Westinghouse Non-Proprietary Class 3

WCAP-15078
Revision 1

Analysis of Capsule V from the Wolf Creek Nuclear Operating Corporation Wolf Creek Reactor Vessel Radiation Surveillance Program

Westinghouse Energy Systems

Westinghouse Non-Proprietary Class 3

WCAP-15078
Revision 1

Analysis of Capsule V from the Wolf Creek Nuclear Operating Corporation Wolf Creek Reactor Vessel Radiation Surveillance Program

Westinghouse Energy Systems

WCAP-15078

Revision 1

ANALYSIS OF CAPSULE V FROM THE WOLF CREEK NUCLEAR OPERATING CORPORATION WOLF CREEK REACTOR VESSEL RADIATION SURVEILLANCE PROGRAM

E. Terek

J. D. Perock

R. G. Lott

September 1998

Work Performed Under Shop Order K6TP-106

Prepared by the Westinghouse Electric Company
for the Wolf Creek Nuclear Operating Corporation

Approved: D. M. Trombola, Manager
Mechanical Systems Integration

Approved: C. H. Boyd
C. H. Boyd, Manager
Engineering & Materials Technology

WESTINGHOUSE ELECTRIC COMPANY
Nuclear Services Division
P.O. Box 355
Pittsburgh, Pennsylvania 15230-0355

This report has been technically reviewed and verified.

Reviewer:

Sections 1 through 5, 7, 8, Appendices A, B, C, and D	T. J. Laubham	T. J. Laubham
Section 6	G. K. Roberts	G K Roberts

TABLE OF CONTENTS

SECTION	TITLE	PAGE
1.0	SUMMARY OF RESULTS	1
2.0	INTRODUCTION	6
3.0	BACKGROUND	7
4.0	DESCRIPTION OF PROGRAM	9
5.0	TESTING OF SPECIMENS FROM CAPSULE V	19
	5.1 Overview	19
	5.2 Charpy V-Notch Impact Test Results	21
	5.3 Tensile Test Results	24
	5.4 1/2T Compact Tension Specimen Tests	25
6.0	RADIATION ANALYSIS AND NEUTRON DOSIMETRY	62
	6.1 Introduction	62
	6.2 Discrete Ordinates Analysis	63
	6.3 Neutron Dosimetry	67
	6.4 Projections of Pressure Vessel Exposure	72
7.0	SURVEILLANCE CAPSULE REMOVAL SCHEDULE	100
8.0	REFERENCES	101

ABLE OF CONTENTS (CONTINUED)

APPENDIX A - LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS

APPENDIX B - CHARPY V-NOTCH SHIFT RESULTS FOR EACH CAPSULE HAND-FIT VS. HYPERBOLIC TANGENT CURVE-FITTING METHOD (CVGRAPH, VERSION 4.1)

APPENDIX C - CHARPY V-NOTCH PLOTS FOR EACH CAPSULE USING HYPERBOLIC TANGENT CURVE-FITTING METHOD

APPENDIX D - Wolf Creek SURVEILLANCE PROGRAM CREDIBILITY ANALYSIS

LIST OF TABLES

Table	Title	Page
1-1	Effect of Irradiation to 2.528 X 10^{19} n/cm^2 (E > 1.0 MeV) on the Notch Toughness Properties of the Wolf Creek Reactor Vessel Surveillance Materials	4
1-2	Comparison of the Wolf Creek Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper Shelf Energy Decrease with Regulatory Guide 1.99, Revision 2, Predictions	5
4-1	Chemical Composition (wt%) of the Wolf Creek Reactor Vessel Beltline Region Surveillance Material	11
4-2	Heat Treatment of the Wolf Creek Reactor Vessel Surveillance Material	12
4-3	Chemical Composition of Four Wolf Creek Charpy Specimens Removed from Surveillance Capsule V	13
4-4	Chemistry Results from the NBS Certified Reference Standards	14
4-5	Chemistry Results from the NBS Certified Reference Standards	15
4-6	Best Estimate Cu and Ni Weight Percent Values for the Wolf Creek Lower Shell Plate R2508-3	16
4-7	Best Estimate Cu and Ni Weight Percent Values for the Wolf Creek Surveillance Program Weld Metal	16
5-1	Charpy V-notch Data for the Wolf Creek Lower Shell Plate R2508-3 Irradiated to a Fluence of 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV) (Longitudinal Orientation)	26

LIST OF TABLES (CONTINUED)

Table	Title	Page
5-2	Charpy V-notch Data for the Wolf Creek Lower Shell Plate R2508-3 Irradiated to a Fluence of 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV) (Transverse Orientation)	27
5-3	Charpy V-notch Data for the Wolf Creek Surveillance Weld Metal Irradiated to a Fluence of 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV)	28
5-4	Charpy V-notch Data for the Wolf Creek Heat-Affected-Zone (HAZ) Metal Irradiated to a Fluence of 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV)	29
5-5	Instrumented Charpy Impact Test Results for the Wolf Creek Lower Shell Plate R2508-3 Irradiated to a Fluence of 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV) (Longitudinal Orientation)	30
5-6	Instrumented Charpy Impact Test Results for the Wolf Creek Lower Shell Plate R2508-3 Irradiated to a Fluence of 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV) (Transverse Orientation)	31
5-7	Instrumented Charpy Impact Test Results for the Wolf Creek Surveillance Weld Metal Irradiated to a Fluence of 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV)	32
5-8	Instrumented Charpy Impact Test Results for the Wolf Creek Heat-Affected-Zone (HAZ) Metal Irradiated to a Fluence of 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV)	33
5-9	Effect Irradiation to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV) on the Notch Toughness Properties of the Wolf Creek Reactor Vessel Surveillance Materials	34

LIST OF TABLES (CONTINUED)

Table	Title	Page
5-10	Comparison of the Wolf Creek Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper Shelf Energy Decreases with Regulatory Guide 1.99, Revision 2, Predictions	35
5-11	Tensile Properties of the Wolf Creek Reactor Vessel Surveillance Materials Irradiated to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV)	36
6-1	Calculated Fast Neutron Exposure Rates and Iron Atom Displacement Rates at the Surveillance Capsule Center	76
6-2	Calculated Azimuthal Variation of Fast Neutron Exposure Rates and Iron Atom Displacement Rates at the Reactor Vessel Clad/Base Metal Interface	77
6-3	Relative Radial Distribution of ϕ(E > 1.0 MeV) Within the Reactor Vessel Wall	78
6-4	Relative Radial Distribution of ϕ(E > 0.1 MeV) Within the Reactor Vessel Wall	79
6-5	Relative Radial Distribution of dpa/sec Within the Reactor Vessel Wall	80
6-6	Nuclear Parameters Used in the Evaluation of Neutron Sensors	81
6-7	Monthly Thermal Generation During The First Nine Fuel Cycles of the Wolf Creek Reactor	82
6-8	Measured Sensor Activities and Reaction Rates	
	- Surveillance Capsule U	83
	- Surveillance Capsule Y	84
	- Surveillance Capsule V	85
6-9	Summary of Neutron Dosimetry Results Surveillance Capsules U, Y and V	86

LIST OF TABLES (CONTINUED)

Table	Title	Page
6-10	Comparison of Measured, Calculated and Best Estimate Reaction Rates at the Surveillance Capsule Center	87
6-11	Best Estimate Neutron Energy Spectrum at the Center of Surveillance Capsule	
	- Capsule U	88
	- Capsule Y	89
	- Capsule V	90
6-12	Comparison of Calculated and Best Estimate Integrated Neutron Exposure of Wolf Creek Surveillance Capsules U, Y and V	91
6-13	Azimuthal Variation of the Neutron Exposure Projections on the Reactor Vessel Clad/Base Metal Interface at Core Midplane	92
6-14	Neutron Exposure Values within the Wolf Creek Reactor Vessel	94
6-15	Updated Lead Factors for Wolf Creek Surveillance Capsules	96
6-16	Fast Neutron (E > 1.0 MeV) Fluence at the Beltline Locations as a Function of Full Power Operating Time	97
7-1	Wolf Creek Reactor Vessel Surveillance Capsule Withdrawal Schedule	95

LIST OF ILLUSTRATIONS

Figure	Title	Page
4-1	Arrangement of Surveillance Capsules in the Wolf Creek Reactor Vessel	17
4-2	Capsule V Diagram Showing the Location of Specimens, Thermal Monitors, and Dosimeters	18
5-1	Charpy V-Notch Impact Energy vs. Temperature for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Longitudinal Orientation)	37
5-2	Charpy V-Notch Lateral Expansion vs. Temperature for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Longitudinal Orientation)	38
5-3	Charpy V-Notch Percent Shear vs. Temperature for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Longitudinal Orientation)	39
5-4	Charpy V-Notch Impact Energy vs. Temperature for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Transverse Orientation)	40
5-5	Charpy V-Notch Lateral Expansion vs. Temperature for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Transverse Orientation)	41
5-6	Charpy V-Notch Percent Shear vs. Temperature for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Transverse Orientation)	42
5-7	Charpy V-Notch Impact Energy vs. Temperature for Wolf Creek Reactor Vessel Weld Metal	43
5-8	Charpy V-Notch Lateral Expansion vs. Temperature for Wolf Creek Reactor Vessel Weld Metal	44

LIST OF ILLUSTRATIONS (CONTINUED)

Figure	Title	Page
5-9	Charpy V-Notch Percent Shear vs. Temperature for Wolf Creek Reactor Vessel Weld Metal	45
5-10	Charpy V-Notch Impact Energy vs. Temperature for Wolf Creek Reactor Vessel Heat-Affected-Zone Material	46
5-11	Charpy V-Notch Lateral Expansion vs. Temperature for Wolf Creek Reactor Vessel Heat-Affected-Zone Material	47
5-12	Charpy V-Notch Percent Shear vs. Temperature for Wolf Creek Reactor Vessel Heat-Affected-Zone Material	48
5-13	Charpy Impact Specimen Fracture Surfaces for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Longitudinal Orientation)	49
5-14	Charpy Impact Specimen Fracture Surfaces for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Transverse Orientation)	50
5-15	Charpy Impact Specimen Fracture Surfaces for Wolf Creek Reactor Vessel Weld Metal	51
5-16	Charpy Impact Specimen Fracture Surfaces for Wolf Creek Reactor Vessel Heat-Affected-Zone Metal	52
5-17	Tensile Properties for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Longitudinal Orientation)	53
5-18	Tensile Properties for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Transverse Orientation)	54

LIST OF ILLUSTRATIONS (CONTINUED)

Figure	Title	Page
5-19	Tensile Properties for Wolf Creek Reactor Vessel Weld Metal	55
5-20	Fractured Tensile Specimens from Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Longitudinal Orientation)	56
5-21	Fractured Tensile Specimens from Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Transverse Orientation)	57
5-22	Fractured Tensile Specimens from Wolf Creek Reactor Vessel Weld Metal	58
5-23	Engineering Stress-Strain Curves for Lower Shell Plate R2508-3 Tensile Specimens AL4, AL5 and AL6 (Longitudinal Orientation)	59
5-24	Engineering Stress-Strain Curves for Lower Shell Plate R2508-3 Tensile Specimens AT4, AT5 and AT6 (Longitudinal Orientation)	60
5-25	Engineering Stress-Strain Curves for Surveillance Weld Metal Tensile Specimens AW4, AW5 and AW6	61
6-1	Plan View of a Dual Reactor Vessel Surveillance Capsule	98
6-2	Fast Neutron (E > 1.0 MeV) Fluence at the Beltline Locations as a Function of Full Power Operating Time	99

SECTION 1.0
SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance capsule V, the third capsule to be removed from the Wolf Creek reactor pressure vessel, led to the following conclusions:

- The capsule received an average fast neutron fluence (E > 1.0 MeV) of 2.528 x 10^{19} n/cm^2 after 9.49 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel lower shell plate R2508-3 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction of the plate (longitudinal orientation), to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 52.03°F and a 50 ft-lb transition temperature increase of 46.86°F. This results in an irradiated 30 ft-lb transition temperature of 27.08°F and an irradiated 50 ft-lb transition temperature of 46.98°F for the longitudinally oriented specimens.

- Irradiation of the reactor vessel lower shell plate R2508-3 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction of the plate (transverse orientation), to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 54.53°F and a 50 ft-lb transition temperature increase of 56.27°F. This results in an irradiated 30 ft-lb transition temperature of 56.54°F and an irradiated 50 ft-lb transition temperature of 90.59°F for transversely oriented specimens.

- Irradiation of the weld metal Charpy specimens to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 46.33°F and a 50 ft-lb transition temperature increase of 52.44°F. This results in an irradiated 30 ft-lb transition temperature of -11.36°F and an irradiated 50 ft-lb transition temperature of 31.79°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 55.91°F and a 50 ft-lb transition temperature increase of 52.01°F. This results in an irradiated 30 ft-lb transition temperature of -88.09°F and an irradiated 50 ft-lb transition temperature of -61.99°F.

- The average upper shelf energy of the lower shell plate R2508-3 (longitudinal orientation) resulted in an average energy decrease of 19 ft-lb after irradiation to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 129 ft-lb for the longitudinally oriented specimens.

- The average upper shelf energy of the lower shell plate R2508-3 (transverse orientation) resulted in an average energy decrease of 6 ft-lb after irradiation to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 88 ft-lb for the transversely oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted in an average energy decrease of 11 ft-lb after irradiation to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 89 ft-lb for the weld metal specimens.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in an average energy increase of 6 ft-lb after irradiation to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV). Hence, this result will be conservatively reported as an unchanged average upper shelf energy of 161 ft-lb for the weld HAZ metal.

- A comparison of the Wolf Creek reactor vessel beltline material test results with the Regulatory Guide 1.99, Revision 2[1], predictions led to the following conclusions:

  - The measured 30 ft-lb shift in transition temperature values of the surveillance materials are less than the Regulatory Guide 1.99, Revision 2, predictions.

  - The measured percent decrease in upper shelf energy for all surveillance materials is less than the Regulatory Guide 1.99, Revision 2, prediction.

The above results can be found in tabular form in Tables 1-1 and 1-2.

- o The calculated end-of-license (35 EFPY) neutron fluence (E > 1.0 MeV) at the core midplane for the Wolf Creek reactor vessel is as follows:

  Vessel inner radius* $= 2.18 \times 10^{19}$ n/cm^2
  Vessel 1/4 thickness $= 1.30 \times 10^{19}$ n/cm^2
  Vessel 3/4 thickness $= 4.61 \times 10^{18}$ n/cm^2

  * Clad/base metal interface

- o The credibility evaluation of the Wolf Creek surveillance program presented in Appendix D of this report indicates that the Wolf Creek reactor vessel surveillance results are credible.

- o All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are expected to maintain an upper shelf energy greater than 50 ft-lb throughout the life of the vessel (35 EFPY) as required by 10CFR50, Appendix G[2].

TABLE 1-1												
Effect of Irradiation to 2.528 X 10^{19} n/cm^2 (E > 1.0 MeV) on the Notch Toughness Properties of the Wolf Creek Reactor Vessel Surveillance Materials												
Material	Average 30 (ft-lb) [a] Transition Temperature (°F)			Average 35 mil Lateral [b] Expansion Temperature (°F)			Average 50 ft-lb [a] Transition Temperature (°F)			Average Energy Absorption [a] at Full Shear (ft-lb)		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔE
Lower Shell Plate R2508-3 (Longitudinal)	- 24.95	27.08	52.03	- 0.4	53.35	53.75	0.11	46.98	46.86	148	129	- 19
Lower Shell Plate R2508-3 (Transverse)	2.0	56.54	54.53	25.44	93.79	68.34	34.32	90.59	56.27	94	88	- 6
Weld Metal	- 57.69	- 11.36	46.33	-27.07	45.52	72.59	-20.64	31.79	52.44	100	89	- 11
HAZ Metal	- 144.01	- 88.09	55.91	- 89.78	- 43.6	46.18	- 114.0	- 61.99	52.01	161	167	+ 6

(a) "Average" is defined as the value read from the curve fit through the data points of the Charpy tests (see Figures 5-1, 5-4, 5-7 and 5-10).

(b) "Average" is defined as the value read from the curve fit through the data points of the Charpy tests (see Figures 5-2, 5-5, 5-8 and 5-11).

TABLE 1-2						
Comparison of the Wolf Creek Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper Shelf Energy Decreases with Regulatory Guide 1.99, Revision 2, Predictions						
Material	Capsule	Fluence (n/cm^2, E > 1.0 MeV)	30 ft-lb Transition Temperature Shift		Upper Shelf Energy Decrease	
			Predicted (°F) (a)	Measured (°F) (b)	Predicted (%) (a)	Measured (%) (c)
Lower Shell Plate R2508-3 (Longitudinal)	U	3.429×10^{18}	40.9	36.46	14.5	2
	Y	1.308×10^{19}	62.4	16.03	20.0	11
	V	2.528×10^{19}	72.4	52.03	24.0	13
Lower Shell Plate R2508-3 (Transverse)	U	3.429×10^{18}	40.9	23.79	14.5	0
	Y	1.308×10^{19}	62.4	35.39	20.0	0
	V	2.528×10^{19}	72.4	54.53	24.0	6
Weld Metal	U	3.429×10^{18}	30.7	27.21	16.5	8
	Y	1.308×10^{19}	46.8	45.09	22.5	6
	V	2.528×10^{19}	54.3	46.33	26.5	11
HAZ Metal	U	3.429×10^{18}	- -	58.41	- -	13
	Y	1.308×10^{19}	- -	12.98	- -	0
	V	2.528×10^{19}	- -	55.91	- -	0

(a) Based on Regulatory Guide 1.99, Revision 2, methodology using the mean weight percent values of copper and nickel of the surveillance material (see Tables 4-6 and 4-7 of this report).

(b) Calculated using measured Charpy data plotted using CVGRAPH, Version 4.1 (See Appendix C).

(c) Values are based on the definition of upper shelf energy given in ASTM E185-82.

SECTION 2.0
INTRODUCTION

This report presents the results of the examination of capsule V, the third capsule to be removed from the reactor in the continuing surveillance program which monitors the effects of neutron irradiation on the Wolf Creek Nuclear Operating Corporation Wolf Creek reactor pressure vessel materials under actual operating conditions.

The surveillance program for the Wolf Creek Nuclear Operating Corporation Wolf Creek reactor pressure vessel materials was designed and recommended by the Westinghouse Electric Corporation. A description of the surveillance program and the preirradiation mechanical properties of the reactor vessel materials is presented in WCAP-10015, "Kansas Gas and Electric Company Wolf Creek Generation Station Unit No. 1 Reactor Vessel Radiation Surveillance Program"[3]. The surveillance program was planned to cover the 40-year design life of the reactor pressure vessel and was based on ASTM E185-79, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels". Capsule V was removed from the reactor after 9.49 EFPY of exposure and shipped to the Westinghouse Science and Technology Center Hot Cell Facility, where the postirradiation mechanical testing of the Charpy V-notch impact and tensile surveillance specimens was performed.

This report summarizes the testing of and the postirradiation data obtained from surveillance capsule V removed from the Wolf Creek Nuclear Operating Corporation Wolf Creek reactor vessel and discusses the analysis of the data.

SECTION 3.0
BACKGROUND

The ability of the large steel pressure vessel containing the reactor core and its primary coolant to resist fracture constitutes an important factor in ensuring safety in the nuclear industry. The beltline region of the reactor pressure vessel is the most critical region of the vessel because it is subjected to significant fast neutron bombardment. The overall effects of fast neutron irradiation on the mechanical properties of low alloy, ferritic pressure vessel steels such as A533 Grade B Class 1 (base material of the Wolf Creek reactor pressure vessel beltline) are well documented in the literature. Generally, low alloy ferritic materials show an increase in hardness and tensile properties and a decrease in ductility and toughness during high-energy irradiation.

A method for ensuring the integrity of reactor pressure vessels has been presented in "Fracture Toughness Criteria for Protection Against Failure," Appendix G to Section XI of the ASME Boiler and Pressure Vessel Code[4]. The method uses fracture mechanics concepts and is based on the reference nil-ductility transition temperature (RT_{NDT}).

RT_{NDT} is defined as the greater of either the drop weight nil-ductility transition temperature (NDTT per ASTM E-208[5]) or the temperature 60°F less than the 50 ft-lb (and 35-mil lateral expansion) temperature as determined from Charpy specimens oriented perpendicular (transverse) to the major working direction of the plate. The RT_{NDT} of a given material is used to index that material to a reference stress intensity factor curve (K_{Ia} curve) which appears in Appendix G to the ASME Code[4]. The K_{Ia} curve is a lower bound of dynamic, crack arrest, and static fracture toughness results obtained from several heats of pressure vessel steel. When a given material is indexed to the K_{Ia} curve, allowable stress intensity factors can be obtained for this material as a function of temperature. Allowable operating limits can then be determined using these allowable stress intensity factors.

RT_{NDT} and, in turn, the operating limits of nuclear power plants can be adjusted to account for the effects of radiation on the reactor vessel material properties. The changes in mechanical properties of a given reactor pressure vessel steel, due to irradiation, can be monitored by a reactor surveillance program, such as the Wolf Creek reactor vessel radiation surveillance program[3], in which a surveillance capsule is periodically removed from the operating nuclear reactor and the encapsulated specimens tested. The increase in the average Charpy V-notch 30 ft-lb temperature

(ΔRT_{NDT}) due to irradiation is added to the initial RT_{NDT}, along with a margin (M) to cover uncertainties, to adjust the RT_{NDT} (ART) for radiation embrittlement. This ART (RT_{NDT} initial + M + ΔRT_{NDT}) is used to index the material to the K_{Ia} curve and, in turn, to set operating limits for the nuclear power plant that take into account the effects of irradiation on the reactor vessel materials.

SECTION 4.0
DESCRIPTION OF PROGRAM

Six surveillance capsules for monitoring the effects of neutron exposure on the Wolf Creek reactor pressure vessel core region (beltline) materials were inserted in the reactor vessel prior to initial plant start-up. The six capsules were positioned in the reactor vessel between the neutron pads and the vessel wall as shown in Figure 4-1. The vertical center of the capsules is opposite the vertical center of the core. The capsules contain specimens made from lower shell plate R2508-3, weld metal fabricated with Weld Wire Type B4, Heat Number 90146 and Linde Type 124 flux, Lot Number 1061, which is identical to that used in the actual fabrication of the intermediate to lower shell circumferential weld seam. The surveillance weld was fabricated with the same heat of weld wire as all beltline region welds and is therefore representative of all of the reactor vessel beltline region welds.

Capsule V was removed after 9.49 effective full power years (EFPY) of plant operation. This capsule contained Charpy V-notch, tensile, and 1/2T-CT fracture mechanics specimens made from lower shell plate R2508-3 and submerged arc weld metal representative of all of the reactor vessel beltline region welds. In addition, this capsule contained Charpy V-notch specimens from the weld Heat-Affected-Zone (HAZ) of lower shell plate R2508-3.

Test material obtained from the lower shell course plate (after the thermal heat treatment and forming of the plate) was taken at least one plate thickness from the quenched ends of the plate. All test specimens were machined from the 1/4 thickness location of the plate after performing a simulated postweld stress-relieving treatment on the test material and also from weld and heat-affected-zone metal of a stress-relieved weldment joining lower shell plate R2508-1 and adjacent lower shell plate R2508-3. All heat-affected-zone specimens were obtained from the weld heat-affected-zone of lower shell plate R2508-3.

Charpy V-notch impact specimens from lower shell plate R2508-3 were machined with some in the longitudinal orientation (longitudinal axis of the specimen parallel to the major working direction of the plate) and some in the transverse orientation (longitudinal axis of the specimen perpendicular to the major working direction of the plate). The core region weld Charpy impact specimens were machined from the weldment such that the long dimension of each Charpy specimen was perpendicular to the weld direction. The notch of the weld metal Charpy specimens was machined such that the direction of crack propagation in the specimen was in the welding direction.

Tensile specimens from lower shell plate R2508-3 were machined in both the longitudinal and transverse orientation. Tensile specimens from the weld metal were oriented with the long dimension of the specimen perpendicular to the weld direction.

Compact tension test specimens from lower shell plate R2508-3 were machined in both the transverse and longitudinal orientations. Compact tension test specimens from the weld metal were machined perpendicular to the weld direction with the notch oriented in the direction of welding. All specimens were fatigue precracked according to ASTM E399.

The chemical composition and heat treatment of the unirradiated surveillance material is presented in Tables 4-1 and 4-2, respectively. The data in Tables 4-1 and 4-2 was obtained from the unirradiated surveillance program, WCAP-10015, Appendix A[3]. Contained in Table 4-3 is the results of a chemical analysis performed on four Charpy specimens removed from capsule V. The results of the NBS certified standards are presented in Tables 4-4 and 4-5. Contained in Tables 4-6 and 4-7 is the determination of the best estimate copper and nickel values for the surveillance materials.

Capsule V contained dosimeter wires of pure copper, iron, nickel, and aluminum-0.15 weight percent cobalt (cadmium-shielded and unshielded). In addition, cadmium shielded dosimeters of neptunium (Np^{237}) and uranium (U^{238}) were placed in the capsule to measure the integrated flux at specific neutron energy levels.

The capsule contained thermal monitors made from two low-melting-point eutectic alloys and sealed in Pyrex tubes. These thermal monitors were used to define the maximum temperature attained by the test specimens during irradiation. The composition of the two eutectic alloys and their melting points are as follows:

2.5% Ag, 97.5% Pb	Melting Point: 579°F (304°C)
1.5% Ag, 1.0% Sn, 97.5% Pb	Melting Point: 590°F (310°C)

The arrangement of the various mechanical specimens, dosimeters and thermal monitors contained in capsule V is shown in Figure 4-2.

TABLE 4-1		
Chemical Composition (wt%) of the Wolf Creek Reactor Vessel Beltline Region Surveillance Material[3]		
Element	Lower Shell Plate R2508-3	Weld Metal[a]
C	0.20	0.11
Mn	1.45	1.46
P	0.008	0.005
S	0.010	0.011
Si	0.20	0.48
Ni	0.62	0.09
Mo	0.55	0.56
Cr	0.05	0.09
Cu	0.07	0.04
Al	0.032	0.009
Co	0.014	0.010
Pb	<0.001	<0.001
W	<0.01	<0.01
Ti	<0.01	<0.01
Zr	<0.001	<0.001
V	0.003	0.005
Sn	0.002	0.003
As	0.007	0.004
Cb	<0.01	<0.01
N_2	0.007	0.006
B	<0.001	<0.001

a) Weld Wire Type B4, Heat Number 90146, Flux Type Linde 124, and Flux Lot Number 1061. Surveillance weldment is from a weld between the Lower shell plates R2508-3 and R2508-1 and is identical to the intermediate to lower shell circumferential weld seam. In addition, this weld is made of the same weld wire heat as the longitudinal weld seams.

TABLE 4-2			
Heat Treatment of the Wolf Creek Reactor Vessel Surveillance Material[3]			
Material	Temperature (°F)	Time	Coolant
Lower Shell Plate R2508-3	Austenitized @ 1600 ± 25	4 hrs.	Water-quenched
	Tempered @ 1225 ± 25	4 hrs.	Air-cooled
	Stress Relieved[a] @ 1150 ± 50	8 hrs 30 min.	Furnace-cooled
Weld	Stress Relieved[a] @ 1150 ± 50	10 hrs 15 min.	Furnace-cooled

(a) The stress relief heat treatment received by the surveillance test plate and weldment have been simulated.

TABLE 4-3

Chemical Composition of Four Wolf Creek Charpy Specimens
Removed from Surveillance Capsule V

Element	Concentration in Weight Percent			
	Weld Metal Specimens			Base Metal Specimen
	AW-18	AW-23	AW-25	AL-35
Fe	92.4	90.8	91.1	98.0
Al	0.011	0.010	0.010	0.019
Co	0.016	0.014	0.015	0.019
Cr	0.110	0.110	0.110	0.069
Cu	0.078	0.074	0.075	0.100
Mn	1.300	1.200	1.200	1.200
Ni	0.100	0.094	0.100	0.530
P	0.013	0.012	0.012	0.011
S	0.012	0.011	0.011	0.009
Sn	<0.010	<0.010	<0.010	<0.010
Ti	0.001	0.001	0.001	0.001
V	0.013	0.012	0.012	0.011
Zr	0.018	0.016	0.017	0.016
C	0.096	0.095	0.097	0.220
Si	0.560	0.540	0.550	0.250

Analyses	Method of Analysis
Metals	EPA Method for ICP Analysis
Carbon	Carbon Determination by Combustion Method
Silicon	Silicon Determination in Metallic Material

TABLE 4-4				
Chemistry Results from the NBS Certified Reference Standards				
	Low Alloy Steel: NIST Control Standard			
	Concentration in Weight Percent			
	NIST 361		NIST 362	
Element	Measured	Certified	Measured	Certified
Fe	98.3	95.6	95.0	95.3
Al	0.018	0.020	0.071	0.083
Co	0.032	0.032	0.260	0.300
Cr	0.620	0.690	0.270	0.300
Cu	0.046	0.042	0.460	0.500
Mn	0.540	0.660	0.850	1.040
Ni	1.600	2.000	0.490	0.590
P	0.018	0.014	0.035	0.041
S	0.017	0.014	0.027	0.036
Sn	<0.001	0.010	0.014	0.016
Ti	0.017	0.020	0.020	0.097
V	0.013	0.011	0.040	0.040
Zr	<0.010	0.009	0.150	0.190
C	0.380	0.380	0.160	0.160
Si	0.220	0.220	0.380	0.390

Analyses	Method of Analysis
Metals	EPA Method for ICP Analysis
Carbon	Carbon Determination by Combustion Method
Silicon	Silicon Determination in Metallic Material

TABLE 4-5				
Chemistry Results from the NBS Certified Reference Standards				
	Low Alloy Steel: NIST Control Standard			
	Concentration in Weight Percent			
	NIST 363		NIST 364	
Element	Measured	Certified	Measured	Certified
Fe	92.7	94.4	91.0	96.7
Al	0.210	0.240	0.012	0.008
Co	0.044	0.048	0.130	0.150
Cr	1.200	1.310	0.063	0.060
Cu	0.120	0.100	0.250	0.240
Mn	1.200	1.500	0.200	0.250
Ni	0.260	0.300	0.120	0.140
P	0.019	0.020	<0.010	0.010
S	0.008	0.007	0.020	0.025
Sn	0.090	0.100	<0.010	0.008
Ti	0.039	0.050	0.190	0.240
V	0.270	0.310	0.095	0.100
Zr	0.046	0.046	0.065	0.068
C	0.620	0.620	0.870	0.870
Si	0.730	0.740	0.068	0.060

Analyses	Method of Analysis
Metals	EPA Method for ICP Analysis
Carbon	Carbon Determination by Combustion Method
Silicon	Silicon Determination in Metallic Material

Table 4-6		
Best Estimate Cu and Ni Weight percent Values for the Wolf Creek Lower Shell Plate R2508-3		
Reference	Measured % Cu	Measured % Ni
3	0.07	0.62
Table 4-3	0.104	0.532
SUM	0.174	1.152
Average	0.087	0.576

Table 4-7		
Best Estimate Cu and Ni Weight percent Values for the Wolf Creek Surveillance Program Weld Metal		
Reference	Measured % Cu	Measured % Ni
3	0.04	0.09
Table 4-3	0.078	0.103
Table 4-3	0.074	0.094
Table 4-3	0.075	0.101
SUM	0.267	0.388
Average	0.067	0.097

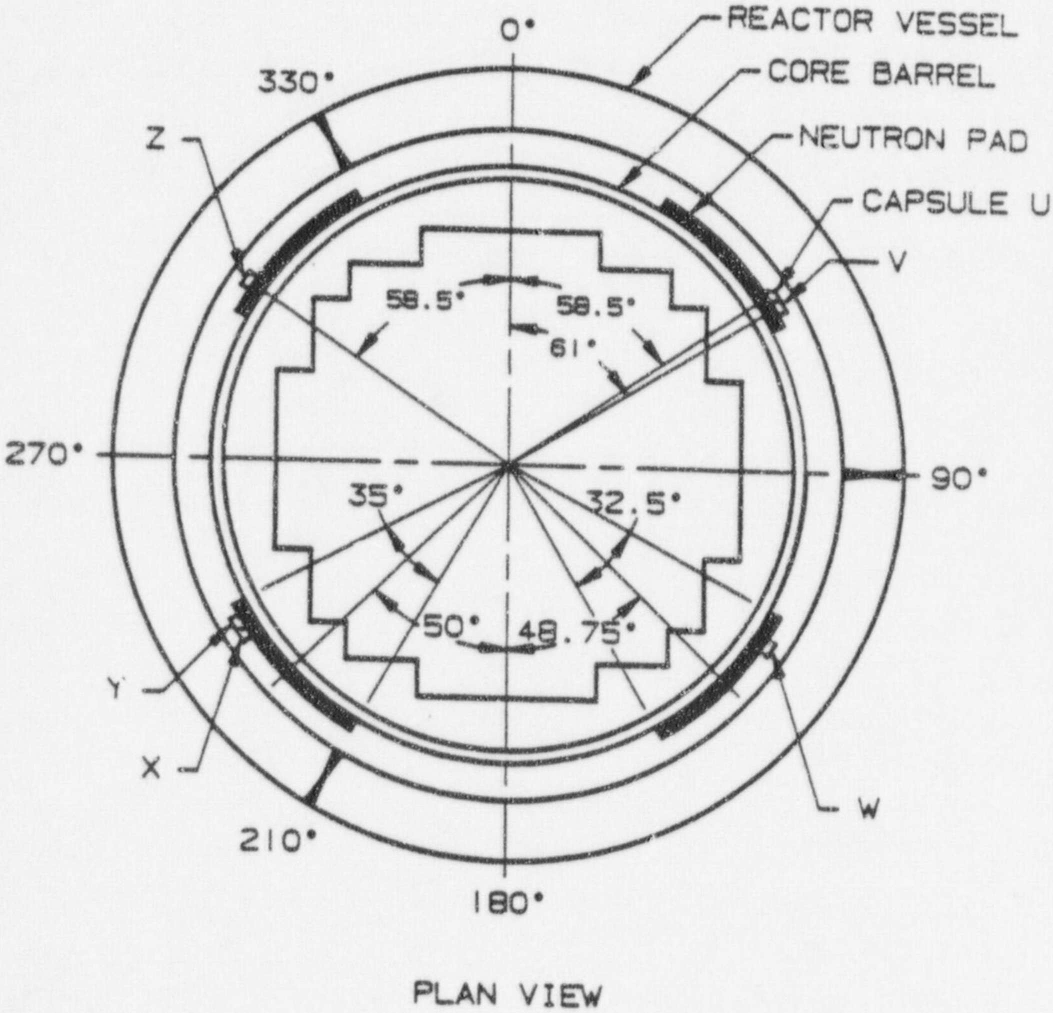
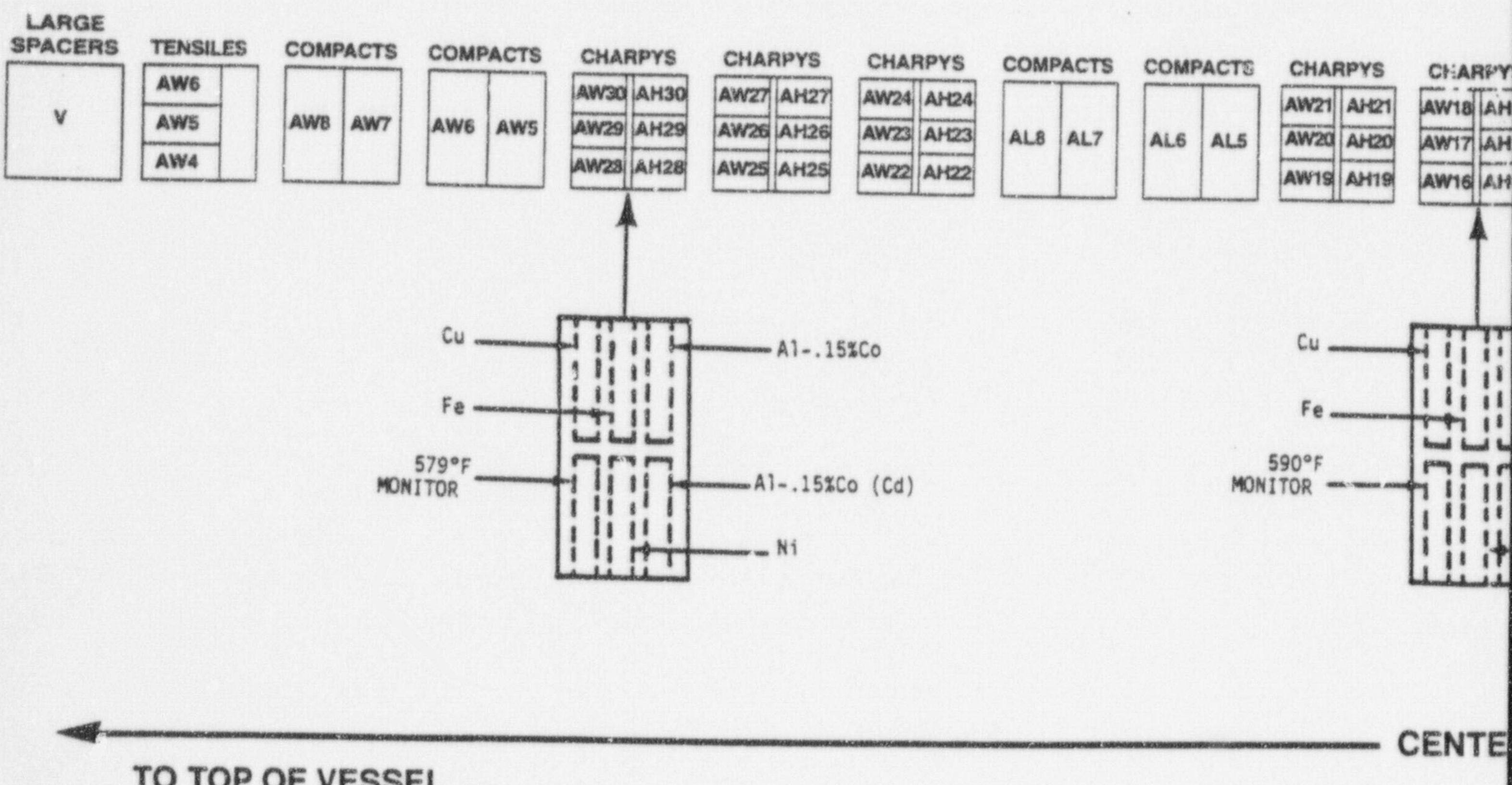
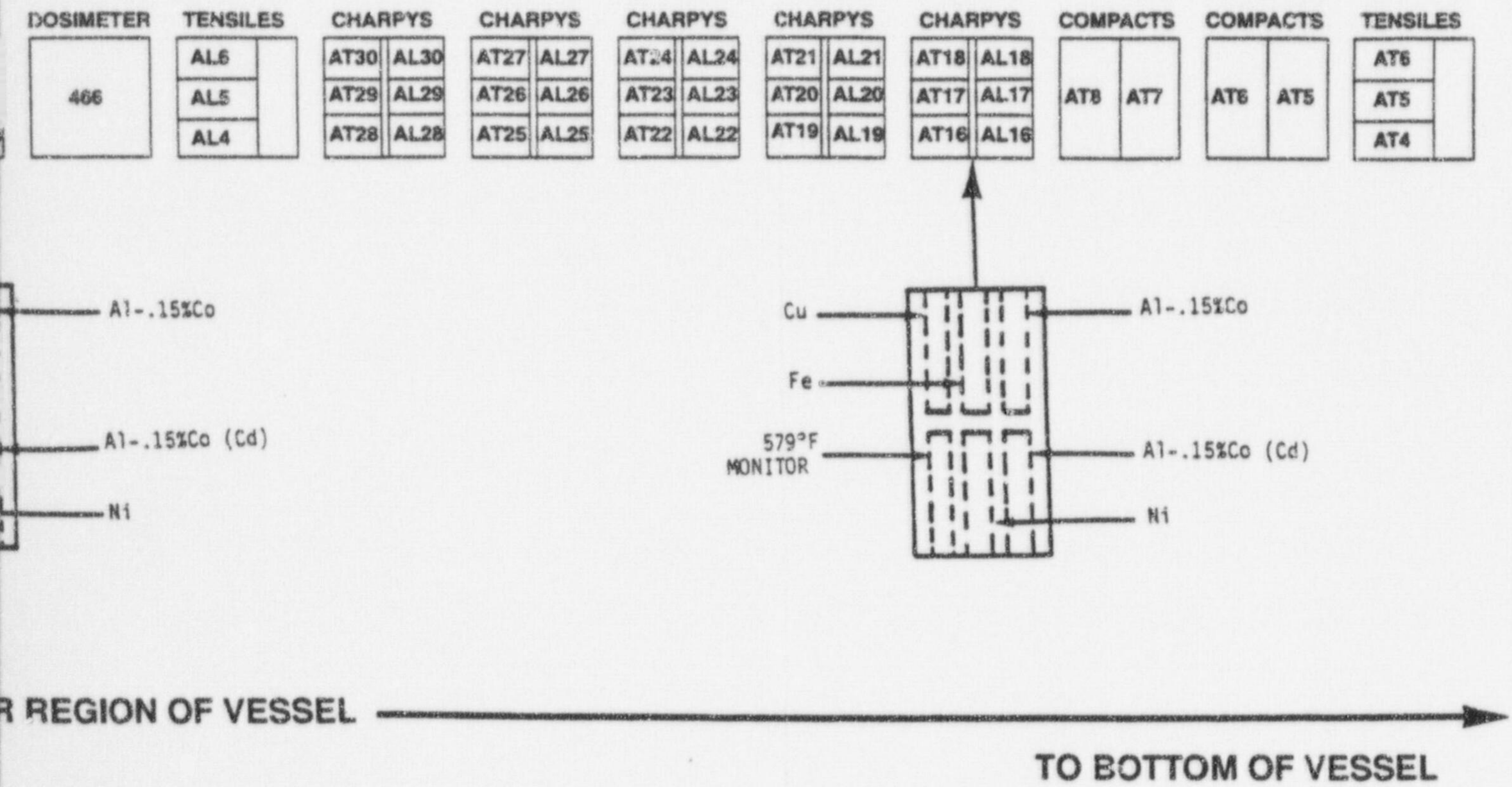


Figure 4-1. Arrangement of Surveillance Capsules in the Wolf Creek Reactor Vessel

LEGEND: AL - LOWER SHELL PLATE R2508-3 (LONGITUDINAL)
AT - LOWER SHELL PLATE R2508-3 (TRANSVERSE)
AW - WELD METAL
AH - HEAT-AFFECTED-ZONE MATERIAL





9809300020-01

Figure 4-2. Capsule V Diagram Showing the Location of Specimens, Thermal Monitors, and Dosimeters

SECTION 5.0

TESTING OF SPECIMENS FROM CAPSULE V

5.1 Overview

The post-irradiation mechanical testing of the Charpy V-notch impact specimens and tensile specimens was performed in the Remote Metallographic Facility (RMF) at the Westinghouse Science and Technology Center. Testing was performed in accordance with 10CFR50, Appendices G and H[2], ASTM Specification E185-82[6], and Westinghouse Procedure RMF 8402, Revision 2 as modified by Westinghouse RMF Procedures 8102, Revision 1, and 8103, Revision 1.

Upon receipt of the capsule at the hot cell laboratory, the specimens and spacer blocks were carefully removed, inspected for identification number, and checked against the master list in WCAP-10015[3]. No discrepancies were found.

Examination of the two low-melting point 579°F (304°C) and 590°F (310°C) eutectic alloys indicated no melting of either type of thermal monitor. Based on this examination, the maximum temperature to which the test specimens were exposed was less than 579°F (304°C).

The Charpy impact tests were performed per ASTM Specification E23-93a[7] and RMF Procedure 8103, Revision 1, on a Tinius-Olsen Model 74, 358J machine. The tup (striker) of the Charpy impact test machine is instrumented with a GRC 830-I instrumentation system, feeding information into an IBM compatible computer. With this system, load-time and energy-time signals can be recorded in addition to the standard measurement of Charpy energy (E_D). From the load-time curve (Appendix A), the load of general yielding (P_{GY}), the time to general yielding (t_{GY}), the maximum load (P_M), and the time to maximum load (t_M) can be determined. Under some test conditions, a sharp drop in load indicative of fast fracture was observed. The load at which fast fracture was initiated is identified as the fast fracture load (P_F), and the load at which fast fracture terminated is identified as the arrest load (P_A). The energy at maximum load (E_M) was determined by comparing the energy-time record and the load-time record. The energy at maximum load is approximately equivalent to the energy required to initiate a crack in the specimen. Therefore, the propagation energy for the crack (E_p) is the difference between the total energy to fracture (E_D) and the energy at maximum load (E_M).

The yield stress (σ_Y) was calculated from the three-point bend formula having the following expression:

$$\sigma_Y = (P_{GY} * L) / [B * (W - a)^2 * C] \qquad (1)$$

where: L = distance between the specimen supports in the impact machine

B = the width of the specimen measured parallel to the notch

W = height of the specimen, measured perpendicularly to the notch

a = notch depth

The constant C is dependent on the notch flank angle (ϕ), notch root radius (ρ) and the type of loading (ie. pure bending or three-point bending). In three-point bending, for a Charpy specimen in which $\phi = 45°$ and $\rho = 0.010$ inch, Equation 1 is valid with C = 1.21. Therefore, (for L = 4W),

$$\sigma_Y = (P_{GY} * L) / [B * (W - a)^2 * 1.21] = (3.33 * P_{GY} * W) / [B * (W - a)^2] \qquad (2)$$

For the Charpy specimen, B = 0.394 inch, W = 0.394 inch and a = 0.079 inch. Equation 2 then reduces to:

$$\sigma_Y = 33.3 * P_{GY} \qquad (3)$$

where σ_Y is in units of psi and P_{GY} is in units of lbs. The flow stress was calculated from the average of the yield and maximum loads, also using the three-point bend formula.

The symbol A in columns 4, 5, and 6 of Tables 5-5 through 5-8 is the cross-section area under the notch of the Charpy specimens:

$$A = B * (W - a) = 0.1241 \text{ sq. in.} \qquad (4)$$

Percent shear was determined from post-fracture photographs using the ratio-of-areas methods in compliance with ASTM Specification A370-92[8]. The lateral expansion was measured using a dial gage rig similar to that shown in the same specification.

Tensile tests were performed on a 20,000-pound Instron, split-console test machine (Model 1115) per ASTM Specification E8-93[9] and E21-92[10], and RMF Procedure 8102, Revision 1. All pull rods, grips, and pins were made of Inconel 718. The upper pull rod was connected through a universal joint to improve axiality of loading. The tests were conducted at a constant crosshead speed of 0.05 inches per minute throughout the test.

Extension measurements were made with a linear variable displacement transducer extensometer. The extensometer knife edges were spring-loaded to the specimen and operated through specimen failure. The extensometer gage length was 1.00 inch. The extensometer is rated as Class B-2 per ASTM E83-93[11].

Elevated test temperatures were obtained with a three-zone electric resistance split-tube furnace with a 9-inch hot zone. All tests were conducted in air. Because of the difficulty in remotely attaching a thermocouple directly to the specimen, the following procedure was used to monitor specimen temperatures. Chromel-Alumel thermocouples were positioned at the center and at each end of the gage section of a dummy specimen and in each tensile machine griper. In the test configuration, with a slight load on the specimen, a plot of specimen temperature versus upper and lower tensile machine griper and controller temperatures was developed over the range from room temperature to 550°F. During the actual testing, the grip temperatures were used to obtain desired specimen temperatures. Experiments have indicated that this method is accurate to ±2°F.

The yield load, ultimate load, fracture load, total elongation, and uniform elongation were determined directly from the load-extension curve. The yield strength, ultimate strength, and fracture strength were calculated using the original cross-sectional area. The final diameter and final gage length were determined from post-fracture photographs. The fracture area used to calculate the fracture stress (true stress at fracture) and percent reduction in area was computed using the final diameter measurement.

5.2 Charpy V-Notch Impact Test Results

The results of the Charpy V-notch impact tests performed on the various materials contained in capsule V, which received a fluence of 2.528×10^{19} n/cm^2 (E > 1.0 MeV) in 9.49 EFPY of operation, are presented in Tables 5-1 through 5-8 and are compared with unirradiated results[3] as shown in

Figures 5-1 through 5-12. The transition temperature increases and upper shelf energy decreases for the capsule V materials are summarized in Table 5-9. These results led to the following conclusions:

- Irradiation of the reactor vessel lower shell plate R2508-3 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction of the plate (longitudinal orientation), to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 52.03°F and a 50 ft-lb transition temperature increase of 46.86°F. This results in an irradiated 30 ft-lb transition temperature of 27.08°F and an irradiated 50 ft-lb transition temperature of 46.98°F for the longitudinally oriented specimens.

- Irradiation of the reactor vessel lower shell plate R2508-3 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction of the plate (transverse orientation), to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 54.53°F and a 50 ft-lb transition temperature increase of 56.27°F. This results in an irradiated 30 ft-lb transition temperature of 56.54°F and an irradiated 50 ft-lb transition temperature of 90.59°F for transversely oriented specimens.

- Irradiation of the weld metal Charpy specimens to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 46.33°F and a 50 ft-lb transition temperature increase of 52.44°F. This results in an irradiated 30 ft-lb transition temperature of -11.36°F and an irradiated 50 ft-lb transition temperature of 31.79°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 55.91°F and a 50 ft-lb transition temperature increase of 52.01°F. This results in an irradiated 30 ft-lb transition temperature of -88.09°F and an irradiated 50 ft-lb transition temperature of -61.99°F.

- The average upper shelf energy of the lower shell plate R2508-3 (longitudinal orientation) resulted in an average energy decrease of 19 ft-lb after irradiation to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 129 ft-lb for the longitudinally oriented specimens.

- The average upper shelf energy of the lower shell plate R2508-3 (transverse orientation) resulted in an average energy decrease of 6 ft-lb after irradiation to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 88 ft-lb for the transversely oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted in an average energy decrease of 11 ft-lb after irradiation to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 89 ft-lb for the weld metal specimens.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in an average energy increase of 6 ft-lb after irradiation to 2.528 x 10^{19} n/cm^2 (E > 1.0 MeV). Hence, this result will be conservatively reported as an unchanged average upper shelf energy of 161 ft-lb for the weld HAZ metal.

A comparison of the Wolf Creek reactor vessel beltline material test results with the Regulatory Guide 1.99, Revision 2[1], predictions is given in Table 5-10 and led to the following conclusions:

- The measured 30 ft-lb shift in transition temperature values of the surveillance materials are lower than the Regulatory Guide 1.99, Revision 2, predictions.

- The measured percent decrease in upper shelf energy for all surveillance materials is less than the Regulatory Guide 1.99, Revision 2, prediction.

The fracture appearance of each irradiated Charpy specimen from the various surveillance capsule V materials is shown in Figures 5-13 through 5-16 and show an increasingly ductile or tougher appearance with increasing test temperature.

All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are expected to maintain an upper shelf energy of no less than 50 ft-lb throughout the life of the vessel (35 EFPY) as required by 10CFR50, Appendix G[2].

The load-time records for individual instrumented Charpy specimen tests are shown in Appendix A.

The Charpy V-notch data presented in WCAP-11553[12] and WCAP-13365[13] was based on hand-fit Charpy curves using engineering judgement. However, the results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1. which is a hyperbolic tangent curve-fitting program. Hence, Appendix B contains a comparison of the Charpy V-notch shift results for each surveillance material (hand-fitting versus hyperbolic tangent curve-fitting). Additionally, Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

A credibility evaluation of the Wolf Creek surveillance program is presented in Appendix D of this report and indicates that the Wolf Creek reactor vessel surveillance program is credible.

5.3 Tensile Test Results

The results of the tensile tests performed on the various materials contained in capsule V irradiated to 2.528×10^{19} n/cm^2 (E > 1.0 MeV) are presented in Table 5-11 and are compared with unirradiated results[3] as shown in Figures 5-17 through 5-19.

The results of the tensile tests performed on the lower shell plate R2508-3 (longitudinal orientation) indicated that irradiation to 2.528×10^{19} n/cm^2 (E > 1.0 MeV) caused approximately a 9 ksi increase in the 0.2 percent offset yield strength and approximately a 4 to 9 ksi increase in the ultimate tensile strength when compared to unirradiated data[3] (Figure 5-17).

The results of the tensile tests performed on the lower shell plate R2508-3 (transverse orientation) indicated that irradiation to 2.528×10^{19} n/cm^2 (E > 1.0 MeV) caused a 8 ksi increase in the 0.2 percent offset yield strength and approximately a 10 ksi increase in the ultimate tensile strength when compared to unirradiated data[3] (Figure 5-18).

The results of the tensile tests performed on the surveillance weld metal indicated that irradiation to 2.528×10^{19} n/cm^2 (E > 1.0 MeV) caused a 2 to 6 ksi increase in the 0.2 percent offset yield strength and a 4 to 10 ksi increase in the ultimate tensile strength when compared to unirradiated data[3] (Figure 5-19).

The fractured tensile specimens for the lower shell plate R2508-3 material are shown in Figures 5-20 and 5-21, while the fractured tensile specimens for the surveillance weld metal are shown in Figure 5-22.

The engineering stress-strain curves for the tensile tests are shown in Figures 5-23 through 5-25.

5.4 1/2T Compact Tension Specimen Tests

Per the surveillance capsule testing contract, the 1/2T Compact Tension Specimens were not tested and are being stored at the Westinghouse Science and Technology Center Hot Cell facility.

TABLE 5-1

Charpy V-notch Data for the Wolf Creek Lower Shell Plate R2508-3
Irradiated to a Fluence of 2.528 X 10^{19} n/cm^2 (E > 1.0 MeV)
(Longitudinal Orientation)

Sample	Temperature		Impact Energy		Lateral Expansion		She[illegible]
Number	(°F)	(°C)	(ft-lb)	(J)	(mils)	(mm)	(%)
AL27	-50	-46	4	5	0	0.000	5
AL30	-25	-32	16	22	8	0.203	10
AL18	0	-18	13	18	4	0.102	10
AL16	25	-4	20	27	14	0.356	15
AL24	35	2	48	65	29	0.737	20
AL19	50	10	56	76	33	0.838	25
AL17	60	16	53	72	34	0.864	25
AL25	75	24	70	95	41	1.041	35
AL26	80	27	107	145	65	1.651	50
AL28	100	38	111	150	65	1.651	50
AL21	125	52	118	160	69	1.753	75
AL29	150	66	125	169	62	1.575	85
AL22	175	79	120	163	72	1.829	90
AL20	200	93	129	175	75	1.905	100
AL23	300	149	128	174	73	1.854	100

TABLE 5-2							
Charpy V-notch Data for the Wolf Creek Lower Shell Plate R2508-3 Irradiated to a Fluence of 2.528 X 10^{19} n/cm^2 (E > 1.0 MeV) (Transverse Orientation)							
Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	(°F)	(°C)	(ft-lb)	(J)	(mils)	(mm)	(%)
AT30	-25	-32	6	8	0	0.000	5
AT24	0	-18	12	16	8	0.203	10
AT23	25	-4	16	22	8	0.203	20
AT16	40	4	26	35	15	0.381	20
AT25	50	10	29	39	19	0.483	35
AT26	60	16	22	30	13	0.330	25
AT18	75	24	45	61	31	0.787	35
AT27	90	32	45	61	35	0.889	50
AT19	100	38	57	77	34	0.864	60
AT28	125	52	78	106	55	1.397	75
AT22	150	66	65	88	45	1.143	80
AT21	175	79	87	118	61	1.549	80
AT20	200	93	85	115	57	1.448	100
AT17	250	121	91	123	64	1.626	100
AT29	300	149	88	119	61	1.549	100

TABLE 5-3							
Charpy V-notch Data for the Wolf Creek Surveillance Weld Metal Irradiated to a Fluence of 2.528 X 10^{19} n/cm^2 (E > 1.0 MeV)							
Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	(°F)	(°C)	(ft-lb)	(J)	(mils)	(mm)	(%)
AW18	-100	-73	5	7	2	0.051	10
AW23	-75	-59	10	14	2	0.051	20
AW25	-50	-46	13	18	9	0.229	15
AW22	-25	-32	18	24	8	0.203	25
AW28	-5	-21	48	65	30	0.762	40
AW16	10	-12	53	72	33	0.838	50
AW20	25	-4	33	45	19	0.483	45
AW27	50	10	56	76	38	0.965	60
AW17	60	16	54	73	37	0.940	60
AW24	75	24	68	92	45	1.143	80
AW26	100	38	78	106	44	1.118	90
AW30	125	52	87	118	64	1.626	100
AW19	150	66	87	118	62	1.575	100
AW29	200	93	88	119	62	1.575	100
AW21	250	121	93	126	67	1.702	100

TABLE 5-4							
Charpy V-notch Data for the Wolf Creek Heat-Affected-Zone (HAZ) Metal Irradiated to a Fluence of 2.528 X 10^{19} n/cm^2 (E > 1.0 MeV)							
Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	(°F)	(°C)	(ft-lb)	(J)	(mils)	(mm)	(%)
AH21	-190	-123	3	4	0	0.000	0
AH20	-150	-101	8	11	0	0.000	5
AH16	-125	-87	11	15	1	0.025	5
AH28	-100	-73	23	31	12	0.305	10
AH24	-80	-62	15	20	2	0.051	10
AH27	-60	-51	26	35	11	0.279	15
AH30	-50	-46	89	121	43	1.092	50
AH25	-40	-40	91	123	42	1.067	55
AH29	-20	-29	77	104	37	0.940	40
AH17	0	-18	141	191	76	1.930	80
AH23	50	10	132	179	71	1.803	85
AH18	50	10	144	195	73	1.854	100
AH19	100	38	131	178	71	1.803	100
AH22	150	66	143	194	67	1.702	100
AH26	250	121	252	342	55	1.397	100

TABLE 5-5

Instrumented Charpy Impact Test Results for the Wolf Creek Lower Shell Plate R2508-3
Irradiated to a Fluence of 2.528 X 10^{19} n/cm^2 (E > 1.0 MeV) (Longitudinal Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2) Charpy E_D/A	Max. E_M/A	Prop. E_P/A	Yield Load P_{GY} (lb)	Time to Yield t_{GY} (μsec)	Max. Load P_M (lb)	Time to Max. t_M (μsec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress σ_Y (ksi)	Flow Stress (ksi)
AL27	-50	4	32	15	17	1929	0.12	1929	0.12	1929	0	64	64
AL30	-25	16	129	65	63	3803	0.16	4232	0.22	4112	0	127	134
AL18	0	13	105	59	45	3749	0.16	4074	0.21	4063	0	125	130
AL16	25	20	161	63	98	3621	0.16	3949	0.22	3847	375	121	126
AL24	35	48	387	324	62	3622	0.16	4665	0.68	4648	0	121	138
AL19	50	56	451	325	125	3593	0.16	4556	0.70	4499	704	120	136
AL17	60	53	427	317	110	3516	0.16	4557	0.68	4541	512	117	134
AL25	75	70	564	325	239	3529	0.16	4531	0.70	4364	1178	118	134
AL26	80	107	862	392	470	3509	0.16	4548	0.82	3634	903	117	134
AL28	100	111	894	399	495	3452	0.16	4582	0.84	3600	1570	115	134
AL21	125	118	950	309	641	3340	0.16	4404	0.69	3089	1567	111	129
AL29	150	125	1007	380	627	3282	0.16	4378	0.83	3502	2338	109	128
AL22	175	120	966	380	586	3230	0.16	4264	0.85	2922	2066	108	125
AL20	200	129	1039	370	669	3089	0.16	4226	0.84	N/A	N/A	103	122
AL23	300	128	1031	357	674	2970	0.16	4081	0.84	N/A	N/A	99	117

N/A - Not Applicable - Fully ductile fracture.

TABLE 5-6													
Instrumented Charpy Impact Test Results for the Wolf Creek Lower Shell Plate R2508-3 Irradiated to a Fluence of 2.528 X 10^{19} n/cm^2 (E > 1.0 MeV) (Transverse Orientation)													
			Normalized Energies (ft-lb/in^2)										
Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Charpy E_D/A	Max. E_M/A	Prop. E_p/A	Yield Load P_{GY} (lb)	Time to Yield t_{GY} (μsec)	Max. Load P_M (lb)	Time to Max. t_M (μsec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress σ_Y (ksi)	Flow Stress (ksi)
AT30	-25	6	48	21	27	2534	0.13	2534	0.14	2534	0	84	84
AT24	0	12	97	41	55	3670	0.16	3733	0.17	3733	325	122	123
AT23	25	16	129	49	80	3611	0.16	3804	0.19	3800	544	120	123
AT16	40	26	209	61	149	3511	0.16	3877	0.22	3795	793	117	123
AT25	50	29	234	63	171	3521	0.16	3901	0.22	3768	1214	117	124
AT26	60	22	177	54	123	3465	0.16	3811	0.20	3807	1241	115	121
AT18	75	45	362	227	135	3471	0.16	4352	0.54	4289	956	116	130
AT27	90	45	362	166	196	3335	0.16	4096	0.43	4079	1955	111	124
AT19	100	57	459	222	237	3360	0.16	4177	0.54	4156	2351	112	125
AT28	125	78	628	301	327	3348	0.16	4333	0.68	4180	2085	111	128
AT22	150	65	523	196	327	3206	0.16	4012	0.50	3952	3078	107	120
AT21	175	87	701	286	414	3133	0.16	4159	0.68	3480	2534	104	121
AT20	200	85	684	275	409	3016	0.16	3991	0.68	N/A	N/A	100	117
AT17	250	91	733	261	472	2966	0.16	3981	0.65	N/A	N/A	99	116
AT29	300	88	709	260	449	2928	0.16	3921	0.66	N/A	N/A	98	114

N/A - Not Applicable - Fully ductile fracture.

TABLE 5-7

Instrumented Charpy Impact Test Results for the Wolf Creek Surveillance Weld Metal
Irradiated to a Fluence of 1.162 X 10^{19} n/cm^2 (E > 1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2) Charpy E_D/A	Max. E_M/A	Prop. E_p/A	Yield Load P_{GY} (lb)	Time to Yield t_{GY} (μsec)	Max. Load P_M (lb)	Time to Max. t_M (μsec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress σ_Y (ksi)	Flow Stress (ksi)
AW18	-100	5	40	17	23	2232	0.12	2232	0.12	2232	0	74	74
AW23	-75	10	81	44	37	3962	0.16	4055	0.18	4051	0	132	133
AW25	-50	13	105	59	46	3936	0.16	4383	0.20	4368	0	131	139
AW22	-25	18	145	65	80	3852	0.16	4290	0.22	4281	495	128	136
AW28	-5	48	387	237	149	3807	0.16	4670	0.51	4576	909	127	141
AW16	10	53	427	239	188	3791	0.16	4685	0.52	1406	0	126	141
AW20	25	33	266	168	98	3707	0.16	4275	0.41	4224	1290	123	133
AW27	50	56	451	228	223	3668	0.16	4428	0.52	4413	1794	122	135
AW17	60	54	435	231	204	3673	0.16	4497	0.52	4427	2013	122	136
AW24	75	68	548	229	319	3664	0.16	4413	0.52	4160	2248	122	134
AW26	100	78	628	303	325	3436	0.16	4304	0.68	3781	2524	114	129
AW30	125	87	701	233	467	3479	0.21	4011	0.59	N/A	N/A	116	125
AW19	150	87	701	289	411	3442	0.16	4213	0.66	N/A	N/A	115	127
AW29	200	88	709	286	423	3351	0.16	4175	0.66	N/A	N/A	112	125
AW21	250	93	749	282	466	3251	0.16	4086	0.67	N/A	N/A	108	122

N/A - Not Applicable - Fully ductile fracture.

TABLE 5-8

Instrumented Charpy Impact Test Results for the Wolf Creek Heat-Affected-Zone (HAZ) Metal Irradiated to a Fluence of 1.162 X 10^{19} n/cm^2 (E > 1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2)			Yield Load P_{GY} (lb)	Time to Yield t_{GY} (μsec)	Max. Load P_M (lb)	Time to Max. t_M (μsec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress σ_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_P/A								
AH21	-190	3	24	14	10	1857	0.12	1870	0.12	1857	0	62	62
AH20	-150	8	64	34	31	3719	0.15	3738	0.15	3719	0	124	124
AH16	-125	11	89	52	37	4405	0.16	4691	0.19	4689	0	147	151
AH28	-100	23	185	76	109	4394	0.16	5027	0.22	4851	0	146	157
AH24	-80	15	121	75	46	3733	0.16	4811	0.24	4811	0	124	142
AH27	-60	26	209	71	138	4143	0.16	4638	0.22	4599	0	138	146
AH30	-50	89	717	356	361	7037	0.16	4949	0.69	4423	522	134	150
AH25	-40	91	733	359	373	4074	0.16	5045	0.69	4551	986	136	152
AH29	-20	77	620	359	261	4070	0.16	5025	0.69	4782	431	136	151
AH17	0	141	1135	356	779	3785	0.16	4901	0.71	2459	1257	126	145
AH23	50	132	1160	423	737	3717	0.16	4755	0.85	N/A	N/A	124	141
AH18	50	144	1063	331	732	3798	0.16	4650	0.69	2899	2036	126	141
AH19	100	131	1055	331	724	3686	0.16	4672	0.69	N/A	N/A	123	139
AH22	150	143	1151	411	741	3498	0.16	4613	0.85	N/A	N/A	116	135
AH26	250	252	2029	382	1647	3250	0.16	4338	0.85	N/A	N/A	108	126

N/A - Not Applicable - Fully ductile fracture.

TABLE 5-9												
Effect of Irradiation to 2.528 X 10^{19} n/cm^2 (E > 1.0 MeV) on the Notch Toughness Properties of the Wolf Creek Reactor Vessel Surveillance Materials												
Material	Average 30 (ft-lb) [a] Transition Temperature (°F)			Average 35 mil Lateral [b] Expansion Temperature (°F)			Average 50 ft-lb [a] Transition Temperature (°F)			Average Energy Absorption [a] at Full Shear (ft-lb)		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔE
Lower Shell Plate R2508-3 (Longitudinal)	- 24.[illegible]	27.08	52.03	- 0.4	53.35	53.75	0.11	46.98	46.86	148	129	- 19
Lower Shell Plate R2508-3 (Transverse)	2.0	56.54	54.53	25.44	93.79	68.34	34.32	90.59	56.27	94	88	- 6
Weld Metal	- 57.69	- 11.36	46.33	-27.07	45.52	72.59	-20.64	31.79	52.44	100	89	- 11
HAZ Metal	- 144.01	- 88.09	55.91	- 89.78	- 43.6	46.18	- 114.0	- 61.99	52.01	161	167	+ 6

(a) "Average" is defined as the value read from the curve fit through the data points of the Charpy tests (see Figures 5-1, 5-4, 5-7 and 5-10).

(b) "Average" is defined as the value read from the curve fit through the data points of the Charpy tests (see Figures 5-2, 5-5, 5-8 and 5-11).

TABLE 5-10						
Comparison of the Wolf Creek Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper Shelf Energy Decreases with Regulatory Guide 1.99, Revision 2, Predictions						
Material	Capsule	Fluence (n/cm^2, E > 1.0 MeV)	30 ft-lb Transition Temperature Shift		Upper Shelf Energy Decrease	
			Predicted (°F) (a)	Measured (°F) (b)	Predicted (%) (a)	Measured (%) (c)
Lower Shell Plate R2508-3 (Longitudinal)	U	3.429×10^{18}	40.9	36.46	14.5	2
	Y	1.308×10^{19}	62.4	16.03	20.0	11
	V	2.528×10^{19}	72.4	52.03	24.0	13
Lower Shell Plate R2508-3 (Transverse)	U	3.429×10^{18}	40.9	23.79	14.5	0
	Y	1.308×10^{19}	62.4	35.39	20.0	0
	V	2.528×10^{19}	72.4	54.53	24.0	6
Weld Metal	U	3.429×10^{18}	30.7	27.21	16.5	8
	Y	1.308×10^{19}	46.8	45.09	22.5	6
	V	2.528×10^{19}	54.3	46.33	26.5	11
HAZ Metal	U	3.429×10^{18}	- -	58.41	- -	13
	Y	1.308×10^{19}	- -	12.98	- -	0
	V	2.528×10^{19}	- -	55.91	- -	0

(a) Based on Regulatory Guide 1.99, Revision 2, methodology using the mean weight percent values of copper and nickel of the surveillance material.

(b) Calculated using measured Charpy data plotted using CVGRAPH, Version 4.1 (See Appendix C).

(c) Values are based on the definition of upper shelf energy given in ASTM E185-82.

