Westinghouse Non-Proprietary Class 3

WCAP-15101

Analysis of Capsule W from the South Carolina Electric & Gas Company V.C. Summer Unit 1 Reactor Vessel Radiation Surveillance Program

Westinghouse Energy Systems

Westinghouse Non-Proprietary Class 3

WCAP - 15101
Revision 0

Analysis of Capsule W from the South Carolina Electric & Gas Company V.C. Summer Unit 1 Reactor Vessel Radiation Surveillance Program

Westinghouse Energy Systems

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-15101

Analysis of Capsule W from the South Carolina Electric & Gas Company V.C. Summer Unit 1 Reactor Vessel Radiation Surveillance Program

T. J. Laubham
J. D. Perock
R. G. Lott

September 1998

Approved: ______________________
C. H. Boyd, Manager
Equipment & Materials Technology

Approved: ______________________ 9/28/98
D. M. Trombola, Manager
Mechanical Systems Integration

Westinghouse Electric Company
Energy Systems
P.O. Box 355
Pittsburgh, PA 15230-0355

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF TABLES (Cont.)

LIST OF FIGURES

LIST OF FIGURES (Cont.)

PREFACE

This report has been technically reviewed and verified by:

Reviewer:

Sections 1 through 5, 7, 8, Appendices A, B and C	Ed Terek	Ed Terek
Section 6	George Roberts	GK Roberts

EXECUTIVE SUMMARY

The purpose of this report is to document the results of the testing of surveillance capsule W from V.C. Summer Unit 1. Capsule W was removed at 10.78 EFPY and post irradiation mechanical tests of the Charpy V notch and tensile specimens was performed, along with a fluence evaluation. The peak clad base/metal vessel fluence after 10.78 EFPY of plant operation was 1.37×10^{19} n/cm^2. A brief summary of the Charpy V-notch testing can be found in Section 1 and the updated capsule removal schedule can be found in Section 7. A supplement to this report is a credibility evaluation, which can be found in Appendix D, that shows the V.C. Summer Unit 1 surveillance data to be credible.

1 SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance capsule W, the fourth capsule to be removed from the V.C. Summer Unit 1 reactor pressure vessel, led to the following conclusions:

- The capsule received an average fast neutron fluence (E> 1.0 MeV) of 4.664 x 10^{19} n/cm^2 after 10.78 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel intermediate shell plate A9154-1 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major rolling direction (Longitudinal orientation), to 4.664 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 66°F and a 50 ft-lb transition temperature increase of 76°F. This results in an irradiated 30 ft-lb transition temperature of 44°F and an irradiated 50 ft-lb transition temperature of 83°F for the Longitudinal oriented specimens.

- Irradiation of the reactor vessel intermediate shell plate A9154-1 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major rolling direction of the plate (Transverse orientation), to 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 58°F and a 50 ft-lb transition temperature increase of 68°F. This results in an irradiated 30 ft-lb transition temperature of 86°F and an irradiated 50 ft-lb transition temperature of 139°F for Transverse oriented specimens.

- Irradiation of the weld metal Charpy specimens to 4.664 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 43°F and a 50 ft-lb transition temperature increase of 52°F. This results in an irradiated 30 ft-lb transition temperature of -10°F and an irradiated 50 ft-lb transition temperature of 40°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 60°F and a 50 ft-lb transition temperature increase of 70°F. This results in an irradiated 30 ft-lb transition temperature of -33°F and an irradiated 50 ft-lb transition temperature of 4°F.

- The average upper shelf energy of the intermediate shell plate A9154-1 (Longitudinal orientation) resulted in an average energy decrease of 6 ft-lb after irradiation to 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV). This results in an irradiated average upper shelf energy of 126 ft-lb for the Longitudinal oriented specimens.

- The average upper shelf energy of the intermediate shell plate A9154-1 (Transverse orientation) resulted in an average energy decrease of 1 ft-lb after irradiation to 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 74 ft-lb for the Transverse oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted an average energy decrease of 4 ft-lb after irradiation to 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 87 ft-lb for the weld metal specimens.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in an average energy decrease of 27 ft-lb after irradiation to 4.664 x 10^{19} n/cm^2 (E> 1.0MeV). This results in an irradiated average upper shelf energy of 103 ft-lb for the weld HAZ metal.

- A comparison of the V.C. Summer Unit 1 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 all surveillance materials are less than the Regulatory Guide 1.99, Revision 2, predictions.

  — The measured USE values of all surveillance materials are less than the Regulatory Guide 1.99, Revision 2, predictions.

- The calculated and best estimate end-of-license (32 EFPY) neutron fluence (E> 1.0 MeV) at the core midplane for the V.C. Summer Unit 1 reactor vessel using the Regulatory Guide 1.99, Revision 2 attenuation formula (ie. Equation # 3) is as follows:

<u>Calculated:</u> Vessel inner radius* = 3.84 x 10^{19} n/cm^2

Vessel 1/4 thickness = 2.41 x 10^{19} n/cm^2

Vessel 3/4 thickness = 9.52 x 10^{18} n/cm^2

<u>Best Estimate:</u> Vessel inner radius* = 3.66 x 10^{19} n/cm^2

Vessel 1/4 thickness = 2.30 x 10^{19} n/cm^2

Vessel 3/4 thickness = 9.07 x 10^{18} n/cm^2

*Clad/base metal interface

- The credibility evaluation of the V.C. Summer Unit 1 surveillance program presented in Appendix D of this report indicates that the V.C. Summer Unit 1 reactor vessel surveillance results are credible.

- 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 (32 EFPY) as required by 10CFR50, Appendix G[2].

2 INTRODUCTION

This report presents the results of the examination of Capsule W, the fourth capsule removed from the reactor in the continuing surveillance program which monitors the effects of neutron irradiation on the South Carolina Electric & Gas Company V.C. Summer Unit 1 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the South Carolina Electric & Gas Company V.C. Summer Unit 1 reactor pressure vessel materials was designed and recommended by the Westinghouse Electric Company. A description of the surveillance program and the preirradiation mechanical properties of the reactor vessel materials is presented in WCAP-9234, "South Carolina Electric & Gas Company Virgil C. Summer Nuclear Plant 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 E185-73, "Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels". Capsule W was removed from the reactor after 10.78 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 post-irradiation data obtained from surveillance capsule W removed from the South Carolina Electric & Gas Company V.C. Summer Unit 1 reactor vessel and discusses the analysis of the data.

3 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 V.C. Summer Unit 1 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 forging. 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 V.C. Summer Unit 1 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.

4 DESCRIPTION OF PROGRAM

Six surveillance capsules for monitoring the effects of neutron exposure on the V.C. Summer Unit 1 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 intermediate shell plate A9154-1, weld metal fabricated with 3/16-inch RACO INMM weld filler wire, heat number 4P4784 Linde 124 flux, lot number 3930 (989), which is identical to that used in the actual fabrication of the intermediate to lower shell girth weld and all longitudinal weld seams of both the intermediate and lower shell plates of the pressure vessel.

Capsule W was removed after 10.78 effective full power years (EFPY) of plant operation. This capsule contained Charpy V-notch, tensile, and 1/2T-CT fracture mechanics specimens made from intermediate shell plate A9154-1 and submerged arc weld metal identical to the closing girth and intermediate and lower shell longitudinal weldseams. In addition, this capsule contained Charpy V-notch specimens from the weld Heat-Affected-Zone (HAZ) of intermediate shell plate A9154-1.

Test material obtained from intermediate shell 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 post-weld stress-relieving treatment on the test material. Specimens from weld metal and heat-affected-zone metal were machined from a stress-relieved weldment joining sections of the lower and intermediate shell plates. All heat-affected-zone specimens were obtained from the weld heat-affected-zone of intermediate shell plate A9154-1.

Charpy V-notch impact specimens from intermediate shell plate A9154-1 were machined with some in the longitudinal orientation (longitudinal axis of the specimen parallel to the major rolling direction) and transverse orientation (longitudinal axis of the specimen perpendicular to the major rolling direction). 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 intermediate shell plate A9154-1 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 plate A9154-1 were machined in both the longitudinal and transverse orientations. Compact tension test specimens from the weld metal were machined perpendicular to the weld direction with the notch oriented in the direction of the weld. All specimens were fatigue precracked according to ASTM E399.

The chemical composition and heat treatment of the surveillance material is presented in Tables 4-1 and 4-2. These tables were obtained from WCAP-10814[44] and reprinted herein.

Capsule W 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)
1.75% Ag, 0.75% Sn, 97.5% Pb	Melting Point: 590°F (310°C)

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

Table 4-1 Chemical Composition (wt%) of the V.C. Summer Unit 1 Reactor Vessel Surveillance Materials[d]

Element	Intermediate Shell plate A9154-1 (Lukens Steel Co. Analysis)	Weld Metal[c] (Lukens Steel Co. Analysis)
C	0.22	0.085
S	0.015	0.012 / 0.007 (b)
N	0.0076	0.015
Co	0.010	0.016 / 0.01 (b)
Cu	0.10	0.05 / 0.04 (b)
Si	0.24	0.48 / 0.42 (b)
Mo	0.49	0.49 / 0.46 (b)
Ni	0.51	0.91 / 0.95 (b)
Mn	1.30	1.32 / 1.50 (b)
Cr	0.08	0.14 / 0.12 (b)
V	0.001 (a)	0.005
P	0.009	0.013 / 0.009 (b)
Sn	0.007	0.0047
Al	0.024	0.007 / 0.03 (b)
B	0.0004	0.0005
Ti	0.0002	0.001
Pb	<0.005	0.0206
Zr	0.001	0.001
As	0.006	0.006
W	<0.01	0.01

Notes:

a. Westinghouse Analysis

b. Analysis performed on irradiated specimen CW14.

c. Surveillance weld was made of the same RAC01 NMM wire heat # 4P4784 and Linde 124 Flux Lot No. 3980 as the beltline welds of the reactor vessel.

d. Reprinted from WCAP-10814[44].

Table 4-2 Heat Treatment of the V.C. Summer Unit 1 Reactor Vessel Surveillance Material[(a)]			
Material	**Temperature (°F)**	**Time (hrs.)**	**Coolant**
Surveillance Program Test Plate A9154-1	1550 / 1650	1/2 hr./in., min	Water-quenched
	1225 ± 25	1/2 hr./in., min	Air Cooled
	1150± 25	43	Furnace Cooled to 600°F
Weldment	1150 ± 25	12	Furnace Cooled

(a) Reprinted from WCAP-10814[44].

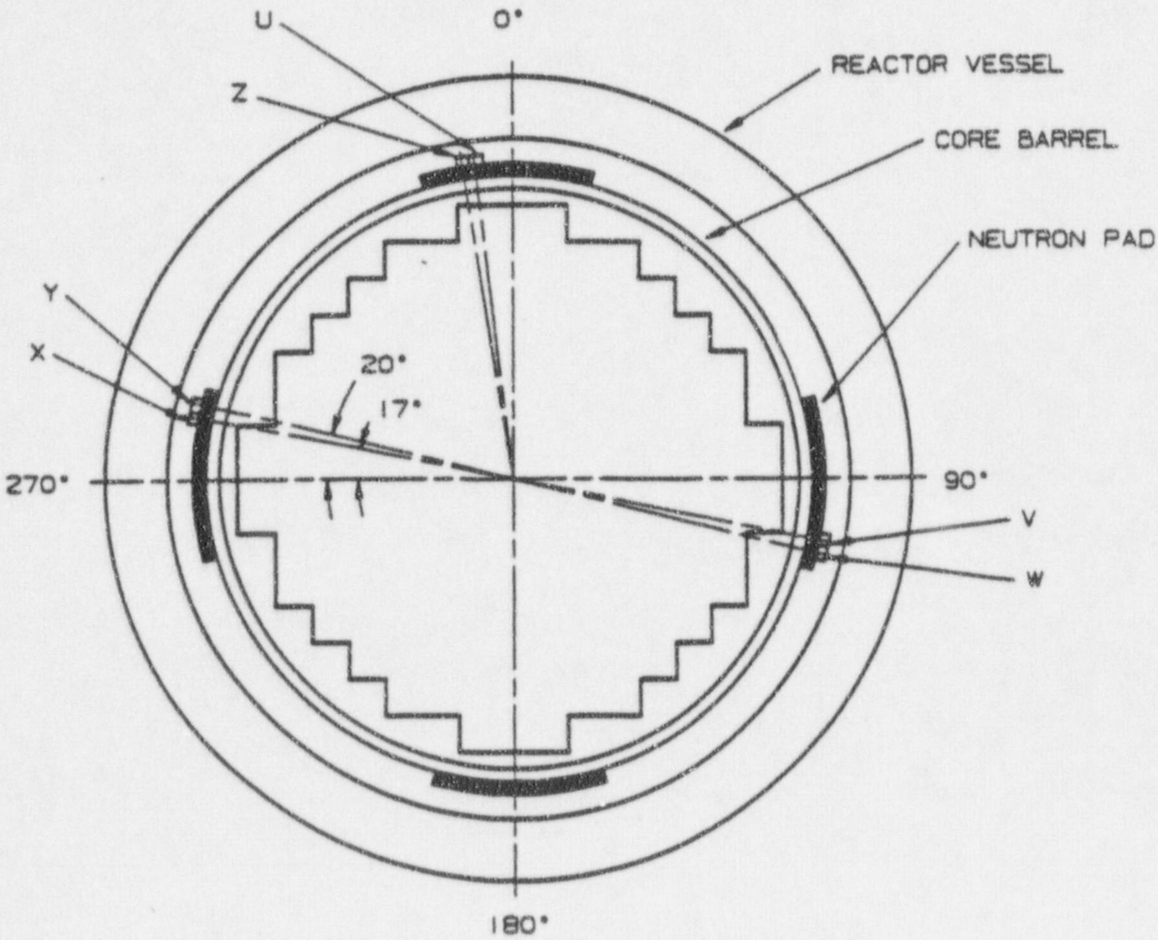


Figure 4-1 Arrangement of Surveillance Capsules in the V.C. Summer Unit 1 Reactor Vessel

SPECIMEN CODE:

CT - PLATE A9154-1 (TRANSVERSE ORIENTATION)

CL - PLATE A9154-1 (LONGITUDINAL ORIENTATION)

CW - CORE REGION WELD METAL

CH - HEAT-AFFECTED-ZONE METAL

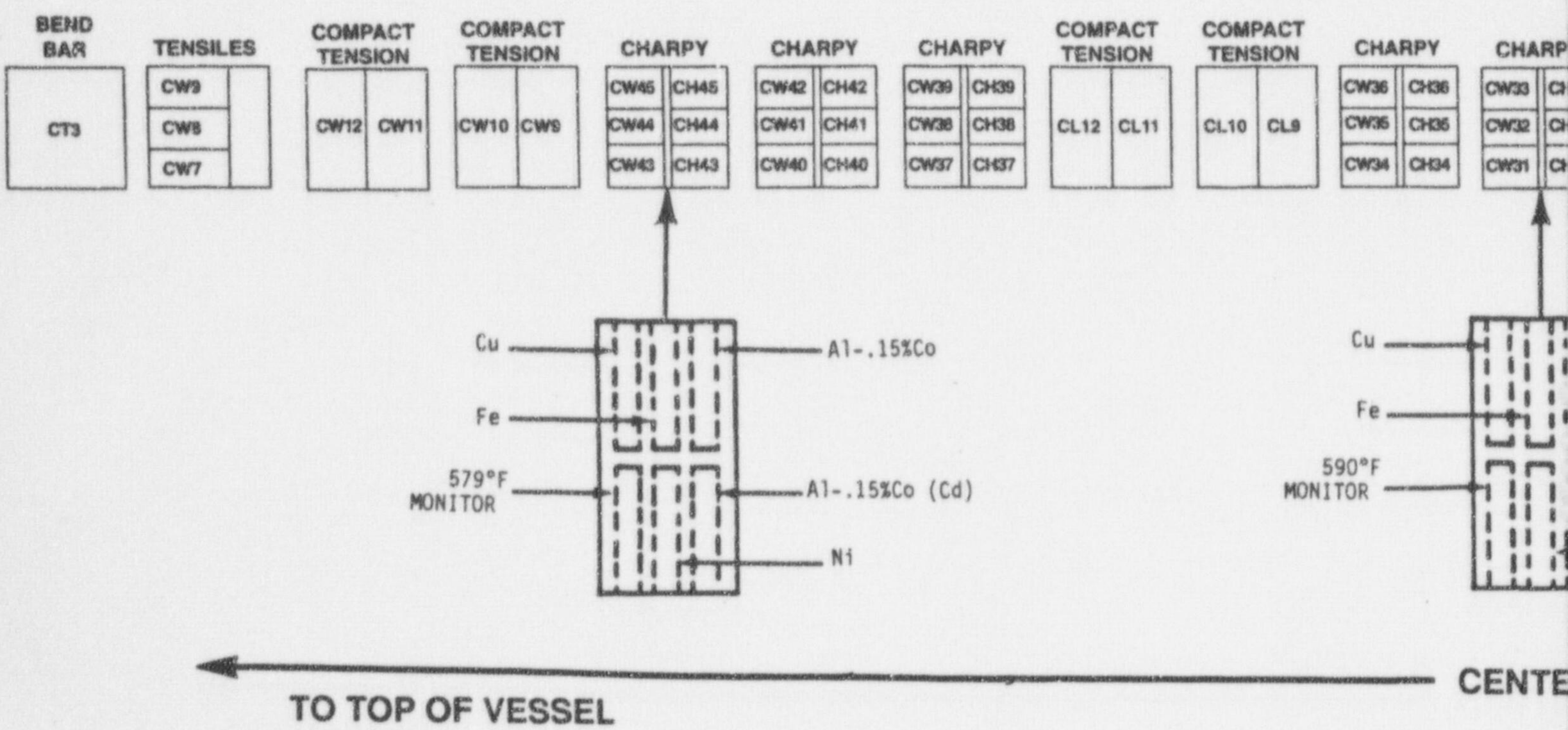
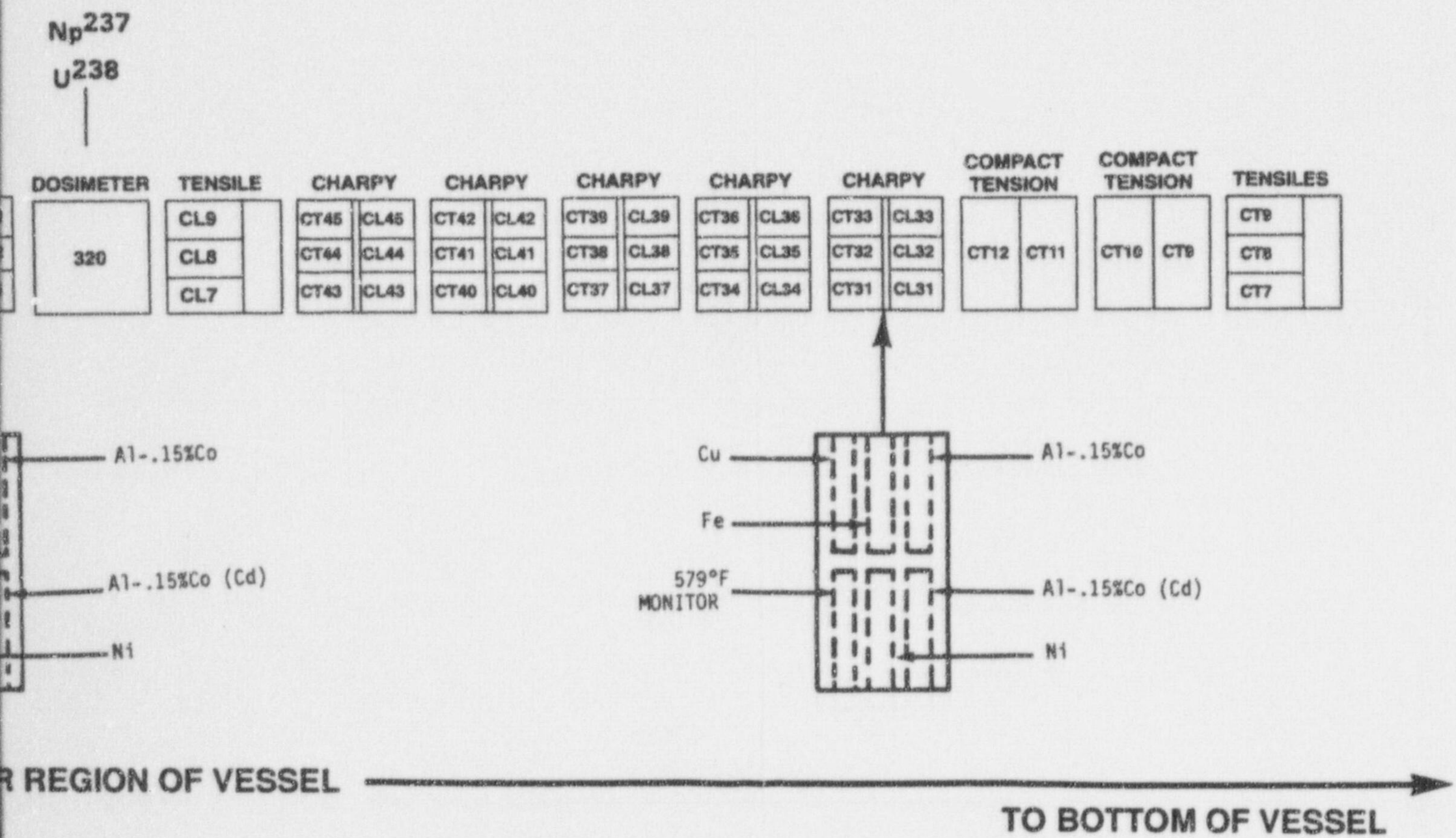


Figure 4-2 Capsule WDiagran
and Dosimeters

CAPSULE W



Showing the Location of Specimens, Thermal Monitors,

9810190027-01

5 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-9234[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 930-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 (i.e., pure bending or three-point bending). In three-point bending, for a Charpy specimen in which ϕ= 45° and ρ = 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 WMF 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 Transverseity 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 W, which received a fluence of 4.664 x 10^{19} n/cm^2(E> 1.0 MeV) in 10.78 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 W materials are summarized in Table 5-9. These results led to the following conclusions:

Irradiation of the reactor vessel intermediate shell plate A9154-1 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (Longitudinal orientation), to 4.664 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 66°F and a 50 ft-lb transition temperature increase of 76°F. This results in an irradiated 30 ft-lb transition temperature of 44°F and an irradiated 50 ft-lb transition temperature of 83°F for the Longitudinal oriented specimens.

Irradiation of the reactor vessel intermediate shell plate A9154-1 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction of the plate (Transverse orientation), to 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 58°F and a 50 ft-lb transition temperature increase of 68°F. This results in an irradiated 30 ft-lb transition temperature of 86°F and an irradiated 50 ft-lb transition temperature of 139°F for Transverse oriented specimens.

Irradiation of the weld metal Charpy specimens to 4.664 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 43°F and a 50 ft-lb transition temperature increase of 52°F. This results in an irradiated 30 ft-lb transition temperature of -10°F and an irradiated 50 ft-lb transition temperature of 40°F.

Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 60°F and a 50 ft-lb transition temperature increase of 70°F. This results in an irradiated 30 ft-lb transition temperature of -33°F and an irradiated 50 ft-lb transition temperature of 4°F.

The average upper shelf energy of the intermediate shell plate A9154-1 (Longitudinal orientation) resulted in an average energy decrease of 6 ft-lb after irradiation to 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV). This results in an irradiated average upper shelf energy of 126 ft-lb for the Longitudinal oriented specimens.

The average upper shelf energy of the intermediate shell plate A9154-1 (Transverse orientation) resulted in an average energy decrease of 1 ft-lb after irradiation to 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 74 ft-lb for the Transverse oriented specimens.

The average upper shelf energy of the weld metal Charpy specimens resulted an average energy decrease of 4 ft-lb after irradiation to 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 87 ft-lb for the weld metal specimens.

The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in an average energy decrease of 27 ft-lb after irradiation to 4.664 x 10^{19} n/cm^2 (E> 1.0MeV). This results in an irradiated average upper shelf energy of 103 ft-lb for the weld HAZ metal.

A comparison of the V.C. Summer Unit 1 reactor vessel beltline material test results with the Regulatory Guide 1.99, Revision 2[1] is presented in Table 5-10 of this report and led to the following conclusions:

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

- The measured USE values of all surveillance materials are less than the Regulatory Guide 1.99, Revision 2, predictions.

- The maximum decrease in Charpy (measured) upper shelf energy (USE) for the reactor vessel specimens was 10 ft-lbs or 7.6 %, which occurred on the plate A9154-1 (longitudinal orientation). This has been plotted on the Reg. Guide 1.99, Revision 2, curve using the guidance set forth in paragraph C.2.2 of Reg. Guide 1.99, Revision 2. Based on actual data, the projected decrease in USE at the projected end-of License (32 EFPY) fluence of 3.84 x 10^{19} n/cm^2, is expected to be less than 10%.

- Using the lowest initial USE value of 75 ft-lb for the intermediate shell plate A9154-1, the resulting EOL USE value is projected to be 67.5 ft-lb. This is above the 50 ft-lb limit and, therefore, is acceptable.

- Using only chemistry and fluence data, the same projected decrease in USE is expected to approximately 27%. Applying this to the same intermediate shell plate, A9154-1, the resulting EOL USE value is expected to be 54.8 ft-lb. This is above the 50 ft-lb limit and, therefore, is acceptable. No further actions are required as outlined in Paragraphs IV.A.1 or V.C of Appendix G to 10 CFR Part 50

The fracture appearance of each irradiated Charpy specimen from the various surveillance capsule W materials is shown in Figures 5-13 through 5-16 and shows 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 (32 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-9234[3], WCAP-10814[44], WCAP-11726[45] and WCAP-12867[46] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a replot of all capsule data using CVGRAPH, Version 4.1, which is a hyperbolic tangent curve-fitting program. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

5.3 TENSILE TEST RESULTS

The results of the tensile tests performed on the various materials contained in capsule W irradiated to 4.664 x 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 intermediate shell plate A9154-1 (Longitudinal orientation) indicated that irradiation to 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 0 to 5 ksi increase in the 0.2 percent offset yield strength and approximately a 8 to 10 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 intermediate shell plate A9154-1 (Transverse orientation) indicated that irradiation to 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV) caused a 8 to 10 ksi increase in the 0.2 percent offset yield strength and approximately a 8 to 10 ksi increase in the ultimate tensile strength when compared to unirradiated data[13] (Figure 5-18).

The results of the tensile tests performed on the surveillance weld metal indicated that irradiation to 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV) caused a 0 to 2 ksi increase in the 0.2 percent offset yield strength and a 0 ksi increase in the ultimate tensile strength when compared to unirradiated data[3] (Figure 5-19).

