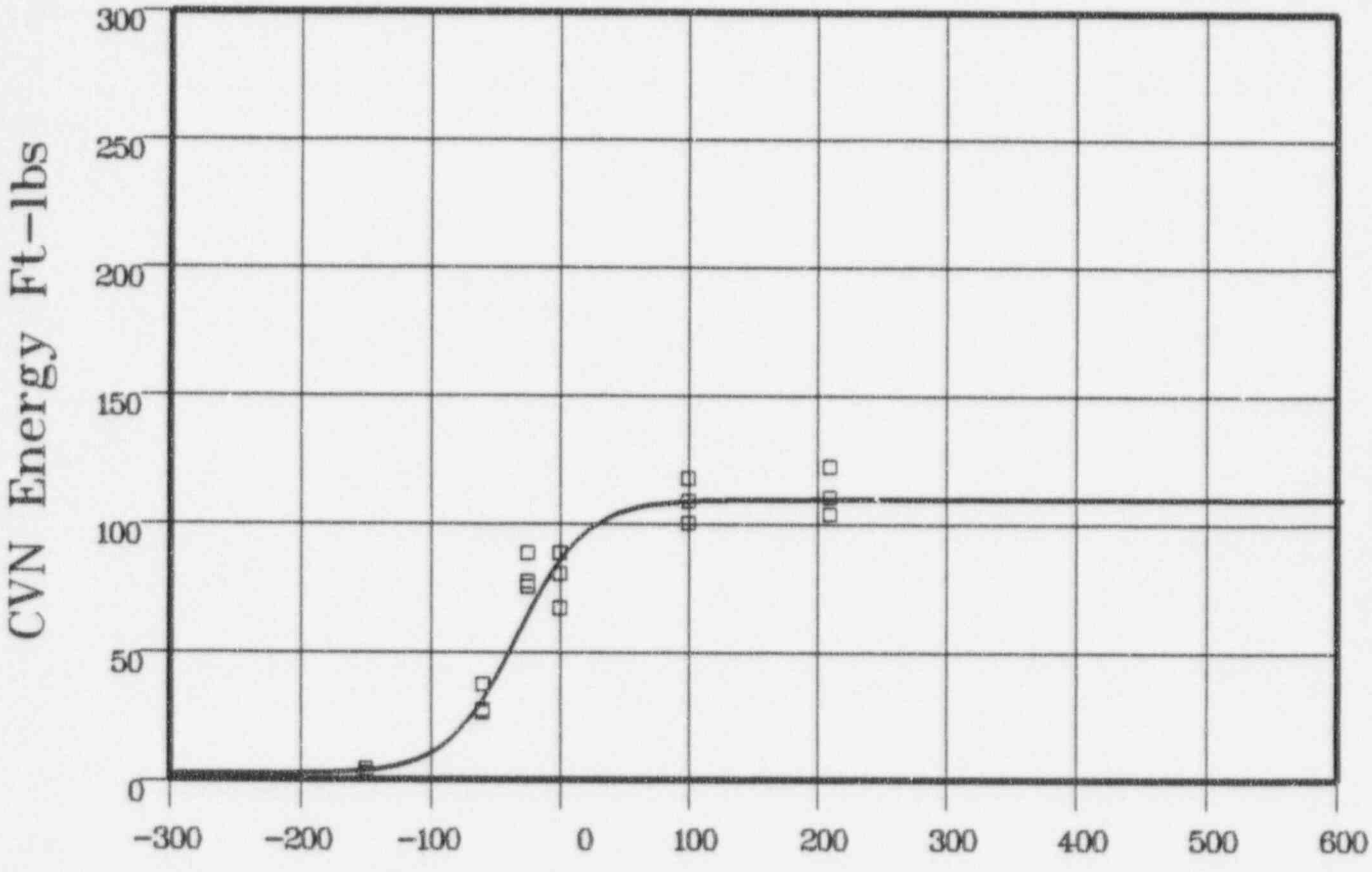
A = 55.73	B = 53.53	C = 53.68	T0 = -37.85