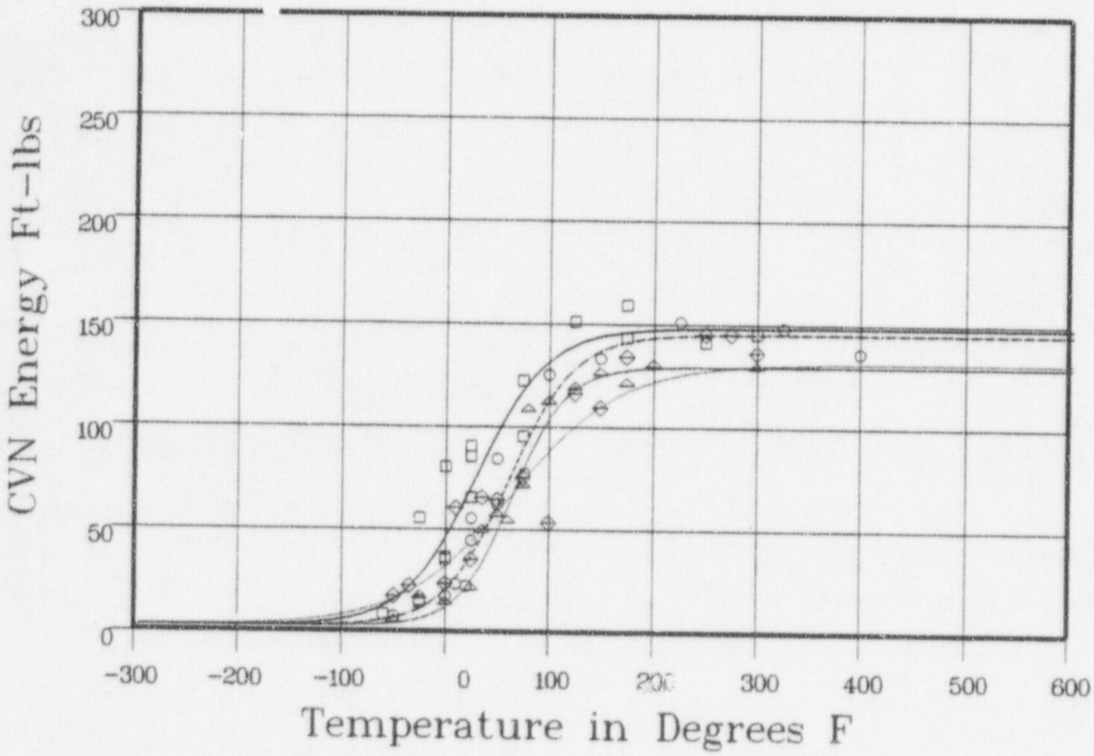
TABLE 5-11										
Tensile Properties of the Wolf Creek Reactor Vessel Surveillance Materials Irradiated to 2.528 X 10^{19} n/cm^2 (E > 1.0 MeV)										
Material	Sample Number	Test Temp. (°F)	0.2% Yield Strength (ksi)	Ultimate Strength (ksi)	Fracture Load (kip)	Fracture Stress (ksi)	Fracture Strength (ksi)	Uniform Elongation (%)	Total Elongation (%)	Reduction in Area (%)
Lower Shell Plate R2508-3 (Longitudinal)	AL4	40	68.8	89.6	2.80	201.8	57.0	10.2	25.3	72
	AL5	140	64.7	83.5	2.60	206.5	53.0	12.0	27.8	74
	AL6	550	58.6	83.1	2.07	129.8	42.1	12.0	23.4	68
Lower Shell Plate R2508-3 (Transverse)	AT4	72	67.2	88.6	3.10	186.2	63.2	13.7	27.2	66
	AT5	165	64.7	83.5	3.00	165.5	61.1	12.0	23.6	63
	AT6	550	59.1	83.3	2.99	179.6	60.9	10.8	20.4	66
Weld Metal	AW4	25	82.0	97.8	3.13	225.3	63.7	12.6	26.7	72
	AW5	125	77.9	97.1	3.03	1798.5	61.6	10.5	23.1	66
	AW6	550	69.8	88.6	3.10	194.6	63.2	12.0	20.4	68

LOWER SHELL PLATE R2508-3 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:13:19 on 05-28-1998

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	148	0	-24.95	0	.11	0
2	0	2.19	0	145	-3	11.51	36.46	34.85	34.73
3	0	2.19	0	131	-17	-8.91	16.03	31.54	31.43
4	0	2.19	0	129	-19	27.08	52.03	46.98	46.86



Curve Legend

1 □——— 2 ○- - - - 3 ◇——— 4 △———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	WC1	UNIRR	PLATE SA533B1	LT	C4935-2
2	WC1	U	PLATE SA533B1	LT	C4935-2
3	WC1	Y	PLATE SA533B1	LT	C4935-2
4	WC1	V	PLATE SA533B1	LT	C4935-2

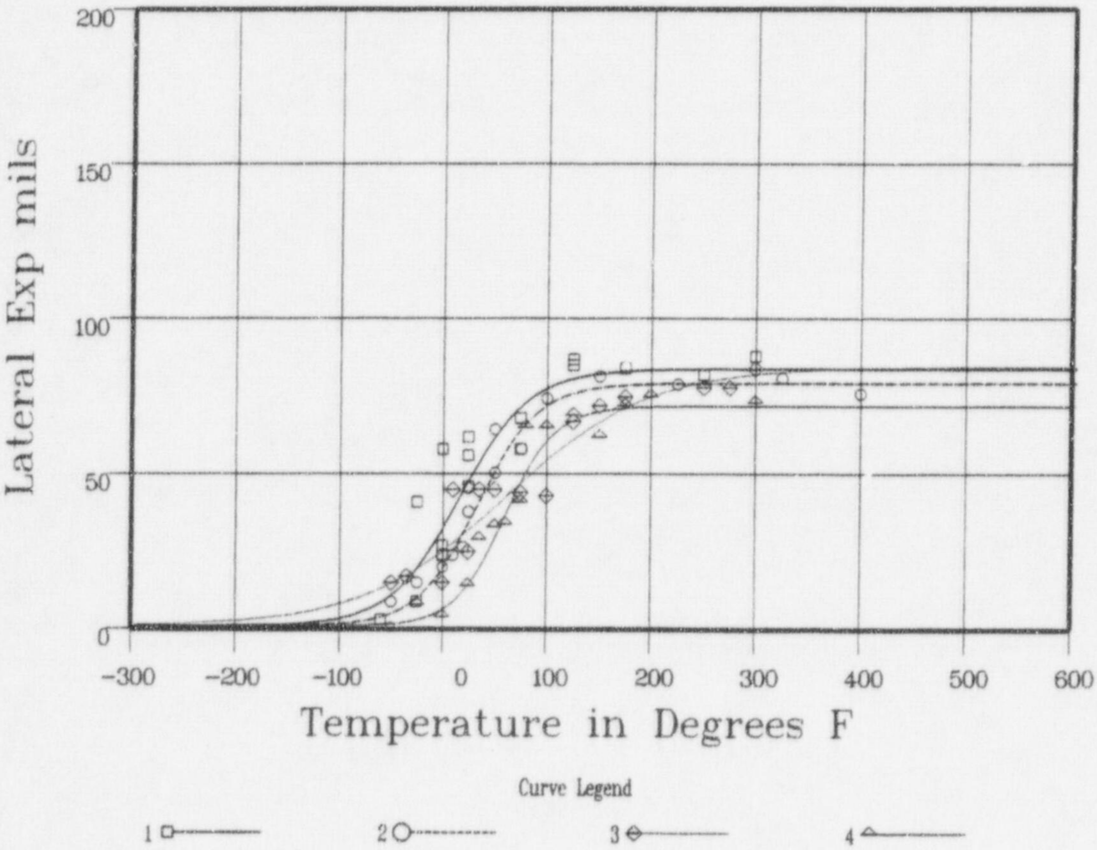
Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Longitudinal Orientation)

LOWER SHELL PLATE R2508-3 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:42:59 on 05-28-1998

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	83.86	0	-.4	0
2	0	79.25	-4.61	21.43	21.83
3	0	84.64	.77	30.43	30.83
4	0	71.88	-11.98	53.35	53.75



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	WC1	UNIRR	PLATE SA533B1	LT	C4935-2
2	WC1	U	PLATE SA533B1	LT	C4935-2
3	WC1	Y	PLATE SA533B1	LT	C4935-2
4	WC1	V	PLATE SA533B1	LT	C4935-2

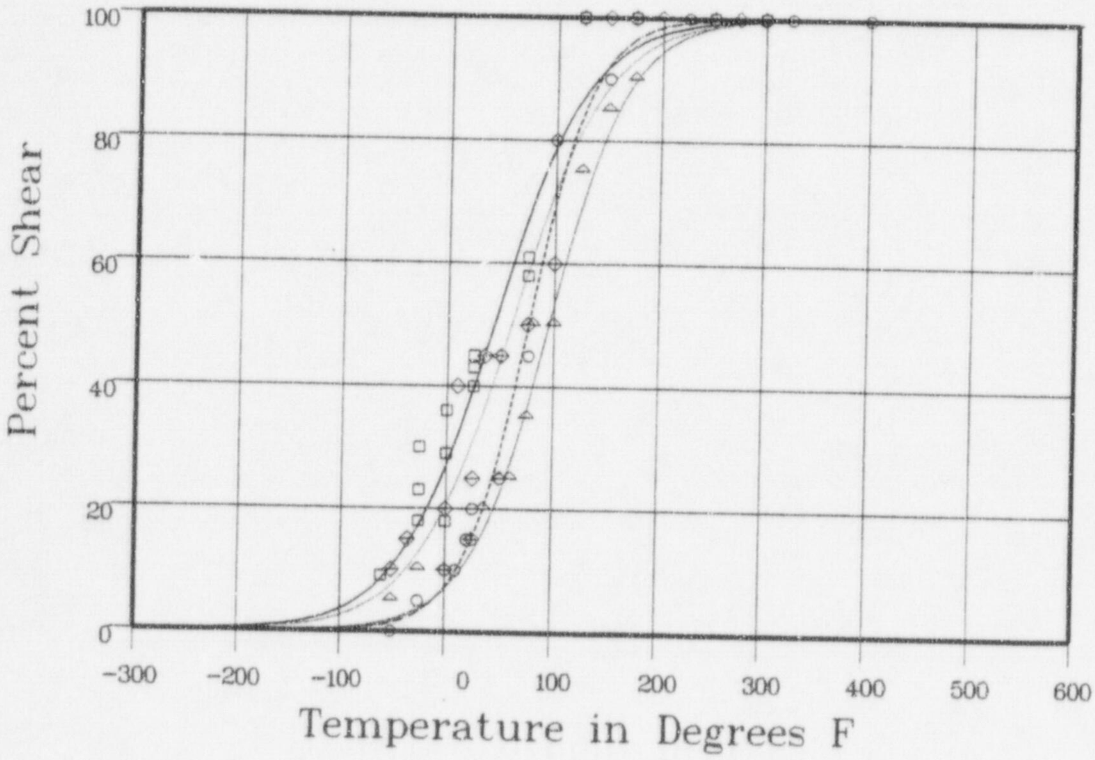
Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Longitudinal Orientation)

LOWER SHELL PLATE R2508-3 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:50:13 on 05-28-1998

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	38.43	0
2	0	71.2	32.76
3	0	54.84	16.4
4	0	90.82	52.38



Curve Legend

1 □——— 2 ○- - - - 3 ◇——— 4 △———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	WC1	UNIRR	PLATE SA533B1	LT	C4935-2
2	WC1	U	PLATE SA533B1	LT	C4935-2
3	WC1	Y	PLATE SA533B1	LT	C4935-2
4	WC1	V	PLATE SA533B1	LT	C4935-2

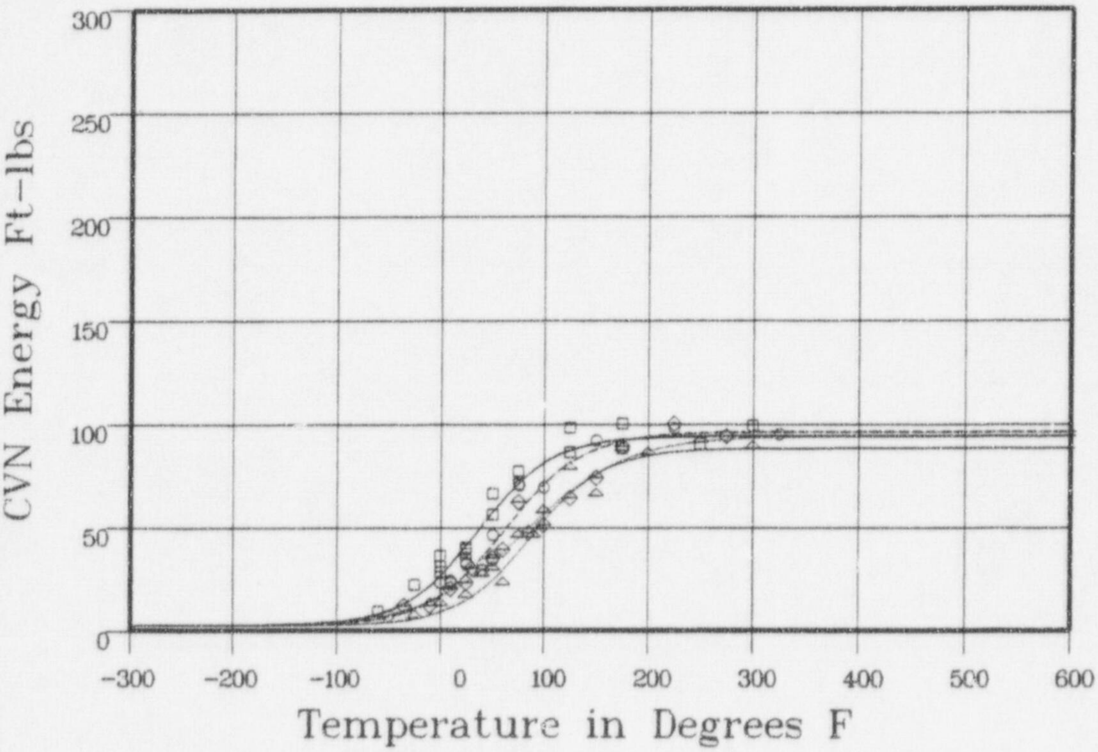
Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Longitudinal Orientation)

LOWER SHELL PLATE R2508-3 (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:30:17 on 05-28-1998

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	94	0	2	0	34.32	0
2	0	2.19	0	96	2	25.8	23.79	59.55	25.23
3	0	2.19	0	94	0	37.39	35.39	81.49	47.16
4	0	2.19	0	88	-6	56.54	54.53	90.59	56.27



Curve Legend

1 □——— 2 ○--------- 3 ◇——— 4 △———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	WC1	UNIRR	PLATE SA533B1	TL	C4935-2
2	WC1	U	PLATE SA533B1	TL	C4935-2
3	WC1	Y	PLATE SA533B1	TL	C4935-2
4	WC1	V	PLATE SA533B1	TL	C4935-2

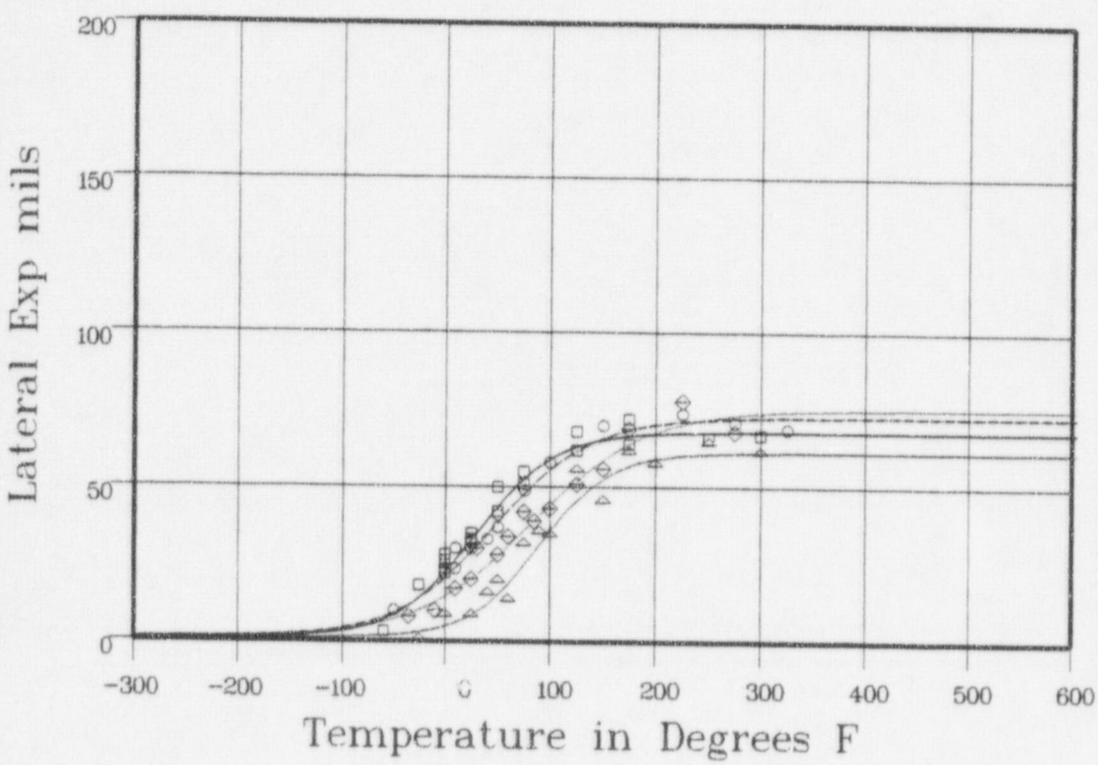
Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Transverse Orientation)

LOWER SHELL PLATE R2508-3 (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:01:30 on 05-28-1998

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	68.05	0	25.44	0
2	0	72.88	4.83	36.36	10.91
3	0	75.48	7.43	67.84	42.39
4	0	61.41	-6.63	93.79	68.34



Curve Legend

1 □———— 2 ○----------- 3 ◇———— 4 △————

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	WC1	UNIRR	PLATE SA533B1	TL	C4935-2
2	WC1	U	PLATE SA533B1	TL	C4935-2
3	WC1	Y	PLATE SA533B1	TL	C4935-2
4	WC1	V	PLATE SA533B1	TL	C4935-2

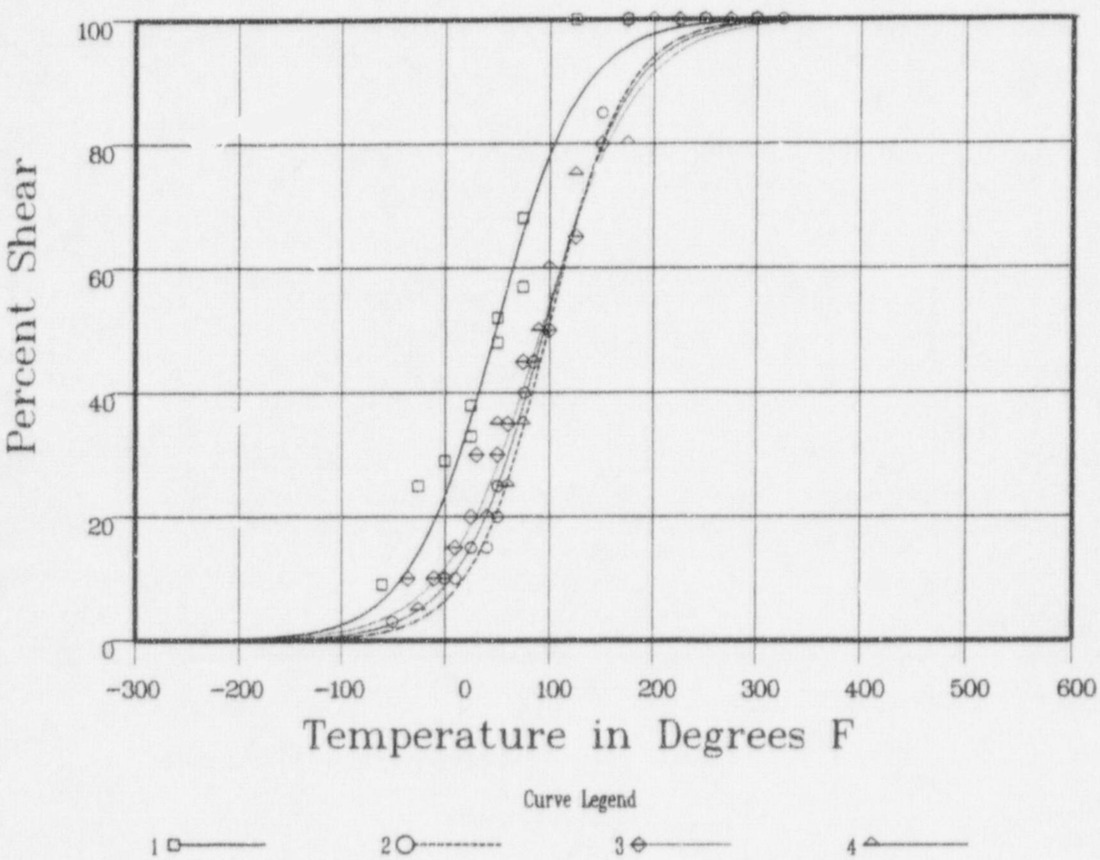
Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Transverse Orientation)

LOWER SHELL PLATE R2508-3 (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:06:59 on 05-28-1998

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	43.59	0
2	0	94.04	50.44
3	0	87.59	44
4	0	90.23	46.64



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	WC1	UNIRR	PLATE SA533B1	TL	C4935-2
2	WC1	U	PLATE SA533B1	TL	C4935-2
3	WC1	Y	PLATE SA533B1	TL	C4935-2
4	WC1	V	PLATE SA533B1	TL	C4935-2

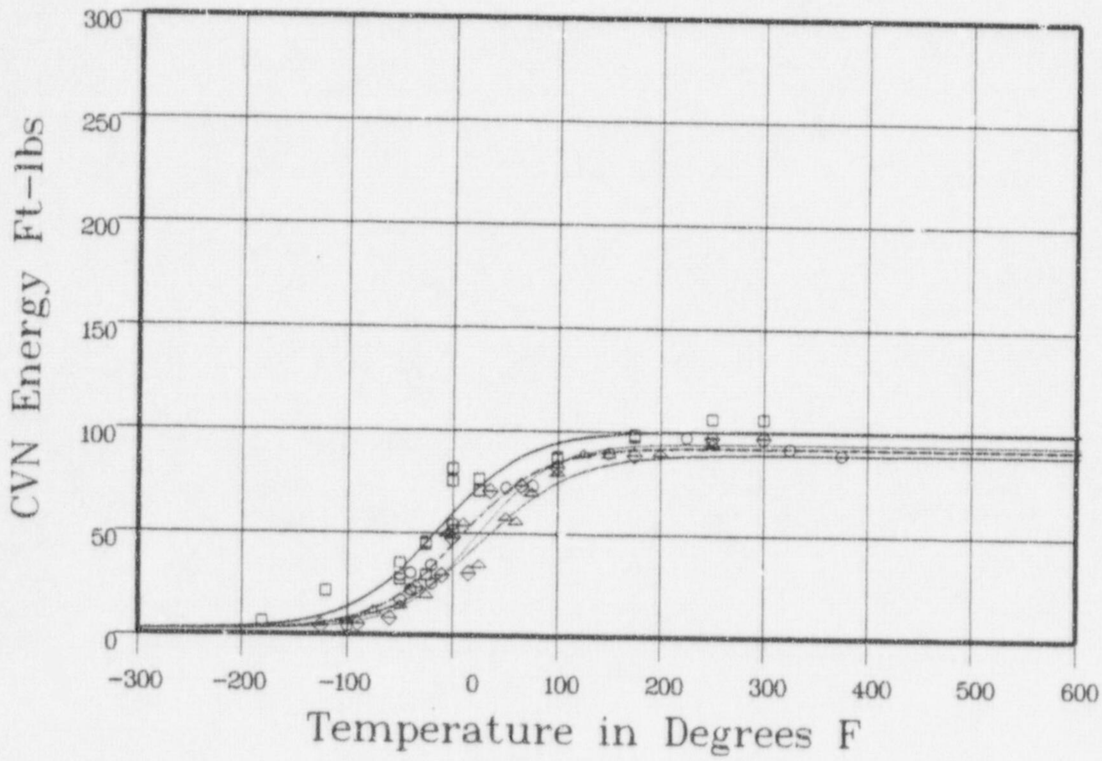
Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Transverse Orientation)

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:15:58 on 05-28-1998

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	100	0	-57.69	0	-20.64	0
2	0	2.19	0	92	-8	-30.47	27.21	6.44	27.09
3	0	2.19	0	94	-6	-12.59	45.09	20.82	41.47
4	0	2.19	0	89	-11	-11.36	46.33	31.79	52.44



Curve Legend

1 □——— 2 ○------- 3 ◇——— 4 △———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	WC1	UNIRR	WELD		90146
2	WC1	U	WELD		90146
3	WC1	Y	WELD		90146
4	WC1	V	WELD		90146

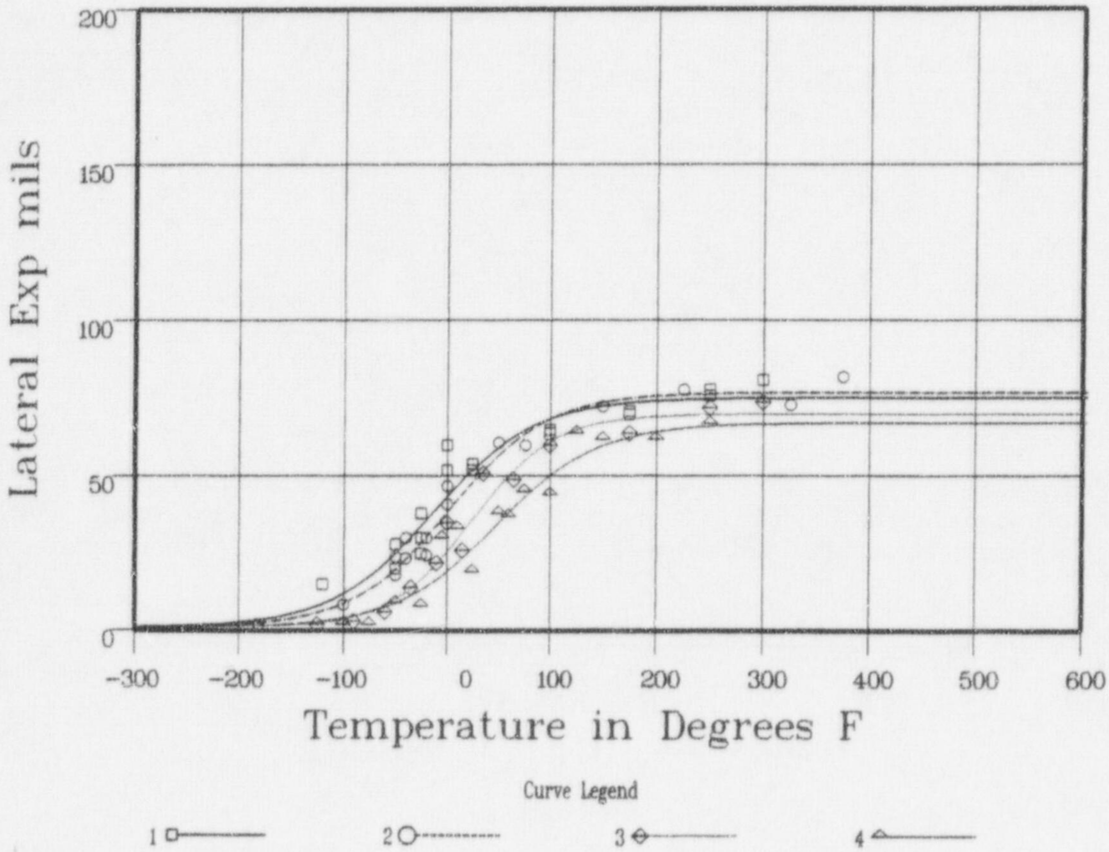
Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for Wolf Creek Reactor Vessel Weld Metal

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:24:17 on 05-28-1998

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	75.26	0	-27.07	0
2	0	77	1.74	-12.81	14.25
3	0	70.08	-5.17	17.96	45.04
4	0	67.22	-8.03	45.52	72.59



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	WC1	UNIRR	WELD		90146
2	WC1	U	WELD		90146
3	WC1	Y	WELD		90146
4	WC1	V	WELD		90146

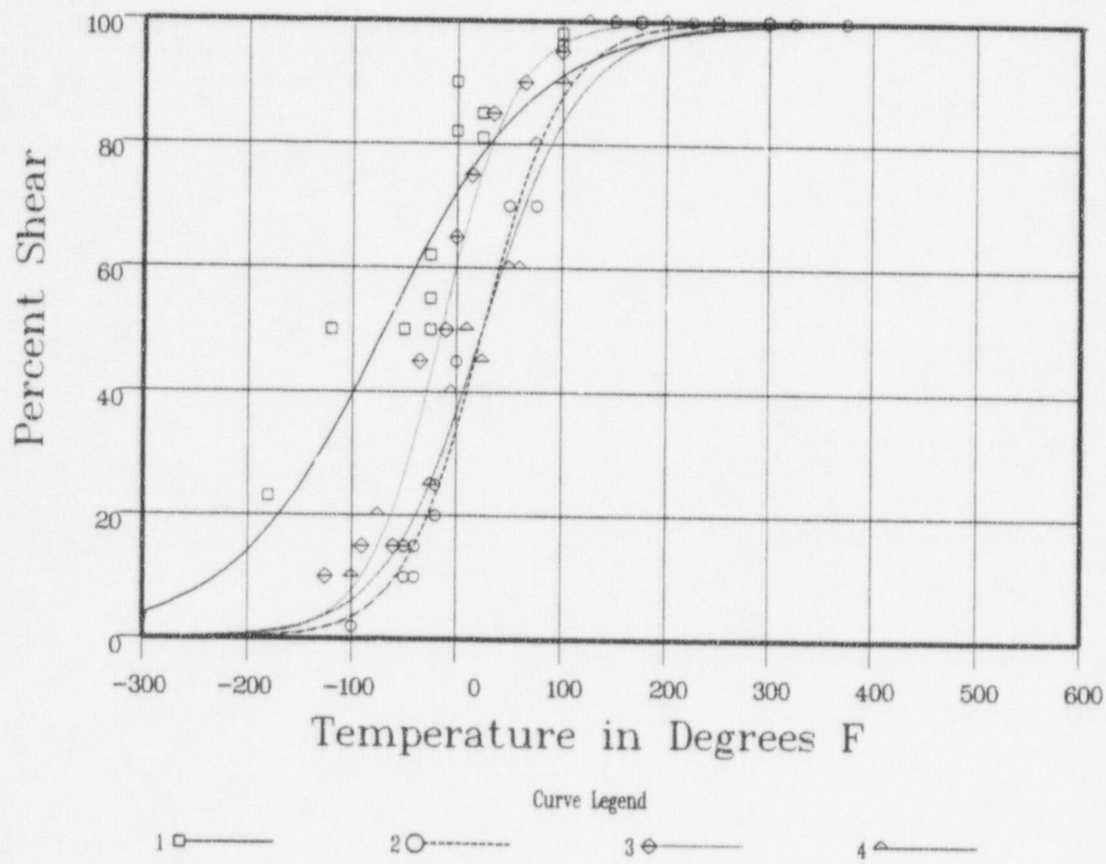
Figure 5-8 Charpy V-Notch Lateral Expansion vs. Temperature for Wolf Creek Reactor Vessel Weld Metal

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:31:21 on 05-28-1998

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	-73.94	0
2	0	20.94	94.89
3	0	-18.91	55.03
4	0	20.76	94.71



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	WC1	UNIRR	WELD		90146
2	WC1	U	WELD		90146
3	WC1	Y	WELD		90146
4	WC1	V	WELD		90146

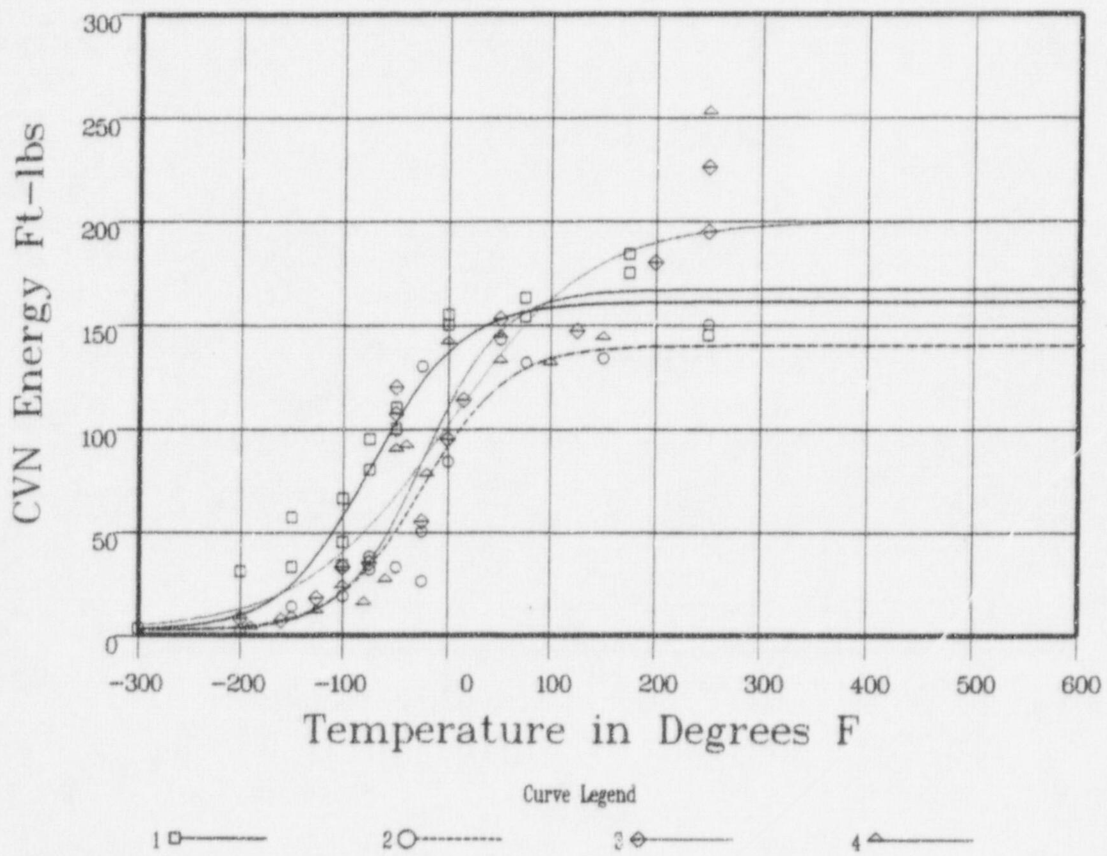
Figure 5-9 Charpy V-Notch Percent Shear vs. Temperature for Wolf Creek Reactor Vessel Weld Metal

HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:39:46 on 05-28-1998

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	161	0	-144.01	0	-114	0
2	0	2.19	0	140	-21	-85.59	58.41	-55.32	58.68
3	0	2.19	0	200	39	-131.02	12.98	-84.82	29.18
4	0	2.19	0	167	6	-88.09	55.91	-61.99	52.01



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	WC1	UNIRR	HEAT AFFD ZONE		
2	WC1	U	HEAT AFFD ZONE		
3	WC1	Y	HEAT AFFD ZONE		
4	WC1	V	HEAT AFFD ZONE		

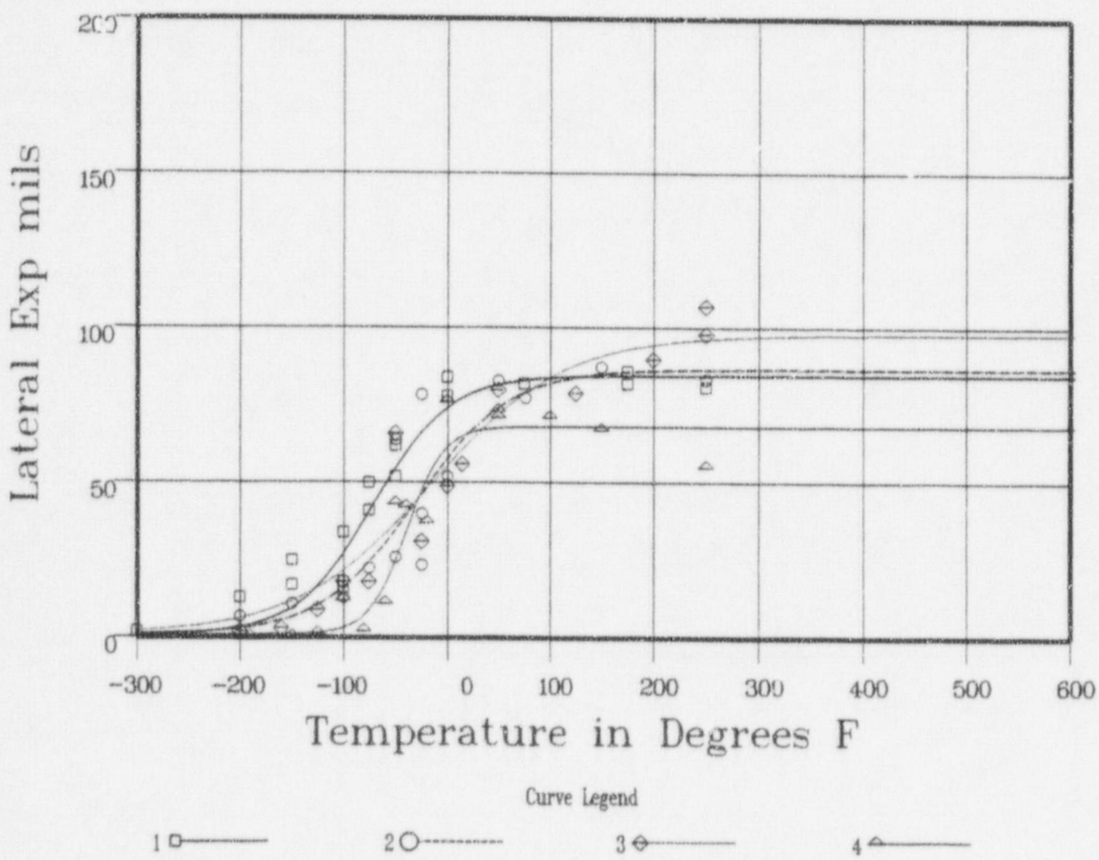
Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for Wolf Creek Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:47:31 on 05-28-1998

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	84.65	0	-89.78	0
2	0	86.77	2.12	-54.25	35.53
3	0	97.96	13.3	-60.51	29.27
4	0	68.14	-16.5	-43.6	46.18



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	WC1	UNIRR	HEAT AFFD ZONE		
2	WC1	U	HEAT AFFD ZONE		
3	WC1	Y	HEAT AFFD ZONE		
4	WC1	V	HEAT AFFD ZONE		

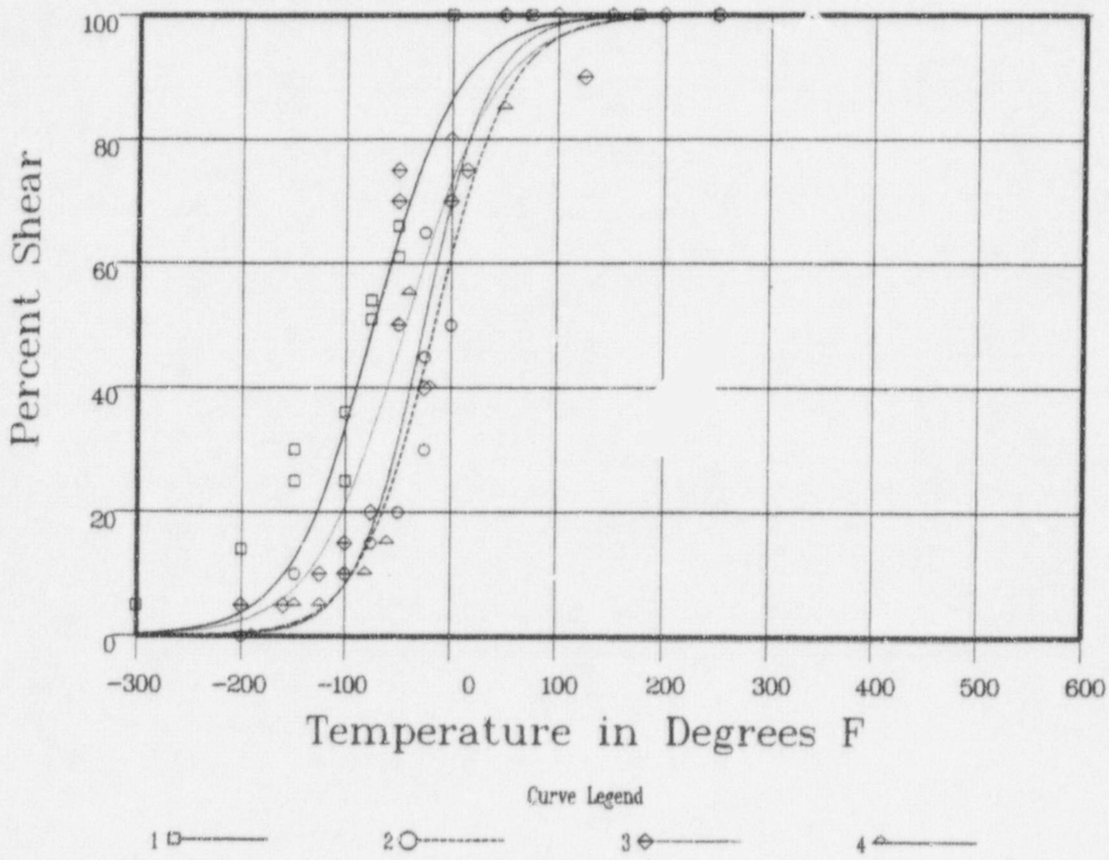
Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for Wolf Creek Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:51:50 on 05-28-1998

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	-77.81	0
2	0	-20.47	57.34
3	0	-47.81	30
4	0	-30.46	47.34



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	WC1	UNIRR	HEAT AFF'D ZONE		
2	WC1	U	HEAT AFF'D ZONE		
3	WC1	Y	HEAT AFF'D ZONE		
4	WC1	V	HEAT AFF'D ZONE		

Figure 5-12 Charpy V-Notch Percent Shear vs. Temperature for Wolf Creek Reactor Vessel Heat-Affected-Zone Material

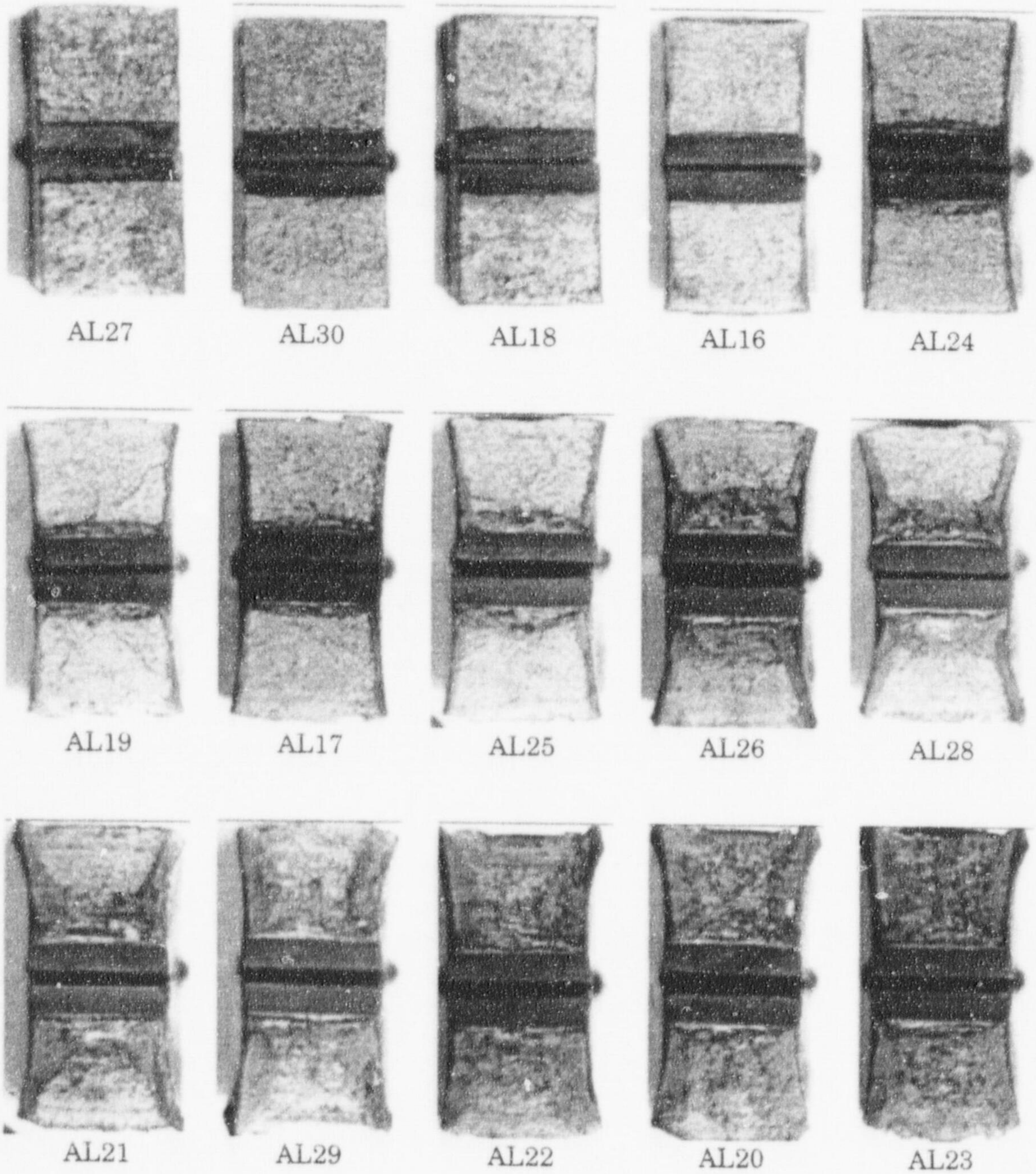


Figure 5-13 Charpy Impact Specimen Fracture Surfaces for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Longitudinal Orientation)

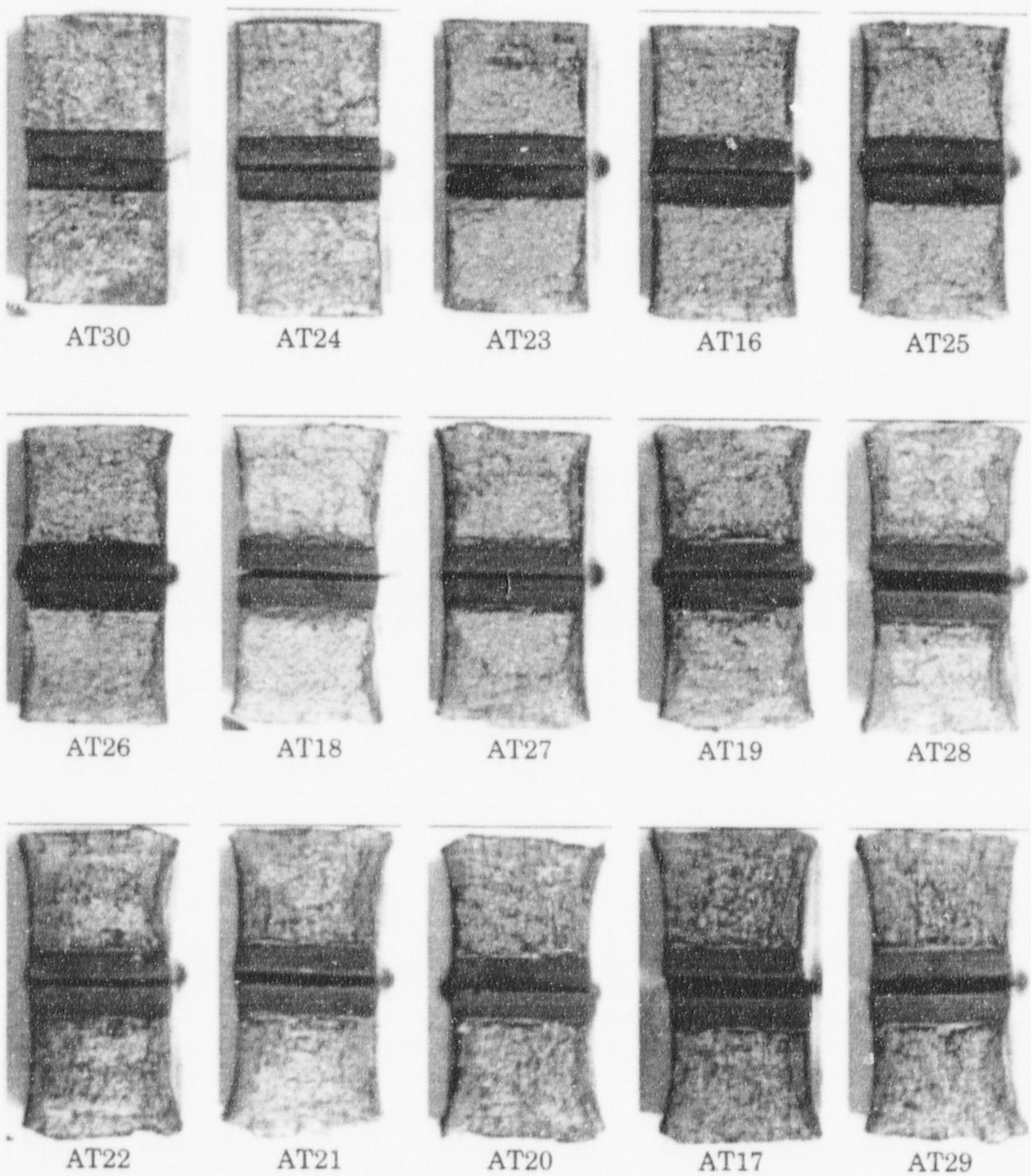


Figure 5-14 Charpy Impact Specimen Fracture Surfaces for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Transverse Orientation)

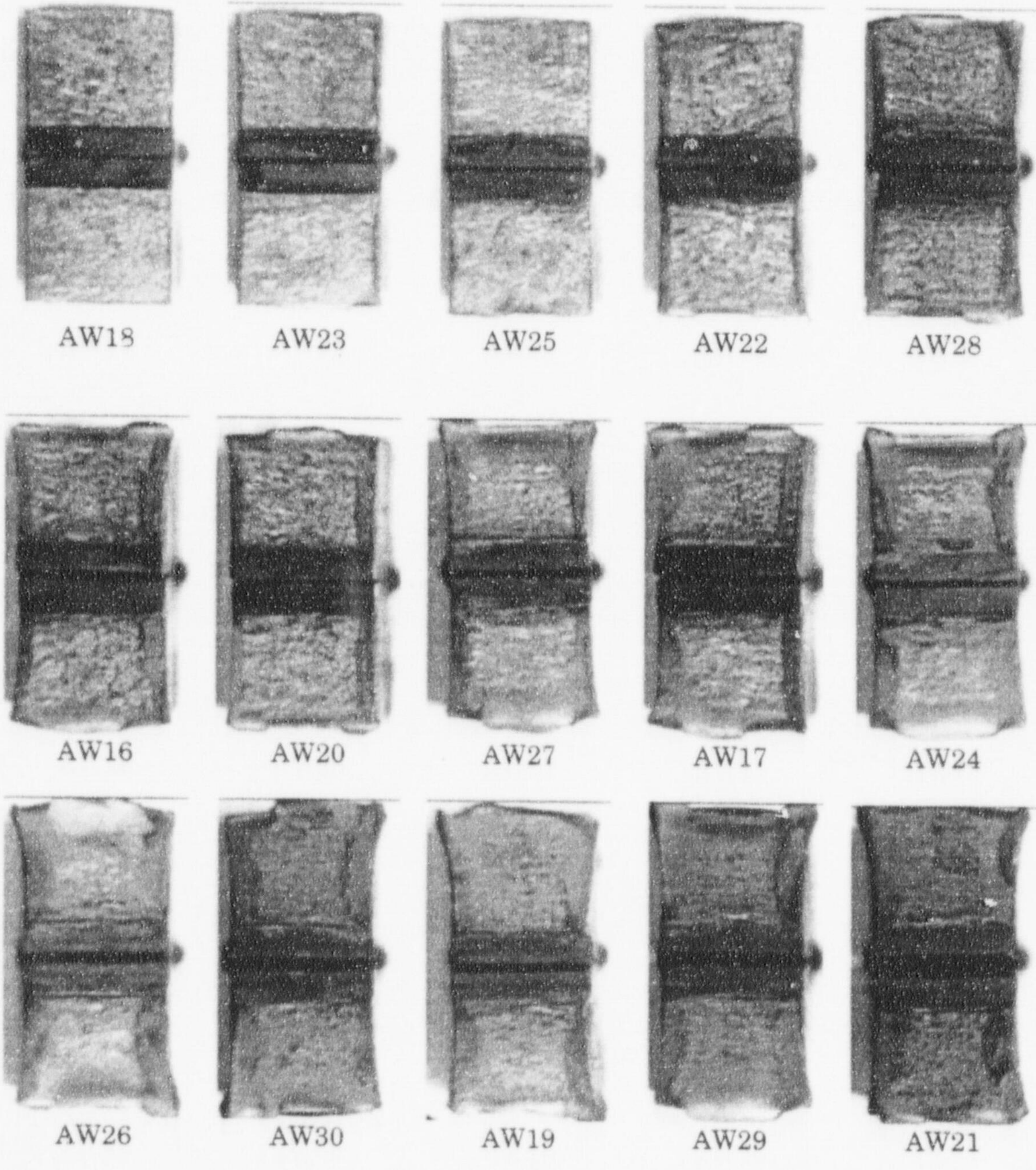


Figure 5-15 Charpy Impact Specimen Fracture Surfaces for Wolf Creek Reactor Vessel Weld Metal

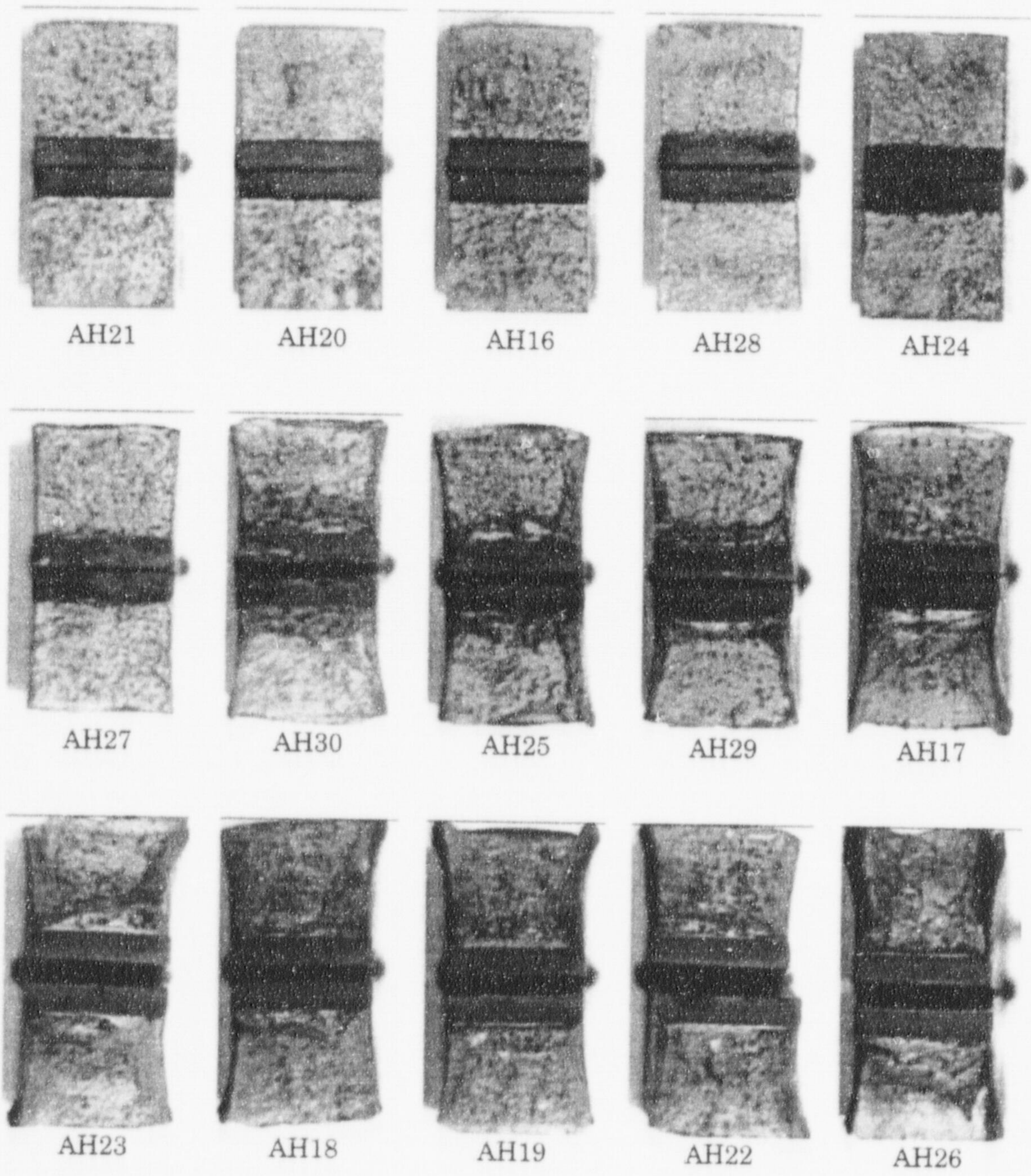


Figure 5-16 Charpy Impact Specimen Fracture Surfaces for Wolf Creek Reactor Vessel Heat-Affected-Zone Metal

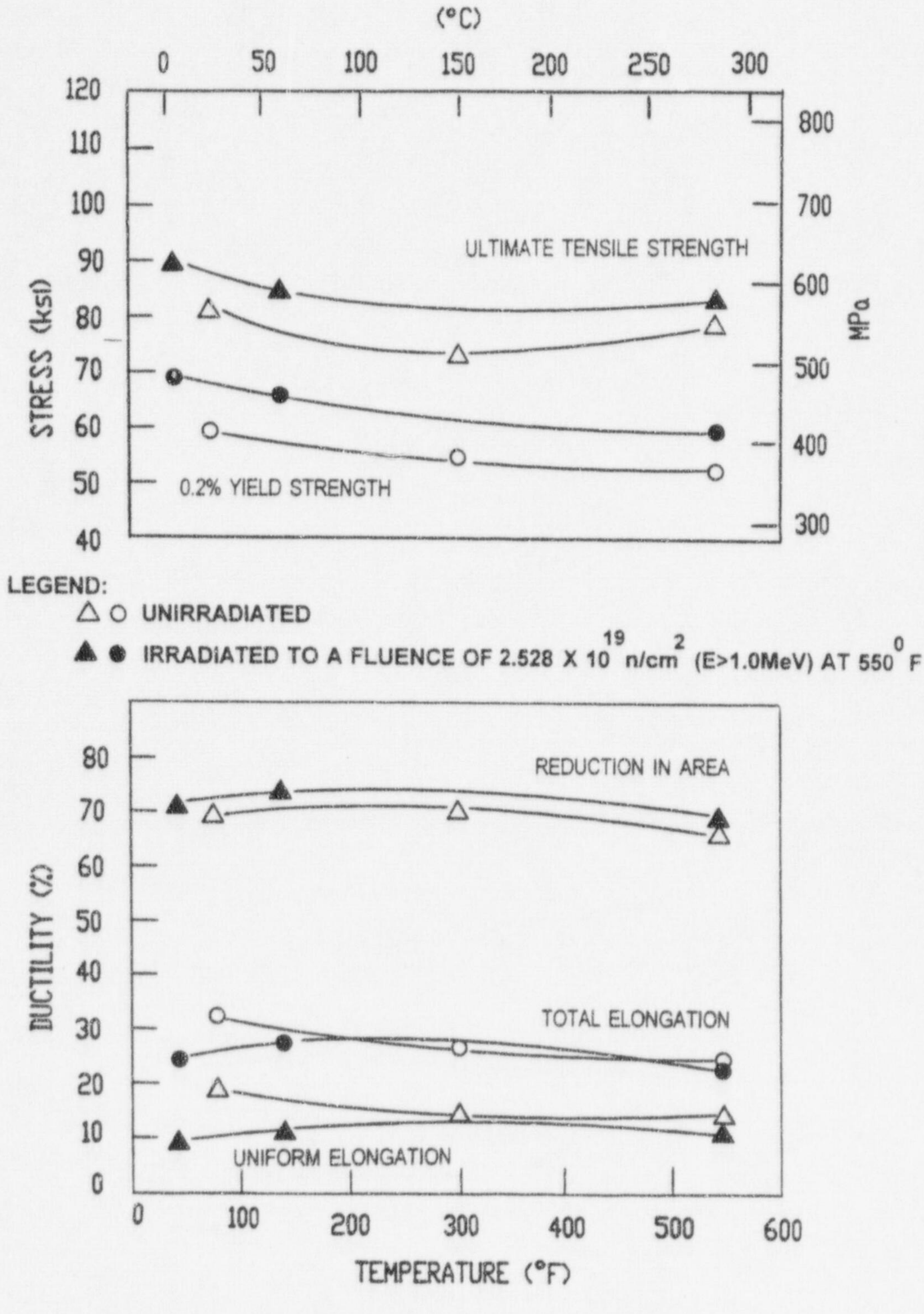


Figure 5-17 Tensile Properties for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Longitudinal Orientation)

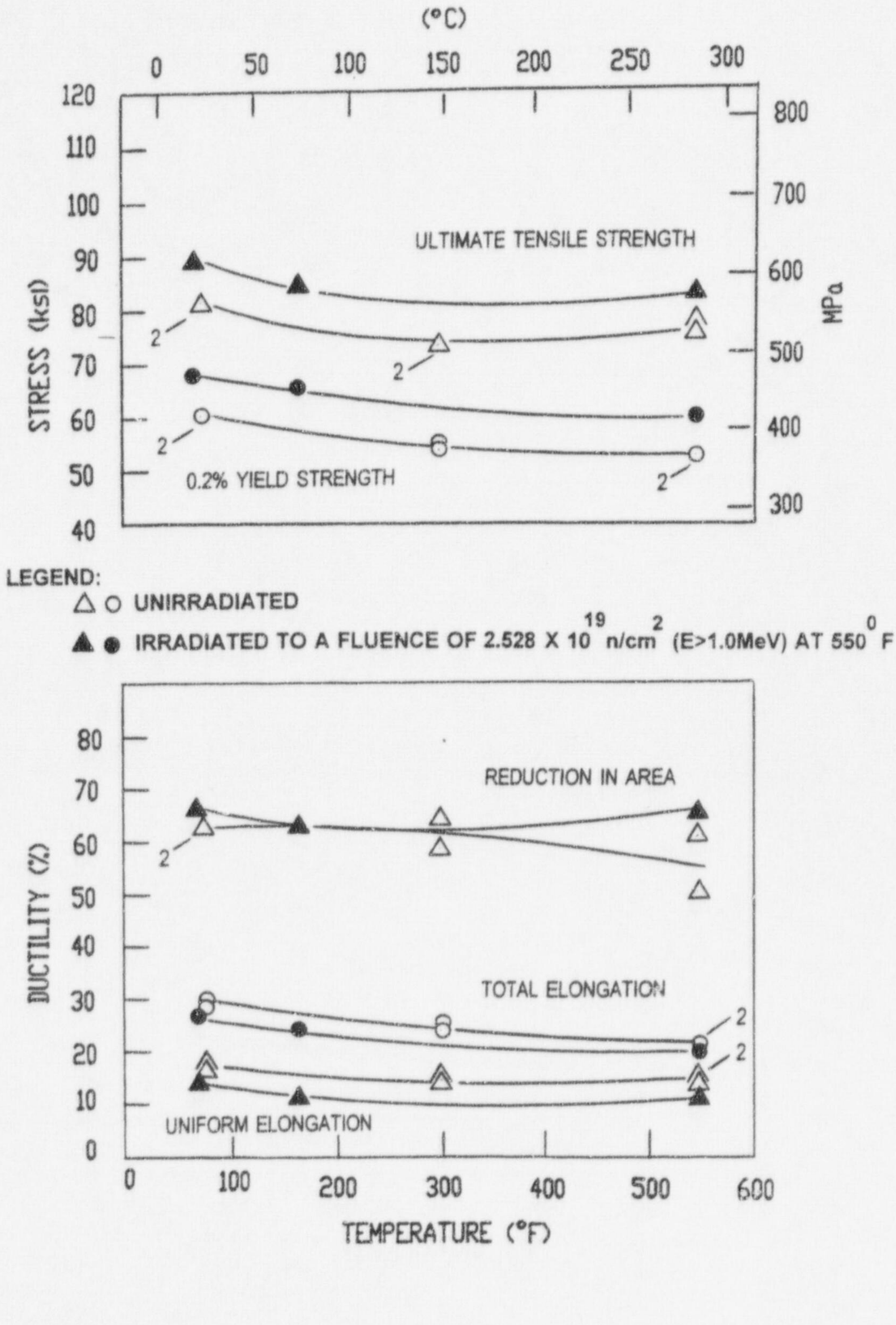


Figure 5-18 Tensile Properties for Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Transverse Orientation)

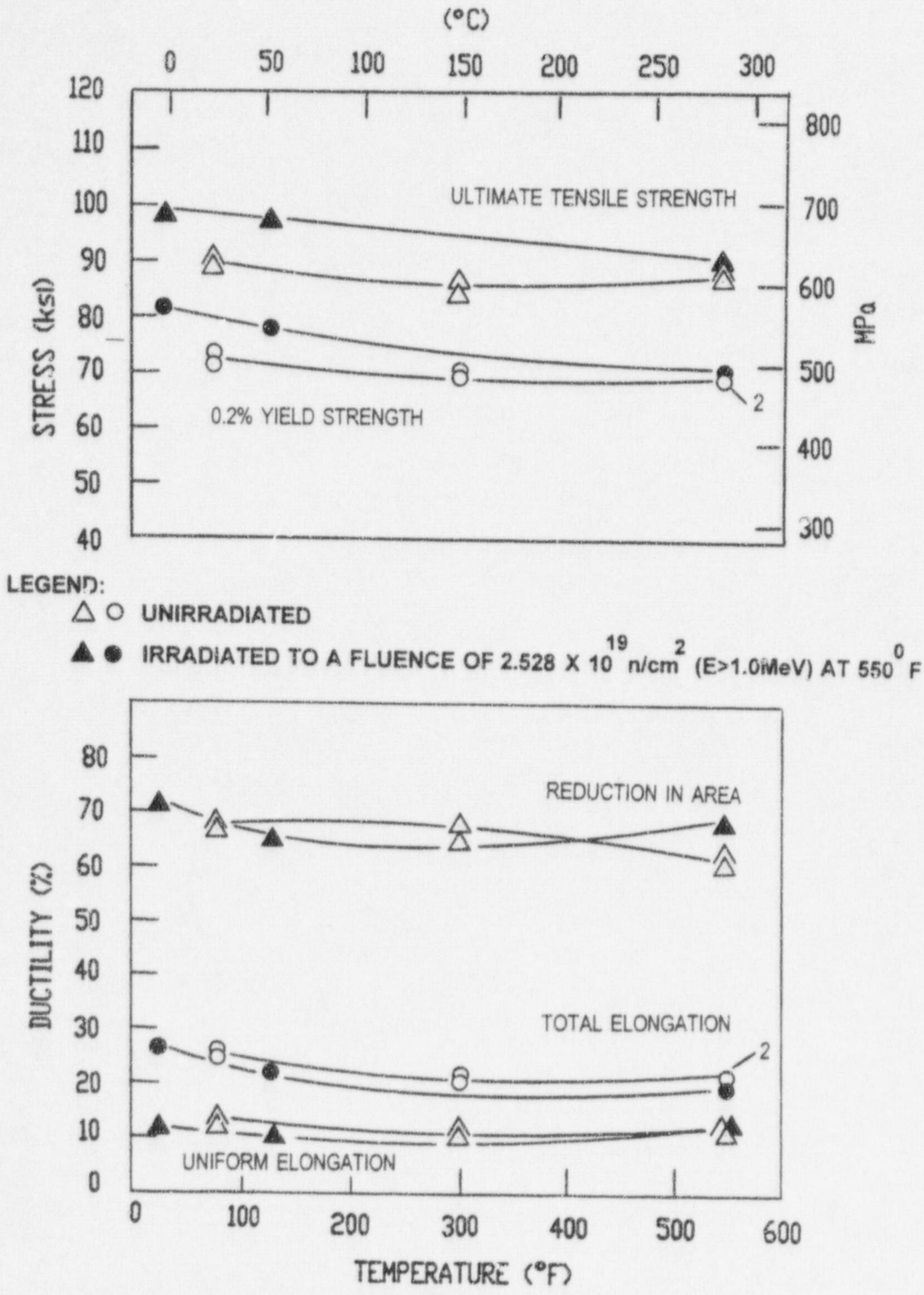
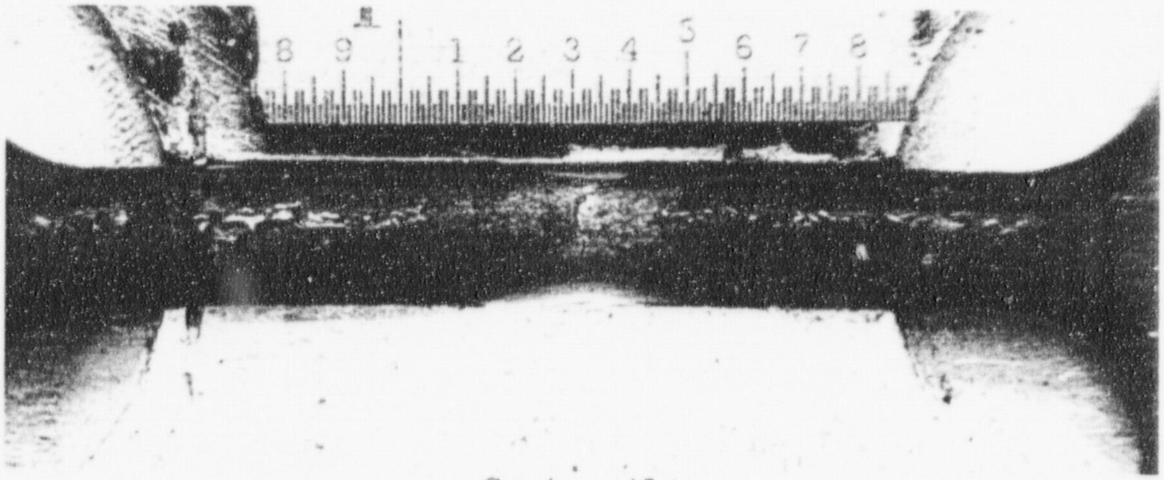
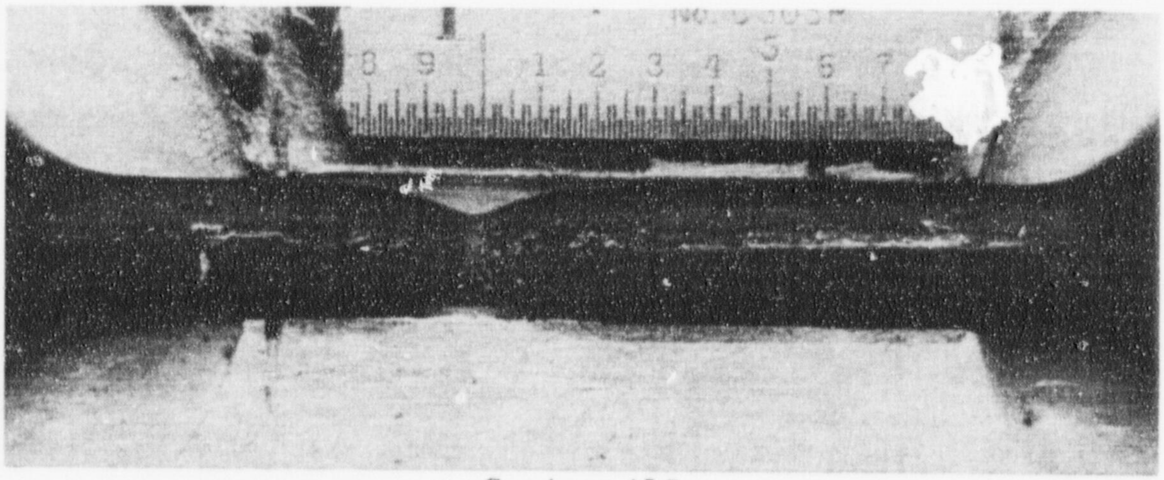


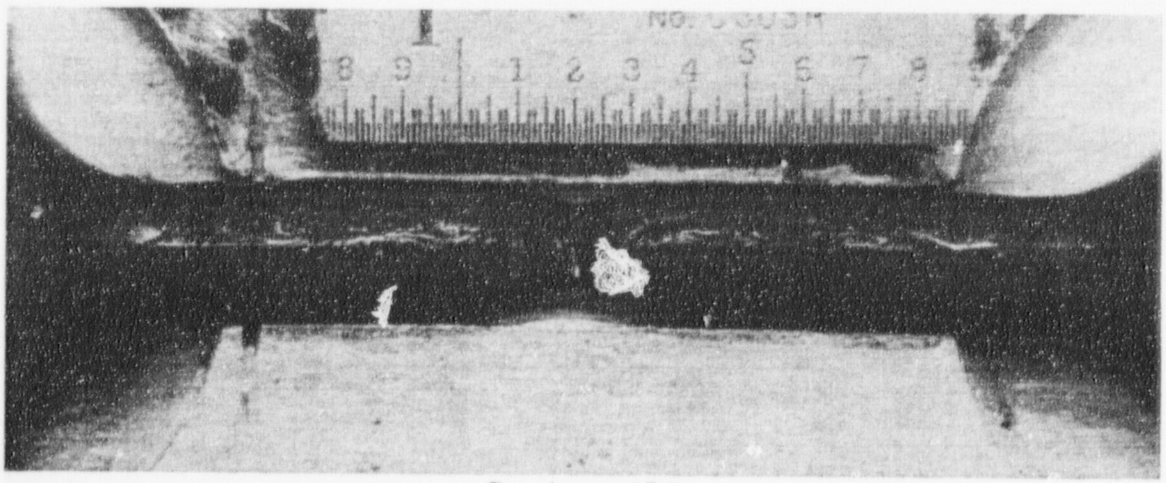
Figure 5-19 Tensile Properties for Wolf Creek Reactor Vessel Weld Metal