The fractured tensile specimens for the intermediate shell plate A9154-1 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 V.C. Summer Unit 1 Intermediate Shell Plate A9154-1 Irradiated to a Fluence of 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV) (Longitudinal Orientation)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	ft-lbs	Joules	mils	mm	%
CL44	-40	-40	4	5	1	0.025	2
CL34	0	-18	11	15	4	0.102	5
CL45	20	-7	23	31	12	0.305	5
CL31	25	-4	32	43	20	0.508	10
CL42	50	10	21	28	15	0.381	10
CL41	72	22	36	49	25	0.635	30
CL38	80	27	61	83	45	1.143	40
CL37	100	38	63	85	44	1.118	40
CL40	125	52	77	104	56	1.422	50
CL35	150	66	92	125	55	1.397	65
CL39	175	79	92	125	66	1.676	80
CL32	200	93	100	136	62	1.575	90
CL43	225	107	128	174	82	2.083	100
CL36	300	149	131	178	82	2.083	100
CL33	350	177	119	161	79	2.007	100

Table 5-2 Charpy V-notch Data for the V.C. Summer Unit 1 Intermediate Shell Forging OS Irradiated to a Fluence of 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV) (Transverse Orientation)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	ft-lbs	Joules	mils	mm	%
CT37	-50	-46	6	8	1	0.025	2
CT33	-10	-23	8	11	3	0.076	5
CT43	25	-4	15	20	8	0.203	10
CT35	50	10	15	20	12	0.305	15
CT42	72	22	27	37	21	0.533	25
CT36	100	38	38	52	27	0.686	35
CT40	125	52	46	62	28	0.711	50
CT31	150	66	46	62	37	0.940	60
CT38	155	68	52	71	42	1.067	75
CT41	175	79	62	84	50	1.270	80
CT32	200	93	64	87	49	1.245	90
CT45	225	107	79	107	59	1.499	100
CT34	250	121	77	104	60	1.524	100
CT44	300	149	75	102	60	1.524	100
CT39	350	177	66	89	51	1.295	100

Table 5-3 Charpy V-notch Data for the V.C. Summer Unit I Surveillance Weld Metal Irradiated to a Fluence of 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	ft-lbs	Joules	mils	mm	%
CW43	-100	-73	4	5	1	0.025	10
CW41	-50	-46	12	16	13	0.330	20
CW35	-25	-32	35	47	24	0.610	25
CW39	-20	-29	24	33	17	0.432	20
CW33	0	-18	32	43	22	0.559	25
CW45	25	-4	45	61	34	0.864	50
CW37	50	10	45	61	37	0.940	60
CW42	55	13	63	85	51	1.295	80
CW31	72	22	68	92	49	1.245	75
CW34	100	38	68	92	57	1.448	85
CW44	125	52	68	92	57	1.448	95
CW38	165	74	86	117	66	1.676	98
CW40	200	93	80	108	61	1.549	100
CW36	250	121	92	125	66	1.676	100
CW32	300	149	90	122	67	1.702	100

Table 5-4 Charpy V-notch Data for the V.C. Summer Unit 1 Heat Affected Zone Material Irradiated to a Fluence of 4.664 x 10^{19} n/cm^2 (E> 1.0 MeV)							
Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	ft-lbs	Joules	mils	mm	%
CH44	-106	-77	4	5	1	0.025	10
CH42	-75	-59	25	34	10	0.254	15
CH36	-50	-46	26	35	13	0.330	20
CH45	-25	-32	29	39	15	0.381	30
CH41	-15	-26	35	47	17	0.432	25
CH40	0	-18	56	76	35	0.889	40
CH33	25	-4	57	77	32	0.813	40
CH39	40	4	57	77	41	1.041	60
CH35	55	13	92	125	66	1.676	90
CH43	72	22	72	98	47	1.194	85
CH32	90	32	88	119	55	1.397	90
CH31	100	38	110	149	67	1.702	85
CH38	125	52	99	134	67	1.702	100
CH34	200	93	99	134	66	1.676	100
CH37	300	149	110	149	57	1.448	100

Table 5-5 Instrumented Charpy Impact Test Results for the V.C. Summer Unit 1 Intermediate Shell Plate A9154-1 Irradiated to a Fluence of 4.664 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)			Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_p/A								
CL44	-40	4	32	16	16	2069	0.12	2069	0.12	2069	0	69	69
CL34	0	11	89	55	34	4031	0.17	4208	0.20	4208	0	134	137
CL45	20	23	185	153	33	3783	0.16	4386	0.37	4384	0	126	136
CL31	25	32	258	214	43	3941	0.17	4602	0.48	4548	0	131	142
CL42	50	21	169	65	104	3910	0.17	4144	0.22	4079	220	130	134
CL41	72	36	290	190	100	3701	0.16	4548	0.44	4535	599	123	137
CL38	80	61	491	316	175	3624	0.16	4485	0.68	4282	0	121	135
CL37	100	63	507	317	191	3667	0.17	4491	0.68	4353	625	122	136
CL40	125	77	620	312	308	3683	0.17	4501	0.67	4164	1118	123	136
CL35	150	92	741	305	436	3336	0.16	4368	0.68	3474	1616	111	128
CL39	175	92	741	299	442	3530	0.17	4296	0.67	3489	2073	118	130
CL32	200	100	805	308	498	3494	0.17	4367	0.69	3611	2312	116	131
CL43	225	128	1031	309	721	3505	0.17	4443	0.68	n/a	n/a	117	132
CL36	300	131	1055	304	751	3191	0.16	4270	0.69	n/a	n/a	106	124
CL33	350	119	958	291	667	3221	0.17	4190	0.68	n/a	n/a	107	123

Table 5-6 Instrumented Charpy Impact Test Results for the V.C. Summer Unit 1 Intermediate Shell Plate A9154-1 Irradiated to a Fluence of 4.664 x 10^{19} n/cm^2 (E>1.0 MeV)(Transverse Orientation)

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} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_p/A								
CT37	-50	6	48	27	21	3143	0.15	3143	0.15	3143	0	105	105
CT33	-10	8	64	35	29	3607	0.16	3607	0.16	3607	0	120	120
CT43	25	15	121	68	53	3967	0.17	4243	0.22	4174	138	132	137
CT35	50	15	121	57	64	3690	0.16	4055	0.20	4049	305	123	129
CT42	72	27	217	66	151	3683	0.16	4135	0.22	4089	1073	123	130
CT36	100	38	306	185	121	3530	0.16	4310	0.45	4301	1010	118	131
CT40	125	46	370	218	153	3421	0.16	4290	0.52	4272	1432	114	128
CT31	150	46	370	200	170	3532	0.17	4151	0.49	4129	1603	118	128
CT38	155	52	419	200	219	3489	0.17	4085	0.50	4023	2486	116	126
CT41	175	62	499	204	295	3316	0.16	4100	0.50	3902	2147	110	123
CT32	200	64	515	201	314	3191	0.16	4010	0.51	3250	2044	106	120
CT45	225	79	636	216	420	3446	0.16	4339	0.51	n/a	n/a	115	130
CT34	250	77	620	211	409	3190	0.16	4216	0.52	n/a	n/a	106	123
CT44	300	75	604	203	401	3476	0.17	4209	0.49	n/a	n/a	116	128
CT39	350	66	531	192	340	3053	0.16	3932	0.50	n/a	n/a	102	116

Table 5-7 Instrumented Charpy Impact Test Results for the V.C. Summer Unit 1 Surveillance Weld Metal Irradiated to a Fluence of 4.664 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} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_p/A								
CW43	-100	4	32	16	17	2105	0.12	2105	0.12	2105	0	70	70
CW41	-50	12	97	49	48	4124	0.17	4180	0.19	4180	295	137	138
CW35	-25	35	282	212	69	4193	0.17	4682	0.46	4654	474	140	148
CW39	-20	24	193	73	120	4191	0.17	4498	0.22	4440	106	140	145
CW33	0	32	258	195	63	4102	0.17	4601	0.44	4579	479	137	145
CW45	25	45	362	242	121	3759	0.16	4611	0.52	4540	1290	125	139
CW37	50	45	362	227	135	3954	0.17	4492	0.50	4436	1173	132	141
CW42	55	63	507	231	276	3916	0.17	4486	0.51	4039	2311	130	140
CW31	72	68	548	327	221	3769	0.16	4682	0.67	4488	1754	126	141
CW34	100	68	548	228	319	3618	0.16	4426	0.52	3916	2194	120	134
CW44	125	68	548	219	328	3532	0.16	4326	0.51	3944	2660	118	131
CW38	165	86	692	222	471	3670	0.17	4291	0.52	3031	1858	122	133
CW40	200	80	644	219	425	3382	0.16	4223	0.52	n/a	n/a	113	127
CW36	250	92	741	221	520	3742	0.17	4370	0.51	n/a	n/a	125	135
CW32	300	90	725	219	505	3383	0.16	4287	0.52	n/a	n/a	113	128

Table 5-8 Instrumented Charpy Impact Test Results for the V.C. Summer Unit 1 Heat-Affected-Zone (HAZ) Metal Irradiated to a Fluence of 4.664 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} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_p/A								
CH44	-106	4	32	14	19	1805	0.12	1812	0.12	1805	0	60	60
CH42	-75	25	201	77	124	4503	0.17	4919	0.22	4736	0	150	157
CH36	-50	26	209	73	136	4435	0.17	4763	0.22	4571	0	148	153
CH45	-25	29	234	72	161	4348	0.17	4669	0.22	4476	100	145	150
CH41	-15	35	282	233	49	4385	0.17	4883	0.48	4862	0	146	154
CH40	0	56	451	248	203	3902	0.16	4743	0.52	4702	871	130	144
CH33	25	57	459	239	220	3929	0.16	4658	0.51	4546	1492	131	143
CH39	40	57	459	241	218	3740	0.16	4644	0.53	4564	1596	125	140
CH35	55	92	741	326	415	3866	0.16	4648	0.67	3544	2344	129	142
CH43	72	72	580	[illegible]	512	3873	0.16	4333	0.22	4234	3973	129	137
CH32	90	88	709	236	473	3915	0.17	4539	0.52	3939	2963	130	141
CH31	100	110	886	333	553	3705	0.16	4698	0.69	3869	2362	123	140
CH38	125	99	797	324	474	3606	0.16	4550	0.68	n/a	n/a	120	136
CH34	200	99	797	221	577	3373	0.16	4306	0.52	n/a	n/a	112	128
CH37	300	110	886	311	575	3529	0.17	4434	0.69	n/a	n/a	118	133

Table 5-9 Effect of Irradiation to 4.664 x 10^{19} n/cm^2 (E>1.0 MeV) on the Notch Toughness Properties of the V.C. Summer Unit 1 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 USE[a] at Full Shear (ft-lb)		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT
Inter. Shell Plate A9154-1 (Long.)	-22	44	66	4	84	80	7	83	76	132	126	-6
Inter. Shell Plate A9154-1 (Trans.)	28	86	58	49	132	83	71	139	68	75	74	-1
Weld Metal	-53	-10	43	-26	28	54	-12	40	52	91	87	-4
HAZ Metal	-93	-33	60	-57	15	72	-66	4	70	130	103	-27

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 V.C. Summer Unit 1 Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper Shelf Energy Decreases with Regulatory Guide 1.99, Revision 2, Predictions

Material	Capsule	Fluence (x 10^{19} n/cm^2)	30 ft-lb Transition Temperature Shift		Upper Shelf Energy Decrease	
			Predicted (°F) [(a)]	Measured (°F) [(b)]	Predicted (%) [(a)]	Measured (%)[(c)]
Intermediate Shell	U	0.654	57.3	36.0	17	1
Plate A9154-1	V	1.538	72.7	52.6	21	7.6
	X	2.543	81.3	37.7	24	5
(Longitudinal)	W	4.664	90.2	65.7	27	4.5
Intermediate Shell	U	0.654	57.3	14.5	17	0
Plate A9154-1	V	1.538	72.7	32.4	21	0
	X	2.543	81.3	26.0	24	3
(Transverse)	W	4.664	90.2	57.8	27	1
Weld Metal	U	0.654	47.6[(a)]	22.2	17	4
	V	1.538	60.4[(a)]	46.5	21	7
	X	2.543	67.5[(a)]	22.4	24	7
	W	4.664	75.0[(a)]	43.3	27	4
HAZ Metal	U	0.654	- -	35.6	- -	7
	V	1.538	- -	50.1	- -	15
	X	2.543	- -	54.1	- -	10
	W	4.664	- -	60.3	- -	21

Notes:

(a) Based on Regulatory Guide 1.99, Revision 2, methodology using the mean weight percent values of copper and nickel of the surveillance material. The predicted value for the weld metal from WCAP-12867 was based on the mean weight percent copper and nickel for the given heat of weld wire (i.e. Best Estimate Average), which was the interpretation of the Reg. Guide 1.99, Revision 2 at the time the report was issued.

(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.

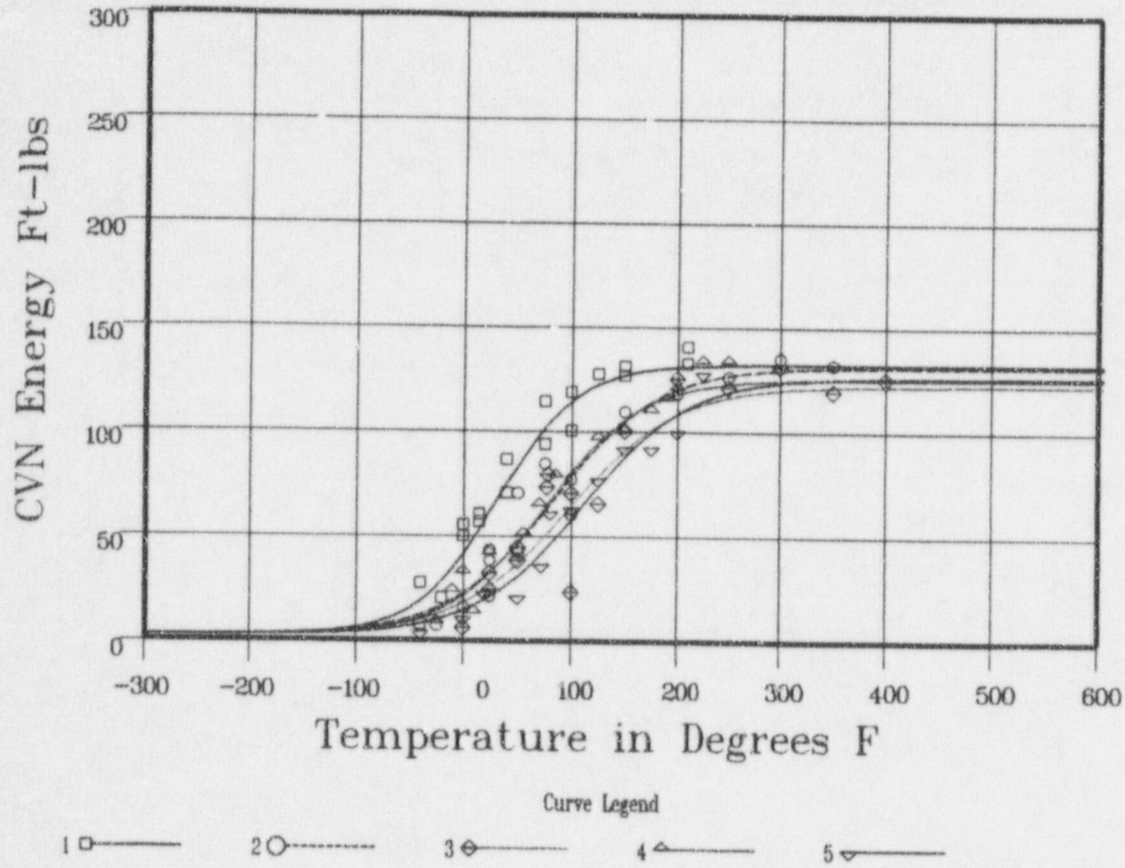
Table 5-11 Tensile Properties of the V.C. Summer Unit 1 Reactor Vessel Surveillance Materials Irradiated to 4.664 x 10^{19} n/cm^2 (E > 1.0 MeV)										
Material	**Sample Number**	**Test Temp. (°F)**	**0.2% Yield Strength (ksi)**	**Ultimate Strength (ksi)**	**Fracture Load (kip)**	**Fracture Stress (ksi)**	**Fracture Strength (ksi)**	**Uniform Elongation (%)**	**Total Elongation (%)**	**Reduction in Area (%)**
Intermediate Plate A9154-1 (Longitudinal)	AL4	74	74.9	98.0	3.25	196.8	66.2	10.5	23.4	66
	AL5	225	71.8	92.7	3.00	194.9	61.1	10.5	22.8	69
	AL6	550	68.2	95.7	3.25	183.9	66.2	9.8	20.4	64
Intermediate Plate A9154-1 (Transverse)	AT4	100	76.4	99.2	3.90	194.0	79.5	12.0	24.0	59
	AT5	225	71.3	92.7	3.30	168.3	67.2	10.5	21.3	60
	AT6	550	68.8	95.1	3.75	167.2	76.4	10.5	18.9	54
Weld Metal	AW4	-40	84.0	97.8	2.97	234.5	60.5	12.8	26.7	74
	AW5	74	75.9	87.6	2.70	216.5	55.0	10.5	24.3	75
	AW6	550	66.2	85.6	2.65	196.6	54.0	9.8	21.7	73

Intermediate Shell Plate (Longitudinal)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:40:53 on 06-23-1998

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	132	0	-21.59	0	6.89	0
2	0	2.19	0	131	-1	14.39	35.99	52.16	45.26
3	0	2.19	0	122	-10	30.95	52.55	71.29	64.39
4	0	2.19	0	125	-7	16.09	37.69	51.03	44.13
5	0	2.19	0	126	-6	44.05	65.65	82.85	75.95



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	VS1	UNNIRR	PLATE SA533B1	LT	A9154-1
2	VS1	U	PLATE SA533B1	LT	A9154-1
3	VS1	V	PLATE SA533B1	LT	A9154-1
4	VS1	X	PLATE SA533B1	LT	A9154-1
5	VS1	W	PLATE SA533B1	LT	A9154-1

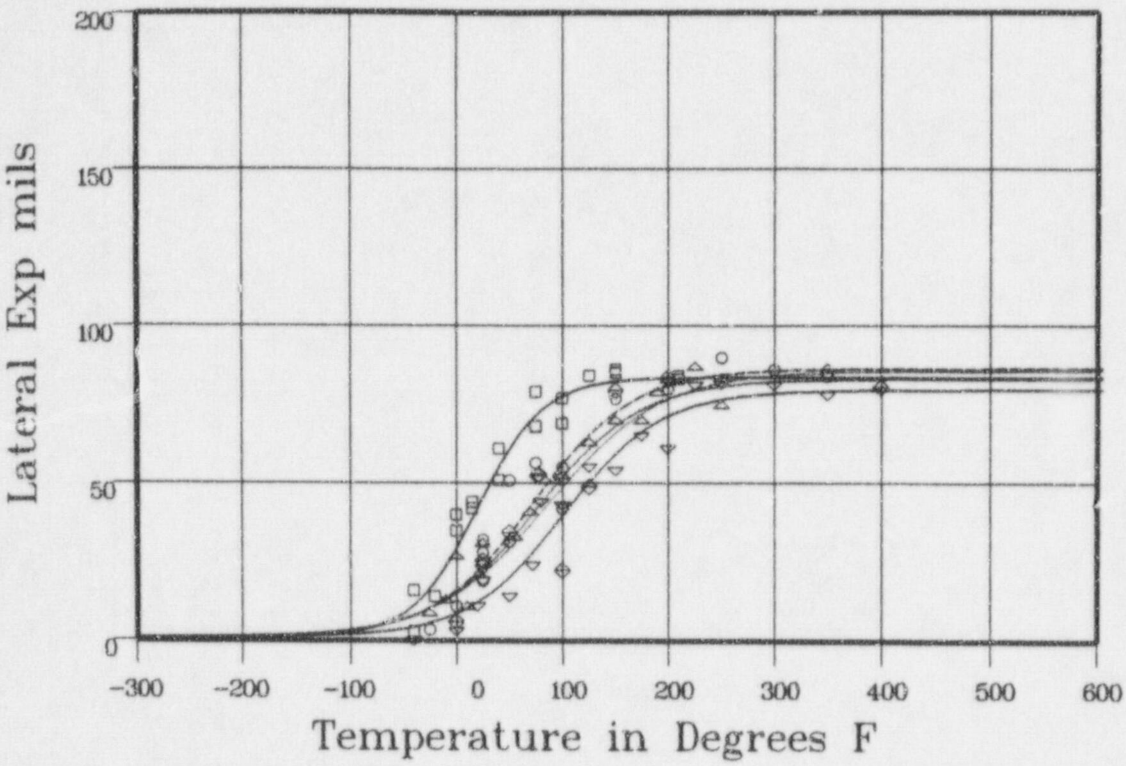
Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for V.C. Summer Unit 1 Reactor Vessel Intermediate Shell Plate A9154-1 (Longitudinal Orientation)

Intermediate Shell Plate (Longitudinal)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:52:16 on 06-23-1998

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	83.55	0	4.44	0
2	0	86.33	2.78	48.1	43.66
3	0	85.67	2.11	60.29	55.84
4	0	83.05	-.49	54.29	49.85
5	0	79.6	-3.95	84.22	79.77



Curve Legend

1 □ 2 ○ 3 ◇ 4 △ 5 ▽

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	VS1	UNNIRR	PLATE SA533B1	LT	A9154-1
2	VS1	U	PLATE SA533B1	LT	A9154-1
3	VS1	V	PLATE SA533B1	LT	A9154-1
4	VS1	X	PLATE SA533B1	LT	A9154-1
5	VS1	W	PLATE SA533B1	LT	A9154-1

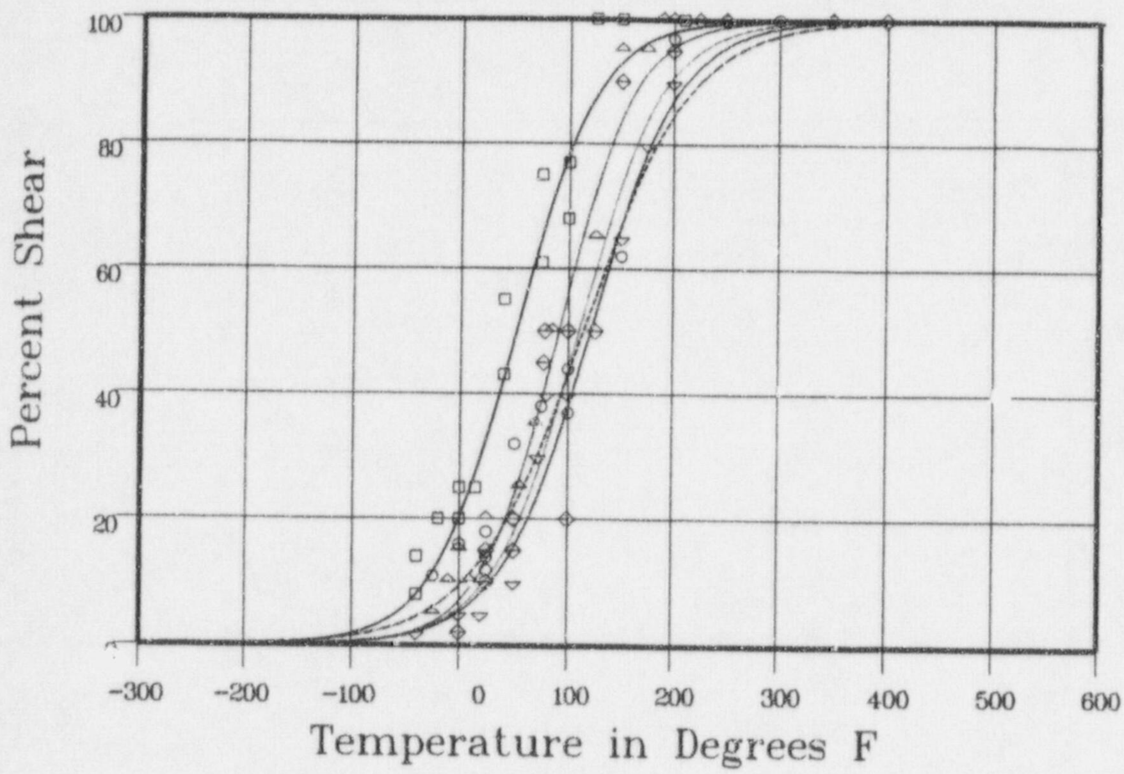
Figure 5-2 **Charpy V-Notch Lateral Expansion vs. Temperature for V.C. Summer Unit 1 Reactor Vessel Intermediate Shell Plate A9154-1 (Longitudinal Orientation)**

Intermediate Shell Plate (Longitudinal)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:58:32 on 06-23-1998

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	46.87	0
2	0	109.57	62.69
3	0	105.46	58.59
4	0	86.71	39.84
5	0	116.14	69.27



Curve Legend

1 □ —— 2 ○ ------ 3 ◇ —— 4 △ —— 5 ▽ ——

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	VS1	UNNIRR	PLATE SA533B1	LT	A9154-1
2	VS1	U	PLATE SA533B1	LT	A9154-1
3	VS1	V	PLATE SA533B1	LT	A9154-1
4	VS1	X	PLATE SA533B1	LT	A9154-1
5	VS1	W	PLATE SA533B1	LT	A9154-1

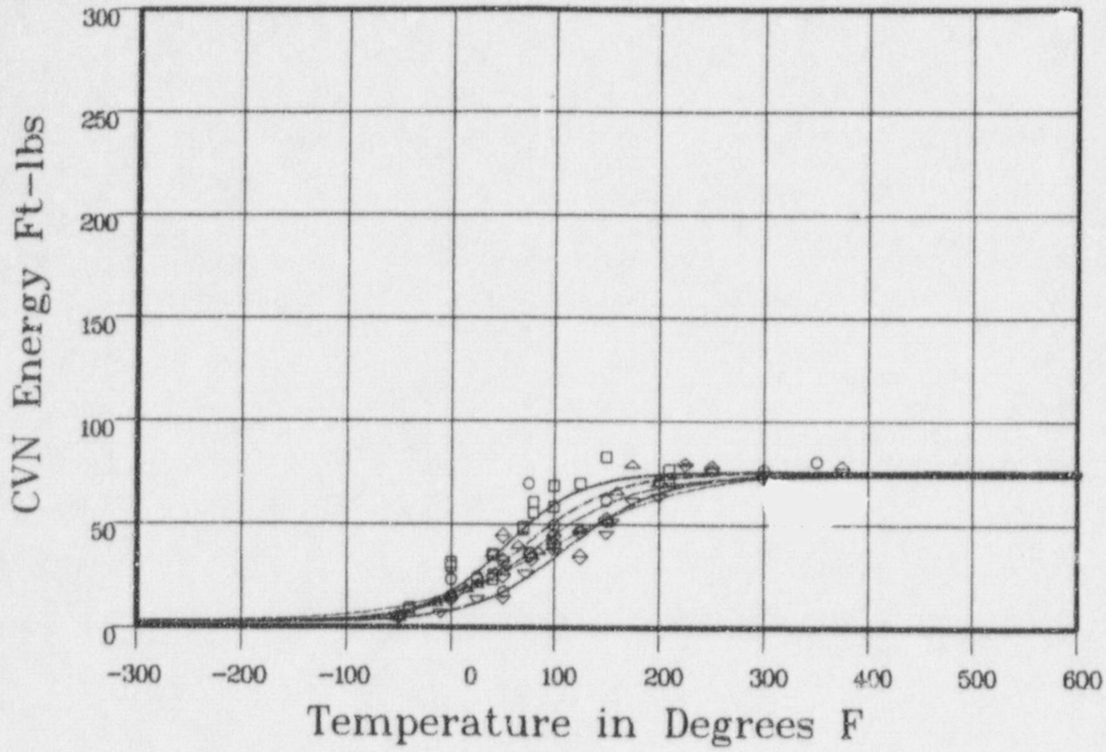
Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for V.C. Summer Unit 1 Reactor Vessel Intermediate Shell Plate A9154-1 (Longitudinal Orientation)