Equation is: CVN = A + B * [tanh((T - T0)/C)]

Upper Shelf Energy: 109.26 Temp. at 30 ft-lbs: -65.9 Temp. at 50 ft-lbs: -43.6 Lower Shelf Energy: 2.2 Fixed

Material: WELD Heat Number: 305424 Orientation:

Capsule: Unirr Total Fluence: 0.0



Data Set(s) Plotted

Plant: BV1 Cap.: Unirr Material: WELD Ori.: Heat #: 305424

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-150	2	3.81	-1.81
-150	4	3.81	.18
-150	2.5	3.81	-1.31
-60	26	34.82	-8.82
-60	37	34.82	2.17
-60	27	34.82	-7.82
-25	75	68.3	6.69

**** Data continued on next page ****

Figure 10. Unirradiated Charpy V-Notch Weld Data

Beaver Valley Unit 1 - Weld Metal (Unirr)

Material: WELD Heat Number: 305424 Orientation:

Capsule: Unirr Total Fluence: 0.0

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	88	68.3	19.69
-25	77	68.3	8.69
0	88	88.26	-.26
0	66.5	88.26	-21.76
0	80	88.26	-8.26
100	108.5	108.63	-.13
100	100	108.63	-8.63
100	117.5	108.63	8.86
210	103.5	109.25	-5.75
210	122	109.25	12.74
210	110	109.25	.74

SUM of RESIDUALS = -4.8

Beaver Valley Unit 1 - Weld Metal (V)

CVGRAPH 4.0 Hyperbolic Tangent Curve Printed at 17:16:33 on 12-12-1995

Page 1

Coefficients of Curve 2

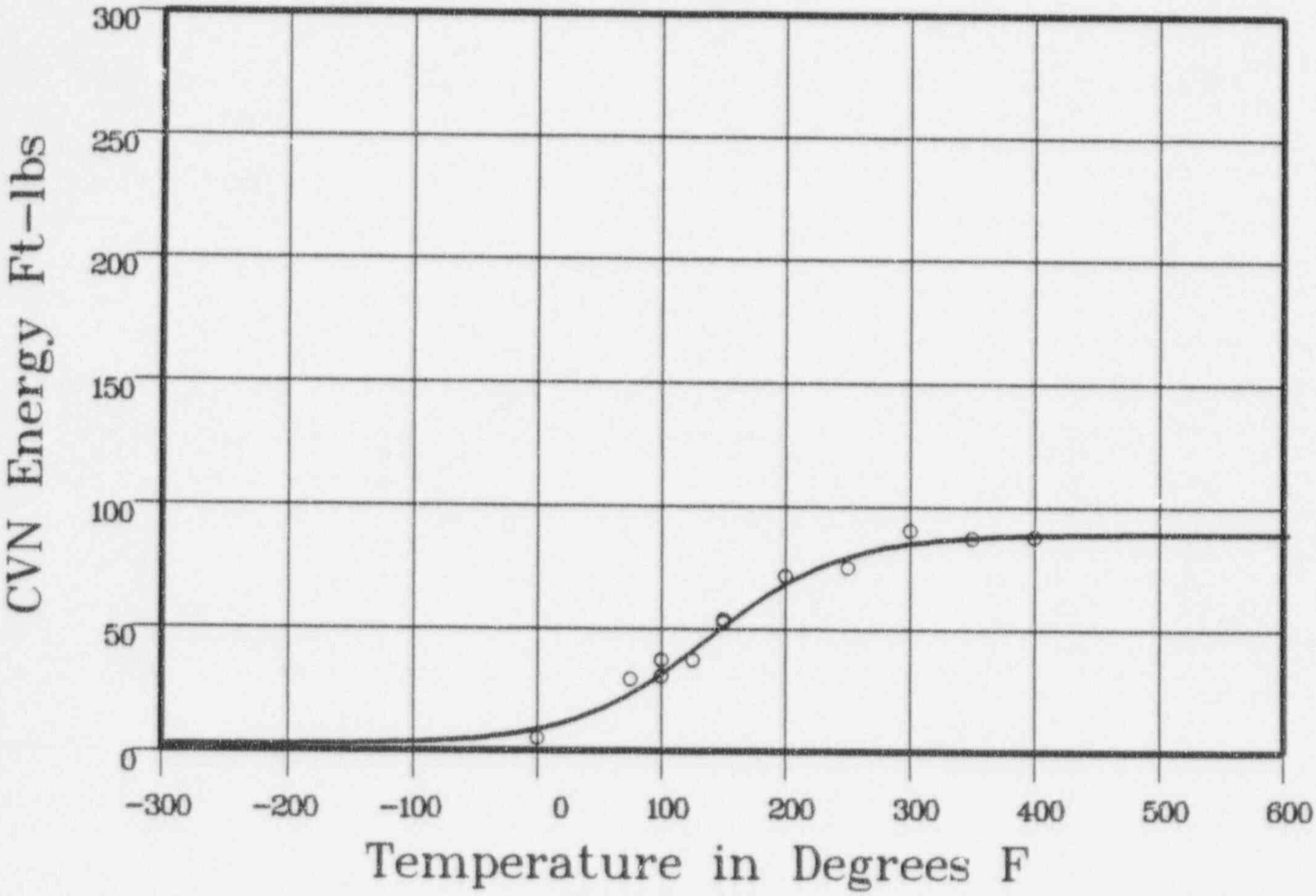
A = 45.56	B = 43.36	C = 109.18	T0 = 132.81