Specimen AL4

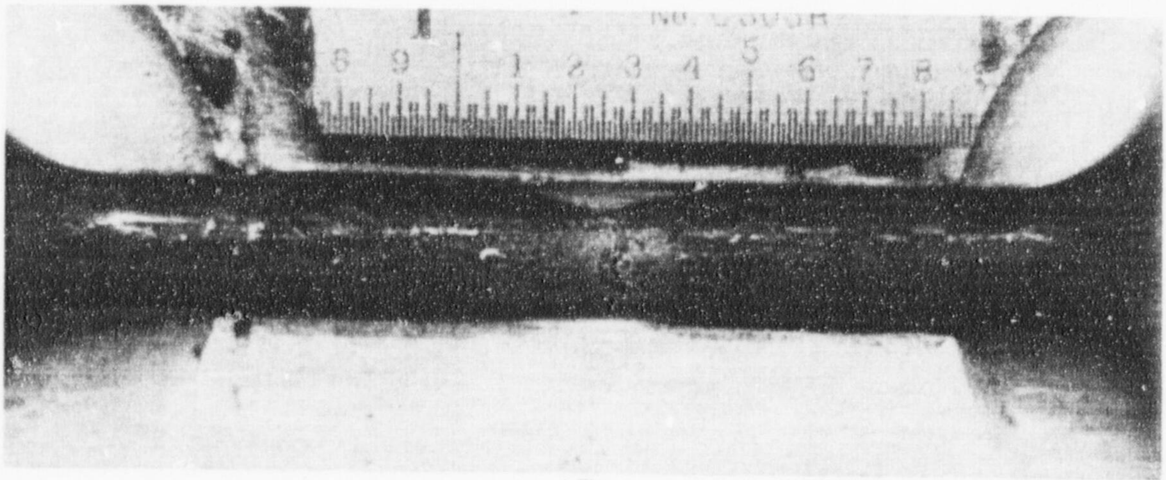


Specimen AL5

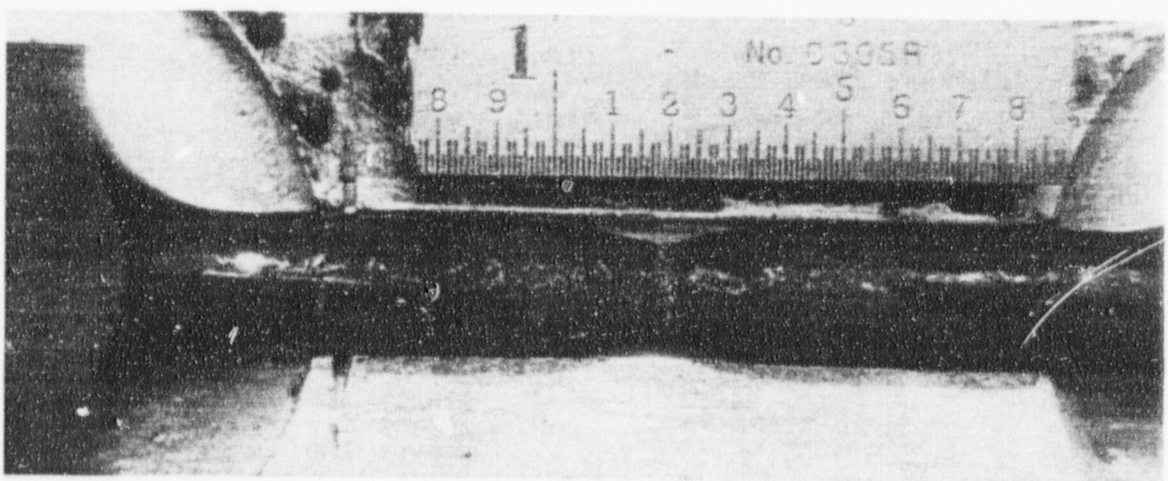


Specimen AL6

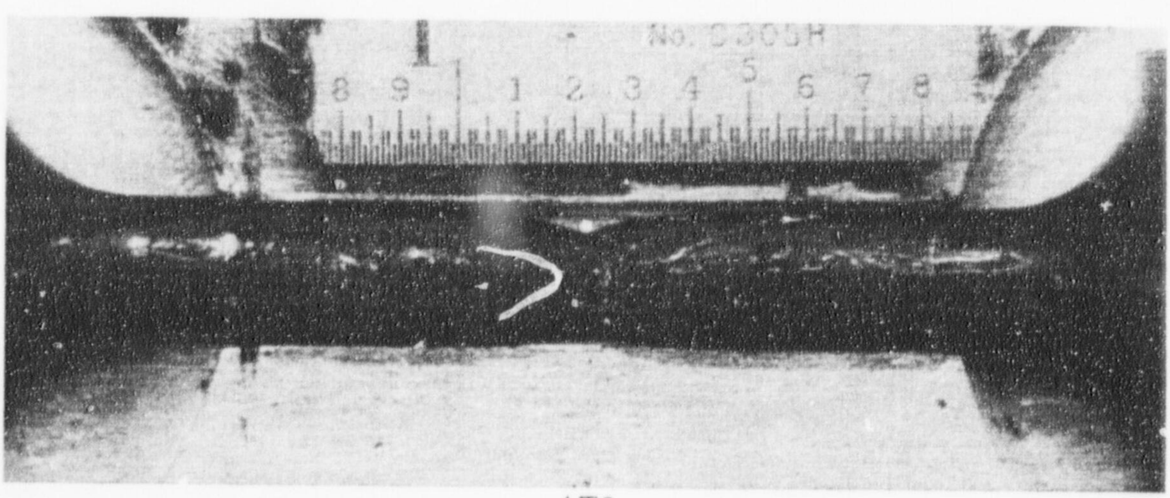
Figure 5-20 Fractured Tensile Specimens from Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Longitudinal Orientation)



AT4

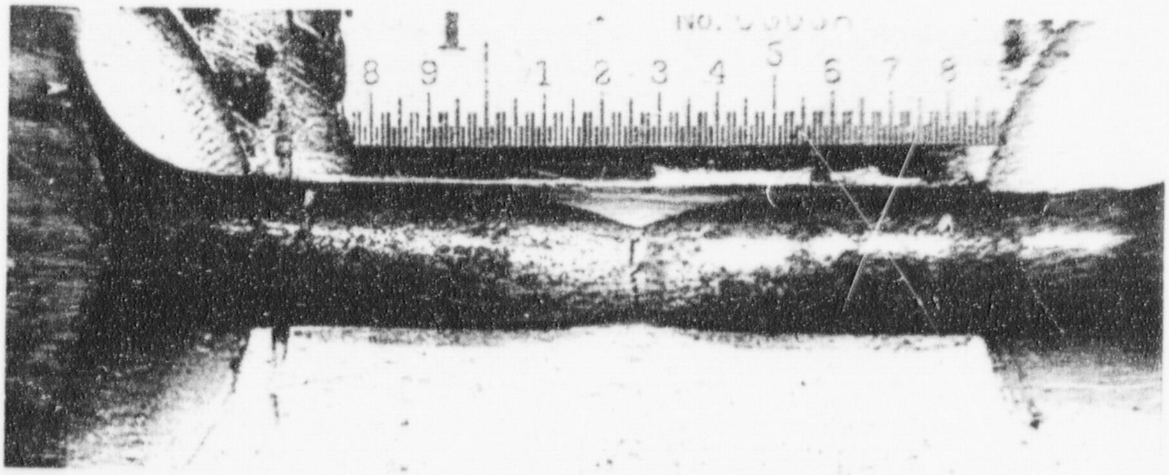


AT5

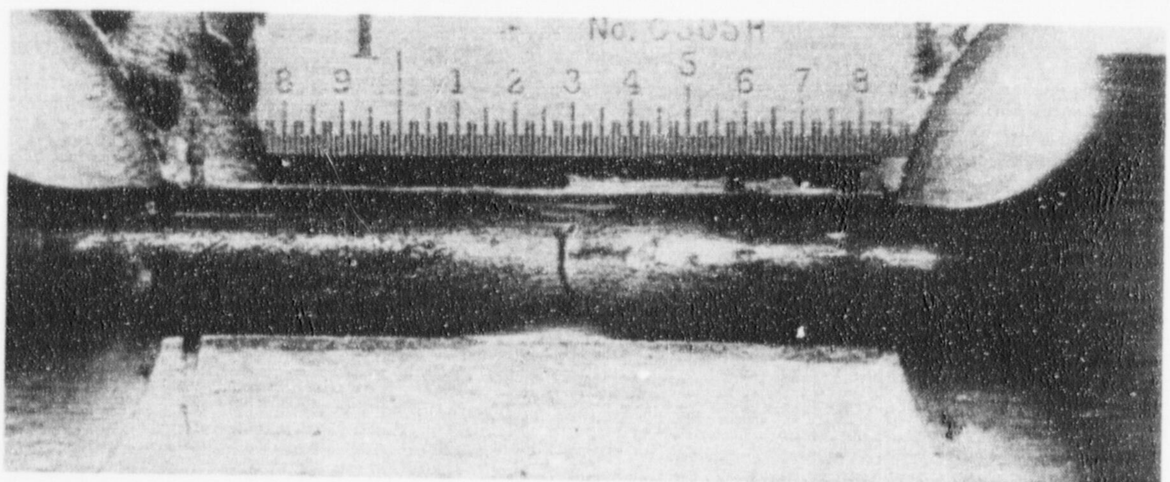


AT6

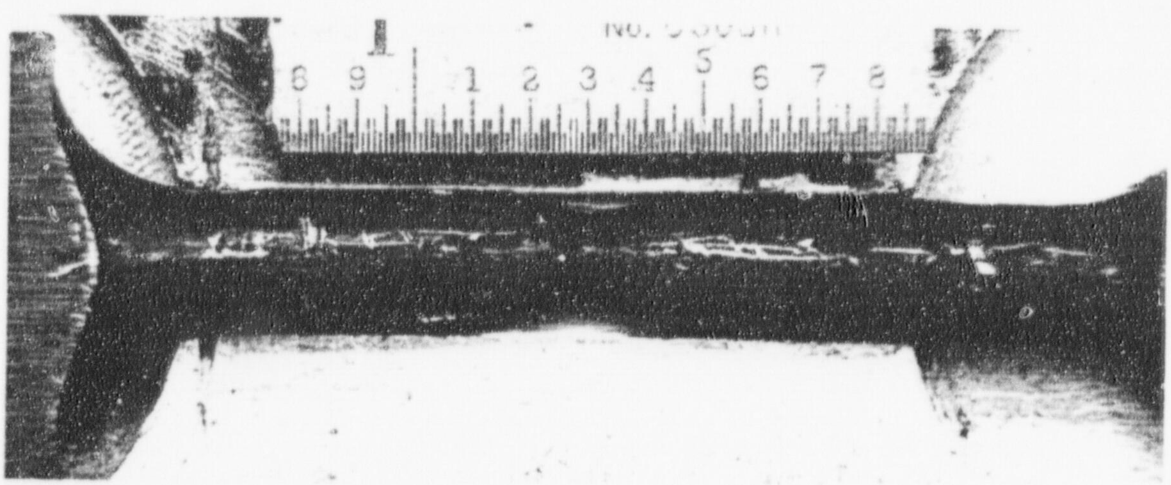
Figure 5-21 Fractured Tensile Specimens from Wolf Creek Reactor Vessel Lower Shell Plate R2508-3 (Transverse Orientation)



AW4

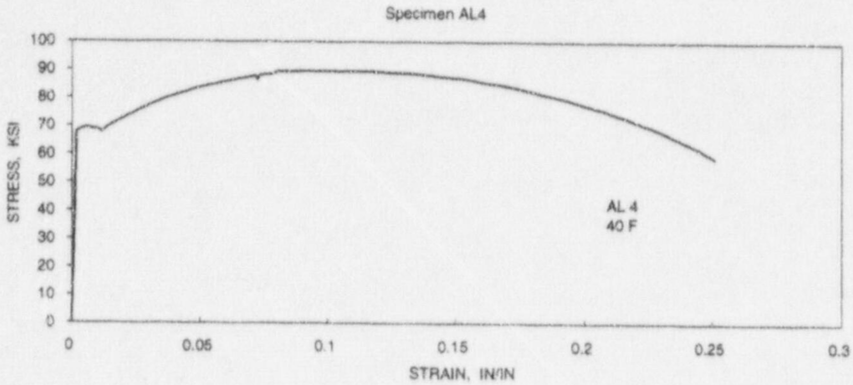


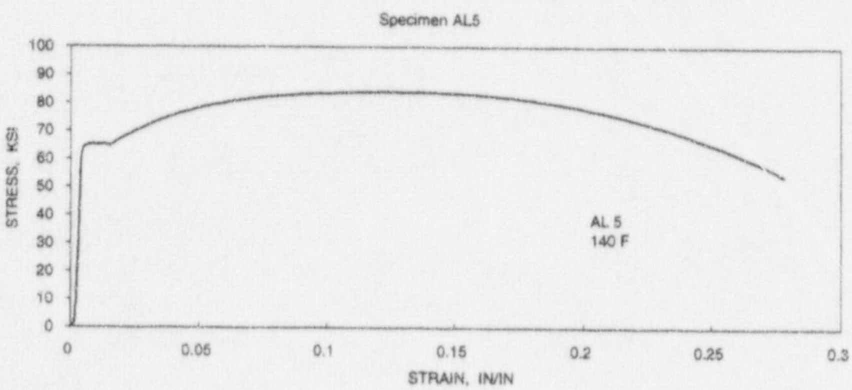
AW5



AW6

Figure 5-22 Fractured Tensile Specimens from Wolf Creek Reactor Vessel Weld Metal





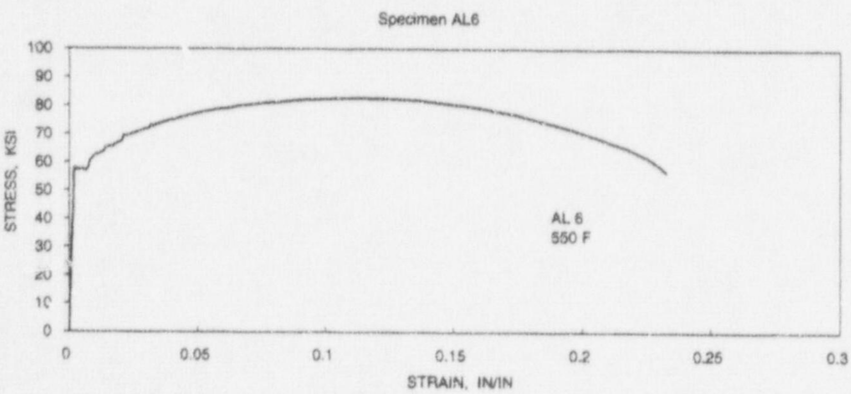


Figure 5-23 Engineering Stress-Strain Curves for Lower Shell Plate R2508-3 Tensile Specimens AL4, AL5 and AL6 (Longitudinal Orientation)

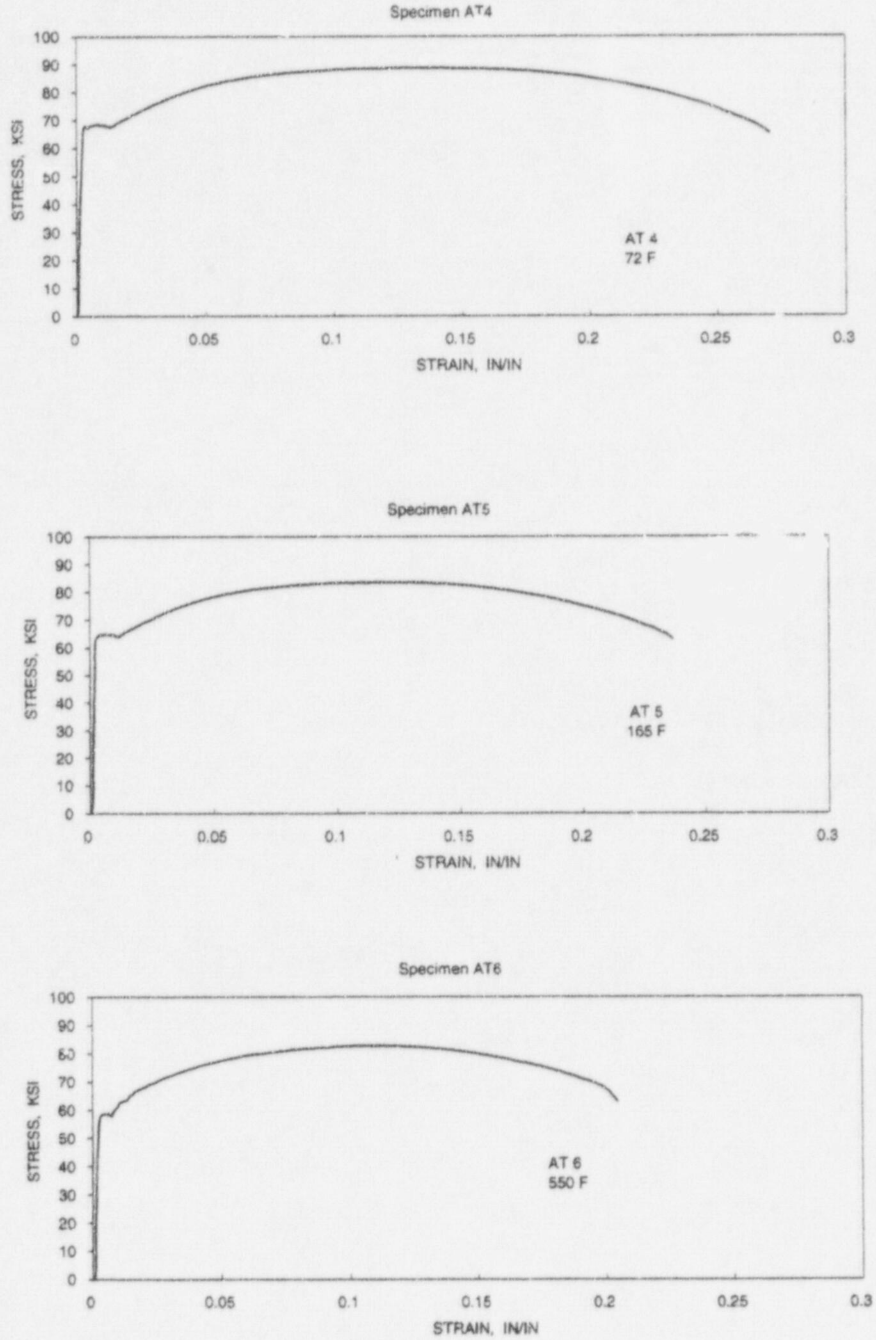


Figure 5-24 Engineering Stress-Strain Curve for Lower Shell Plate R2508-3 Tensile Specimen AT4, AT5 and AT6 (Transverse Orientation)

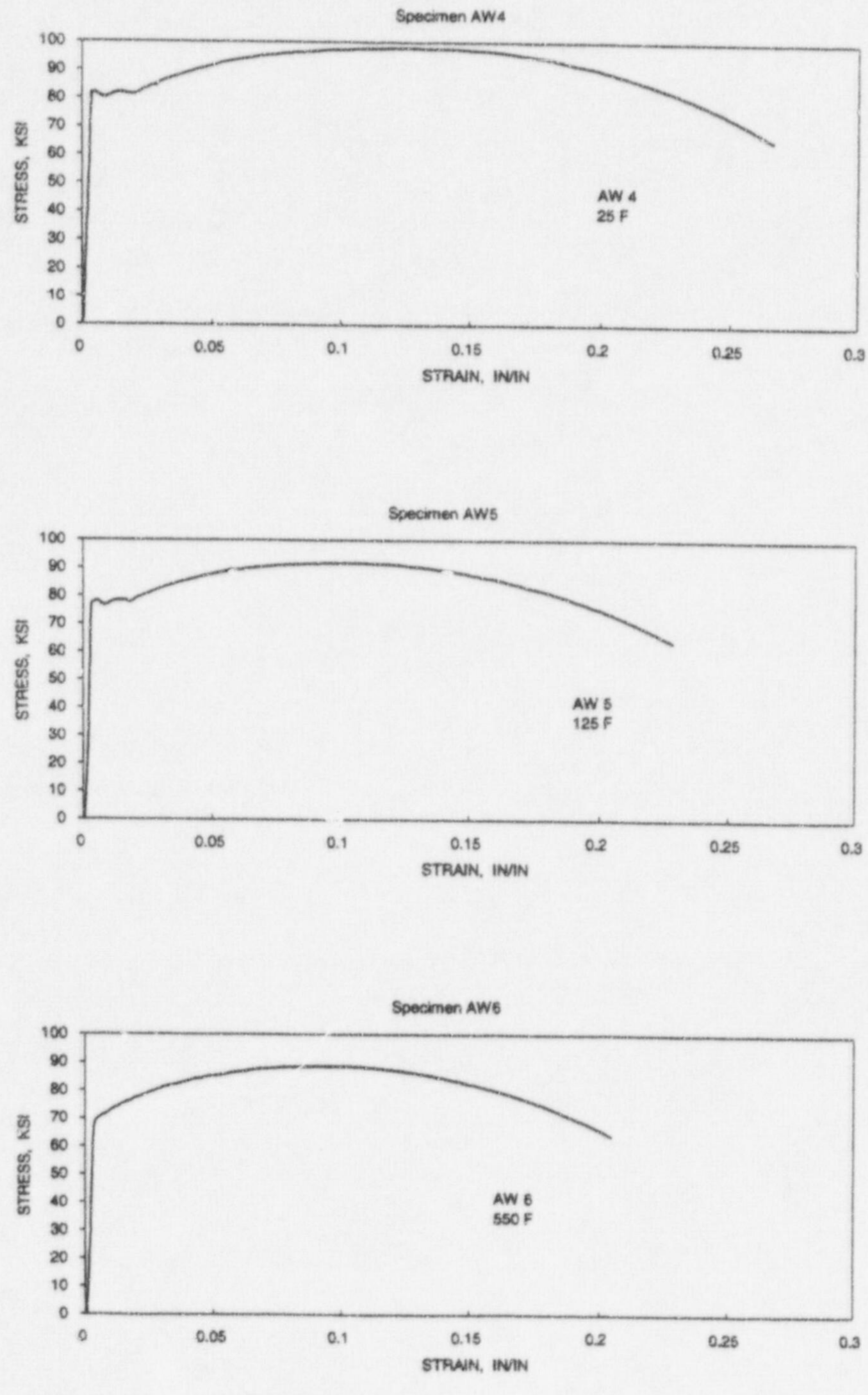


Figure 5-25 Engineering Stress-Strain Curves for Surveillance Weld Metal Tensile Specimens AW4, AW5 and AW6

SECTION 6.0
RADIATION ANALYSIS AND NEUTRON DOSIMETRY

6.1 Introduction

Knowledge of the neutron environment within the reactor vessel and surveillance capsule geometry is required as an integral part of LWR reactor vessel surveillance programs for two reasons. First, in order to interpret the neutron radiation induced material property changes observed in the test specimens, the neutron environment (energy spectrum, flux, fluence) to which the test specimens were exposed must be known. Second, in order to relate the changes observed in the test specimens to the present and future condition of the reactor vessel, a relationship must be established between the neutron environment at various positions within the reactor vessel and that experienced by the test specimens. The former requirement is normally met by employing a combination of rigorous analytical techniques and measurements obtained with passive neutron flux monitors contained in each of the surveillance capsules. The latter information is generally derived solely from analysis.

The use of fast neutron fluence (E > 1.0 MeV) to correlate measured material property changes to the neutron exposure of the material has traditionally been accepted for development of damage trend curves as well as for the implementation of trend curve data to assess vessel condition. In recent years, however, it has been suggested that an exposure model that accounts for differences in neutron energy spectra between surveillance capsule locations and positions within the vessel wall could lead to an improvement in the uncertainties associated with damage trend curves as well as to a more accurate evaluation of damage gradients through the reactor vessel wall.

Because of this potential shift away from a threshold fluence toward an energy dependent damage function for data correlation, ASTM Standard Practice E853, "Analysis and Interpretation of Light-Water Reactor Surveillance Results," recommends reporting displacements per iron atom (dpa) along with fluence (E > 1.0 MeV) to provide a data base for future reference. The energy dependent dpa function to be used for this evaluation is specified in ASTM Standard Practice E693, "Characterizing Neutron Exposures in Iron and Low Alloy Steels in Terms of Displacements per Atom." The application of the dpa parameter to the assessment of embrittlement gradients through the thickness of the reactor vessel wall has already been promulgated in Revision 2 to Regulatory Guide 1.99, "Radiation Embrittlement of Reactor Vessel Materials."

This section provides the results of the neutron dosimetry evaluations performed in conjunction with the analysis of test specimens contained in surveillance Capsules U, Y, and V which were withdrawn during the first, fifth, and ninth fuel cycles, respectively. This evaluation 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 data base. This report provides a consistent up-to-date neutron exposure data base for use in evaluating the material properties of the Wolf Creek reactor vessel.

In each capsule dosimetry evaluation, fast neutron exposure parameters in terms of neutron fluence (E > 1.0 MeV), neutron fluence (E > 0.1 MeV), and iron atom displacements (dpa) are established for the capsule irradiation history. The analytical formalism relating the measured capsule exposure to the exposure of the vessel wall is described and used to project the integrated exposure of the vessel wall. Also, uncertainties associated with the derived exposure parameters at the surveillance capsules and with the projected exposure of the reactor vessel are provided.

6.2 Discrete Ordinates Analysis

A plan view of the reactor geometry at the core midplane is shown in Figure 4-1. Six irradiation capsules attached to the neutron pads are included in the reactor design to constitute the reactor vessel surveillance program. The capsules are located at azimuthal angles of 58.5°, 61°, 121.5°, 238.5°, 241°, and 301.5° relative to the core cardinal axis as shown in Figure 4-1.

A plan view of a dual surveillance capsule holder attached to the neutron pad is shown in Figure 6-1. The stainless steel specimen containers are 1.182 by 1-inch and approximately 56 inches in height. The containers are positioned axially such that the test specimens are centered on the core midplane, thus spanning the central 5 feet of the 12-foot high reactor core.

From a neutronic standpoint, the surveillance capsules and associated support structures are significant. The presence of these materials has a marked effect on both the spatial distribution of neutron flux and the neutron energy spectrum in the water annulus between the neutron pad and the reactor vessel. In order to determine the neutron environment at the test specimen location, the capsules themselves must be included in the analytical model.

In performing the fast neutron exposure evaluations for the surveillance capsules and reactor vessel, two distinct sets of transport calculations were carried out. The first, a single computation in the conventional forward mode, was used primarily to obtain relative neutron energy distributions throughout the reactor geometry as well as to establish relative radial distributions of exposure parameters {$\phi(E > 1.0$ MeV), $\phi(E > 0.1$ MeV), and dpa/sec} through the vessel wall. The neutron spectral information was required for the interpretation of neutron dosimetry withdrawn from the surveillance capsule as well as for the determination of exposure parameter ratios, i.e., [dpa/sec]/[$\phi(E > 1.0$ MeV)], within the reactor vessel geometry. The relative radial gradient information was required to permit the projection of measured exposure parameters to locations interior to the reactor vessel wall, i.e., the ¼T and ¾T locations.

The second set of calculations consisted of a series of adjoint analyses relating the fast neutron flux, $\phi(E > 1.0$ MeV), at surveillance capsule positions and at several azimuthal locations on the reactor vessel inner radius to neutron source distributions within the reactor core. The source importance functions generated from these adjoint analyses provided the basis for all absolute exposure calculations and comparison with measurement. These importance functions, when combined with fuel cycle specific neutron source distributions, yielded absolute predictions of neutron exposure at the locations of interest for each cycle of irradiation. They also established the means to perform similar predictions and dosimetry evaluations for all subsequent fuel cycles. It is important to note that the cycle specific neutron source distributions utilized in these analyses included not only spatial variations of fission rates within the reactor core but also accounted for the effects of varying neutron yield per fission and fission spectrum introduced by the build-up of plutonium as the burnup of individual fuel assemblies increased.

The absolute cycle-specific data from the adjoint evaluations together with the relative neutron energy spectra and radial distribution information from the reference forward calculation provided the means to:

1 - Evaluate neutron dosimetry obtained from surveillance capsules,
2 - Relate dosimetry results to key locations at the inner radius and through the thickness of the reactor vessel wall,

3 - Enable a direct comparison of analytical prediction with measurement, and

4 - Establish a mechanism for projection of reactor vessel exposure as the design of each new fuel cycle evolves.

The forward transport calculation for the reactor model summarized in Figures 4-1 and 6-1 was carried out in R,θ geometry using the DORT two-dimensional discrete ordinates code Version 3.1[14] and the BUGLE-93 cross-section library [15]. The BUGLE-93 library is a 47 energy group ENDF/B-VI based data set produced specifically for light water reactor applications. In these analyses, anisotropic scattering was treated with a P_3 expansion of the scattering cross-sections and the angular discretization was modeled with an S_8 order of angular quadrature.

The core power distribution utilized in the reference forward transport calculation was derived from statistical studies of long-term operation of Westinghouse 4-loop plants. Inherent in the development of this reference core power distribution is the use of an out-in fuel management strategy, i.e., fresh fuel on the core periphery. Furthermore, for the peripheral fuel assemblies, the neutron source was increased by a 2σ margin derived from the statistical evaluation of plant-to-plant and cycle-to-cycle variations in peripheral power. Since it is unlikely that any single reactor would exhibit power levels on the core periphery at the nominal + 2σ value for a large number of fuel cycles, the use of this reference distribution is expected to yield somewhat conservative results.

All adjoint calculations were also carried out using an S_8 order of angular quadrature and the P_3 cross-section approximation from the BUGLE-93 library. Adjoint source locations were chosen at several azimuthal locations along the reactor vessel inner radius as well as at the geometric center of each surveillance capsule. Again, these calculations were run in R,θ geometry to provide neutron source distribution importance functions for the exposure parameter of interest, in this case $\phi(E > 1.0\ \text{MeV})$.

Having the importance functions and appropriate core source distributions, the response of interest could be calculated as:

$$R(r,\theta) = \int_r \int_\theta \int_E I(r,\theta,E)\ S(r,\theta,E)\ r\ dr\ d\theta\ dE$$

where:

$R(r,\theta)$ =	$\phi(E > 1.0$ MeV) at radius r and azimuthal angle θ.
$I(r,\theta,E)$=	Adjoint source importance function at radius r, azimuthal angle θ, and neutron source energy E.
$S(r,\theta,E)$=	Neutron source strength at core location r,θ and energy E.

Although the adjoint importance functions used in this analysis were based on a response function defined by the threshold neutron flux $\phi(E > 1.0$ MeV), prior calculations [16] have shown that, while the implementation of low leakage loading patterns significantly impacts both the magnitude and spatial distribution of the neutron field, changes in the relative neutron energy spectrum are of second order. Thus, for a given location, the ratio of [dpa/sec]/[$\phi(E > 1.0$ MeV)] is insensitive to changing core source distributions. In the application of these adjoint importance functions to the Wolf Creek reactor, therefore, the iron atom displacement rates (dpa/sec) and the neutron flux $\phi(E > 0.1$ MeV) were computed on a cycle-specific basis by using [dpa/sec]/[$\phi(E > 1.0$ MeV)] and [$\phi(E > 0.1$ MeV)]/[$\phi(E > 1.0$ MeV)] ratios from the forward analysis in conjunction with the cycle specific $\phi(E > 1.0$ MeV) solutions from the individual adjoint evaluations.

The reactor core power distributions used in the plant specific adjoint calculations were taken from the fuel cycle design reports for the first nine operating cycle of Wolf Creek [17 through 25].

Selected results from the neutron transport analyses are provided in Tables 6-1 through 6-5. The data listed in these tables establish the means for absolute comparisons of analysis and measurement for the Capsules U, Y, and V irradiation periods and provide the means to correlate dosimetry results with the corresponding exposure of the reactor vessel wall.

In Table 6-1, the calculated exposure parameters [$\phi(E > 1.0$ MeV), $\phi(E > 0.1$ MeV), and dpa/sec] are given at the geometric center of the two azimuthally symmetric surveillance capsule positions (29° and 31.5°) for both the reference and the plant specific core power distributions. The plant-specific data, based on the adjoint transport analysis, are meant to establish the absolute comparison of measurement with analysis. The reference data derived from the forward calculation are provided as a conservative exposure evaluation against which plant specific fluence calculations can be compared. Similar data are given in Table 6-2 for the reactor vessel inner radius. Again, the three pertinent exposure parameters are listed for the reference and Cycles 1 to 9 plant specific power distributions. It is important to note that the data for the vessel inner radius were taken at the clad/base metal interface, and, thus, epresent the maximum predicted exposur: levels of the vessel plates and welds.

Radial gradient information applicable to $\phi(E > 1.0\ MeV)$, $\phi(E > 0.1\ MeV)$, and dpa/sec is given in Tables 6-3, 6-4, and 6-5, respectively. The data, obtained from the reference forward neutron transport calculation, are presented on a relative basis for each exposure parameter at several azimuthal locations. Exposure distributions through the vessel wall may be obtained by normalizing the calculated or projected exposure at the vessel inner radius to the gradient data listed in Tables 6-3 through 6-5.

For example, the neutron flux $\phi(E > 1.0\ MeV)$ at the ¼T depth in the reactor vessel wall along the 0° azimuth is given by:

$$\phi_{1/4T}(0°) = \phi(220.35,0°)\ F(225.87,0°)$$

where:

$\phi_{1/4T}(0°)$ = Projected neutron flux at the ¼T position on the 0° azimuth.

$\phi(220.35,0°)$ = Projected or calculated neutron flux at the vessel inner radius on the 0° azimuth.

$F(225.87,0°)$ = Ratio of the neutron flux at the ¼T position to the flux at the vessel inner radius for the 0° azimuth. This data is obtained from Table 6-3.

Similar expressions apply for exposure parameters expressed in terms of $\phi(E > 0.1\ MeV)$ and dpa/sec where the attenuation function F is obtained from Tables 6-4 and 6-5, respectively.

6.3 Neutron Dosimetry

The passive neutron sensors included in the Wolf Creek surveillance program are listed in Table 6-6. Also given in Table 6-6 are the primary nuclear reactions and associated nuclear constants that were used in the evaluation of the neutron energy spectrum within the surveillance capsules and in the subsequent determination of the various exposure parameters of interest [$\phi(E > 1.0\ MeV)$, $\phi(E > 0.1\ MeV)$, dpa/sec]. The relative locations of the neutron sensors within the capsules are shown in Figure 4-2. The iron, nickel, copper, and cobalt-aluminum monitors, in wire form, were placed in holes drilled in spacers at several axial levels within the capsules. The cadmium shielded uranium and neptunium fission monitors were accommodated within the dosimeter block located near the center of the capsule.

The use of passive monitors such as those listed in Table 6-6 does not yield a direct measure of the energy dependent neutron flux at the point of interest. Rather, the activation or fission process is a measure of the integrated effect that the time and energy dependent neutron flux has on the target material over the course of the irradiation period. An accurate assessment of the average neutron flux level incident on the various monitors may be derived from the activation measurements only if the irradiation parameters are well known. In particular, the following variables are of interest:

- The measured specific activity of each monitor,
- The physical characteristics of each monitor,
- The operating history of the reactor[26],
- The energy response of each monitor, and
- The neutron energy spectrum at the monitor location.

The specific activity of each of the neutron monitors was determined using established ASTM procedures [27 through 40]. Following sample preparation and weighing, the activity of each monitor was determined by means of a lithium-drifted germanium, Ge(Li), gamma spectrometer. The irradiation history of the Wolf Creek reactor was obtained from Wolf Creek Nuclear Operating Corporation personnel [26] and data reported in NUREG-0020, "Licensed Operating Reactors Status Summary Report," for the Cycles 1 to 9 operating periods. The irradiation history applicable to the exposure of Capsules U, Y, and V is given in Table 6-7.

Having the measured specific activities, the physical characteristics of the sensors, and the operating history of the reactor, reaction rates referenced to full-power operation were determined from the following equation:

$$R = \frac{A}{N_0\, F\, Y \sum \frac{P_j}{P_{ref}}\, C_j\, [1 - e^{-\lambda t_j}]\, [e^{-\lambda t_d}]}$$

where:

R	=	Reaction rate averaged over the irradiation period and referenced to operation at a core power level of P_{ref} (rps/nucleus).
A	=	Measured specific activity (dps/gm).
N_0	=	Number of target element atoms per gram of sensor.
F	=	Weight fraction of the target isotope in the sensor material.
Y	=	Number of product atoms produced per reaction.
P_j	=	Average core power level during irradiation period j (MW).
P_{ref}	=	Maximum or reference power level of the reactor (MW).
C_j	=	Calculated ratio of $\phi(E > 1.0$ MeV) during irradiation period j to the time weighted average $\phi(E > 1.0$ MeV) over the entire irradiation period.
λ	=	Decay constant of the product isotope (1/sec).
t_j	=	Length of irradiation period j (sec).
t_d	=	Decay time following irradiation period j (sec).

and the summation is carried out over the total number of monthly intervals comprising the irradiation period.

In the equation describing the reaction rate calculation, the ratio $[P_j]/[P_{ref}]$ accounts for month-by-month variation of reactor core power level within any given fuel cycle as well as over multiple fuel cycles. The ratio C_j, which can be calculated for each fuel cycle using the adjoint transport technology discussed in Section 6.2, accounts for the change in sensor reaction rates caused by variations in flux level induced by changes in core spatial power distributions from fuel cycle to fuel cycle. For a single cycle irradiation, C_j is normally taken to be 1.0. However, for multiple-cycle irradiations, particularly those employing low leakage fuel management, the additional C_j term should be employed. The impact of changing flux levels for constant power operation can be quite significant for sensor sets that have been irradiated for many cycles in a reactor that has transitioned from non-low leakage to low leakage fuel management or for sensor sets contained in surveillance capsules that have been moved from one capsule location to another.

For the irradiation history of Capsule U, Y, and V the flux level term in the reaction rate calculations was set to 1.0 for Capsule U only. Measured and saturated reaction product specific activities as well as the derived full power reaction rates are listed in Table 6-8 referenced to 3565 MWt. The specific activities and reaction rates of the ^{238}U sensors provided in Table 6-8 include corrections for ^{235}U impurities, plutonium build-in, and gamma ray induced fissions. Corrections for gamma ray induced fissions were also included in the specific activities and reaction rates for the ^{237}Np sensors as well.

Values of key fast neutron exposure parameters were derived from the measured reaction rates using the FERRET least squares adjustment code [41]. The FERRET approach used the measured reaction rate data, sensor reaction cross-sections, and a calculated trial spectrum as input and proceeded to adjust the group fluxes from the trial spectrum to produce a best fit (in a least squares sense) within the constraints of the parameter uncertainties. The best estimate exposure parameters, along with the associated uncertainties, were then obtained from the best estimate spectrum.

In the FERRET evaluations, a log-normal least squares algorithm weights both the a priori values and the measured data in accordance with the assigned uncertainties and correlations. In general, the measured values, f, are linearly related to the flux, ϕ, by some response matrix, A:

$$f_i^{(s,\alpha)} = \sum_g A_{ig}^{(s)} \phi_g^{(\alpha)}$$

where i indexes the measured values belonging to a single data set s, g designates the energy group, and α delineates spectra that may be simultaneously adjusted. For example,

$$R_i = \sum_g \sigma_{ig} \phi_g$$

relates a set of measured reaction rates, R_i, to a single spectrum, ϕ_g, by the multi-group reaction cross-section, σ_{ig}. The log-normal approach automatically accounts for the physical constraint of positive fluxes, even with large assigned uncertainties.

In the least squares adjustment, the continuous quantities (i.e., neutron spectra and cross-sections) were approximated in a multi-group format consisting of 53 energy groups. The trial input spectrum was converted to the FERRET 53 group structure using the SAND-II code[42]. This procedure was carried out by first expanding the 47 group calculated spectrum into the SAND-II 620 group structure using a SPLINE interpolation procedure in regions where group boundaries do not coincide. The 620 point spectrum was then re-collapsed into the group structure used in FERRET.

The sensor set reaction cross-sections, obtained from the ENDF/B-VI dosimetry file [43], were also collapsed into the 53 energy group structure using the SAND-II code. In this instance, the trial spectrum, as expanded to 620 groups, was employed as a weighting function in the cross-section collapsing procedure. Reaction cross-section uncertainties in the form of a 53 × 53 covariance matrix for each sensor reaction were also constructed from the information contained on the ENDF/B-VI data files. These matrices included energy group to energy group uncertainty correlations for each of the individual reactions. However, correlations between cross-sections for different sensor reactions were not included. The omission of this additional uncertainty information does not significantly impact the results of the adjustment.

Due to the importance of providing a trial spectrum that exhibits a relative energy distribution close to the actual spectrum at the sensor set locations, the neutron spectrum input to the FERRET evaluation was taken from the center of the surveillance capsule modeled in the reference forward transport calculation. While the 53 × 53 group covariance matrices applicable to the sensor reaction cross-sections were developed from the ENDF/B-VI data files, the covariance matrix for the input trial spectrum was constructed from the following relation:

$$M_{g'g} = R_n^2 + R_g \, R_{g'} \, P_{g'g}$$

where R_n specifies an overall fractional normalization uncertainty (i.e., complete correlation) for the set of values. The fractional uncertainties, R_g, specify additional random uncertainties for group g that are correlated with a correlation matrix given by:

$$P_{g'g} = [1-\theta] \, \delta_{g'g} + \theta \, e^{-H}$$

where:

$$H = \frac{(g-g')^2}{2\,\gamma^2}$$

The first term in the correlation matrix equation specifies purely random uncertainties, while the second term describes short range correlations over a group range γ (θ specifies the strength of the latter term). The value of δ is 1 when $g = g'$ and 0 otherwise. For the trial spectrum used in the current evaluations, a short range correlation of $\gamma = 6$ groups was used. This choice implies that neighboring groups are strongly correlated when θ is close to 1. Strong long-range correlations (or anti-correlations) were justified based on information presented by R. E. Maerker[44]. The uncertainties associated with the measured reaction rates included both statistical (counting) and systematic components. The systematic component of the overall uncertainty accounts for counter efficiency, counter calibrations, irradiation history corrections, and corrections for competing reactions in the individual sensors.

Results of the FERRET evaluation of the Capsule U, Y, and V dosimetry are given in Table 6-9. The data summarized in this table include fast neutron exposure evaluations in terms of $\Phi(E > 1.0\ \text{MeV})$, $\Phi(E > 0.1\ \text{MeV})$, and dpa. In general, excellent results were achieved in the fits of the best estimate spectra to the individual measured reaction rates. The measured, calculated and best estimate reaction rates for each reaction are given in Table 6-10. An examination of Table 6-10 shows that, in all cases, reaction rates calculated with the best estimate spectra match the measured reaction rates to better than 14%. The best estimate spectra from the least squares evaluation is given in Table 6-11 in the FERRET 53 energy group structure.

In Table 6-12, absolute comparisons of the best estimate and calculated fluence at the center of Capsules U, Y, and V are presented. The results for the Capsules U, Y, and V dosimetry evaluation (BE/C ratio of 0.975 for $\Phi(E > 1.0\ \text{MeV})$) are consistent with results obtained from similar evaluations of dosimetry from other reactors using methodologies based on ENDF/B-VI cross-sections.

6.4 Projections of Reactor Vessel Exposure

The best estimate exposure of the Wolf Creek reactor vessel was developed using a combination of absolute plant specific transport calculations and all available plant specific measurement data. In the case of Wolf Creek, the measurement data base contains three surveillance capsules discussed in this report.

Combining this measurement data base with the plant-specific calculations, the best estimate vessel exposure is obtained from the following relationship:

$$\Phi_{Best\ Est.} = K\ \Phi_{Calc.}$$

where:

$\Phi_{Best\ Est.}$ = The best estimate fast neutron exposure at the location of interest.

K = The plant specific best estimate/calculation (BE/C) bias factor derived from the surveillance capsule dosimetry data.

$\Phi_{Calc.}$ = The absolute calculated fast neutron exposure at the location of interest.

The approach defined in the above equation is based on the premise that the measurement data represent the most accurate plant-specific information available at the locations of the dosimetry; and, further that the use of the measurement data on a plant-specific basis essentially removes biases present in the analytical approach and mitigates the uncertainties that would result from the use of analysis alone.

That is, at the measurement points the uncertainty in the best estimate exposure is dominated by the uncertainties in the measurement process. At locations within the reactor vessel wall, additional uncertainty is incurred due to the analytically determined relative ratios among the various measurement points and locations within the reactor vessel wall.

For Wolf Creek, the derived plant specific bias factors were 0.975, 1.069, and 1.031 for $\Phi(E > 1.0\ MeV)$, $\Phi(E > 0.1\ MeV)$, and dpa, respectively. Bias factors of this magnitude are fully consistent with experience using the BUGLE-93 cross-section library.

The use of the bias factors derived from the measurement data base acts to remove plant-specific biases associated with the definition of the core source, actual versus assumed reactor dimensions, and operational variations in water density within the reactor. As a result, the overall uncertainty in the best estimate exposure projections within the vessel wall depends on the individual uncertainties in the measurement process, the uncertainty in the dosimetry location, and, in the uncertainty in the calculated ratio of the neutron exposure at the point of interest to that at the measurement location.

The uncertainty in the derived neutron flux for an individual measurement is obtained directly from the results of a least squares evaluation of dosimetry data. The least squares approach combines individual uncertainty in the calculated neutron energy spectrum, the uncertainties in dosimetry cross-sections, and the uncertainties in measured foil specific activities to produce a net uncertainty in the derived neutron flux at the measurement point. The associated uncertainty in the plant specific bias factor, K, derived from the BE/C data base, in turn, depends on the total number of available measurements as well as on the uncertainty of each measurement.

In developing the overall uncertainty associated with the reactor vessel exposure, the positioning uncertainties for dosimetry are taken from parametric studies of sensor position performed as part a series of analytical sensitivity studies included in the qualification of the methodology. The uncertainties in the exposure ratios relating dosimetry results to positions within the vessel wall are again based on the analytical sensitivity studies of the vessel thickness tolerance, downcomer water density variations, and vessel inner radius tolerance. Thus, this portion of the overall uncertainty is controlled entirely by dimensional tolerances associated with the reactor design and by the operational characteristics of the reactor.

The net uncertainty in the bias factor, K, is combined with the uncertainty from the analytical sensitivity study to define the overall fluence uncertainty at the reactor vessel wall. In the case of Wolf Creek, the derived uncertainties in the bias factor, K, and the additional uncertainty from the analytical sensitivity studies combine to yield a net uncertainty of ±7%.

Based on this best estimate approach, neutron exposure projections at key locations on the reactor vessel inner radius are given in Table 6-13; furthermore, calculated neutron exposure projections are also provided for comparison purposes. Along with the current (9.49 EFPY) exposure, projections are also provided for exposure periods of 16 EFPY, 32 EFPY, and 54 EFPY. Projections for future operation were based on the assumption that the exposure rates averaged over Cycle 6 through 9 (low-leakage loading pattern) would continue to be applicable throughout plant life.

In the derivation of best estimate and calculated exposure gradients within the reactor vessel wall for the Wolf Creek reactor vessel, exposure projections to 16, 32, and 54 EFPY were also employed. Data based on both a $\Phi(E > 1.0\ \text{MeV})$ slope and a plant-specific dpa slope through the vessel wall are provided in Table 6-14.

In order to assess RT_{NDT} versus fluence curves, dpa equivalent fast neutron fluence levels for the ¼T and ¾T positions were defined by the relations:

$$\phi(\_T) = \phi(0T)\ \frac{dpa(\_T)}{dpa(0T)}$$

and

$$\phi(\_T) = \phi(0T)\ \frac{dpa(\_T)}{dpa(0T)}$$

Using this approach results in the dpa equivalent fluence values listed in Table 6-14.

In Table 6-15, updated lead factors are listed for each of the Wolf Creek surveillance capsules.

Graphical representation of the best estimate and calculated plant specific fast neutron fluence at key locations on the pressure vessel clad/base metal interface are shown in Figure 6-2 as a function of full power operating time. Pressure vessel data are presented for the 0°, 15°, 30°, and 45° azimuthal locations. The data for the plots is also tabulated in Table 6-16 for reference.

In regard to Figure 6-2, the solid portions of the curves are based directly on the cycle-specific core loading patterns through Cycle 9. The dashed portions of these curves, however, involve a projection into the future. As mentioned previously, the neutron flux averaged over Cycles 6 through 9 were used to project future fluence levels. In the Wolf Creek reactor, the neutron fluence at the 30° and 45° azimuthal locations are nearly identical and the maximum location is projected at the 30° azimuth.

Table 6-1

Calculated Fast Neutron Exposure Rates And Iron Atom Displacement Rates At The Surveillance Capsule Center

Cycle No.	$\phi(E > 1.0$ MeV) (n/cm^2-sec) 29°	31.5°
Reference	1.39E+11	1.48E+11
1	9.919E+10	1.057E+11
2	1.035E+11	1.141E+11
3	8.596E+10	9.316E+10
4	8.357E+10	9.172E+10
5	8.402E+10	8.943E+10
6	7.708E+10	8.136E+10
7	7.459E+10	8.065E+10
8	9.093E+10	9.639E+10
9	7.375E+10	8.377E+10

Cycle No.	$\phi(E > 0.1$ MeV) (n/cm^2-sec) 29°	31.5°
Reference	5.96E+11	6.37E+11
1	4.256E+11	4.538E+11
2	4.441E+11	4.900E+11
3	3.689E+11	3.999E+11
4	3.586E+11	3.938E+11
5	3.605E+11	3.839E+11
6	3.307E+11	3.493E+11
7	3.201E+11	3.462E+11
8	3.902E+11	4.138E+11
9	3.165E+11	3.596E+11

Cycle No.	Displacement Rate (dpa/sec) 29°	31.5°
Reference	2.63E-10	2.80E-10
1	1.875E-10	1.998E-10
2	1.956E-10	2.157E-10
3	1.625E-10	1.761E-10
4	1.579E-10	1.734E-10
5	1.588E-10	1.690E-10
6	1.457E-10	1.538E-10
7	1.410E-10	1.524E-10
8	1.719E-10	1.822E-10
9	1.394E-10	1.583E-10

Table 6-2

Calculated Azimuthal Variation Of Fast Neutron Exposure Rates
And Iron Atom Displacement Rates At The Reactor Vessel
Clad/Base Metal Interface

$\phi(E > 1.0\ MeV)$ (n/cm^2-sec)

Cycle No.	0°	15°	30°	45°
Reference	1.951E+10	2.929E+10	3.325E+10	3.409E+10
1	1.387E+10	2.051E+10	2.389E+10	2.413E+10
2	1.502E+10	2.153E+10	2.507E+10	2.894E+10
3	1.199E+10	1.779E+10	2.108E+10	2.031E+10
4	1.380E+10	1.888E+10	2.061E+10	2.145E+10
5	1.339E+10	1.932E+10	2.059E+10	1.997E+10
6	1.069E+10	1.772E+10	1.893E+10	1.817E+10
7	9.037E+09	1.477E+10	1.834E+10	1.780E+10
8	1.109E+10	1.929E+10	2.219E+10	1.914E+10
9	9.130E+09	1.265E+10	1.828E+10	1.982E+10

$\phi(E > 0.1\ MeV)$ (n/cm^2-sec)

Cycle No.	0°	15°	30°	45°
Reference	4.104E+10	6.224E+10	7.226E+10	8.535E+10
1	2.918E+10	4.358E+10	5.191E+10	6.042E+10
2	3.160E+10	4.576E+10	5.447E+10	7.246E+10
3	2.523E+10	3.781E+10	4.580E+10	5.085E+10
4	2.904E+10	4.012E+10	4.480E+10	5.371E+10
5	2.817E+10	4.106E+10	4.473E+10	5.000E+10
6	2.250E+10	3.766E+10	4.113E+10	4.549E+10
7	1.901E+10	3.138E+10	3.985E+10	4.457E+10
8	2.332E+10	4.099E+10	4.821E+10	4.793E+10
9	1.921E+10	2.689E+10	3.973E+10	4.964E+10

Displacement Rate (dpa/sec)

Cycle No.	0°	15°	30°	45°
Reference	3.024E-11	4.496E-11	5.118E-11	5.384E-11
1	2.150E-11	3.148E-11	3.676E-11	3.810E-11
2	2.328E-11	3.305E-11	3.858E-11	4.569E-11
3	1.859E-11	2.731E-11	3.244E-11	3.207E-11
4	2.139E-11	2.898E-11	3.173E-11	3.387E-11
5	2.076E-11	2.966E-11	3.168E-11	3.153E-11
6	1.657E-11	2.720E-11	2.913E-11	2.869E-11
7	1.401E-11	2.267E-11	2.822E-11	2.810E-11
8	1.718E-11	2.961E-11	3.414E-11	3.022E-11
9	1.415E-11	1.942E-11	2.814E-11	3.130E-11

Table 6-3

Relative Radial Distribution Of ϕ (E > 1.0 Mev)
Within The Reactor Vessel Wall

RADIUS (cm)	AZIMUTHAL ANGLE 0°	15°	30°	45°
220.35	1.000	1.000	1.000	1.000
221.00	0.959	0.958	0.956	0.957
222.30	0.852	0.851	0.844	0.846
223.60	0.739	0.736	0.729	0.729
224.89	0.634	0.630	0.623	0.622
225.87	0.561	0.557	0.549	0.547
227.01	0.486	0.482	0.473	0.472
228.63	0.395	0.390	0.382	0.380
230.09	0.325	0.320	0.314	0.311
231.39	0.273	0.269	0.263	0.260
232.68	0.229	0.225	0.219	0.217
234.14	0.188	0.184	0.179	0.176
235.76	0.150	0.146	0.142	0.140
236.90	0.128	0.124	0.121	0.118
237.88	0.111	0.107	0.105	0.102
239.18	0.092	0.089	0.086	0.084
240.47	0.076	0.072	0.071	0.069
241.77	0.063	0.058	0.057	0.055
242.42	0.060	0.055	0.054	0.052

Note: Base Metal Inner Radius = 220.35 cm
Base Metal ¼T = 225.87 cm
Base Metal ½T = 231.39 cm
Base Metal ¾T = 236.90 cm
Base Metal Outer Radius = 242.42 cm

Table 6-4

Relative Radial Distribution Of ϕ (E > 0.1 Mev)
Within The Reactor Vessel Wall

RADIUS (cm)	AZIMUTHAL ANGLE 0°	15°	30°	45°
220.35	1.000	1.000	1.000	1.000
221.00	1.014	1.012	1.011	1.009
222.30	1.003	0.997	0.993	0.989
223.60	0.968	0.958	0.953	0.946
224.89	0.923	0.909	0.904	0.894
225.87	0.886	0.870	0.865	0.852
227.01	0.840	0.821	0.816	0.802
228.63	0.775	0.754	0.749	0.733
230.09	0.716	0.693	0.689	0.672
231.39	0.664	0.639	0.636	0.618
232.68	0.612	0.587	0.584	0.566
234.14	0.556	0.530	0.528	0.509
235.76	0.496	0.469	0.468	0.449
236.90	0.455	0.428	0.427	0.409
237.88	0.419	0.392	0.391	0.373
239.18	0.374	0.346	0.346	0.328
240.47	0.330	0.301	0.301	0.284
241.77	0.286	0.254	0.255	0.238
242.42	0.276	0.244	0.245	0.228

Note: Base Metal Inner Radius = 220.35 cm
Base Metal ¼T = 225.87 cm
Base Metal ½T = 231.39 cm
Base Metal ¾T = 236.90 cm
Base Metal Outer Radius = 242.42 cm

Table 6-5

Relative Radial Distribution Of dpa/sec
Within The Reactor Vessel Wall

RADIUS (cm)	AZIMUTHAL ANGLE 0°	15°	30°	45°
220.35	1.000	1.000	1.000	1.000
221.00	0.965	0.965	0.964	0.965
222.30	0.877	0.876	0.873	0.879
223.60	0.785	0.783	0.779	0.788
224.89	0.699	0.696	0.692	0.703
225.87	0.639	0.635	0.631	0.643
227.01	0.576	0.571	0.567	0.580
228.63	0.497	0.491	0.488	0.501
230.09	0.435	0.428	0.427	0.439
231.39	0.386	0.379	0.378	0.389
232.68	0.343	0.335	0.334	0.345
234.14	0.300	0.291	0.291	0.301
235.76	0.257	0.249	0.249	0.258
236.90	0.231	0.221	0.223	0.230
237.88	0.209	0.200	0.200	0.207
239.18	0.183	0.173	0.174	0.180
240.47	0.159	0.149	0.150	0.154
241.77	0.137	0.125	0.126	0.129
242.42	0.133	0.120	0.121	0.124

Note: Base Metal Inner Radius = 220.35 cm
Base Metal ¼T = 225.87 cm
Base Metal ½T = 231.39 cm
Base Metal ¾T = 236.90 cm
Base Metal Outer Radius = 242.42 cm

Table 6-6

Nuclear Parameters Used In The Evaluation Of Neutron Sensors

Monitor Material	Reaction of Interest	Target Atom Fraction	Response Range	Product Half-life	Fission Yield (%)
Copper	^{63}Cu (n,α)	0.6917	E > 4.7 MeV	5.271 y	
Iron	^{54}Fe (n,p)	0.0585	E > 1.0 MeV	312.1 d	
Nickel	^{58}Ni (n,p)	0.6808	E > 1.0 MeV	70.88 d	
Uranium-238	^{238}U (n,f)	1.0000	E > 0.4 MeV	30.07 y	6.02
Neptunium-237	^{237}Np (n,f)	1.0000	E > 0.08 MeV	30.07 y	6.17
Cobalt-Al	^{59}Co (n,γ)	0.0015	non-threshold	5.271 y	

Note: ^{238}U and ^{237}Np monitors are cadmium shielded.

Table 6-7
Monthly Thermal Generation During The First Nine Fuel Cycles
Of The Wolf Creek Reactor

Yr	Mo	Thermal Generat. (MW-hr)	Yr	Mo	Thermal Generat. (MW-hr)	Yr	Mo	Thermal Generat. (MW-hr)	Yr	Mo	Thermal Generat. (MW-hr)
85	6	356676	88	8	2533606	91	10	0	94	12	2636320
85	7	1025780	88	9	2450165	91	11	0	95	1	2639803
85	8	1643803	88	10	492163	91	12	0	95	2	2383600
85	9	2053023	88	11	0	92	1	1268945	95	3	2020996
85	10	2086772	88	12	0	92	2	1524407	95	4	2543603
85	11	2366472	89	1	2095086	92	3	321390	95	5	2634001
85	12	2368666	89	2	2113705	92	4	2446580	95	6	2524794
86	1	2480479	89	3	2535552	92	5	2534299	95	7	2632369
86	2	2005668	89	4	2454150	92	6	2453249	95	8	2634129
86	3	2513225	89	5	2498149	92	7	2535304	95	9	2468895
86	4	933250	89	6	2448863	92	8	2531360	95	10	2637097
86	5	2341310	89	7	2493515	92	9	2453478	95	11	2549850
86	6	1670026	89	8	2534633	92	10	2534881	95	12	2640215
86	7	2210358	89	9	2453774	92	11	2296524	96	1	2481700
86	8	2439547	89	10	2516573	92	12	2535128	96	2	0
86	9	2406802	89	11	2450503	93	1	2534643	96	3	0
86	10	1219774	89	12	2536033	93	2	2288546	96	4	1784195
86	11	0	90	1	2534772	93	3	282997	96	5	2622027
86	12	650000	90	2	2017613	93	4	0	96	6	2349911
87	1	1533313	90	3	599723	93	5	1124412	96	7	2642811
87	2	2192444	90	4	0	93	6	2453687	96	8	2603985
87	3	2471746	90	5	1003923	93	7	2535510	96	9	2564802
87	4	2247475	90	6	2442569	93	8	2535563	96	10	2621302
87	5	2436662	90	7	2515109	93	9	2453641	96	11	2564301
87	6	2250313	90	8	2534494	93	10	2532824	96	12	2649864
87	7	2066874	90	9	2453417	93	11	2435990	97	1	2648915
87	8	2527262	90	10	2533710	93	12	2557464	97	2	2393586
87	9	1954923	90	11	2421081	94	1	2051879	97	3	2650251
87	10	0	90	12	2531359	94	2	2312015	97	4	2564428
87	11	0	91	1	2363291	94	3	2561261	97	5	2218326
87	12	0	91	2	1840498	94	4	2531248	97	6	2563505
88	1	1216547	91	3	1969185	94	5	2597022	97	7	2648185
88	2	956585	91	4	1506284	94	6	2520895	97	8	2649138
88	3	2526972	91	5	1692964	94	7	2573456	97	9	2563192
88	4	2452604	91	6	2434282	94	8	2577876	97	10	188631
88	5	2533966	91	7	2534580	94	9	1098290			
88	6	2451743	91	8	2466385	94	10	0			
88	7	2531412	91	9	1221097	94	11	2306676			

Table 6-8

Measured Sensor Activities And Reaction Rates

Surveillance Capsule U

Reaction	Location	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
^{63}Cu (n,a) ^{60}Co	Top	4.44E+04	3.70E+05	5.65E-17
	Middle	4.40E+04	3.67E+05	5.60E-17
	Bottom	4.75E+04	3.96E+05	6.05E-17
^{54}Fe (n,p) ^{54}Mn	Top	1.51E+06	3.66E+06	5.80E-15
	Middle	1.50E+06	3.64E+06	5.76E-15
	Bottom	1.80E+06	4.36E+06	6.92E-15
^{58}Ni (n,p) ^{58}Co	Top	1.64E+07	5.67E+07	8.11E-15
	Middle	1.61E+07	5.56E+07	7.96E-15
	Bottom	1.76E+07	6.08E+07	8.70E-15
^{59}Co (n,g) ^{60}Co	Top	1.04E+07	8.68E+07	5.66E-12
	Middle	1.00E+07	8.34E+07	5.44E-12
	Bottom	1.01E+07	8.43E+07	5.50E-12
^{59}Co (n,g) ^{60}Co (Cd)	Top	5.27E+06	4.40E+07	2.87E-12
	Middle	5.14E+06	4.29E+07	2.80E-12
	Bottom	4.89E+06	4.08E+07	2.66E-12
^{238}U (n,f) ^{137}Cs	Middle	1.43E+05	6.17E+06	4.05E-14
^{237}Np (n,f) ^{137}Cs	Middle	1.24E+06	5.35E+07	3.41E-13

The ^{238}U (n,f) ^{137}Cs reaction rate after correcting for ^{235}U impurities, plutonium build-in, and photofissions is 3.41E-14 rps/atom.

The ^{237}Np (n,f) ^{137}Cs reaction rate after correcting for photofissions is 3.37E-13 rps/atom.

Table 6-8 cont'd

Measured Sensor Activities And Reaction Rates

Surveillance Capsule Y

Reaction	Location	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
^{63}Cu (n,a) ^{60}Co	Top	1.37E+05	3.52E+05	5.38E-17
	Middle	1.20E+05	3.09E+05	4.71E-17
	Bottom	1.21E+05	3.11E+05	4.75E-17
^{54}Fe (n,p) ^{54}Mn	Top	1.66E+06	3.13E+06	4.96E-15
	Middle	1.49E+06	2.81E+06	4.46E-15
	Bottom	1.48E+06	2.79E+06	4.43E-15
^{58}Ni (n,p) ^{58}Co	Top	8.04E+06	4.59E+07	6.58E-15
	Middle	7.38E+06	4.22E+07	6.04E-15
	Bottom	7.33E+06	4.19E+07	6.00E-15
^{59}Co (n,g) ^{60}Co	Top	2.59E+07	6.66E+07	4.35E-12
	Bottom	2.57E+07	6.61E+07	4.31E-12
^{59}Co (n,g) ^{60}Co (Cd)	Top	1.30E+07	3.34E+07	2.18E-12
	Middle	1.36E+07	3.50E+07	2.28E-12
	Bottom	1.39E+07	3.58E+07	2.33E-12
^{238}U (n,f) ^{137}Cs	Middle	5.43E+05	5.57E+06	3.66E-14
^{237}Np (n,f) ^{137}Cs	Middle	4.40E+06	4.51E+07	2.88E-13

The ^{238}U (n,f) ^{137}Cs reaction rate after correcting for ^{235}U impurities, plutonium build-in, and photofissions is 2.95E-14 rps/atom.

The ^{237}Np (n,f) ^{137}Cs reaction rate after correcting for photofissions is 2.85E-13 rps/atom.

Table 6-8 cont'd

Measured Sensor Activities And Reaction Rates

Surveillance Capsule V

Reaction	Location	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
^{63}Cu (n,a) ^{60}Co	Top	1.64E+05	2.79E+05	4.25E-17
	Middle	1.61E+05	2.74E+05	4.17E-17
	Bottom	1.85E+05	3.14E+05	4.80E-17
^{54}Fe (n,p) ^{54}Mn	Top	1.35E+06	2.63E+06	4.17E-15
	Middle	1.37E+06	2.67E+06	4.23E-15
	Bottom	1.51E+06	2.94E+06	4.66E-15
^{58}Ni (n,p) ^{58}Co	Top	4.01E+06	4.33E+07	6.20E-15
	Middle	4.00E+06	4.32E+07	6.18E-15
	Bottom	4.37E+06	4.72E+07	6.75E-15
^{59}Co (n,g) ^{60}Co	Top	2.78E+07	4.72E+07	3.08E-12
	Middle	3.13E+07	5.32E+07	3.47E-12
	Bottom	2.63E+07	4.47E+07	2.92E-12
^{59}Co (n,g) ^{60}Co (Cd)	Top	1.66E+07	2.82E+07	1.84E-12
	Middle	1.62E+07	2.75E+07	1.80E-12
	Bottom	1.57E+07	2.67E+07	1.74E-12
^{238}U (n,f) ^{137}Cs	Middle	1.14E+06	5.98E+06	3.93E-14
^{237}Np (n,f) ^{137}Cs	Middle	8.16E+06	4.28E+07	2.73E-13

The ^{238}U (n,f) ^{137}Cs reaction rate after correcting for ^{235}U impurities, plutonium build-in, and photofissions is 3.01E-14 rps/atom.

The ^{237}Np (n,f) ^{137}Cs reaction rate after correcting for photofissions is 2.71E-13 rps/atom.

Table 6-9

Summary Of Neutron Dosimetry Results
Surveillance Capsules U, Y, and V

Best Estimate Flux and Fluence for Capsule U

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	Uncertainty
ϕ (E > 1.0 MeV)	1.042E+11	Φ (E > 1.0 MeV)	3.380E+18	7%
ϕ (E > 0.1 MeV)	4.755E+11	Φ (E > 0.1 MeV)	1.543E+19	15%
ϕ (E < 0.414 eV)	1.158E+11	Φ (E < 0.414 eV)	3.757E+18	28%
dpa/sec	2.050E-10	dpa	6.650E-03	11%

Best Estimate Flux and Fluence for Capsule Y

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	Uncertainty
ϕ (E > 1.0 MeV)	8.496E+10	Φ (E > 1.0 MeV)	1.230E+19	7%
ϕ (E > 0.1 MeV)	4.145E+11	Φ (E > 0.1 MeV)	6.000E+19	15%
ϕ (E < 0.414 eV)	8.810E+10	Φ (E < 0.414 eV)	1.275E+19	28%
dpa/sec	1.739E-10	dpa	2.517E-02	11%

Best Estimate Flux and Fluence for Capsule V

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	Uncertainty
ϕ (E > 1.0 MeV)	8.424E+10	Φ (E > 1.0 MeV)	2.523E+19	7%
ϕ (E > 0.1 MeV)	3.951E+11	Φ (E > 0.1 MeV)	1.183E+20	15%
ϕ (E < 0.414 eV)	6.098E+10	Φ (E < 0.414 eV)	1.826E+19	29%
dpa/sec	1.673E-10	dpa	5.010E-02	11%

Table 6-10

Comparison Of Measured, Calculated, And Best Estimate Reaction Rates At The Surveillance Capsule Center

Surveillance Capsule U

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,a)	5.77E-17	5.46E-17	5.67E-17	0.98	1.04	1.06
^{54}Fe (n,p)	6.16E-15	6.24E-15	6.12E-15	0.99	0.98	0.99
^{58}Ni (n,p)	8.26E-15	8.76E-15	8.58E-15	1.04	0.98	0.94
^{238}U (n,f) (Cd)	3.41E-14	3.37E-14	3.28E-14	0.96	0.97	1.01
^{237}Np (n,f)	3.38E-13	3.22E-13	3.30E-13	0.98	1.02	1.05
^{59}Co (n,g)	5.53E-12	4.39E-12	5.51E-12	1.00	1.26	1.26
^{59}Co (n,g) (Cd)	2.78E-12	3.07E-12	2.79E-12	1.00	0.91	0.91

Surveillance Capsule Y

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,a)	4.94E-17	4.74E-17	4.76E-17	0.96	1.00	1.04
^{54}Fe (n,p)	4.62E-15	5.36E-15	4.83E-15	1.05	0.90	0.86
^{58}Ni (n,p)	6.60E-15	7.51E-15	6.80E-15	1.03	0.91	0.88
^{238}U (n,f) (Cd)	2.95E-14	2.88E-14	2.64E-14	0.89	0.92	1.02
^{237}Np (n,f)	2.85E-13	2.75E-13	2.78E-13	0.98	1.01	1.04
^{59}Co (n,g)	4.33E-12	3.67E-12	4.31E-12	1.00	1.17	1.18
^{59}Co (n,g) (Cd)	2.27E-12	2.59E-12	2.28E-12	1.00	0.88	0.88

Surveillance Capsule V

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,a)	4.41E-17	4.42E-17	4.27E-17	0.97	0.97	1.00
^{54}Fe (n,p)	4.35E-15	5.00E-15	4.59E-15	1.06	0.92	0.87
^{58}Ni (n,p)	6.38E-15	7.01E-15	6.50E-15	1.02	0.93	0.91
^{238}U (n,f) (Cd)	3.01E-14	2.69E-14	2.59E-14	0.86	0.96	1.12
^{237}Np (n,f)	2.71E-13	2.57E-13	2.69E-13	0.99	1.05	1.05
^{59}Co (n,g)	3.16E-12	3.43E-12	3.15E-12	1.00	0.92	0.92
^{59}Co (n,g) (Cd)	1.79E-12	2.42E-12	1.80E-12	1.01	0.74	0.74

Table 6-11

Best Estimate Neutron Energy Spectrum At The
Center Of Surveillance Capsules

Capsule U

Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	7.59E+06	28	9.12E-03	2.21E+10
2	1.49E+01	1.63E+07	29	5.53E-03	2.84E+10
3	1.35E+01	6.01E+07	30	3.36E-03	8.82E+09
4	1.16E+01	1.64E+08	31	2.84E-03	8.40E+09
5	1.06E+01	3.71E+08	32	2.40E-03	8.11E+09
6	8.61E+00	6.44E+08	33	2.04E-03	2.35E+10
7	7.41E+00	1.55E+09	34	1.23E-03	2.25E+10
8	6.07E+00	2.36E+09	35	7.49E-04	2.03E+10
9	4.97E+00	4.87E+09	36	4.54E-04	1.81E+10
10	3.68E+00	5.71E+09	37	2.75E-04	1.97E+10
11	2.87E+00	1.12E+10	38	1.67E-04	1.92E+10
12	2.23E+00	1.55E+10	39	1.01E-04	2.05E+10
13	1.74E+00	2.15E+10	40	6.14E-05	2.05E+10
14	1.35E+00	2.51E+10	41	3.73E-05	2.03E+10
15	1.11E+00	4.40E+10	42	2.26E-05	1.99E+10
16	8.21E-01	5.18E+10	43	1.37E-05	1.94E+10
17	6.39E-01	5.69E+10	44	8.32E-06	1.87E+10
18	4.98E-01	3.91E+10	45	5.04E-06	1.80E+10
19	3.88E-01	5.95E+10	46	3.06E-06	1.78E+10
20	3.02E-01	6.29E+10	47	1.86E-06	1.77E+10
21	1.83E-01	6.26E+10	48	1.13E-06	1.24E+10
22	1.11E-01	4.61E+10	49	6.83E-07	1.45E+10
23	6.74E-02	3.61E+10	50	4.14E-07	2.07E+10
24	4.09E-02	1.96E+10	51	2.51E-07	2.05E+10
25	2.55E-02	2.28E+10	52	1.52E-07	1.95E+10
26	1.99E-02	1.10E+10	53	9.24E-08	5.51E+10
27	1.50E-02	1.93E+10			

Note: Tabulated energy levels represent the upper energy in each group.

Table 6-11 cont'd

Best Estimate Neutron Energy Spectrum At The
Center Of Surveillance Capsules

Capsule Y

Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	7.20E+06	28	9.12E-03	1.91E+10
2	1.49E+01	1.52E+07	29	5.53E-03	2.42E+10
3	1.35E+01	5.50E+07	30	3.36E-03	7.53E+09
4	1.16E+01	1.47E+08	31	2.84E-03	7.17E+09
5	1.00E+01	3.23E+08	32	2.40E-03	6.90E+09
6	8.61E+00	5.44E+08	33	2.04E-03	2.00E+10
7	7.41E+00	1.27E+09	34	1.23E-03	1.90E+10
8	6.07E+00	1.85E+09	35	7.49E-04	1.71E+10
9	4.97E+00	3.71E+09	36	4.54E-04	1.51E+10
10	3.68E+00	4.37E+09	37	2.75E-04	1.63E+10
11	2.87E+00	8.76E+09	38	1.67E-04	1.57E+10
12	2.23E+00	1.25E+10	39	1.01E-04	1.70E+10
13	1.74E+00	1.78E+10	40	6.14E-05	1.70E+10
14	1.35E+00	2.09E+10	41	3.73E-05	1.69E+10
15	1.11E+00	3.74E+10	42	2.26E-05	1.66E+10
16	8.21E-01	4.49E+10	43	1.37E-05	1.62E+10
17	6.39E-01	5.01E+10	44	8.32E-06	1.56E+10
18	4.98E-01	3.49E+10	45	5.04E-06	1.50E+10
19	3.88E-01	5.34E+10	46	3.06E-06	1.48E+10
20	3.02E-01	5.65E+10	47	1.86E-06	1.47E+10
21	1.83E-01	5.64E+10	48	1.13E-06	1.03E+10
22	1.11E-01	4.14E+10	49	6.83E-07	1.17E+10
23	6.74E-02	3.21E+10	50	4.14E-07	1.65E+10
24	4.09E-02	1.72E+10	51	2.51E-07	1.60E+10
25	2.55E-02	2.00E+10	52	1.52E-07	1.50E+10
26	1.99E-02	9.54E+09	53	9.24E-08	4.06E+10
27	1.50E-02	1.65E+10			

Note: Tabulated energy levels represent the upper energy in each group.