Intermediate Shell Plate (Transverse)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:05:48 on 09-24-1998

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	75	0	28.19	0	70.91	0
2	0	2.19	0	75	0	42.65	14.46	93.74	22.82
3	0	2.19	0	76	1	60.54	32.35	137	66.08
4	0	2.19	0	73	-2	54.2	26.01	111.59	40.67
5	0	2.19	0	74	-1	85.99	57.8	139.08	68.16



Curve Legend

1 □———— 2 ○------- 3 ◇———— 4 △———— 5 ▽————

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	VS1	UNNIRR	PLATE SA533B1	TL	A9154-1
2	VS1	U	PLATE SA533B1	TL	A9154-1
3	VS1	V	PLATE SA533B1	TL	A9154-1
4	VS1	X	PLATE SA533B1	TL	A9154-1
5	VS1	W	PLATE SA533B1	TL	A9154-1

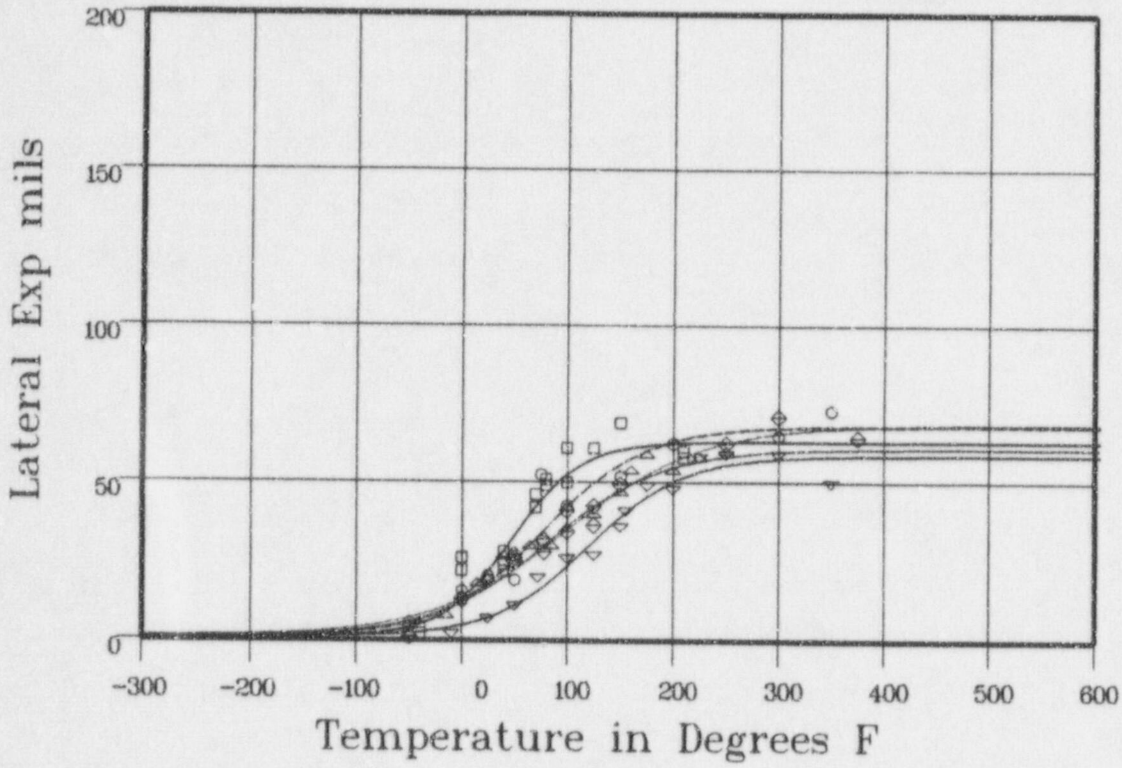
Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for V.C. Summer Unit 1 Reactor Vessel Intermediate Shell Plate A9154-1 (Transverse Orientation)

Intermediate Shell Plate (Transverse)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:21:51 on 06-23-1998

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	63.15	0	49.35	0
2	0	68.14	4.99	73.78	24.43
3	0	68.68	5.53	95.51	46.16
4	0	60.96	-2.18	91.5	42.15
5	0	58.7	-4.44	131.5	82.15



Curve Legend

1 □——— 2 ○--------- 3 ◇——— 4 △——— 5 ▽———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	VS1	UNNIRR	PLATE SA533B1	TL	A9154-1
2	VS1	U	PLATE SA533B1	TL	A9154-1
3	VS1	V	PLATE SA533B1	TL	A9154-1
4	VS1	X	PLATE SA533B1	TL	A9154-1
5	VS1	W	PLATE SA533B1	TL	A9154-1

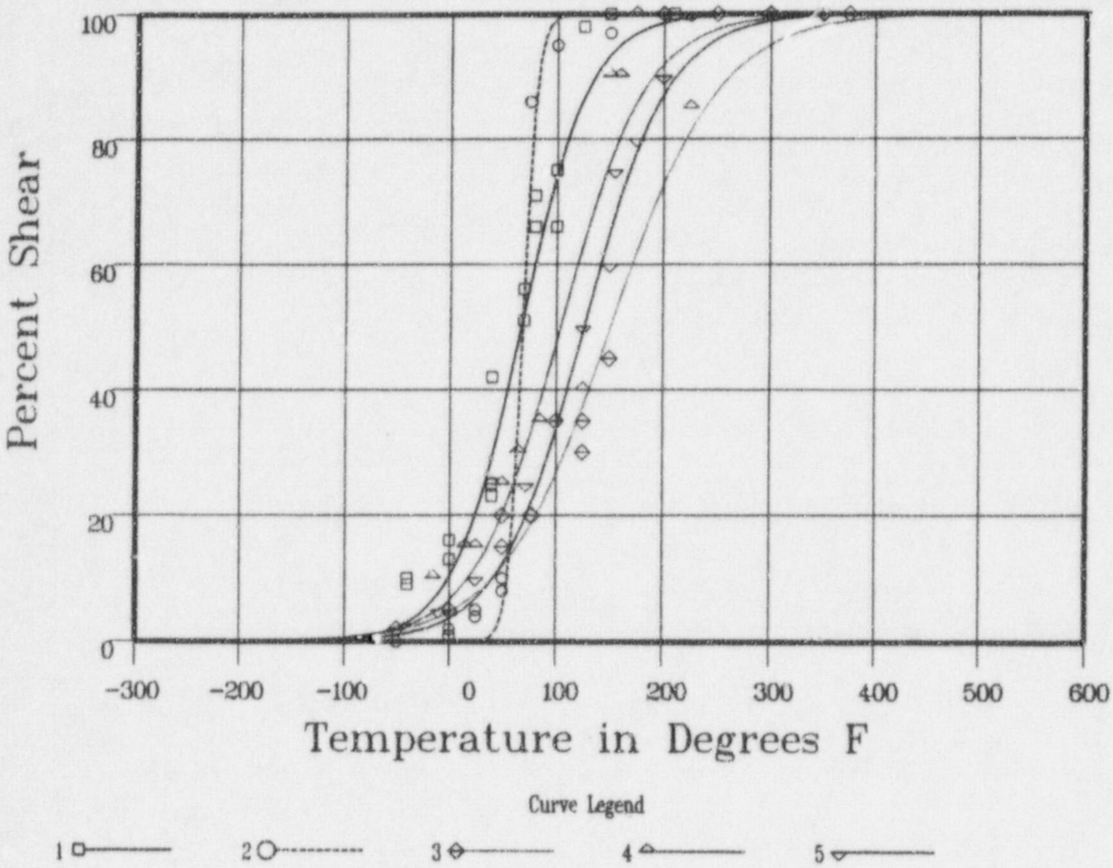
Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for V.C. Summer Unit 1 Reactor Vessel Intermediate Shell Plate A9154-1 (Transverse Orientation)

Intermediate Shell Plate (Transverse)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:29:00 on 06-23-1998

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	62.81	0
2	0	64.16	1.34
3	0	146.48	83.67
4	0	99.51	36.69
5	0	121.58	58.76



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	VS1	UNNIRR	PLATE SA533B1	TL	A9154-1
2	VS1	U	PLATE SA533B1	TL	A9154-1
3	VS1	V	PLATE SA533B1	TL	A9154-1
4	VS1	X	PLATE SA533B1	TL	A9154-1
5	VS1	W	PLATE SA533B1	TL	A9154-1

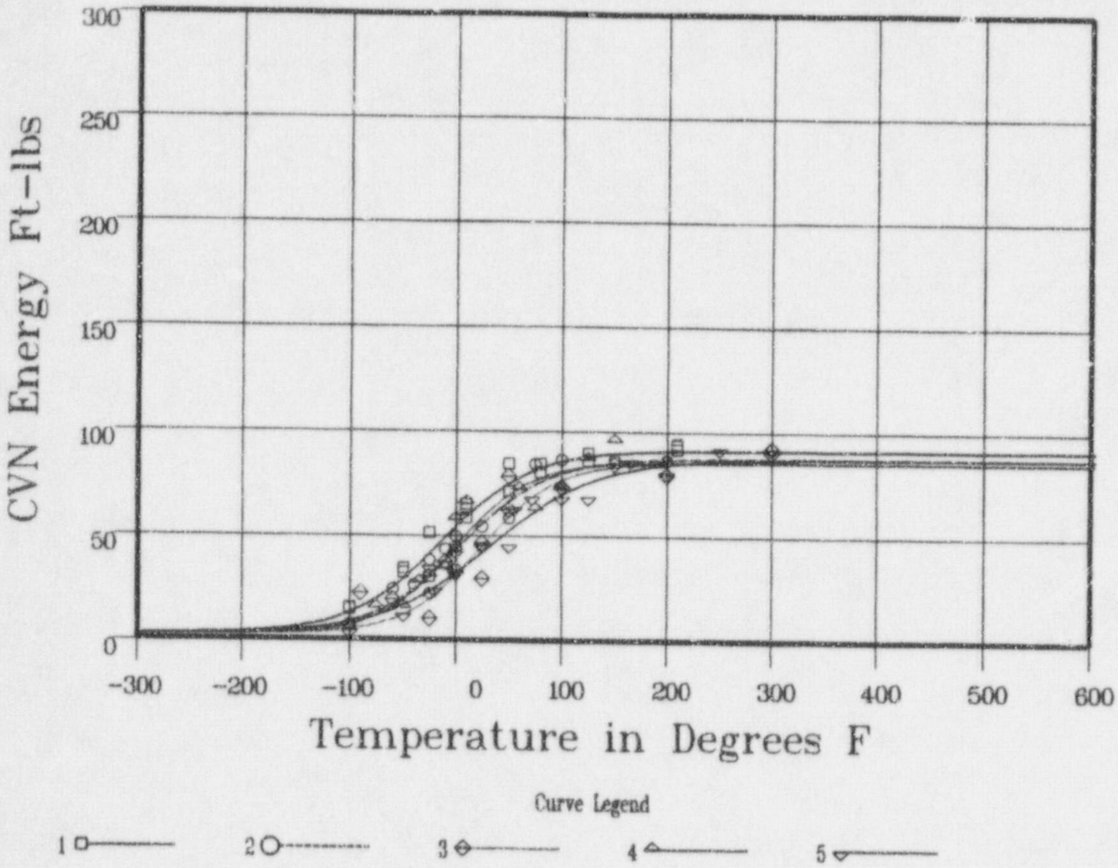
Figure 5-6 **Charpy V-Notch Percent Shear vs. Temperature for V.C. Summer Unit 1 Reactor Vessel Intermediate Shell Plate A9154-1 (Transverse Orientation)**

Weld Material

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:36:21 on 06-23-1998

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	91	0	-52.78	0	-12.3	0
2	0	2.19	0	87	-4	-30.58	22.2	9.63	21.94
3	0	2.19	0	85	-6	-6.3	46.47	29.51	41.81
4	0	2.19	0	85	-6	-30.33	22.44	4.98	17.28
5	0	2.19	0	87	-4	-9.57	43.21	40.29	52.6



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	VS1	UNNIRR	WELD		4P47841
2	VS1	U	WELD		4P4784
3	VS1	V	WELD		4P4784
4	VS1	X	WELD		4P4784
5	VS1	W	WELD		4P4784

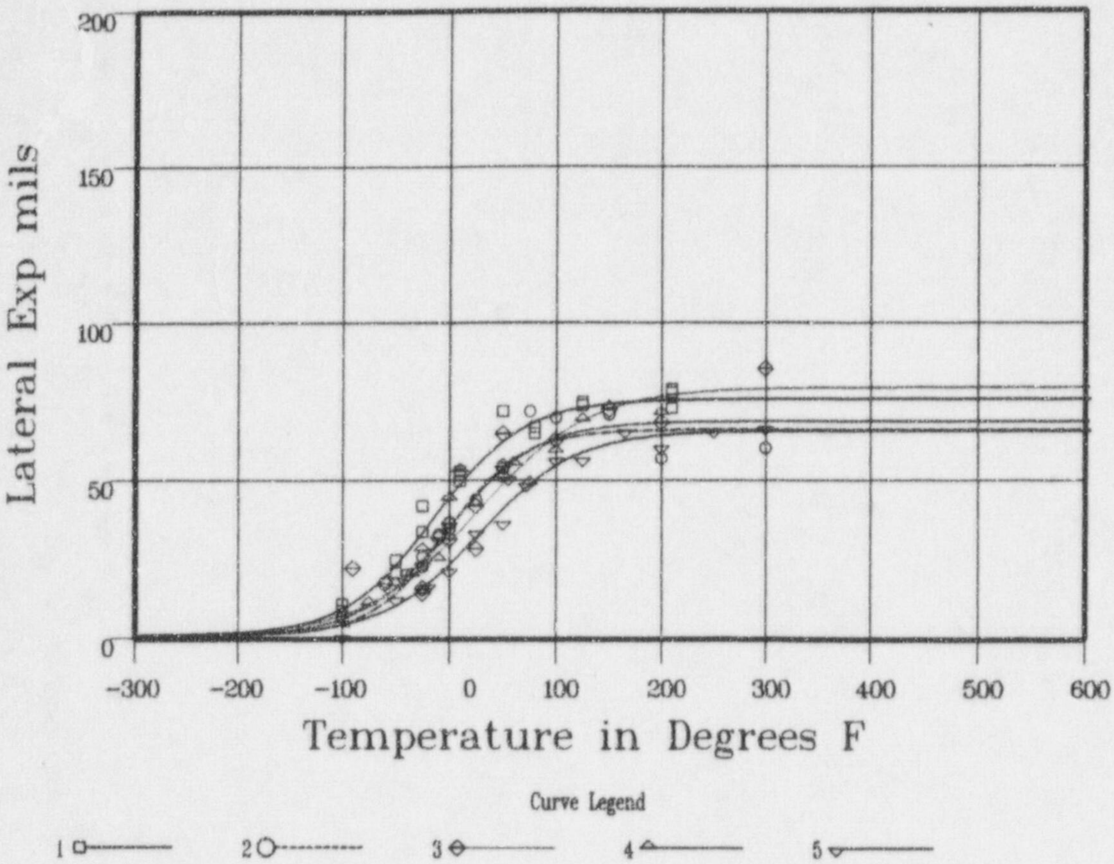
Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for V.C. Summer Unit 1 Reactor Vessel Weld Metal

Weld Material

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:42:29 on 06-23-1998

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	75.94	0	-26.57	0
2	0	66.21	-9.73	-4.5	22.07
3	0	79.62	3.67	7.17	33.75
4	0	68.85	-7.09	-4.98	21.59
5	0	65.81	-10.12	27.86	54.44



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	VS1	UNNIRR	WELD		4P47841
2	VS1	U	WELD		4P4784
3	VS1	V	WELD		4P4784
4	VS1	X	WELD		4P4784
5	VS1	W	WELD		4P4784

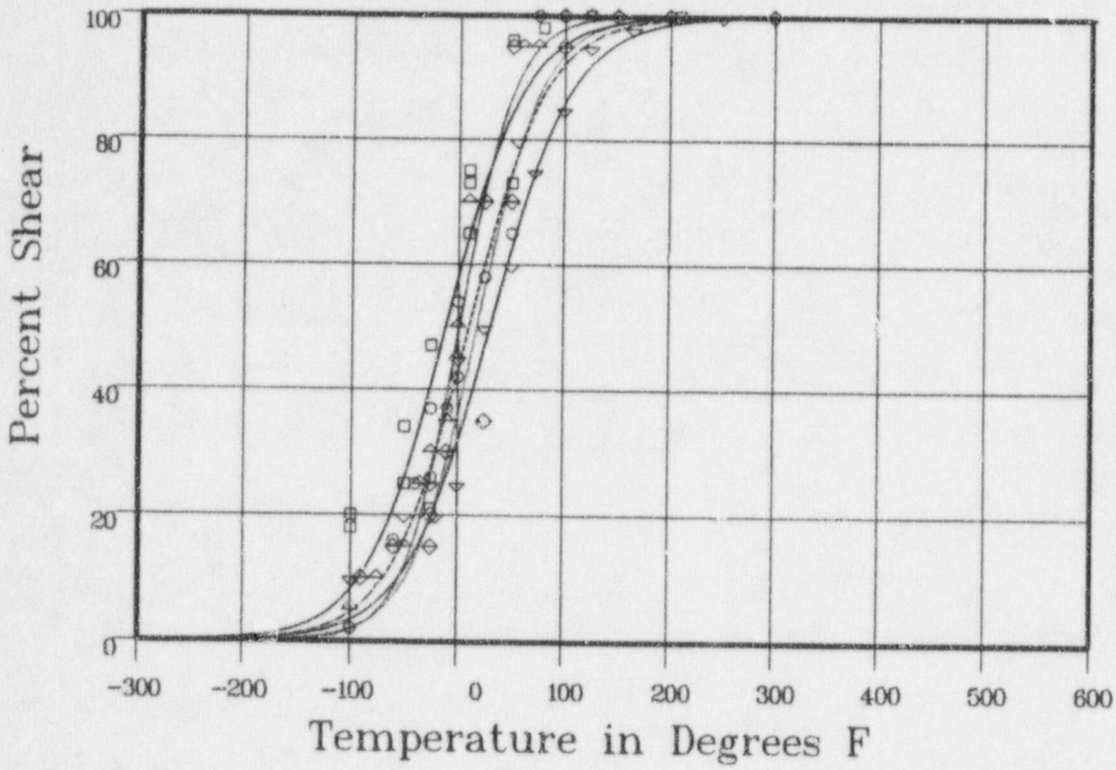
Figure 5-8 Charpy V-Notch Lateral Expansion vs. Temperature for V.C. Summer Unit 1 Reactor Vessel Weld Metal

Weld Material

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:50:44 on 06-23-1998

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	-16.14	0
2	0	5.6	21.75
3	0	13.12	29.27
4	0	-3.28	12.86
5	0	25.37	41.52



Curve Legend

1 □ — 2 ○ ---- 3 ◇ — 4 △ — 5 ▽ —

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	VS1	UNNIRR	WELD		4P47841
2	VS1	U	WELD		4P4784
3	VS1	V	WELD		4P4784
4	VS1	X	WELD		4P4784
5	VS1	W	WELD		4P4784

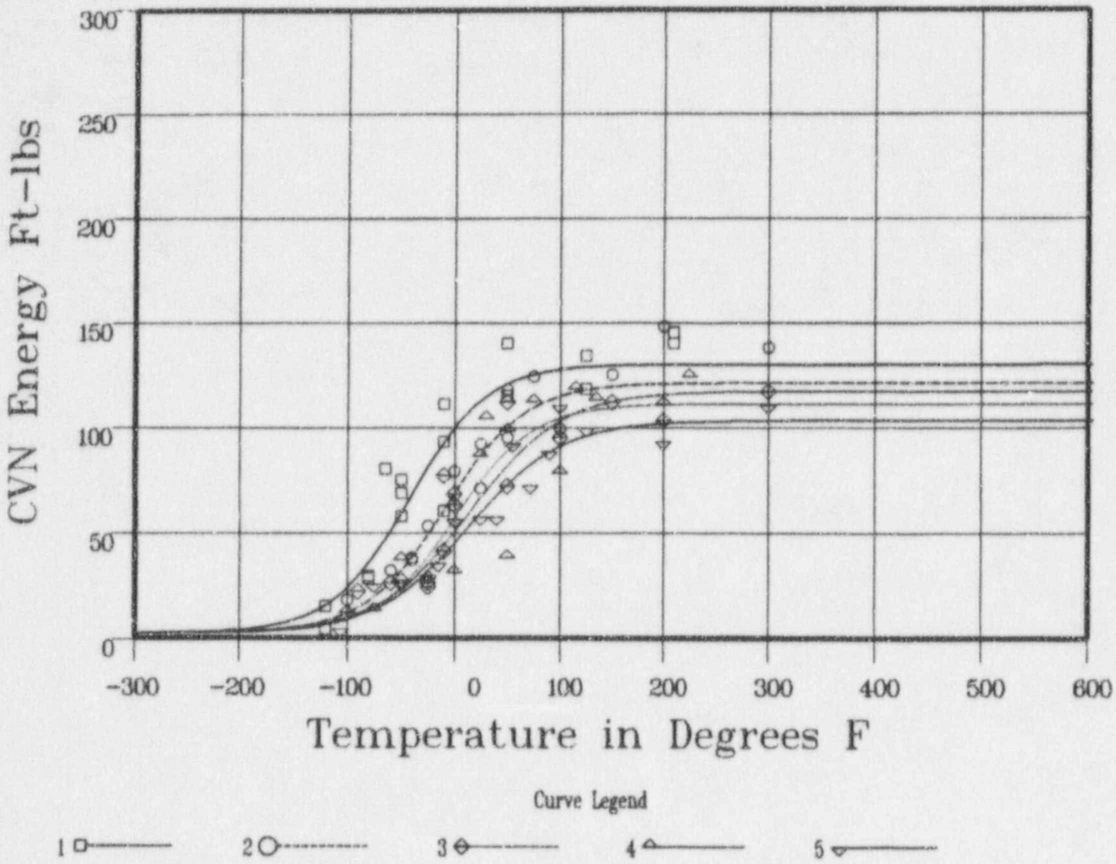
Figure 5-9 Charpy V-Notch Percent Shear vs Temperature for V.C. Summer Unit 1 Reactor Vessel Weld Metal

Heat Affected Zone

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:59:34 on 06-23-1998

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	130	0	-93.36	0	-65.57	0
2	0	2.19	0	121	-9	-57.76	35.59	-28.01	37.55
3	0	2.19	0	111	-19	-43.28	50.07	-13.12	52.44
4	0	2.19	0	117	-13	-39.23	54.13	-4.35	61.22
5	0	2.19	0	103	-27	-33.01	60.34	4.42	69.99



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	VS1	UNNIRR	HEAT AFFD ZONE		
2	VS1	U	HEAT AFFD ZONE		
3	VS1	V	HEAT AFFD ZONE		
4	VS1	X	HEAT AFFD ZONE		
5	VS1	W	HEAT AFFD ZONE		

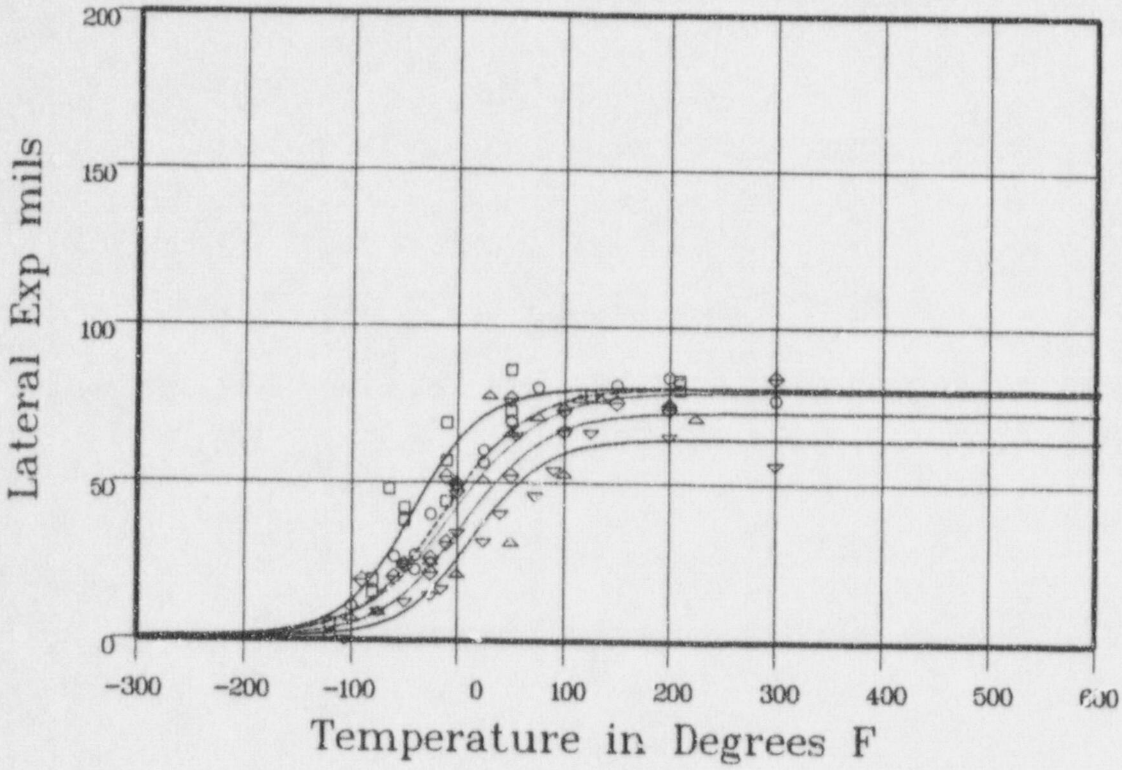
Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for V.C. Summer Unit 1 Reactor Vessel Heat-Affected-Zone Material