Equation is: CVN = A + B * [tanh((T - T0)/C)]

Upper Shelf Energy: 88.93 Temp. at 30 ft-lbs: 91.7 Temp. at 50 ft-lbs: 144 Lower Shelf Energy: 2.2 Fixed

Material: WELD Heat Number: 305424 Orientation:

Capsule: V Total Fluence: 3.16E18



Data Set(s) Plotted

Plant: BV1 Cap.: V Material: WELD Ori.: Heat #: 305424

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	5	9.2	-4.2
75	29	24.53	4.46
100	30.5	32.91	-2.41
100	37	32.91	4.08
125	37	42.47	-5.47
150	53.5	52.34	1.15
150	52.5	52.34	.15

**** Data continued on next page ****

Figure 11. Capsule V Charpy V-Notch Weld Data

Beaver Valley Unit 1 – Weld Metal (V)

Page 2

Material: WELD   Heat Number: 305424   Orientation:

Capsule: V   Total Fluence: 3.16E18

Charpy V–Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
200	71.5	69.33	2.16
250	75	79.86	−4.86
300	90	85.06	4.93
350	87	87.34	−.34
400	87.5	88.29	−.79

SUM of RESIDUALS = −1.12

Beaver Valley Unit 1 – Weld Metal (U)

CVGRAPH 4.0 Hyperbolic Tangent Curve Printed at 17:16:33 on 12-12-1995

Page 1

Coefficients of Curve 3

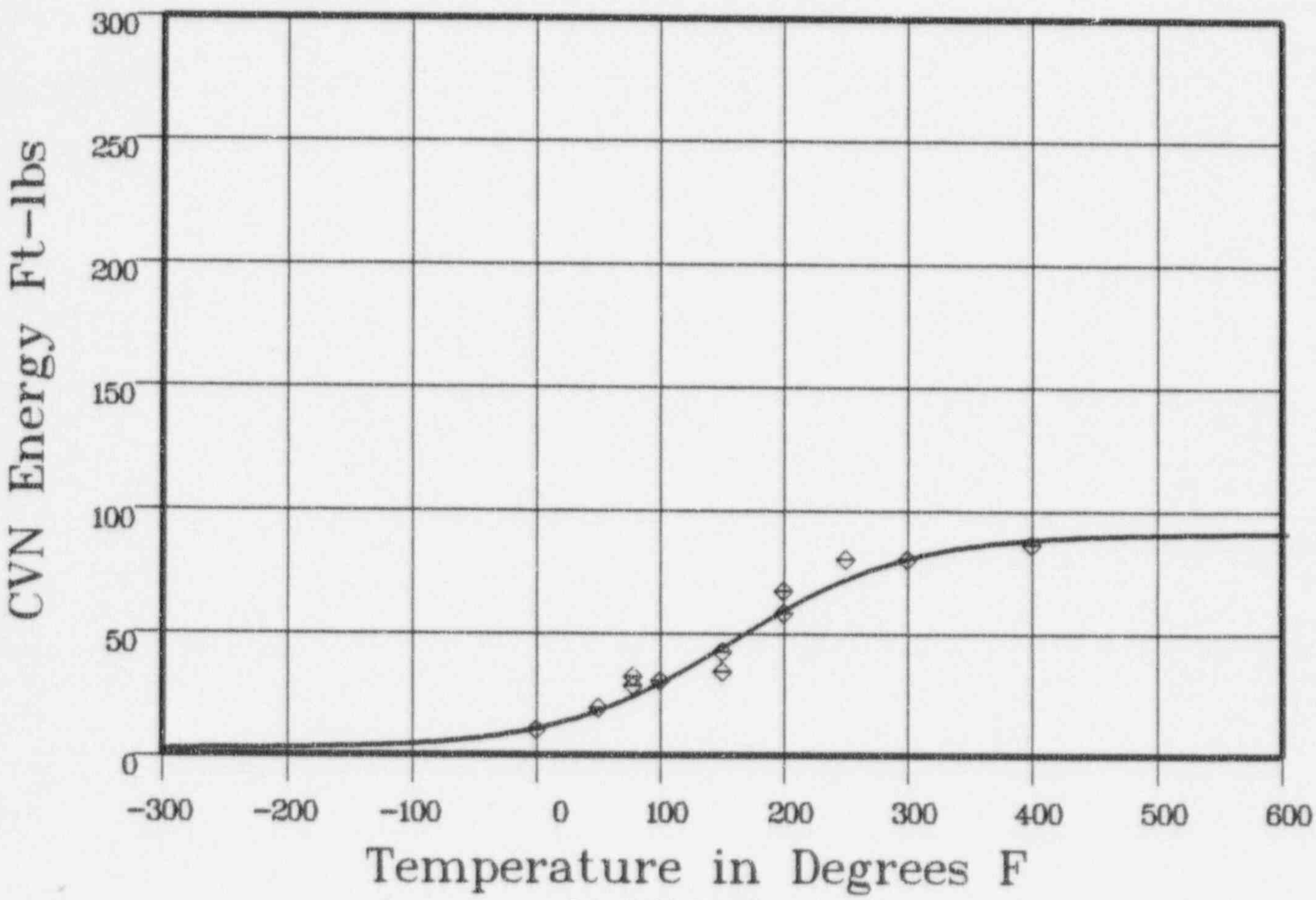
A = 46.5	B = 44.3	C = 141.38	T0 = 153.75

Equation is: $CVN = A + B * [\tanh((T - T0)/C)]$

Upper Shelf Energy: 90.8 Temp. at 30 ft-lbs: 98.4 Temp. at 50 ft-lbs: 164.9 Lower Shelf Energy: 2.2 Fixed

Material: WELD Heat Number: 305424 Orientation:

Capsule: U Total Fluence: 6.90E18



Data Set(s) Plotted

Plant: BV1 Cap.: U Material: WELD Ori.: Heat #: 305424

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	10	11.24	-1.24
50	19	18.79	.2
78	32	24.8	7.19
78	28	24.8	3.19
100	30	30.42	-.42
150	34	45.32	-11.32
150	42	45.32	-3.32

**** Data continued on next page ****

Figure 12. Capsule U Charpy V-Notch Weld Data

Beaver Valley Unit 1 - Weld Metal (U)

Material: WELD Heat Number: 305424 Orientation:

Capsule: U Total Fluence: 6.90E18

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
200	67	60.5	6.49
200	58	60.5	-2.5
250	80	72.73	7.26
300	80	80.87	-.87
400	86	88.16	-2.16

SUM of RESIDUALS = 2.48

Beaver Valley Unit 1 - Weld Metal (W)

CVGRAPH 4.0 Hyperbolic Tangent Curve Printed at 17:16:33 on 12-12-1995

Page 1

Coefficients of Curve 4

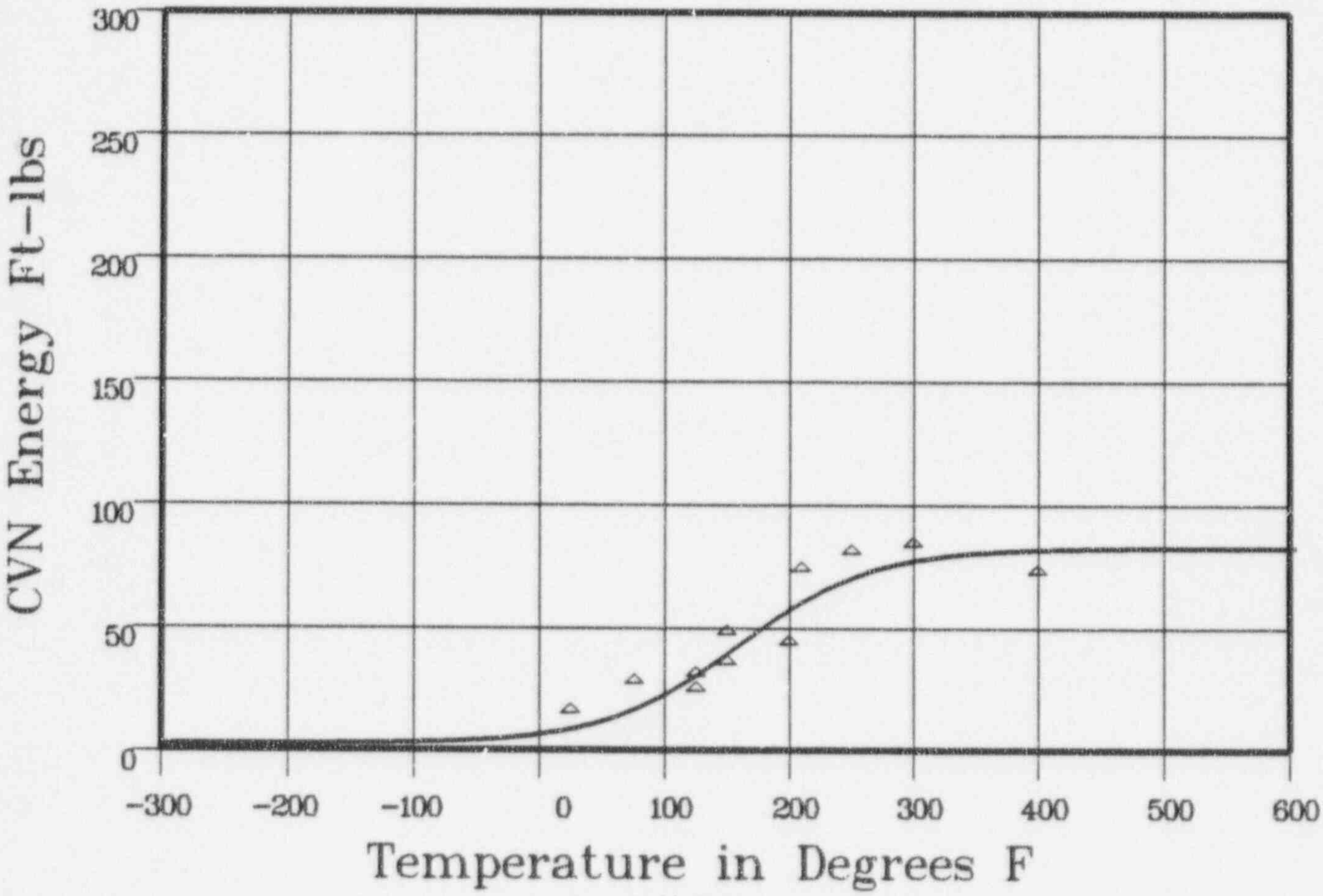
A = 42.3	B = 40.1	C = 107.92	T0 = 153.8

Equation is: CVN = A + B * [tanh((T - T0)/C)]