Table 6-11 cont'd

Best Estimate Neutron Energy Spectrum At The Center Of Surveillance Capsules

Capsule V

Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	6.08E+06	28	9.12E-03	1.68E+10
2	1.49E+01	1.29E+07	29	5.53E-03	2.13E+10
3	1.35E+01	4.69E+07	30	3.36E-03	6.61E+09
4	1.16E+01	1.27E+08	31	2.84E-03	6.26E+09
5	1.00E+01	2.83E+08	32	2.40E-03	6.00E+09
6	8.61E+00	4.85E+08	33	2.04E-03	1.72E+10
7	7.41E+00	1.16E+09	34	1.23E-03	1.62E+10
8	6.07E+00	1.73E+09	35	7.49E-04	1.44E+10
9	4.97E+00	3.56E+09	36	4.54E-04	1.25E+10
10	3.68E+00	4.27E+09	37	2.75E-04	1.34E+10
11	2.87E+00	8.70E+09	38	1.67E-04	1.23E+10
12	2.23E+00	1.25E+10	39	1.01E-04	1.39E+10
13	1.74E+00	1.79E+10	40	6.14E-05	1.39E+10
14	1.35E+00	2.08E+10	41	3.73E-05	1.40E+10
15	1.11E+00	3.69E+10	42	2.26E-05	1.39E+10
16	8.21E-01	4.38E+10	43	1.37E-05	1.36E+10
17	6.39E-01	4.82E+10	44	8.32E-06	1.32E+10
18	4.98E-01	3.32E+10	45	5.04E-06	1.27E+10
19	3.88E-01	5.00E+10	46	3.06E-06	1.26E+10
20	3.02E-01	5.22E+10	47	1.86E-06	1.25E+10
21	1.83E-01	5.14E+10	48	1.13E-06	8.74E+09
22	1.11E-01	3.74E+10	49	6.83E-07	9.45E+09
23	6.74E-02	2.88E+10	50	4.14E-07	1.27E+10
24	4.09E-02	1.54E+10	51	2.51E-07	1.18E+10
25	2.55E-02	1.78E+10	52	1.52E-07	1.07E+10
26	1.99E-02	8.46E+09	53	9.24E-08	2.58E+10
27	1.50E-02	1.46E+10			

Note: Tabulated energy levels represent the upper energy in each group.

Table 6-12

Comparison Of Calculated And Best Estimate Integrated Neutron Exposure Of Wolf Creek Surveillance Capsules U, Y, and V

CAPSULE U

	Calculated	Best Estimate	BE/C
Φ(E > 1.0 MeV) [n/cm2]	3.429E+18	3.380E+18	0.99
Φ(E > 0.1 MeV) [n/cm2]	1.472E+19	1.543E+19	1.05
dpa	6.481E-03	6.650E-03	1.03

CAPSULE Y

	Calculated	Best Estimate	BE/C
Φ(E > 1.0 MeV) [n/cm2]	1.308E+19	1.230E+19	0.94
Φ(E > 0.1 MeV) [n/cm2]	5.612E+19	6.000E+19	1.07
dpa	2.472E-02	2.517E-02	1.02

CAPSULE V

	Calculated	Best Estimate	BE/C
Φ(E > 1.0 MeV) [n/cm2]	2.528E+19	2.523E+19	1.00
Φ(E > 0.1 MeV) [n/cm2]	1.085E+20	1.183E+20	1.09
dpa	4.778E-02	5.010E-02	1.05

AVERAGE BE/C RATIOS

	BE/C
Φ (E > 1.0 MeV) [n/cm^2]	0.975
Φ (E > 0.1 MeV) [n/cm^2]	1.069
dpa	1.031

Table 6-13

Azimuthal Variations Of The Neutron Exposure Projections
On The Reactor Vessel Clad/Base Metal Interface At Core Midplane

Best Estimate

9.49 EFPY

	0 Deg	15 Deg	30 Deg[a]	45 Deg
E>1.0 MeV	3.42E+18	5.15E+18	6.03E+18	6.02E+18
E>0.1 MeV	7.88E+18	1.20E+19	1.44E+19	1.65E+19
dpa	5.60E-03	8.36E-03	9.82E-03	1.01E-02

16 EFPY

E>1.0 MeV	5.42E+18	8.38E+18	9.93E+18	9.77E+18
E>0.1 MeV	1.25E+19	1.95E+19	2.37E+19	2.68E+19
dpa	8.88E-03	1.36E-02	1.62E-02	1.63E-02

32 EFPY

E>1.0 MeV	1.03E+19	1.63E+19	1.95E+19	1.90E+19
E>0.1 MeV	2.38E+19	3.80E+19	4.65E+19	5.22E+19
dpa	1.69E-02	2.65E-02	3.17E-02	3.17E-02

54 EFPY

E>1.0 MeV	1.71E+19	2.72E+19	3.26E+19	3.17E+19
E>0.1 MeV	3.94E+19	6.34E+19	7.78E+19	8.70E+19
dpa	2.80E-02	4.42E-02	5.31E-02	5.29E-02

Note:
Maximum neutron exposure projection reported for 30° vessel location representing the octant containing the 12.5° neutron pad span.

Table 6-13, cont'd

Azimuthal Variations Of The Neutron Exposure Projections
On The Reactor Vessel Clad/Base Metal Interface At Core Midplane

Calculated

	0 Deg	15 Deg	30 Deg[a]	45 Deg
9.49 EFPY				
E>1.0 MeV	3.50E+18	5.29E+18	6.19E+18	6.18E+18
E>0.1 MeV	7.37E+18	1.12E+19	1.34E+19	1.55E+19
dpa	5.43E-03	8.11E-03	9.53E-03	9.75E-03
16 EFPY				
E>1.0 MeV	5.56E+18	8.60E+18	1.02E+19	1.00E+19
E>0.1 MeV	1.17E+19	1.83E+19	2.21E+19	2.51E+19
dpa	8.61E-03	1.32E-02	1.57E-02	1.58E-02
32 EFPY				
E>1.0 MeV	1.06E+19	1.67E+19	2.00E+19	1.95E+19
E>0.1 MeV	2.23E+19	3.55E+19	4.35E+19	4.88E+19
dpa	1.64E-02	2.57E-02	3.08E-02	3.08E-02
54 EFPY				
E>1.0 MeV	1.75E+19	2.79E+19	3.35E+19	3.25E+19
E>0.1 MeV	3.69E+19	5.93E+19	7.28E+19	8.14E+19
dpa	2.72E-02	4.28E-02	5.15E-02	5.13E-02

Note:
Maximum neutron exposure projection reported for 30° vessel location representing the octant containing the 12.5° neutron pad span.

Table 6-14

Neutron Exposure Values Within The
Wolf Creek Reactor Vessel

Best Estimate Fluence Based on E > 1.0 MeV Slope

16 EFPY	0 Deg	15 Deg	30 Deg[a]	45 Deg
Surface	5.42E+18	8.38E+18	9.93E+18	9.77E+18
1/4 T	3.04E+18	4.67E+18	5.45E+18	5.35E+18
3/4 T	6.93E+17	1.04E+18	1.20E+18	1.15E+18
32 EFPY				
Surface	1.03E+19	1.63E+19	1.95E+19	1.90E+19
1/4 T	5.80E+18	9.08E+18	1.07E+19	1.04E+19
3/4 T	1.32E+18	2.02E+18	2.36E+18	2.24E+18
54 EFPY				
Surface	1.71E+19	2.72E+19	3.26E+19	3.17E+19
1/4 T	9.59E+18	1.52E+19	1.79E+19	1.73E+19
3/4 T	2.19E+18	3.37E+18	3.95E+18	3.74E+18

Best Estimate Fluence Based on dpa Slope

16 EFPY	0 Deg	15 Deg	30 Deg[a]	45 Deg
Surface	5.42E+18	8.38E+18	9.93E+18	9.77E+18
1/4 T	3.46E+18	5.32E+18	6.26E+18	6.28E+18
3/4 T	1.25E+18	1.85E+18	2.21E+18	2.25E+18
32 EFPY				
Surface	1.03E+19	1.63E+19	1.95E+19	1.90E+19
1/4 T	6.60E+18	1.04E+19	1.23E+19	1.22E+19
3/4 T	2.39E+18	3.60E+18	4.35E+18	4.37E+18
54 EFPY				
Surface	1.71E+19	2.72E+19	3.26E+19	3.17E+19
1/4 T	1.09E+19	1.73E+19	2.06E+19	2.04E+19
3/4 T	3.95E+18	6.01E+18	7.28E+18	7.28E+18

Note:
Maximum neutron exposure projection reported for 30° vessel location representing the octant containing the 12.5° neutron pad span.

Table 6-14, cont'd

Neutron Exposure Values Within The
Wolf Creek Reactor Vessel

Calculated Fluence Based on E > 1.0 MeV Slope

16 EFPY	0 Deg	15 Deg	30 Deg[a]	45 Deg
Surface	5.56E+18	8.60E+18	1.02E+19	1.00E+19
1/4 T	3.12E+18	4.79E+18	5.59E+18	5.485E+18
3/4 T	7.11E+17	1.07E+18	1.23E+18	1.183E+18
32 EFPY				
Surface	1.06E+19	1.67E+19	2.00E+19	1.95E+19
1/4 T	5.95E+18	9.32E+18	1.10E+19	1.066E+19
3/4 T	1.36E+18	2.07E+18	2.42E+18	2.299E+18
54 EFPY				
Surface	1.75E+19	2.79E+19	3.35E+19	3.25E+19
1/4 T	9.84E+18	1.55E+19	1.84E+19	1.78E+19
3/4 T	2.24E+18	3.46E+18	4.05E+18	3.83E+18

Calculated Fluence Based on dpa Slope

16 EFPY	0 Deg	15 Deg	30 Deg[a]	45 Deg
Surface	5.56E+18	8.60E+18	1.02E+19	1.00E+19
1/4 T	3.55E+18	5.46E+18	6.43E+18	6.45E+18
3/4 T	1.28E+18	1.90E+18	2.27E+18	2.31E+18
32 EFPY				
Surface	1.06E+19	1.67E+19	2.00E+19	1.95E+19
1/4 T	6.77E+18	1.06E+19	1.26E+19	1.25E+19
3/4 T	2.45E+18	3.70E+18	4.46E+18	4.48E+18
54 EFPY				
Surface	1.75E+19	2.79E+19	3.35E+19	3.25E+19
1/4 T	1.12E+19	1.77E+19	2.11E+19	2.09E+19
3/4 T	4.05E+18	6.17E+18	7.47E+18	7.47E+18

Note:

Maximum neutron exposure projection reported for 30° vessel location representing the octant containing the 12.5° neutron pad span.

Table 6-15

Updated Lead Factors For Wolf Creek
Surveillance Capsules

Capsule	Lead Factor
U[a]	4.38
Y[b]	4.00
V[c]	4.08
W[d]	4.42
X[d]	4.42
Z[d]	4.42

[a] - Withdrawn at the end of Cycle 1.
[b] - Withdrawn at the end of Cycle 5.
[c] - Withdrawn at the end of Cycle 9.
[d] - Not withdrawn; standby.

Table 6-16

Fast Neutron (E > 1.0 MeV) Fluence at the Beltline Locations
as a Function of Full Power Operating Time

Best Estimate Fluence (n/cm^2)

EFPY	Azimuthal Angle 0°	15°	30°	45°
1.03	4.39E+17	6.48E+17	7.55E+17	7.63E+17
1.68	7.39E+17	1.08E+18	1.26E+18	1.34E+18
2.32	9.77E+17	1.43E+18	1.67E+18	1.74E+18
3.42	1.44E+18	2.07E+18	2.37E+18	2.47E+18
4.59	1.92E+18	2.76E+18	3.11E+18	3.19E+18
5.56	2.24E+18	3.30E+18	3.68E+18	3.73E+18
6.83	2.60E+18	3.87E+18	4.39E+18	4.42E+18
8.03	3.01E+18	4.58E+18	5.21E+18	5.13E+18
9.49	3.42E+18	5.15E+18	6.03E+18	6.02E+18
15.00	5.11E+18	7.88E+18	9.33E+18	9.20E+18
20.00	6.64E+18	1.04E+19	1.23E+19	1.21E+19
25.00	8.18E+18	1.28E+19	1.53E+19	1.50E+19
30.00	9.72E+18	1.53E+19	1.83E+19	1.78E+19
35.00	1.13E+19	1.78E+19	2.13E+19	2.07E+19

Calculated Fluence (n/cm^2)

EFPY	Azimuthal Angle 0°	15°	30°	45°
1.03	4.50E+17	6.65E+17	7.75E+17	7.83E+17
1.68	7.58E+17	1.11E+18	1.29E+18	1.38E+18
2.32	1.00E+18	1.47E+18	1.72E+18	1.79E+18
3.42	1.48E+18	2.12E+18	2.43E+18	2.53E+18
4.59	1.97E+18	2.83E+18	3.19E+18	3.27E+18
5.56	2.30E+18	3.38E+18	3.77E+18	3.83E+18
6.83	2.66E+18	3.97E+18	4.50E+18	4.54E+18
8.03	3.09E+18	4.70E+18	5.35E+18	5.27E+18
9.49	3.50E+18	5.29E+18	6.19E+18	6.18E+18
15.00	5.24E+18	8.09E+18	9.57E+18	9.44E+18
20.00	6.82E+18	1.06E+19	1.26E+19	1.24E+19
25.00	8.39E+18	1.32E+19	1.57E+19	1.53E+19
30.00	9.97E+18	1.57E+19	1.88E+19	1.83E+19
35.00	1.15E+19	1.83E+19	2.18E+19	2.13E+19

Figure 6-1

Plan View Of A Dual Reactor Vessel Surveillance Capsule

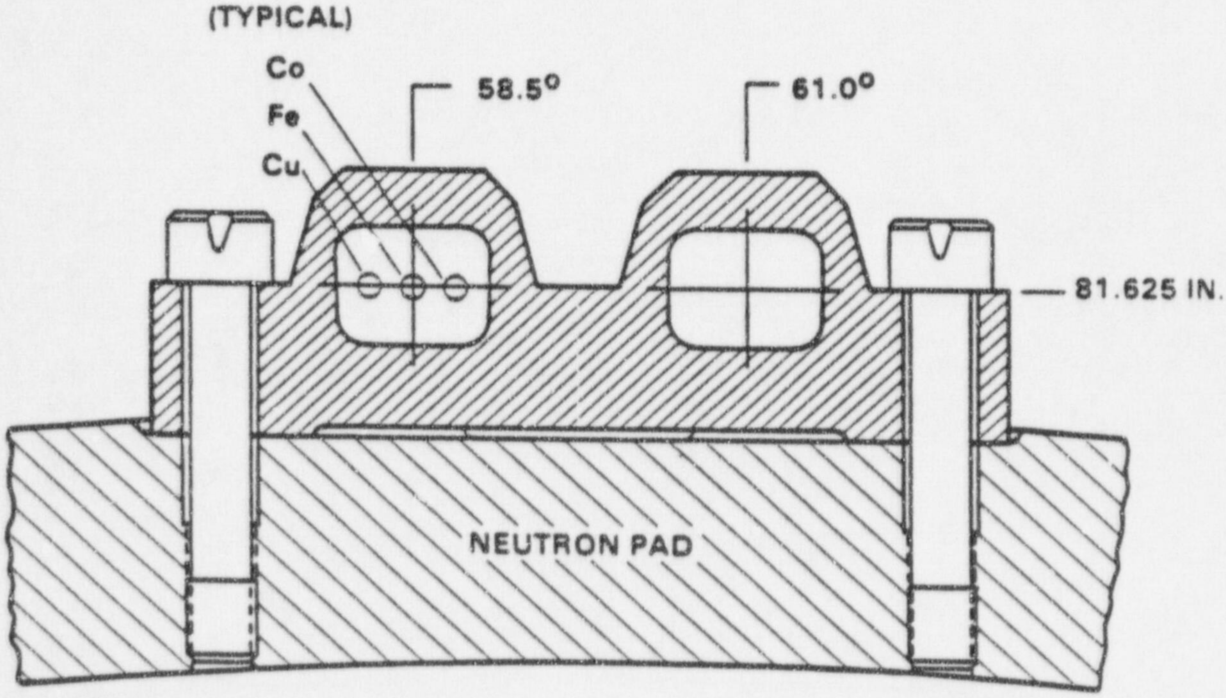
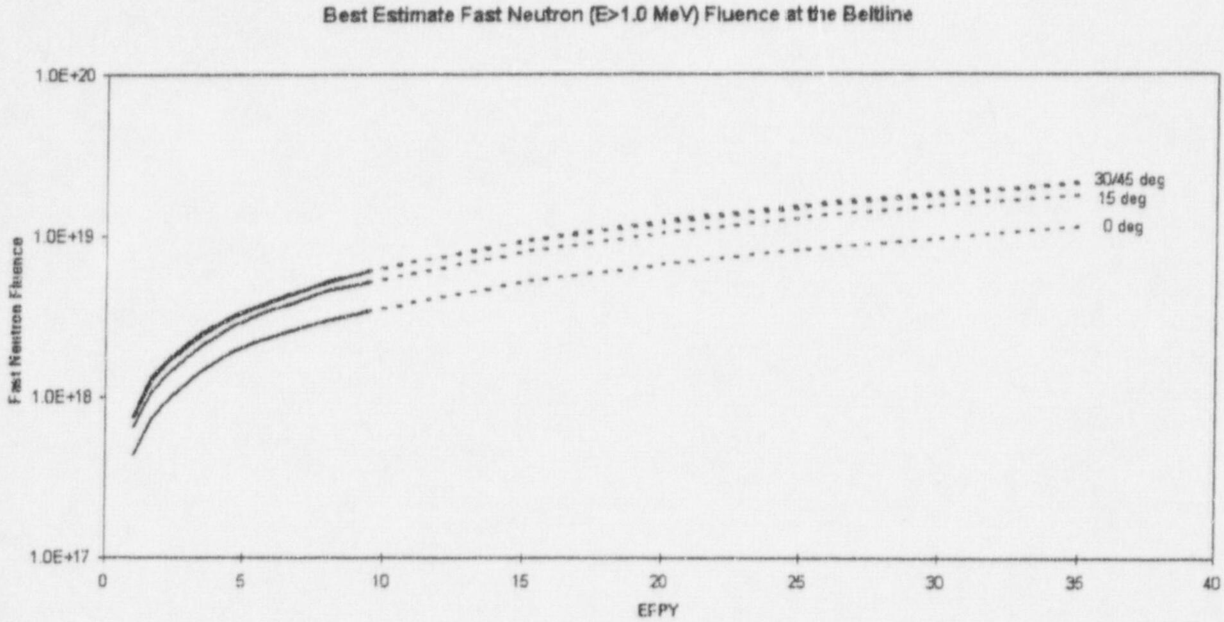
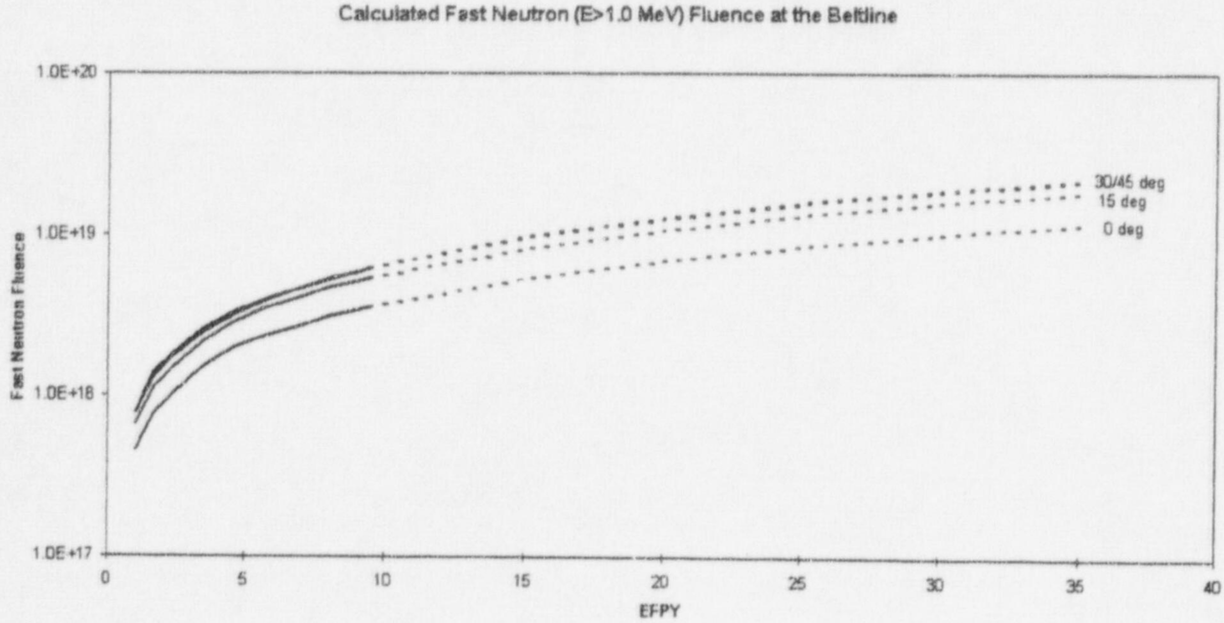


Figure 6-2

Fast Neutron (E > 1.0 MeV) Fluence at the Beltline Locations
as a Function of Full Power Operating Time





SECTION 7.0
SURVEILLANCE CAPSULE REMOVAL SCHEDULE

The following surveillance capsule removal schedule meets the requirements of ASTM E185-82 and is recommended for future capsules to be removed from the Wolf Creek reactor vessel. This recommended removal schedule is applicable to 32 EFPY of operation.

TABLE 7-1				
Wolf Creek Reactor Vessel Surveillance Capsule Withdrawal Schedule				
Capsule	Location	Lead Factor[a]	Removal Time (EFPY)[b]	Fluence (n/cm^2, E > 1.0 MeV)[a]
U	58.5°	4.38	1.08	3.429×10^{18} [c]
Y	241.0°	4.00	4.79	1.308×10^{19} [c]
V	60.1°	4.08	9.49	2.528×10^{19} [c]
X[d]	238.5°	4.42	Standby	- - -
W[d]	121.5°	4.42	Standby	- - -
Z[d]	301.5°	4.42	Standby	- - -

(a) Updated in Section 6 of this report.

(b) Effective Full Power Years (EFPY) from plant startup.

(c) Plant specific evaluation.

(d) The standby capsules X, W, and Z will reach the peak vessel clad/base metal fluence at 54 EFPY at approximately 12.4 EFPY. Hence, it is recommended that the standby capsules be removed and placed in storage at the closest outage to 12.4 EFPY of operation.

SECTION 8.0

REFERENCES

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

2. Code of Federal Regulations, 10CFR50, Appendix G, *Fracture Toughness Requirements*, and Appendix H, *Reactor Vessel Material Surveillance Program Requirements*, U.S. Nuclear Regulatory Commission, Washington, D.C.

3. WCAP-10015, *Kansas Gas and Electric Company Wolf Creek Generation Station Unit No. 1 Reactor Vessel Radiation Surveillance Program*, L. R. Singer, June 1982.

4. Section XI of the ASME Boiler and Pressure Vessel Code, Appendix G, *Fracture Toughness Criteria for Protection Against Failure.*

5. ASTM E208, *Standard Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels*, in ASTM Standards, Section 3, American Society for Testing and Materials, Philadelphia, PA.

6. ASTM E185-82, *Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels, E706 (IF)*, in ASTM Standards, Section 3, American Society for Testing and Materials, Philadelphia, PA, 1993.

7. ASTM E23-93a, *Standard Test Methods for Notched Bar Impact Testing of Metallic Materials*, in ASTM Standards, Section 3, American Society for Testing and Materials, Philadelphia, PA, 1993.

8. ASTM A370-92, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*, in ASTM Standards, Section 3, American Society for Testing and Materials, Philadelphia, PA, 1993.

9. ASTM E8-93, *Standard Test Methods for Tension Testing of Metallic Materials*, in ASTM Standards, Section 3, American Society for Testing and Materials, Philadelphia, PA, 1993.

10. ASTM E21-92, *Standard Test Methods for Elevated Temperature Tension Tests of Metallic Materials*, in ASTM Standards, Section 3, American Society for Testing and Materials, Philadelphia, PA, 1993.

11. ASTM E83-93, *Standard Practice for Verification and Classification of Extensometers*, in ASTM Standards, Section 3, American Society for Testing and Materials, Philadelphia, PA, 1993.

12. WCAP-11553, *Analysis of Capsule U from the Wolf Creek Nuclear Operating Corporation Wolf Creek Reactor Vessel Radiation Surveillance Program*, S. E. Yanichko, et al., August 1987.

13. WCAP-13365, Revision 1, *Analysis of Capsule Y from the Wolf Creek Nuclear Operating Corporation Wolf Creek Reactor Vessel Radiation Surveillance Program*, J. M. Chicots, et al., April 1993.

14. RSICC Computer Code Collection CCC-650, *DOORS 3.1, One, Two- and Three-Dimensional Discrete Ordinates Neutron/Photon Transport Code System, Version 3.1*, August 1996.

15. RSICC Data Library Collection DLC-175, *BUGLE-93, Production and Testing of the VITAMIN-B6 Fine Group and the BUGLE-93 Broad Group Neutron/Photon Cross-Section Libraries Derived from ENDF/B-VI Nuclear Data*, April 1994.

16. R. E. Maerker, et al., *Accounting for Changing Source Distributions in Light Water Reactor Surveillance Dosimetry Analysis*, Nuclear Science and Engineering, Volume 94, Pages 291-308, 1986.

17. P. C. Cook, et al., *The Nuclear Design and Core Physics Characteristics of the Wolf Creek Generating Station Unit 1 Cycle 1*, WCAP-10483, February 1984. [Westinghouse Proprietary Class 2]

18. D. S. Leach, et al., *The Nuclear Parameters and Operations Package for Wolf Creek, Cycle 2*, WCAP-11251, Rev. 1, December 1986. [Westinghouse Proprietary Class 2]

19. D. S. Leach, et al., *The Nuclear Parameters and Operations Package for Wolf Creek, Cycle 3*, WCAP-11543, September 1987. [Westinghouse Proprietary Class 2]

20. D. S. Leach, et al., *The Nuclear Parameters and Operations Package for Wolf Creek, Cycle 4*, WCAP-11956, October 1988. [Westinghouse Proprietary Class 2]

21. M. M. Baker, et al., *Nuclear Parameters and Operations Package for Wolf Creek, Cycle 5*, WCAP-12530, April 1990. [Westinghouse Proprietary Class 2]

22. H. Q. Lam, et al., *Nuclear Parameters and Operations Package for Wolf Creek, Cycle 6*, WCAP-13079, November 1991. [Westinghouse Proprietary Class 2]

23. Wolf Creek transmittal to J. D. Perock (Westinghouse) of selected Wolf Creek Cycle 7 core design data, March 1998.

24. Wolf Creek transmittal to J. D. Perock (Westinghouse) of selected Wolf Creek Cycle 8 core design data, March 1998.

25. Wolf Creek transmittal to J. D. Perock (Westinghouse) of selected Wolf Creek Cycle 9 core design data, March 1998.

26. M. K. Morris (Wolf Creek Nuclear Operating Company) email to J. D. Perock (Westinghouse) transmitting selected Wolf Creek operating plant history data, April 2, 1998.

27. ASTM Designation E482-89 (Re-approved 1996), *Standard Guide for Application of Neutron Transport Methods for Reactor Vessel Surveillance*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 1997.

28. ASTM Designation E560-84 (Re-approved 1996), *Standard Recommended Practice for Extrapolating Reactor Vessel Surveillance Dosimetry Results*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 1997.

29. ASTM Designation E693-94, *Standard Practice for Characterizing Neutron Exposures in Iron and Low Alloy Steels in Terms of Displacements per Atom (dpa)*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 1997.

30. ASTM Designation E706-87 (Re-approved 1994), *Standard Master Matrix for Light-Water Reactor Pressure Vessel Surveillance Standard*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 1997.

31. ASTM Designation E853-87 (Re-approved 1995), *Standard Practice for Analysis and Interpretation of Light-Water Reactor Surveillance Results*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 1997.

32. ASTM Designation E261-96, *Standard Practice for Determining Neutron Fluence Rate, Fluence, and Spectra by Radioactivation Techniques*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 1997.

33. ASTM Designation E262-86 (Re-approved 1991), *Standard Method for Determining Thermal Neutron Reaction and Fluence Rates by Radioactivation Techniques*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 1997.

34. ASTM Designation E263-93, *Standard Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Iron*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 1997.

35. ASTM Designation E264-92 (Re-approved 1996), *Standard Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Nickel*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 1997.

36. ASTM Designation E481-86 (Re-approved 1991), *Standard Method for Measuring Neutron-Fluence Rate by Radioactivation of Cobalt and Silver*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 1997.

37. ASTM Designation E523-92 (Re-approved 1996), *Standard Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Copper*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 1997.

38. ASTM Designation E704-96, *Standard Test Method for Measuring Reaction Rates by Radioactivation of Uranium-238*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 1997.

39. ASTM Designation E705-96, *Standard Test Method for Measuring Reaction Rates by Radioactivation of Neptunium-237*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 1997.

40. ASTM Designation E1005-84 (Re-approved 1991), *Standard Test Method for Application and Analysis of Radiometric Monitors for Reactor Vessel Surveillance*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 1997.

41. F. A. Schmittroth, *FERRET Data Analysis Core*, HEDL-TME 79-40, Hanford Engineering Development Laboratory, Richland, WA, September 1979.

42. W. N. McElroy, S. Berg and T. Crocket, *A Computer-Automated Iterative Method of Neutron Flux Spectra Determined by Foil Activation*, AFWL-TR-7-41, Vol. I-IV, Air Force Weapons Laboratory, Kirkland AFB, NM, July 1967.

43. RSICC Data Library Collection DLC-178, "SNLRML Recommended Dosimetry Cross-Section Compendium", July 1994.

44. EPRI-NP-2188, *Development and Demonstration of an Advanced Methodology for LWR Dosimetry Applications*, R. E. Maerker, et al., 1981.