Heat Affected Zone

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:05:58 on 06-23-1998

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	80.56	0	-56.52	0
2	0	80.74	.18	-28.18	28.34
3	0	79.49	-1.07	-20.3	36.21
4	0	72.99	-7.56	-2.91	53.6
5	0	64.34	-16.21	15.28	71.81



Curve Legend

1 □ ——— 2 ○ - - - - 3 ◇ ——— 4 △ ——— 5 ▽ ———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	VS1	UNNIRR	HEAT AFFD ZONE		
2	VS1	U	HEAT AFFD ZONE		
3	VS1	V	HEAT AFFD ZONE		
4	VS1	X	HEAT AFFD ZONE		
5	VS1	W	HEAT AFFD ZONE		

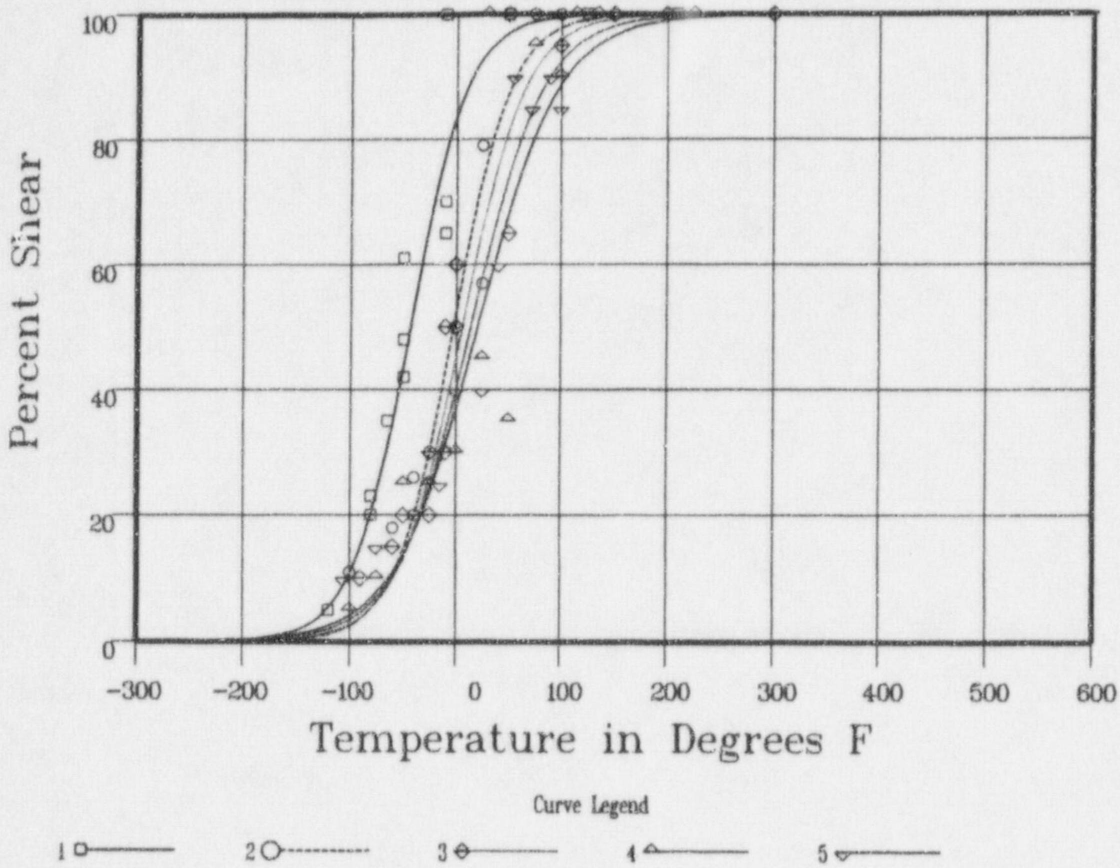
Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for V.C. Summer Unit 1 Reactor Vessel Heat-Affected-Zone Material

Heat Affected Zone

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:14:12 on 06-23-1998

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	-48.18	0
2	0	-7	41.18
3	0	1.4	49.59
4	0	9.37	57.56
5	0	15.93	64.12



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	VS1	UNNIRR	HEAT AFFD ZONE		
2	VS1	U	HEAT AFFD ZONE		
3	VS1	V	HEAT AFFD ZONE		
4	VS1	X	HEAT AFFD ZONE		
5	VS1	W	HEAT AFFD ZONE		

Figure 5-12 Charpy V-Notch Percent Shear vs. Temperature for V.C. Summer Unit 1 Reactor Vessel Heat-Affected-Zone Material

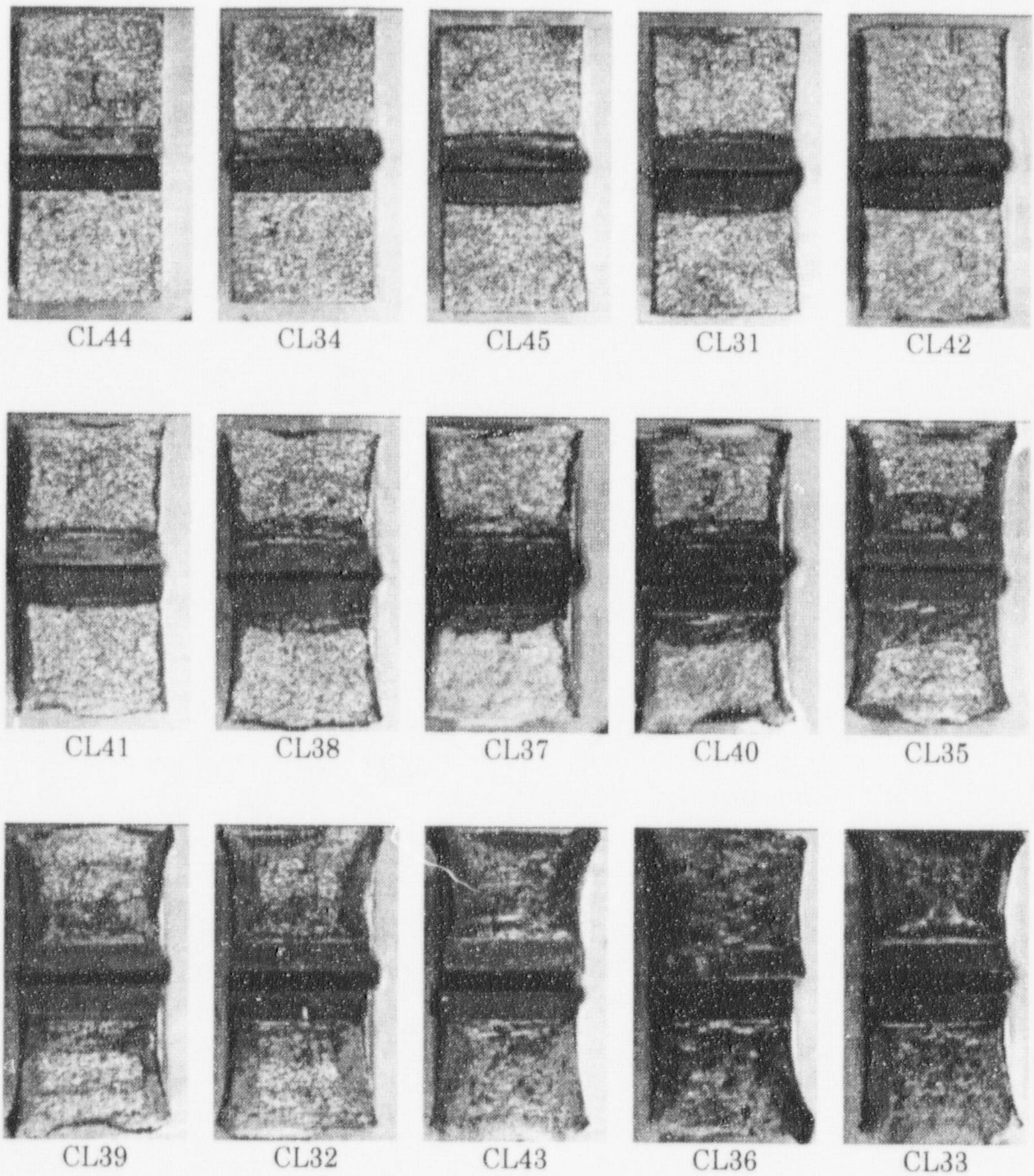


Figure 5-13 Charpy Impact Specimen Fracture Surfaces for V.C. Summer Unit 1 Reactor Vessel Intermediate Shell Plate A9154-1 (Longitudinal Orientation)

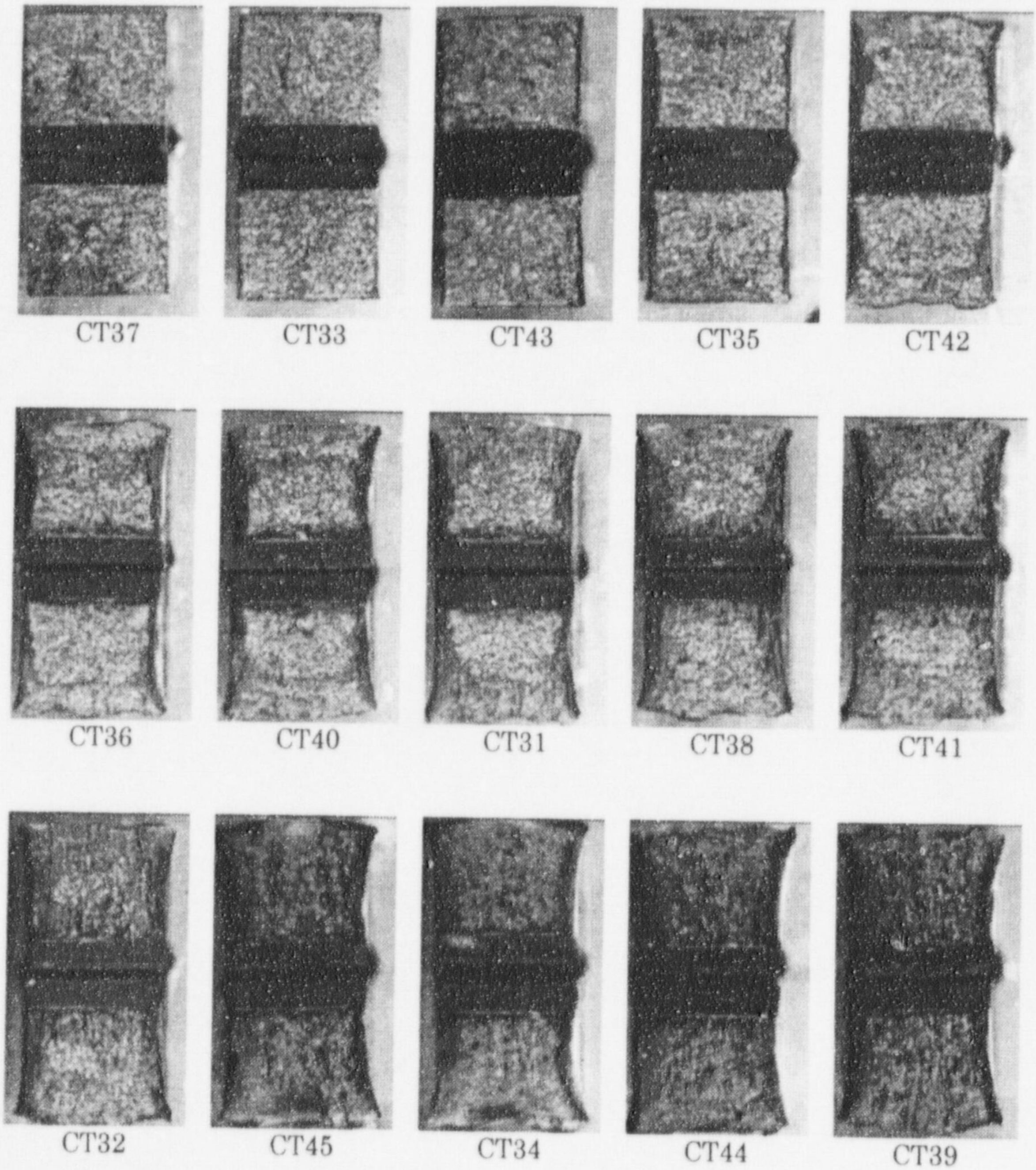


Figure 5-14 Charpy Impact Specimen Fracture Surfaces for V.C. Summer Unit 1 Reactor Vessel Intermediate Shell Plate A9154-1 (Transverse Orientation)

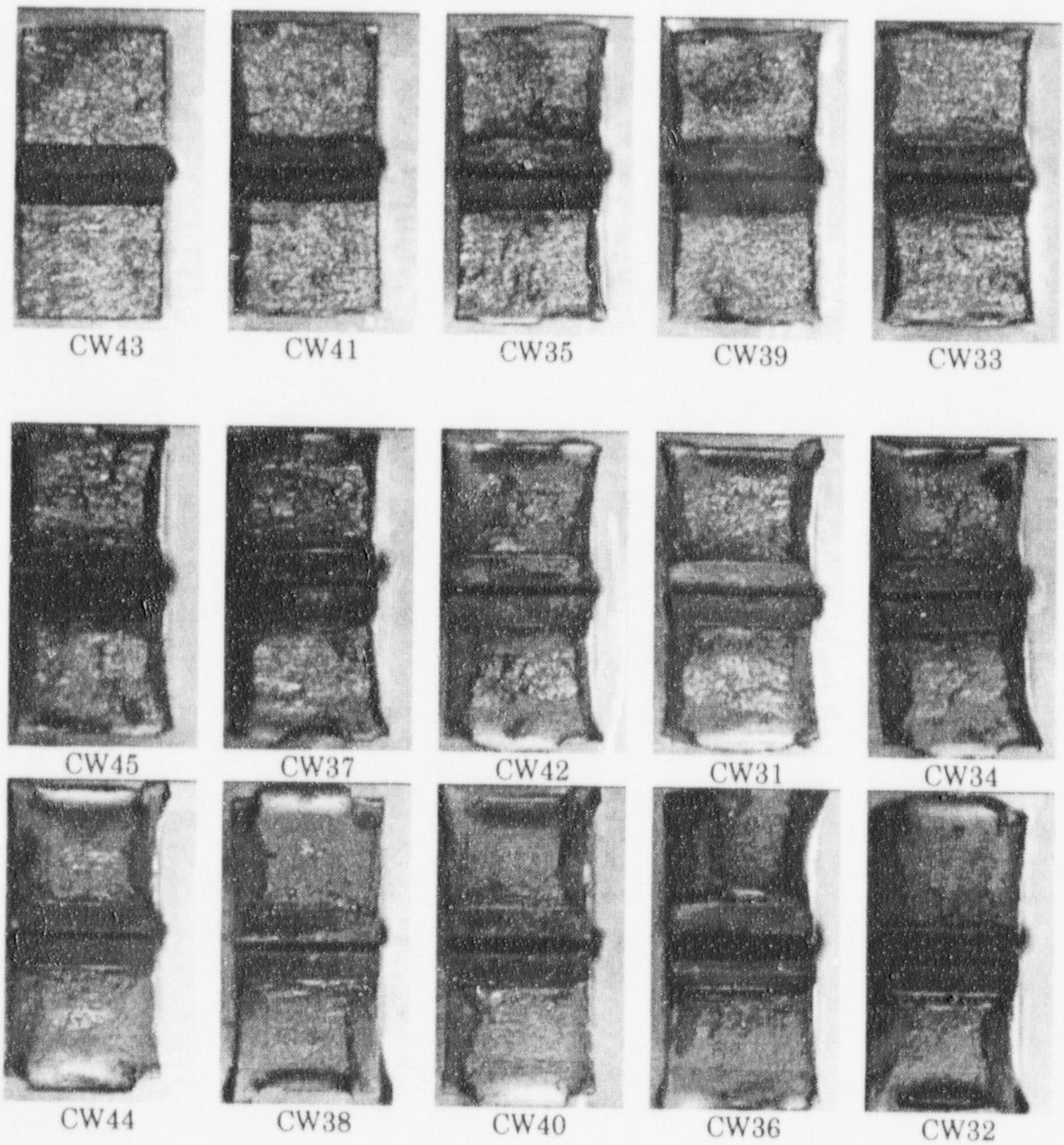


Figure 5-15 Charpy Impact Specimen Fracture Surfaces for V.C. Summer Unit 1 Reactor Vessel Weld Metal

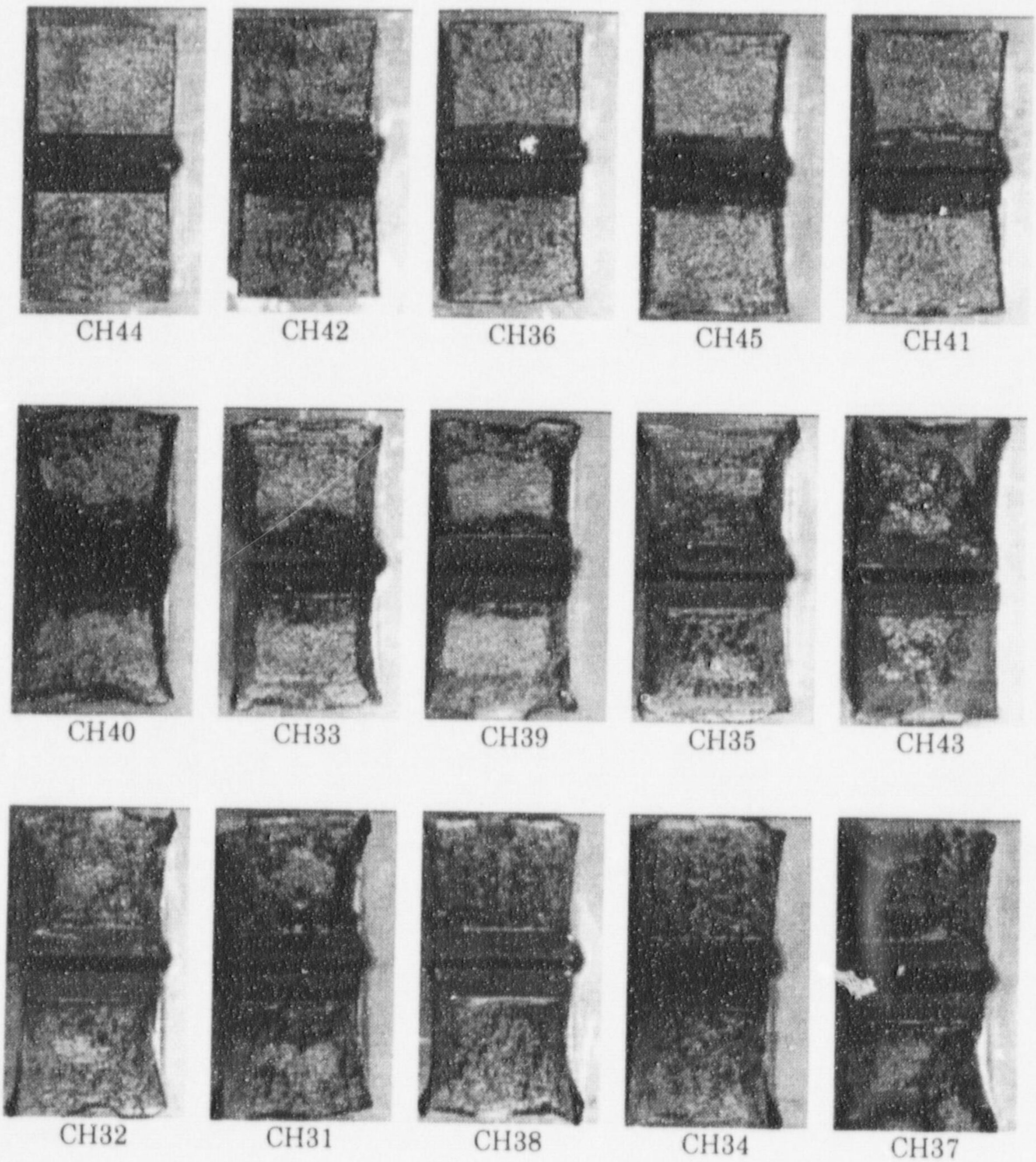


Figure 5-16 Charpy Impact Specimen Fracture Surfaces for V.C. Summer Unit 1 Reactor Vessel Heat-Affected-Zone Metal

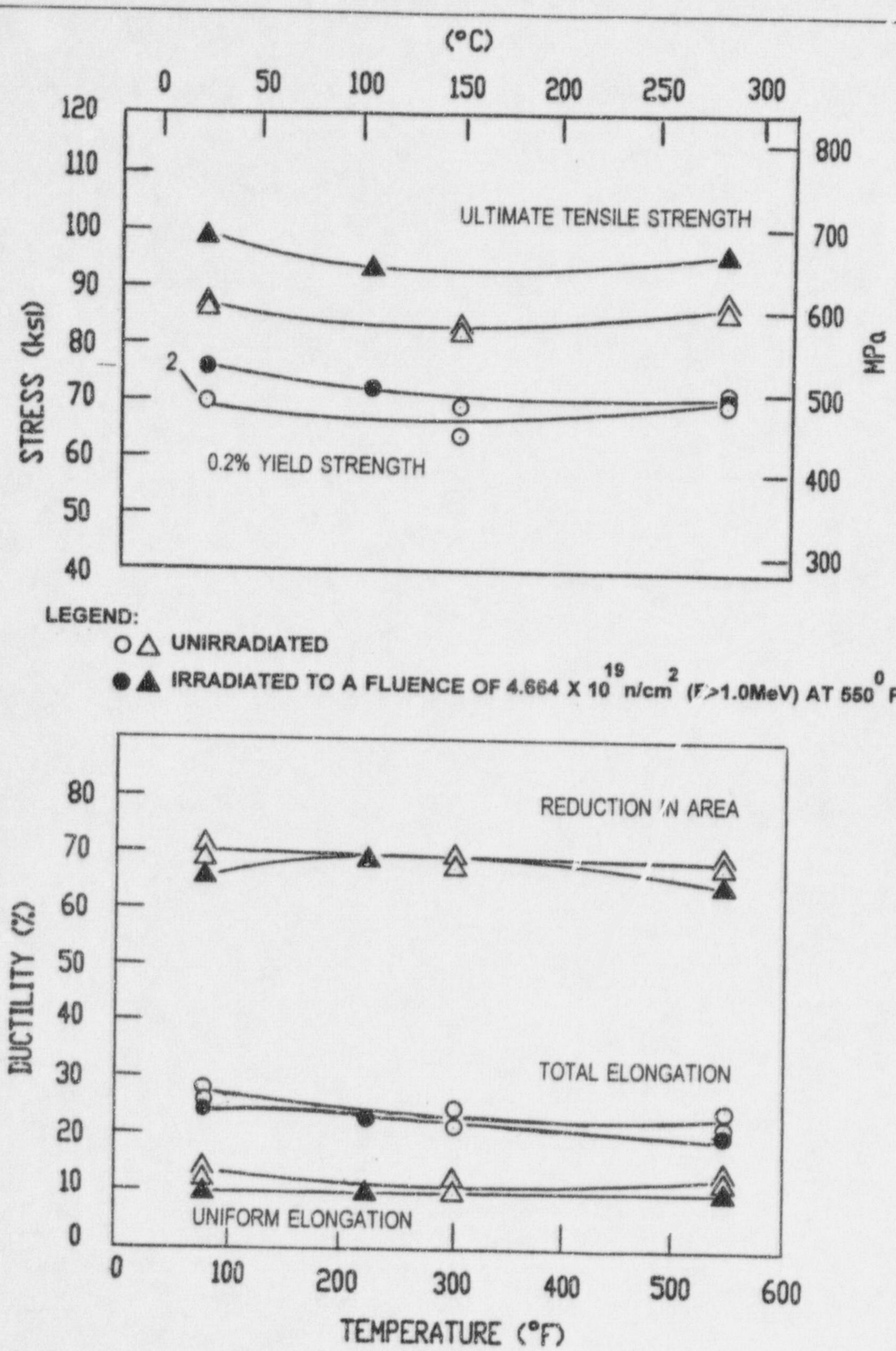


Figure 5-17 Tensile Properties for V.C. Summer Unit 1 Reactor Vessel Intermediate Shell Plate A9154-1 (Longitudinal Orientation)

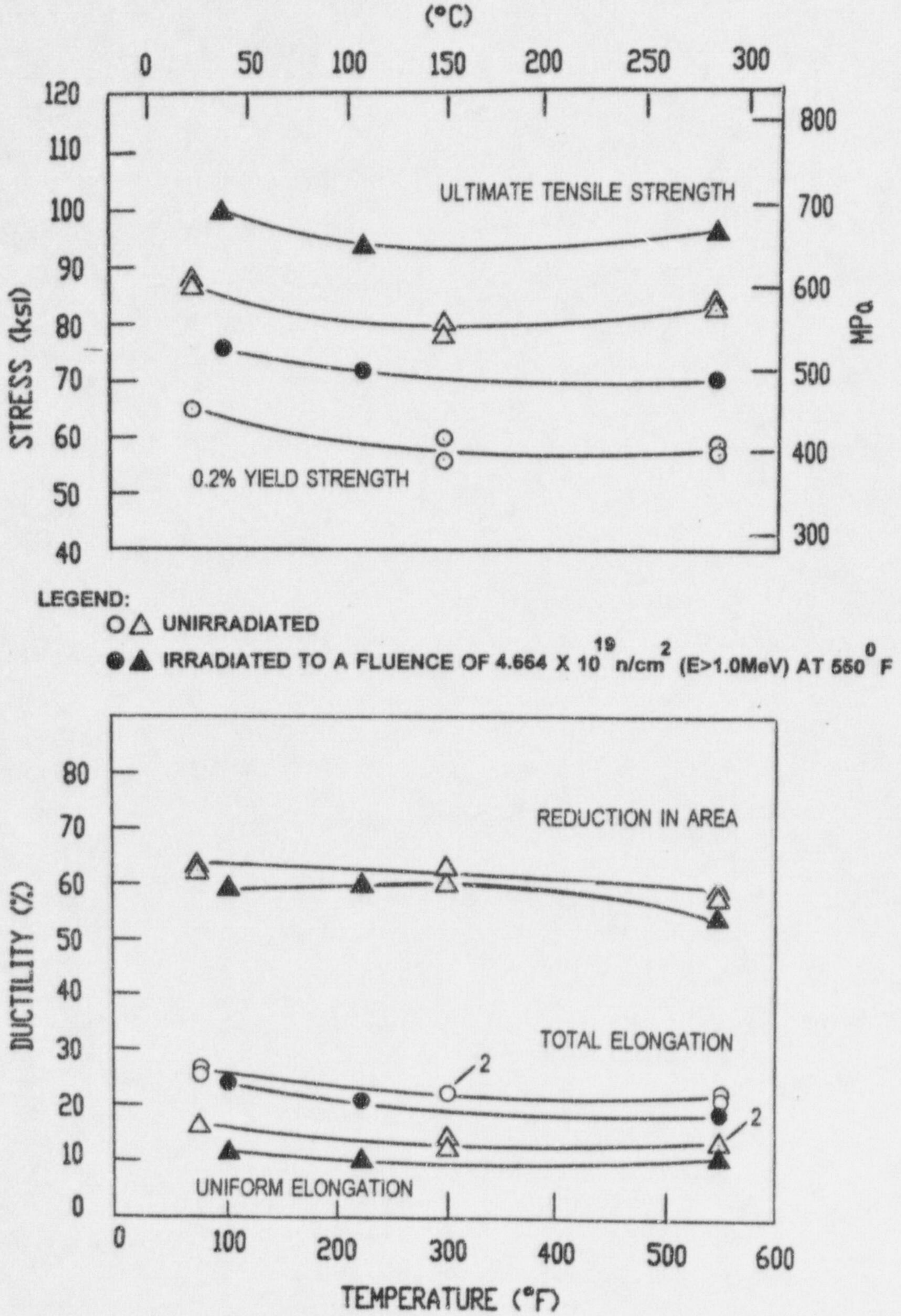


Figure 5-18 Tensile Properties for V.C. Summer Unit 1 Reactor Vessel Intermediate Shell Plate A9154-1 (Transverse Orientation)