Upper Shelf Energy: 82.41 Temp. at 30 ft-lbs: 119.5 Temp. at 50 ft-lbs: 174.7 Lower Shelf Energy: 2.2 Fixed

Material: WELD Heat Number: 305424 Orientation:

Capsule: W Total Fluence: 9.15E18



Data Set(s) Plotted

Plant: BV1 Cap: W Material: WELD Ori: Heat #: 305424

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
25	15	8.95	6.04
76	27	17.54	9.45
125	30	31.84	-1.84
125	24	31.84	-7.84
150	35	40.89	-5.89
150	47	40.89	6.1
200	43	58.49	-15.49

**** Data continued on next page ****

Figure 13. Capsule W Charpy V-Notch Weld Data

Beaver Valley Unit 1 - Weld Metal (W)

Material: WELD   Heat Number: 305424   Orientation:

Capsule: W   Total Fluence: 9.15E18

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
210	73	61.48	11.51
250	80	70.86	9.13
300	83	77.4	5.59
400	72	81.58	-9.58

SUM of RESIDUALS = 7.2

APPENDIX B

Determination of Margin Term for Plate B6903-1 from Industry Data

Scatter of Embrittlement Data for Vessel Plate Materials

In the original development of the Regulatory Guide 1.99, Revision 2[B-1], embrittlement trend curves, 51 weld data points and 126 base metal data points existed in the database. Scatter in the predicted Charpy T_{30} shifts versus the actual measured T_{30} shift data was observed to be different between weld material and base metal material; the regression analyses performed at that time yielded mean residual errors of 28°F for welds and 17°F for base materials. Therefore, this was the basis for the margin term in Regulatory Guide 1.99, Revision 2. However, much new surveillance capsule data has been generated since the development of Regulatory Guide 1.99, Revision 2, and this study examined the scatter in the available surveillance database for base metal materials.

Around 200 data points now exist for shift in plates and forgings from commercial reactor surveillance capsule programs. These data have been gathered for inclusion in the new EPRI PREP4 database, and curve-fits to the new data have been performed by ATI Consulting. Updated fluence values were also used from the Westinghouse surveillance capsule neutron fluence reevaluation[B-2].

The actual measured versus predicted (Regulatory Guide 1.99, Revision 2) shift values were calculated and a statistical analysis performed to determine the scatter (i.e. sigma) for the overall data set. The combined plot showing the residual (actual minus predicted) scatter in the base metal data is shown in Figure 14. These data show more scatter than the original data set used to develop the Regulatory Guide 1.99, Revision 2, margin term. The residual scatter in the original 126 base metal data points varied from -50 to +50°F, with a 1-sigma value of 17°F while the residual scatter of the 194 data points shown in Figure 10 varied from -98 to +60°F, with a 1-sigma value of 29.1°F. The residual scatter of these data are characterized in the histogram shown in Figure 15. Additionally, the residual data distribution shows a characteristic normal distribution with a mean at -10.95°F. Therefore, this shows that the current Regulatory Guide 1.99, Revision 2, equations for predicting ΔRT_{NDT} in base metals tends to overpredict the amount of shift by approximately 11°F.

Furthermore, from the amount of scatter observed in all base metal data, actual data shift values falling within 1-sigma (i.e. 29.1°F) of the best-fit prediction would be determined to be credible by the Regulatory Guide 1.99, Revision 2, definition. The maximum scatter in these data is -27.5°F, which is well within 1-sigma of the scatter of all base metal data. A mean plus 1-sigma line is shown on the plot in Figure 14. It is noted that all of the Beaver Valley Unit 1 plate data fall within this upper bound line indicating that the data are credible.