APPENDIX A

Load-Time Records for Charpy Specimen Tests

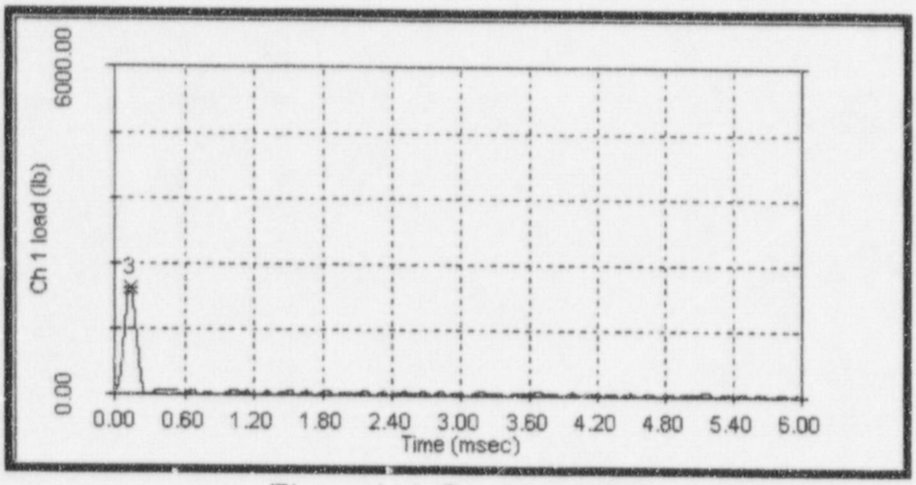


Figure A. 1 Specimen AL27

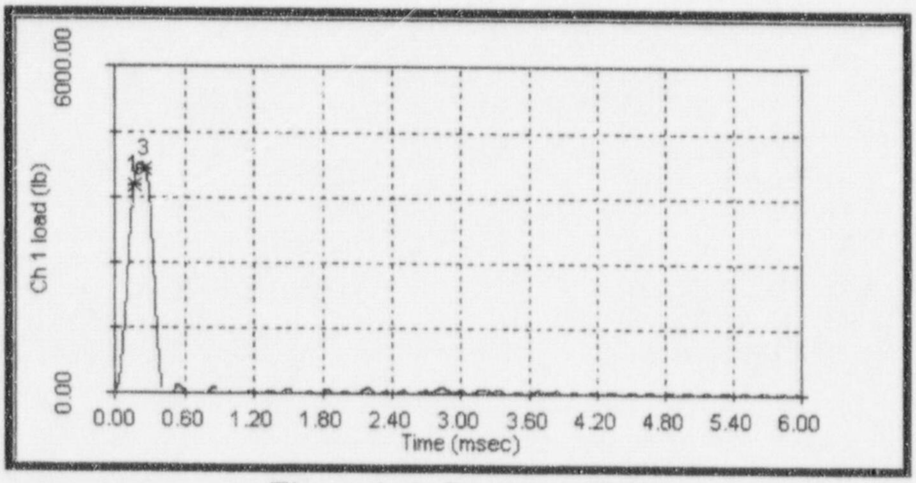


Figure A. 2 Specimen AL30

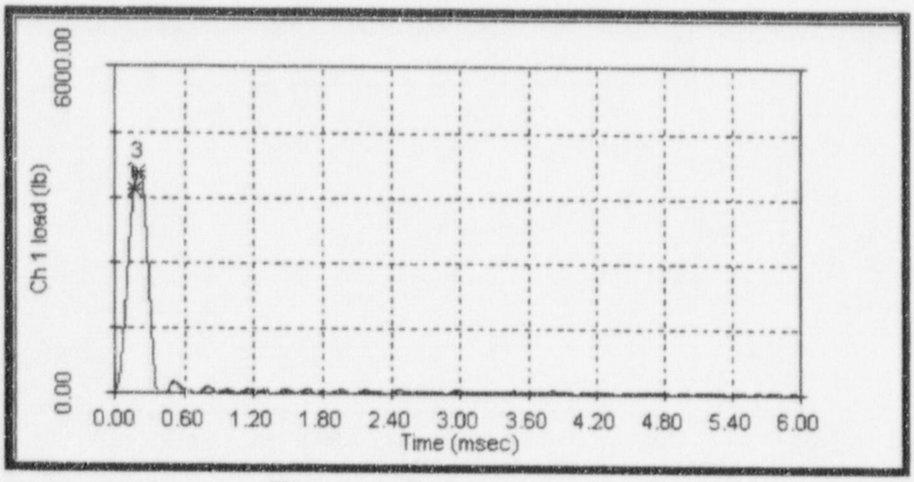


Figure A. 3 Specimen AL18

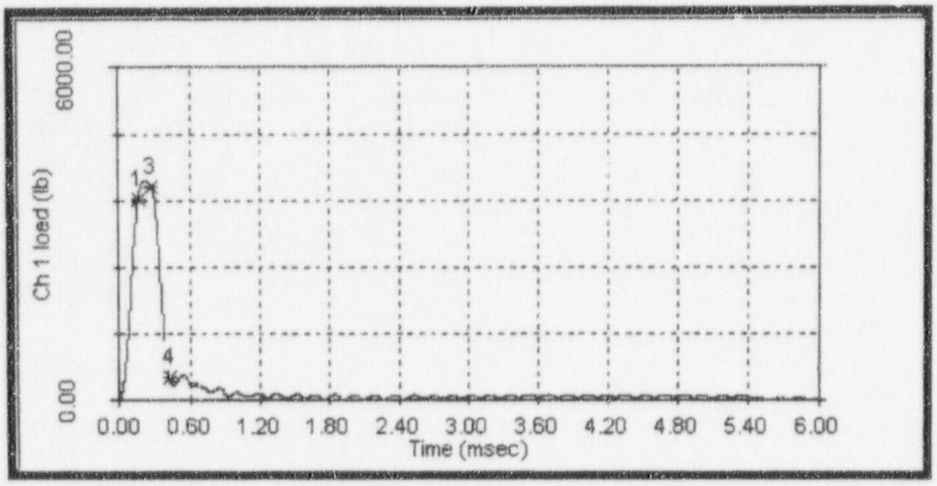


Figure A. 4 Specimen AL16

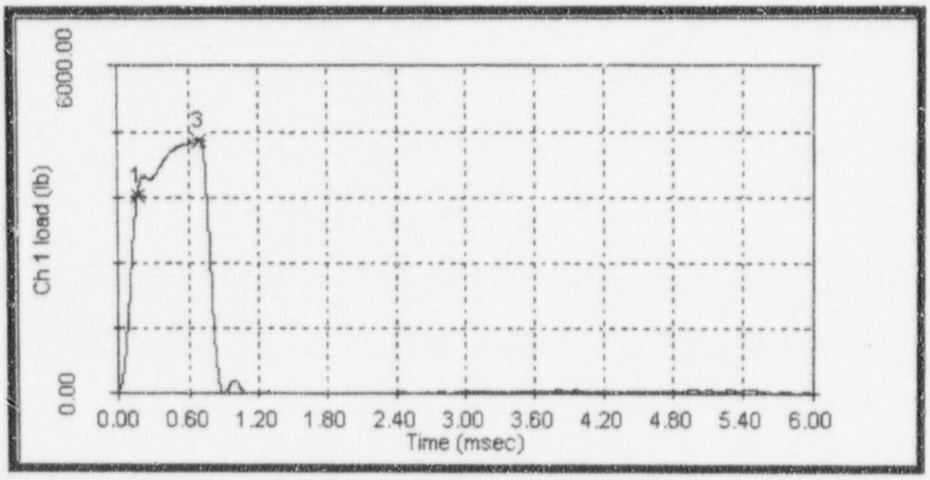


Figure A. 5 Specimen AL24

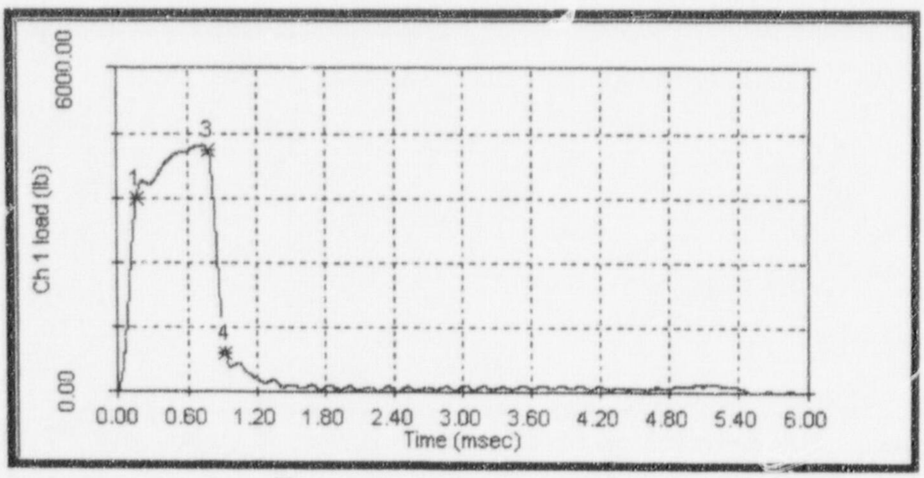


Figure A. 6 Specimen AL19

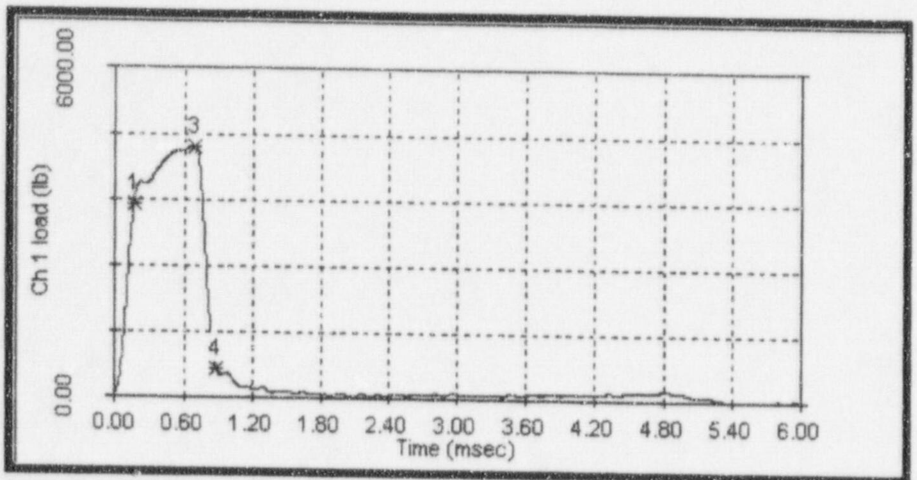


Figure A. 7 Specimen AL17

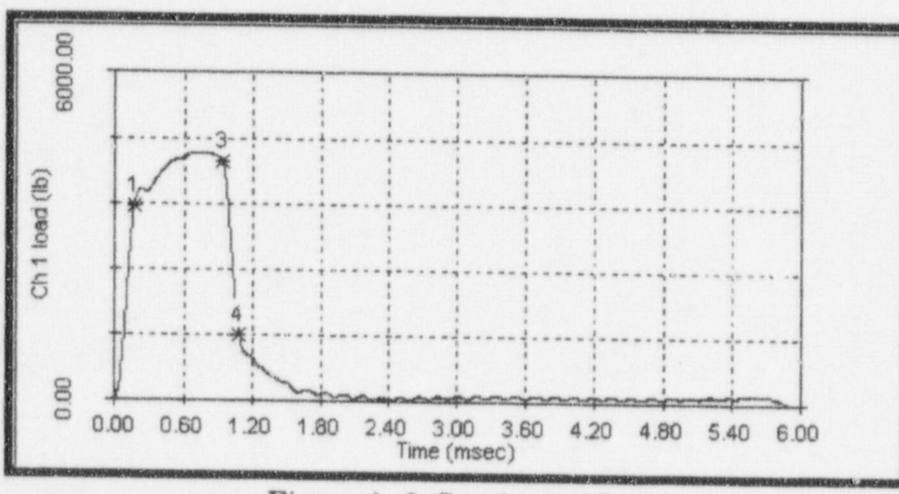


Figure A. 8 Specimen AL25

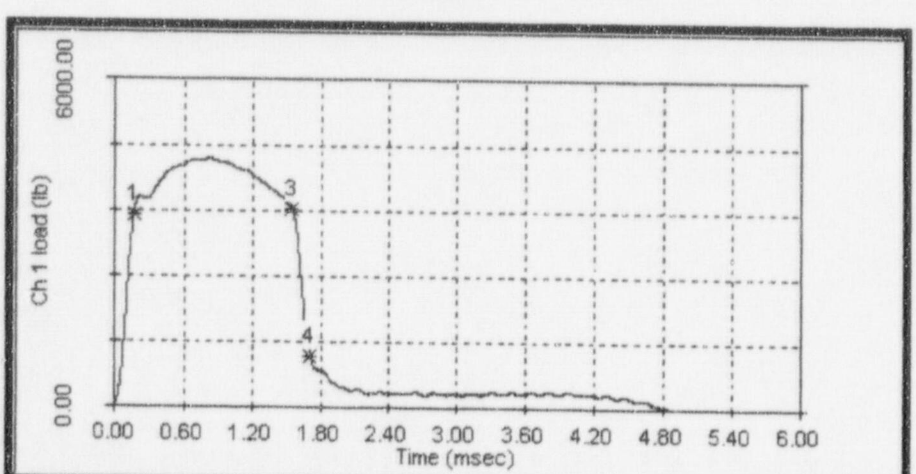


Figure A. 9 Specimen AL26

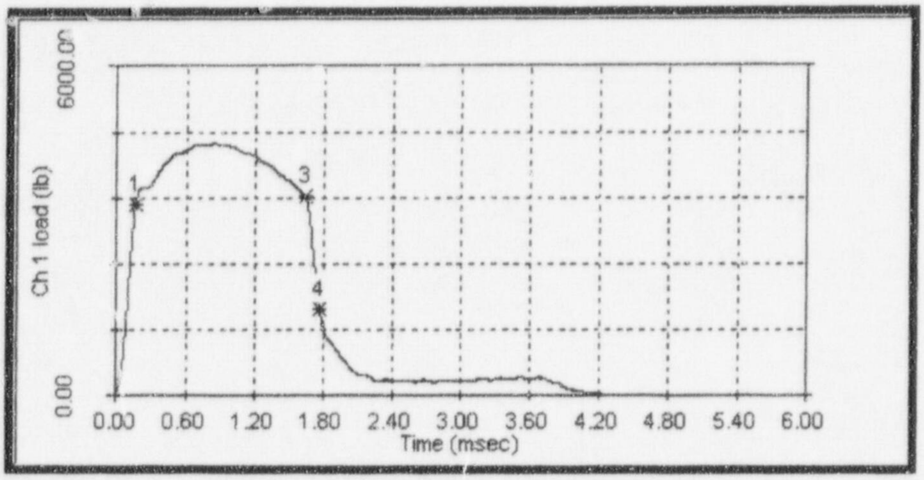


Figure A. 10 Specimen AL28

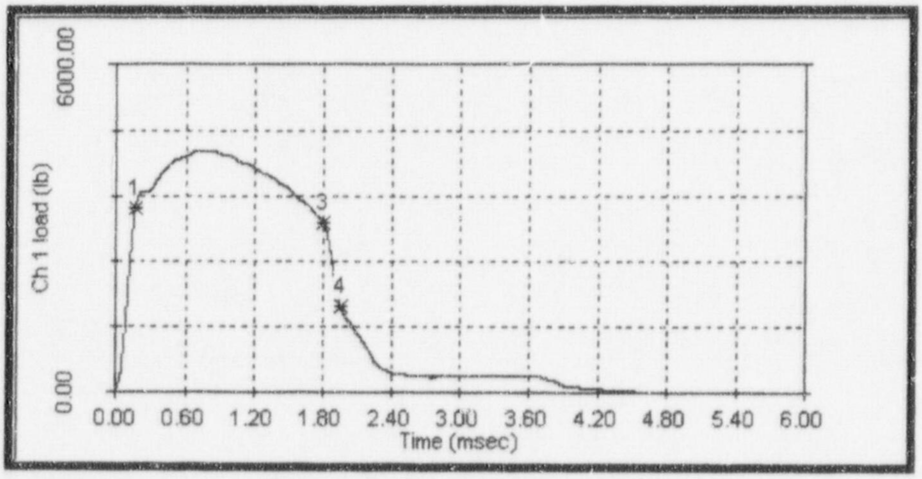


Figure A. 11 Specimen AL21

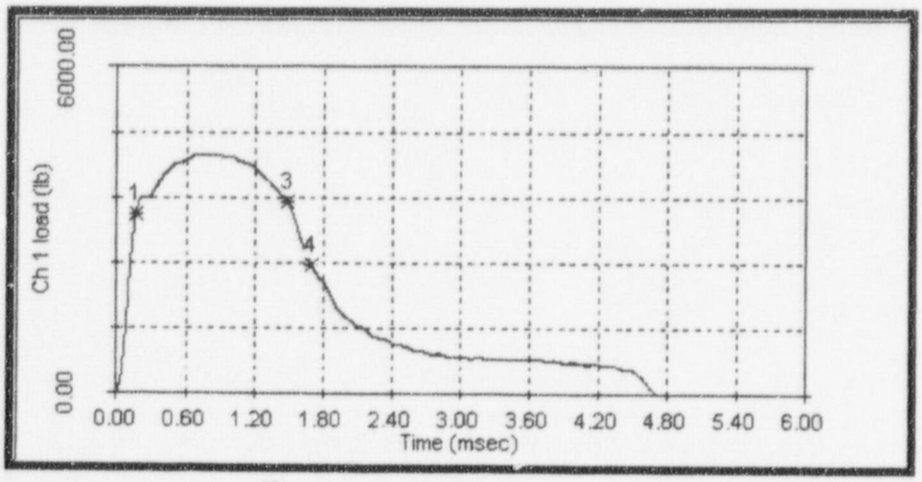


Figure A. 12 Specimen AL29

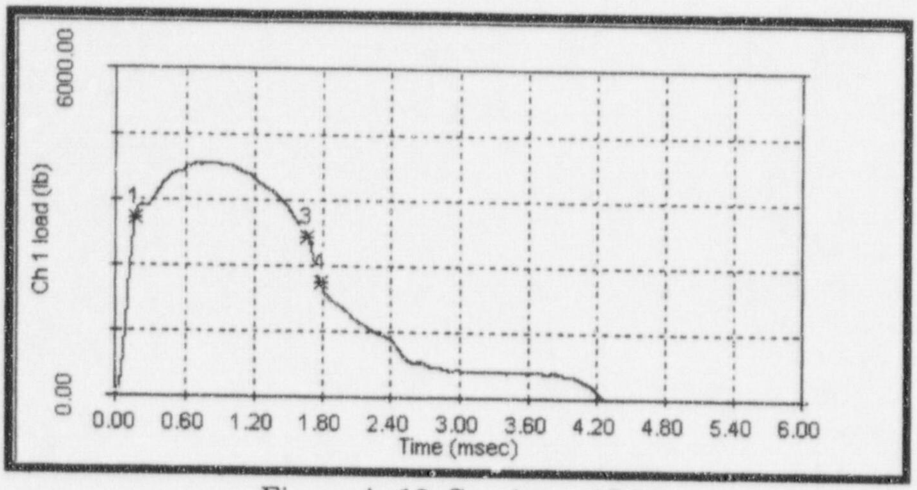


Figure A. 13 Specimen AL22

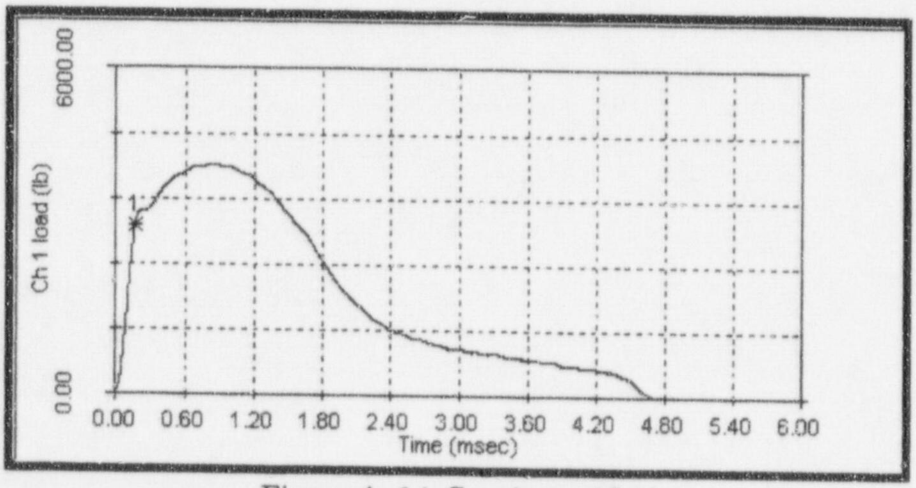


Figure A. 14 Specimen AL20

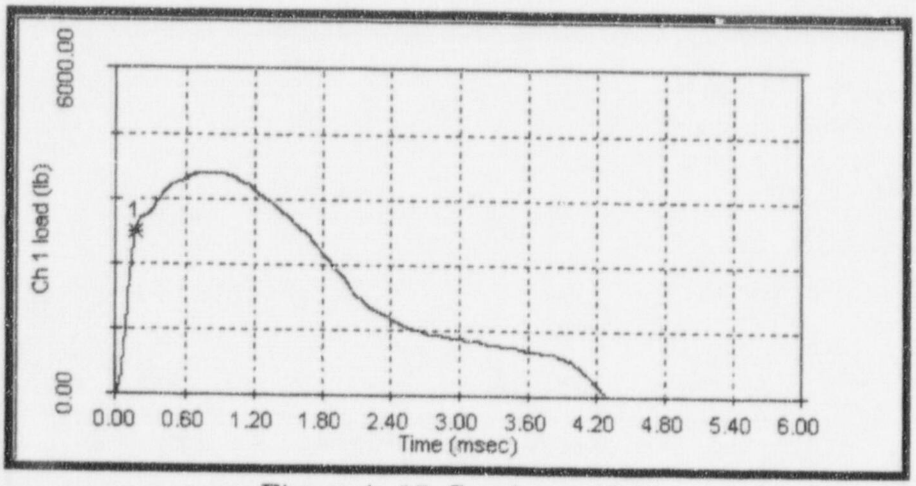


Figure A. 15 Specimen AL23

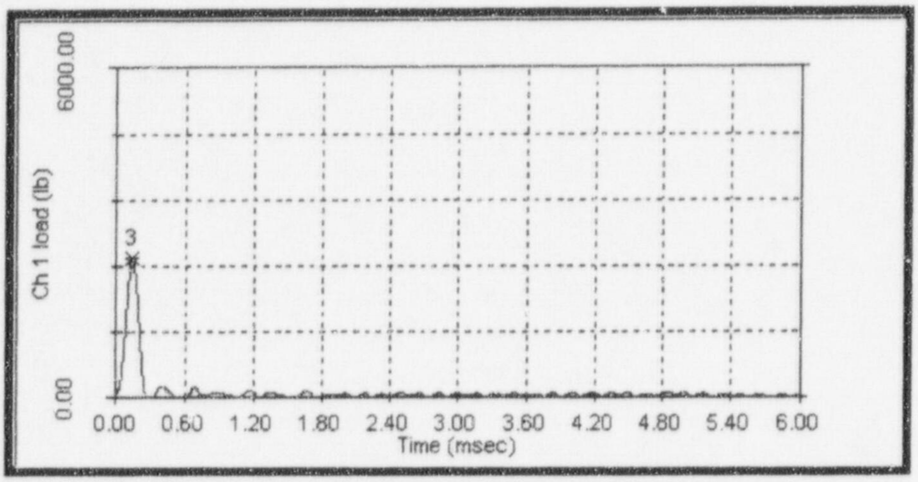


Figure A. 16 Specimen AT30

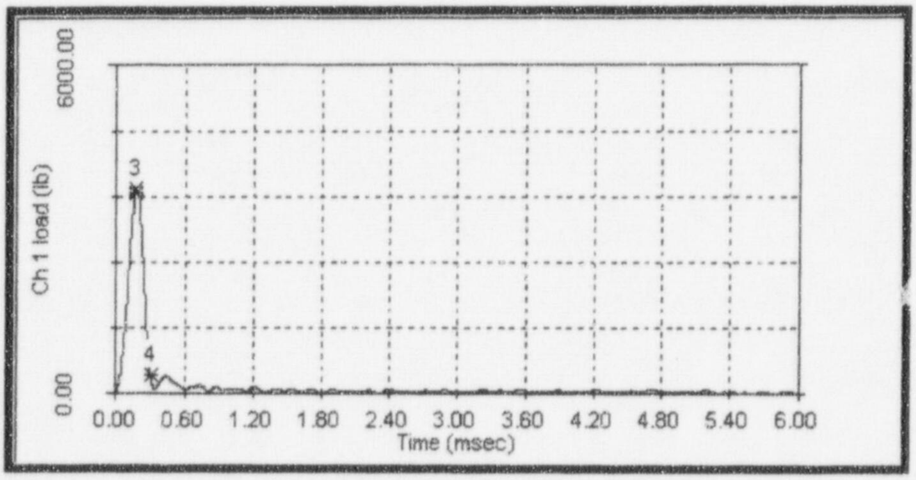


Figure A. 17 Specimen AT24

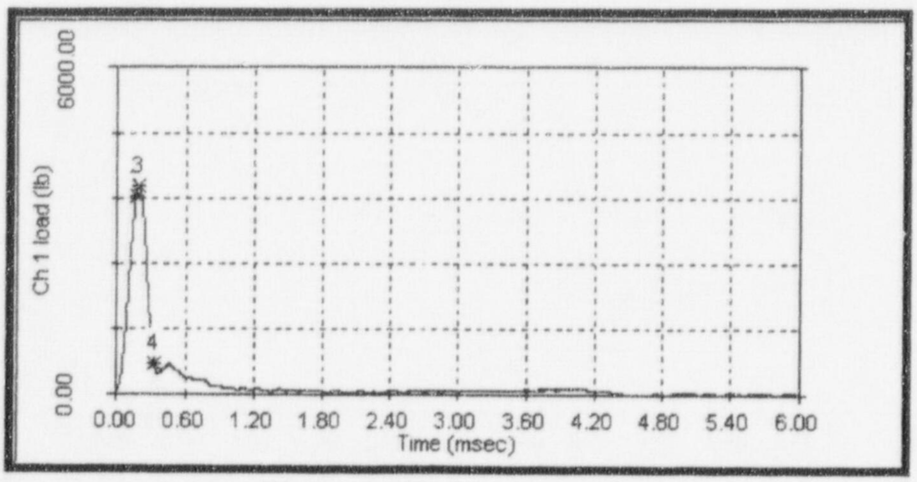


Figure A. 18 Specimen AT23

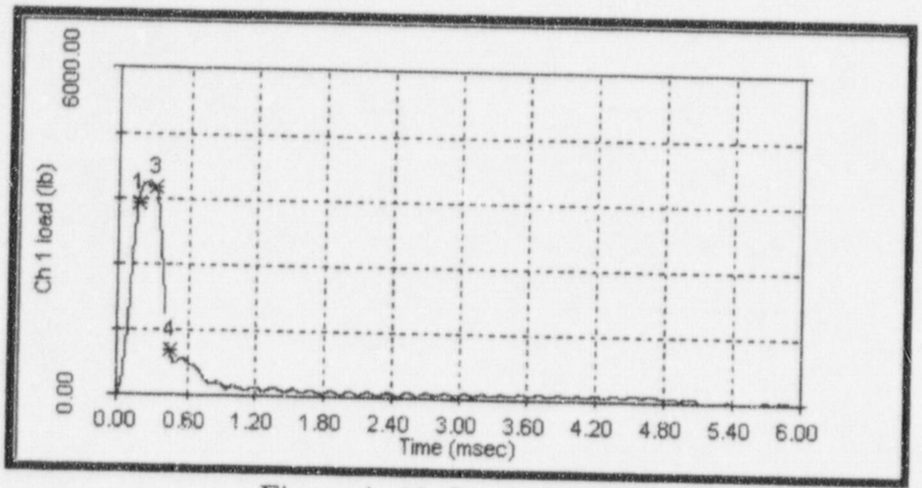


Figure A. 19 Specimen AT16

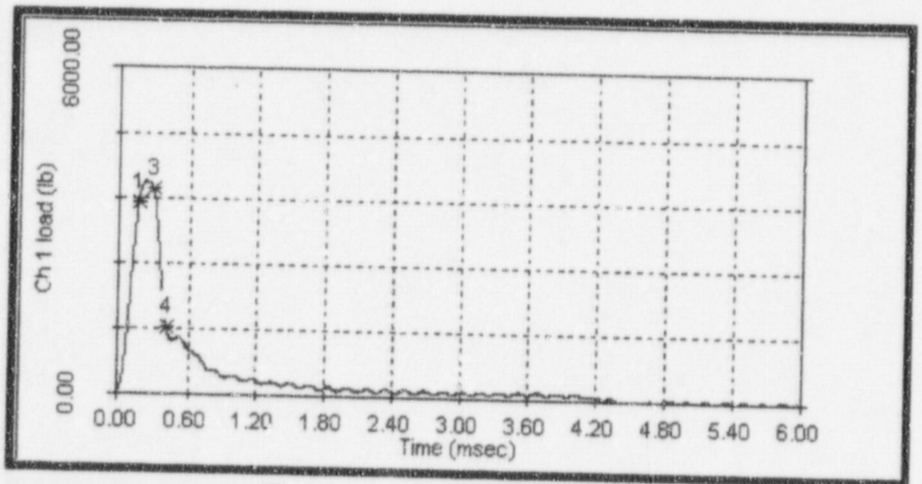


Figure A. 20 Specimen AT25

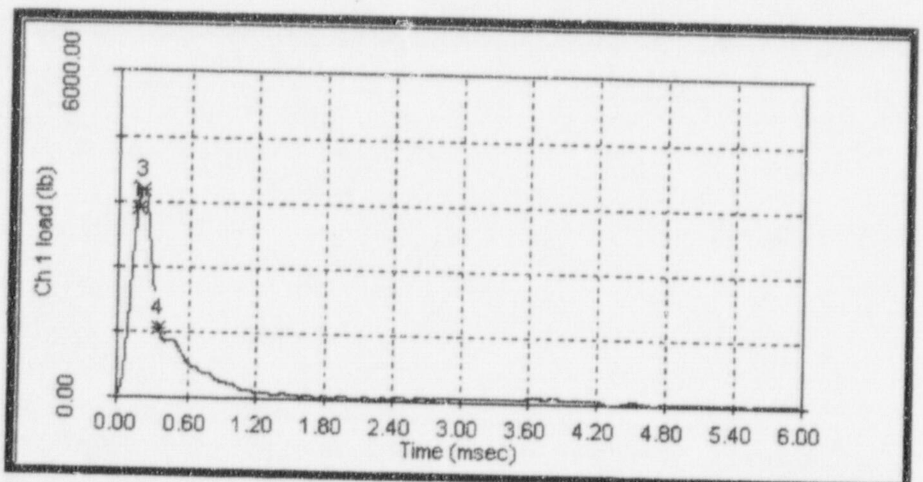


Figure A. 21 Specimen AT26

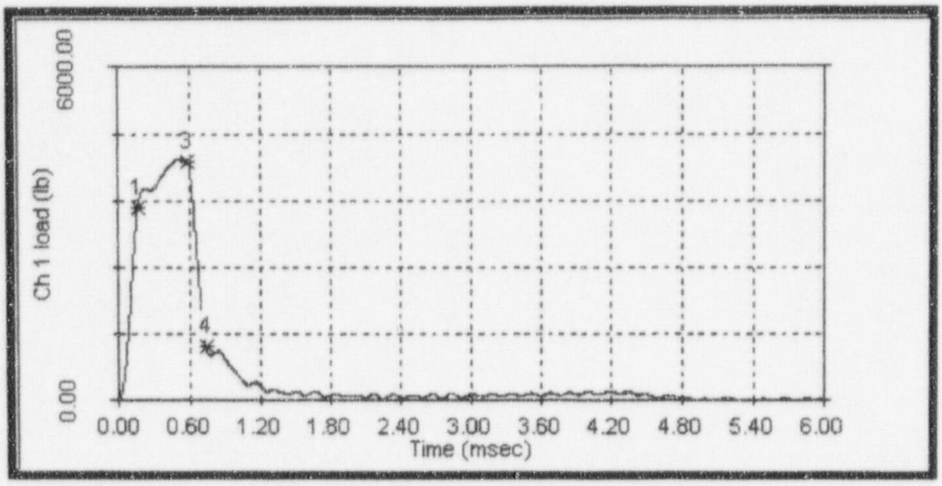


Figure A. 22 Specimen AT18

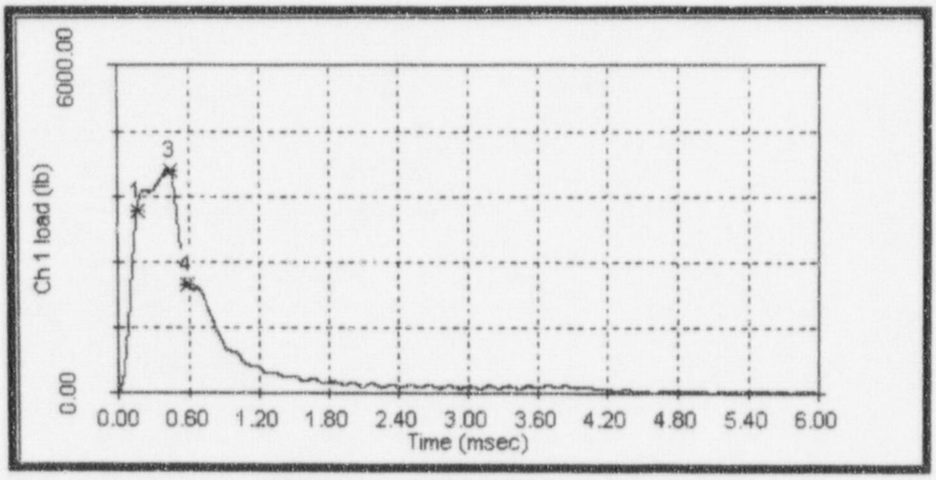


Figure A. 23 Specimen AT27

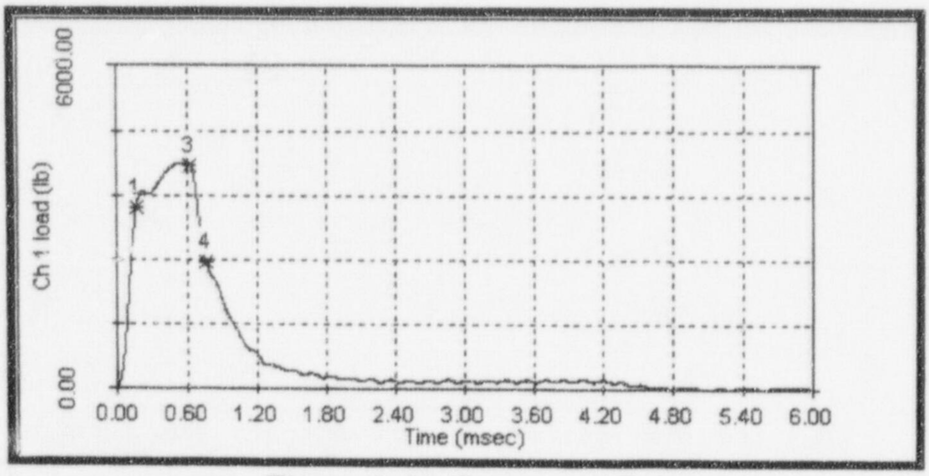


Figure A. 24 Specimen AT19

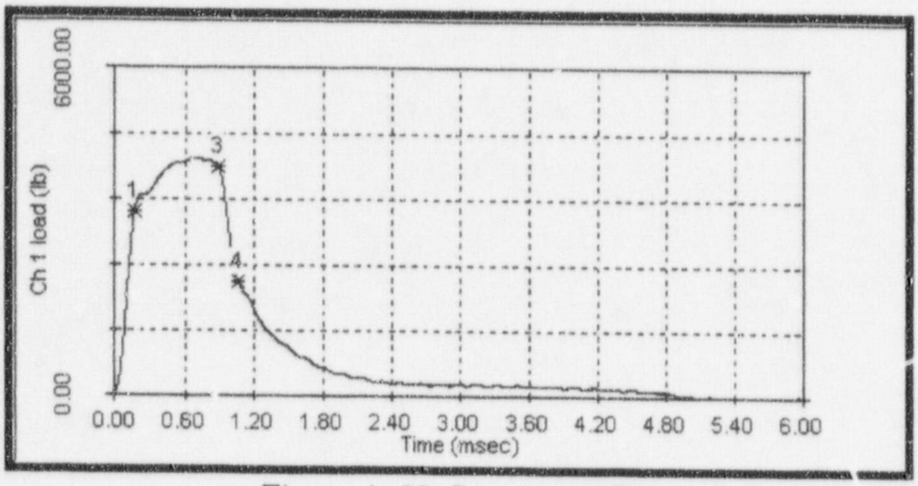


Figure A. 25 Specimen AT28

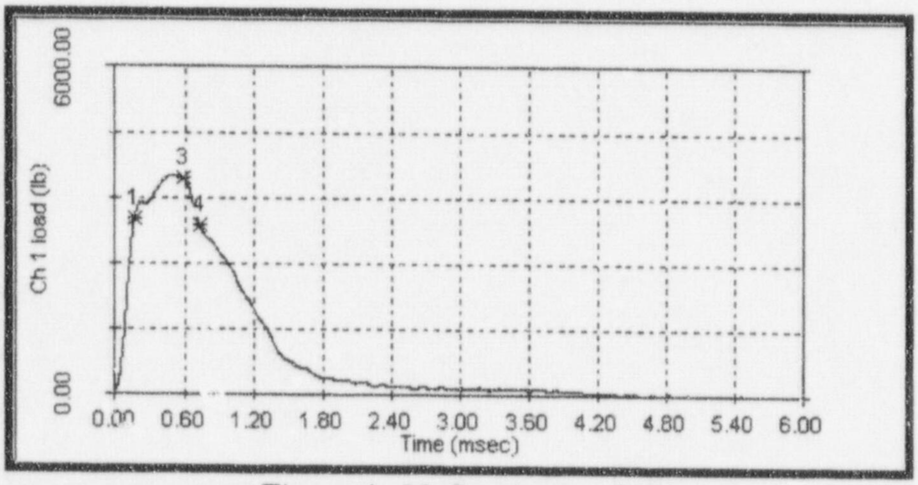


Figure A. 26 Specimen AT22

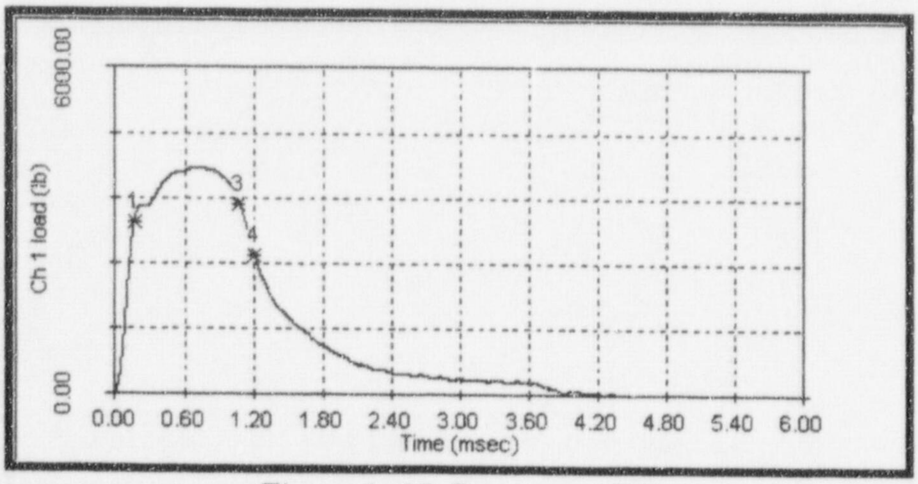


Figure A. 27 Specimen AT21

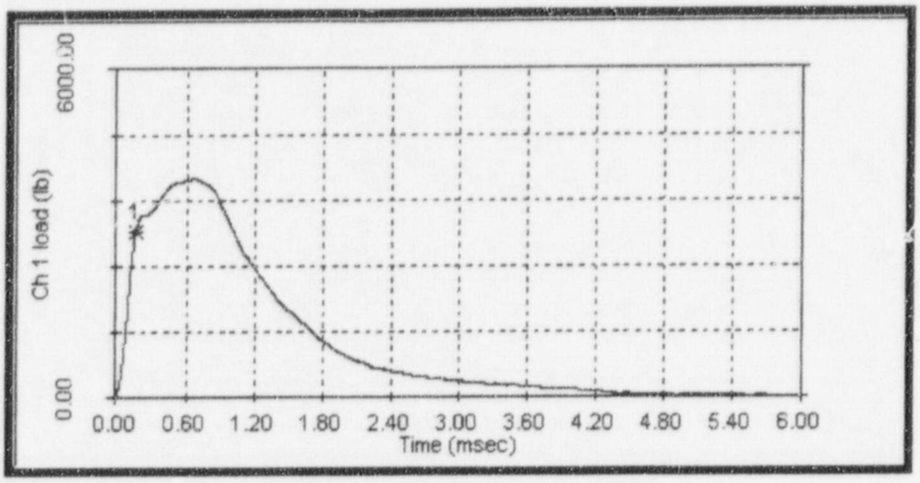


Figure A. 28 Specimen AT20

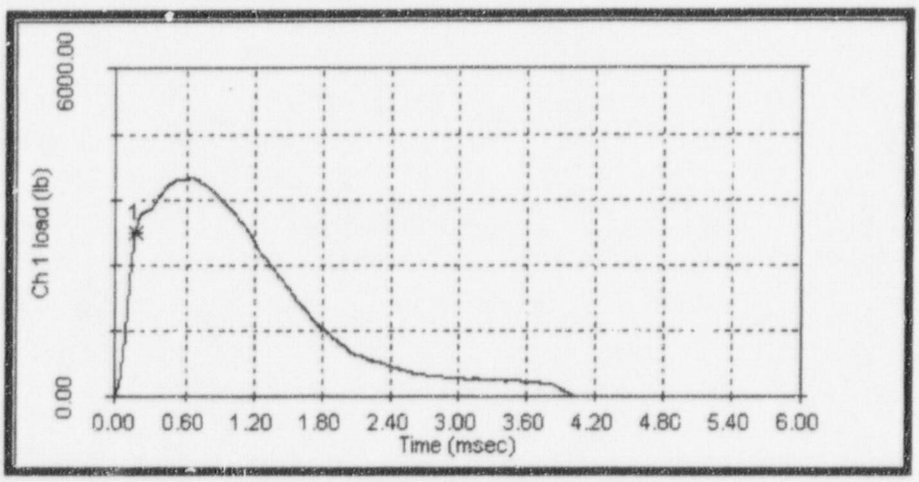


Figure A. 29 Specimen AT17

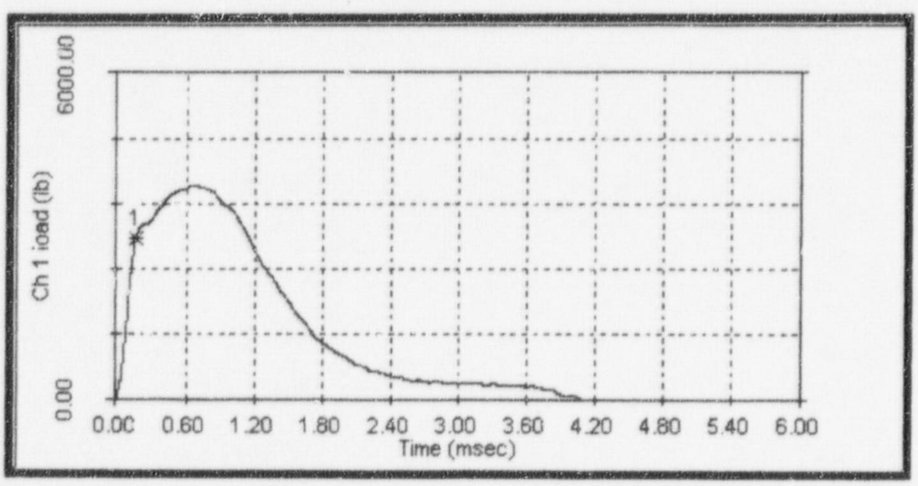


Figure A. 30 Specimen AT29

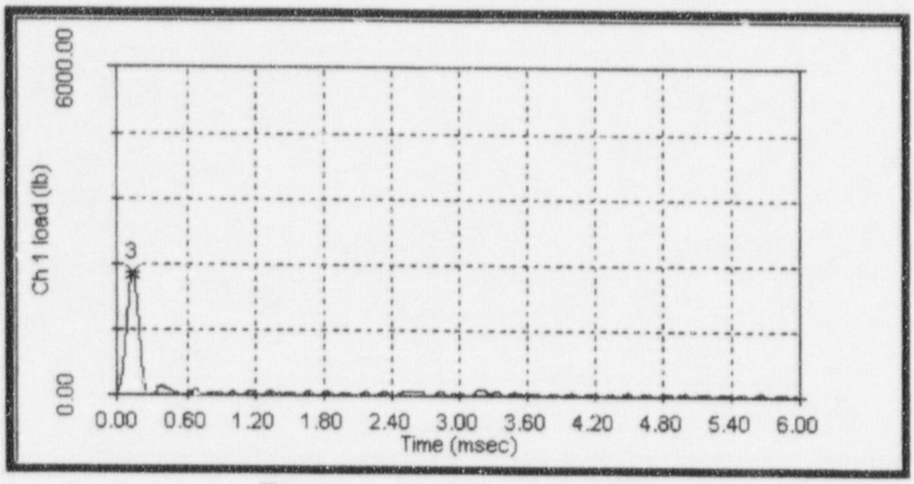


Figure A. 31 Specimen AW18

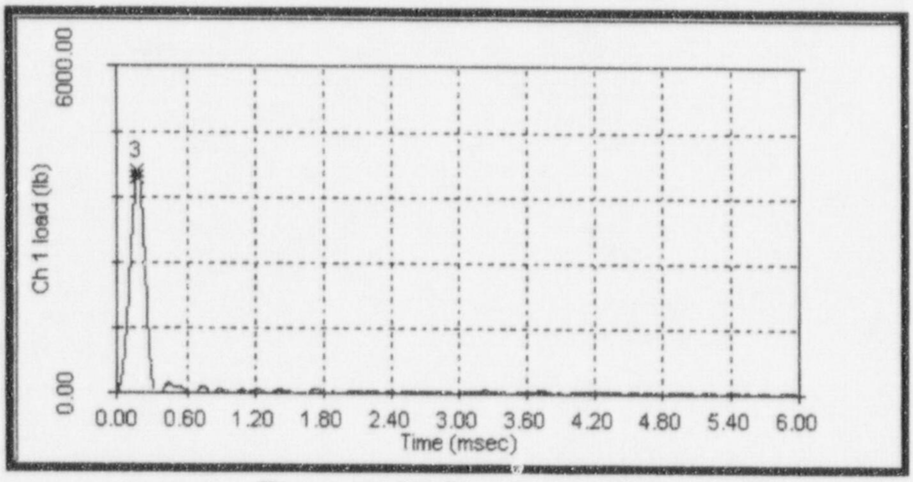


Figure A. 32 Specimen AW23

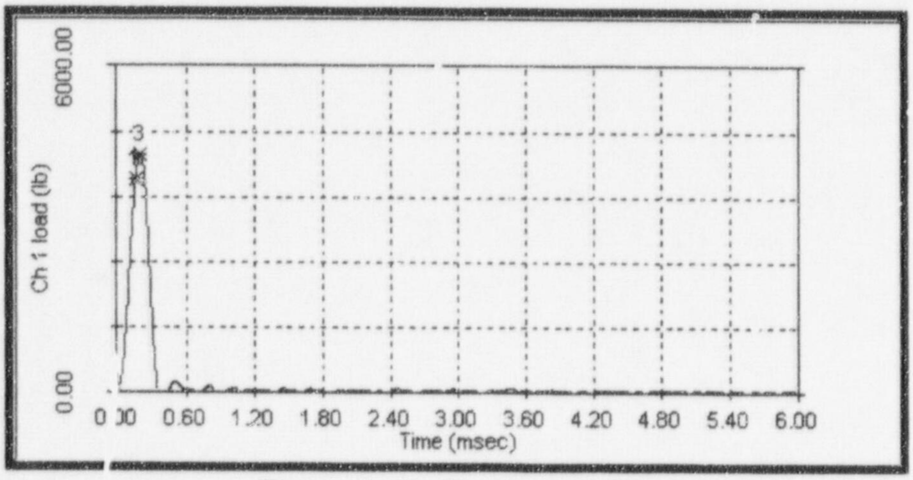


Figure A. 33 Specimen AW25

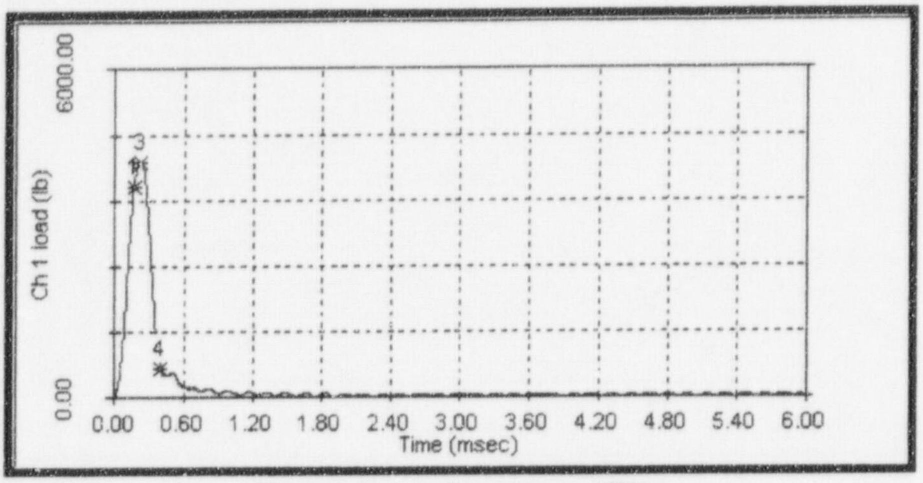


Figure A. 34 Specimen AW22

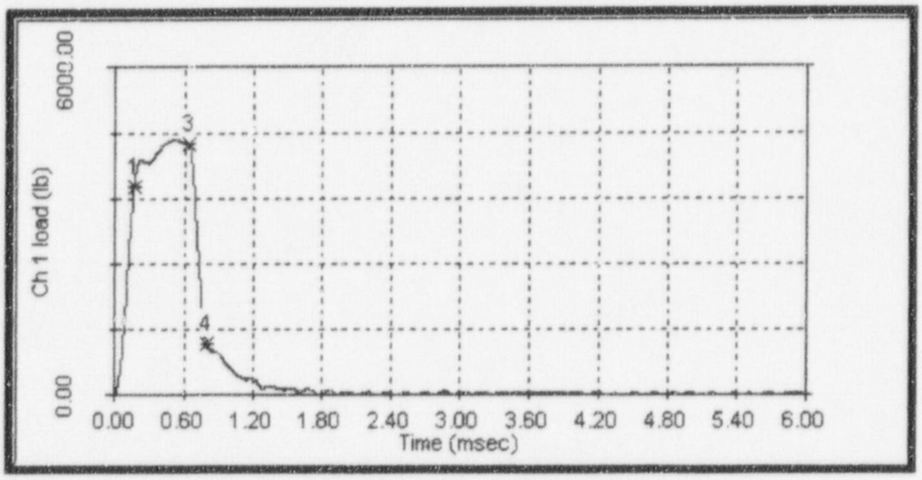


Figure A. 35 Specimen AW28

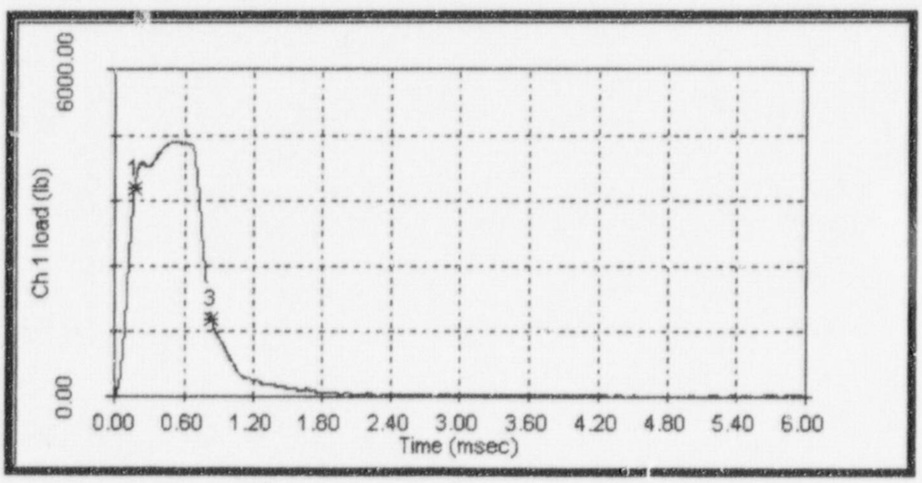


Figure A. 36 Specimen AW16

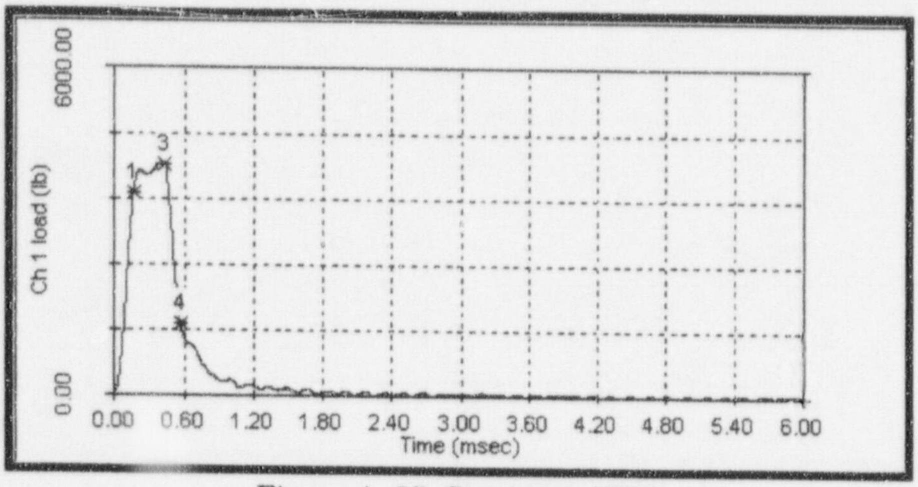


Figure A. 37 Specimen AW20

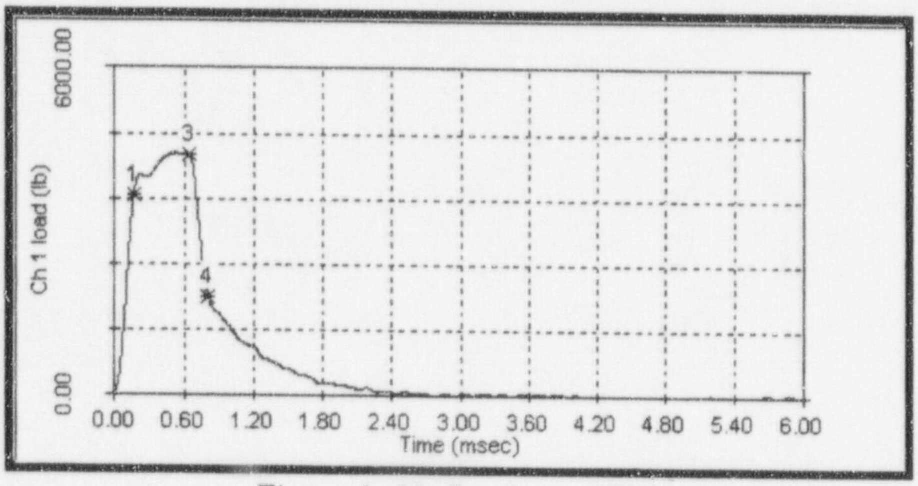


Figure A. 38 Specimen AW27

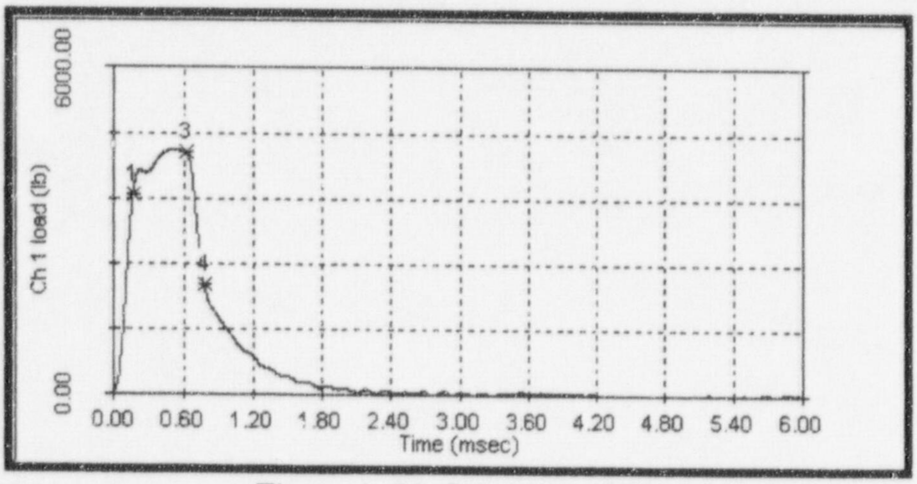


Figure A. 39 Specimen AW17

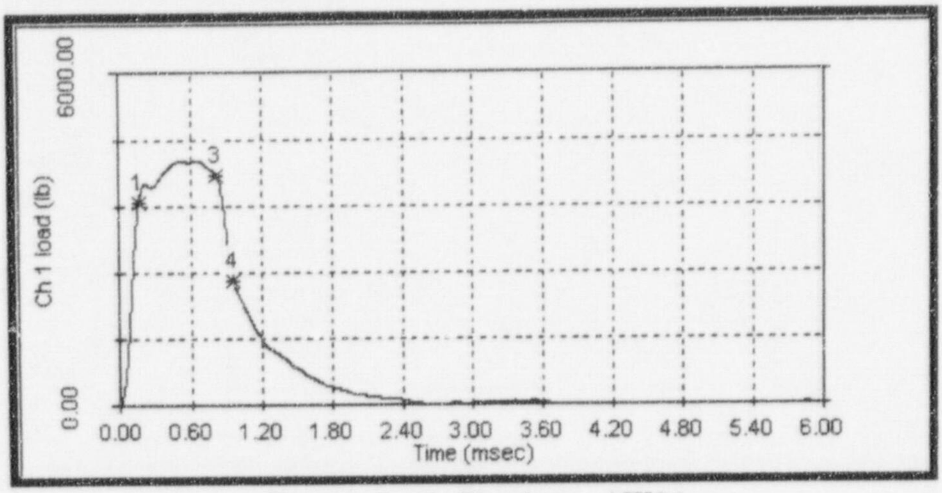


Figure A. 40 Specimen AW24

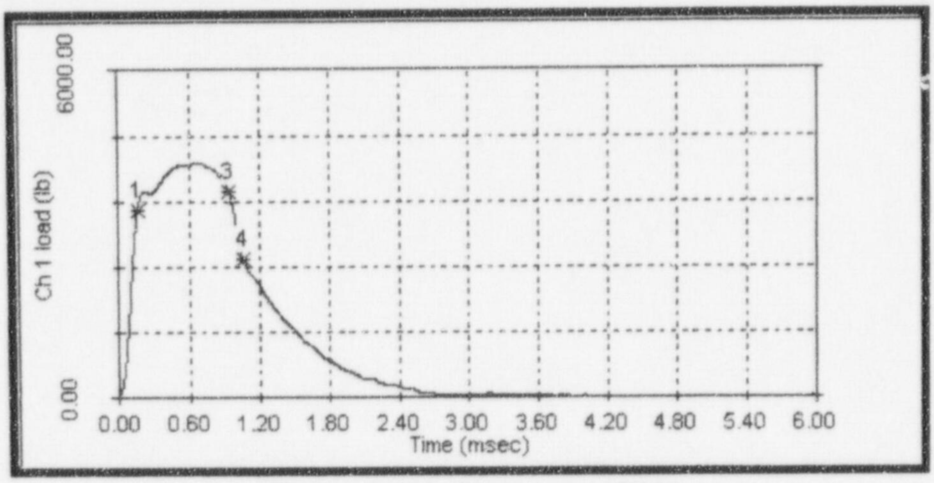


Figure A. 41 Specimen AW26

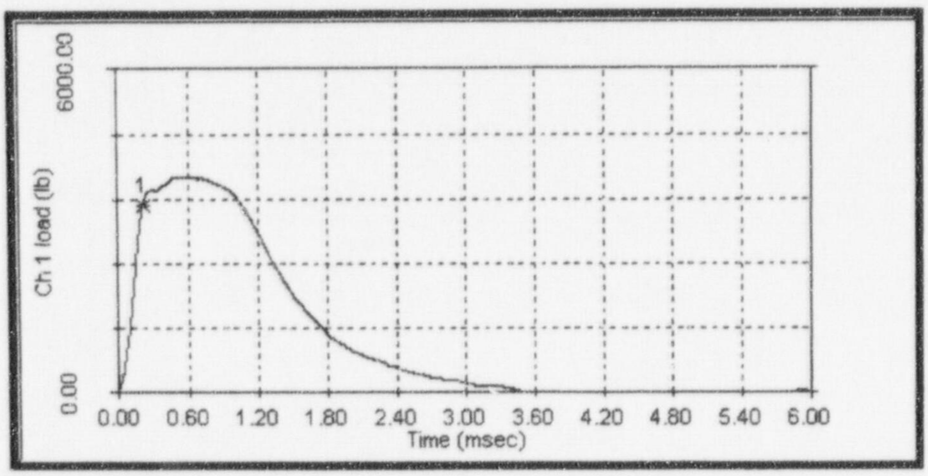


Figure A. 42 Specimen AW30

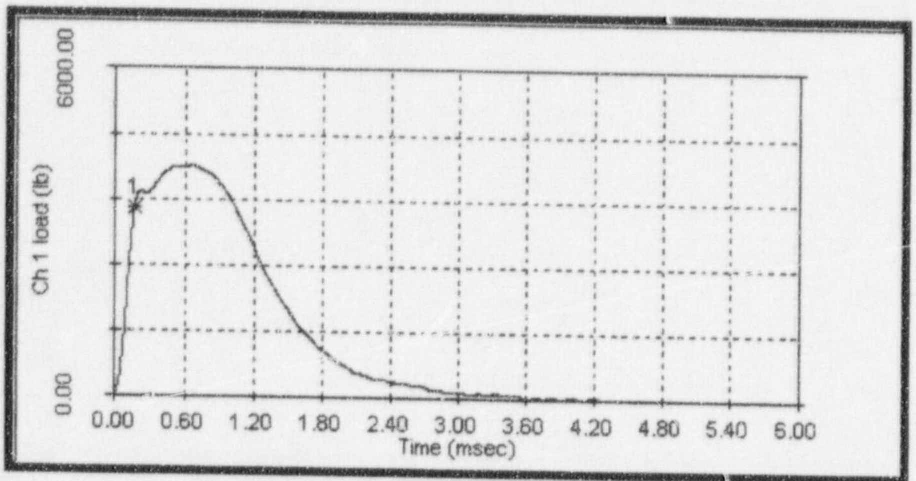


Figure A. 43 Specimen AW19

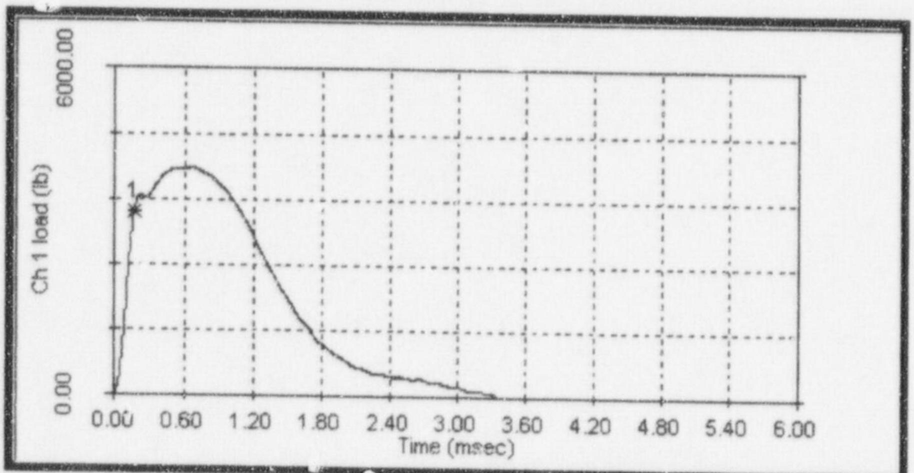


Figure A. 44 Specimen AW29

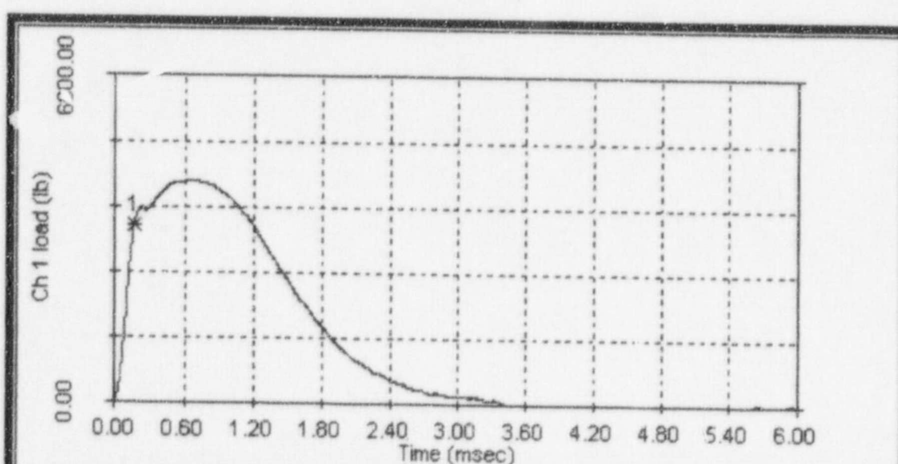


Figure A. 45 Specimen AW21

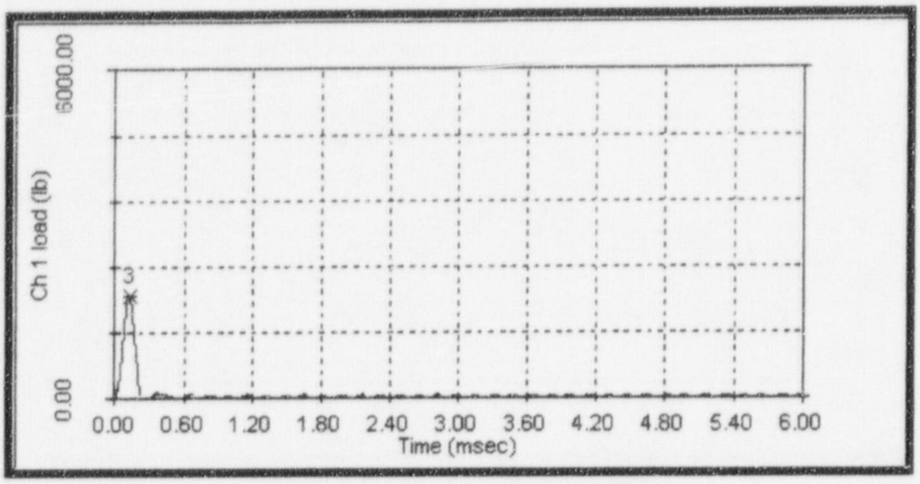


Figure A. 46 Specimen AH21

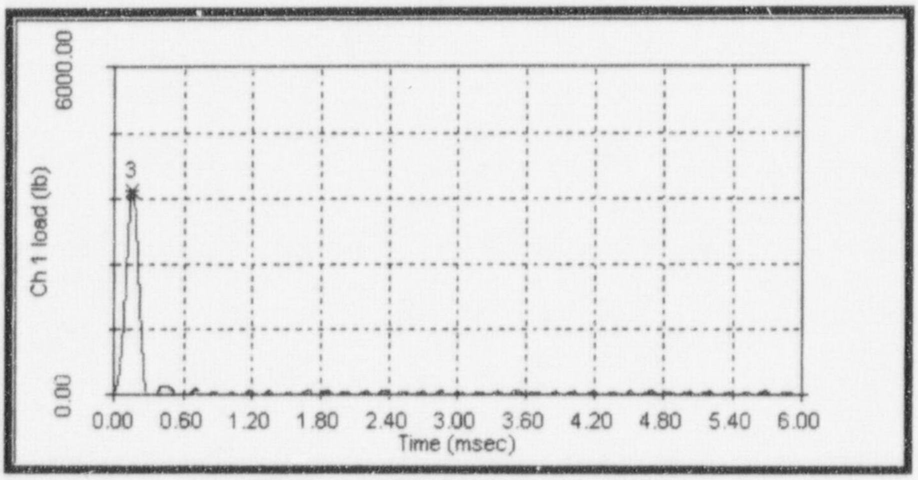


Figure A. 47 Specimen AH20

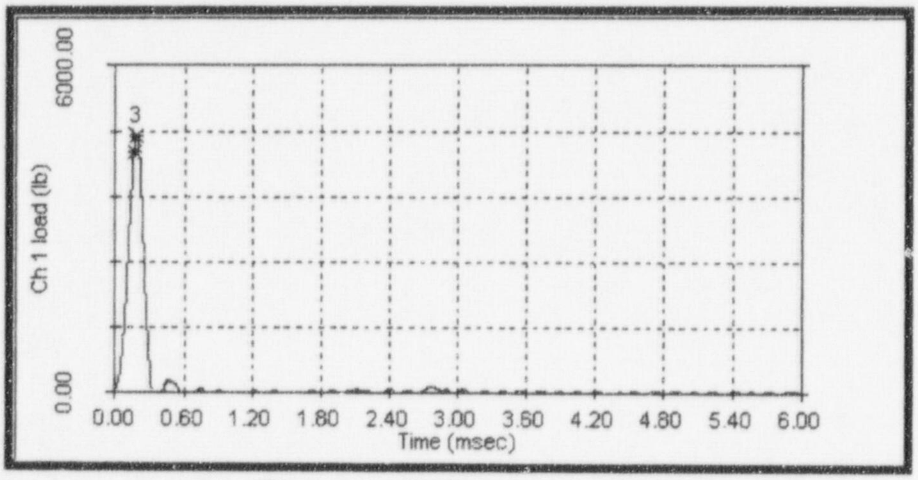


Figure A. 48 Specimen AH16

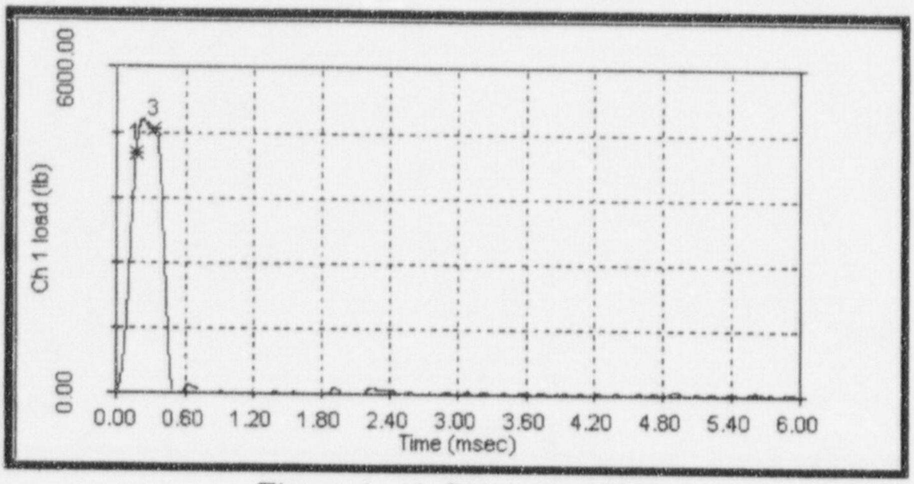


Figure A. 49 Specimen AH28

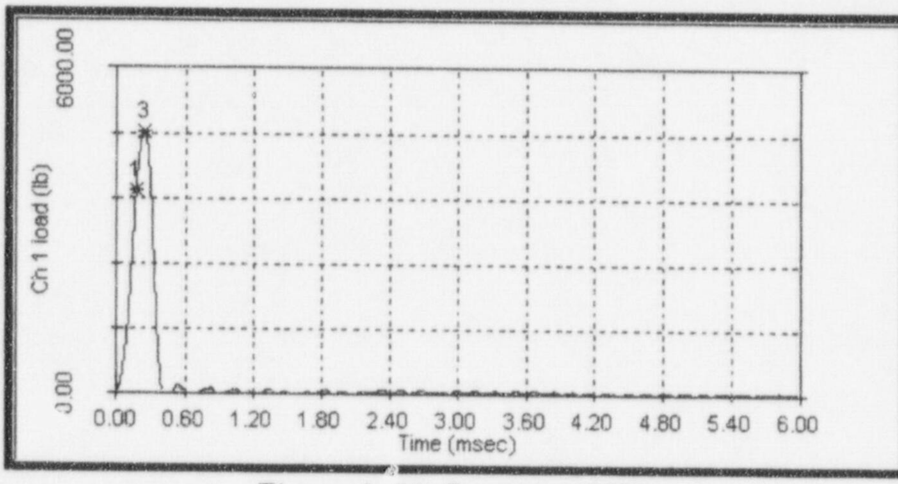


Figure A. 50 Specimen AH24

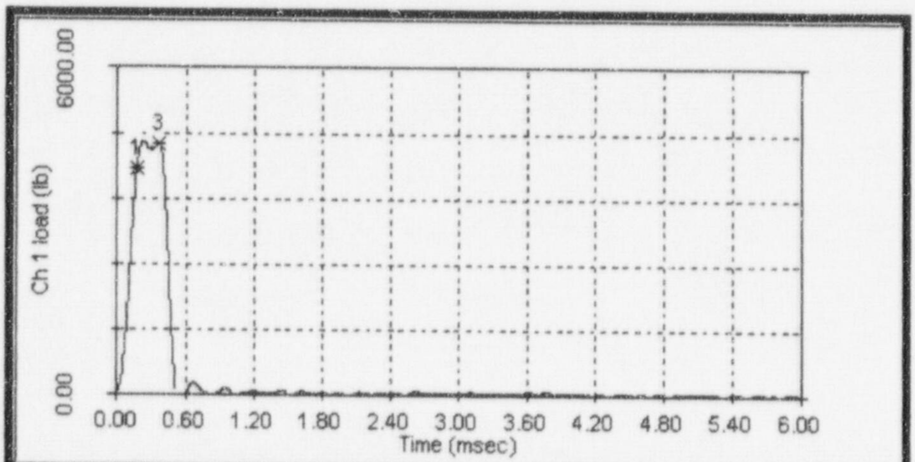


Figure A. 51 Specimen AH27

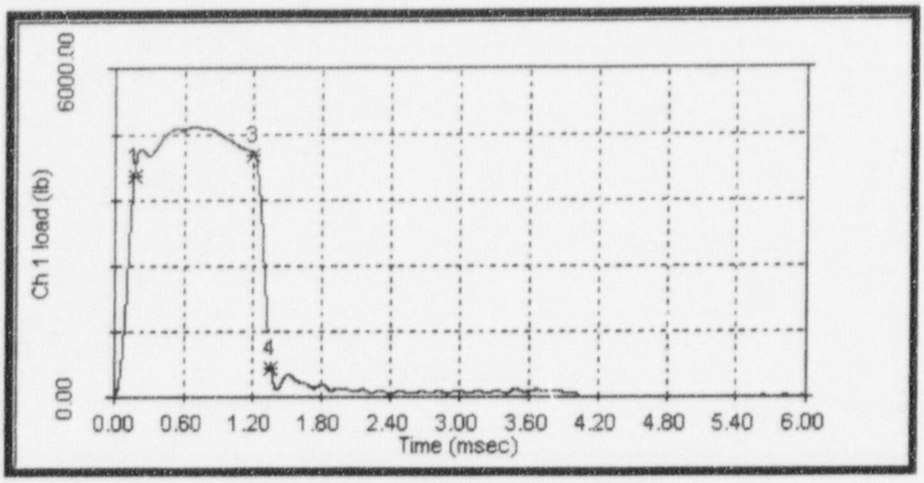


Figure A. 52 Specimen AH30

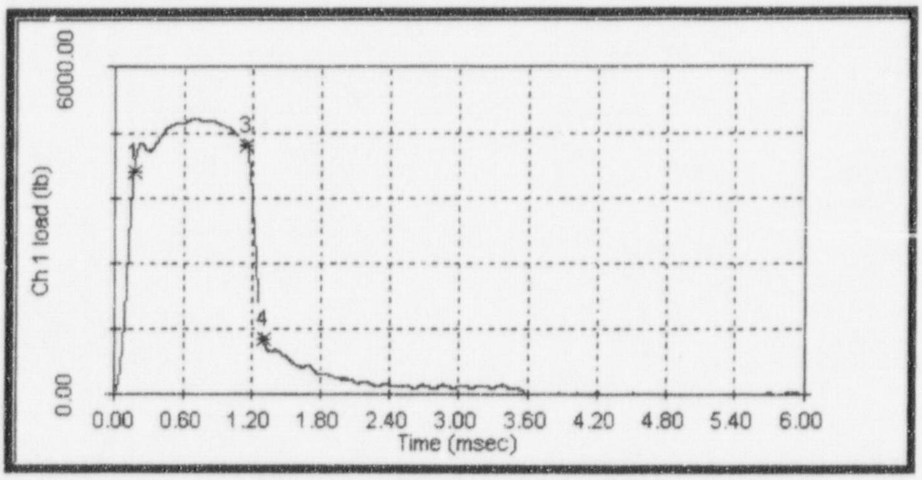


Figure A. 53 Specimen AH25

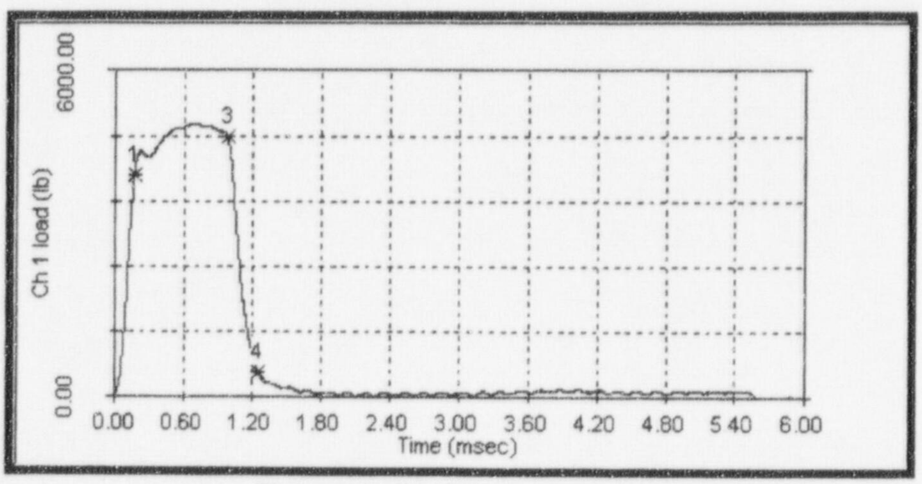


Figure A. 54 Specimen AH29

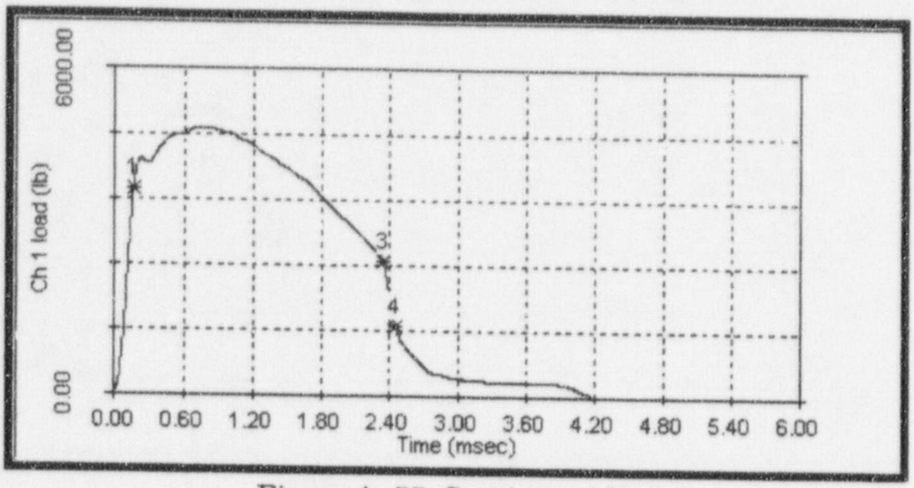


Figure A. 55 Specimen AH17

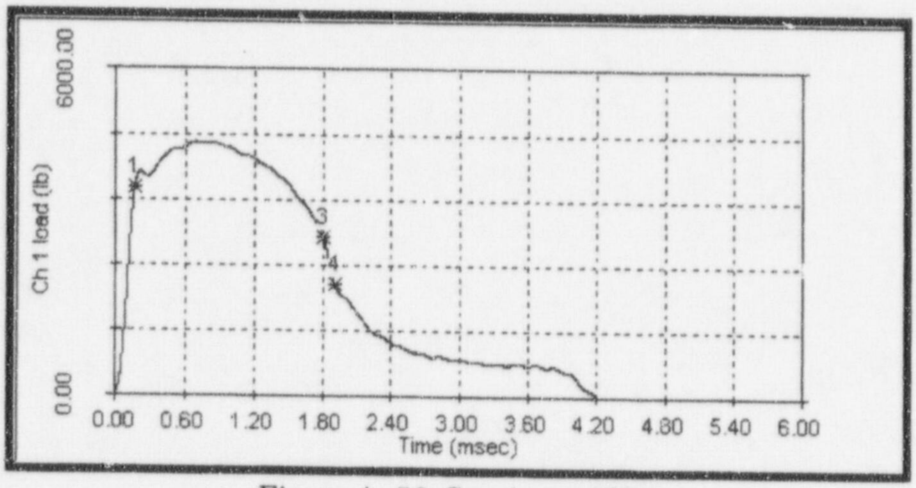


Figure A. 56 Specimen AH23

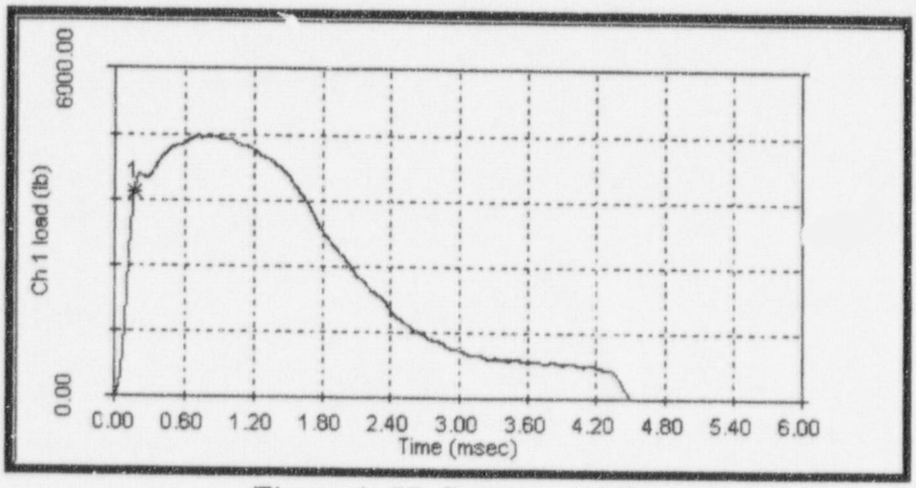


Figure A. 57 Specimen AH18

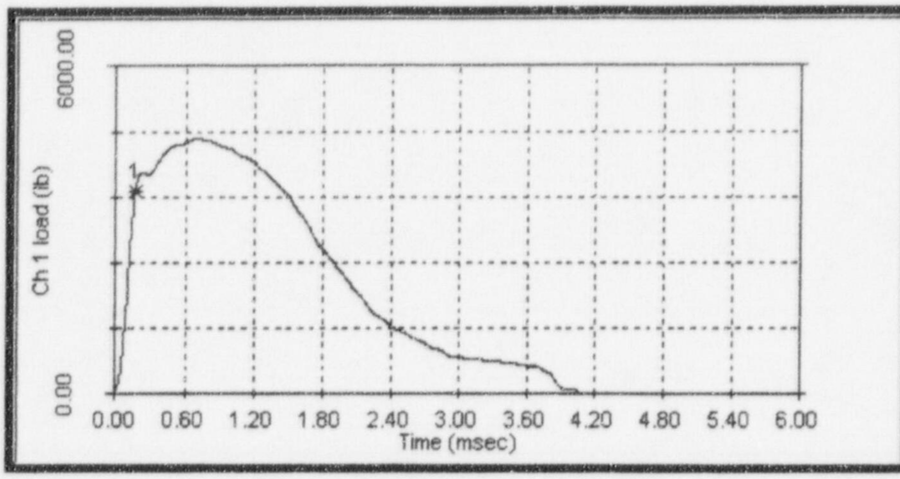


Figure A. 58 Specimen AH19

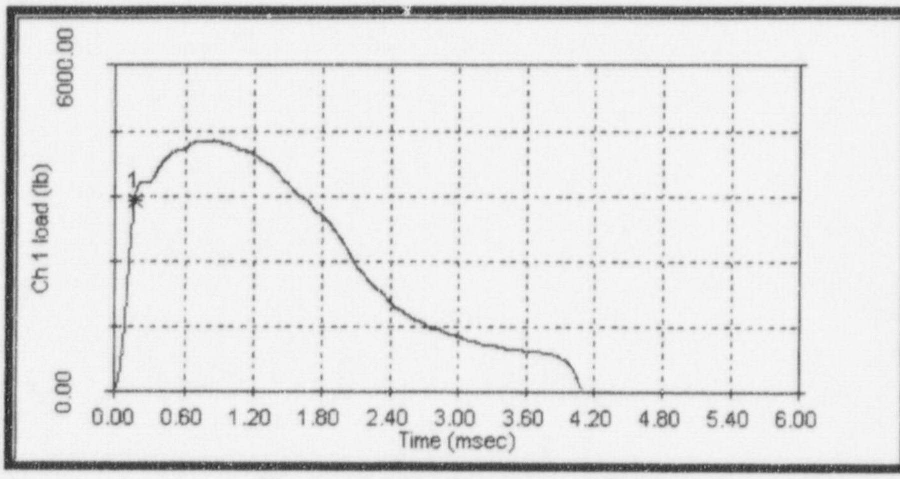


Figure A. 59 Specimen AH22

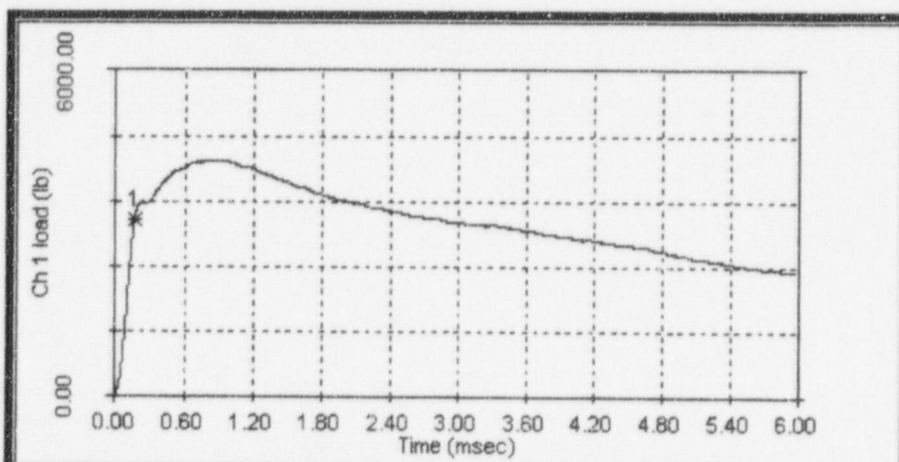


Figure A. 60 Specimen AH26

APPENDIX B

Charpy V-Notch Shift Results for Each Capsule Hand-Fit vs. Hyperbolic Tangent Curve-Fitting Method (CVGRAPH, Version 4.1)

TABLE B-1

Changes in Average 30 ft-lb Temperatures for Lower Shell

Plate R2508-3 (Longitudinal Orientation)

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{30}	Unirradiated	CVGRAPH Fit	ΔT_{30}
U	- 20°F	10°F	30°F	- 24.95°F	11.51°F	36.46°F
Y	- 20°F	10°F	30°F	- 24.95°F	- 8.91°F	16.03°F
V	- 20°F	- -	- -	- 24.95°F	- 24.95°F	52.03°F

TABLE B-2

Changes in Average 50 ft-lb Temperatures for Lower Shell

Plate R2508-3 (Longitudinal Orientation)

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{50}	Unirradiated	CVGRAPH Fit	ΔT_{50}
U	0°F	30°F	30°F	0.11°F	34.85°F	34.73°F
Y	0°F	40°F	40°F	0.11°F	31.54°F	31.43°F
V	0°F	- -	- -	0.11°F	46.98°F	46.86°F

TABLE B-3

Changes in Average 35 mil Lateral Expansion Temperatures for Lower Shell Plate R2508-3 (Longitudinal Orientation)

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{35}	Unirradiated	CVGRAPH Fit	ΔT_{35}
U	- 10°F	20°F	30°F	- 0.4°F	21.43°F	21.83°F
Y	- 10°F	45°F	55°F	- 0.4°F	30.43°F	30.83°F
V	- 10°F	- -	- -	- 0.4°F	53.35°F	53.75°F

TABLE B-4

Changes in Average Energy Absorption at Full Shear for Lower Shell Plate R2508-3 (Longitudinal Orientation)

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔE	Unirradiated	CVGRAPH Fit	ΔE
U	148 ft-lb	145 ft-lb	- 3 ft-lb	148 ft-lb	145 ft-lb	- 3 ft-lb
Y	148 ft-lb	121 ft-lb*	- 27 ft-lb	148 ft-lb	131 ft-lb*	- 17 ft-lb
V	148 ft-lb	- -	- -	148 ft-lb	129 ft-lb	- 19 ft-lb

* There was a typo in WCAP-13365, Revision 1, Table 5-1 reported a ft-lb value for specimen AL65 of 88 ft-lb and Table 5-3 reported a ft-lb value of 145 ft-lb. The correct value is 145 ft-lb.

TABLE B-5

Changes in Average 30 ft-lb Temperatures for Lower Shell

Plate R2508-3 (Transverse Orientation)

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{30}	Unirradiated	CVGRAPH Fit	ΔT_{30}
U	0°F	25°F	25°F	2°F	25.8°F	23.79°F
Y	0°F	40°F	40°F	2°F	37.39°F	35.39°F
V	0°F	- -	- -	2°F	56.54°F	54.53°F

TABLE B-6

Changes in Average 50 ft-lb Temperatures for Lower Shell

Plate R2508-3 (Transverse Orientation)

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{50}	Unirradiated	CVGRAPH Fit	ΔT_{50}
U	40°F	65°F	25°F	34.32°F	59.55°F	25.23°F
Y	40°F	85°F	45°F	34.32°F	81.49°F	47.16°F
V	40°F	- -	- -	34.32°F	90.59°F	56.27°F

TABLE B-7

Changes in Average 35 mil Lateral Expansion Temperatures for Lower Shell

Plate R2508-3 (Transverse Orientation)

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{35}	Unirradiated	CVGRAPH Fit	ΔT_{35}
U	25°F	45°F	20°F	25.44°F	36.36°F	10.91°F
Y	25°F	45°F	20°F	25.44°F	67.84°F	42.39°F
V	25°F	- -	- -	25.44°F	93.79°F	68.34°F

TABLE B-8

Changes in Average Energy Absorption at Full Shear for Lower Shell

Plate R2508-3 (Transverse Orientation)

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔE	Unirradiated	CVGRAPH Fit	ΔE
U	93 ft-lb	95 ft-lb	+ 2 ft-lb	94 ft-lb	96 ft-lb	+ 2 ft-lb
Y	93 ft-lb	94 ft-lb	+ 1 ft-lb	94 ft-lb	94 ft-lb	0 ft-lb
V	93 ft-lb	- -	- -	94 ft-lb	88 ft-lb	- 6 ft-lb

TABLE B-9

Changes in Average 30 ft-lb Temperatures for the Surveillance Weld Material

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{30}	Unirradiated	CVGRAPH Fit	ΔT_{30}
U	- 50°F	- 30°F	20°F	- 57.69°F	- 30.47°F	27.21°F
Y	- 50°F	0°F	50°F	- 57.69°F	- 12.59°F	45.09°F
V	- 50°F	- -	- -	- 57.69°F	- 11.36°F	46.33°F

TABLE B-10

Changes in Average 50 ft-lb Temperatures for the Surveillance Weld Material

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{50}	Unirradiated	CVGRAPH Fit	ΔT_{50}
U	- 15°F	5°F	20°F	- 20.64°F	6.44°F	27.09°F
Y	- 15°F	30°F	45°F	- 20.64°F	20.82°F	41.47°F
V	- 15°F	- -	- -	- 20.64°F	31.79°F	52.44°F

TABLE B-11

Changes in Average 35 mil Lateral Expansion Temperatures for the

Surveillance Weld Material

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{35}	Unirradiated	CVGRAPH Fit	ΔT_{35}
U	- 25°F	- 10°F	15°F	- 27.07°F	- 12.81°F	14.25°F
Y	- 25°F	20°F	45°F	- 27.07°F	17.96°F	45.04°F
V	- 25°F	- -	- -	- 27.07°F	45.52°F	72.59°F

TABLE B-12

Changes in Average Energy Absorption at Full Shear for the

Surveillance Weld Material

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔE	Unirradiated	CVGRAPH Fit	ΔE
U	100 ft-lb	92 ft-lb	- 8 ft-lb	100 ft-lb	92 ft-lb	- 8 ft-lb
Y	100 ft-lb	94 ft-lb	- 6 ft-lb	100 ft-lb	94 ft-lb	- 6 ft-lb
V	100 ft-lb	- -	- -	100 ft-lb	89 ft-lb	- 11 ft-lb

TABLE B-13

Changes in Average 30 ft-lb Temperatures for the Weld Heat-Affected-Zone Material

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{30}	Unirradiated	CVGRAPH Fit	ΔT_{30}
U	- 145°F	- 80°F	65°F	- 144.01°F	- 85.59°F	58.41°F
Y	- 145°F	- 95°F	50°F	- 144.01°F	- 131.02°F	12.98°F
V	- 145°F	- -	- -	- 144.01°F	- 88.09°F	55.91°F

TABLE B-14

Changes in Average 50 ft-lb Temperatures for the Weld Heat-Affected-Zone Material

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{50}	Unirradiated	CVGRAPH Fit	ΔT_{50}
U	- 110°F	- 45°F	65°F	- 114°F	- 55.32°F	58.68°F
Y	- 110°F	- 70°F	40°F	- 114°F	- 84.82°F	29.18°F
V	- 110°F	- -	- -	- 114°F	- 61.99°F	52.01°F

TABLE B-15

Changes in Average 35 mil Lateral Expansion Temperatures for the Weld

Heat-Affected-Zone Material

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{35}	Unirradiated	CVGRAPH Fit	ΔT_{35}
U	- 90°F	- 35°F	55°F	- 89.78°F	- 54.25°F	-35.53°F
Y	- 90°F	- 25°F	65°F	- 89.78°F	- 60.54°F	29.27°F
V	- 90°F	- -	- -	- 89.78°F	- 43.6°F	46.18°F

TABLE B-16

Changes in Average Energy Absorption at Full Shear for the Weld

Heat-Affected-Zone Material

Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔE	Unirradiated	CVGRAPH Fit	ΔE
U	161 ft-lb	140 ft-lb	- 21 ft-lb	161 ft-lb	140 ft-lb	- 21 ft-lb
Y	161 ft-lb	180 ft-lb	+ 19 ft-lb	161 ft-lb	200 ft-lb	+39 ft-lb
V	161 ft-lb	- -	- -	161 ft-lb	167 ft-lb	+ 6 ft-lb

APPENDIX C

Charpy V-Notch Plots for Each Capsule Using Hyperbolic Tangent Curve-Fitting Method

Contained in Table C-1 are the upper shelf energy values used as input for the generation of the Charpy V-notch plots using CVGRAPH, Version 4.1. Lower shelf energy values were fixed at 2.2 ft-lb. The unirradiated and irradiated upper shelf energy values were calculated per the ASTM E185-82 definition of upper shelf energy.

TABLE C-1

Upper Shelf Energy Values Fixed in CVGRAPH

Material	Unirradiated	Capsule U	Capsule Y	Capsule V
Lower shell plate R2508-3 (Heat # C4935-2) (Longitudinal Orientation)	148 ft-lb	145 ft-lb	131 ft-lb	129 ft-lb
Lower shell plate R2508-3 (Heat # C4935-2) (Transverse Orientation)	94 ft-lb	96 ft-lb	94 ft-lb	88 ft-lb
Weld Metal (Heat 90146)	100 ft-lb	92 ft-lb	94 ft-lb	89 ft-lb
HAZ Material	161 ft-lb	140 ft-lb	200 ft-lb	167 ft-lb

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:13:19 on 05-28-1998

Page 1

Coefficients of Curve 1

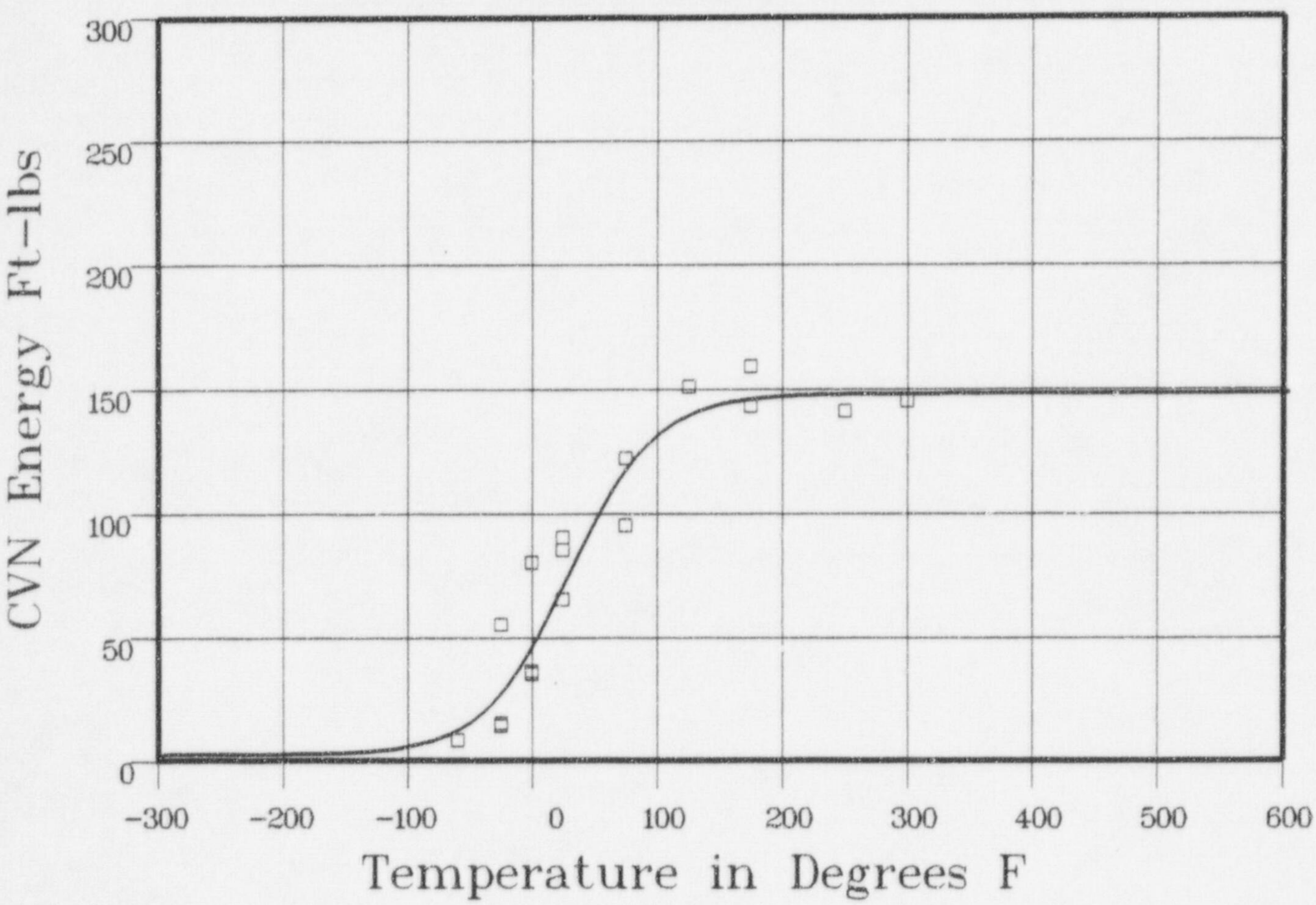
A = 75.09	B = 72.9	C = 68.88	T0 = 24.84

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

Upper Shelf Energy: 148 Fixed Temp. at 30 ft-lbs: -24.9 Temp. at 50 ft-lbs: .1 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: UNIRR Material: PLATE SA533B1 Ori.: LT Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-60	8	13.64	-5.64
-25	55	29.96	25.03
-25	15	29.96	-14.96
-25	14	29.96	-15.96
0	35	49.89	-14.89
0	36	49.89	-13.89
0	80	49.89	30.1
25	90	75.26	14.73
25	65	75.26	-10.26

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

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
25	85	75.26	9.73
75	122	120.43	1.56
75	95	120.43	-25.43
125	151	140.45	10.54
125	151	140.45	10.54
175	143	146.15	-3.15
175	159	146.15	12.84
250	141	147.78	-6.78
300	145	147.95	-2.95

SUM of RESIDUALS = 1.14

CAPSULE U (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:13:19 on 05-28-1998

Page 1

Coefficients of Curve 2

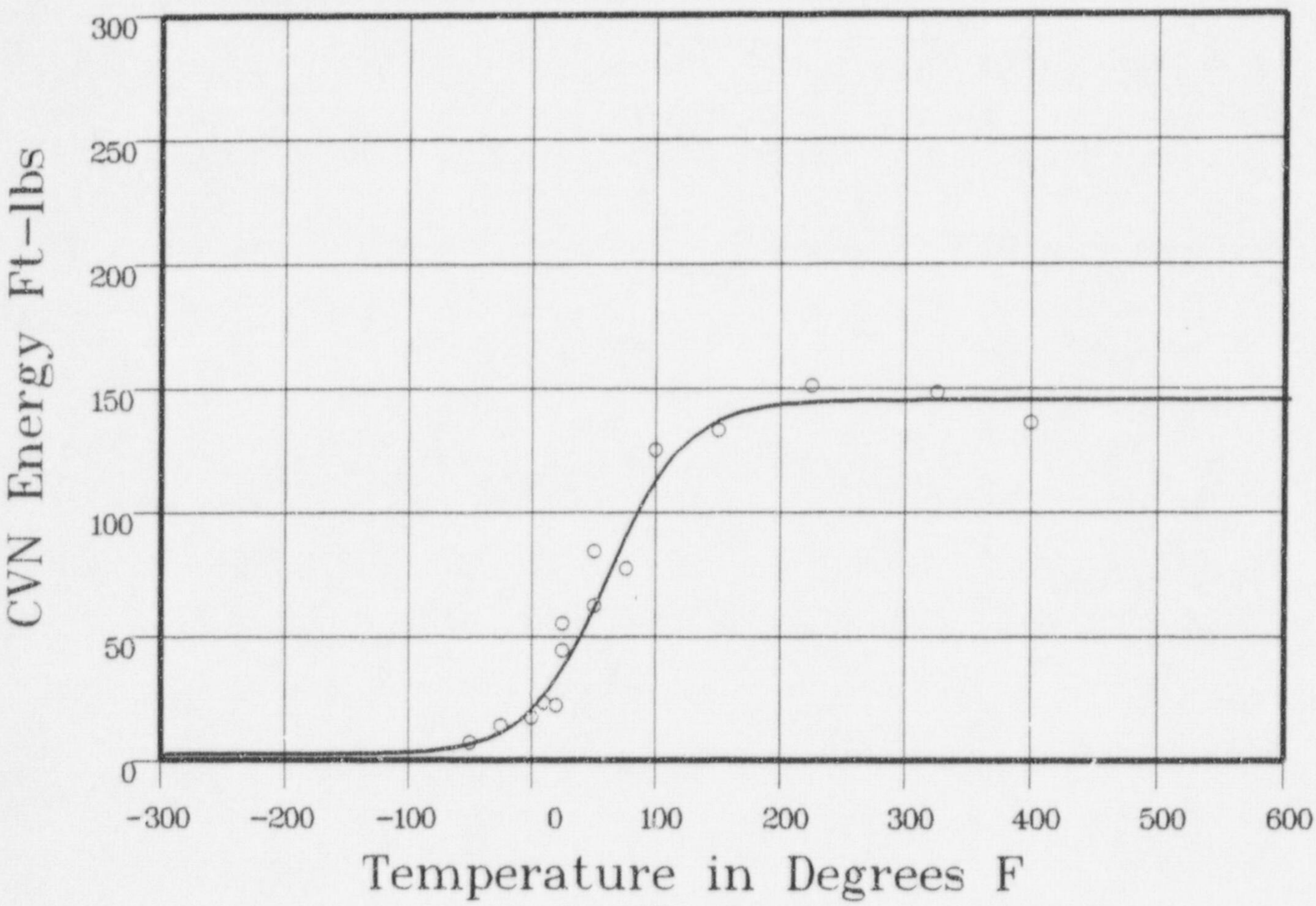
A = 73.59	B = 71.4	C = 63.67	T0 = 56.71

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

Upper Shelf Energy: 145 Fixed Temp. at 30 ft-lbs: 11.5 Temp. at 50 ft-lbs: 34.8 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: U Material: PLATE SA533B1 Ori.: LT Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	7	7.03	-.03
-25	14	12.38	1.61
0	17	22.78	-5.78
10	23	28.95	-5.95
20	22	36.45	-14.45
25	44	40.7	3.29
25	55	40.7	14.29
50	62	66.09	-4.09

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

CAPSULE U (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	84	66.09	17.9
76	77	94.58	-17.58
100	125	115.82	9.17
150	133	137.76	-4.76
225	151	144.28	6.71
325	148	144.96	3.03
400	136	144.99	-8.99

SUM of RESIDUALS = -5.62

CAPSULE Y (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:13:19 on 05-28-1998

Page 1

Coefficients of Curve 3

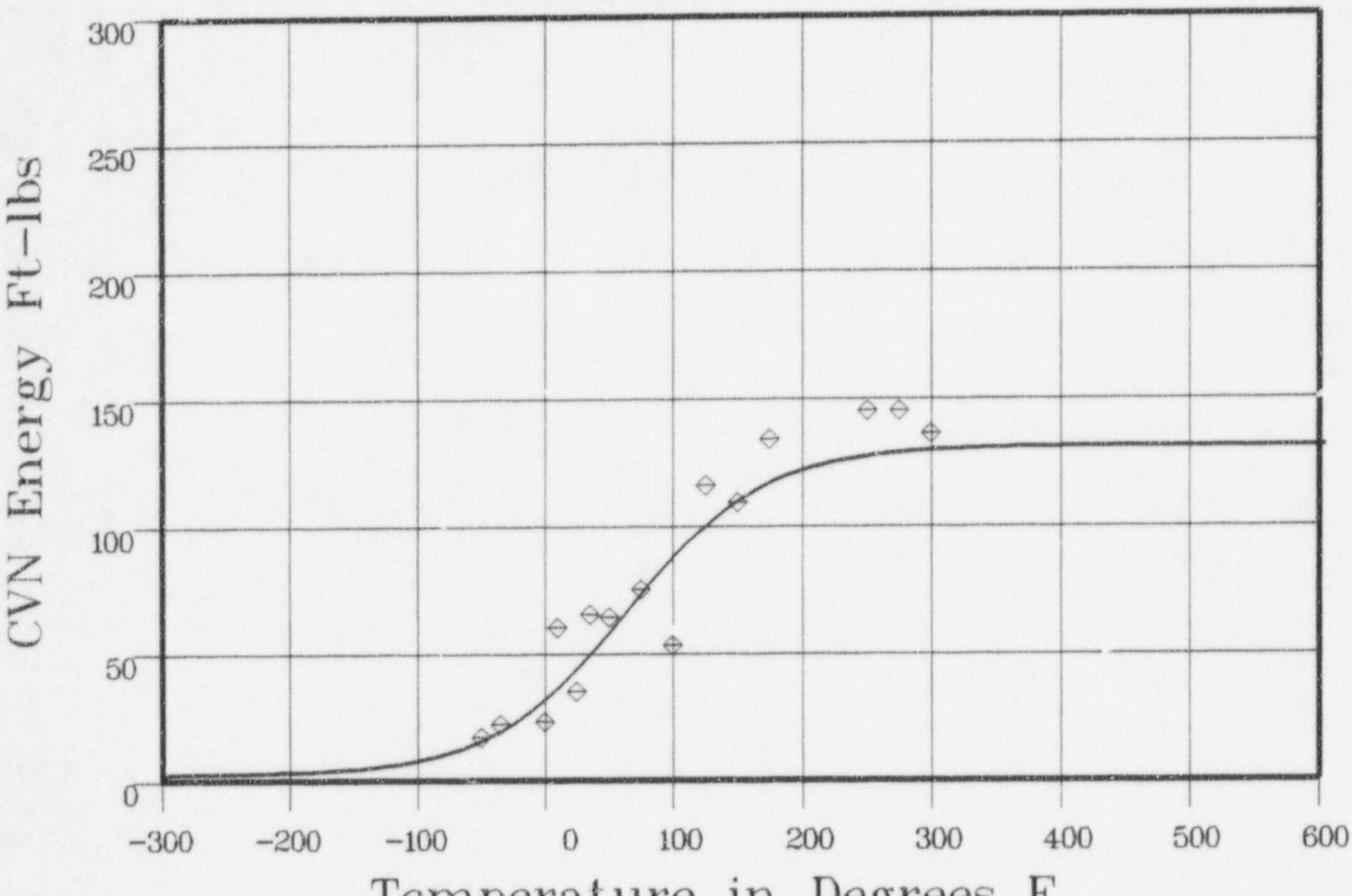
A = 66.59	B = 64.4	C = 106.11	T0 = 59.53

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

Upper Shelf Energy: 131 Fixed Temp. at 30 ft-lbs: -8.9 Temp. at 50 ft-lbs: 31.5 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap: Y Material: PLATE SA533B1 Ori.: LT Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	17	16.7	.29
-35	22	20.75	1.24
0	23	33.83	-10.83
10	60	38.54	21.45
25	35	46.35	-11.35
35	65	51.97	13.02
50	64	60.83	3.16
75	75	75.92	-.92

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

CAPSULE Y (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
100	53	90.03	-37.03
125	116	101.95	14.04
150	109	111.19	-2.19
175	134	117.87	16.12
250	145	127.54	17.45
275	145	128.81	16.18
300	136	129.62	6.37

SUM of RESIDUALS = 47.02

CAPSULE V (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:13:19 on 05-28-1998

Page 1

Coefficients of Curve 4

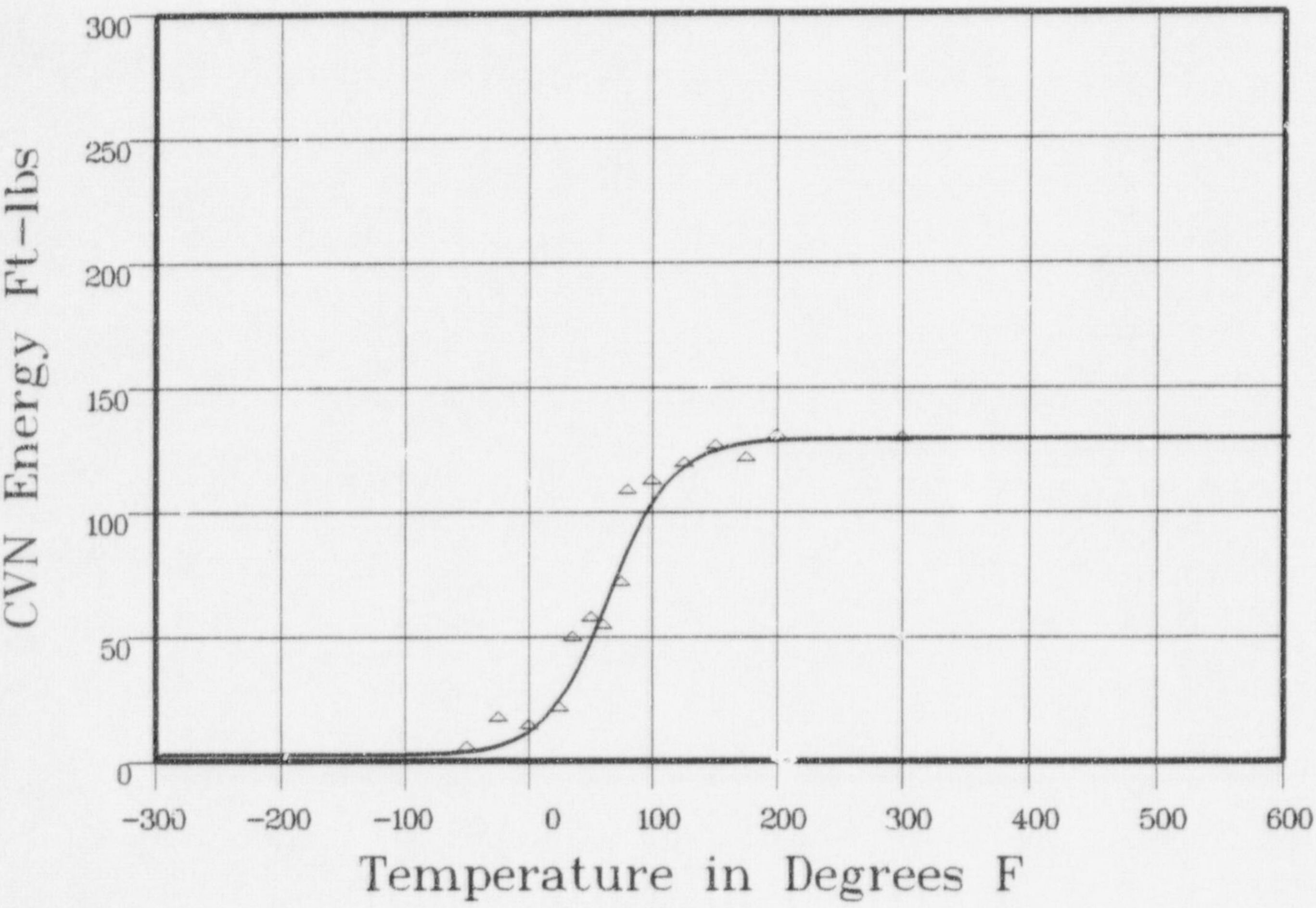
A = 65.59	B = 63.4	C = 51.82	T0 = 60

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

Upper Shelf Energy: 129 Fixed Temp. at 30 ft-lbs: 27 Temp. at 50 ft-lbs: 46.9 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: V Material: PLATE SA533B1 Ori.: LT Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	4	3.99	0
-25	16	6.79	9.2
0	13	13.59	-.59
25	20	28.29	-8.29
35	48	37.18	10.81
50	56	53.51	2.48
60	53	65.59	-12.59

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

CAPSULE V (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
75	70	83.45	-13.45
80	107	88.92	18.07
100	111	106.68	4.31
125	118	119.45	-1.45
150	125	125.18	-.18
175	12[illegible]	127.51	-7.51
200	129	128.43	.56
300	128	128.98	-.98
		SUM of RESIDUALS =	.38