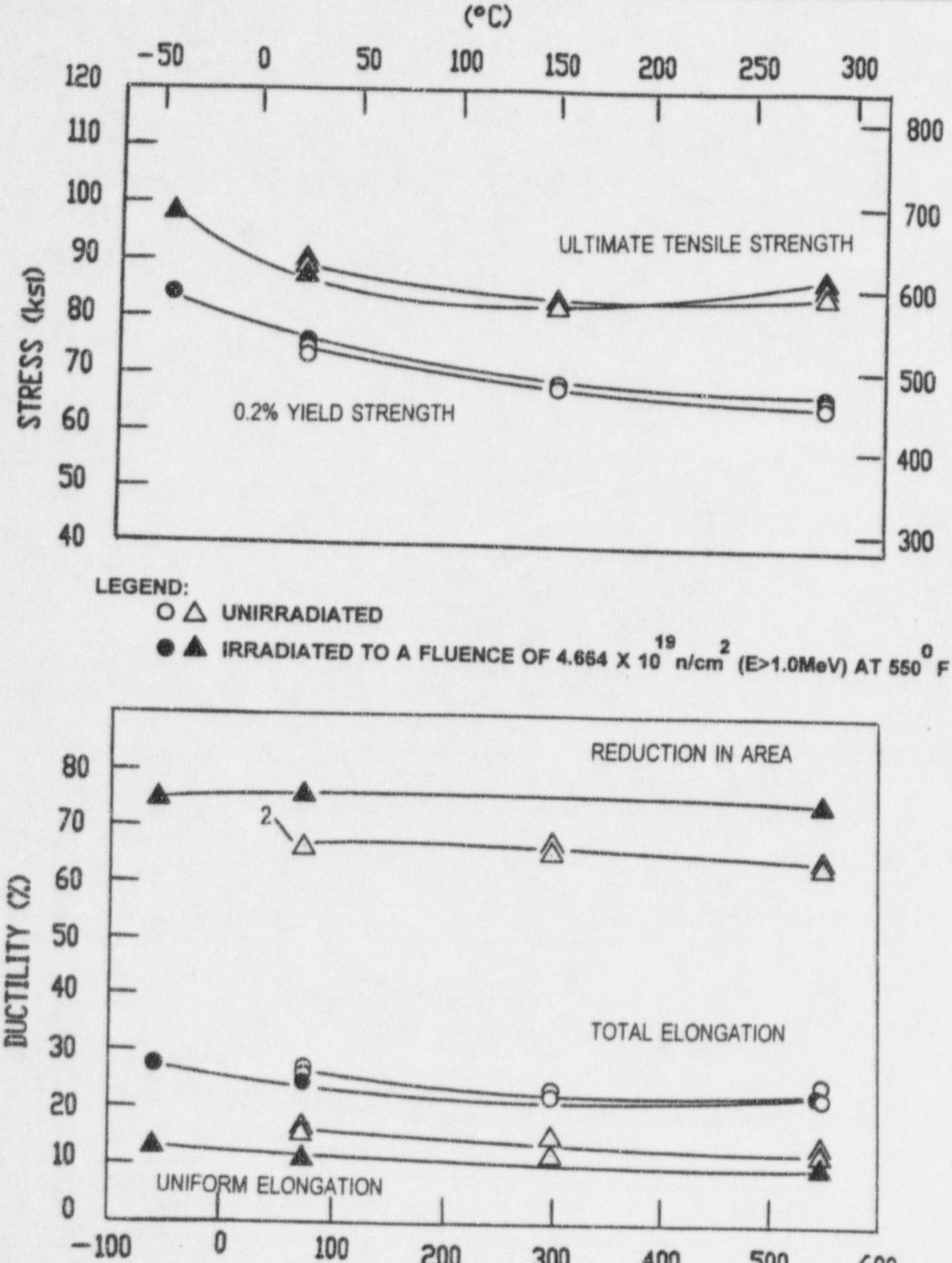
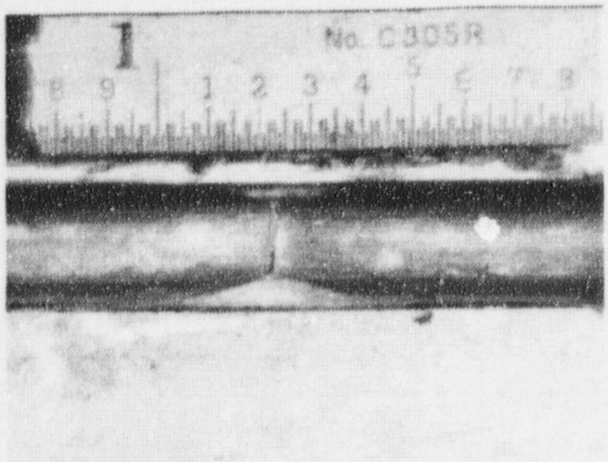
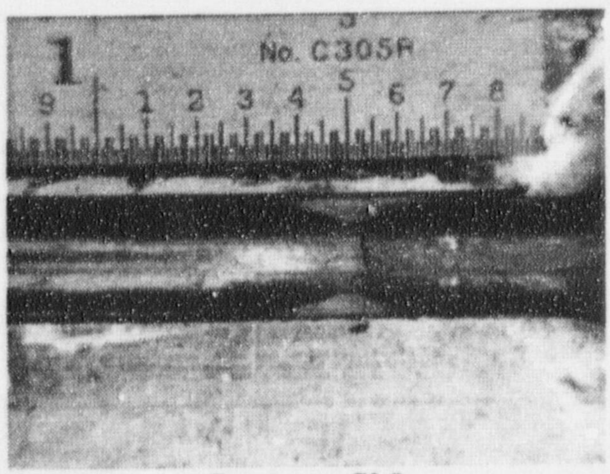


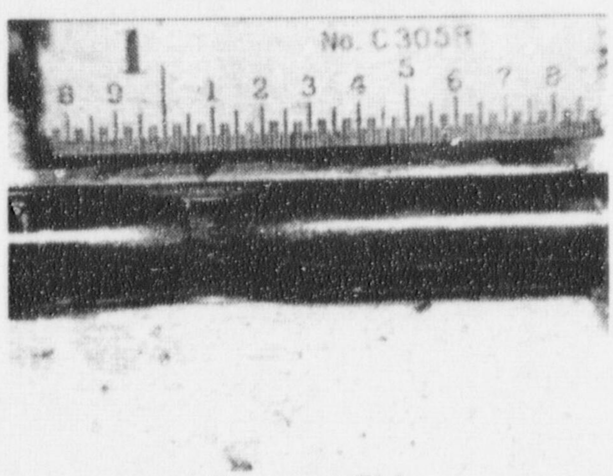
Figure 5-19 Tensile Properties for V.C. Summer Unit 1 Reactor Vessel Weld Metal



Specimen CL7

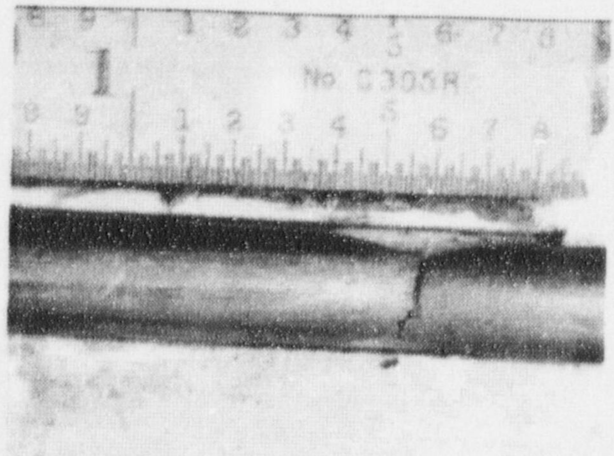


Specimen CL8

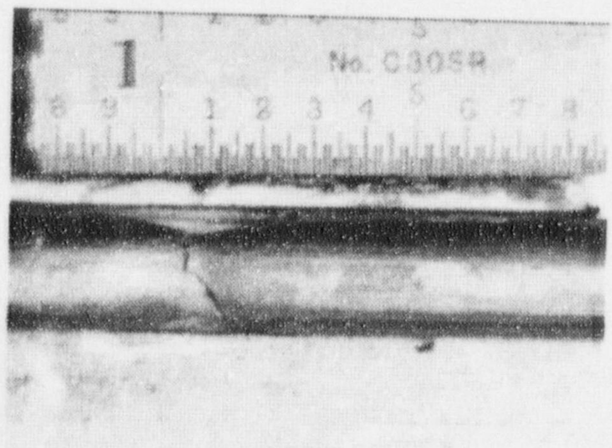


Specimen CL9

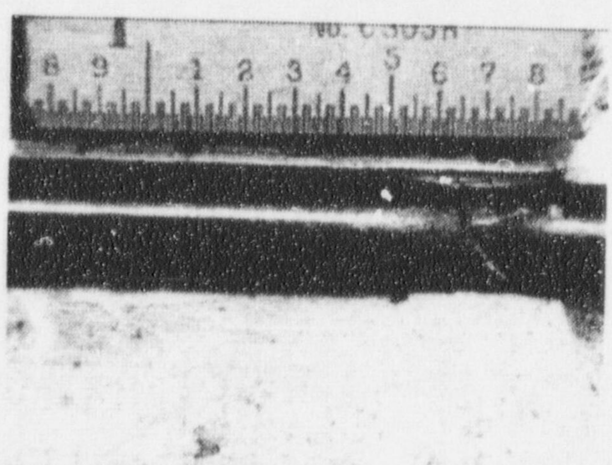
Figure 5-20 Fractured Tensile Specimens from V.C. Summer Unit 1 Reactor Vessel Intermediate Shell Plate A9154-1 (Longitudinal Orientation)



CT7

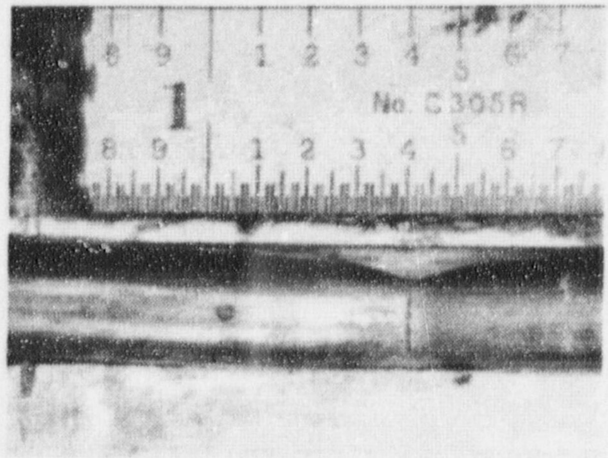


CT8

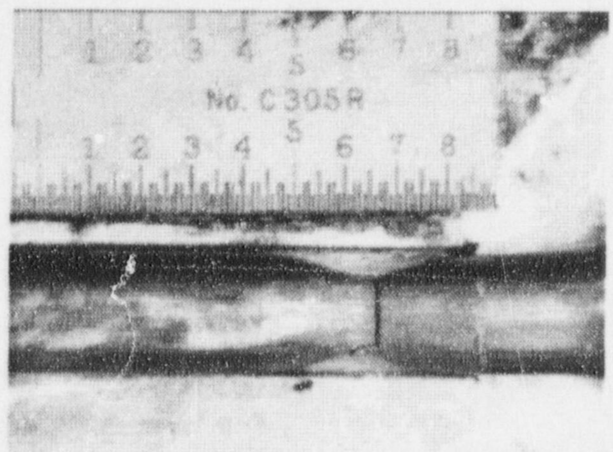


CT9

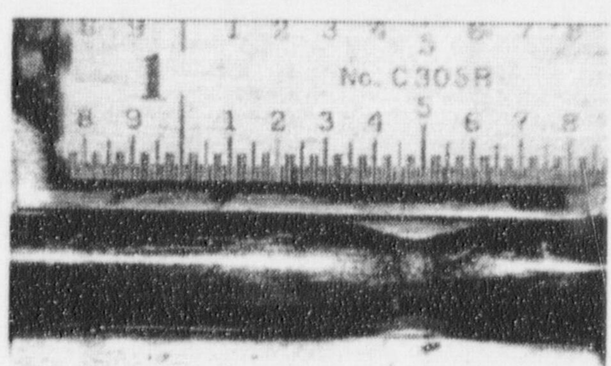
Figure 5-21 Fractured Tensile Specimens from V.C. Summer Unit 1 Reactor Vessel Intermediate Shell Plate A9154-1 (Transverse Orientation)



CW7

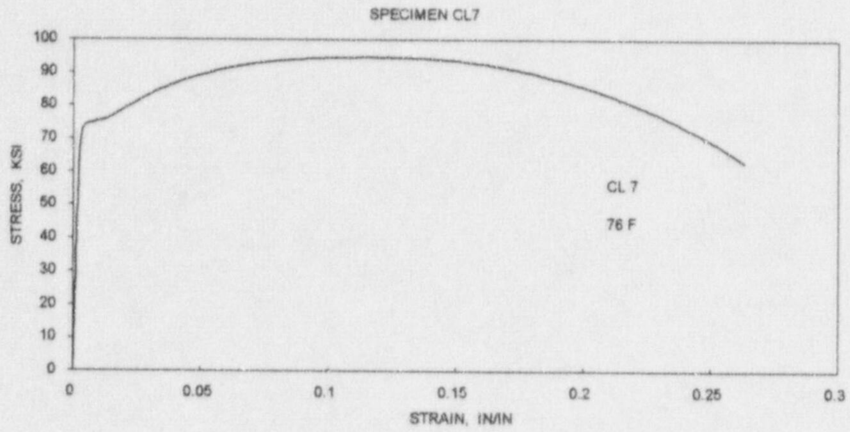


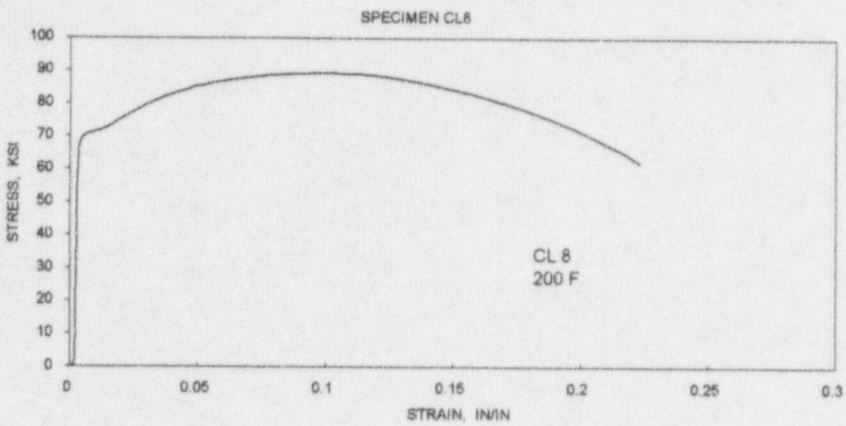
CW8



CW9

Figure 5-22 Fractured Tensile Specimens from V.C. Summer Unit 1 Reactor Vessel Weld Metal





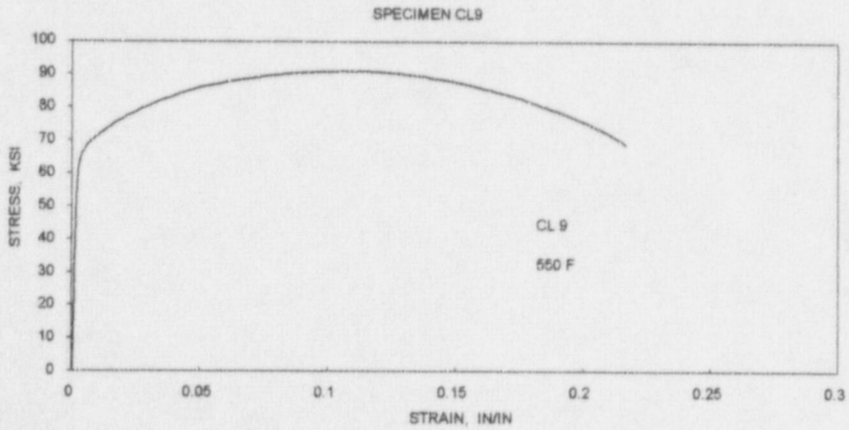


Figure 5-23 Engineering Stress-Strain Curves for Intermediate Shell Plate A9154-1 Tensile Specimens CL7, CL8 and CL9 (Longitudinal Orientation)

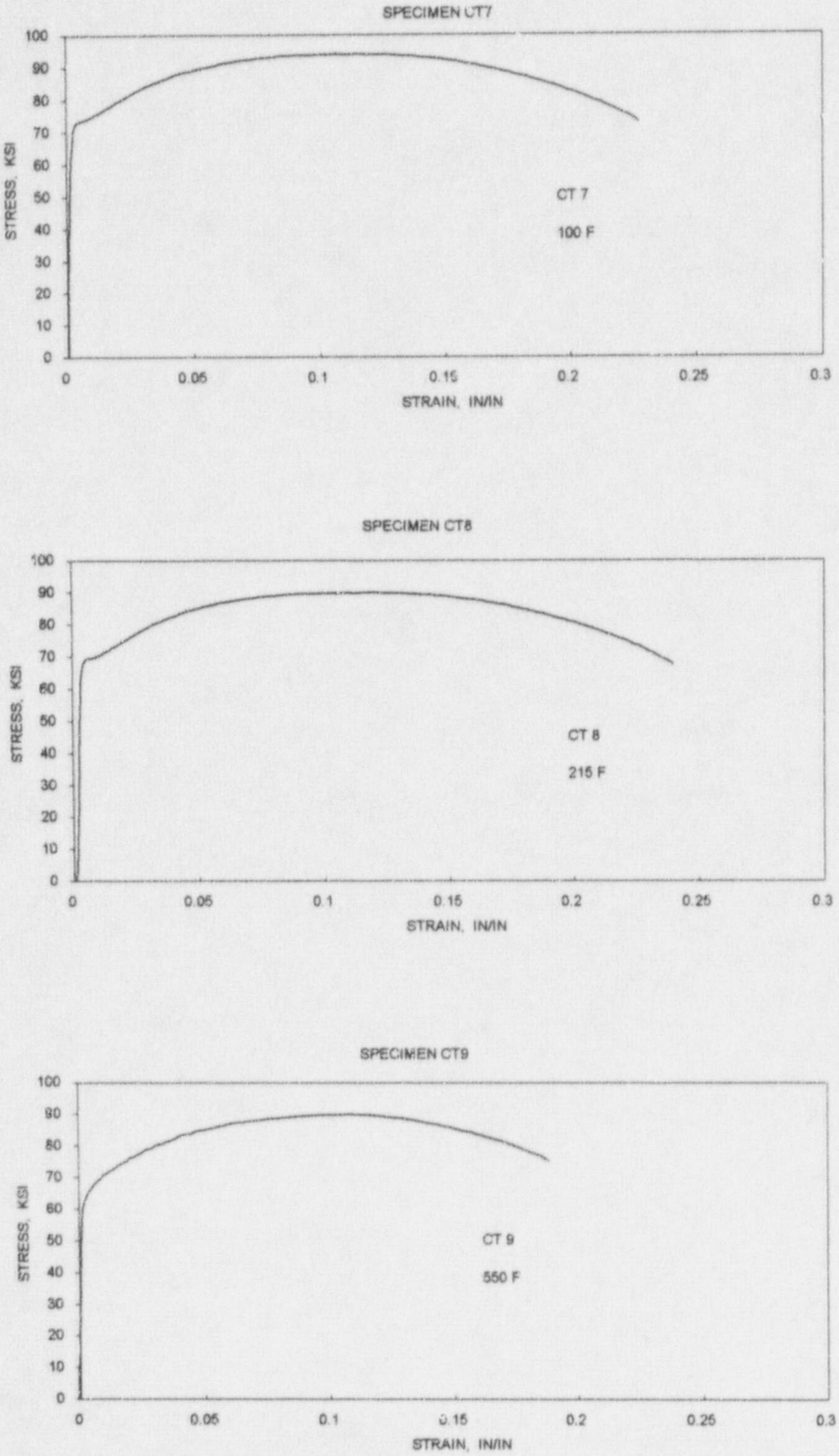
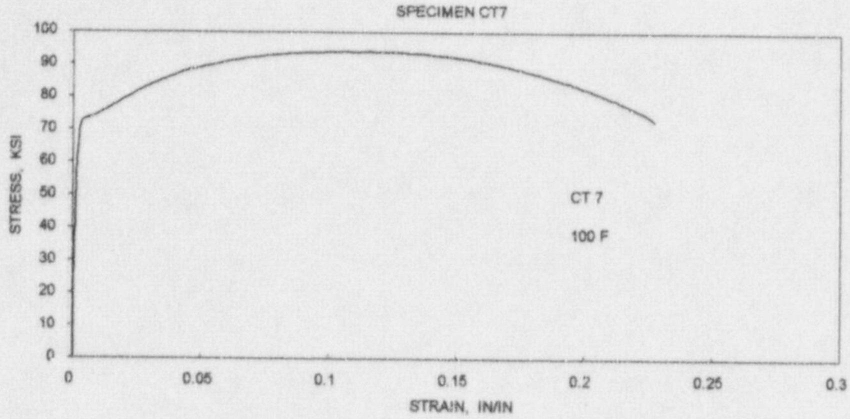
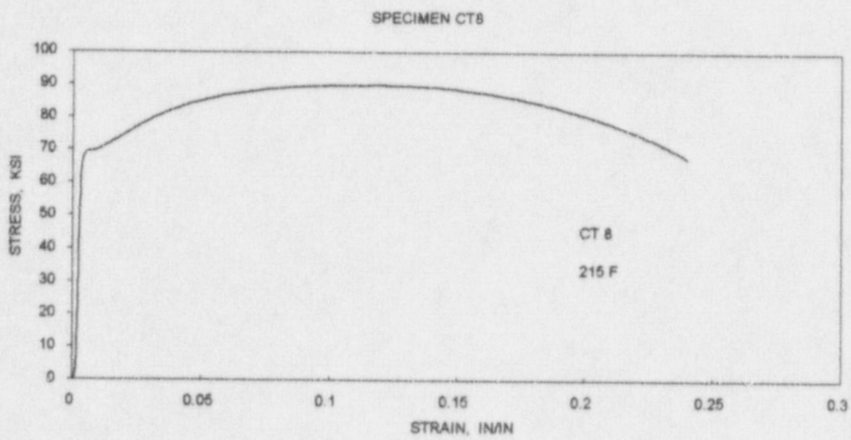


Figure 5-24 Engineering Stress-Strain Curves for Intermediate Shell Plate A9154-1 Tensile Specimens CT7, CT8 and CT9 (Transverse Orientation)





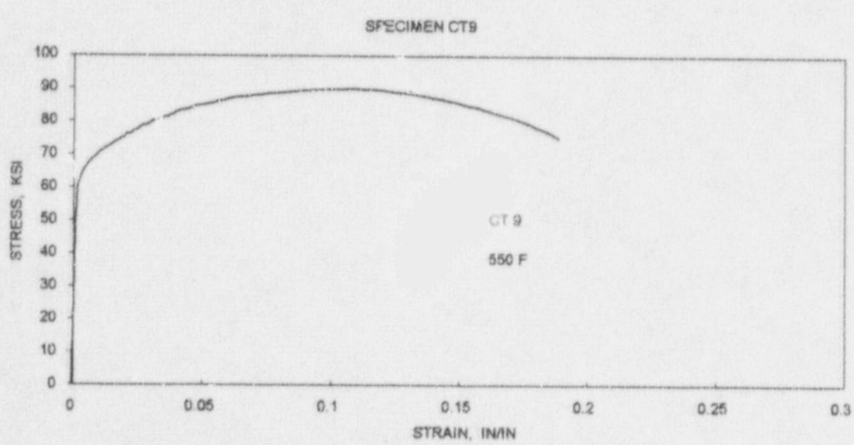


Figure 5-25 Engineering Stress-Strain Curves for Weld Metal Tensile Specimens CW7, CW8 and CW9

6 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, V, X, and W which were withdrawn during the first, third, fifth, and tenth 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 V. C. Summer Unit 1 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 107°, 110°, 287°, 290°, 340°, and 343° 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 1.128 by 1.603-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 {$\phi(E > 1.0\ \text{MeV})$, $\phi(E > 0.1\ \text{MeV})$, 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]/[$\phi(E > 1.0\ \text{MeV})$], 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, $\phi(E > 1.0\ \text{MeV})$, 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[12] and the BUGLE-96 cross-section library [13]. The BUGLE-96 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 3-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-96 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 fu..ctions and appropriate core source distributions, th. 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,θ) = φ(E > 1.0 MeV) at radius r and azimuthal angle θ.

I(r,θ,E)= Adjoint source importance function at radius r, azimuthal angle θ, and neutron source energy E.

S(r,θ,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 Φ(E > 1.0 MeV), prior calculations [14] 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]/[Φ(E > 1.0 MeV)] is insensitive to changing core source distributions. In the application of these adjoint importance functions to the V. C. Summer Unit 1 reactor, therefore, the iron atom displacement rates (dpa/sec) and the neutron flux Φ(E > 0.1 MeV) were computed on a cycle-specific basis by using [dpa/sec]/[Φ(E > 1.0 MeV)] and[Φ(E > 0.1 MeV)]/[Φ(E > 1.0 MeV)] ratios from the forward analysis in conjunction with the cycle specific Φ(E > 1.0 MeV) solutions from tl individual adjoint evaluations.