Therefore, this mean plus 1-sigma bounding relation was used to predict the RT_{PTS} in the limiting lower shell plate B6903-1 from the Beaver Valley Unit 1 reactor vessel. The margin term to be used in calculating RT_{PTS} was reduced from a (2-sigma) value of 34°F to a (1-sigma) value of 29.1°F.

REFERENCES:

B-1. Regulatory Guide 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials", May 1988.

B-2. WCAP-14044, "Westinghouse Surveillance Capsule Neutron Fluence Reevaluation", E. P. Lippincott, April 1994.

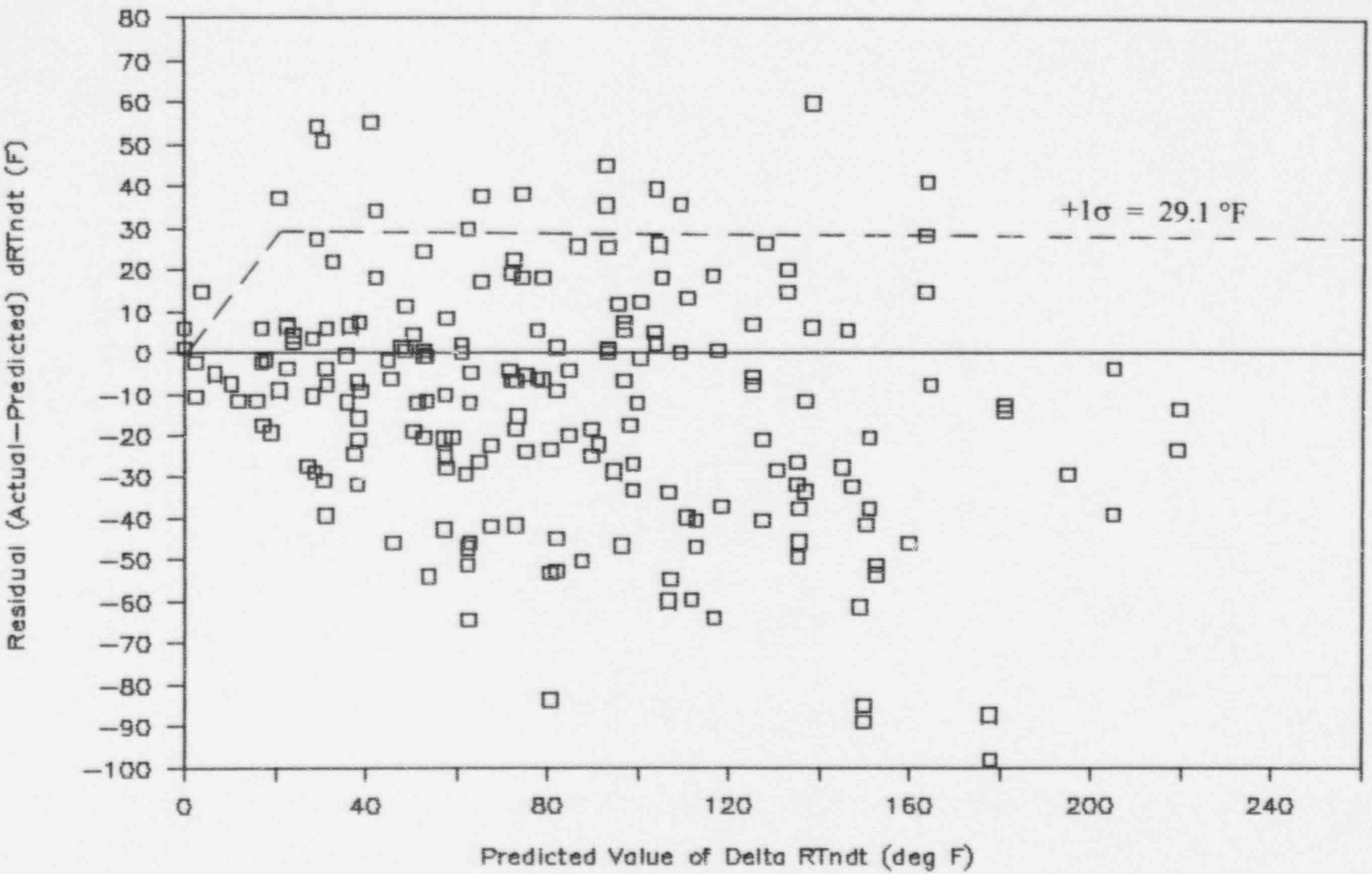


Figure 14 Calculated (Actual - Predicted) Scatter in Base Metal Data

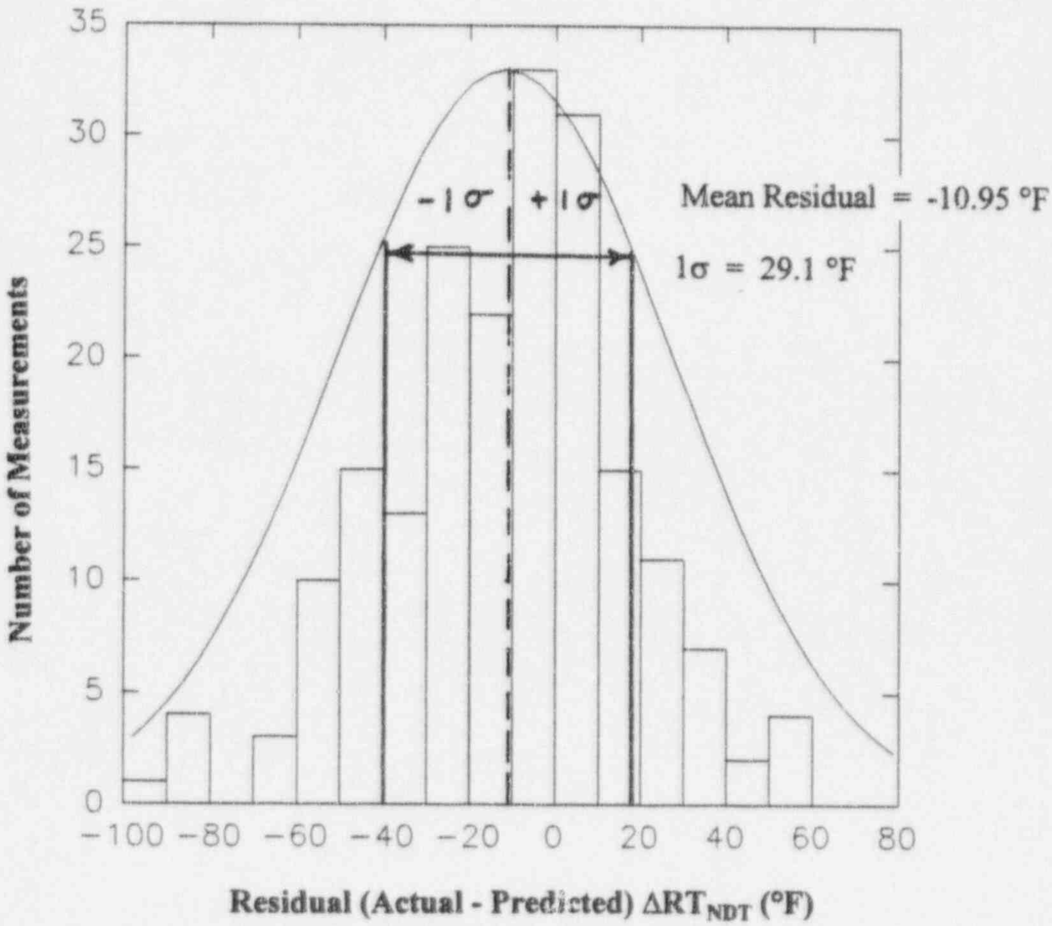


Figure 15 **Histogram Showing Calculated Scatter in Base Metal Data**