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:42:59 on 05-28-1998

Page 1

Coefficients of Curve 1

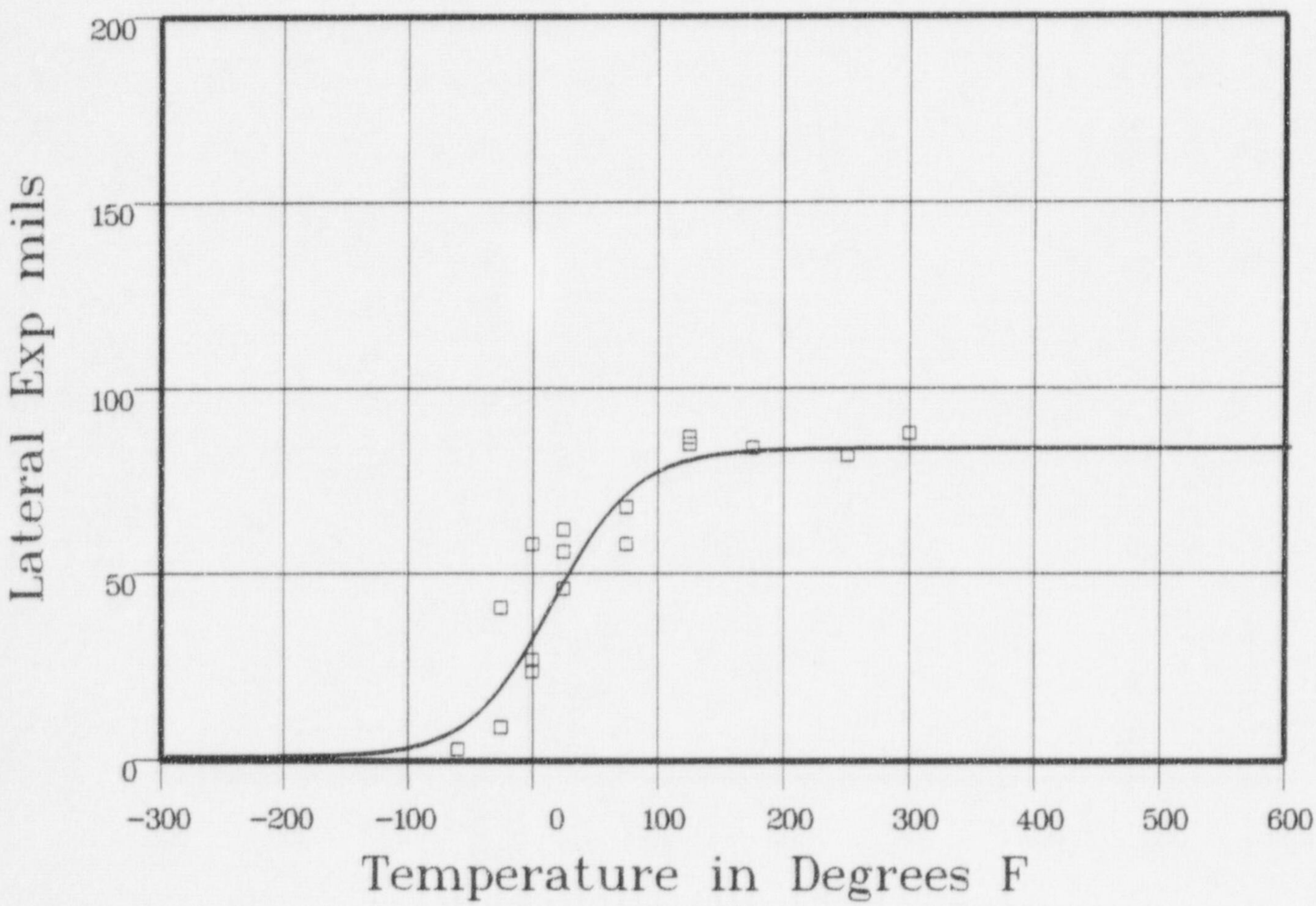
A = 42.43	B = 41.43	C = 66.81	T0 = 11.71

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

Upper Shelf L.E.: 83.86 Temperature at L.E. 35: -.4 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: UNIRR Material: PLATE SA533B1 Ori.: LT Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-60	3	9.67	-6.67
-25	41	21.71	19.28
-25	9	21.71	-12.71
-25	9	21.71	-12.71
0	24	35.24	-11.24
0	27	35.24	-8.24
0	58	35.24	22.75
25	62	50.56	11.43
25	46	50.56	-4.56

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

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
25	56	50.56	5.43
75	68	73.03	-5.03
75	58	73.03	-15.03
125	85	81.16	3.83
125	87	81.16	5.83
175	84	83.24	.75
175	84	83.24	.75
250	82	83.8	-1.8
300	88	83.85	4.14

SUM of RESIDUALS = -3.77

CAPSULE U (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:42:59 on 05-28-1998

Page 1

Coefficients of Curve 2

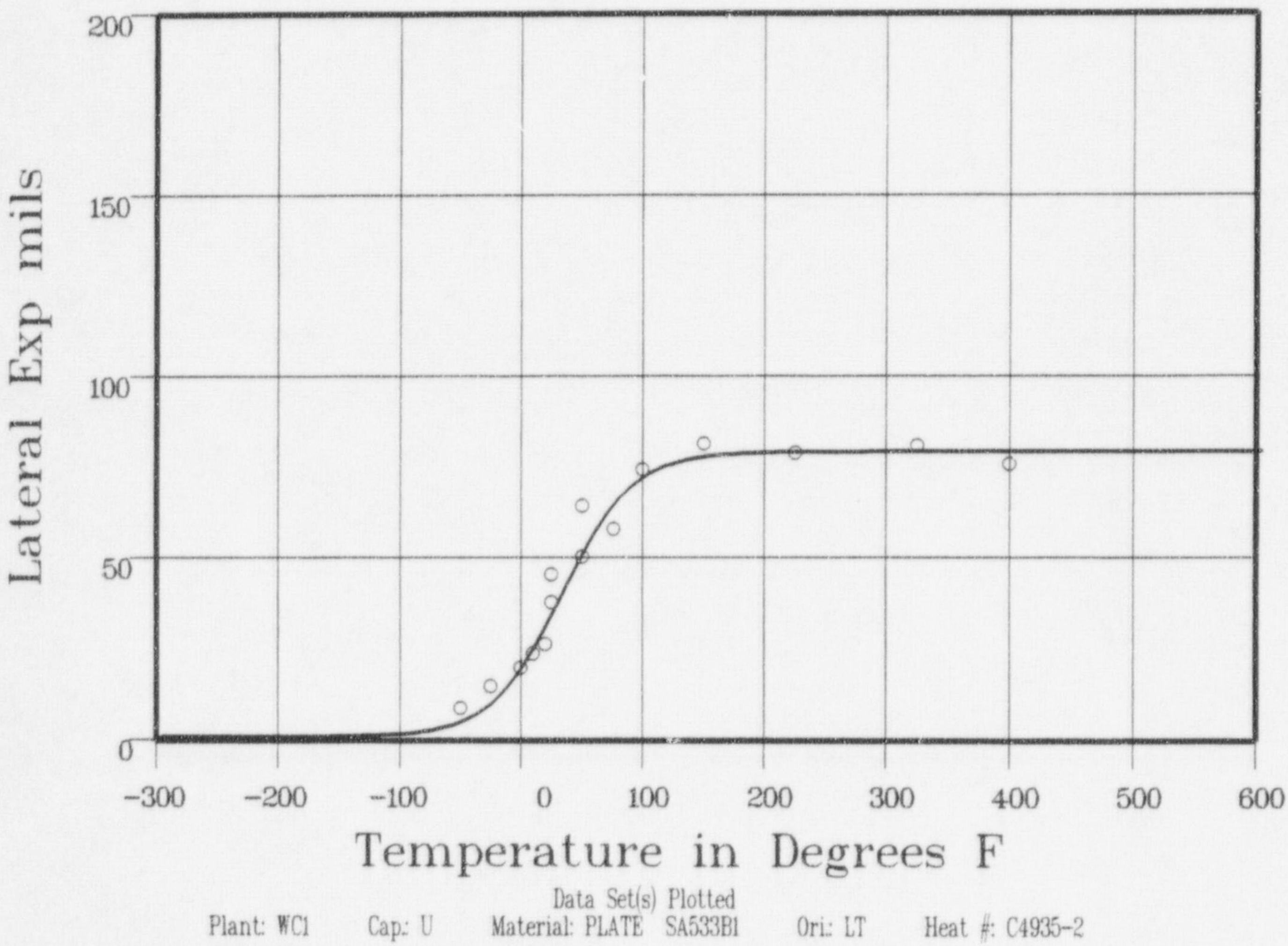
A = 40.12	B = 39.12	C = 57.85	T0 = 29.06

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

Upper Shelf L.E.: 79.25 Temperature at L.E. 35: 21.4 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: U Material: PLATE SA533B1 Ori.: LT Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	9	5.77	3.22
-25	15	11.45	3.54
0	20	21.97	-1.97
10	24	27.68	-3.68
20	26.5	34.04	-7.54
25	38	37.38	.61
25	45.5	37.38	8.11
50	50.5	53.7	-3.2

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

CAPSULE U (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
50	64.5	53.7	10.79
76	58	66.35	-8.35
100	74.5	73.05	1.44
150	81.5	78.07	3.42
225	79	79.16	-.16
325	81	79.25	1.74
400	76	79.25	-3.25

SUM of RESIDUALS = 4.74

CAPSULE Y (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:42:59 on 05-28-1998

Page 1

Coefficients of Curve 3

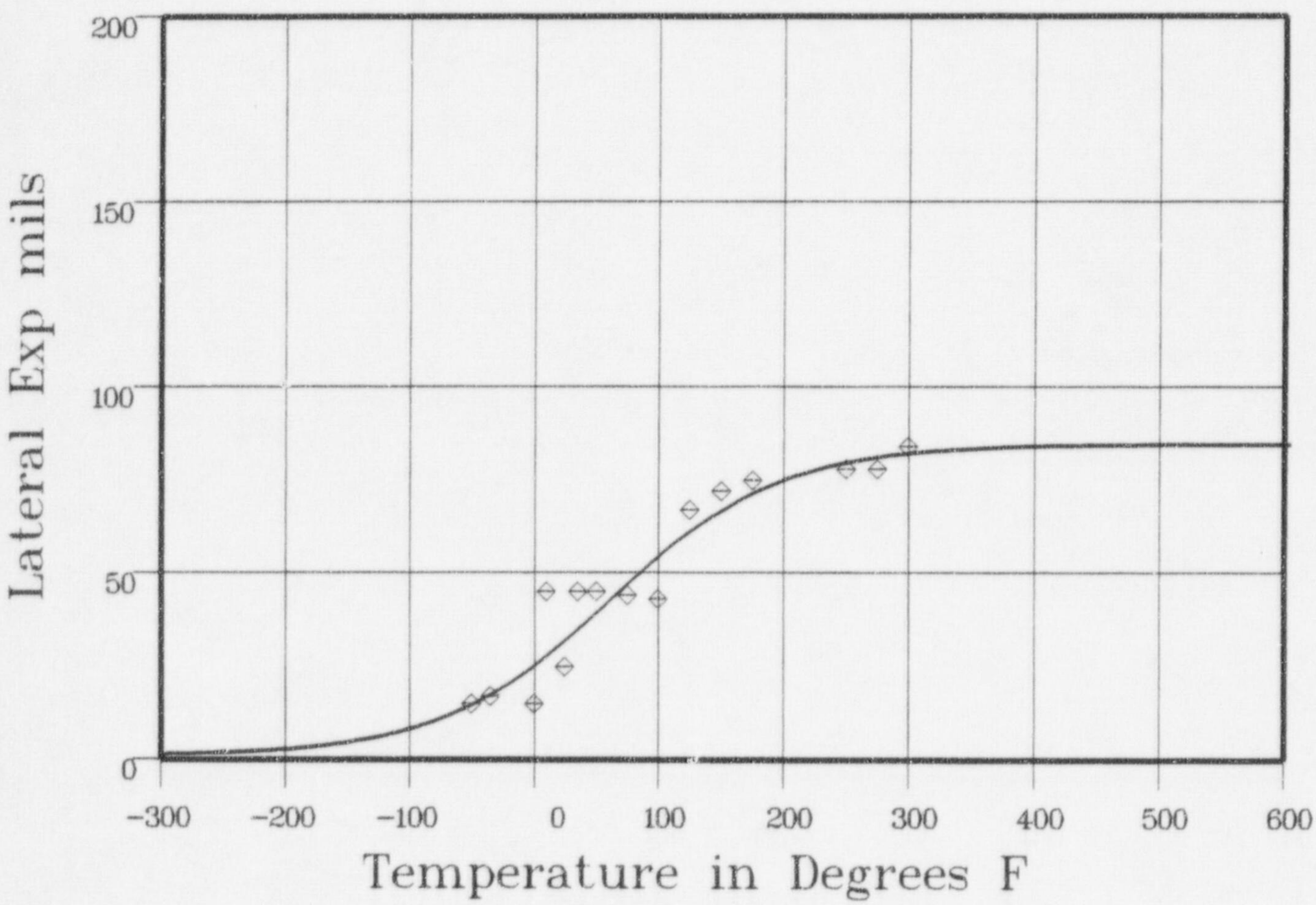
A = 42.82	B = 41.82	C = 136.44	T0 = 56.25

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

Upper Shelf L.E: 84.64 Temperature at L.E. 35: 30.4 Lower Shelf L.E: 1 Fixed

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: Y Material: PLATE SA533B1 Ori.: LT Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	15	15.55	-.55
-35	17	18.38	-1.38
0	15	26.49	-11.49
10	45	29.16	15.83
25	25	33.4	-8.4
35	45	36.35	8.64
50	45	40.9	4.09
75	44	48.53	-4.53

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

CAPSULE Y (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientatior: LT

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
100	43	55.78	-12.78
125	67	62.27	4.72
150	72	67.75	4.24
175	75	72.15	2.84
250	78	80.02	-2.02
275	78	81.38	-3.38
300	84	82.35	1.64

SUM of RESIDUALS = -2.54

CAPSULE V (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:42:59 on 05-28-1998

Page 1

Coefficients of Curve 4

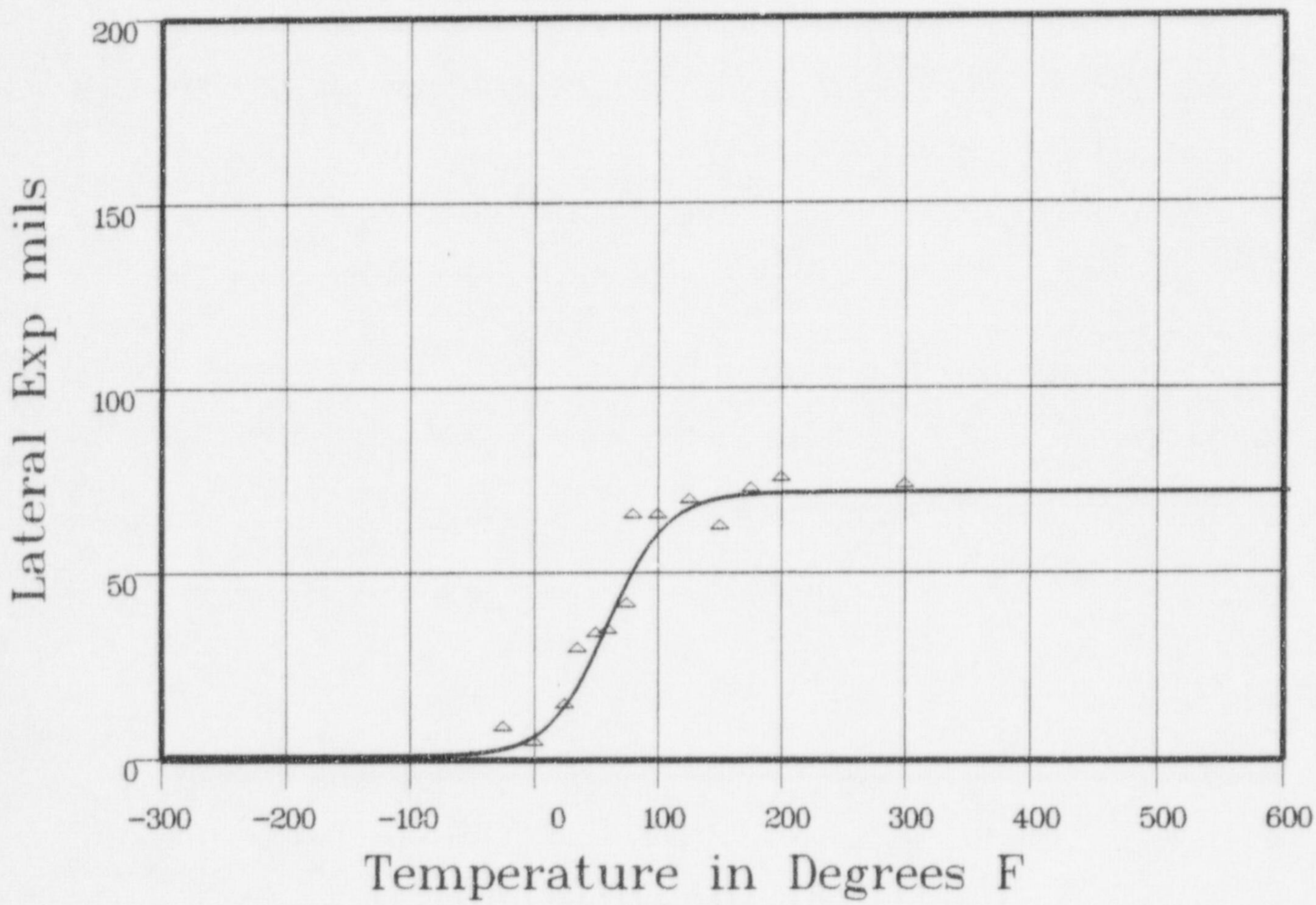
A = 36.44	B = 35.44	C = 48.03	T0 = 55.31

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

Upper Shelf L.E.: 71.88 Temperature at L.E. 35: 53.3 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: V Material: PLATE SA533B1 Ori.: LT Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	0	1.87	-1.87
-25	8	3.41	4.58
0	4	7.44	-3.44
25	14	16.63	-2.63
35	29	22.28	6.71
50	33	32.53	.46
60	34	39.88	-5.88

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

CAPSULE V (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
75	41	50.2	-9.2
80	65	53.2	11.79
100	65	62.34	2.65
125	69	68.19	.8
150	62	70.53	-8.53
175	72	71.4	.59
200	75	71.71	3.28
300	73	71.88	1.11

SUM of RESIDUALS = .43

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:50:13 on 05-28-1998

Page 1

Coefficients of Curve 1

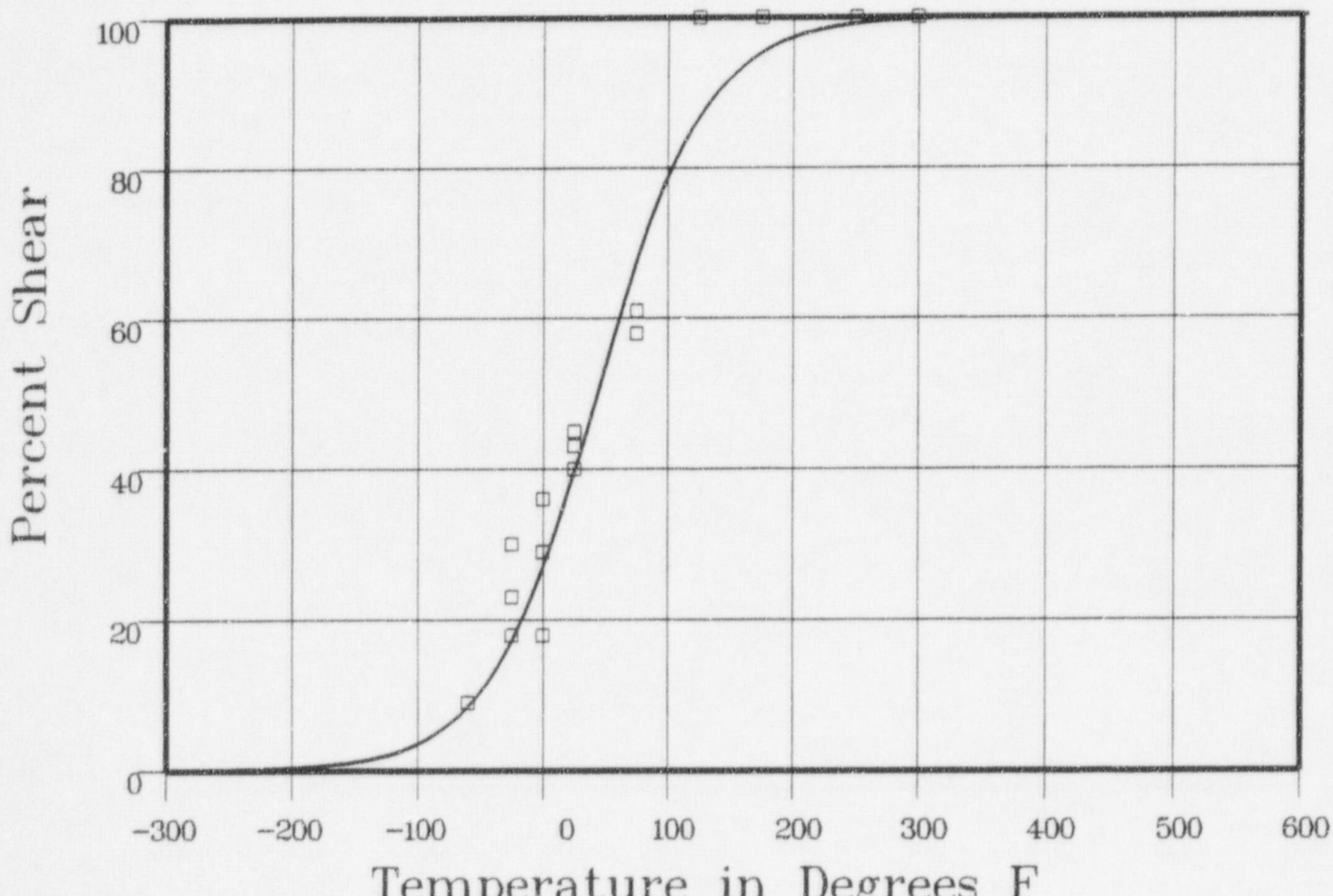
A = 50	B = 50	C = 86.99	T0 = 38.43

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

Temperature at 50% Shear: 38.4

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: UNIRR Material: PLATE SA533B1 Ori.: LT Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-60	9	9.42	-.42
-25	30	18.87	11.12
-25	18	18.87	-.87
-25	23	18.87	4.12
0	18	29.24	-11.24
0	29	29.24	-.24
0	36	29.24	6.75
25	45	42.33	2.66
25	40	42.33	-2.33

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

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25	43	42.33	.66
75	61	69.85	-8.85
75	58	69.85	-11.85
125	100	87.97	12.02
125	100	87.97	12.02
175	100	95.84	4.15
175	100	95.84	4.15
250	100	99.23	.76
300	100	99.75	.24

SUM of RESIDUALS = 22.87

CAPSULE U (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:50:13 on 05-28-1998

Page 1

Coefficients of Curve 2

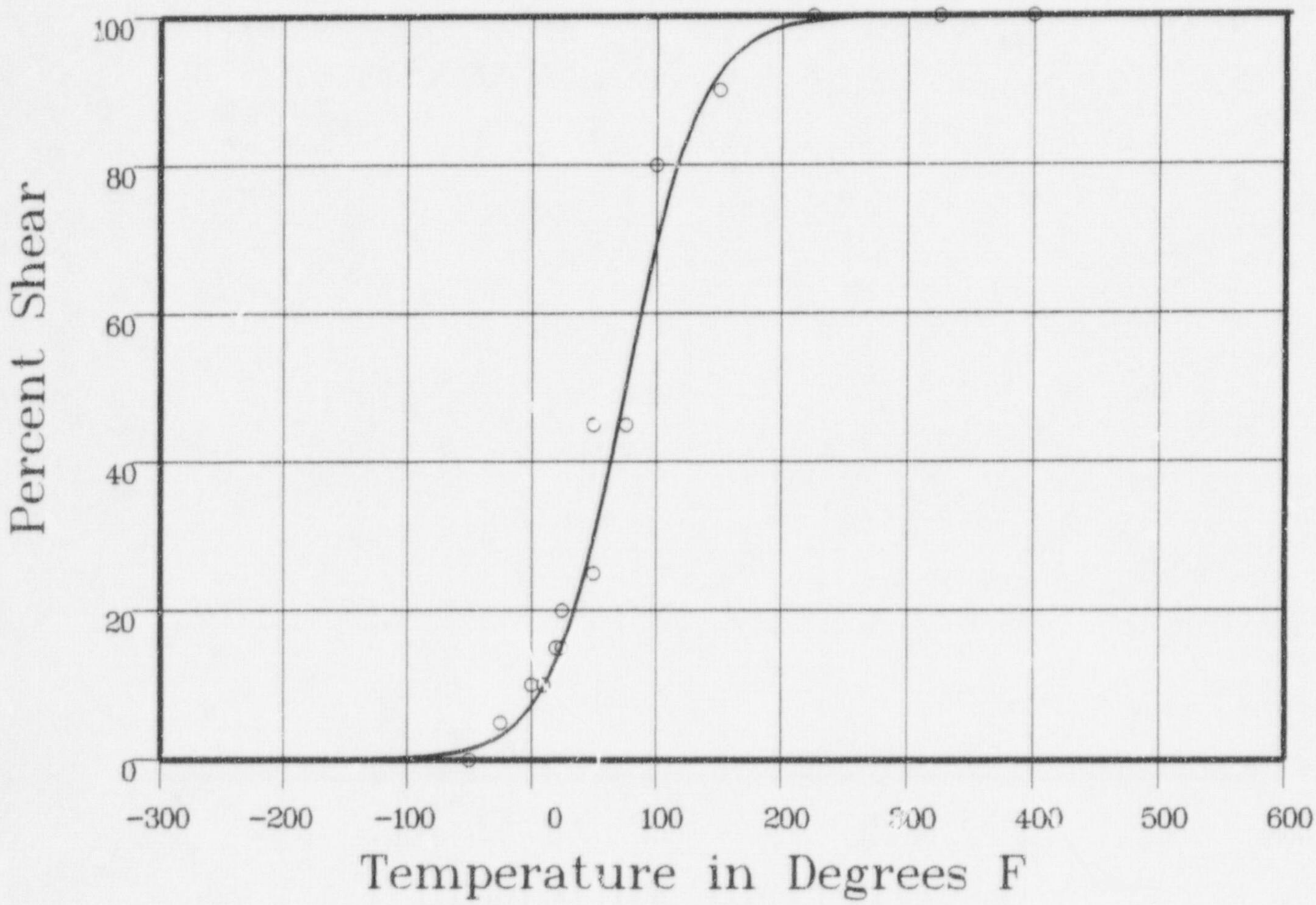
A = 50	B = 50	C = 59.5	T0 = 71.2

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

Temperature at 50% Shear: 71.2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: U Material: PLATE SA533B1 Ori.: LT Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	0	1.67	-1.67
-25	5	3.79	1.2
0	10	8.36	1.63
10	10	11.33	-1.33
20	15	15.17	-.17
25	15	17.46	-2.46
25	20	17.46	2.53
50	25	32.89	-7.89

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

CAPSULE U (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50	45	32.89	12.1
76	45	54.02	-9.02
100	80	72.46	7.53
150	90	93.39	-3.39
225	100	99.43	.56
325	100	99.98	.01
400	100	99.99	0

SUM of RESIDUALS = -.36

CAPSULE Y (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:50:13 on 05-28-1998

Page 1

Coefficients of Curve 3

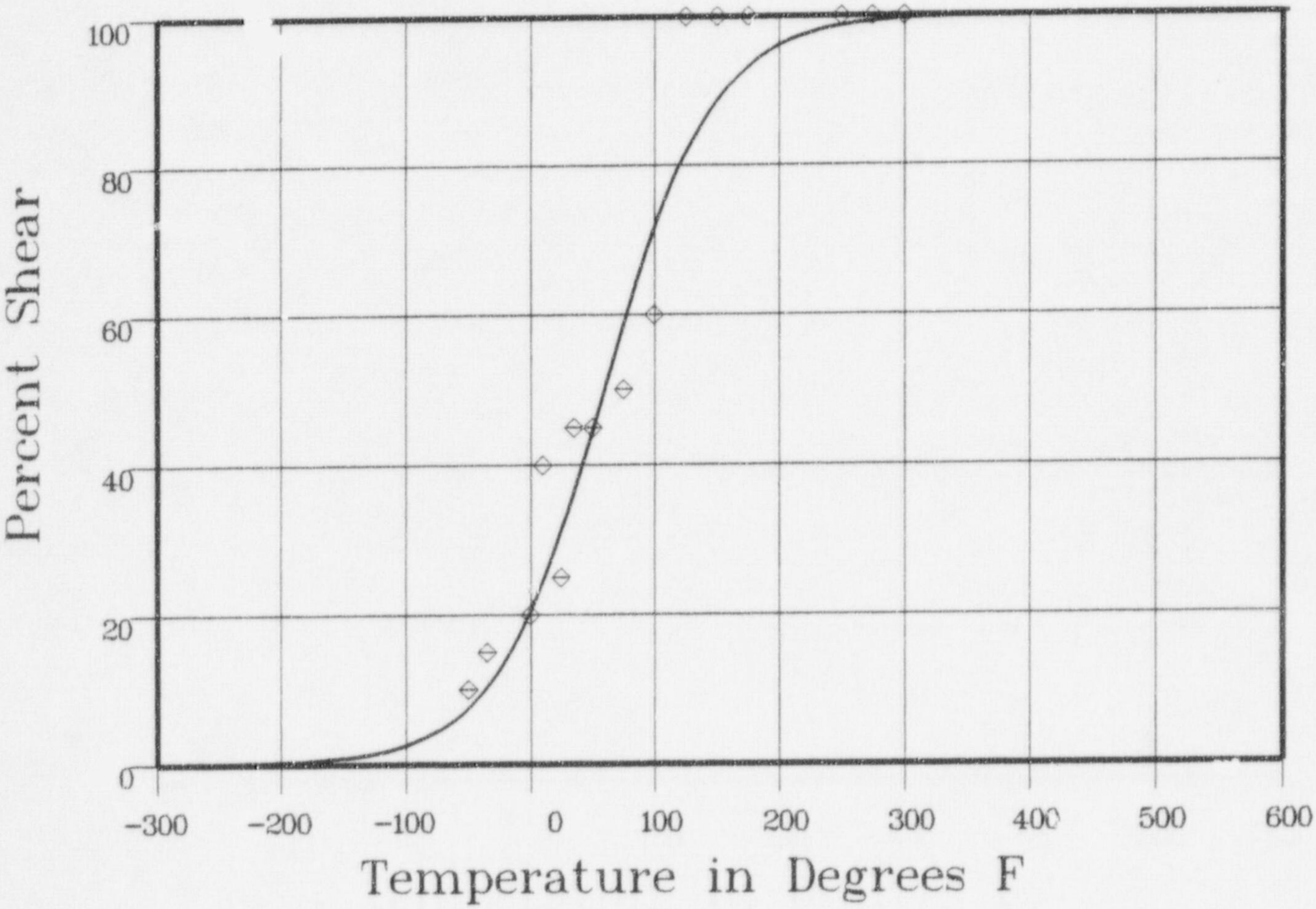
A = 50	B = 50	C = 87.61	T0 = 54.84

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

Temperature at 50% Shear: 54.8

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: Y Material: PLATE SA533B1 Ori.: LT Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	10	8.36	1.63
-35	15	11.39	3.6
0	20	22.23	-2.23
10	40	26.43	13.56
25	25	33.59	-8.59
35	45	38.86	6.13
50	45	47.23	-2.23
75	50	61.3	-11.3

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

CAPSULE Y (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100	60	73.7	-13.7
125	100	83.22	16.77
150	100	89.77	10.22
175	100	93.95	6.04
250	100	98.85	1.14
275	100	99.34	.65
300	100	99.63	.36

SUM of RESIDUALS = 22.07

CAPSULE V (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:50:13 on 05-28-1998

Page 1

Coefficients of Curve 4

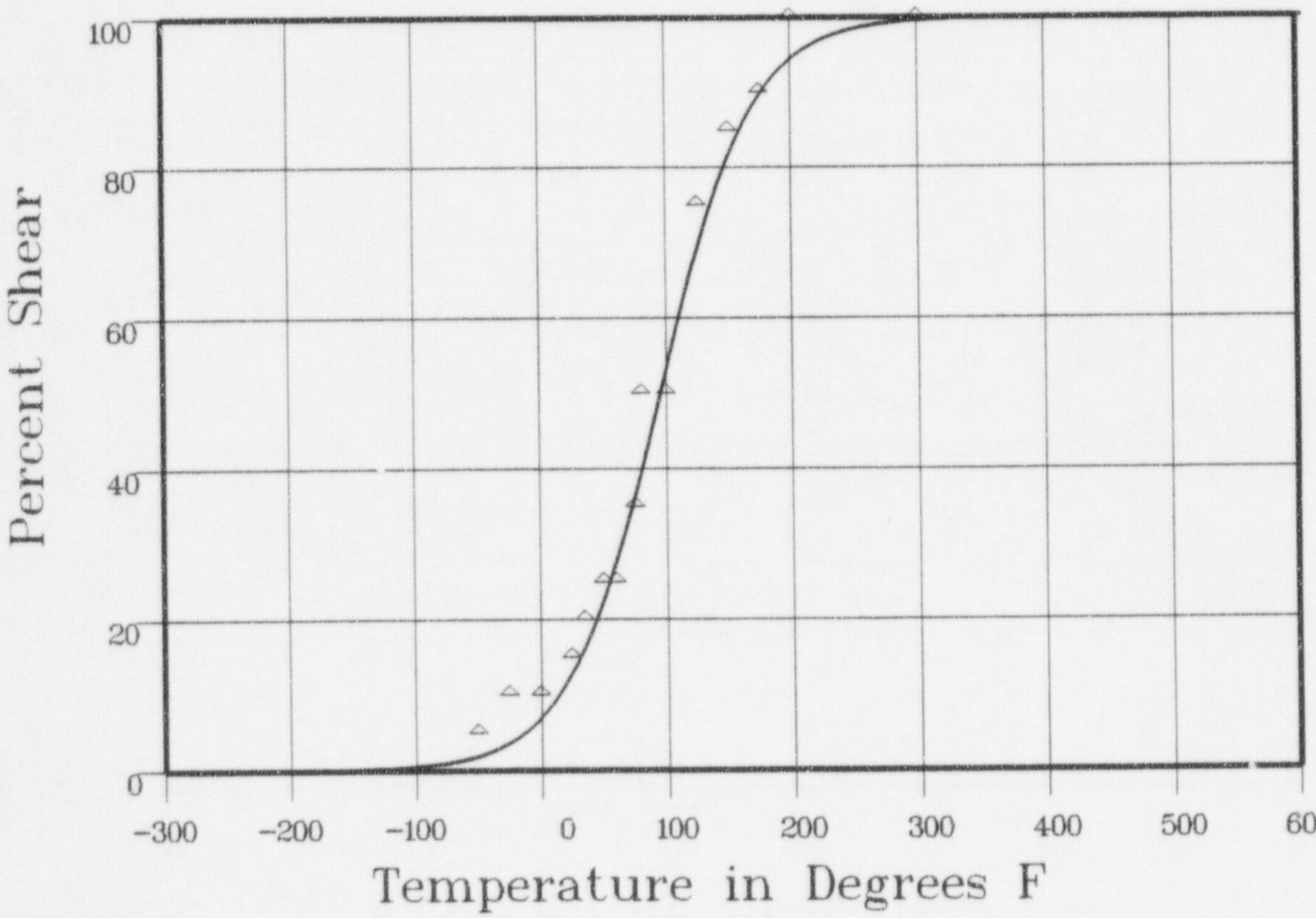
A = 50	B = 50	C = 73.61	T0 = 90.82

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

Temperature at 50% Shear: 90.8

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: V Material: PLATE SA533B1 Ori.: LT Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	5	2.13	2.86
-25	10	4.12	5.87
0	10	7.81	2.18
25	15	14.32	.67
35	20	17.99	2
50	25	24.8	.19
60	25	30.2	-5.2

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

CAPSULE V (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: LT

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
75	35	39.41	-4.41
80	50	42.7	7.29
100	50	56.2	-6.2
125	75	71.67	3.32
150	85	83.31	1.68
175	90	90.77	-.77
200	100	95.1	4.89
300	100	99.66	.33

SUM of RESIDUALS = 14.72

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:30:17 on 05-28-1998

Page 1

Coefficients of Curve 1

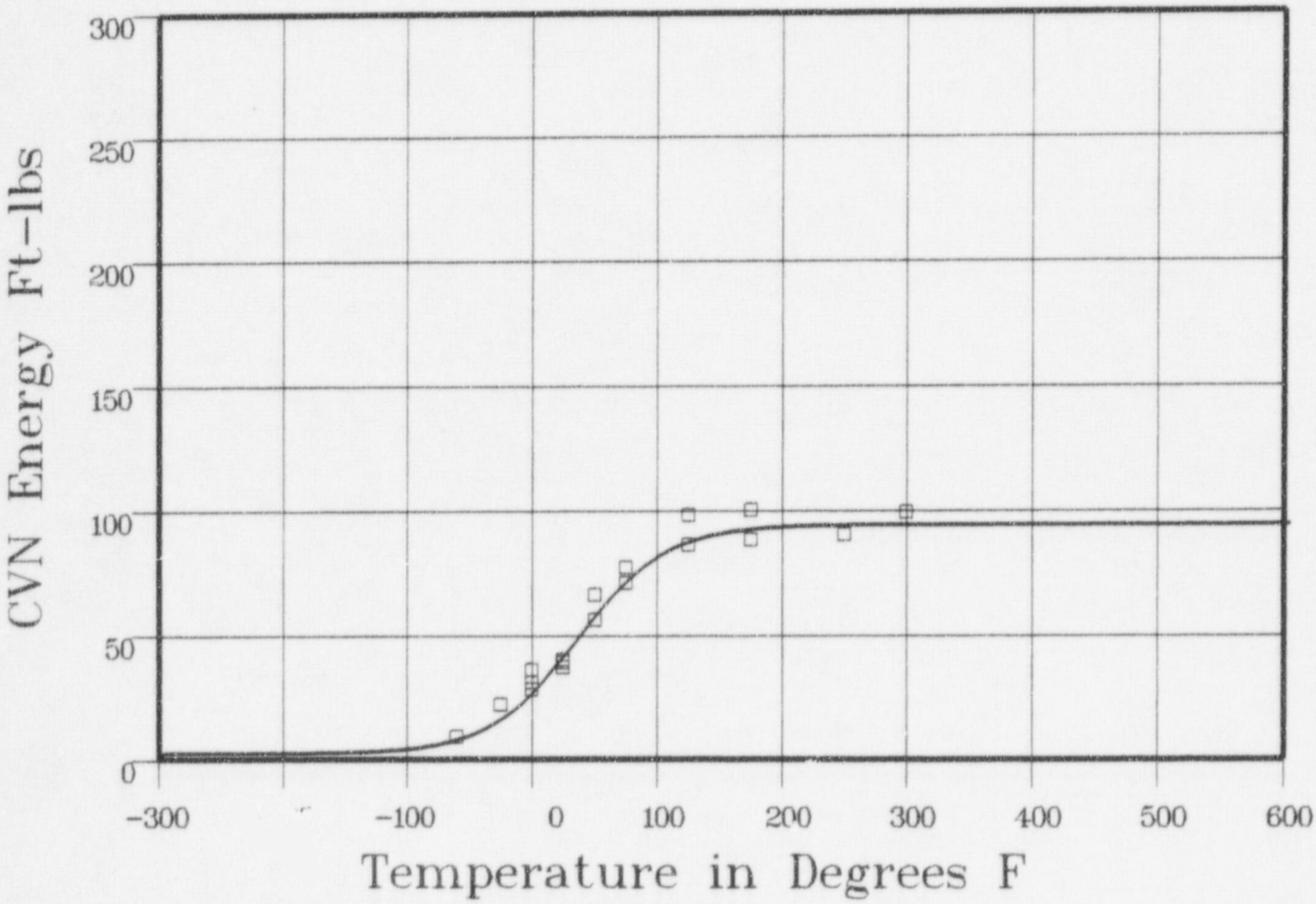
A = 48.09	B = 45.9	C = 70.51	T0 = 31.4

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

Upper Shelf Energy: 94 Fixed Temp. at 30 ft-lbs: 2 Temp. at 50 ft-lbs: 34.3 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: UNIRR Material: PLATE SA533B1 Ori.: TL Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-60	9	8.59	.4
-25	22	17.62	4.37
0	31	28.91	2.08
0	36	28.91	7.08
0	28	28.91	-.91
25	39	43.94	-4.94
25	40	43.94	-3.94
25	37	43.94	-6.94
50	56	59.92	-3.92

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

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	66	59.92	6.07
75	77	73.33	3.66
75	71	73.33	-2.33
125	86	87.96	-1.96
125	98	87.96	10.03
175	88	92.46	-4.46
175	100	92.46	7.53
250	90	93.81	-3.81
300	99	93.95	5.04

SUM of RESIDUALS = 13.06

CAPSULE U (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:30:17 on 05-28-1998

Page 1

Coefficients of Curve 2

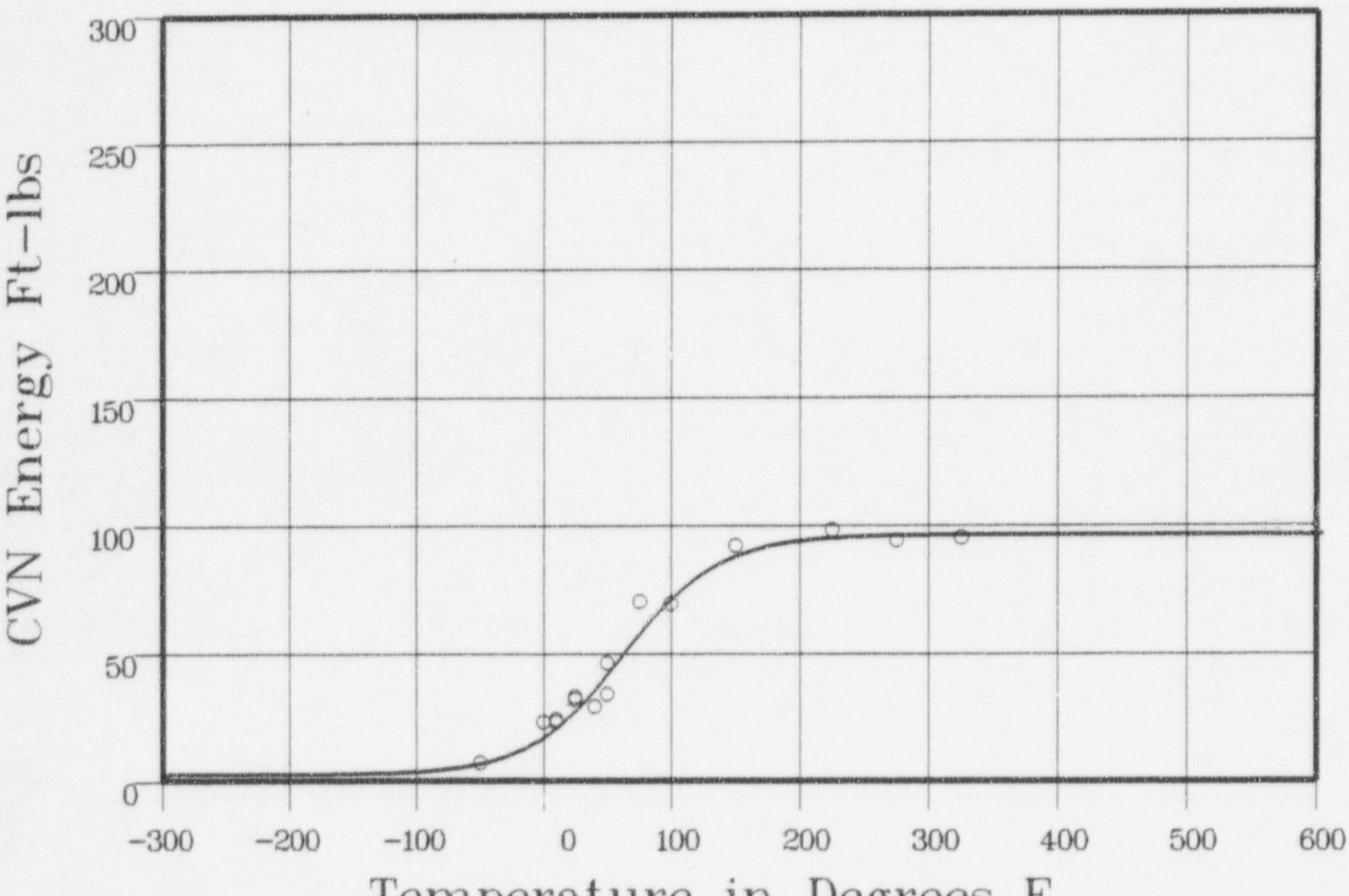
A = 49.09	B = 46.9	C = 74.76	T0 = 58.12

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

Upper Shelf Energy: 96 Fixed Temp. at 30 ft-lbs: 25.8 Temp. at 50 ft-lbs: 59.5 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	7	7.12	-.12
0	23	18.55	4.44
10	23	22.48	.51
10	24	22.48	1.51
25	32	29.58	2.41
25	33	29.58	3.41
40	29	37.94	-8.94
50	46	44.02	1.97

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

CAPSULE U (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	34	44.02	-10.02
76	70	60.1	9.89
100	69	72.92	-3.92
150	92	88.6	3.39
225	98	94.93	3.06
275	94	95.71	-1.71
325	95	95.92	-.92

SUM of RESIDUALS = 4.96

CAPSULE Y (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:30:17 on 05-28-1998

Page 1

Coefficients of Curve 3

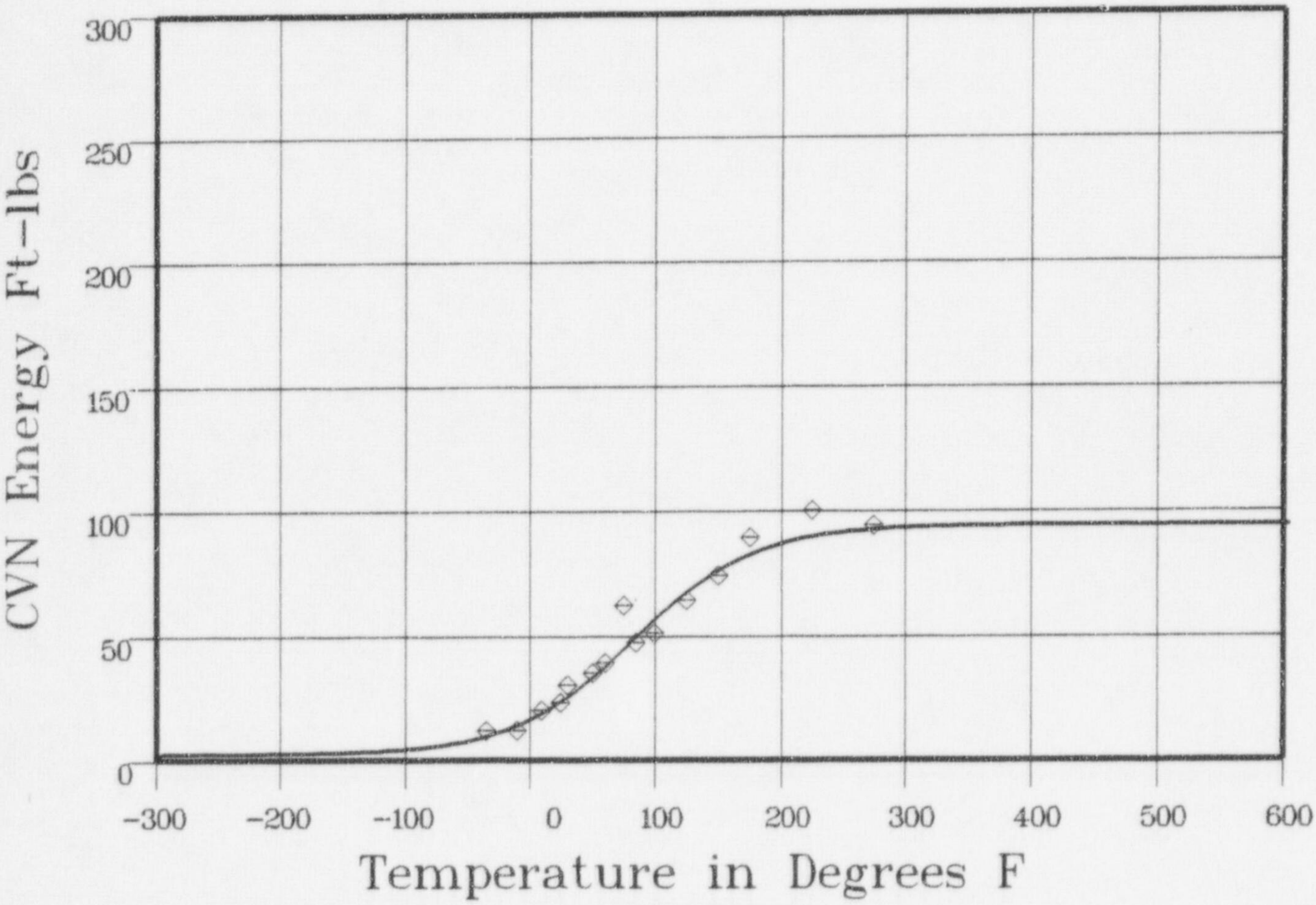
A = 48.09	B = 45.9	C = 96.2	T0 = 77.5

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

Upper Shelf Energy: 94 Fixed   Temp. at 30 ft-lbs: 37.3   Temp. at 50 ft-lbs: 81.4   Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1   Heat Number: C4935-2   Orientation: TL

Capsule: Y   Total Fluence:



Data Set(s) Plotted

Plant: WC1   Cap.: Y   Material: PLATE SA533B1   Ori.: TL   Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-35	12	10.27	1.72
-10	12	15	-3
10	20	20.3	-.3
25	23	25.27	-2.27
30	30	27.11	2.88
50	35	35.32	-.32
60	39	39.83	-.83
75	62	46.9	15.09

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

CAPSULE Y (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
85	47	51.66	-4.66
100	51	58.63	-7.63
125	64	69.08	-5.08
150	74	77.34	-3.34
175	89	83.31	5.68
225	100	89.91	10.08
275	94	92.51	1.48

SUM of RESIDUALS = 9.48

CAPSULE V (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:30:17 on 05-28-1998

Page 1

Coefficients of Curve 4

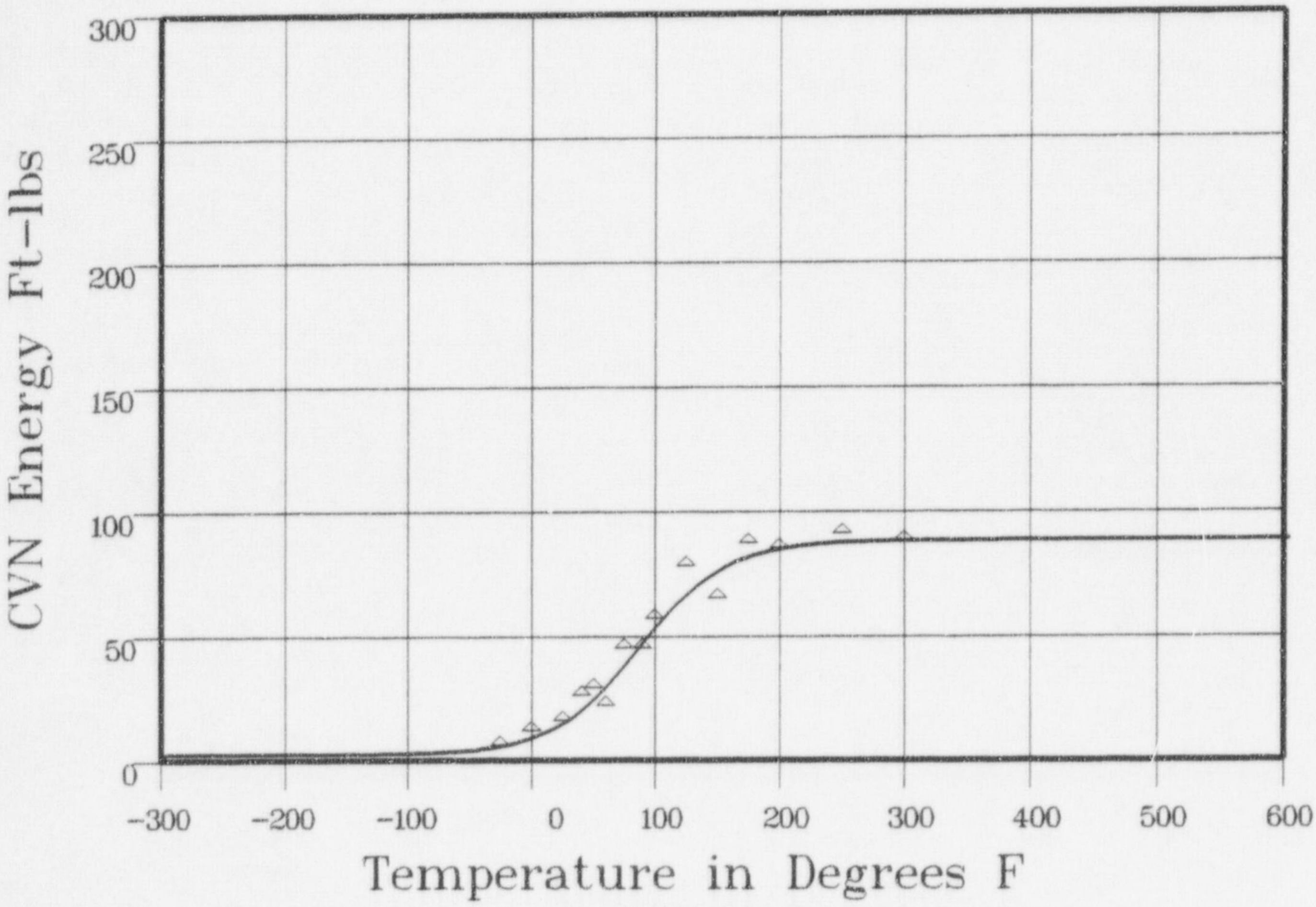
A = 45.09	B = 42.9	C = 70.59	T0 = 82.49

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

Upper Shelf Energy: 88 Fixed Temp. at 30 ft-lbs: 56.5 Temp. at 50 ft-lbs: 90.5 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: V Material: PLATE SA533B1 Ori.: TL Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	6	6.09	-.09
0	12	9.75	2.24
25	16	16.26	-.26
40	26	21.99	4
50	29	26.63	2.36
60	22	31.87	-9.87
75	45	40.56	4.43

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

CAPSULE V (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
90	45	49.64	-4.64
100	57	55.52	1.47
125	78	68.2	9.79
150	65	76.95	-11.95
175	87	82.18	4.81
200	85	85.03	-.03
250	91	87.26	3.73
300	88	87.81	.18

SUM of RESIDUALS = 6.19

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:01:30 on 05-28-1998

Page 1

Coefficients of Curve 1

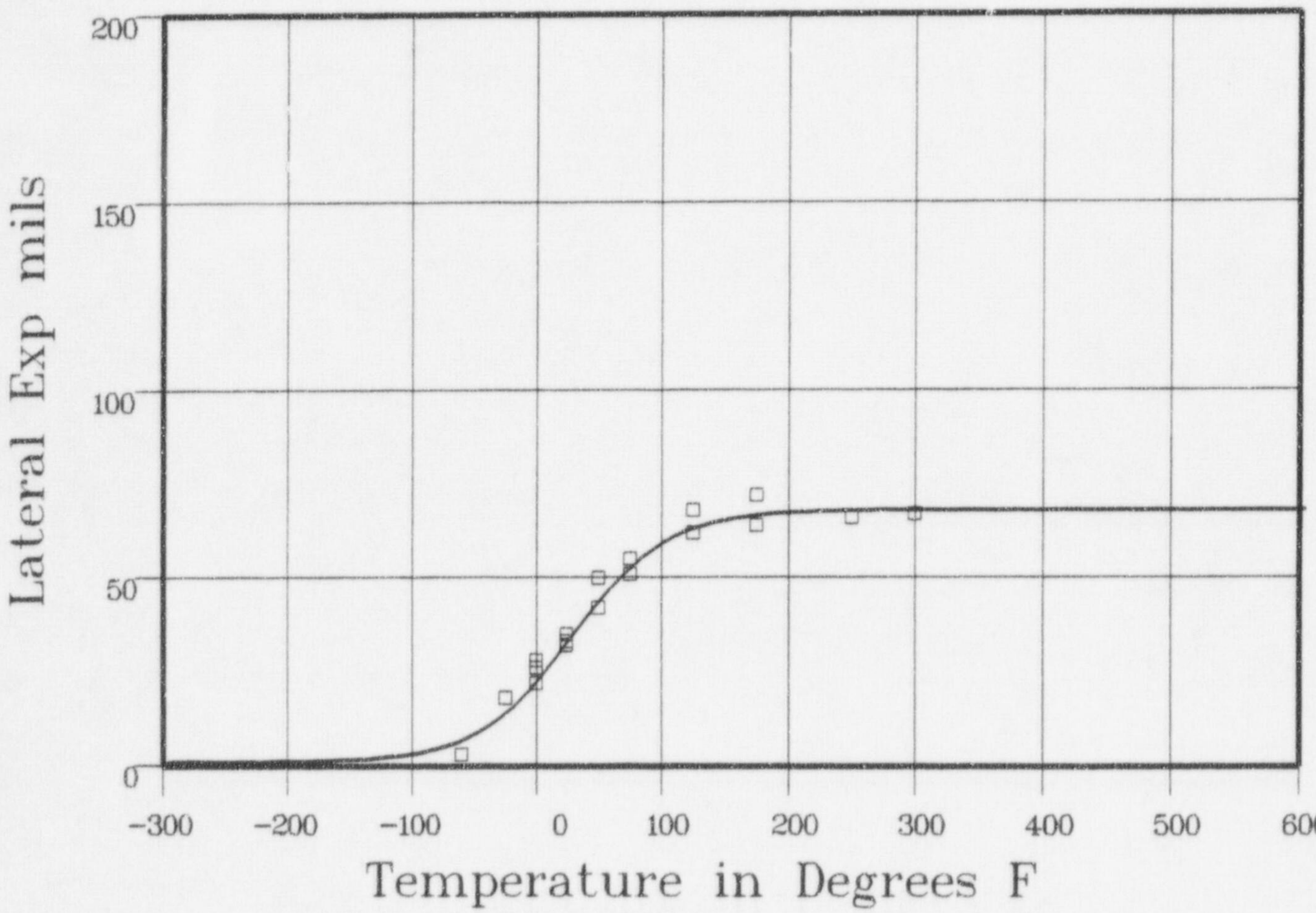
A = 34.52	B = 33.52	C = 75.94	T0 = 24.37

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

Upper Shelf L.E.: 68.05 Temperature at L.E. 35: 25.4 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: UNIRR Material: PLATE SA533B1 Ori.: TL Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-60	3	7.55	-4.55
-25	18	15.35	2.64
0	26	24.11	1.88
0	28	24.11	3.88
0	22	24.11	-2.11
25	35	34.8	.19
25	32	34.8	-2.8
25	33	34.8	-1.8
50	42	45.42	-3.42

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

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
50	50	45.42	4.57
75	55	54.06	.93
75	51	54.06	-3.06
125	62	63.62	-1.62
125	68	63.62	4.37
175	64	66.8	-2.8
175	72	66.8	5.19
250	66	67.87	-1.87
300	67	68	-1

SUM of RESIDUALS = -1.4

CAPSULE U (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:01:30 on 05-28-1998

Page 1

Coefficients of Curve 2

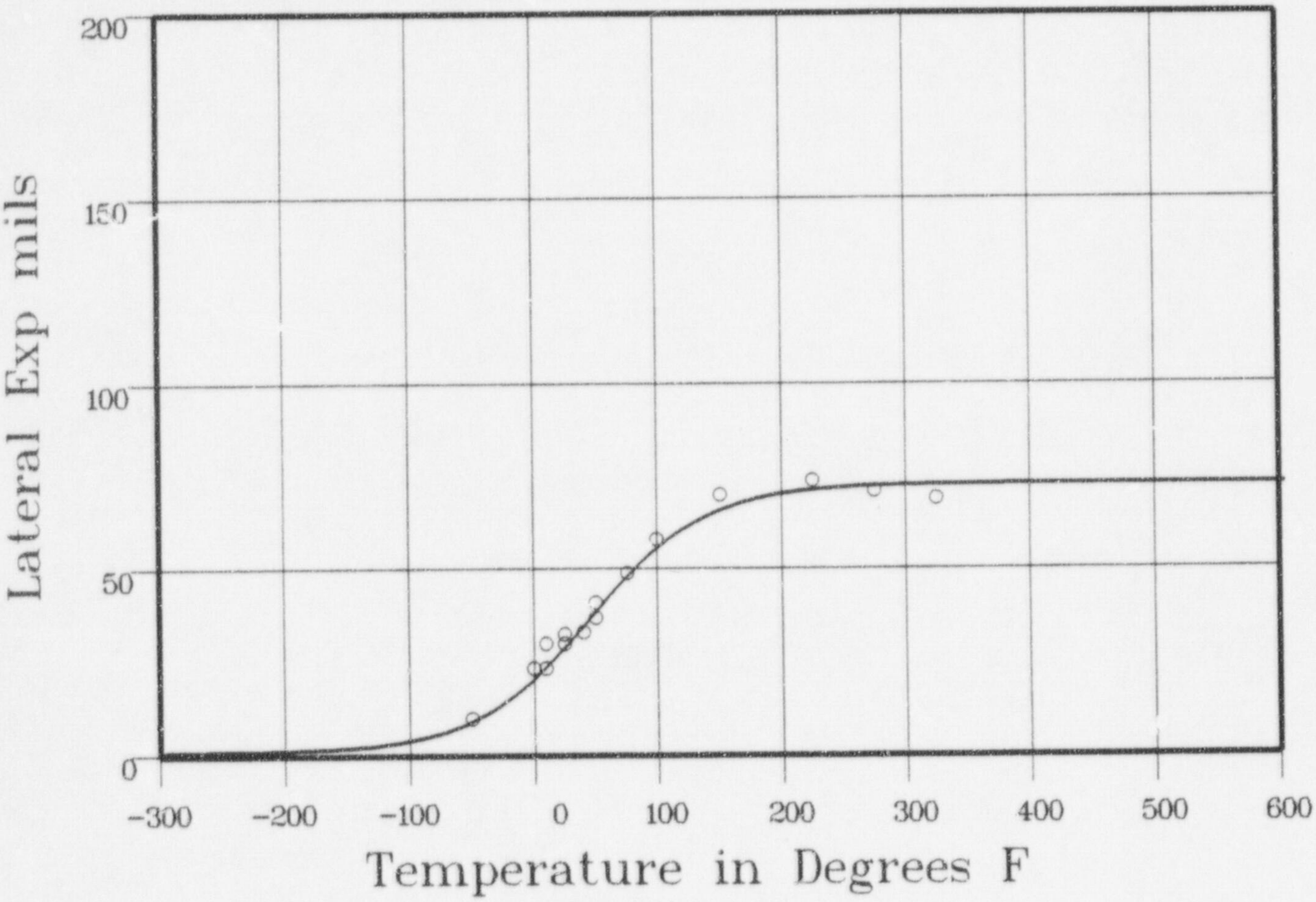
A = 36.94	B = 35.94	C = 93.37	T0 = 41.41

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

Upper Shelf L.E.: 72.88 Temperature at L.E. 35: 36.3 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	10	9.89	.1
0	23.5	21.96	1.53
10	23.5	25.28	-1.78
10	30	25.28	4.71
25	30	30.68	-.68
25	32.5	30.68	1.81
40	33	36.39	-3.39
50	41	40.23	.76

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

CAPSULE U (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
50	37	40.23	-3.23
76	49	49.67	-.67
100	58	56.93	1.06
150	70	66.48	3.51
225	74	71.5	2.49
275	71	72.4	-1.4
325	69	72.72	-3.72
		SUM of RESIDUALS =	1.09

CAPSULE Y (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:01:30 on 05-28-1998

Page 1

Coefficients of Curve 3

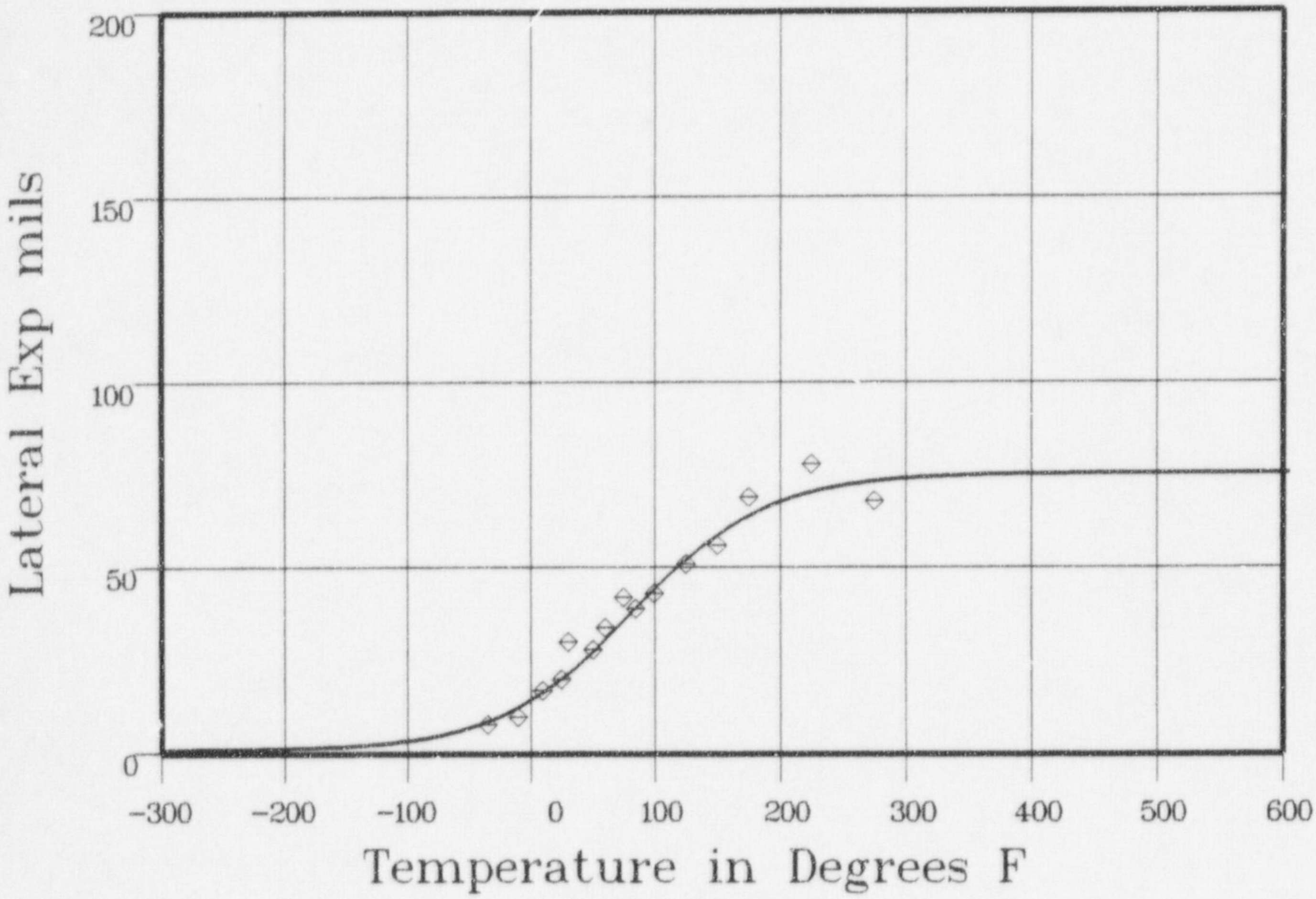
A = 38.24	B = 37.24	C = 108.84	T0 = 77.34

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

Upper Shelf L.E.: 75.48 Temperature at L.E. 35: 67.8 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: Y Material: PLATE SA533B1 Ori.: TL Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-35	8	9.38	-1.38
-10	10	13.46	-3.46
10	17	17.75	-.75
25	20	21.59	-1.59
30	30	22.99	7
50	28	29.07	-1.07
60	34	32.35	1.64
75	42	37.44	4.55

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

CAPSULE Y (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
85	39	40.85	-1.85
100	43	45.88	-2.88
125	51	53.58	-2.58
150	56	59.96	-3.96
175	69	64.86	4.13
225	78	70.85	7.14
275	68	73.56	-5.56

SUM of RESIDUALS = -.65

CAPSULE V (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:01:30 on 05-28-1998

Page 1

Coefficients of Curve 4

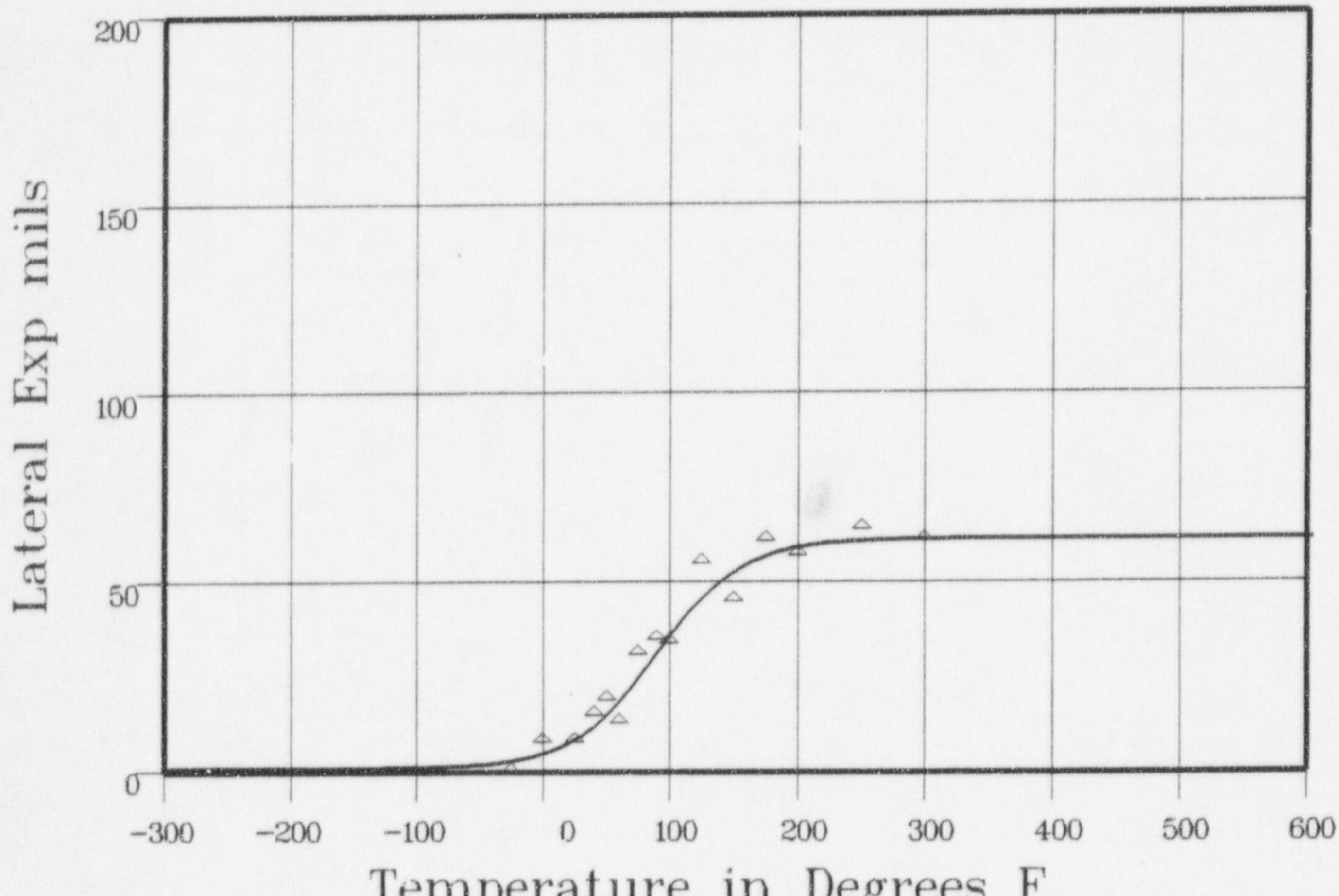
A = 31.2	B = 30.2	C = 67.2	T0 = 85.31

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

Upper Shelf L.E.: 61.41   Temperature at L.E. 35: 93.7   Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1   Heat Number: C4935-2   Orientation: TL

Capsule: V   Total Fluence:



Data Set(s) Plotted

Plant: WC1   Cap.: V   Material: PLATE SA533B1   Ori.: TL   Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	0	3.18	-3.18
0	8	5.42	2.57
25	8	9.6	-1.6
40	15	13.45	1.54
50	19	16.65	2.34
60	13	20.34	-7.34
75	31	26.61	4.38