The reactor core power distributions used in the plant specific adjoint calculations were taken from the fuel cycle design reports and data from plant personnel for the first ten operating cycle of V. C. Summer Unit 1 [15 through 24].

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, V, X, and W 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 [Φ(E > 1.0 MeV), Φ(E > 0.1 MeV), and dpa/sec] are given at the geometric center of the two azimuthally symmetric surveillance capsule positions (17° and 20°) 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 10 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, represent the maximum predicted exposure 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:

$$\phi_{\frac{1}{4}T}(0^\circ) = \phi(199.95, 0^\circ)\, F(204.95, 0^\circ)$$

where:

$\Phi_{¼T}(0^\circ)$ = Projected neutron flux at the ¼T position on the 0° azimuth.

$\Phi(199.95,0^\circ)$ = Projected or calculated neutron flux at the vessel inner radius on the 0° azimuth.

$F(204.95,0^\circ)$ = 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 V. C. Summer Unit 1 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 [25],
- 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 [26 through 39]. 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 V. C. Summer Unit 1 reactor was obtained from South Carolina Gas and Electric Company personnel[25] as reported in NUREG-0020, "Licensed Operating Reactors Status Summary Report," for the Cycles 1 to 10 operating periods. The irradiation history applicable to the exposure of Capsules U, V, X, and W 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 $\Phi(E > 1.0 \text{ MeV})$ during irradiation period j to the time weighted average $\Phi(E > 1.0 \text{ MeV})$ 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, V, X, and W 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. The 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 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 [40]. 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[41]. 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 [42], 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 x 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 correlation's for each of the individual reactions. However, correlation's 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 x 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:

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

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:

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

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 correlation's 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 correlation's (or anti-correlation's) were justified based on information presented by R. E. Maerker[43]. 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, V, X, and W dosimetry are given in Table 6-9. The data summarized in this table include fast neutron exposure evaluations in terms of $\phi(E > 1.0\ MeV)$, $\phi(E > 0.1\ MeV)$, 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 12%. 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, V, X, and W are presented. The result for the Capsules U, V, X, and W dosimetry evaluation (BE/C ratio of 0.951 for $\phi(E > 1.0\ MeV)$) 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 V. C. Summer Unit 1 reactor vessel was developed using a combination of absolute plant specific transport calculations and all available plant specific measurement data. In the case of V. C. Summer Unit 1, the measurement data base contains four 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 V. C. Summer Unit 1, the derived plant specific bias factors were 0.951, 1.015, and 0.995 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 ENDF/B-VI based cross-section libraries.

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 V. C. Summer Unit 1, the derived uncertainties in the bias factor, K, and the additional uncertainty from the analytical sensitivity studies combine to yield a net uncertainty of ±6.4%.

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 (10.78 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 7 through 10 (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 V. C. Summer Unit 1 reactor vessel, exposure projections to 16, 32, and 54 EFPY were also employed. Data based on both a $\phi(E > 1.0\ MeV)$ 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:

$$\phi(\tfrac{1}{4}T) = \phi(0T)\,\frac{dpa(\tfrac{1}{4}T)}{dpa(0T)}$$

and

$$\phi(\tfrac{3}{4}T) = \phi(0T)\,\frac{dpa(\tfrac{3}{4}T)}{dpa(0T)}$$

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 V. C. Summer Unit 1 surveillance capsules.

Figure 6-1

Plan View Of A Dual Reactor Vessel Surveillance Capsule

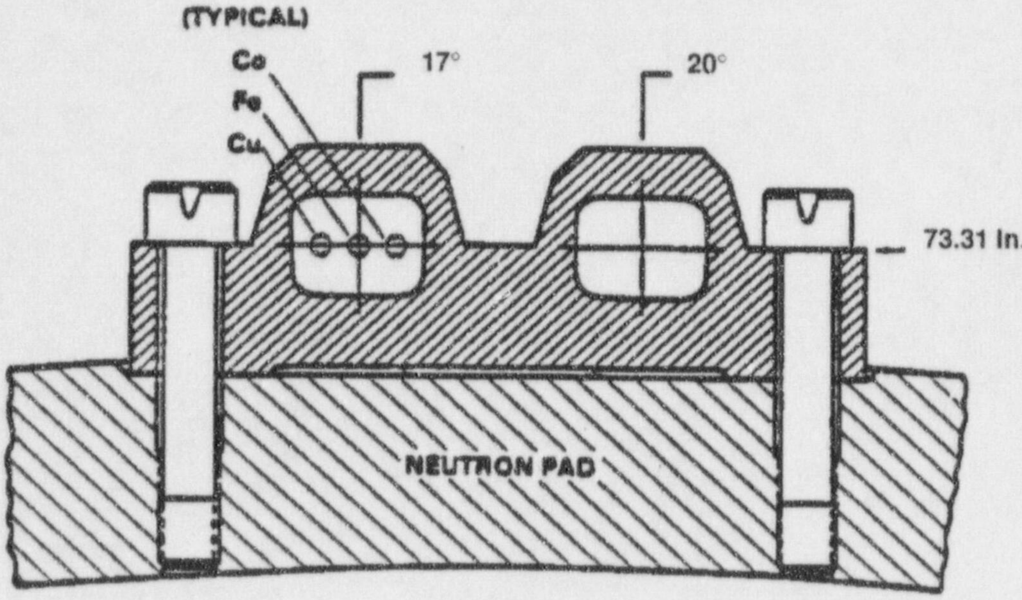


Table 6-1

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

Cycle No.	$\phi(E > 1.0\ MeV)$ $(n/cm^2\text{-sec})$ 17°	20°
Reference	2.310E+11	1.995E+11
1	1.917E+11	1.659E+11
2	1.692E+11	1.523E+11
3	1.596E+11	1.399E+11
4	1.437E+11	1.272E+11
5	1.744E+11	1.564E+11
6	1.783E+11	1.572E+11
7	1.405E+11	1.263E+11
8	1.481E+11	1.298E+11
9	1.341E+11	1.179E+11
10	1.288E+11	1.152E+11

Cycle No.	$\phi(E > 0.1\ MeV)$ $(n/cm^2\text{-sec})$ 17°	20°
Reference	1.130E+12	9.367E+11
1	9.377E+11	7.787E+11
2	8.275E+11	7.150E+11
3	7.806E+11	6.570E+11
4	7.031E+11	5.973E+11
5	8.530E+11	7.342E+11
6	8.724E+11	7.383E+11
7	6.875E+11	5.931E+11
8	7.243E+11	6.093E+11
9	6.560E+11	5.536E+11
10	6.300E+11	5.409E+11

Cycle No.	Displacement Rate (dpa/sec) 17°	20°
Reference	4.669E-10	3.939E-10
1	3.874E-10	3.274E-10
2	3.419E-10	3.006E-10
3	3.225E-10	2.762E-10
4	2.905E-10	2.512E-10
5	3.524E-10	3.087E-10
6	3.604E-10	3.104E-10
7	2.840E-10	2.494E-10
8	2.992E-10	2.562E-10
9	2.710E-10	2.328E-10
10	2.603E-10	2.274E-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

	ϕ(E > 1.0 MeV) (n/cm^2-sec)			
Cycle No.	0°	15°	30°	45°
Reference	7.032E+10	3.879E+10	2.897E+10	1.921E+10
1	5.774E+10	3.218E+10	2.380E+10	1.652E+10
2	4.310E+10	2.796E+10	2.090E+10	1.250E+10
3	3.808E+10	2.637E+10	1.915E+10	1.273E+10
4	3.674E+10	2.395E+10	1.835E+10	1.241E+10
5	4.145E+10	2.870E+10	2.136E+10	1.342E+10
6	4.281E+10	2.946E+10	2.198E+10	1.542E+10
7	3.703E+10	2.353E+10	1.983E+10	1.525E+10
8	4.075E+10	2.492E+10	1.929E+10	1.407E+10
9	3.787E+10	2.261E+10	1.750E+10	1.305E+10
10	3.186E+10	2.149E+10	1.778E+10	1.456E+10

	ϕ(E > 0.1 MeV) (n/cm^2-sec)			
Cycle No.	0°	15°	30°	45°
Reference	1.801E+11	9.220E+10	6.125E+10	4.007E+10
1	1.479E+11	7.650E+10	5.032E+10	3.445E+10
2	1.104E+11	6.645E+10	4.419E+10	2.608E+10
3	9.752E+10	6.268E+10	4.049E+10	2.655E+10
4	9.409E+10	5.693E+10	3.878E+10	2.589E+10
5	1.061E+11	6.823E+10	4.516E+10	2.800E+10
6	1.096E+11	7.002E+10	4.647E+10	3.217E+10
7	9.483E+10	5.594E+10	4.192E+10	3.181E+10
8	1.043E+11	5.924E+10	4.078E+10	2.934E+10
9	9.697E+10	5.374E+10	3.699E+10	2.723E+10
10	8.159E+10	5.108E+10	3.759E+10	3.036E+10

	Displacement Rate (dpa/sec)			
Cycle No.	0°	15°	30°	45°
Reference	1.101E-10	6.009E-11	4.381E-11	2.929E-11
1	9.042E-11	4.985E-11	3.599E-11	2.519E-11
2	6.749E-11	4.330E-11	3.160E-11	1.907E-11
3	5.963E-11	4.085E-11	2.896E-11	1.941E-11
4	5.753E-11	3.710E-11	2.774E-11	1.893E-11
5	6.490E-11	4.446E-11	3.230E-11	2.047E-11
6	6.703E-11	4.563E-11	3.324E-11	2.352E-11
7	5.799E-11	3.645E-11	2.998E-11	2.326E-11
8	6.381E-11	3.860E-11	2.917E-11	2.145E-11
9	5.930E-11	3.502E-11	2.645E-11	1.991E-11
10	4.989E-11	3.328E-11	2.689E-11	2.220E-11

Table 6-3

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

RADIUS	AZIMUTHAL ANGLE			
(cm)	0°	15°	30°	45°
199.95	1.000	1.000	1.000	1.000
200.54	0.961	0.963	0.962	0.963
201.72	0.861	0.867	0.867	0.868
202.89	0.754	0.765	0.763	0.765
204.07	0.653	0.667	0.664	0.667
204.95	0.585	0.601	0.597	0.601
205.25	0.562	0.578	0.575	0.578
206.42	0.482	0.499	0.495	0.499
207.60	0.412	0.429	0.425	0.429
208.78	0.351	0.368	0.364	0.368
209.95	0.299	0.315	0.311	0.315
211.13	0.254	0.270	0.265	0.269
212.30	0.215	0.230	0.226	0.230
213.48	0.182	0.196	0.192	0.195
214.66	0.153	0.166	0.163	0.166
214.95	0.147	0.160	0.156	0.160
215.83	0.129	0.141	0.138	0.141
217.01	0.108	0.119	0.116	0.119
218.19	0.089	0.100	0.097	0.101
219.36	0.072	0.083	0.080	0.085
219.95	0.069	0.080	0.077	0.082

Note: Base Metal Inner Radius = 199.95 cm
Base Metal ¼T = 204.95 cm
Base Metal ½T = 209.95 cm
Base Metal ¾T = 214.95 cm
Base Metal Outer Radius = 219.95 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°
199.95	1.000	1.000	1.000	1.000
200.54	1.005	1.012	1.009	1.011
201.72	0.982	0.999	0.994	0.999
202.89	0.941	0.968	0.958	0.966
204.07	0.891	0.927	0.914	0.925
204.95	0.852	0.894	0.878	0.890
205.25	0.839	0.882	0.866	0.879
206.42	0.786	0.835	0.816	0.831
207.60	0.733	0.787	0.766	0.783
208.78	0.682	0.738	0.717	0.735
209.95	0.631	0.690	0.669	0.688
211.13	0.582	0.643	0.621	0.642
212.30	0.534	0.596	0.575	0.596
213.48	0.487	0.549	0.529	0.552
214.66	0.442	0.504	0.485	0.509
214.95	0.431	0.493	0.474	0.498
215.83	0.398	0.459	0.442	0.466
217.01	0.354	0.415	0.400	0.425
218.19	0.310	0.371	0.358	0.385
219.36	0.263	0.326	0.316	0.346
219.95	0.253	0.317	0.308	0.338

Note: Base Metal Inner Radius = 199.95 cm
Base Metal ¼T = 204.95 cm
Base Metal ½T = 209.95 cm
Base Metal ¾T = 214.95 cm
Base Metal Outer Radius = 219.95 cm

Table 6-5

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

RADIUS	AZIMUTHAL ANGLE			
(cm)	0°	15°	30°	45°
199.95	1.000	1.000	1.000	1.000
200.54	0.968	0.971	0.968	0.969
201.72	0.889	0.896	0.888	0.889
202.89	0.805	0.816	0.803	0.805
204.07	0.725	0.740	0.722	0.724
204.95	0.670	0.687	0.666	0.669
205.25	0.651	0.669	0.647	0.651
206.42	0.585	0.604	0.580	0.584
207.60	0.524	0.545	0.519	0.524
208.78	0.470	0.492	0.465	0.470
209.95	0.421	0.443	0.416	0.422
211.13	0.377	0.399	0.373	0.379
212.30	0.336	0.359	0.334	0.340
213.48	0.300	0.323	0.298	0.305
214.66	0.266	0.289	0.266	0.273
214.95	0.258	0.281	0.258	0.266
215.83	0.235	0.258	0.236	0.244
217.01	0.206	0.229	0.209	0.218
218.19	0.178	0.202	0.184	0.194
219.36	0.150	0.176	0.161	0.173
219.95	0.144	0.172	0.157	0.169

Note: Base Metal Inner Radius = 199.95 cm
Base Metal ¼T = 204.95 cm
Base Metal ½T = 209.95 cm
Base Metal ¾T = 214.95 cm
Base Metal Outer Radius = 219.95 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,a)	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,g)	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 Ten Fuel Cycles
Of The V. C. Summer Unit 1 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)
82	11	143789	86	8	2037220	90	5	305992	94	2	1409728
82	12	651071	86	9	1957929	90	6	1996109	94	3	561136
83	1	975351	86	10	1835749	90	7	1928248	94	4	1372821
83	2	844552	86	11	1862802	90	8	2062867	94	5	1948780
83	3	566778	86	12	1844820	90	9	1996519	94	6	1988440
83	4	0	87	1	1977210	90	10	2065391	94	7	2012704
83	5	265111	87	2	1838160	90	11	1934930	94	8	1695707
83	6	1673672	87	3	333666	90	12	1584367	94	9	474744
83	7	1863508	87	4	0	91	1	1148347	94	10	0
83	8	1758090	87	5	0	91	2	1788866	94	11	0
83	9	1749405	87	6	1193818	91	3	1620472	94	12	726122
83	10	1810240	87	7	2016975	91	4	1149242	95	1	1894224
83	11	1518120	87	8	2027808	91	5	1554304	95	2	1850003
83	12	800616	87	9	1113384	91	6	1973325	95	3	2039466
84	1	1996935	87	10	1830508	91	7	2040323	95	4	1992024
84	2	1666309	87	11	19[illegible]5917	91	8	2027464	95	5	1260629
84	3	1459743	87	12	20[illegible]1914	91	9	1274200	95	6	1996654
84	4	119028	88	1	[illegible]062574	91	10	0	95	7	2063076
84	5	1704230	88	2	1781887	91	11	413834	95	8	2062747
84	6	1847339	88	3	2063020	91	12	1906910	95	9	1996136
84	7	833316	88	4	1993177	92	1	2062943	95	10	2062822
84	8	1844750	88	5	1810598	92	2	1905360	95	11	1995979
84	9	1405054	88	6	1275619	92	3	1977379	95	12	2062677
84	10	0	88	7	1894116	92	4	1992177	96	1	2062493
84	11	0	88	8	2062884	92	5	1314957	96	2	1929354
84	12	455882	88	9	1060457	92	6	1982126	96	3	2061981
85	1	1515633	88	10	0	92	7	2061744	96	4	898979
85	2	1578286	88	11	0	92	8	2062266	96	5	249239
85	3	1896308	88	12	60592	92	9	1995350	96	6	2059531
85	4	1682110	89	1	1859584	92	10	2064688	96	7	2156111
85	5	1256696	89	2	1102850	92	11	1995108	96	8	2078796
85	6	1989561	89	3	318386	92	12	2059893	96	9	2041466
85	7	2053141	89	4	1512841	93	1	1684289	96	10	2158755
85	8	1742390	89	5	1801387	93	2	1857004	96	11	2046243
85	9	1836663	89	6	1270231	93	3	315170	96	12	2155936
85	10	292854	89	7	1914784	93	4	0	97	1	2144735
85	11	0	89	8	1624424	93	5	1605283	97	2	1947032
85	12	661338	89	9	1068974	93	6	1955688	97	3	2155644
86	1	2039156	89	10	1292027	93	7	2062003	97	4	1609409
86	2	1638382	89	11	1996106	93	8	2035039	97	5	2144058
86	3	2061270	89	12	1869076	93	9	1972425	97	6	2072987
86	4	1898100	90	1	2057016	93	10	2059993	97	7	2154810
86	5	2021310	90	2	1861708	93	11	1635767	97	8	2155123
86	6	1461204	90	3	1508020	93	12	2053574	97	9	2074453
86	7	1898812	90	4	0	94	1	2061907	97	10	188895

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	7.23E+04	5.82E+05	8.88E-17
	Middle	7.13E+04	5.74E+05	8.75E-17
	Bottom	7.44E+04	5.99E+05	9.13E-17
^{54}Fe (n,p) ^{54}Mn	Top	2.34E+06	5.76E+06	9.14E-15
	Middle	2.32E+06	5.72E+06	9.06E-15
	Bottom	2.52E+06	6.21E+06	9.84E-15
^{58}Ni (n,p) ^{58}Co	Top	2.90E+07	9.58E+07	1.37E-14
	Middle	2.74E+07	9.05E+07	1.30E-14
	Bottom	2.96E+07	9.78E+07	1.40E-14
^{59}Co (n,g) ^{60}Co	Top	1.60E+07	1.29E+08	8.40E-12
	Middle	1.65E+07	1.33E+08	8.66E-12
	Bottom	1.65E+07	1.33E+08	8.66E-12
^{59}Co (n,g) ^{60}Co	Top	1.34E+07	1.08E+08	7.04E-12
	Middle	1.35E+07	1.09E+08	7.09E-12
	Bottom	1.45E+07	1.17E+08	7.61E-12
^{59}Co (n,g) ^{60}Co (Cd)	Top	8.83E+06	7.11E+07	4.64E-12
	Middle	8.99E+06	7.24E+07	4.72E-12
	Bottom	9.12E+06	7.34E+07	4.79E-12
^{238}U (n,f) ^{137}Cs	Middle	2.56E+05	1.05E+07	6.91E-14
^{237}Np (n,f) ^{137}Cs	Middle	2.41E+06	9.90E+07	6.32E-13

The ^{238}U (n,f) ^{137}Cs reaction rate after correcting for ^{235}U impurities, plutonium build-in, and photofissions is 5.79E-14 rps/atom.

The ^{237}Np (n,f) ^{137}Cs reaction rate after correcting for photofissions is 6.28E-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	1.47E+05	5.34E+05	8.15E-17
	Middle	1.51E+05	5.49E+05	8.37E-17
	Bottom	1.47E+05	5.34E+05	8.15E-17
^{54}Fe (n,p) ^{54}Mn	Top	2.98E+06	5.49E+06	8.70E-15
	Middle	3.08E+06	5.67E+06	8.99E-15
	Bottom	2.91E+06	5.36E+06	8.49E-15
^{58}Ni (n,p) ^{58}Co	Top	2.20E+07	8.48E+07	1.21E-14
	Middle	2.24E+07	8.63E+07	1.24E-14
	Bottom	2.11E+07	8.13E+07	1.16E-14
^{59}Co (n,g) ^{60}Co	Top	2.86E+07	1.04E+08	6.78E-12
	Middle	2.84E+07	1.03E+08	6.74E-12
	Bottom	2.82E+07	1.03E+08	6.69E-12
^{59}Co (n,g) ^{60}Co	Top	3.23E+07	1.17E+08	7.66E-12
	Middle	3.37E+07	1.23E+08	7.99E-12
	Bottom	3.33E+07	1.21E+08	7.90E-12
^{59}Co (n,g) ^{60}Co (Cd)	Top	2.03E+07	7.38E+07	4.82E-12
	Middle	1.84E+07	6.69E+07	4.36E-12
	Bottom	1.84E+07	6.69E+07	4.36E-12
^{238}U (n,f) ^{137}Cs	Middle	6.09E+05	9.95E+06	6.53E-14
^{237}Np (n,f) ^{137}Cs	Middle	5.25E+06	8.58E+07	5.47E-13

The ^{238}U (n,f) ^{137}Cs reaction rate after correcting for ^{235}U impurities, plutonium build-in, and photofissions is 5.25E-14 rps/atom.

The ^{237}Np (n,f) ^{137}Cs reaction rate after correcting for photofissions is 5.44E-13 rps/atom.

Table 6-8 cont'd

Measured Sensor Activities And Reaction Rates

Surveillance Capsule X

Reaction	Location	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
^{63}Cu (n,a) ^{60}Co	Top	2.01E+05	5.27E+05	8.04E-17
	Middle	1.99E+05	5.22E+05	7.96E-17
	Bottom	2.08E+05	5.45E+05	8.32E-17
^{54}Fe (n,p) ^{54}Mn	Top	2.31E+06	5.14E+06	8.15E-15
	Middle	2.26E+06	5.03E+06	7.98E-15
	Bottom	2.40E+06	5.34E+06	8.47E-15
^{58}Ni [illegible] ^{58}Co	Top	9.22E+06	7.85E+07	1.12E-14
	Middle	9.01E+06	7.67E+07	1.10E-14
	Bottom	9.73E+06	8.28E+07	1.19E-14
^{59}Co (n,g) ^{60}Co	Top	3.40E+07	8.92E+07	5.82E-12
	Middle	4.13E+07	1.08E+08	7.07E-12
	Bottom	3.53E+07	9.26E+07	6.04E-12
^{59}Co (n,g) ^{60}Co	Top	4.04E+07	1.06E+08	6.91E-12
	Middle	3.29E+07	8.63E+07	5.63E-12
^{59}Co (n,g) ^{60}Co (Cd)	Top	2.30E+07	6.03E+07	3.93E-12
	Middle	2.30E+07	6.03E+07	3.93E-12
	Bottom	2.22E+07	5.82E+07	3.80E-12
^{238}U (n,f) ^{137}Cs	Middle	1.05E+06	1.04E+07	6.82E-14
^{237}Np (n,f) ^{137}Cs	Middle	8.41E+06	8.32E+07	5.31E-13

The ^{238}U (n,f) ^{137}Cs reaction rate after correcting for ^{235}U impurities, plutonium build-in, and photofissions is 5.27E-14 rps/atom.

The ^{237}Np (n,f) ^{137}Cs reaction rate after correcting for photofissions is 5.27E-13 rps/atom.

Table 6-8 cont'd

Measured Sensor Activities And Reaction Rates

Surveillance Capsule W

Reaction	Location	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
^{63}Cu (n,a) ^{60}Co	Top	2.66E+0[illegible]	4.54E+05	6.93E-17
	Middle	2.57E+05	4.39E+05	6.69E-17
	Bottom	2.72E+05	4.64E[illegible]	7.08E-17
^{54}Fe (n,p) ^{54}Mn	Top	2.21E+06	4.51E+06	7.15E-15
	Middle	2.16E+06	4.41E+06	6.99E-15
	Bottom	2.31E+06	4.71E+06	[illegible]47E-15
^{58}Ni (n,p) ^{58}Co	Top	8.15E+06	7.22E+07	[illegible]E-14
	Middle	7.71E+06	6.83E+07	[illegible]E-15
	Bottom	8.33E+06	7.38E+07	1.[illegible]E-14
^{59}Co (n,g) ^{60}Co	Top	4.45E+07	7.59E+07	4.95E-12
	Middle	4.48E+07	7.65E+07	4.99E-12
	Bottom	4.52E+07	7.71E+07	5.03E-12
^{59}Co (n,g) ^{60}Co	Top	3.72E+07	6.35E+07	4.14E-12
	Middle	3.75E+07	6.40E+07	4.18E-12
	Bottom	4.02E+07	6.86E+07	4.48E-12
^{59}Co (n,g) ^{60}Co (Cd)	Top	2.53E+07	4.32E+07	2.82E-12
	Middle	2.61E+07	4.45E+07	2.91E-12
	Bottom	2.53E+07	4.32E+07	2.82E-12
^{238}U (n,f) ^{137}Cs	Middle	2.11E+06	1.01E+07	6.65E-14
^{237}Np (n,f) ^{137}Cs	Middle	1.36E+07	6.53E+07	4.17E-13

The ^{238}U (n,f) ^{137}Cs reaction rate after correcting for ^{235}U impurities, plutonium build-in, and photofissions is 4.70E-14 rps/atom.

The ^{237}Np (n,f) ^{137}Cs reaction rate after correcting for photofissions is 4.14E-13 rps/atom.

Table 6-9

Summary Of Neutron Dosimetry Results
Surveillance Capsules U, V, X, and W

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)	1.832E+11	Φ (E > 1.0 MeV)	6.25[illegible]E+18	7%
ϕ (E > 0.1 MeV)	9.740E+11	Φ (E > 0.1 MeV)	3.324E+19	15%
ϕ (E < 0.414 eV)	1.281E+11	Φ (E < 0.414 eV)	4.372E+18	29%
dpa/sec	3.919E-10	dpa	1.338E-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)	1.625E+11	Φ (E > 1.0 MeV)	1.435E+19	7%
ϕ (E > 0.1 MeV)	8.482E+11	Φ (E > 0.1 MeV)	7.492E+19	15%
ϕ (E < 0.414 eV)	1.116E+11	Φ (E < 0.414 eV)	9.858E+18	30%
dpa/sec	3.441E-10	dpa	3.039E-02	11%

Best Estimate Flux and Fluence for Capsule X

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	Uncertainty
ϕ (E > 1.0 MeV)	1.563E+11	Φ (E > 1.0 MeV)	2.377E+19	7%
ϕ (E > 0.1 MeV)	8.308E+11	Φ (E > 0.1 MeV)	1.264E+20	16%
ϕ (E < 0.414 eV)	9.866E+10	Φ (E < 0.414 eV)	1.501E+19	30%
dpa/sec	3.346E-10	dpa	5.089E-02	11%

Best Estimate Flux and Fluence for Capsule W

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	Uncertainty
ϕ (E > 1.0 MeV)	1.344E+11	Φ (E > 1.0 MeV)	4.573E+19	7%
ϕ (E > 0.1 MeV)	6.499E+11	Φ (E > 0.1 MeV)	2.211E+20	15%
ϕ (E < 0.414 eV)	7.263E+10	Φ (E < 0.414 eV)	2.471E+19	30%
dpa/sec	2.707E-10	dpa	9.210E-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)	8.92E-17	8.17E-17	8.70E-17	0.98	1.06	1.09
^{54}Fe (n,p)	9.35E-15	1.00E-14	9.65E-15	1.03	0.97	0.94
^{58}Ni (n,p)	1.36E-14	1.43E-14	1.37E-14	1.01	0.96	0.95
^{238}U (n,f) (Cd)	5.79E-14	5.79E-14	5.49E-14	0.95	0.95	1.00
^{237}Np (n,f)	6.28E-13	6.20E-13	6.19E-13	0.99	1.00	1.01
^{59}Co (n,g)	7.91E-12	6.11E-12	7.86E-12	0.99	1.29	1.29
^{59}Co (n,g) (Cd)	4.72E-12	4.70E-12	4.74E-12	1.00	1.01	1.00

Surveillance Capsule Y

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,a)	8.23E-17	7.43E-17	8.02E-17	0.97	1.08	1.11
^{54}Fe (n,p)	8.73E-15	9.10E-15	8.81E-15	1.01	0.97	0.96
^{58}Ni (n,p)	1.20E-14	1.30E-14	1.25E-14	1.04	0.96	0.92
^{238}U (n,f) (Cd)	5.25E-14	5.26E-14	4.93E-14	0.94	0.94	1.00
^{237}Np (n,f)	5.44E-13	5.63E-13	5.40E-13	0.99	0.96	0.97
^{59}Co (n,g)	7.29E-12	5.55E-12	7.24E-12	0.99	1.30	1.31
^{59}Co (n,g) (Cd)	4.51E-12	4.27E-12	4.54E-12	1.01	1.06	1.06

Surveillance Capsule X

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,a)	8.11E-17	7.13E-17	7.82E-17	0.96	1.10	1.14
^{54}Fe (n,p)	8.20E-15	8.74E-15	8.39E-15	1.02	0.96	0.94
^{58}Ni (n,p)	1.14E-14	1.24E-14	1.19E-14	1.04	0.96	0.92
^{238}U (n,f) (Cd)	5.27E-14	5.05E-14	4.72E-14	0.90	0.93	1.04
^{237}Np (n,f)	5.27E-13	5.41E-13	5.24E-13	0.99	0.97	0.97
^{59}Co (n,g)	6.29E-12	5.33E-12	6.26E-12	1.00	1.17	1.18
^{59}Co (n,g) (Cd)	3.89E-12	4.10E-12	3.91E-12	1.01	0.95	0.95

Surveillance Capsule W

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,a)	6.90E-17	6.38E-17	6.73E-17	0.98	1.05	1.08
^{54}Fe (n,p)	7.20E-15	7.55E-15	7.42E-15	1.03	0.98	0.95
^{58}Ni (n,p)	1.02E-14	1.07E-14	1.05E-14	1.03	0.98	0.95
^{238}U (n,f) (Cd)	4.70E-14	4.22E-14	4.13E-14	0.88	0.98	1.11
^{237}Np (n,f)	4.14E-13	4.33E-13	4.23E-13	1.02	0.98	0.96
^{59}Co (n,g)	4.63E-12	3.98E-12	4.60E-12	0.99	1.16	1.16
^{59}Co (n,g) (Cd)	2.85E-12	3.08E-12	2.86E-12	1.00	0.93	0.93

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	1.15E+07	28	9.12E-03	4.13E+10
2	1.49E+01	2.46E+07	29	5.53E-03	4.25E+10
3	1.35E+01	9.15E+07	30	3.36E-03	1.38E+10
4	1.16E+01	2.51E+08	31	2.84E-03	1.35E+10
5	1.00E+01	5.69E+08	32	2.40E-03	1.33E+10
6	8.61E+00	9.92E+08	33	2.04E-03	4.03E+10
7	7.41E+00	2.38E+09	34	1.23E-03	4.11E+10
8	6.07E+00	3.63E+09	35	7.49E-04	4.00E+10
9	4.97E+00	7.57E+09	36	4.54E-04	2.95E+10
10	3.68E+00	9.20E+09	37	2.75E-04	3.33E+10
11	2.87E+00	1.84E+10	38	1.67E-04	3.45E+10
12	2.23E+00	2.62E+10	39	1.01E-04	3.58E+10
13	1.74E+00	3.79E+10	40	6.14E-05	3.59E+10
14	1.35E+00	4.54E+10	41	3.73E-05	3.48E+10
15	1.11E+00	8.97E+10	42	2.26E-05	3.31E+10
16	8.21E-01	1.01E+11	43	1.37E-05	3.14E+10
17	6.39E-01	1.22E+11	44	8.32E-06	2.89E+10
18	4.98E-01	8.11E+10	45	5.04E-06	2.52E+10
19	3.88E-01	1.34E+11	46	3.06E-06	2.27E+10
20	3.02E-01	1.32E+11	47	1.86E-06	2.01E+10
21	1.83E-01	1.45E+11	48	1.13E-06	1.16E+10
22	1.11E-01	8.21E+10	49	6.83E-07	1.36E+10
23	6.74E-02	8.09E+10	50	4.14E-07	2.15E+10
24	4.09E-02	3.92E+10	51	2.51E-07	2.17E+10
25	2.55E-02	4.95E+10	52	1.52E-07	2.13E+10
26	1.99E-02	1.95E+10	53	9.24E-08	6.37E+10
27	1.50E-02	3.74E+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	1.05E+07	28	9.12E-03	3.71E+10
2	1.49E+01	2.26E+07	29	5.53E-03	3.84E+10
3	1.35E+01	8.43E+07	30	3.36E-03	1.25E+10
4	1.16E+01	2.32E+08	31	2.84E-03	1.22E+10
5	1.00E+01	5.26E+08	32	2.40E-03	1.22E+10
6	8.61E+00	9.17E+08	33	2.04E-03	3.70E+10
7	7.41E+00	2.19E+09	34	1.23E-03	3.80E+10
8	6.07E+00	3.34E+09	35	7.49E-04	3.71E+10
9	4.97E+00	6.93E+09	36	4.54E-04	2.76E+10
10	3.68E+00	8.36E+09	37	2.75E-04	3.13E+10
11	2.87E+00	1.65E+10	38	1.67E-04	3.33E+10
12	2.23E+00	2.34E+10	39	1.01E-04	3.37E+10
13	1.74E+00	3.35E+10	40	6.14E-05	3.36E+10
14	1.35E+00	3.98E+10	41	3.73E-05	3.24E+10
15	1.11E+00	7.80E+10	42	2.26E-05	3.07E+10
16	8.21E-01	8.73E+10	43	1.37E-05	2.90E+10
17	6.39E-01	1.05E+11	44	8.32E-06	2.65E+10
18	4.98E-01	7.01E+10	45	5.04E-06	2.31E+10
19	3.88E-01	1.16E+11	46	3.06E-06	2.07E+10
20	3.02E-01	1.15E+11	47	1.86E-06	1.83E+10
21	1.83E-01	1.27E+11	48	1.13E-06	1.05E+10
22	1.11E-01	7.18E+10	49	6.83E-07	1.23E+10
23	6.74E-02	7.11E+10	50	4.14E-07	1.92E+10
24	4.09E-02	3.46E+10	51	2.51E-07	1.92E+10
25	2.55E-02	4.39E+10	52	1.52E-07	1.86E+10
26	1.99E-02	1.74E+10	53	9.24E-08	5.45E+10
27	1.50E-02	3.35E+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 X

Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	1.06E+07	28	9.12E-03	3.57E+10
2	1.49E+01	2.28E+07	29	5.53E-03	3.68E+10
3	1.35E+01	8.47E+07	30	3.36E-03	1.19E+10
4	1.16E+01	2.31E+08	31	2.84E-03	1.16E+10
5	1.00E+01	5.20E+08	32	2.40E-03	1.15E+10
6	8.61E+00	8.97E+08	33	2.04E-03	3.45E+10
7	7.41E+00	2.12E+09	34	1.23E-03	3.51E+10
8	6.07E+00	3.18E+09	35	7.49E-04	3.40E+10
9	4.97E+00	6.51E+09	36	4.54E-04	2.50E+10
10	3.68E+00	7.87E+09	37	2.75E-04	2.80E+10
11	2.87E+00	1.56E+10	38	1.67E-04	2.84E+10
12	2.23E+00	2.24E+10	39	1.01E-04	3.00E+10
13	1.74E+00	3.24E+10	40	6.14E-05	3.02E+10
14	1.35E+00	3.85E+10	41	3.73E-05	2.94E+10
15	1.11E+00	7.59E+10	42	2.26E-05	2.80E+10
16	8.21E-01	8.54E+10	43	1.37E-05	2.67E+10
17	6.39E-01	1.03E+11	44	8.32E-06	2.46E+10
18	4.98E-01	6.91E+10	45	5.04E-06	2.15E+10
19	3.88E-01	1.14E+11	46	3.06E-06	1.93E+10
20	3.02E-01	1.13E+11	47	1.86E-06	1.71E+10
21	1.83E-01	1.25E+11	48	1.13E-06	9.92E+09
22	1.11E-01	7.06E+10	49	6.83E-07	1.14E+10
23	6.74E-02	6.96E+10	50	4.14E-07	1.76E+10
24	4.09E-02	3.38E+10	51	2.51E-07	1.74E+10
25	2.55E-02	4.27E+10	52	1.52E-07	1.67E+10
26	1.99E-02	1.68E+10	53	9.24E-08	4.69E+10
27	1.50E-02	3.23E+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 W

Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	8.72E+06	28	9.12E-03	2.61E+10
2	1.49E+01	1.87E+07	29	5.53E-03	2.70E+10
3	1.35E+01	6.97E+07	30	3.36E-03	8.71E+09
4	1.16E+01	1.92E+08	31	2.84E-03	8.51E+09
5	1.00E+01	4.38E+08	32	2.40E-03	8.40E+09
6	8.61E+00	7.67E+08	33	2.04E-03	2.52E+10
7	7.41E+00	1.86E+09	34	1.23E-03	2.56E+10
8	6.07E+00	2.83E+09	35	7.49E-04	2.50E+10
9	4.97E+00	5.83E+09	36	4.54E-04	1.85E+10
10	3.68E+00	7.00E+09	37	2.75E-04	2.02E+10
11	2.87E+00	1.40E+10	38	1.67E-04	2.08E+10
12	2.23E+00	1.98E+10	39	1.01E-04	2.19E+10
13	1.74E+00	2.80E+10	40	6.14E-05	2.18E+10
14	1.35E+00	3.24E+10	41	3.73E-05	2.12E+10
15	1.11E+00	6.20E+10	42	2.26E-05	2.03E+10
16	8.21E-01	6.80E+10	43	1.37E-05	1.93E+10
17	6.39E-01	8.04E+10	44	8.32E-06	1.78E+10
18	4.98E-01	5.30E+10	45	5.04E-06	1.56E+10
19	3.88E-01	8.65E+10	46	3.06E-06	1.40E+10
20	3.02E-01	8.41E+10	47	1.86E-06	1.24E+10
21	1.83E-01	9.19E+10	48	1.13E-06	7.19E+09
22	1.11E-01	5.16E+10	49	6.83E-07	8.26E+09
23	6.74E-02	5.05E+10	50	4.14E-07	1.28E+10
24	4.09E-02	2.46E+10	51	2.51E-07	1.27E+10
25	2.55E-02	3.09E+10	52	1.52E-07	1.22E+10
26	1.99E-02	1.23E+10	53	9.24E-08	3.49E+10
27	1.50E-02	2.36E+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 V. C. Summer Unit 1 Surveillance Capsules U, V, X, and W

CAPSULE U

	Calculated	Best Estimate	BE/C
ϕ(E > 1.0 MeV) [n/cm2]	6.542E+18	6.253E+18	0.96
ϕ(E > 0.1 MeV) [n/cm2]	3.200E+19	3.324E+19	1.04
dpa	1.322E-02	1.338E-02	1.01

CAPSULE V

	Calculated	Best Estimate	BE/C
ϕ(E > 1.0 MeV) [n/cm2]	1.538E+19	1.435E+19	0.93
ϕ(E > 0.1 MeV) [n/cm2]	7.526E+19	7.492E+19	1.00
dpa	3.109E-02	3.039E-02	0.98

CAPSULE X

	Calculated	Best Estimate	BE/C
ϕ(E > 1.0 MeV) [n/cm2]	2.543E+19	2.377E+19	0.93
ϕ(E > 0.1 MeV) [n/cm2]	1.244E+20	1.264E+20	1.02
dpa	5.139E-02	5.089E-02	0.99

CAPSULE W

	Calculated	Best Estimate	BE/C
ϕ(E > 1.0 MeV) [n/cm2]	4.664E+19	4.573E+19	0.98
ϕ(E > 0.1 MeV) [n/cm2]	2.190E+20	2.211E+20	1.01
dpa	9.207E-02	9.210E-02	1.00

AVERAGE BE/C RATIOS

	BE/C
ϕ(E > 1.0 MeV) [n/cm^2]	0.951
ϕ(E > 0.1 MeV) [n/cm^2]	1.015
dpa	0.995

Table 6-13

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

Best Estimate

10.78 EFPY	0 Deg	15 Deg	30 Deg	45 Deg
E>1.0 MeV	1.31E+19	8.36E+18	6.42E+18	4.55E+18
E>0.1 MeV	3.57E+19	2.12E+19	1.45E+19	1.01E+19
dpa	2.14E-02	1.35E-02	1.02E-02	7.27E-03

16 EFPY	0 Deg	15 Deg	30 Deg	45 Deg
E>1.0 MeV	1.88E+19	1.20E+19	9.34E+18	6.78E+18
E>0.1 MeV	5.15E+19	3.04E+19	2.11E+19	1.51E+19
dpa	3.09E-02	1.94E-02	1.48E-02	1.08E-02

32 EFPY	0 Deg	15 Deg	30 Deg	45 Deg
E>1.0 MeV	3.66E+19	2.31E+19	1.83E+19	1.36E+19
E>0.1 MeV	9.99E+19	5.86E+19	4.12E+19	3.03E+19
dpa	5.99E-02	3.74E-02	2.89E-02	2.17E-02

54 EFPY	0 Deg	15 Deg	30 Deg	45 Deg
E>1.0 MeV	6.09E+19	3.84E+19	3.06E+19	2.30E+19
E>0.1 MeV	1.66E+20	9.73E+19	6.89E+19	5.12E+19
dpa	9.98E-02	6.22E-02	4.83E-02	3.67E-02

Table 6-13, cont'd

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

Calculated

10.78 EFPY				
	0 Deg	15 Deg	30 Deg	45 Deg
E>1.0 MeV	1.37E+19	8.79E+18	6.75E+18	4.79E+18
E>0.1 MeV	3.52E+19	2.09E+19	1.43E+19	9.99E+18
dpa	2.15E-02	1.36E-02	1.02E-02	7.30E-03

16 EFPY				
	0 Deg	15 Deg	30 Deg	45 Deg
E>1.0 MeV	1.98E+19	1.26E+19	9.82E+18	7.13E+18
E>0.1 MeV	5.07E+19	3.00E+19	2.08E+19	1.49E+19
dpa	3.10E-02	1.95E-02	1.48E-02	1.09E-02

32 EFPY				
	0 Deg	15 Deg	30 Deg	45 Deg
E>1.0 MeV	3.84E+19	2.43E+19	1.92E+19	1.43E+19
E>0.1 MeV	9.84E+19	5.77E+19	4.06E+19	2.99E+19
dpa	6.02E-02	3.76E-02	2.90E-02	2.18E-02

54 EFPY				
	0 Deg	15 Deg	30 Deg	45 Deg
E>1.0 MeV	6.40E+19	4.03E+19	3.21E+19	2.42E+19
E>0.1 MeV	1.64E+20	9.59E+19	6.79E+19	5.05E+19
dpa	1.00E-01	6.25E-02	4.86E-02	3.69E-02

Table 6-14

Neutron Exposure Values Within The V. C. Summer Unit 1 Reactor Vessel

Best Estimate Fluence Based on E > 1.0 MeV Slope

		0 Deg	15 Deg	30 Deg	45 Deg
	Surface	1	1	1	1
	¼ T	0.585	0.601	0.597	0.601
	¾ T	0.147	0.160	0.156	0.160
16 EFPY	Surface	1.88E+19	1.20E+19	9.34E+18	6.78E+18
	¼ T	1.10E+19	7.20E+18	5.57E+18	4.08E+18
	¾ T	2.77E+18	1.92E+18	1.46E+18	1.09E+18
32 EFPY	Surface	3.65E+19	2.31E+19	1.83E+19	1.36E+19
	¼ T	2.14E+19	1.39E+19	1.09E+19	8.18E+18
	¾ T	5.37E+18	3.70E+18	2.85E+18	2.18E+18
54 EFPY	Surface	6.09E+19	3.84E+19	3.06E+19	2.30E+19
	¼ T	3.56E+19	2.31E+19	1.82E+19	1.38E+19
	¾ T	8.95E+18	6.14E+18	4.77E+18	3.68E+18

Best Estimate Fluence Based on dpa Slope

		0 Deg	15 Deg	30 Deg	45 Deg
	Surface	1	1	1	1
	1/4 T	0.670	0.687	0.666	0.669
	3/4 T	0.258	0.281	0.258	0.266
16 EFPY	Surface	1.88E+19	1.20E+19	9.34E+18	6.78E+18
	1/4 T	1.26E+19	8.23E+18	6.22E+18	4.54E+18
	3/4 T	4.86E+18	3.37E+18	2.41E+18	1.80E+18
32 EFPY	Surface	3.65E+19	2.31E+19	1.83E+19	1.36E+19
	1/4 T	2.45E+19	1.59E+19	1.22E+19	9.11E+18
	3/4 T	9.43E+18	6.49E+18	4.71E+18	3.62E+18
54 EFPY	Surface	6.09E+19	3.84E+19	3.06E+19	2.30E+19
	1/4 T	4.08E+19	2.64E+19	2.03E+19	1.54E+19
	3/4 T	1.57E+19	1.08E+19	7.88E+18	6.12E+18

Table 6-14, cont'd

Neutron Exposure Values Within The V. C. Summer Unit 1 Reactor Vessel

Calculated Fluence Based on E > 1.0 MeV Slope

		0 Deg	15 Deg	30 Deg	45 Deg
	Surface	1	1	1	1
	1/4 T	0.585	0.601	0.597	0.601
	3/4 T	0.147	0.160	0.156	0.160
16 EFPY	Surface	1.98E+19	1.26E+19	9.82E+18	7.13E+18
	1/4 T	1.16E+19	7.57E+18	5.86E+18	4.29E+18
	3/4 T	2.91E+18	2.02E+18	1.53E+18	1.14E+18
32 EFPY	Surface	3.84E+19	2.43E+19	1.92E+19	1.43E+19
	1/4 T	2.25E+19	1.46E+19	1.15E+19	8.61E+18
	3/4 T	5.65E+18	3.89E+18	3.00E+18	2.29E+18
54 EFPY	Surface	6.40E+19	4.03E+19	3.21E+19	2.42E+19
	1/4 T	3.75E+19	2.42E+19	1.92E+19	1.45E+19
	3/4 T	9.41E+18	6.46E+18	5.01E+18	3.87E+18

Calculated Fluence Based on dpa Slope

		0 Deg	15 Deg	30 Deg	45 Deg
	Surface	1	1	1	1
	1/4 T	0.670	0.687	0.666	0.669
	3/4 T	0.258	0.281	0.258	0.266
16 EFPY	Surface	1.98E+19	1.26E+19	9.82E+18	7.13E+18
	1/4 T	1.33E+19	8.66E+18	6.54E+18	4.77E+18
	3/4 T	5.11E+18	3.54E+18	2.53E+18	1.90E+18
32 EFPY	Surface	3.84E+19	2.43E+19	1.92E+19	1.43E+19
	1/4 T	2.57E+19	1.67E+19	1.28E+19	9.58E+18
	3/4 T	9.91E+18	6.82E+18	4.96E+18	3.81E+18
54 EFPY	Surface	6.40E+19	4.03E+19	3.21E+19	2.42E+19
	1/4 T	4.29E+19	2.77E+19	2.14E+19	1.62E+19
	3/4 T	1.65E+19	1.13E+19	8.29E+18	6.44E+18

Table 6-15

Updated Lead Factors For V. C. Summer Unit 1
Surveillance Capsules

Capsule	Lead Factor
U[a]	3.32
V[b]	3.72
X[c]	3.84
W[d]	3.40
Y[e]	3.40
Z[e]	3.40

[a] - Withdrawn at the end of Cycle 1.
[b] - Withdrawn at the end of Cycle 3.
[c] - Withdrawn at the end of Cycle 5.
[d] - Withdrawn at the end of Cycle 10.
[e] - Not withdrawn; standby.

7 SURVEILLANCE CAPSULE REMOVAL [illegible]EDULE

The following surveillance capsule removal schedule meets the requirements of ASTM E185-82 and is recommended for future capsules to be removed from the V.C. Summer Unit 1 reactor vessel. This recommended removal schedule is applicable to 32 EFPY of operation.

Table 7-1 V.C. Summer Unit 1 Reactor Vessel Surveillance Capsule Withdrawal Schedule

Capsule	Location	Lead Factor[(a)]	Removal Time (EFPY)[(b)]	Fluence (n/cm^2, E>1.0 MeV)[(a)]	Estimated Fluence (n/cm^2, E>1.0 MeV)[(e)]
U	343°	3.32	1.13	6.542×10^{18} (c)	6.392×10^{18}
V	107°	3.72	2.93	1.538×10^{19} (c)	1.66×10^{19}
X	287°	3.84	5.03	2.543×10^{19} (c)	3.32×10^{19}
W	110°	3.40	10.78	4.664×10^{19} (c)	5.75×10^{19}
Y	290°	3.40	Standby	(d)	9.58×10^{19}
Z	340°	3.40	Standby	(d)	- - -

Notes:

(a) Updated in Capsule W dosimetry analysis, see Table 6-15.

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

(c) Plant specific evaluation.

(d) This capsule will reach a fluence of 5.76×10^{19} (48 EFPY Peak Fluence) at approximately 14.4 EFPY

(e) Original estimate of fluence at the time of capsule removal, see WCAP-10814.

8 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-9234, "South Carolina Electric & Gas Company Virgil C. Summer Nuclear Plant Unit No.1 Reactor Vessel Radiation Surveillance Program", J. A. Davidson, January, 1978.

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. 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.

13. RSICC Data Library Collection DLC-185, "BUGLE-96, Coupled 47 Neutron, 20 Gamma-Ray Group Cross Section Library Derived from ENDF/B-VI for LWR Shielding and Pressure Vessel Dosimetry Applications," March 1996.

14. 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.

15. R. J. Fabean, et al., "The Nuclear Design of the Virgil C. Summer Power Plant Unit 1", WCAP-9685, March 1980. [Westinghouse Proprietary Class 2]

16. R. M. Smith, "The Nuclear Design and Core Management of the Virgil C. Summer Power Plant Cycle 2", WCAP-10663, Rev. 1, March 1985. [Westinghouse Proprietary Class 2]

17. M. A. Petrunyak, et al., "The Nuclear Design and Operations Package for Virgil C. Summer Power Plant Cycle 3", WCAP-10974, March 1986. [Westinghouse Proprietary Class 2]

18. M. A. Petrunyak, et al., "The Nuclear Design and Operations Package for Virgil C. Summer Power Plant Cycle 4", WCAP-11430, June 1987. [Westinghouse Proprietary Class 2]

19. M. A. Petrunyak, et al., "The Nuclear Design Report for Virgil C. Summer Power Plant Cycle 5", WCAP-11990, October 1988. [Westinghouse Proprietary Class 2]

20. R. M. Smith, et al., " The Nuclear Design Report for Virgil C. Summer Power Plant Cycle 6", WCAP-12564, June 1990. [Westinghouse Proprietary Class 2]

21. B. Johnson, et al., "The Nuclear Design and Core Management of the Virgil C. Summer Nuclear Station Cycle 7", WCAP-13110, January 1992. [Westinghouse Proprietary Class 2]

22. N. Smith, et al., "The Nuclear Design and Core Management Report V. C. Summer Nuclear Station Cycle 8", August 1993.

23. N. Smith, et al., "The Nuclear Design and Core Management Report V. C. Summer Nuclear Station Cycle 9", February 1995.

24. S. Skidmore (South Carolina Electric & Gas Company) transmittal to J. D. Perock (Westinghouse) of selected V. C. Summer Unit 1 Cycle 10 core design data, May 1998.

25. S. Skidmore (South Carolina Electric & Gas Company) fax to J. D. Perock (Westinghouse) transmitting selected V. C. Summer Unit 1 operating plant history data, May 14, 1998.

26. 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.

27. 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.

28. 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.

29. 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.

30. 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.

31. 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.

32. 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.

33. 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.

34. 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.

35. 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.

36 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.

37. 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.

38. 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.

39. 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.

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

41. 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.

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

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

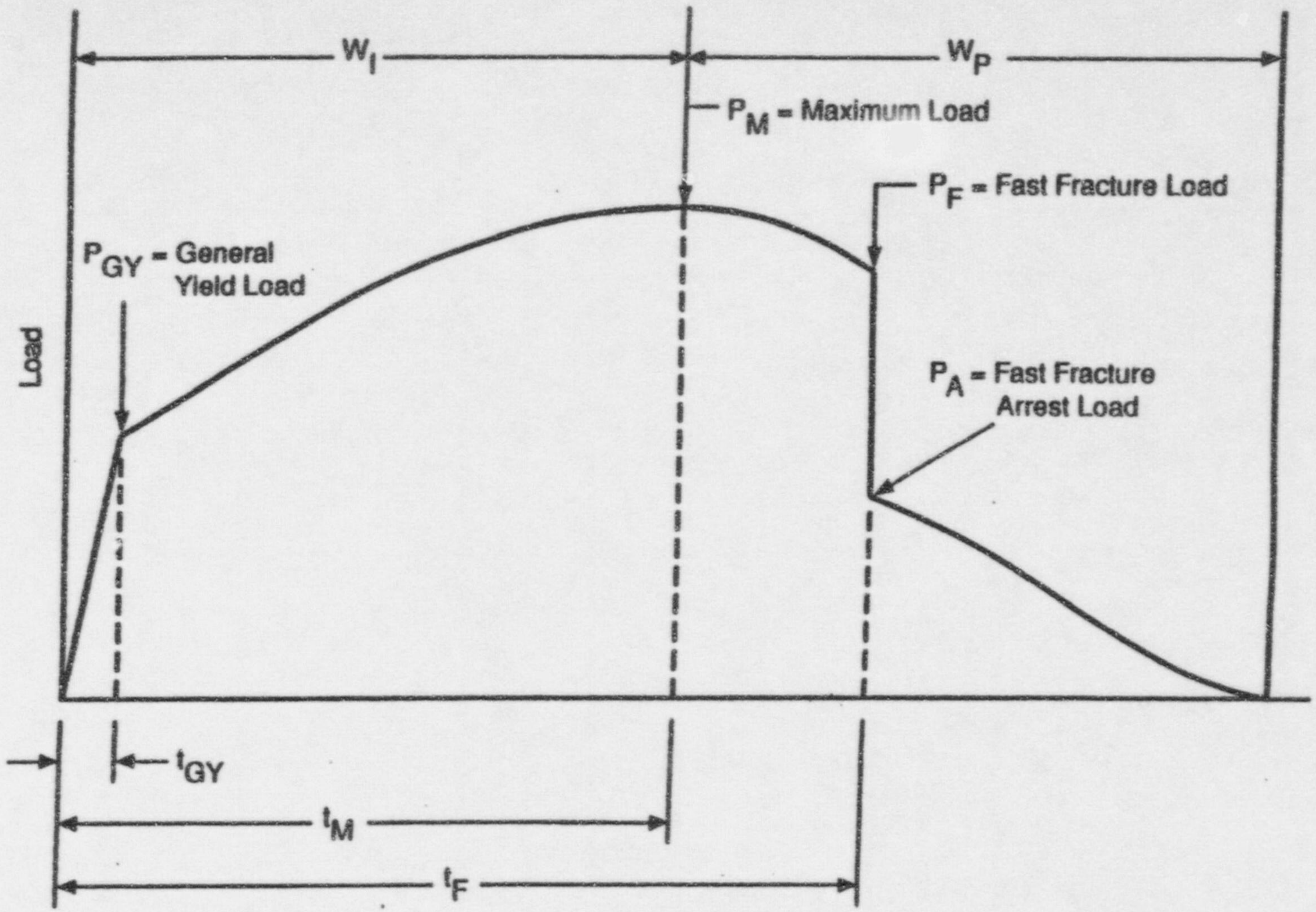
44. WCAP-10814, "Analysis of Capsule U From the South Carolina Electric & Gas Company Virgil C. Summer Unit 1 Reactor Vessel Radiation Surveillance Program", R. S. Boggs, June, 1985.