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

CAPSULE V (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
90	35	33.31	1.68
100	34	37.7	-3.7
125	55	47.22	7.77
150	45	53.72	-8.72
175	61	57.5	3.49
200	57	59.49	-2.49
250	64	60.97	3.02
300	61	61.31	-.31

SUM of RESIDUALS = -.53

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:06:59 on 05-28-1998

Page 1

Coefficients of Curve 1

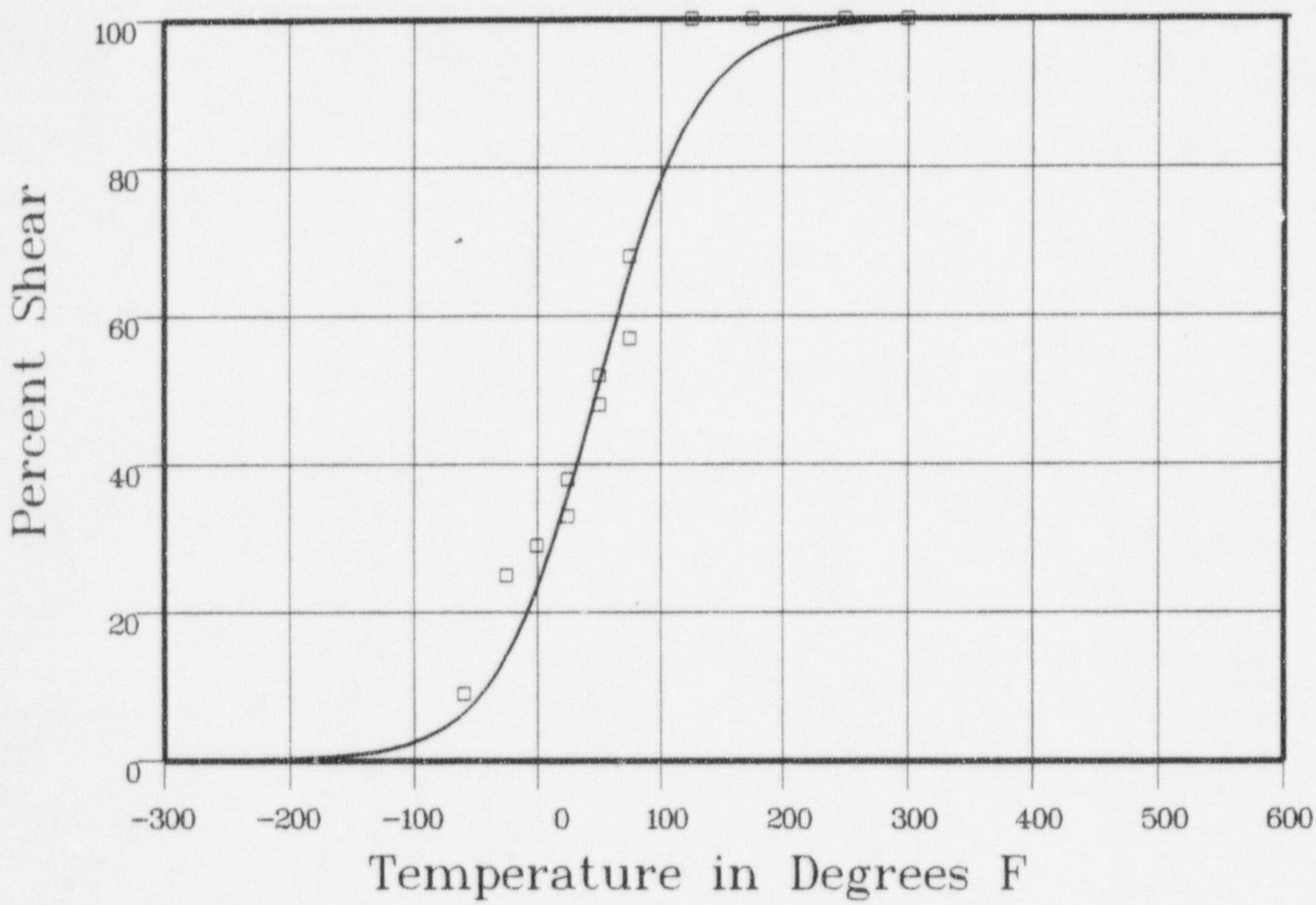
A = 50	B = 50	C = 81.28	T0 = 43.59

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

Temperature at 50% Shear: 43.5

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: UNIRR Material: PLATE SA533B1 Ori.: TL Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-60	9	7.24	1.75
-25	25	15.6	9.39
0	29	25.49	3.5
0	29	25.49	3.5
0	29	25.49	3.5
25	38	38.75	-.75
25	38	38.75	-.75
25	33	38.75	-5.75
50	48	53.93	-5.93

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

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50	52	53.93	-1.93
75	68	68.41	-.41
75	57	68.41	-11.41
125	100	88.11	11.88
125	100	88.11	11.88
175	100	96.2	3.79
175	100	96.2	3.79
250	100	99.38	.61
300	100	99.81	.18

SUM of RESIDUALS = 26.87

CAPSULE U (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:06:59 on 05-28-1998
Page 1
Coefficients of Curve 2

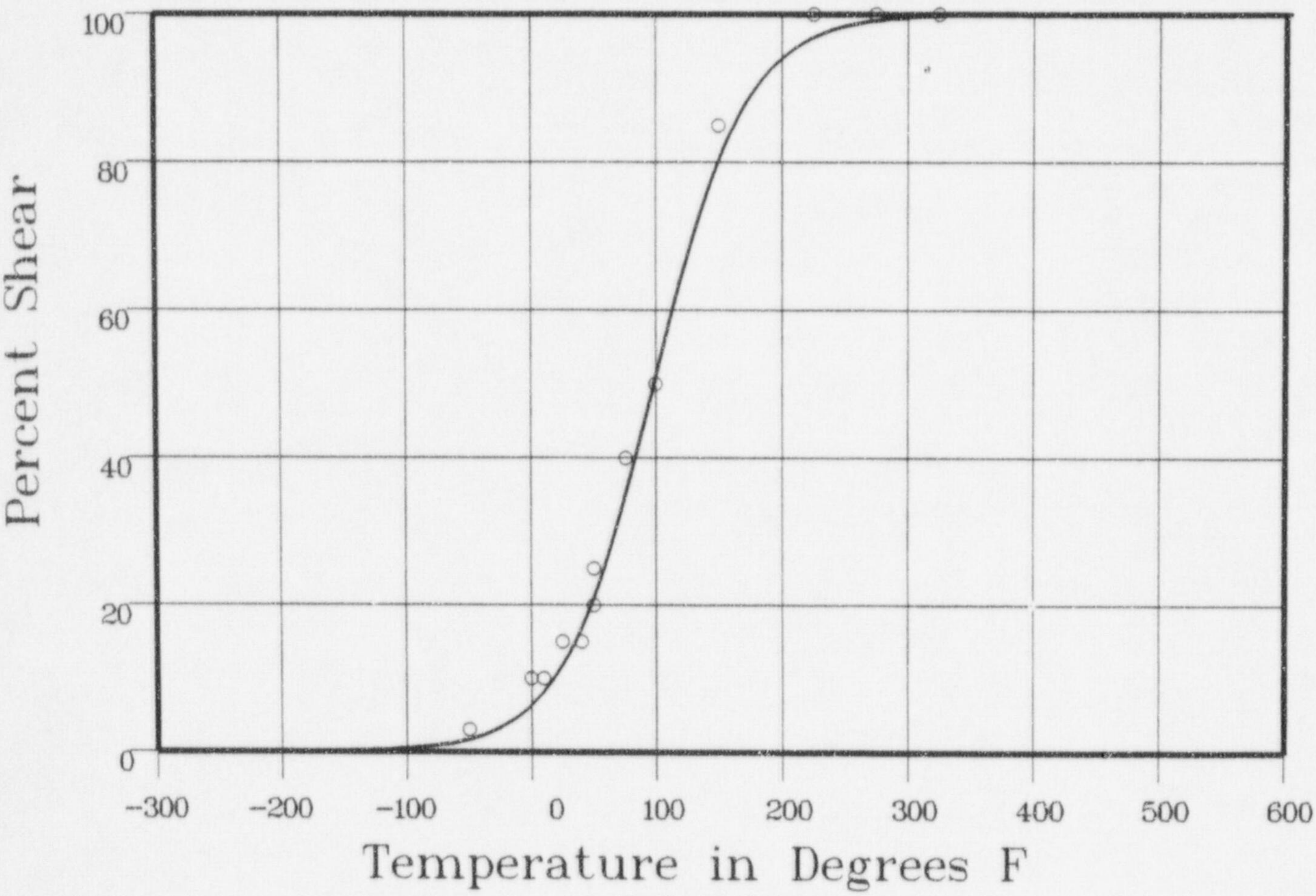
A = 50	B = 50	C = 73.44	T0 = 94.04

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

Temperature at 50% Shear: 94

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: U Total Fluence:



Data Set(s) Plotted
Plant: WC1 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	3	1.94	1.05
0	10	7.16	2.83
10	10	9.2	.79
10	10	9.2	.79
25	15	13.23	1.76
25	15	13.23	1.76
40	15	18.66	-3.66
50	25	23.15	1.84

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

CAPSULE U (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50	20	23.15	-3.15
76	40	37.95	2.04
100	50	54.04	-4.04
150	85	82.1	2.89
225	100	97.25	2.74
275	100	99.28	.71
325	100	99.81	.18

SUM of RESIDUALS = 8.55

CAPSULE Y (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:06:59 on 05-28-1998

Page 1

Coefficients of Curve 3

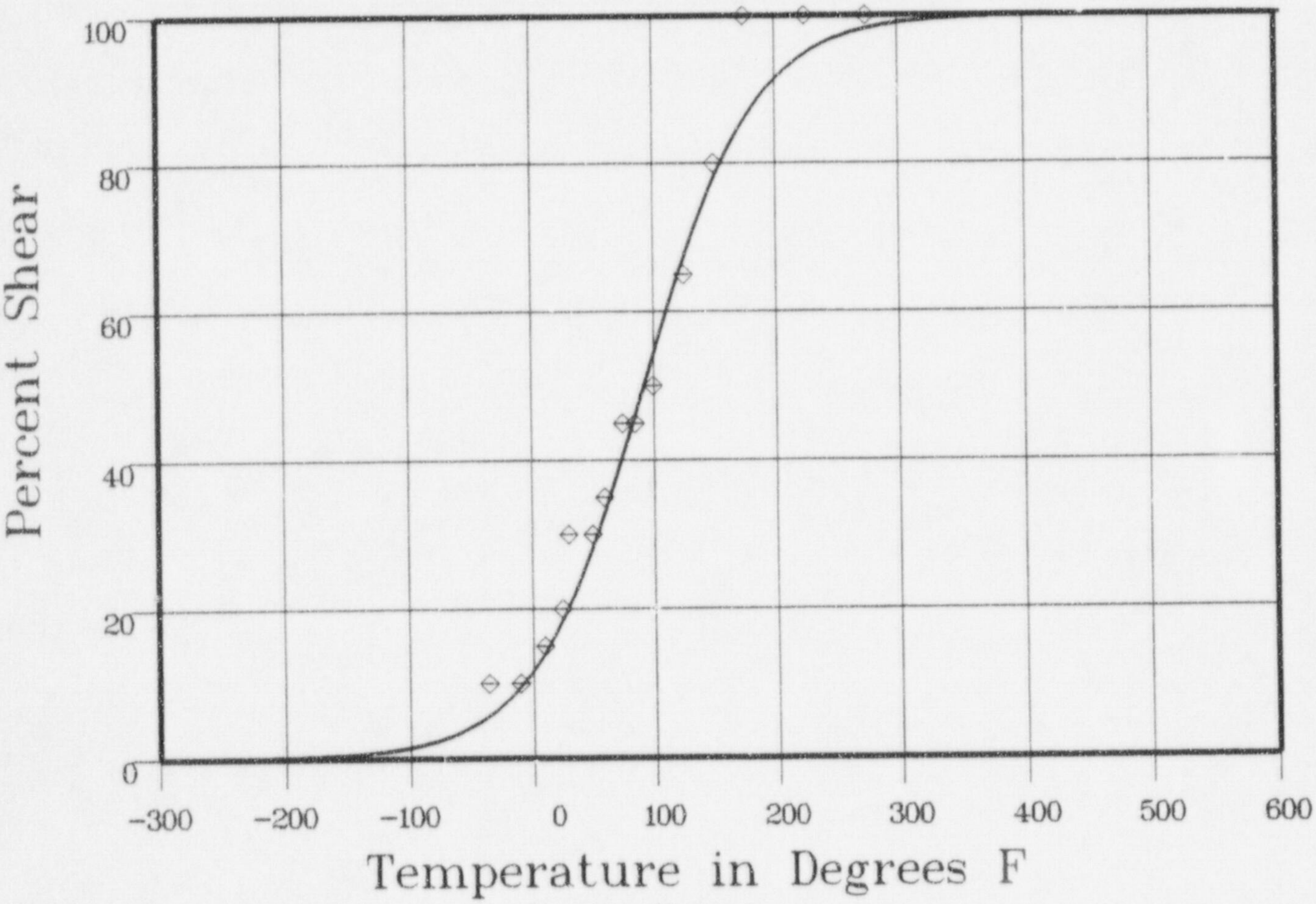
A = 50	B = 50	C = 91.17	T0 = 87.59

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

Temperature at 50% Shear: 87.5

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: Y Material: PLATE SA533B1 Ori.: TL Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-35	10	6.36	3.63
-10	10	10.51	-.51
10	15	15.41	-.41
25	20	20.21	-.21
30	30	22.03	7.96
50	30	30.47	-.47
60	35	35.31	-.31
75	45	43.13	1.86

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

CAPSULE Y (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
85	45	48.57	-3.57
100	50	56.75	-6.75
125	65	69.43	-4.43
150	80	79.71	.28
175	100	87.18	12.81
225	100	95.31	4.68
275	100	98.38	1.61

SUM of RESIDUALS = 16.14

CAPSULE V (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:06:59 on 05-28-1998

Page 1

Coefficients of Curve 4

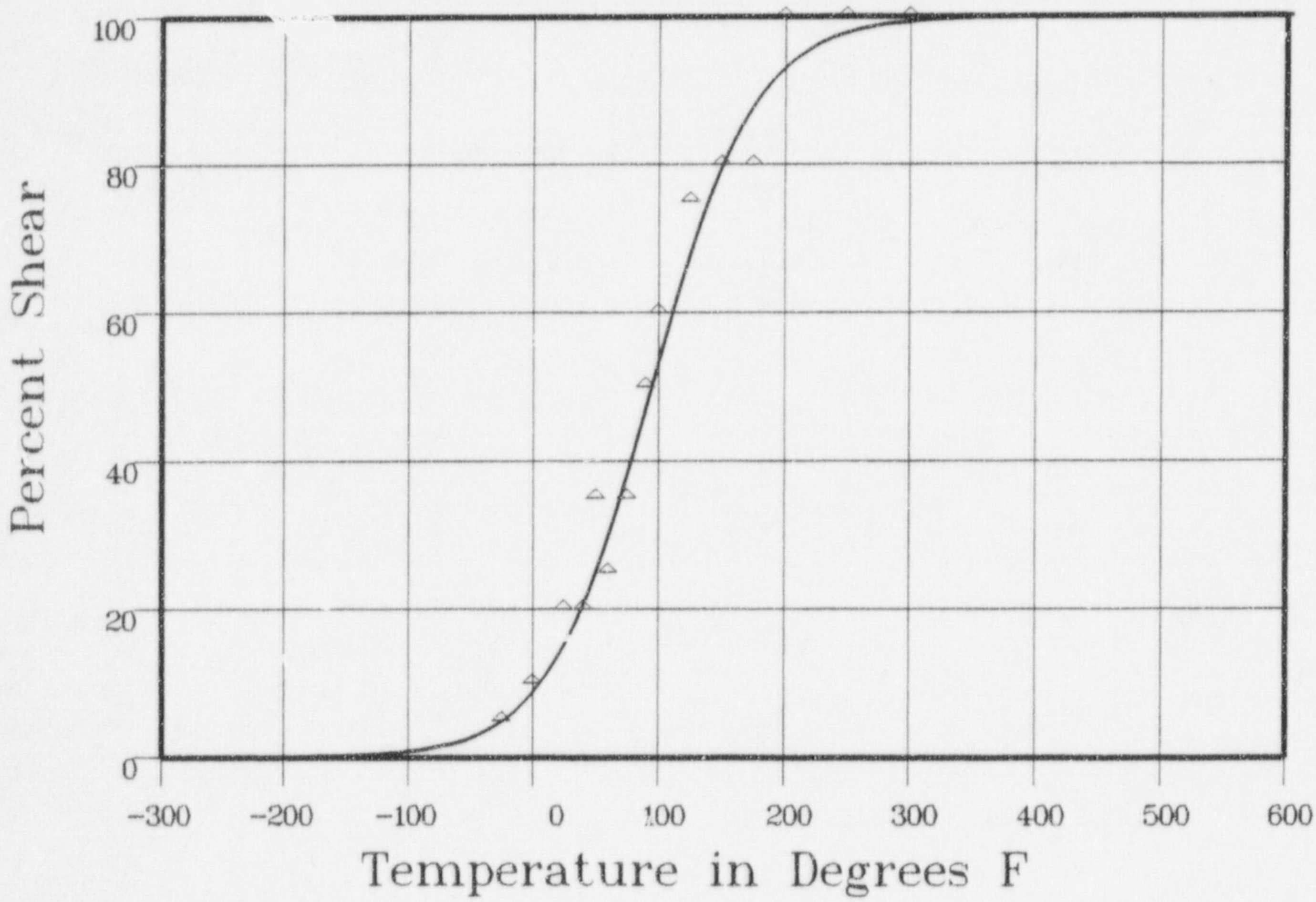
A = 50	B = 50	C = 81.13	T0 = 90.23

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

Temperature at 50% Shear: 90.2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: V Material: PLATE SA533B1 Ori.: TL Heat #: C4935-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	5	5.51	-.51
0	10	9.75	.24
25	20	16.68	3.31
40	20	22.47	-2.47
50	35	27.05	7.94
60	25	32.18	-7.18
75	35	40.72	-5.72

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

CAPSULE V (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C4935-2 Orientation: TL

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
90	50	49.85	.14
100	60	55.98	4.01
125	75	70.2	4.79
150	80	81.35	-1.35
175	80	88.98	-8.98
200	100	93.73	6.26
250	100	98.08	1.91
300	100	99.43	.56

SUM of RESIDUALS = 2.95

UNIRRADIATED (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:15:58 on 05-28-1998

Page 1

Coefficients of Curve 1

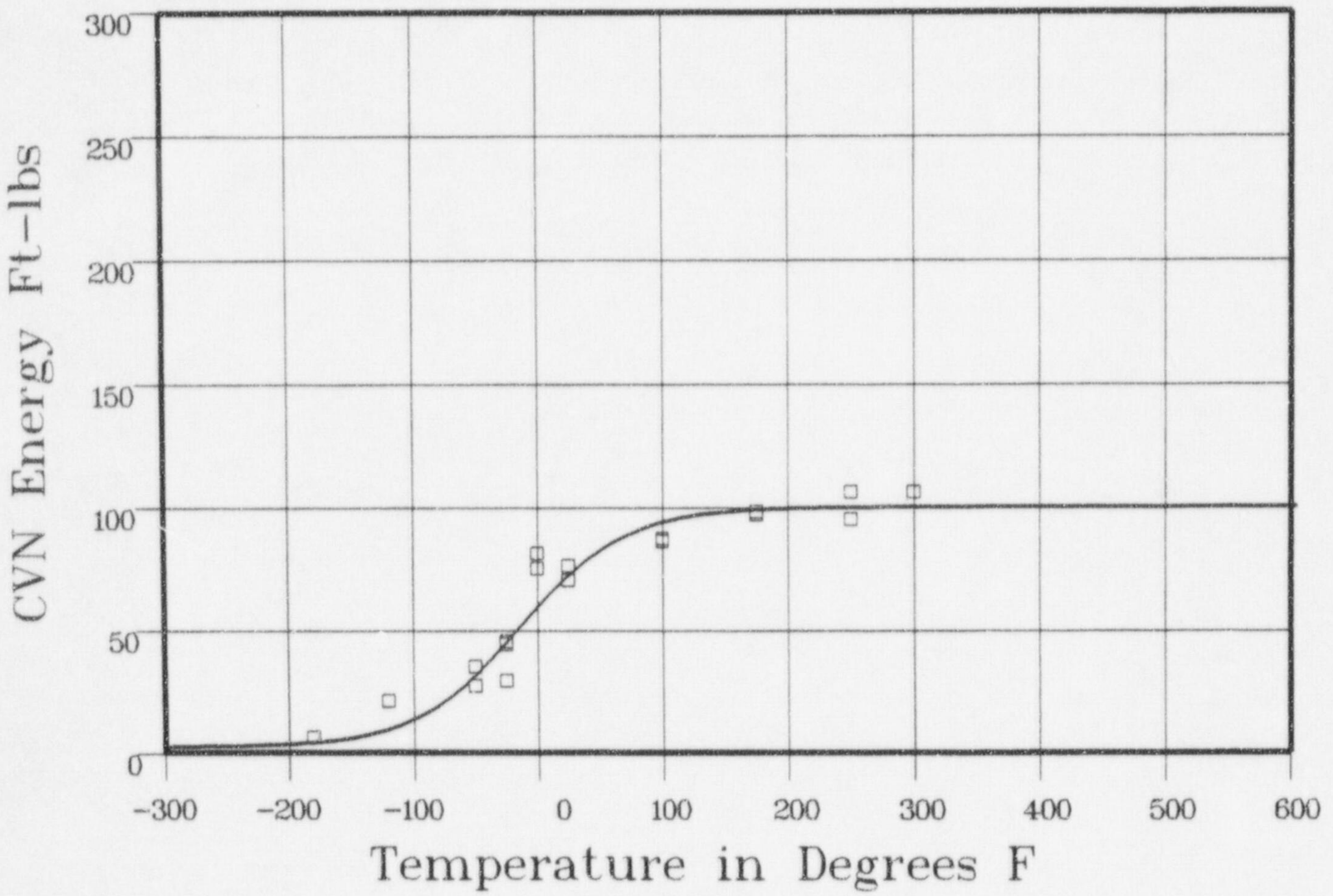
A = 51.09	B = 48.9	C = 84.35	T0 = -18.75

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

Upper Shelf Energy: 100 Fixed Temp. at 30 ft-lbs: -57.6 Temp. at 50 ft-lbs: -20.6 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 90146 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: UNIRR Material: WELD Ori.: Heat #: 90146

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-180	6	4.29	1.7
-120	21	10.32	10.67
-50	35	33.76	1.23
-50	27	33.76	-6.76
-25	29	47.48	-18.48
-25	45	47.48	-2.48
-25	44	47.48	-3.48
0	75	61.79	13.2
0	81	61.79	19.2

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

UNIRRADIATED (WELD)

Page 2

Material: WELD Heat Number: 90146 Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
25	76	74.4	1.59
25	70	74.4	-4.4
100	87	94.47	-7.47
100	86	94.47	-8.47
175	98	99.02	-1.02
175	97	99.02	-2.02
250	95	99.83	-4.83
250	106	99.83	6.16
300	106	99.94	6.05

SUM of RESIDUALS = .37

CAPSULE U (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:15:58 on 05-28-1998

Page 1

Coefficients of Curve 2

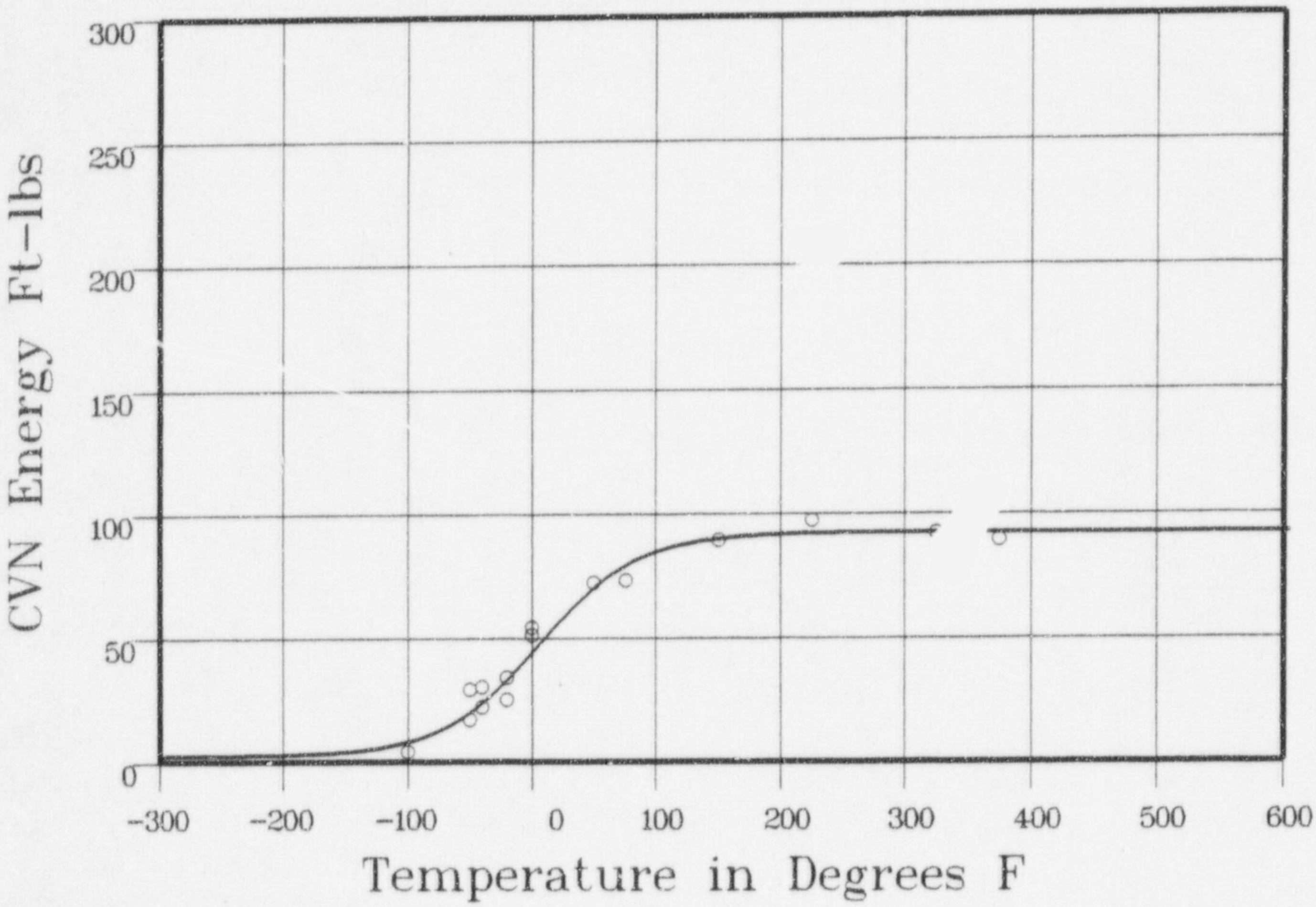
A = 47.09	B = 44.9	C = 79.28	T0 = 1.31

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

Upper Shelf Energy: 92 Fixed Temp. at 30 ft-lbs: -30.4 Temp. at 50 ft-lbs: 6.4 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 90146 Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap: U Material: WELD Ori.: Heat #: 90146

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	4	8.66	-4.66
-50	17	21.51	-4.51
-50	29	21.51	7.48
-40	22	25.61	-3.61
-40	30	25.61	4.38
-20	34	35.3	-1.3
-20	25	35.3	-10.3
0	51	46.35	4.64

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

CAPSULE U (WELD)

Page 2

Material: WELD   Heat Number: 90146   Orientation:

Capsule: U   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	54	46.35	7.64
50	72	71.65	.34
76	73	80.15	-7.15
150	89	89.93	-.93
225	97	91.68	5.31
325	92	91.97	.02
375	89	91.99	-2.99

SUM of RESIDUALS = -5.64

CAPSULE Y (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:15:58 on 05-28-1998

Page 1

Coefficients of Curve 3

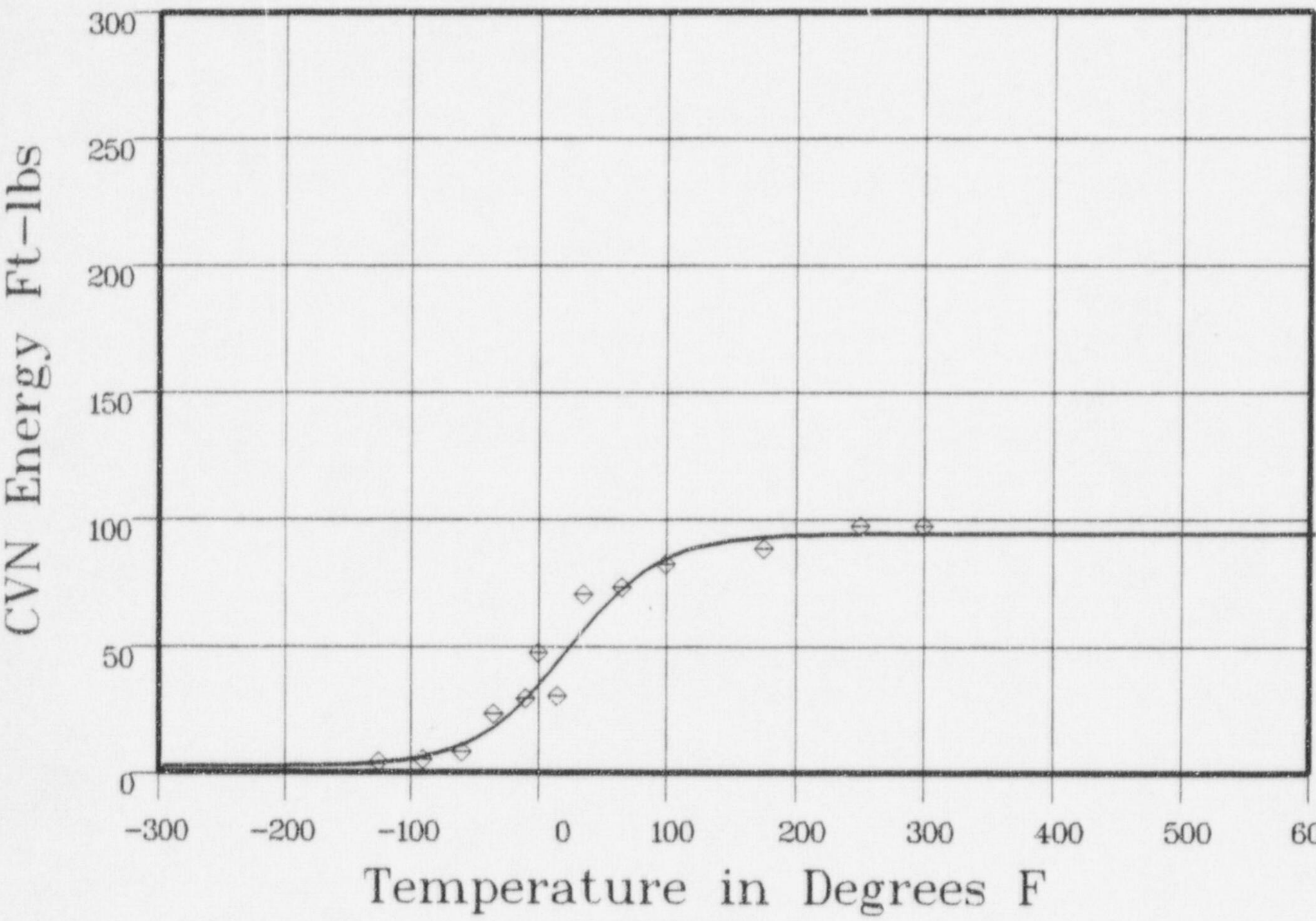
A = 48.09	B = 45.9	C = 72.92	T0 = 17.8

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

Upper Shelf Energy: 94 Fixed Temp. at 30 ft-lbs: -12.5 Temp. at 50 ft-lbs: 20.8 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 90146 Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: Y Material: WELD Ori.: Heat #: 90146

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-125	4	3.99	0
-90	5	6.73	-1.73
-60	8	11.91	-3.91
-35	23	19.66	3.33
-10	29	31.39	-2.39
0	47	37.1	9.89
15	30	46.33	-16.33
35	70	58.72	11.27

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

CAPSULE Y (WELD)

Page 2

Material: WELD Heat Number: 90146 Orientation:

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
65	73	74.24	-1.24
100	82	85.27	-3.27
175	88	92.78	-4.78
250	97	93.84	3.15
300	97	93.96	3.03

SUM of RESIDUALS = -2.99

CAPSULE V (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:15:58 on 05-28-1998

Page 1

Coefficients of Curve 4

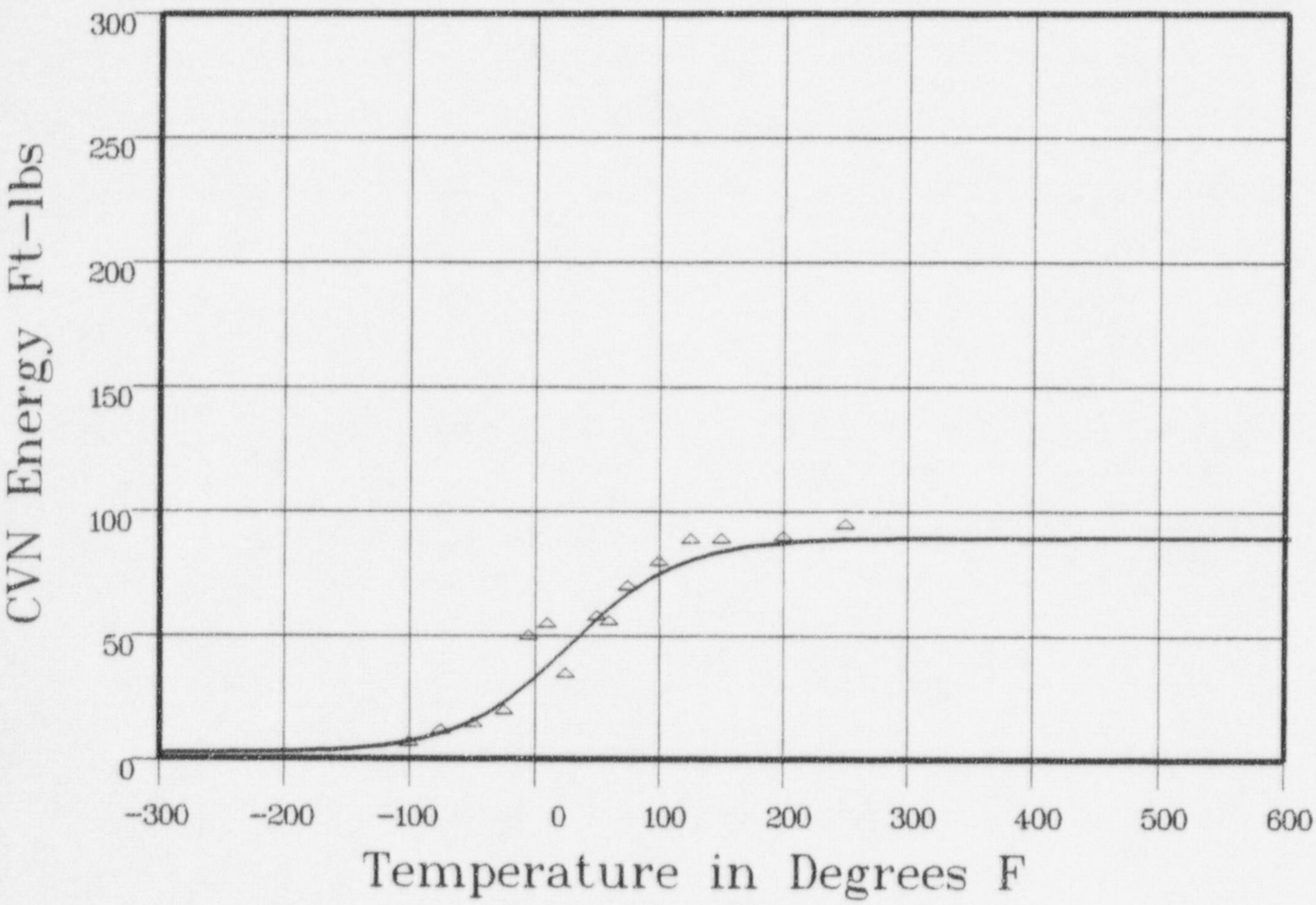
A = 45.59	B = 43.4	C = 90.29	T0 = 22.6

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

Upper Shelf Energy: 89 Fixed Temp. at 30 ft-lbs: -11.3 Temp. at 50 ft-lbs: 31.7 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 90146 Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: V Material: WELD Ori.: Heat #: 90146

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	5	7.58	-2.58
-75	10	11.15	-1.15
-50	13	16.68	-3.68
-25	18	24.62	-6.62
-5	48	32.72	15.27
10	53	39.57	13.42
25	33	46.74	-13.74

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

CAPSULE V (WELD)

Page 2

Material: WELD Heat Number: 90146 Orientation:

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	56	58.37	-2.37
60	54	62.6	-8.6
75	68	68.28	-.28
100	78	75.75	2.24
125	87	80.85	6.14
150	87	84.12	2.87
200	88	87.32	.67
250	93	88.43	4.56

SUM of RESIDUALS = 6.11

UNIRRADIATED (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:24:17 on 05-28-1998

Page 1

Coefficients of Curve 1

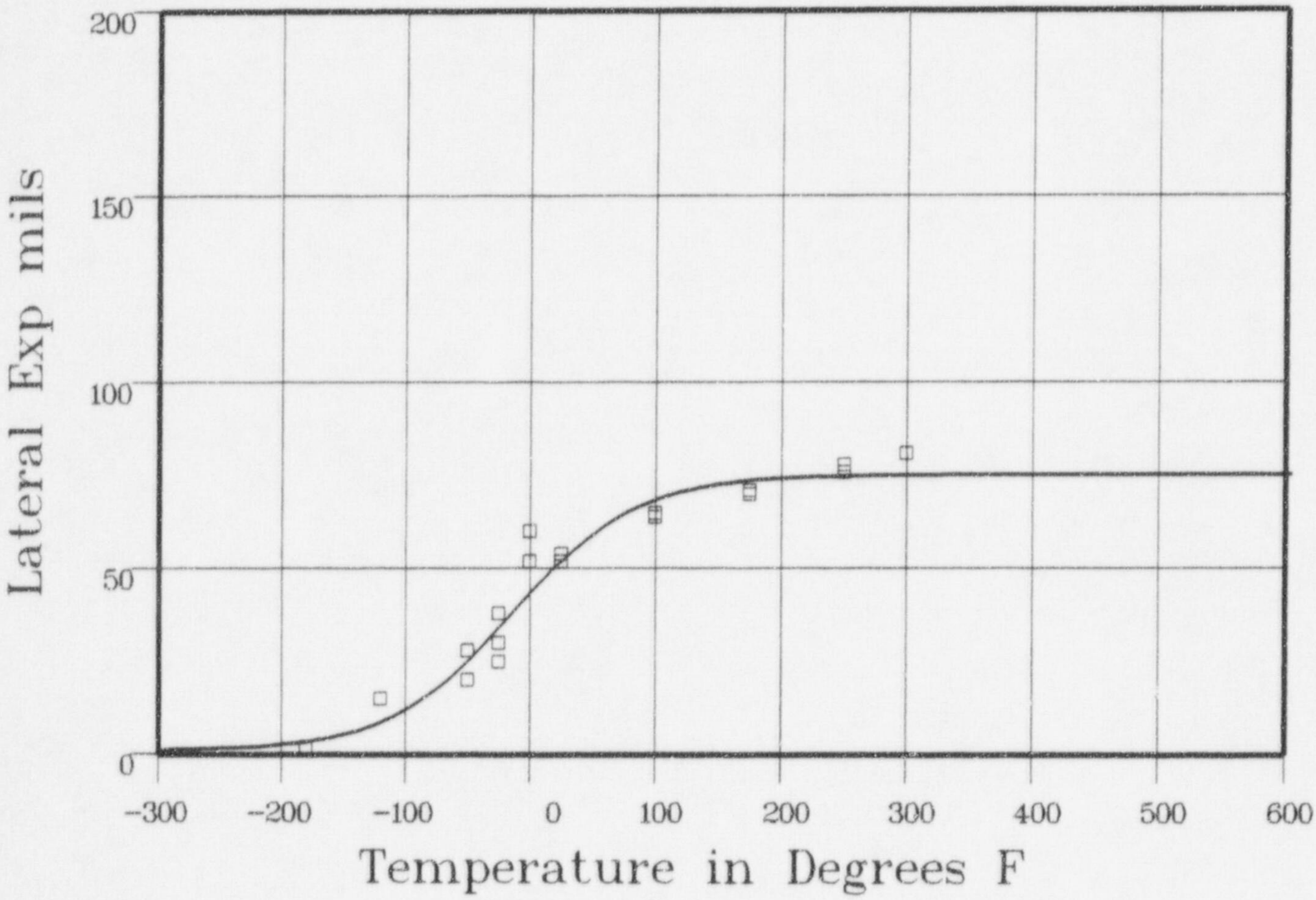
A = 38.13	B = 37.13	C = 98.43	T0 = -18.75

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

Upper Shelf L.E.: 75.26 Temperature at L.E. 35: -27 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 90146 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: UNIRR Material: WELD Ori.: Heat #: 90146

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-180	2	3.7	-1.7
-120	15	9.41	5.58
-50	28	26.72	1.27
-50	20	26.72	-6.72
-25	25	35.77	-10.77
-25	38	35.77	2.22
-25	30	35.77	-5.77
0	52	45.12	6.87
0	60	45.12	14.87

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

UNIRRADIATED (WELD)

Page 2

Material: WELD Heat Number: 90146 Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
25	54	53.62	.37
25	52	53.62	-1.62
100	65	69.15	-4.15
100	64	69.15	-5.15
175	71	73.84	-2.84
175	70	73.84	-3.84
250	76	74.94	1.05
250	78	74.94	3.05
300	81	75.14	5.85

SUM of RESIDUALS = -1.44

CAPSULE U (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:24:17 on 05-28-1998

Page 1

Coefficients of Curve 2

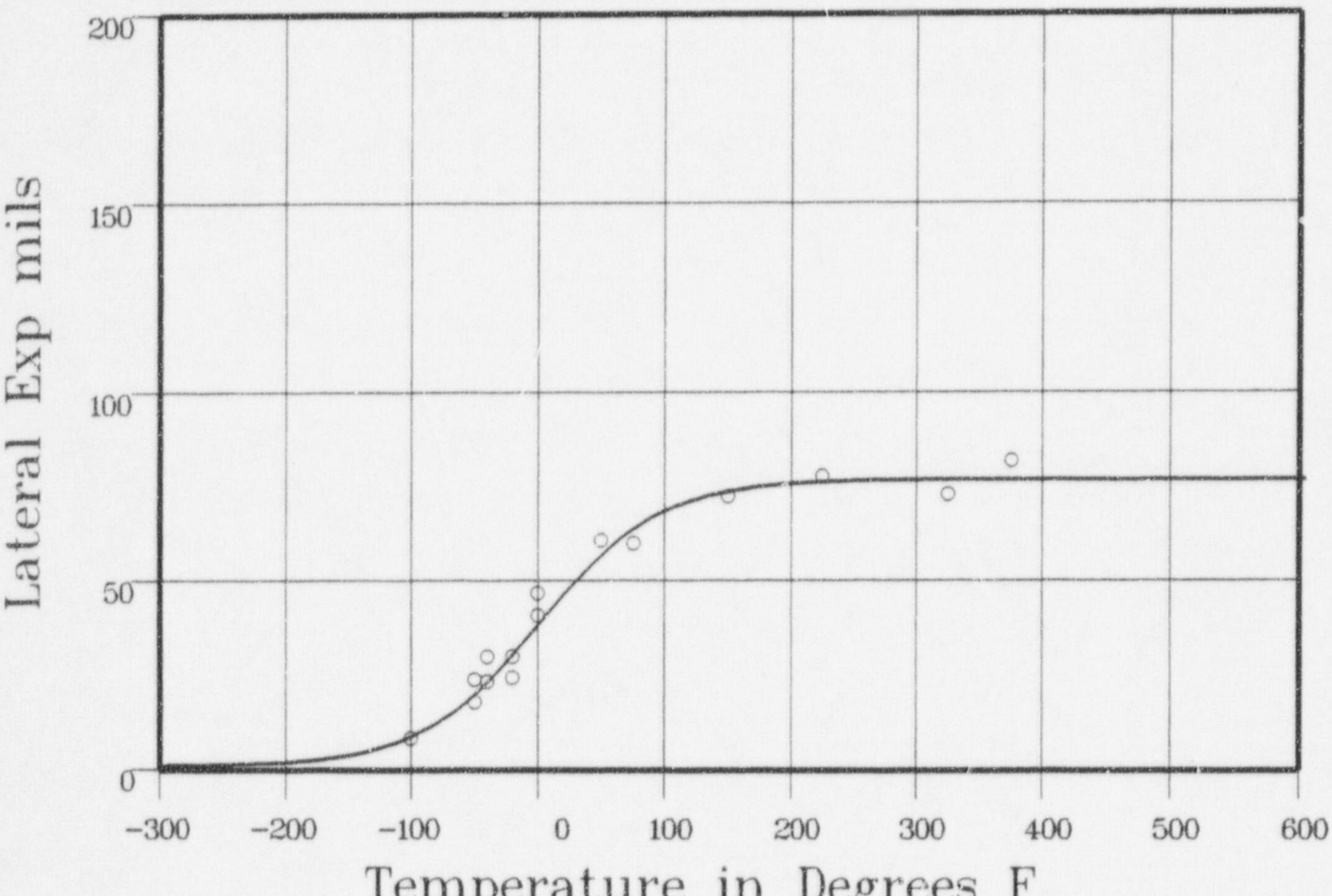
A = 39	B = 38	C = 94.54	T0 = -2.81

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

Upper Shelf L.E.: 77 Temperature at L.E. 35: -12.8 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 90146 Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: U Material: WELD Ori.: Heat #: 90146

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	8.5	9.62	-1.12
-50	18	21.46	-3.46
-50	24	21.46	2.53
-40	23.5	24.78	-1.28
-40	30	24.78	5.21
-20	30	32.17	-2.17
-20	24.5	32.17	-7.67
0	47	40.13	6.86

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

CAPSULE U (WELD)

Page 2

Material: WELD   Heat Number: 90146   Orientation:

Capsule: U   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	41	40.13	.86
50	61	58.27	2.72
76	60	64.94	-4.94
150	72.5	74.12	-1.62
225	78	76.4	1.59
325	73	76.93	-3.93
375	82	76.98	5.01

SUM of RESIDUALS = -1.39

CAPSULE Y (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:24:17 on 05-28-1998

Page 1

Coefficients of Curve 3

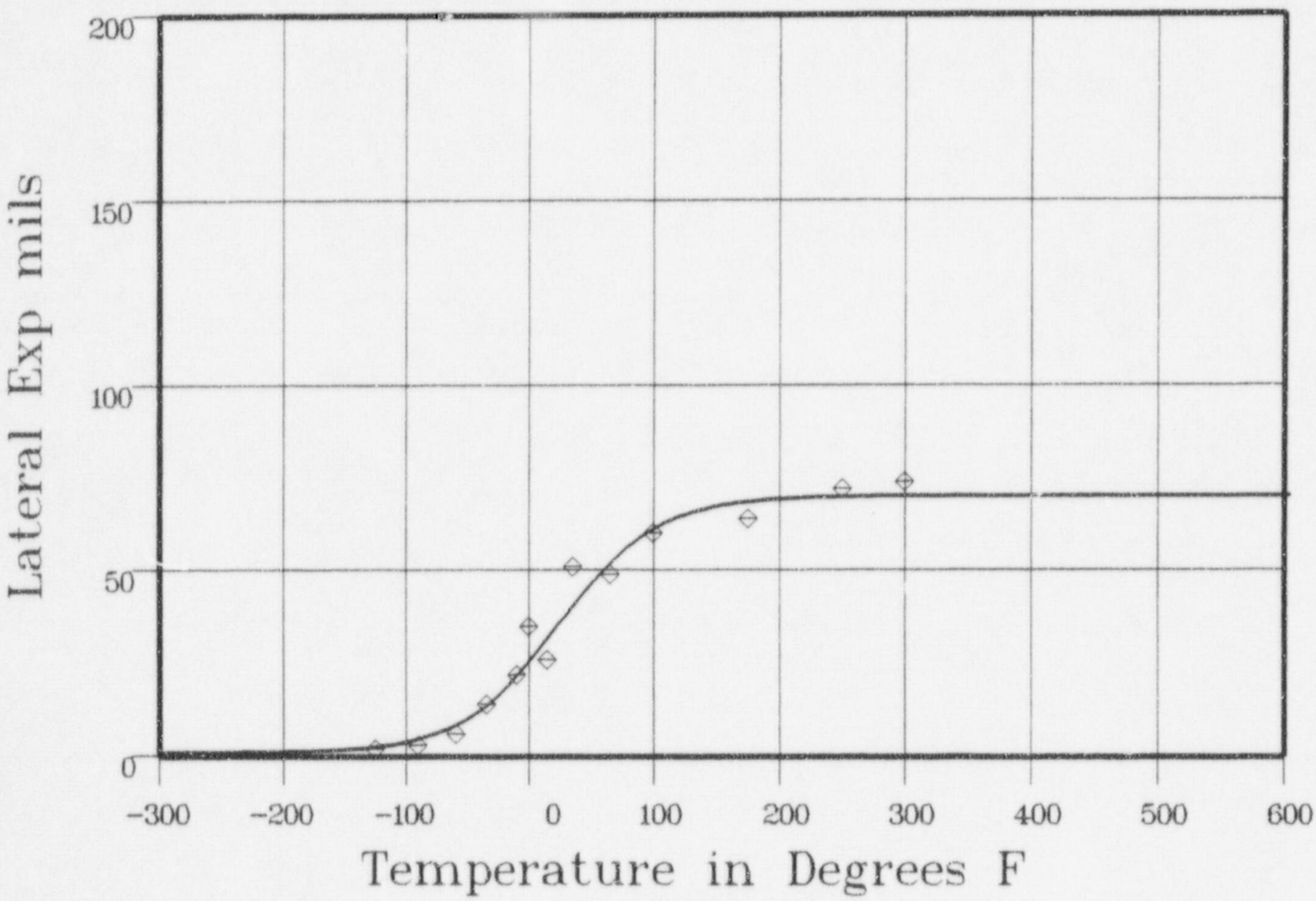
A = 35.54	B = 34.54	C = 79.49	T0 = 19.21

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

Upper Shelf L.E.: 70.08 Temperature at L.E. 35: 17.9 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 90146 Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: Y Material: WELD Ori.: Heat #: 90146

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-125	2	2.78	-.78
-90	3	5.15	-2.15
-60	6	9.28	-3.28
-35	14	15.06	-1.06
-10	22	23.38	-1.38
0	35	27.35	7.64
15	26	33.71	-7.71
35	51	42.31	8.68

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

CAPSULE Y (WELD)

Page 2

Material: WELD Heat Number: 90146 Orientation:

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
65	49	53.49	-4.49
100	60	62.08	-2.08
175	64	68.74	-4.74
250	72	69.87	2.12
300	74	70.02	3.97

SUM of RESIDUALS = -5.28

CAPSULE V (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:24:17 on 05-28-1998

Page 1

Coefficients of Curve 4

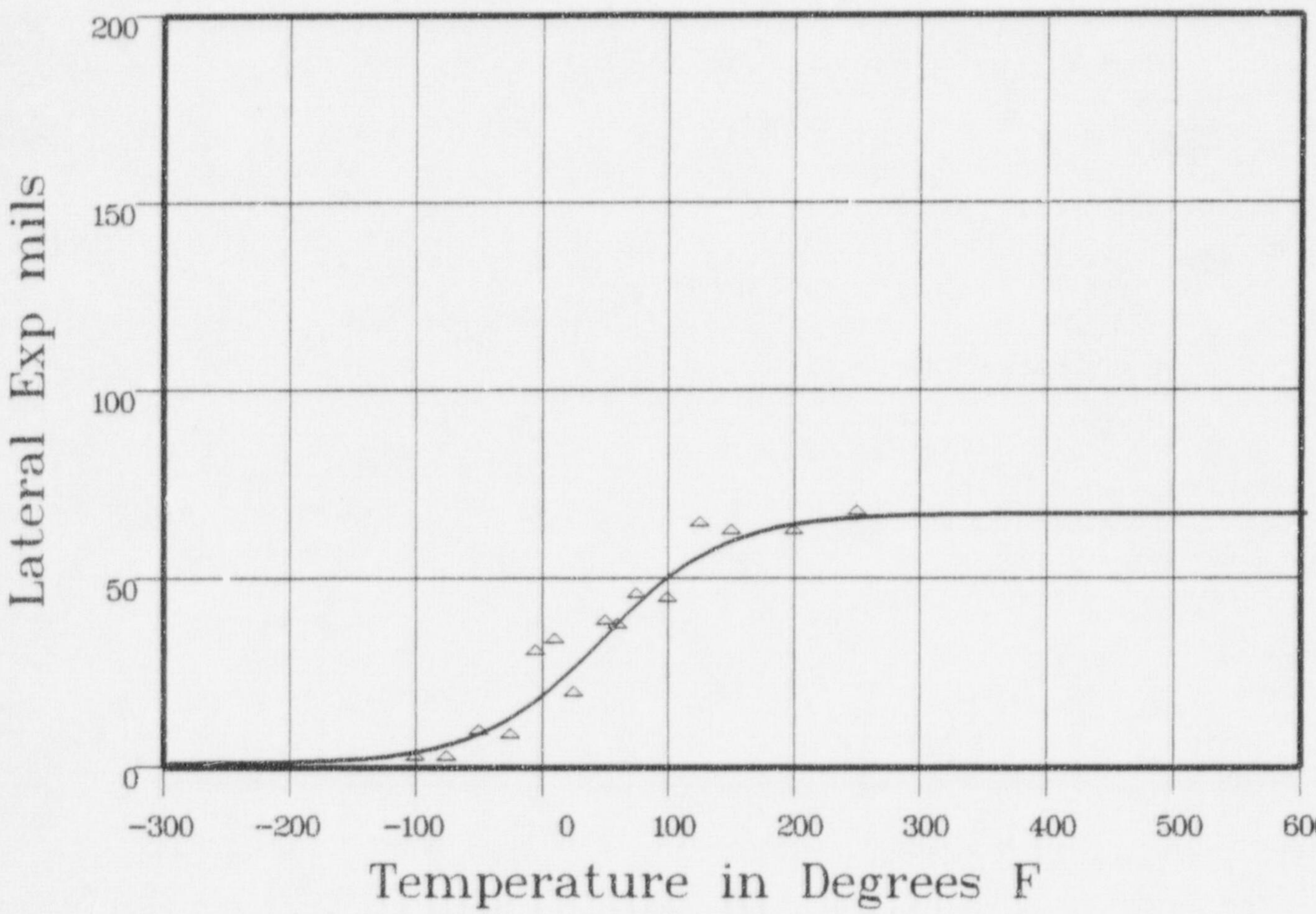
A = 34.11	B = 33.11	C = 98.07	T0 = 42.89

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

Upper Shelf L.E.: 67.22 Temperature at L.E. 35: 45.5 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 90146 Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: V Material: WELD Ori.: Heat #: 90146

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	2	4.4	-2.4
-75	2	6.48	-4.48
-50	9	9.65	-.65
-25	8	14.26	-6.26
-5	30	19.11	10.88
10	33	23.4	9.59
25	19	28.13	-9.13

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

CAPSULE V (WELD)

Page 2

Material: WELD Heat Number: 90146 Orientation:

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
50	38	36.5	1.49
60	37	39.82	-2.82
75	45	44.57	.42
100	44	51.47	-7.47
125	64	56.77	7.22
150	62	60.52	1.47
200	62	64.64	-2.64
250	67	66.26	.73

SUM of RESIDUALS = -4.06

UNIRRADIATED (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:31:21 on 05-28-1998

Page 1

Coefficients of Curve 1

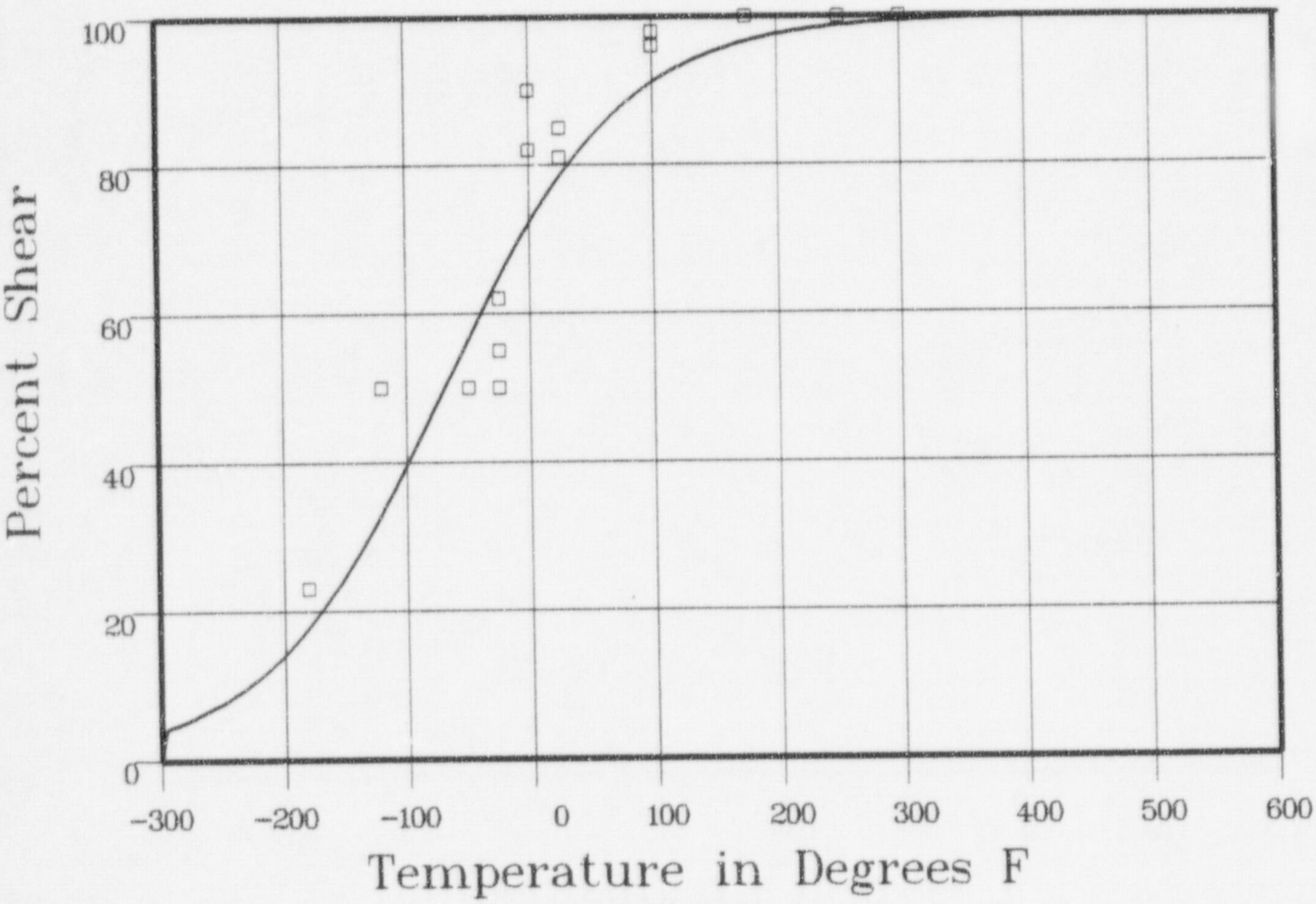
A = 50	B = 50	C = 145.17	T0 = -73.94

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

Temperature at 50% Shear: -73.9

Material: WELD Heat Number: 90146 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: UNIRR Material: WELD Ori.: Heat #: 90146

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-180	23	18.83	4.16
-120	50	34.65	15.34
-50	50	58.17	-8.17
-50	50	58.17	-8.17
-25	50	66.24	-16.24
-25	62	66.24	-4.24
-25	55	66.24	-11.24
0	82	73.47	8.52
0	90	73.47	16.52

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

UNIRRADIATED (WELD)

Page 2

Material: WELD Heat Number: 90146 Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25	81	79.62	1.37
25	85	79.62	5.37
100	98	91.65	6.34
100	96	91.65	4.34
175	100	96.86	3.13
175	100	96.86	3.13
250	100	98.86	1.13
250	100	98.86	1.13
300	100	99.42	.57

SUM of RESIDUALS = 23.04

CAPSULE U (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:31:21 on 05-28-1998

Page 1

Coefficients of Curve 2

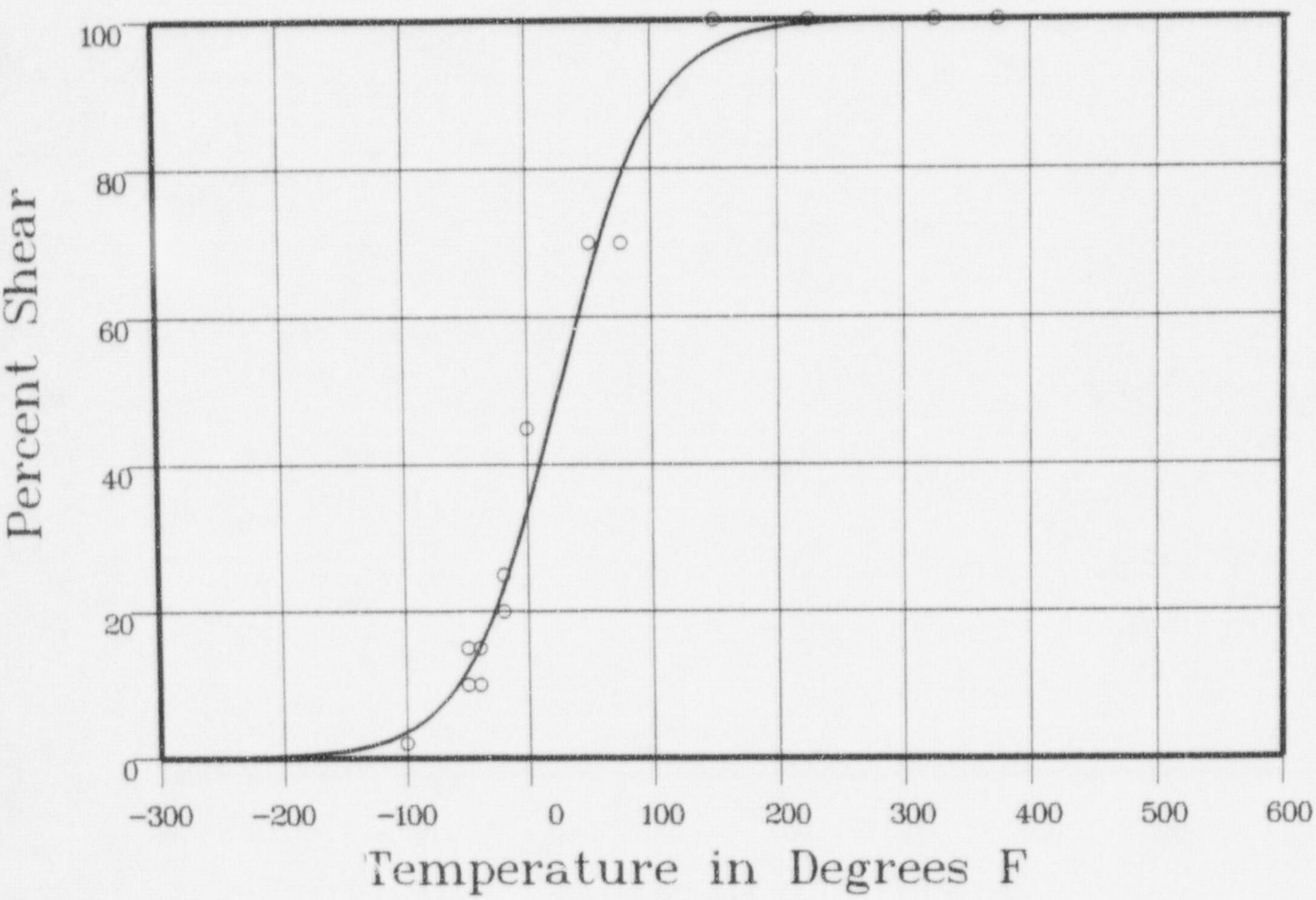
A = 50	B = 50	C = 76.06	T0 = 20.94

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

Temperature at 50% Shear: 20.9

Material: WELD Heat Number: 90146 Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: U Material: WELD Ori.: Heat #: 90146

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	2	3.99	-1.99
-50	10	13.4	-3.4
-50	15	13.4	1.59
-40	15	16.76	-1.76
-40	10	16.76	-6.76
-20	25	25.41	-.41
-20	20	25.41	-5.41
0	45	36.56	8.43

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

CAPSULE U (WELD)

Page 2

Material: WELD Heat Number: 90146 Orientation:

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	45	36.56	8.43
50	70	68.22	1.77
76	70	80.96	-10.96
150	100	96.74	3.25
225	100	99.53	.46
325	100	99.96	.03
375	100	99.99	0

SUM of RESIDUALS = -6.71

CAPSULE Y (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:31:21 on 05-28-1998

Page 1

Coefficients of Curve 3

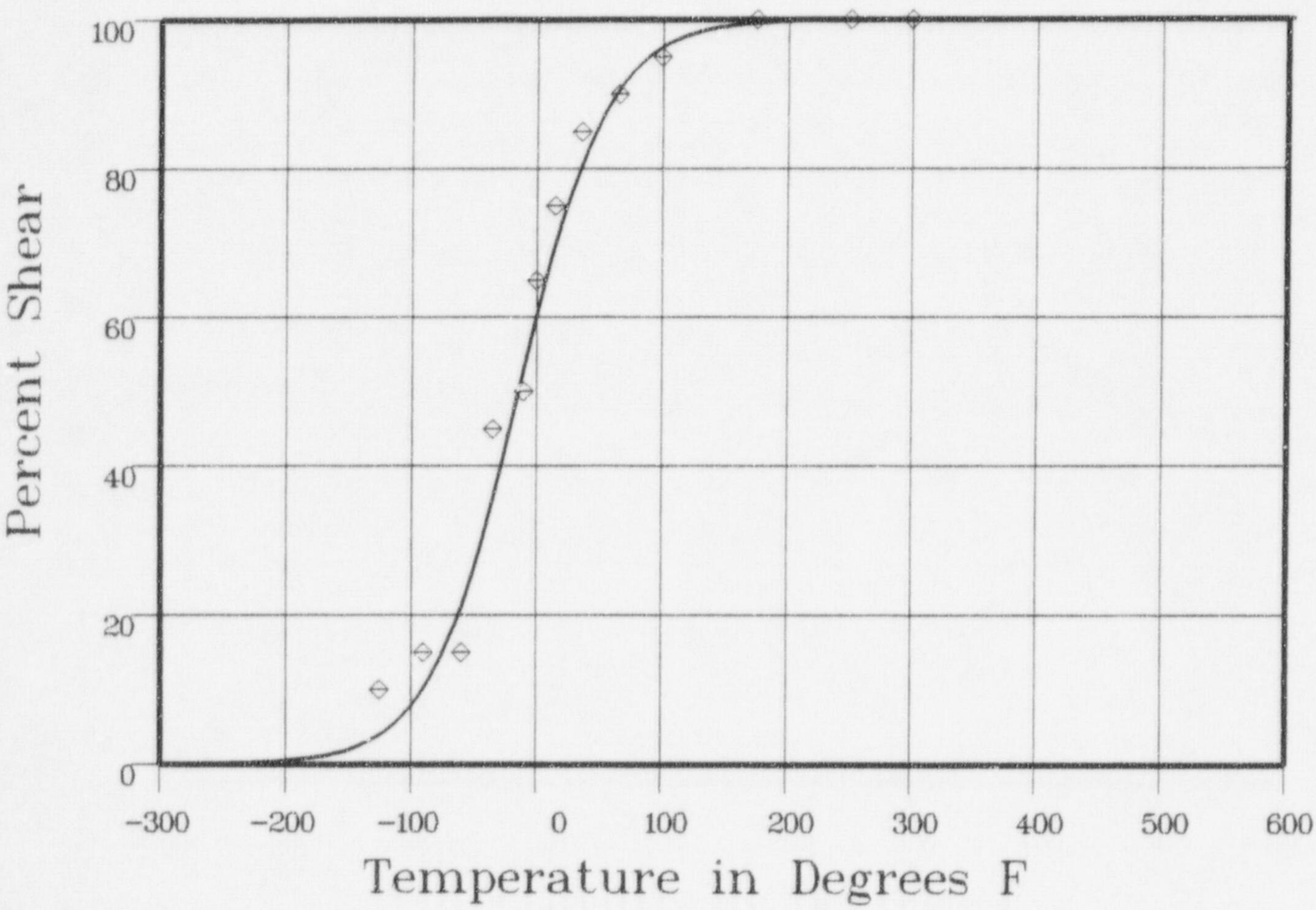
A = 50	B = 50	C = 69.71	T0 = -18.91

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

Temperature at 50% Shear: -18.9

Material: WELD Heat Number: 90146 Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: Y Material: WELD Ori.: Heat #: 90146

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-125	10	4.55	5.44
-90	15	11.51	3.48
-60	15	23.52	-8.52
-35	45	38.66	6.33
-10	50	56.35	-6.35
0	65	63.24	1.75
15	75	72.56	2.43
35	85	82.44	2.55

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

CAPSULE Y (WELD)

Page 2

Material: WELD　　Heat Number: 90146　　Orientation:

Capsule: Y　　Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
65	90	91.73	-1.73
100	95	96.8	-1.8
175	100	99.61	.38
250	100	99.95	.04
300	100	99.98	.01

SUM of RESIDUALS = 4.02

CAPSULE V (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:31:21 on 05-28-1998

Page 1

Coefficients of Curve 4

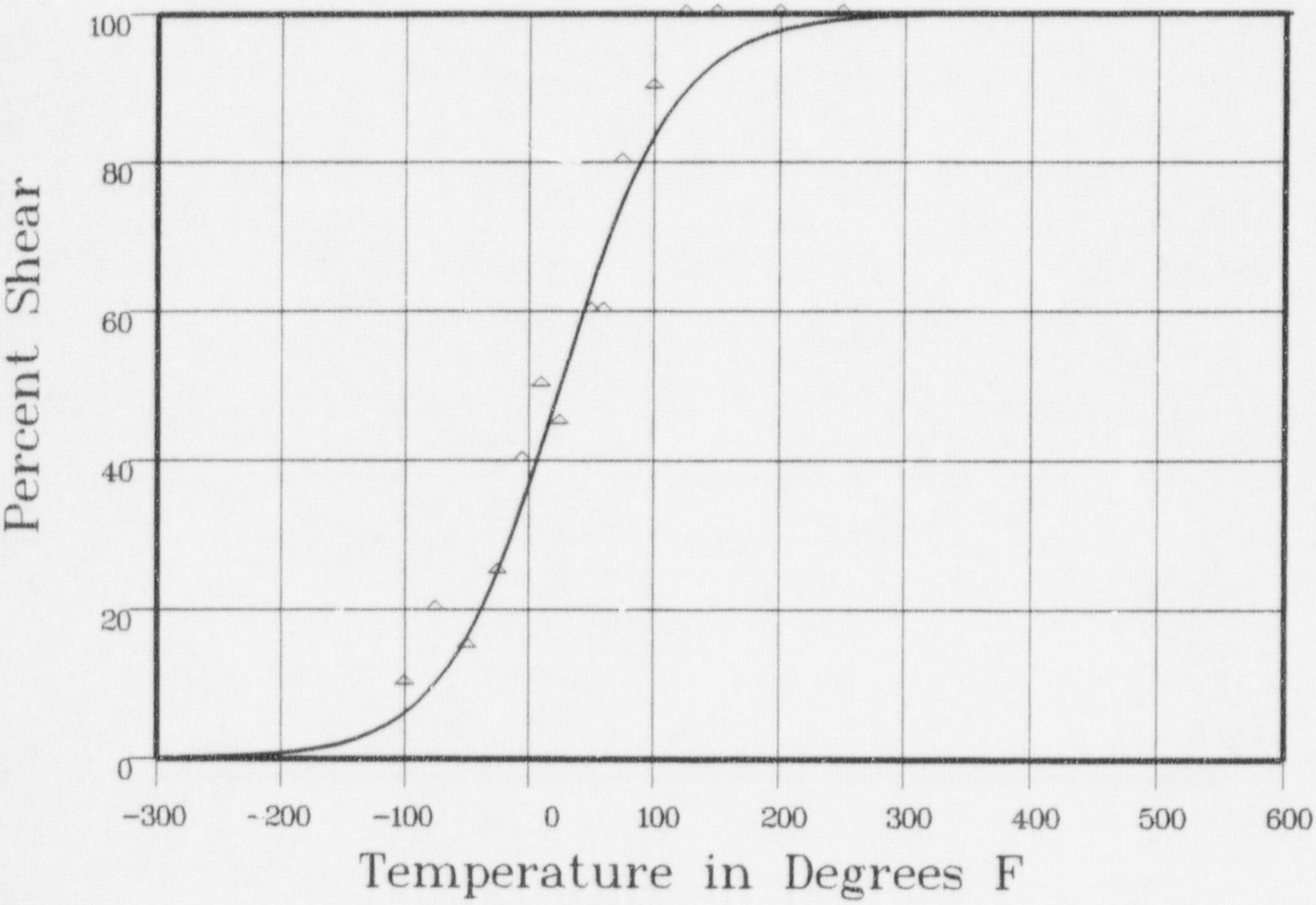
A = 50	B = 50	C = 92.62	T0 = 20.76

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

Temperature at 50% Shear: 20.7

Material: WELD Heat Number: 90146 Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: V Material: WELD Ori.: Heat #: 90146

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	10	6.86	3.13
-75	20	11.22	8.77
-50	15	17.82	-2.82
-25	25	27.12	-2.12
-5	40	36.44	3.55
10	50	44.21	5.78
25	45	52.28	-7.28

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

CAPSULE V (WELD)

Page 2

Material: WELD Heat Number: 90146 Orientation:

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50	60	65.27	-5.27
60	60	69.99	-9.99
75	80	76.33	3.66
100	90	84.69	5.3
125	100	90.47	9.52
150	100	94.21	5.78
200	100	97.95	2.04
250	100	99.29	.7

SUM of RESIDUALS = 20.76

UNIRRADIATED (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:39:46 on 05-28-1998

Page 1

Coefficients of Curve 1

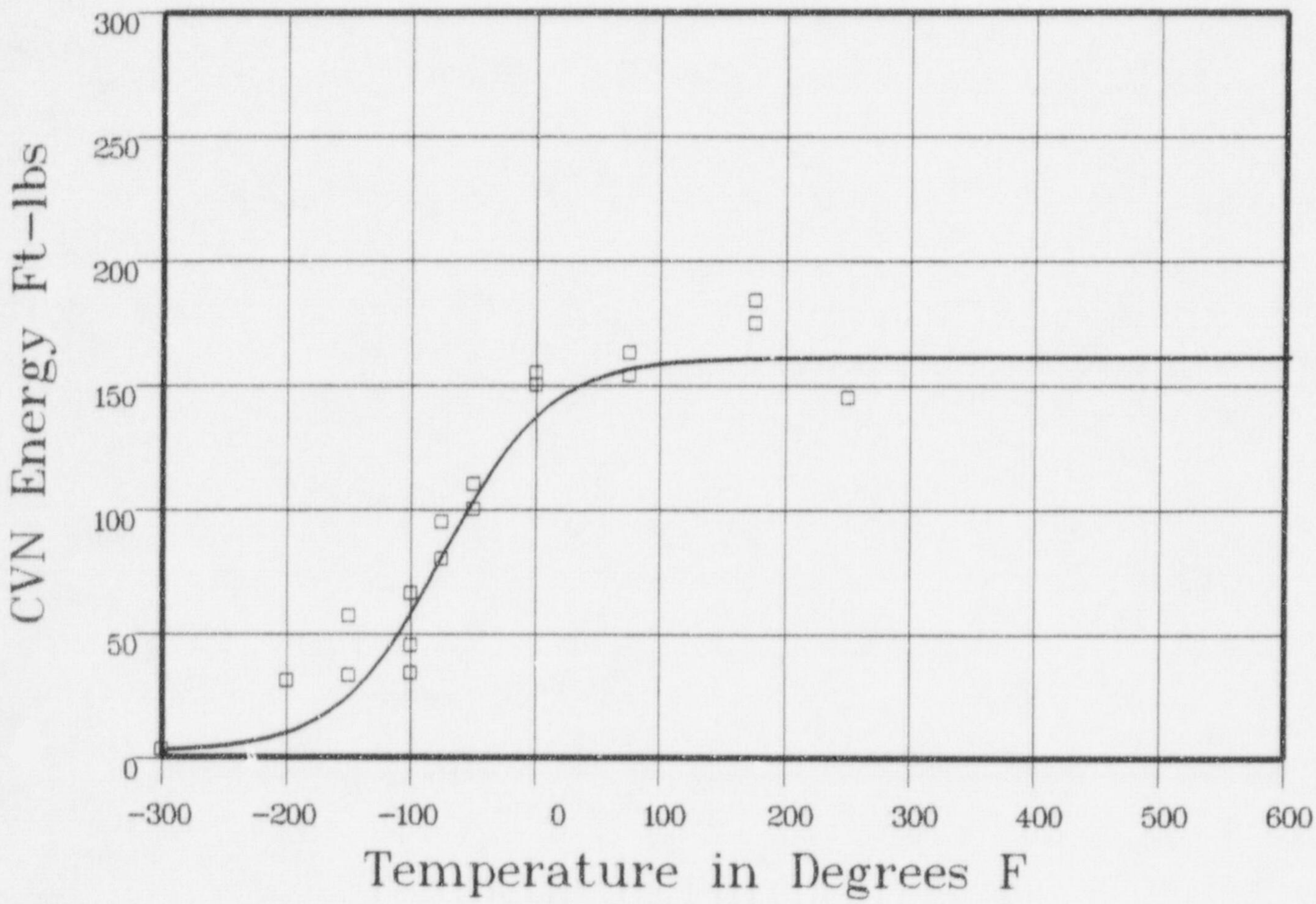
A = 81.59	B = 79.4	C = 84.8	T0 = -78.28

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

Upper Shelf Energy: 161 Fixed   Temp. at 30 ft-lbs: -144   Temp. at 50 ft-lbs: -114   Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: UNIRR   Total Fluence:



Data Set(s) Plotted

Plant: WC1   Cap.: UNIRR   Material: HEAT AFFD ZONE   Ori.:   Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-300	3	3.04	-.04
-200	31	10.71	20.28
-150	57	26.91	30.08
-150	33	26.91	6.08
-100	34	61.69	-27.69
-100	45	61.69	-16.69
-100	66	61.69	4.3
-75	95	84.67	10.32
-75	80	84.67	-4.67

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

UNIRRADIATED (HAZ)

Page 2

Material: HEAT AFF'D ZONE Heat Number: Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	110	107.13	2.86
-50	100	107.13	-7.13
0	150	139.34	10.65
0	155	139.34	15.65
75	154	156.83	-2.83
75	163	156.83	6.16
175	184	160.59	23.4
175	175	160.59	14.4
250	145	160.93	-15.93

SUM of RESIDUALS = 69.2

CAPSULE U (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:39:46 on 05-28-1998

Page 1

Coefficients of Curve 2

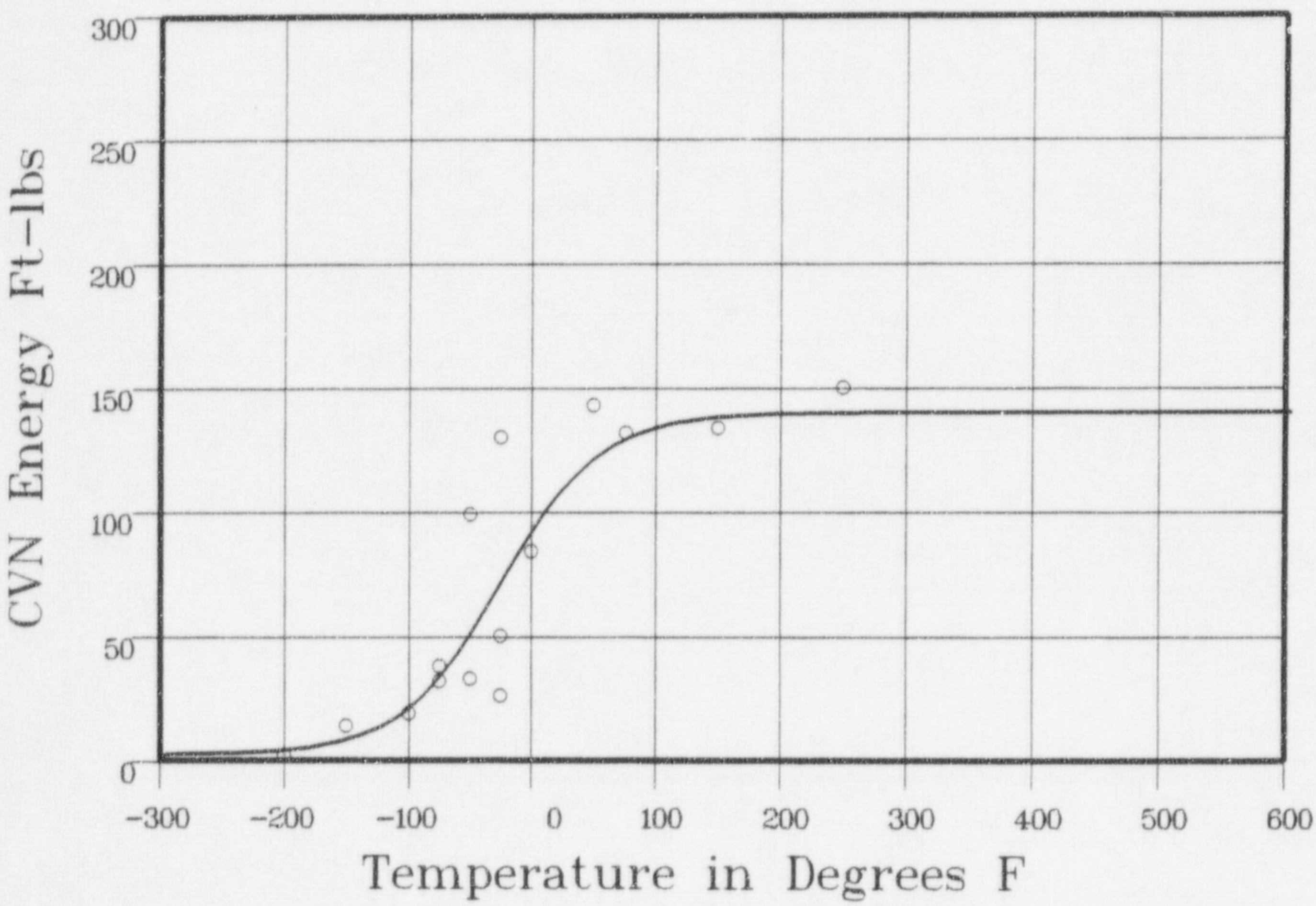
A = 71.09	B = 68.9	C = 81.52	T0 = -29.53

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

Upper Shelf Energy: 140 Fixed Temp. at 30 ft-lbs: -85.5 Temp. at 50 ft-lbs: -55.3 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: U Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-200	2	4.27	-2.27
-150	14	9.01	4.98
-100	19	22.97	-3.97
-75	38	36.21	1.78
-75	32	36.21	-4.21
-50	99	54.15	44.84
-50	33	54.15	-21.15
-25	50	74.92	-24.92

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

CAPSULE U (HAZ)

Page 2

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: U   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	26	74.92	-48.92
-25	130	74.92	55.07
0	84	95.02	-11.02
50	143	122.85	20.14
76	132	130.37	1.62
150	134	138.33	-4.33
250	150	139.85	10.14

SUM of RESIDUALS = 17.77

CAPSULE Y (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:39:46 on 05-28-1998

Page 1

Coefficients of Curve 3

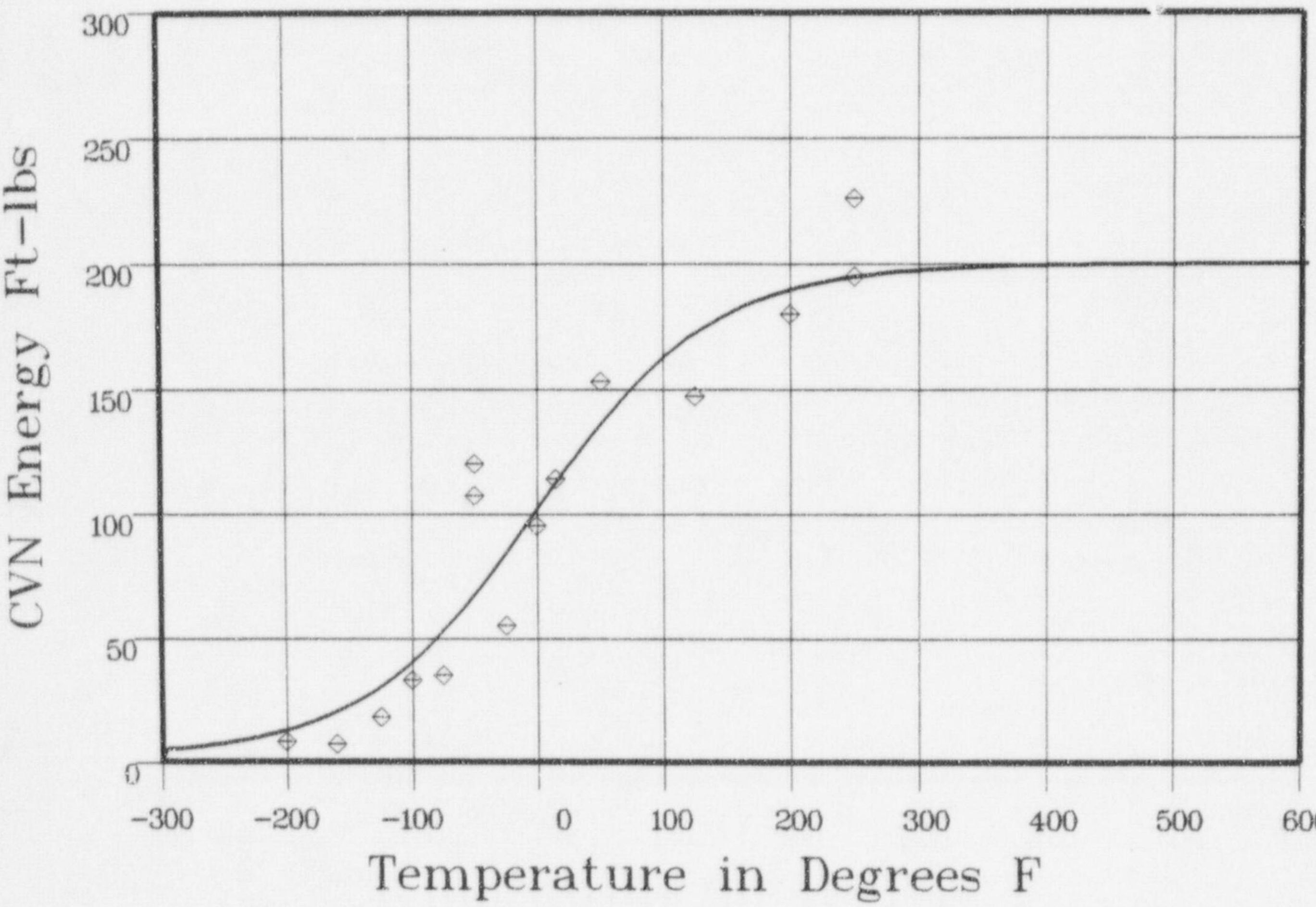
A = 101.09	B = 98.9	C = 138.51	T0 = -5.62

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

Upper Shelf Energy: 200 Fixed Temp. at 30 ft-lbs: -131 Temp. at 50 ft-lbs: -84.8 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFF'D ZONE Heat Number: Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: Y Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-200	8	13.46	-5.46
-160	7	21.42	-14.42
-125	18	32.14	-14.14
-100	33	42.51	-9.51
-75	35	55.32	-20.32
-50	107	70.45	36.54
-50	120	70.45	49.54
-25	55	87.35	-32.35

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

CAPSULE Y (HAZ)

Page 2

Material: HEAT AFF'D ZONE   Heat Number: Orientation:

Capsule: Y   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	95	105.11	-10.11
15	114	115.71	-1.71
50	153	138.81	14.18
125	147	173.95	-26.95
200	180	190.33	-10.33
250	195	195.18	-.18
250	226	195.18	30.81

SUM of RESIDUALS = -14.45

CAPSULE V (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:39:46 on 05-28-1998

Page 1

Coefficients of Curve 4

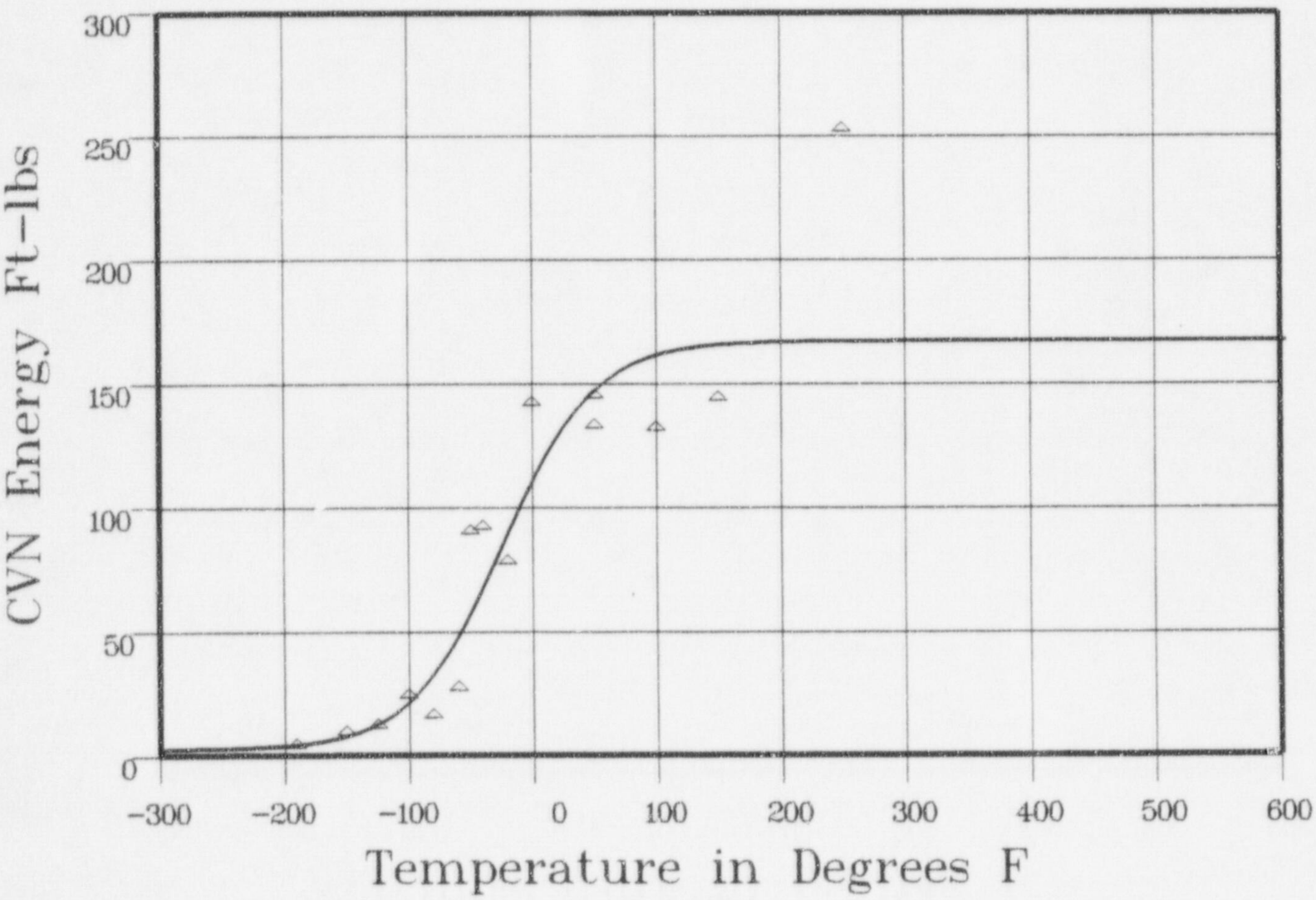
A = 84.59	B = 82.4	C = 74.61	T0 = -28.59

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

Upper Shelf Energy: 167 Fixed Temp. at 30 ft-lbs: -88 Temp. at 50 ft-lbs: -61.9 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: V Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-190	3	4.34	-1.34
-150	8	8.32	-.32
-125	11	13.76	-2.76
-100	23	23.38	-.38
-80	15	35.38	-20.38
-60	26	51.83	-25.83
-50	89	61.58	27.41

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

CAPSULE V (HAZ)

Page 2

Material: HEAT AFF'D ZONE   Heat Number: Orientation:

Capsule: V   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-40	91	72.1	18.89
-20	77	94.04	-17.04
0	141	114.71	26.28
50	144	149.12	-5.12
50	132	149.12	-17.12
100	131	161.91	-30.91
150	143	165.63	-22.63
250	252	166.9	85.09

SUM of RESIDUALS = 13.79

UNIRRADIATED (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:47:31 on 05-28-1998

Page 1

Coefficients of Curve 1

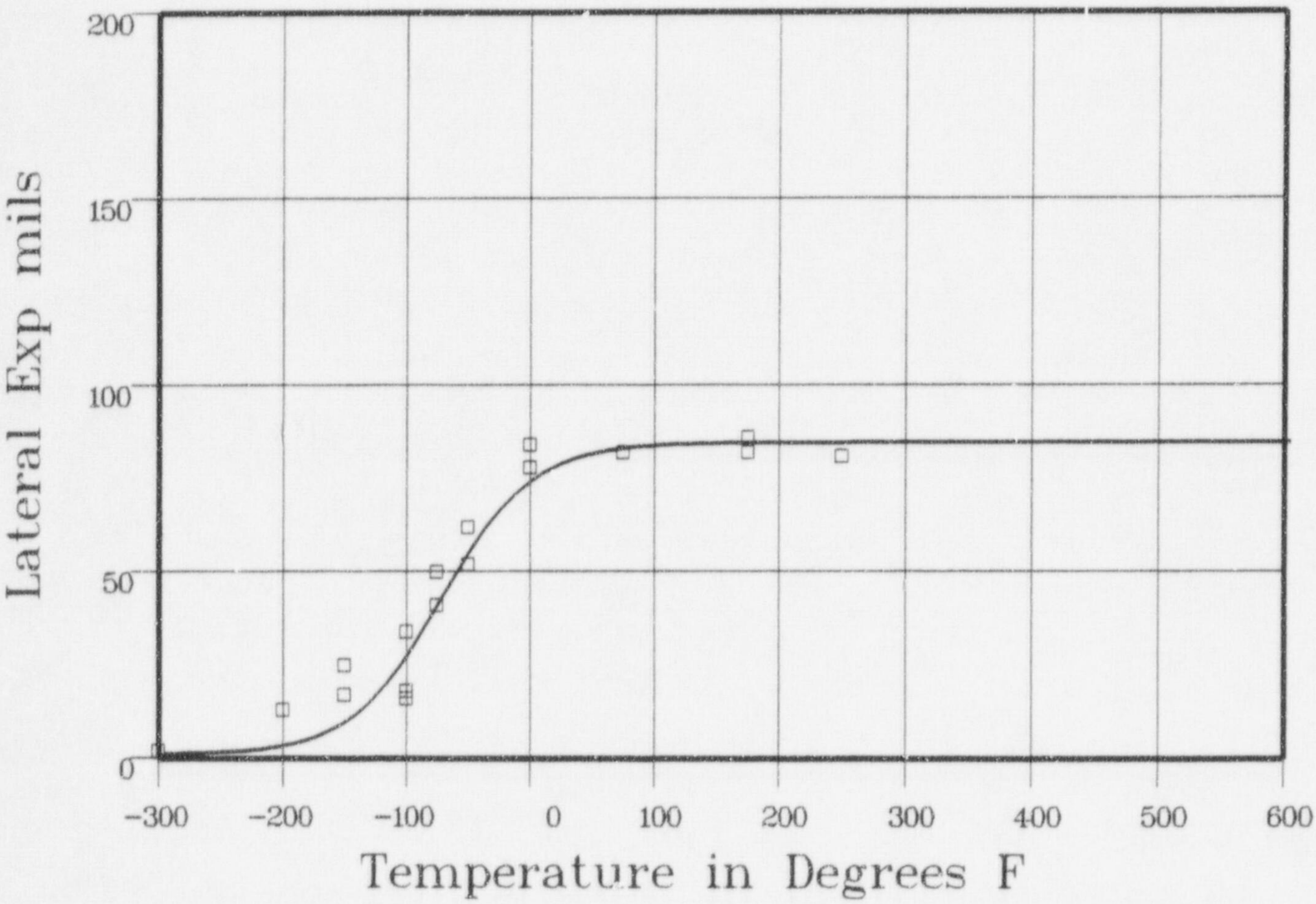
A = 42.82	B = 41.82	C = 73.15	T0 = -75.93

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

Upper Shelf L.E.: 84.65 Temperature at L.E. 35: -89.7 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: UNIRR Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-300	2	1.18	.81
-200	13	3.72	9.27
-150	25	10.75	14.24
-150	17	10.75	6.24
-100	16	29.54	-13.54
-100	18	29.54	-11.54
-100	34	29.54	4.45
-75	50	43.36	6.63
-75	41	43.36	-2.36

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

UNIRRADIATED (HAZ)

Page 2

Material: HEAT AFF'D ZONE   Heat Number: Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	62	57.06	4.93
-50	52	57.06	-5.06
0	78	75.33	2.66
0	84	75.33	8.66
75	82	83.32	-1.32
75	82	83.32	-1.32
175	82	84.56	-2.56
175	86	84.56	1.43
250	81	84.64	-3.64

SUM of RESIDUALS = 18

CAPSULE U (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:47:31 on 05-28-1998

Page 1

Coefficients of Curve 2

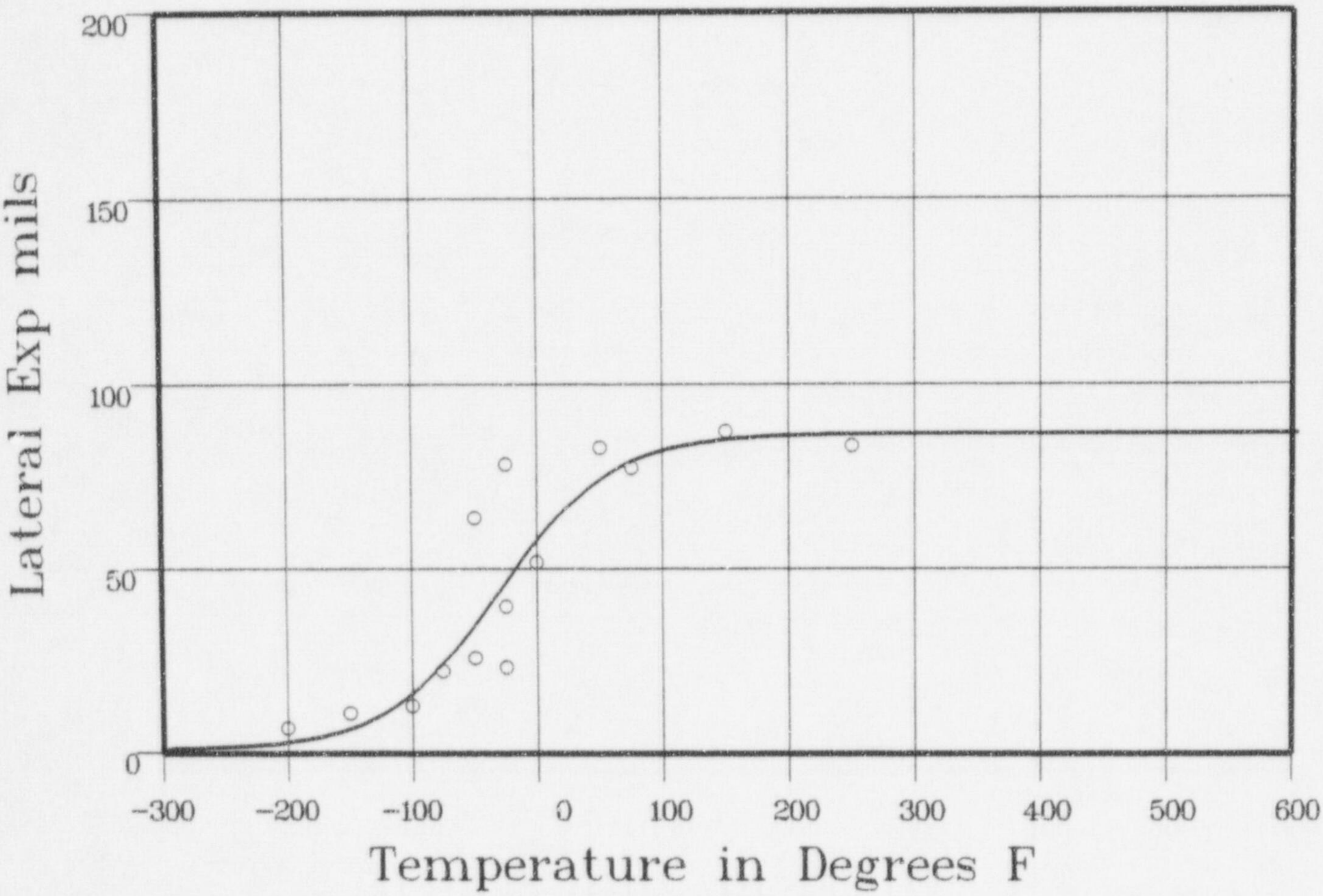
A = 43.88	B = 42.88	C = 90.78	T0 = -35.15

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

Upper Shelf L.E.: 86.77 Temperature at L.E. 35: -54.2 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFF'D ZONE Heat Number: Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: U Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-200	7	3.21	3.78
-150	11	7.32	3.67
-100	13	17.58	-4.58
-75	22.5	26.18	-3.68
-75	22.5	26.18	-3.68
-50	64	36.93	27.06
-50	26	36.93	-10.93
-25	40	48.66	-8.66

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

CAPSULE U (HAZ)

Page 2

Material: HEAT AFF'D ZONE Heat Number: Orientation:

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	23.5	48.66	-25.16
-25	78.5	48.66	29.83
0	52	59.71	-7.71
50	83	75.38	7.61
76	77.5	79.95	-2.45
150	87.5	85.35	2.14
250	83.5	86.61	-3.11

SUM of RESIDUALS = 4.09

CAPSULE Y (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:47:31 on 05-28-1998

Page 1

Coefficients of Curve 3

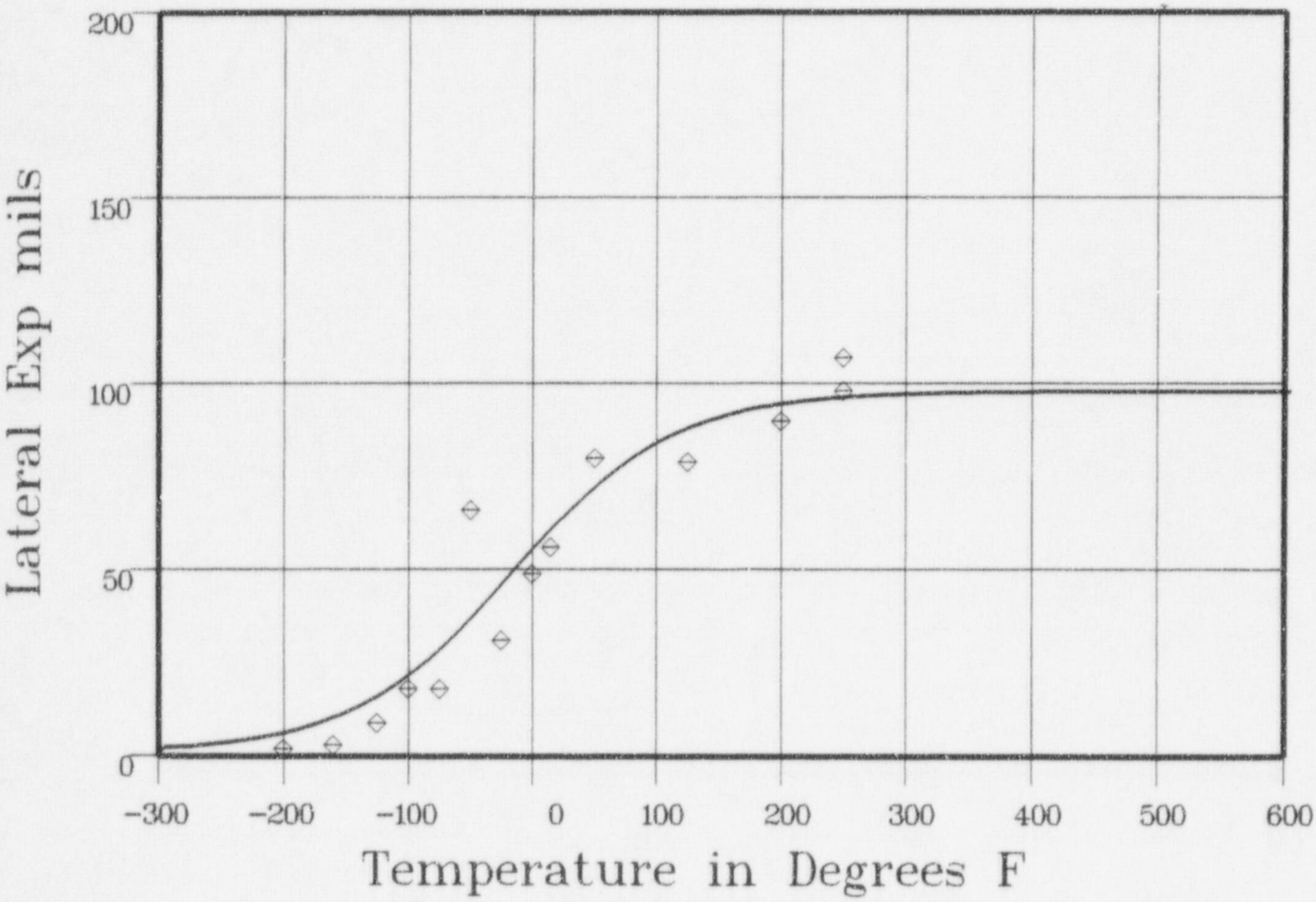
A = 49.48	B = 48.48	C = 129.49	[illegible] 6.32

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

Upper Shelf L.E.: 97.96 Temperature at L.E. 35: -60.5 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: Y Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-200	2	6.71	-4.71
-160	3	11.09	-8.09
-125	9	17.12	-8.12
-100	18	22.99	-4.99
-75	18	30.24	-12.24
-50	66	38.66	27.33
-50	66	38.66	27.33
-25	31	47.84	-16.84

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

CAPSULE Y (HAZ)

Page 2

Material: HEAT AFF'D ZONE   Heat Number: Orientation:

Capsule: Y   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	49	57.13	-8.13
15	56	62.49	-6.49
50	80	73.57	6.42
125	79	88.7	-9.7
200	90	94.85	-4.85
250	98	96.49	1.5
250	107	96.49	10.5

SUM of RESIDUALS = -11.11

CAPSULE V (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:47:31 on 05-28-1998

Page 1

Coefficients of Curve 4

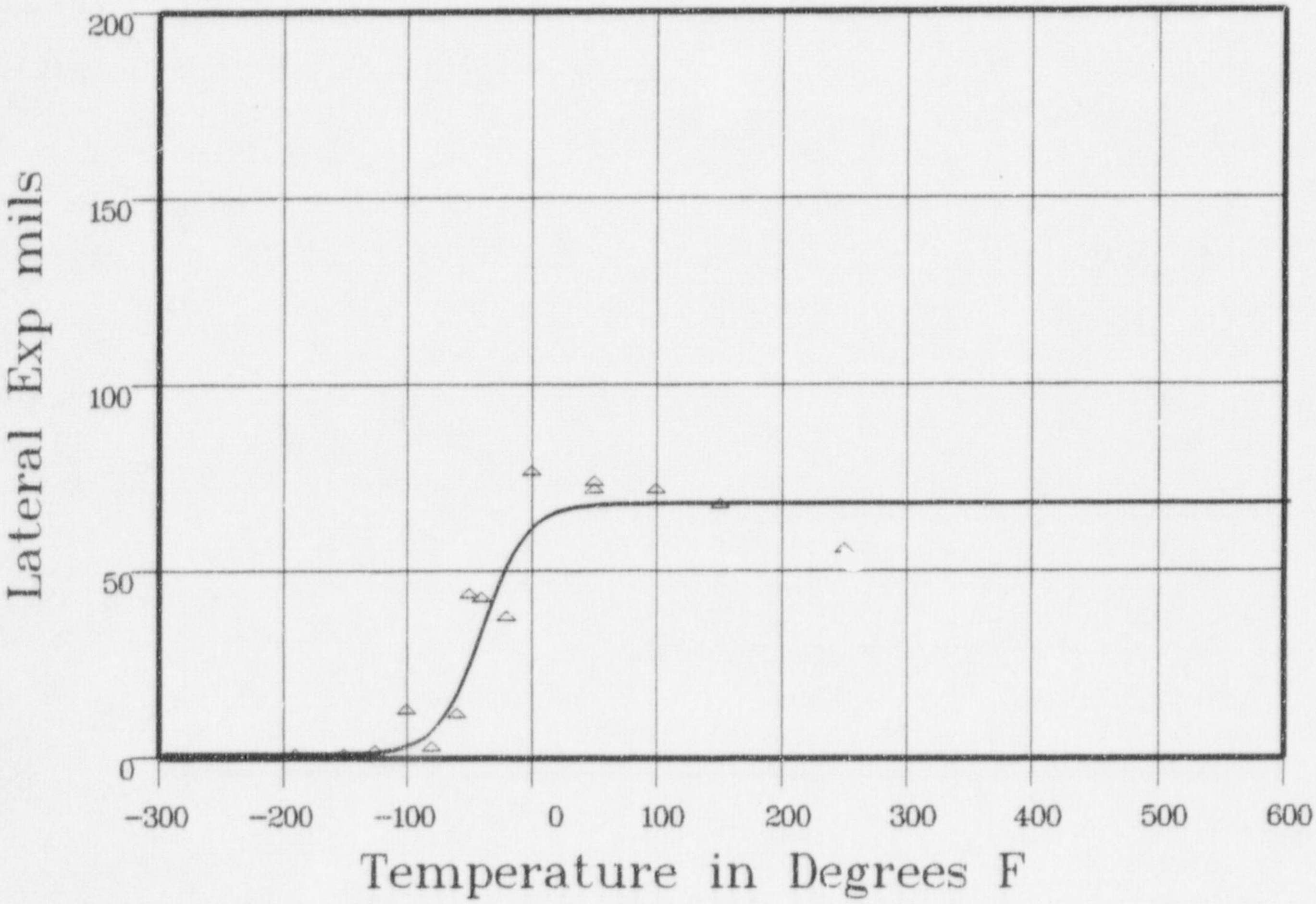
A = 34.57	B = 33.57	C = 35.77	T0 = -44.06

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

Upper Shelf L.E: 68.14 Temperature at L.E. 35: -43.6 Lower Shelf L.E: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: V Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-190	0	1.01	-1.01
-150	0	1.17	-1.17
-125	1	1.71	-.71
-100	12	3.82	8.17
-80	2	8.94	-6.94
-60	11	20.53	-9.53
-50	43	29.05	13.94

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

CAPSULE V (HAZ)

Page 2

Material: HEAT AFF'D ZONE   Heat Number: Orientation:

Capsule: V   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-40	42	38.37	3.62
-20	37	54.27	-17.27
0	76	62.87	13.12
50	73	67.8	5.19
50	71	67.8	3.19
100	71	68.12	2.87
150	67	68.14	-1.14
250	55	68.14	-13.14

SUM of RESIDUALS = -.81

UNIRRADIATED (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:51:50 on 05-28-1998

Page 1

Coefficients of Curve 1

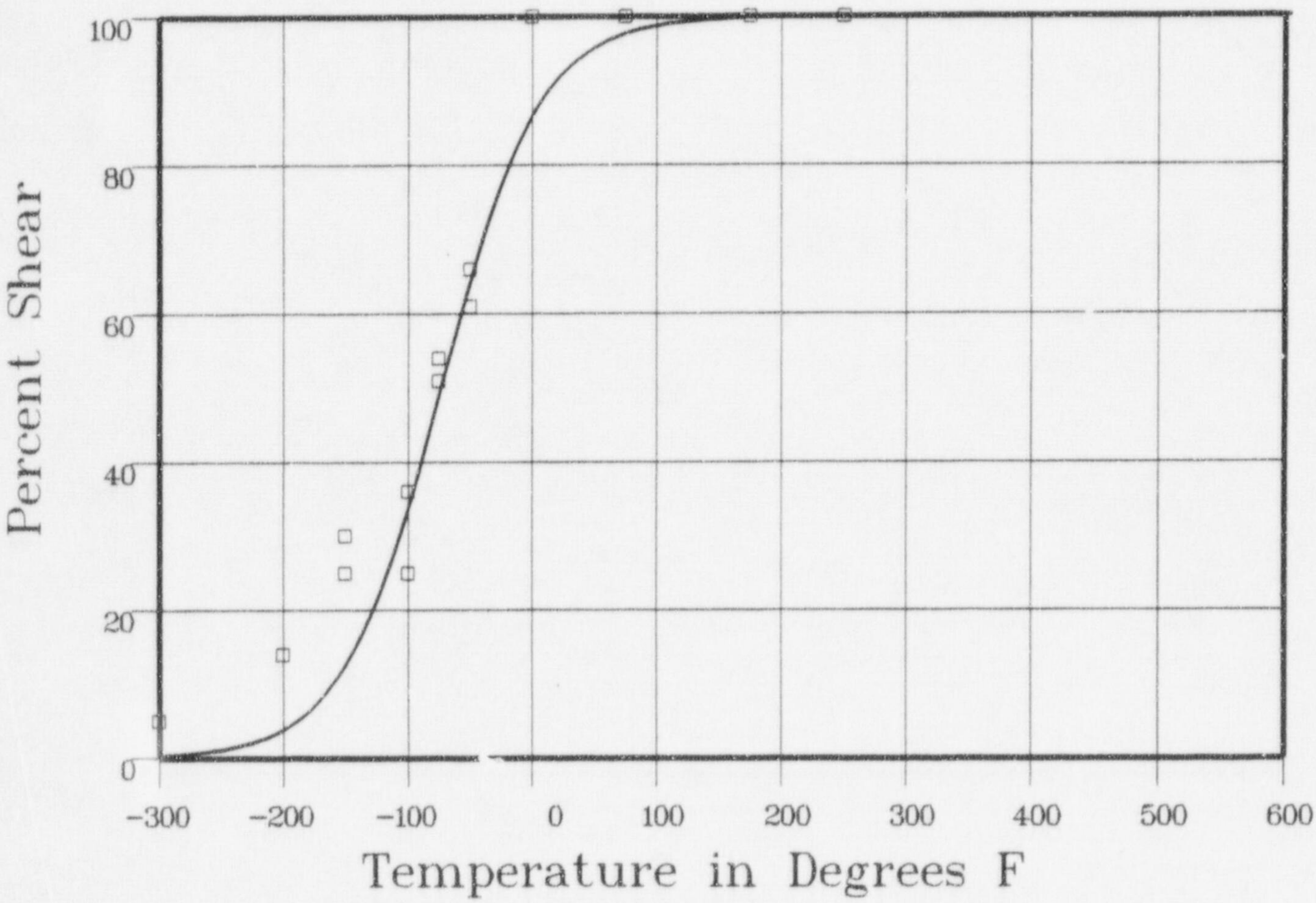
A = 50	B = 50	C = 78.8	T0 = -77.81

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

Temperature at 50% Shear: -77.8

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: UNIRR Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-300	5	.35	4.64
-200	14	4.3	9.69
-150	30	13.8	16.19
-150	25	13.8	11.19
-100	25	36.28	-11.28
-100	25	36.28	-11.28
-100	36	36.28	-.28
-75	51	51.78	-.78
-75	54	51.78	2.21

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

UNIRRADIATED (HAZ)

Page 2

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V--Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	66	66.94	-.94
-50	61	66.94	-5.94
0	100	87.81	12.18
0	100	87.81	12.18
75	100	97.97	2.02
75	100	97.97	2.02
175	100	99.83	.16
175	100	99.83	.16
250	100	99.97	.02

SUM of RESIDUALS = 42.2

CAPSULE U (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:51:50 on 05-28-1998

Page 1

Coefficients of Curve 2

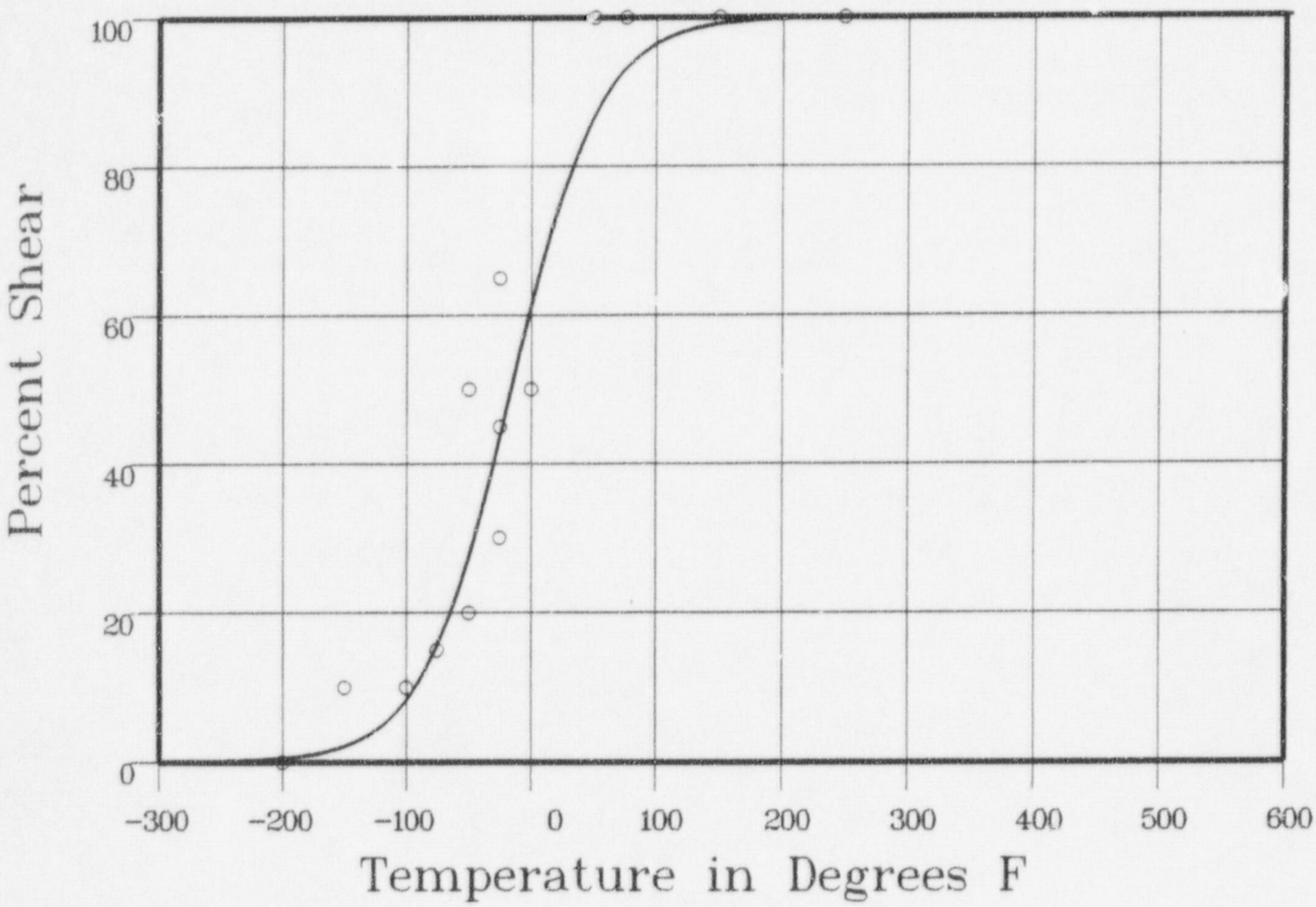
A = 50	B = 50	C = 70.05	T0 = -20.47

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

Temperature at 50% Shear: -20.4

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: U   Total Fluence:



Data Set(s) Plotted

Plant: WC1   Cap.: U   Material: HEAT AFFD ZONE   Ori.:   Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-200	0	.59	-.59
-150	10	2.41	7.58
-100	10	9.36	.63
-75	15	17.41	-2.41
-75	15	17.41	-2.41
-50	50	30.09	19.9
-50	20	30.09	-10.09
-25	45	46.77	-1.77

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

CAPSULE U (HAZ)

Page 2

Material: HEAT AFF'D ZONE   Heat Number: Orientation:

Capsule: U   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	30	46.77	-16.77
-25	65	46.77	18.22
0	50	64.2	-14.2
50	100	88.2	11.79
76	100	94.01	5.98
150	100	99.23	.76
250	100	99.95	.04

SUM of RESIDUALS = 16.68

CAPSULF Y (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:51:50 on 05-28-1998

Page 1

Coefficients of Curve 3

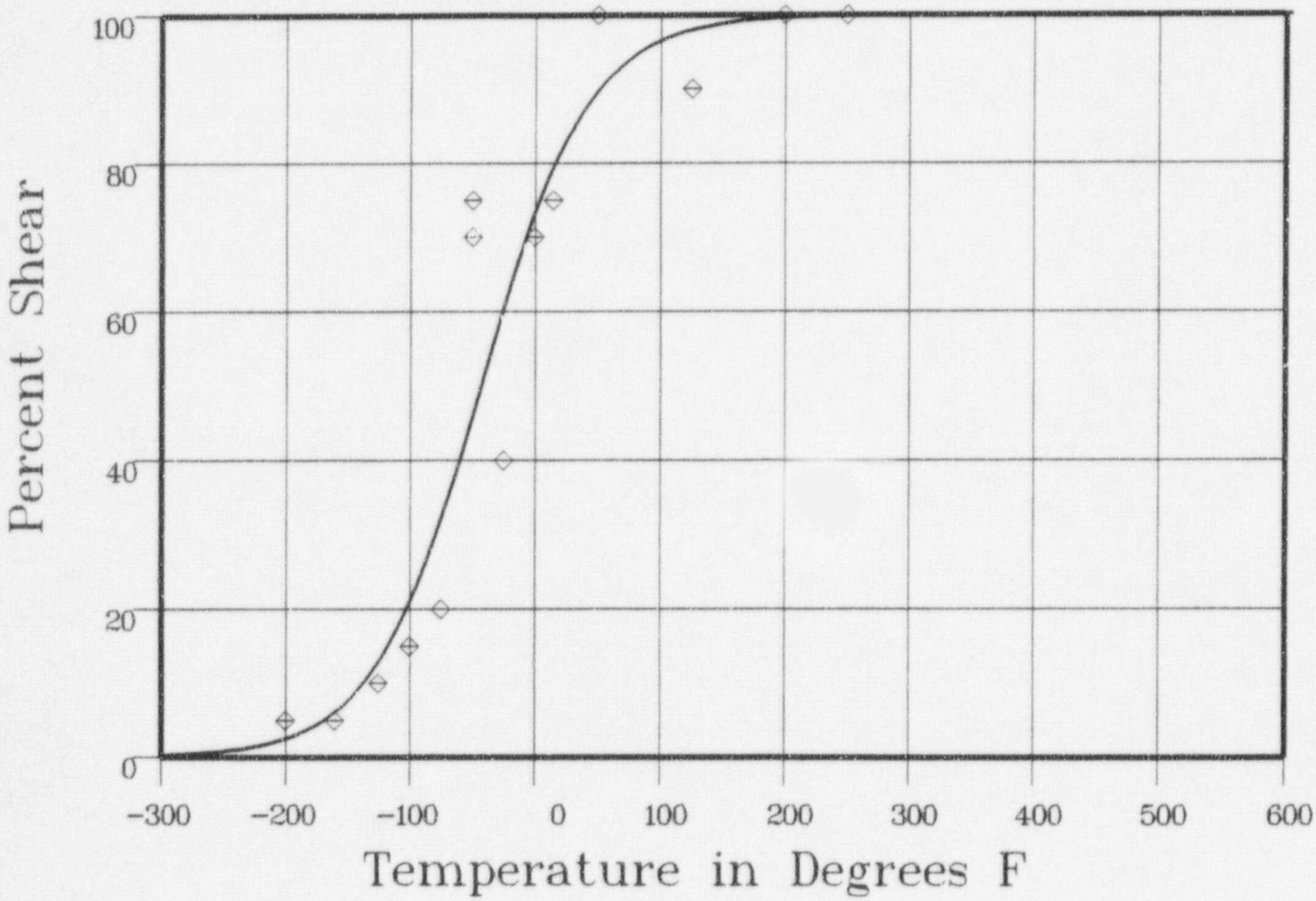
A = 50	B = 50	C = 85.89	T0 = -47.81

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

Temperature at 50% Shear: -47.8

Material: HEAT AFF'D ZONE Heat Number: Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: Y Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-200	5	2.8	2.19
-160	5	6.83	-1.83
-125	10	14.21	-4.21
-100	15	22.87	-7.87
-75	20	34.68	-14.68
-50	70	48.72	21.27
-50	75	48.72	26.27
-25	40	62.97	-22.97

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

CAPSULE Y (HA'')

Page 2

Material: HEAT AFF'D ZONE   Heat Number: Orientation:

Capsule: Y   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	70	75.27	-5.27
15	75	81.19	-6.19
50	100	90.69	9.3
125	90	98.24	-8.24
200	100	99.68	.31
250	100	99.9	.09
250	100	99.9	.09

SUM of RESIDUALS = -11.75

CAPSULE V (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:51:50 on 05-28-1998

Page 1

Coefficients of Curve 4

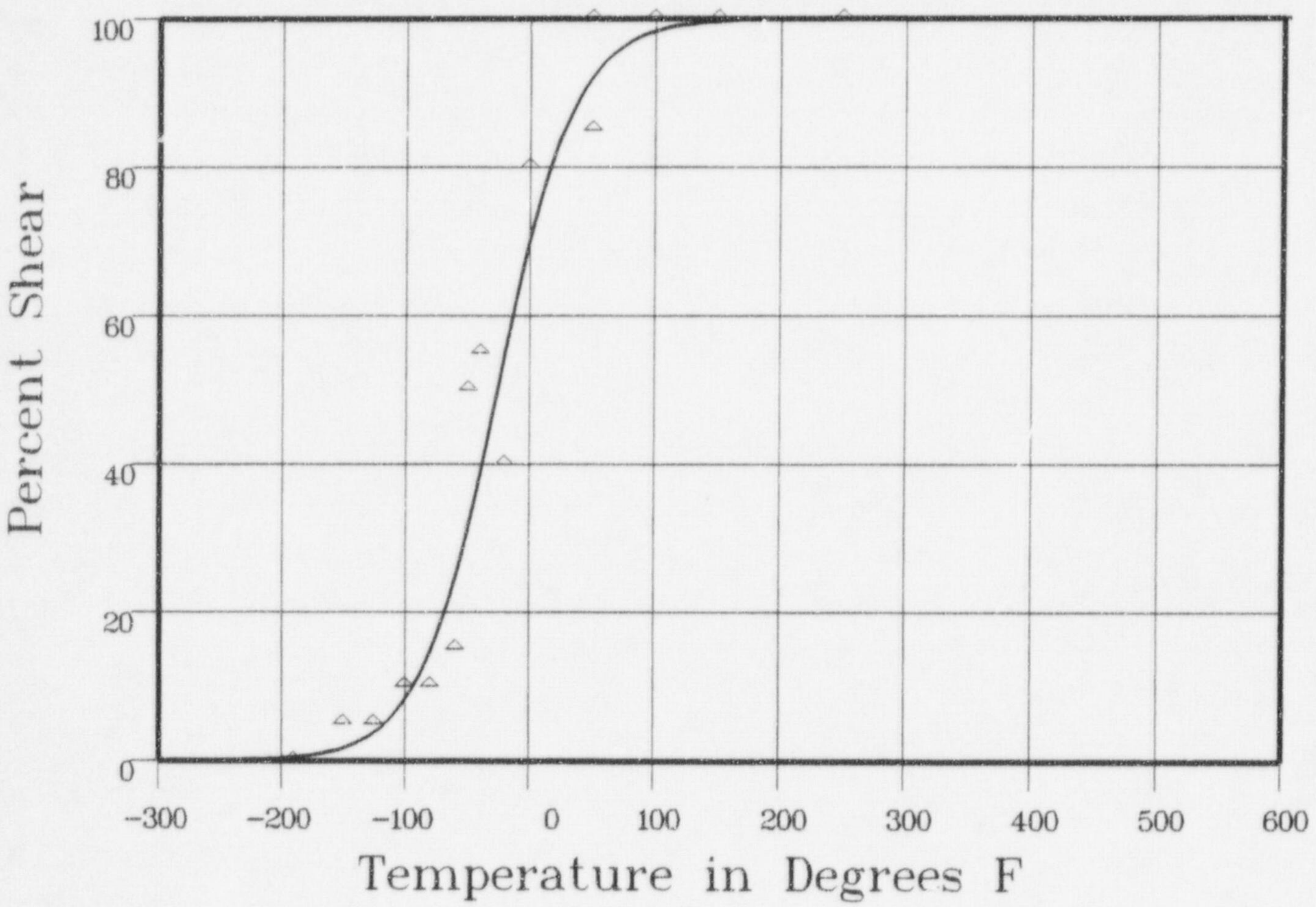
A = 50	B = 50	C = 61.53	T0 = -30.46

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

Temperature at 50% Shear: -30.4

Material: HEAT AFF'D ZONE Heat Number: Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: WC1 Cap.: V Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-190	0	.55	-.55
-150	5	2.01	2.98
-125	5	4.42	.57
-100	10	9.45	.54
-80	10	16.66	-6.66
-60	15	27.69	-12.69
-50	50	34.64	15.35

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

CAPSULE V (HAZ)

Page 2

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40	55	42.31	12.68
-20	40	58.42	-18.42
0	80	72.91	7.08
50	100	93.18	6.81
50	85	93.18	-8.18
100	100	98.58	1.41
150	100	99.71	.28
250	100	99.98	.01

SUM of RESIDUALS = 1.24

APPENDIX D

Wolf Creek Unit 1 Surveillance Program Credibility Analysis

INTRODUCTION:

Regulatory Guide 1.99, Revision 2, describes general procedures acceptable to the NRC staff for calculating the effects of neutron radiation embrittlement of the low-alloy steels currently used for light-water-cooled reactor vessels. Position C.2 of Regulatory Guide 1.99, Revision 2, describes the method for calculating the adjusted reference temperature and Charpy upper-shelf energy of reactor vessel beltline materials using surveillance capsule data. The methods of Position C.2 can only be applied when two or more credible surveillance data sets become available from the reactor in question.

To date there has been three surveillance capsules removed from the Wolf Creek Unit 1 reactor vessel. To use these surveillance data sets, they must be shown to be credible. In accordance with the discussion of Regulatory Guide 1.99, Revision 2, there are five requirements that must be met for the surveillance data to be judged credible.

The purpose of this evaluation is to apply the credibility requirements of Regulatory Guide 1.99, Revision 2, to the Wolf Creek Unit 1 reactor vessel surveillance data and determine if the Wolf Creek Unit 1 surveillance data is credible.

EVALUATION:

Criterion 1: Materials in the capsules should be those judged most likely to be controlling with regard to radiation embrittlement.

The beltline region of the reactor vessel is defined in Appendix G to 10 CFR Part 50, "Fracture Toughness Requirements", as follows:

> "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."

The Wolf Creek Unit 1 reactor vessel consists of the following beltline region materials:

- Intermediate shell plate R2005-1,
- Intermediate shell plate R2005-2,
- Intermediate shell plate R2005-3,
- Lower shell plate R2508-1,
- Lower shell plate R2508-2,
- Lower shell plate R2508-3, and
- All vessel beltline weld seams were fabricated with weld wire heat number 90146. The intermediate to lower shell circumferential weld seam 101-171 was fabricated with Flux Type 124 Lot Number 1061. The intermediate and lower shell longitudinal weld seams 101-124A, B & C and 101-142A, B & C were fabricated with Flux Type 0091 Lot Number 0842. The surveillance weld metal was fabricated with weld wire heat number 90146, Flux Type 124 Lot Number 1061. Per Regulatory Guide 1.99, Revision 2, "weight-percent copper" and "weight percent nickel" are the best-estimate values for the material, which will normally be the mean of the measured values for a plate or forging or for weld samples made with the weld wire heat number that matches the critical vessel weld". The surveillance weld metal was made with the same weld wire heat as all of the vessel beltline weld seams and is therefore representative of all of the beltline weld seams.

The Wolf Creek Unit 1 surveillance program utilizes longitudinal and transverse test specimens from lower shell plate R2508-3. The surveillance weld metal was fabricated with weld wire heat number 90146, Flux Type 124 Lot Number 1061.

The Wolf Creek Unit 1 surveillance program was based on ASTM E185-79. When the surveillance program material was selected it was believed that copper and phosphorus were the elements most important to embrittlement of reactor vessel steels. Lower shell plate R2508-3 had the highest initial RT_{NDT} and the lowest initial USE of all plate materials in the beltline region. In addition, lower shell plate R2508-3 had approximately the same copper and phosphorous content as the other beltline plate materials. Hence, based on the highest initial RT_{NDT} and lowest initial upper shelf energy, lower shell plate R2508-3 was chosen for the surveillance program.

Per Regulatory Guide 1.99, Revision 2, "weight-percent copper" and "weight percent nickel" are the best-estimate values for the material, which will normally be the mean of the measured values for a plate or forging or for weld samples made with the weld wire heat number that matches the critical vessel weld". Since, the surveillance weld metal was made with the same weld wire heat as all of the vessel beltline weld seams, it is representative of the limiting beltline weld metal.

Based on the above discussion, the Wolf Creek Unit 1 surveillance material meets the intent of this criteria.

Criterion 2: Scatter in the plots of Charpy energy versus temperature for the irradiated and unirradiated conditions should be small enough to permit the determination of the 30 ft-lb temperature and upper shelf energy unambiguously.

Plots of Charpy energy versus temperature for the unirradiated and irradiated condition are presented Appendix A of this calcnote.

Based on engineering judgement, the scatter in the data presented in these plots is small enough to permit the determination of the 30 ft-lb temperature and the upper shelf energy of the Wolf Creek Unit 1 surveillance materials unambiguously. Hence, the Wolf Creek Unit 1 surveillance program meets this criterion.

Criterion 3: When there are two or more sets of surveillance data from one reactor, the scatter of ΔRT_{NDT} values about a best-fit line drawn as described in Regulatory Position 2.1 normally should be less than 28°F for welds and 17°F for base metal. Even if the fluence range is large (two or more orders of magnitude), the scatter should not exceed twice those values. Even if the data fail this criterion for use in shift calculations, they may be credible for determining decrease in upper shelf energy if the upper shelf can be clearly determined, following the definition given in ASTM E185-82.

The functional form of the least squares method as described in Regulatory Position 2.1 will be utilized to determine a best-fit line for this data and to determine if the scatter of these ΔRT_{NDT} values about this line is less than 28°F for welds and less than 17°F for the plate.

Following is the calculation of the best fit line as described in Regulatory Position 2.1 of Regulatory Guide 1.99, Revision 2.

NOTE: **Since the calculated vessel fluence values are greater than the best estimate vessel fluences values, the calculated fluence values will be used for all calculations.**

TABLE D-1

Wolf Creek Surveillance Capsule Data

Material	Capsule	$F^{(1)}$	$FF^{(2)}$	ΔRT_{NDT}	$FF x \Delta RT_{NDT}$	FF^2
Lower Shell Plate R2508-3 (Longitudinal)	U	0.3429	0.705	36.46°F	25.70°F	0.50
	Y	1.308	1.075	16.03°F	17.23°F	1.16
	V	2.528	1.249	52.03°F	64.99°F	1.56
Lower Shell Plate R2508-3 (Transverse)	U	0.3429	0.705	23.79°F	16.77°F	0.50
	Y	1.308	1.075	35.39°F	38.04°F	1.16
	V	2.528	1.249	54.53°F	68.11°F	1.56
				SUM	230.84°F	6.44
	$CF_{R2508\text{-}3} = \Sigma(FF^*RT_{NDT}) \div \Sigma(FF^2) = (230.84°F) \div (6.44) = 35.8°F$					
Weld Metal(3)	U	0.3429	0.705	27.21°F	19.18°F	0.50
	Y	1.308	1.075	45.09°F	48.47°F	1.16
	V	2.528	1.249	46.33°F	57.87°F	1.56
				SUM	125.52°F	3.22
	$CF_{weld} = \Sigma(FF^*RT_{NDT}) \div \Sigma(FF^2) = (125.52) \div (3.22) = 39.0°F$					

(1) F = Calculated Fluence (10^{19} n/cm^2, E > 1.0 MeV). These values were re-evaluated as part of the capsule V analysis (See Section 6 of this report).

(2) FF = Fluence Factor = $F^{(0.28 - 0.1 * \log F)}$

(3) ΔRT_{NDT} values do not include the adjustment ratio procedure of Regulatory Guide 1.99, Revision 2, Position 2.1, since this calculation is based on the actual surveillance weld metal measured shift values.

The scatter of ΔRT_{NDT} values about the functional form of a best-fit line drawn as described in Regulatory Position 2.1 is presented in Table D-2.

TABLE D-2

Predicted Versus Best-Estimate ΔRT_{NDT} Values for the Wolf Creek Unit 1 Surveillance Materials

Material	Capsule	CF	FF	Best-Estimate ΔRT_{NDT} [(a)]	Measured ΔRT_{NDT} [(b)]	Change in ΔRT_{NDT}
Lower Shell Plate R2508-3 (Longitudinal)	U	35.8°F	0.705	25.24	36.46°F	-11.2
	Y	35.8°F	1.075	38.49	16.03°F	22.46
	V	35.8°F	1.249	44.71	52.03°F	-7.32
Lower Shell Plate R2508-3 (Transverse)	U	35.8°F	0.705	25.24	23.79°F	1.45
	Y	35.8°F	1.075	38.49	35.39°F	3.10
	V	35.8°F	1.249	44.71	54.53°F	-9.82
Surveillance Program Weld Metal	U	39.0°F	0.705	27.50	27.21°F	0.29
	Y	39.0°F	1.075	41.93	45.09°F	-3.16
	V	39.0°F	1.249	48.71	46.33°F	2.38

NOTES:

(a) Best-estimate ΔRT_{NDT} = CF * FF. Where the CF used when comparing best-estimate ΔRT_{NDT} values to measured ΔRT_{NDT} values for the credibility analysis were calculated based on the measured surveillance data.

(b) Calculated using measured Charpy data plotted using CVGRAPH 4.1[4] (See Appendix A).

The scatter of ΔRT_{NDT} values about the functional form of a best-fit line drawn as described in Regulatory Position 2.1 (Table C-2) is less than 17°F for all but one plate material data point. One out of six values for the plate material would be expected to be out of the 1 σ range.

However, the capsule Y longitudinal data point is out on the low side (ie. the prediction is 22.5°F higher the measured value) and is less than 2 σ [illegible]. The scatter of ΔRT_{NDT} values about the functional form of a best-fit line drawn as described in Regulatory Position 2.1 (Table C-2) is and less than 28°F for the weld metal. Therefore, this criteria is met for the surveillance data of the Wolf Creek Unit 1 surveillance program material. This result is also presented graphically in Figures D-1 and D-2.

FIGURE D-1

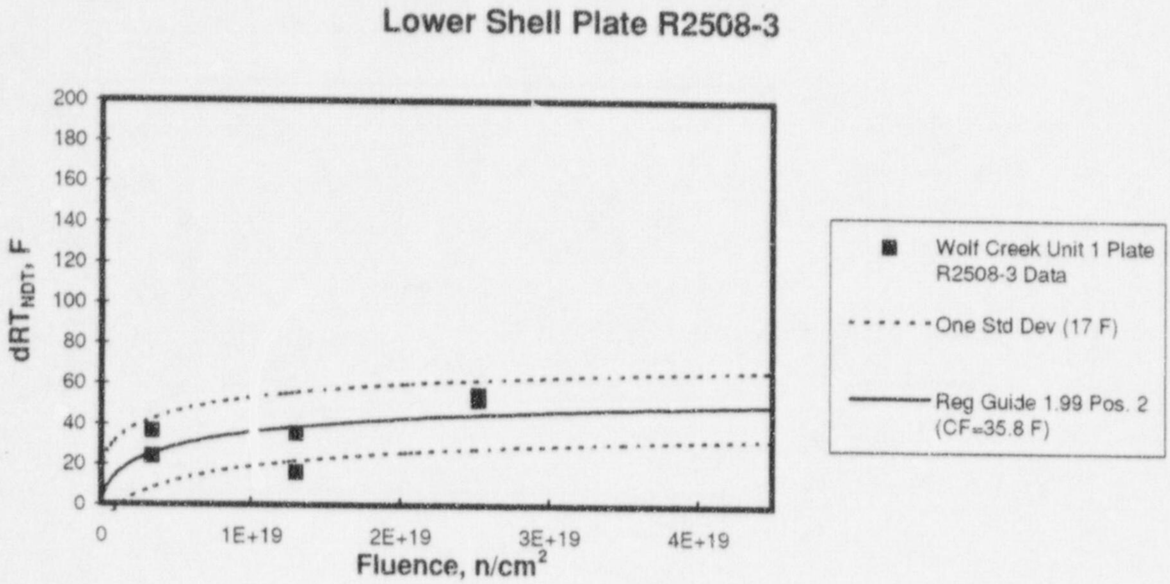
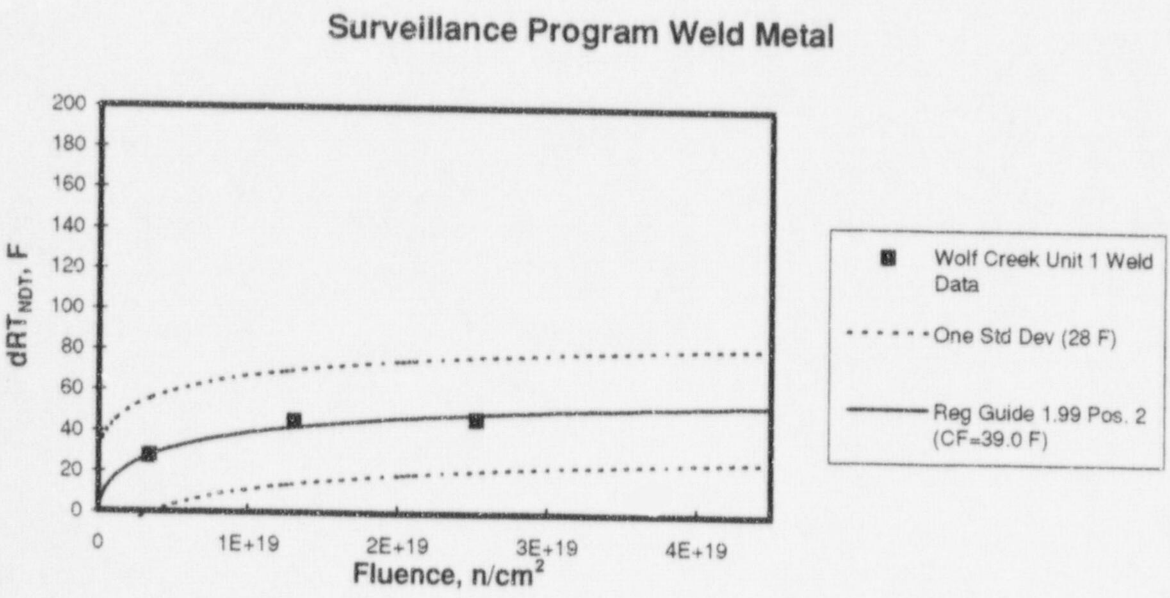


FIGURE D-2



Criterion 4: The irradiation temperature of the Charpy specimens in the capsule should match the vessel wall temperature at the cladding/base metal interface within +/- 25°F.

The capsule specimens are located in the reactor between the neutron pads and the vessel wall and are positioned opposite the center of the core. The test capsules are in baskets attached to the neutron pads. The location of the specimens with respect to the reactor vessel beltline provides assurance that the reactor vessel wall and the specimens experience equivalent operating conditions such that the temperatures will not differ by more than 25°F. Hence, this criteria is met.

Criterion 5: The surveillance data for the correlation monitor material in the capsule should fall within the scatter band of the data base for that material.

The Wolf Creek Unit 1 surveillance program does not contain correlation monitor material. Therefore, this criterion is not applicable to the Wolf Creek Unit 1 surveillance program.

CONCLUSION:

Based on the preceding positive responses to all five criteria of Regulatory Guide 1.99, Revision 2, Section B, the Wolf Creek Unit 1 surveillance data is credible.