45. WCAP-11726, "Analysis of Capsule V From the South Carolina Electric & Gas Company Virgil C. Summer Unit 1 Reactor Vessel Radiation Surveillance Program", D. J. Colburn, January 1988.

46. WCAP-12867, "Analysis of Capsule X From the South Carolina Electric & Gas Company Virgil C. Summer Unit 1 Reactor Vessel Radiation Surveillance Program", J. M. Chicots, March 1991.

APPENDIX A

LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS



W_I = Fracture Initiation Region
W_P = Fracture Propagation Region

t_{GY} = Time to General Yielding
t_M = Time to Maximum Load
t_F = Time to Fast (Brittle) Fracture Start

Fig. A-1-Idealized load-time record

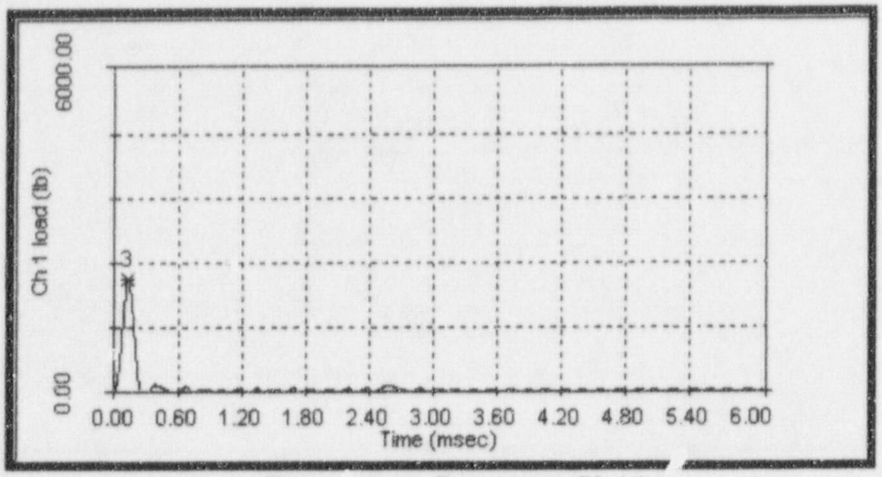


Figure A. 1 Specimen CL44

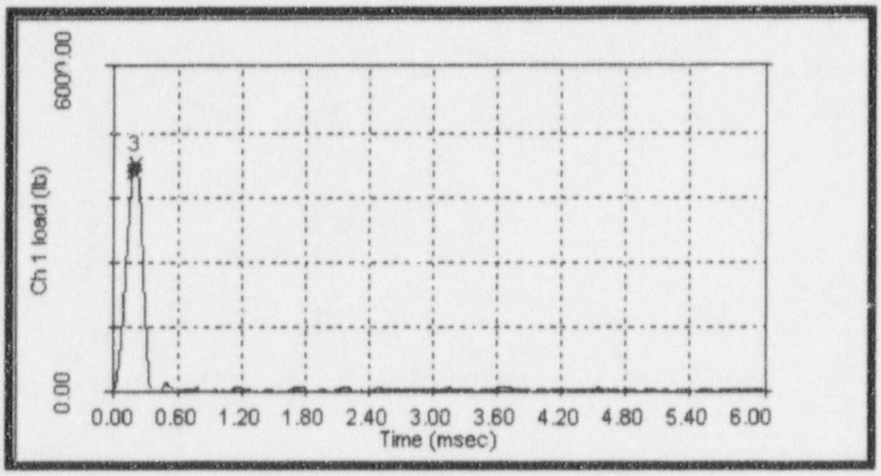


Figure A. 2 Specimen CL34

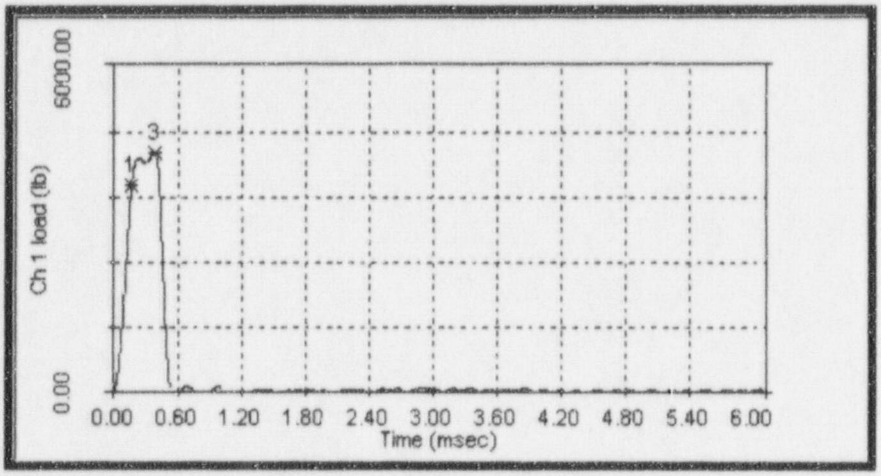


Figure A. 3 Specimen CL45

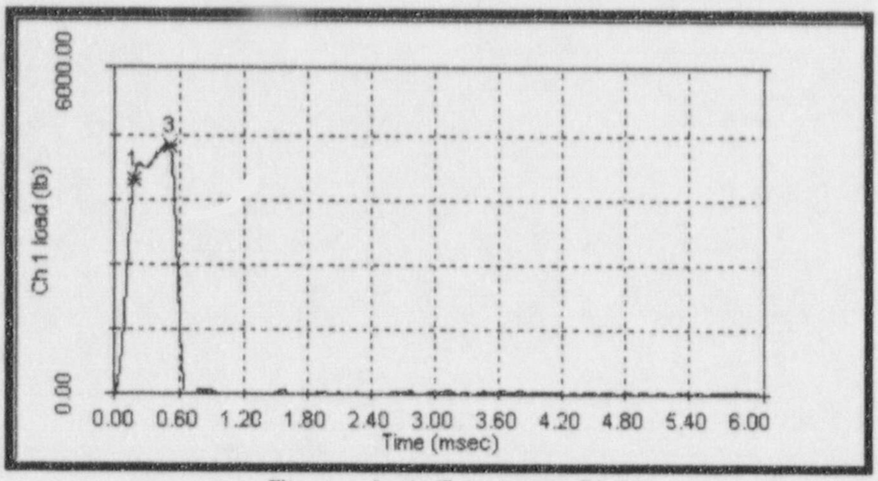


Figure A. 4 Specimen CL31

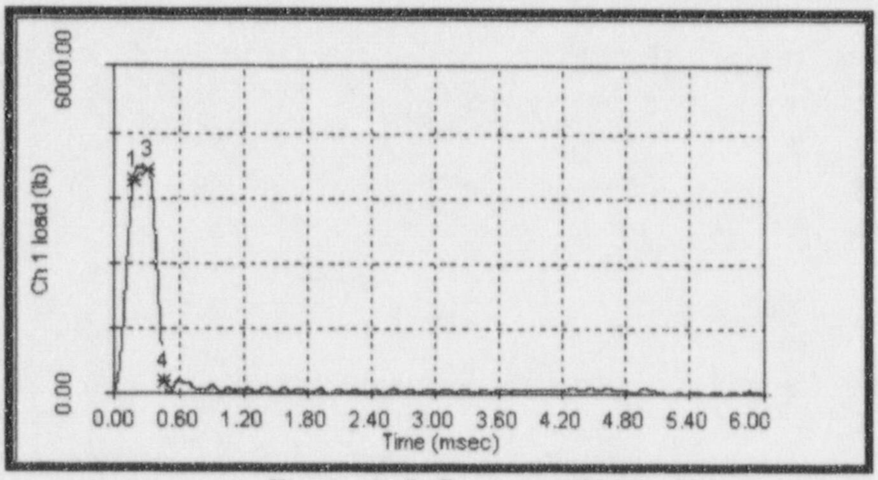


Figure A. 5 Specimen CL42

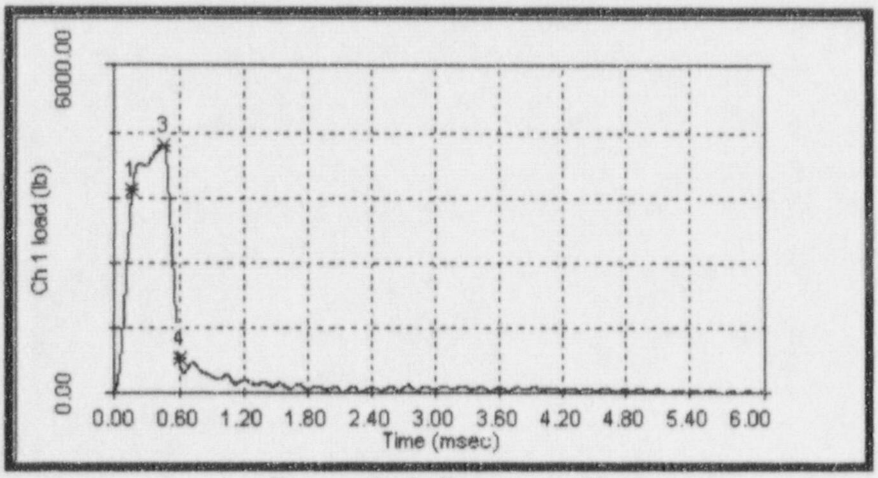


Figure A. 6 Specimen CL41

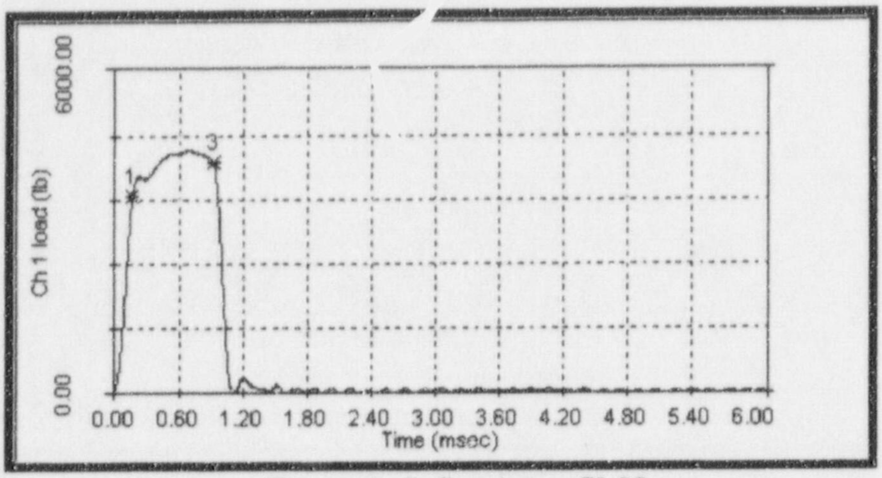


Figure A. 7 Specimen CL38

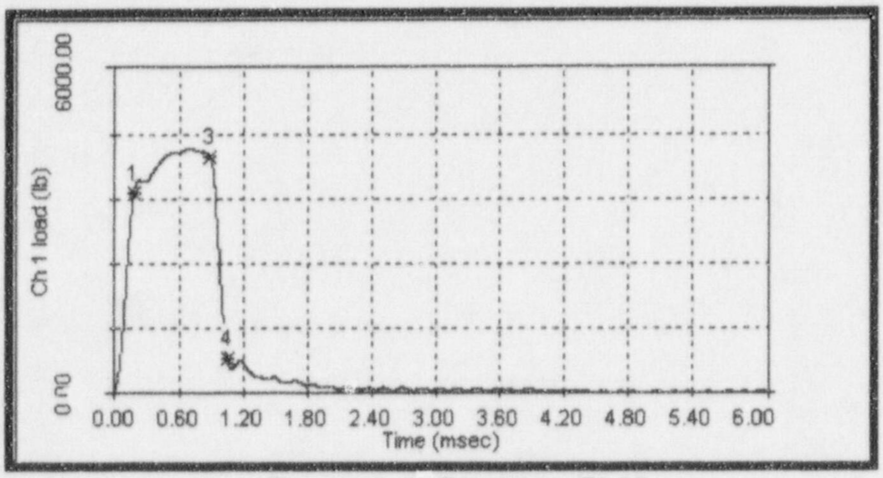


Figure A. 8 Specimen CL37

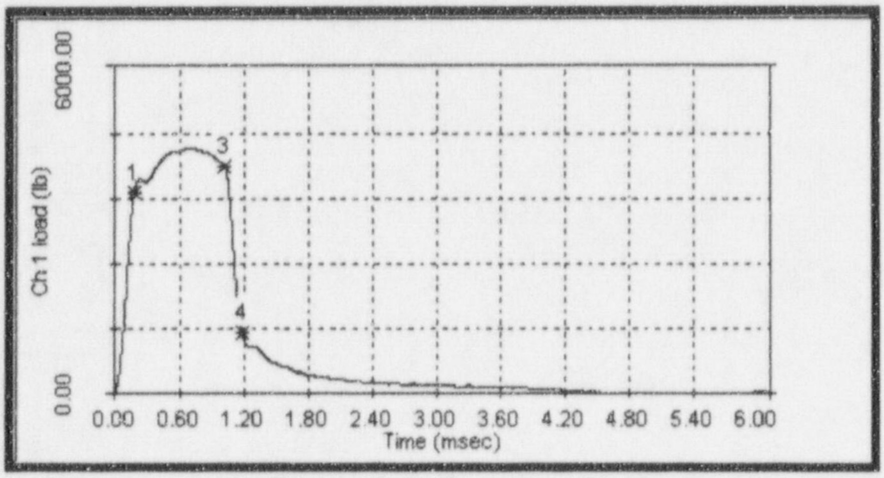


Figure A. 9 Specimen CL40

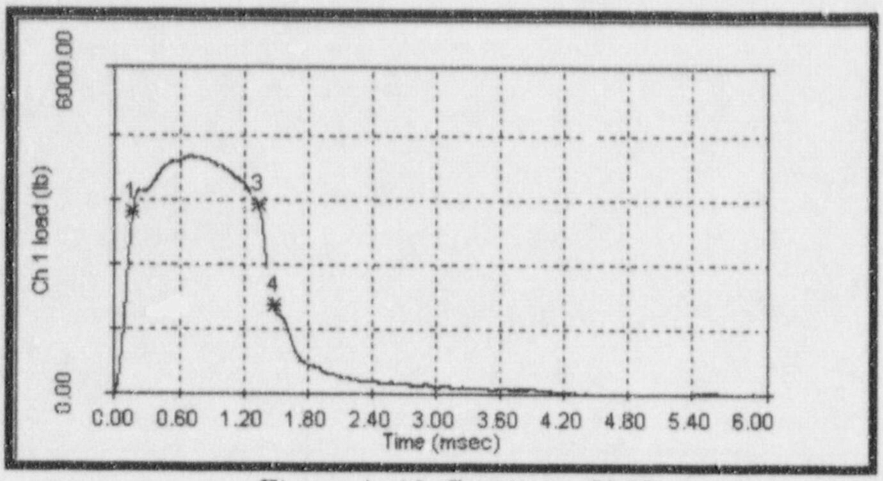


Figure A. 10 Specimen CL35

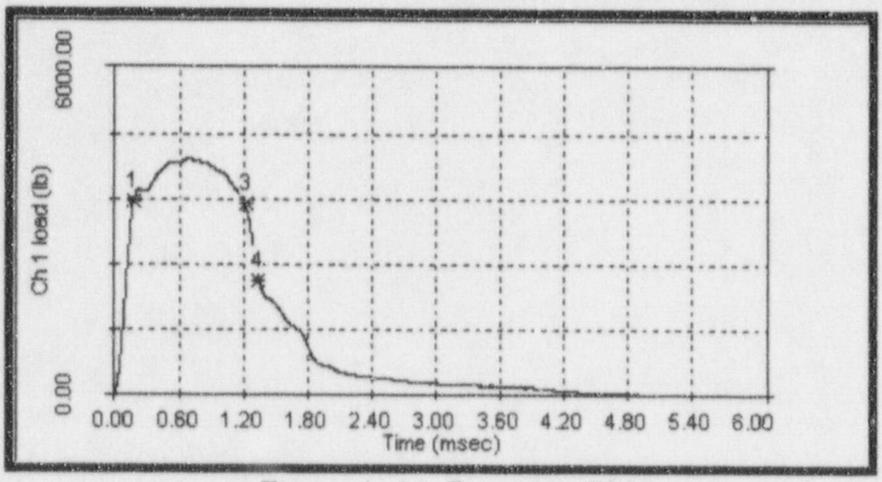


Figure A. 11 Specimen CL39

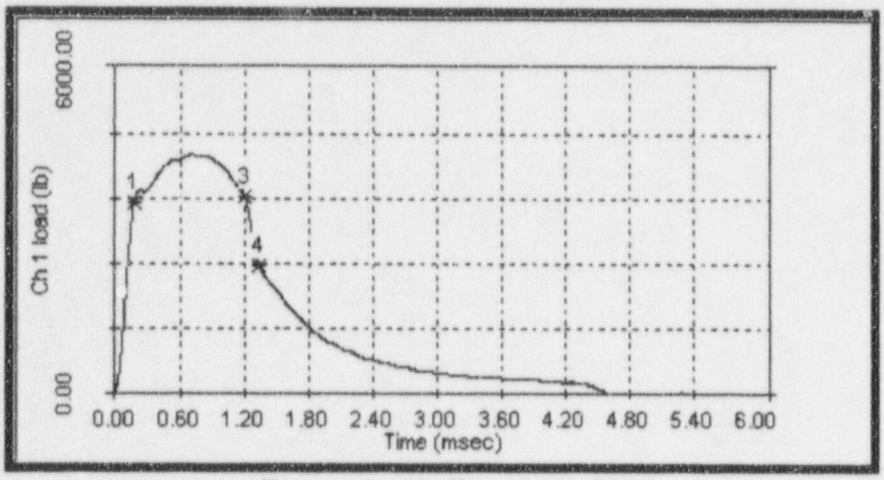


Figure A. 12 Specimen CL32

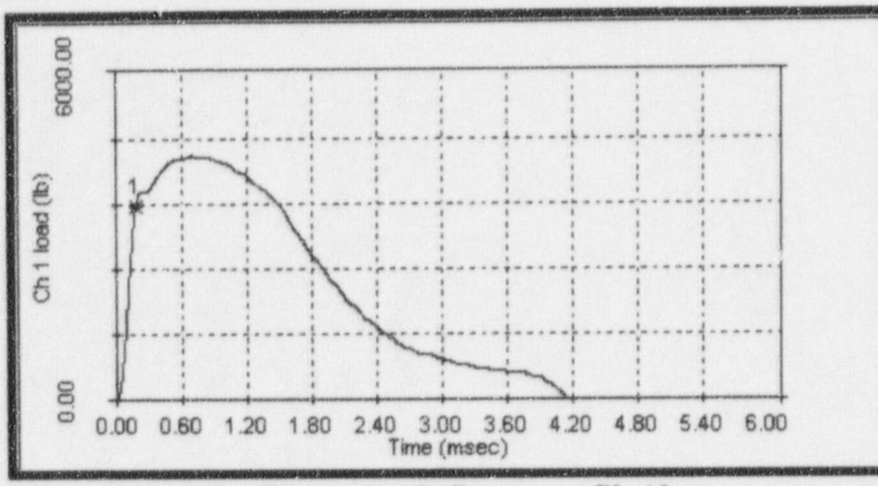


Figure A. 13 Specimen CL 43

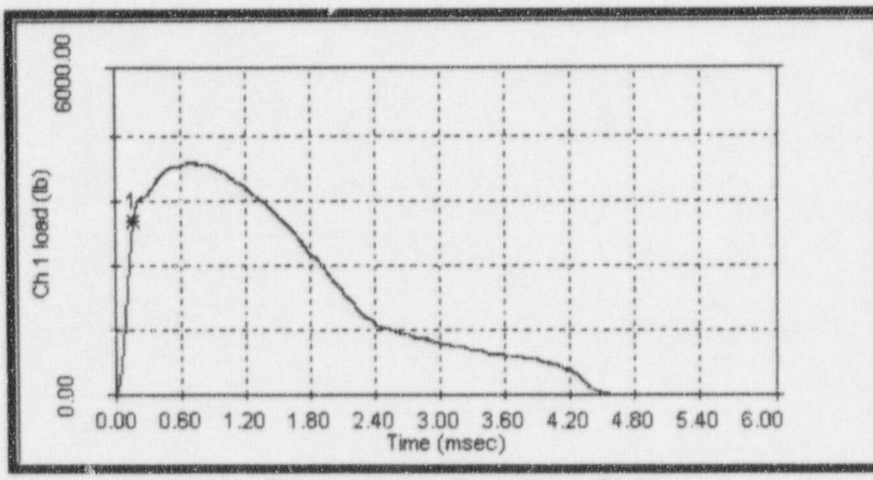


Figure A. 14 Specimen CL36

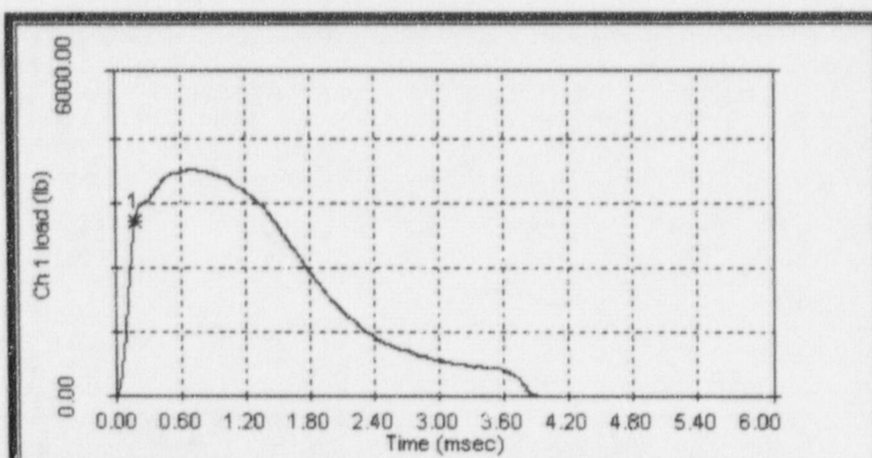


Figure A. 15 Specimen CL33

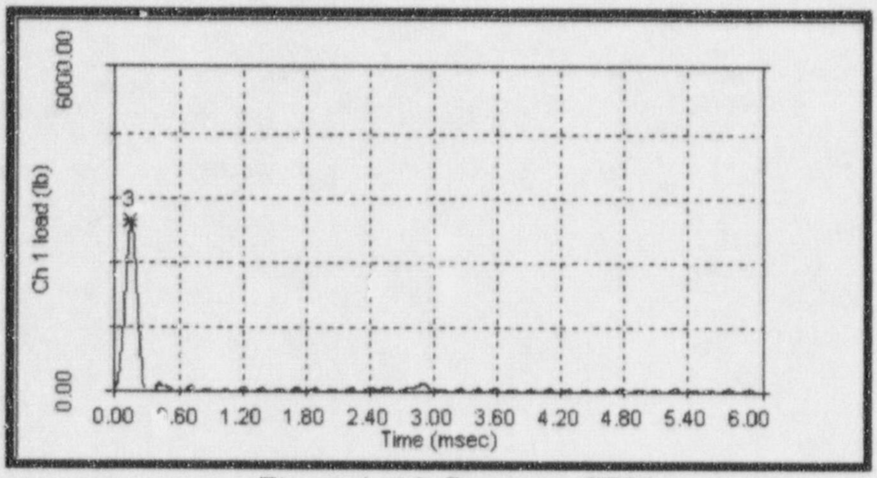


Figure A. 16 Specimen CT37

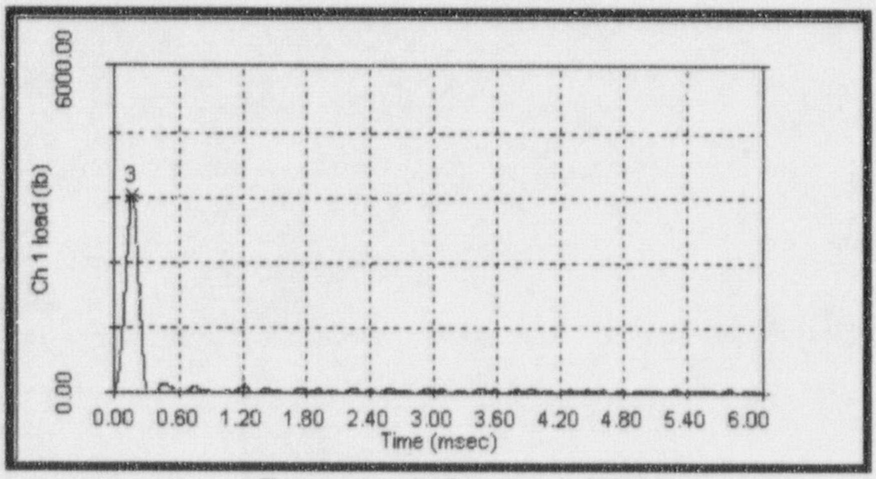


Figure A. 17 Specimen CT33

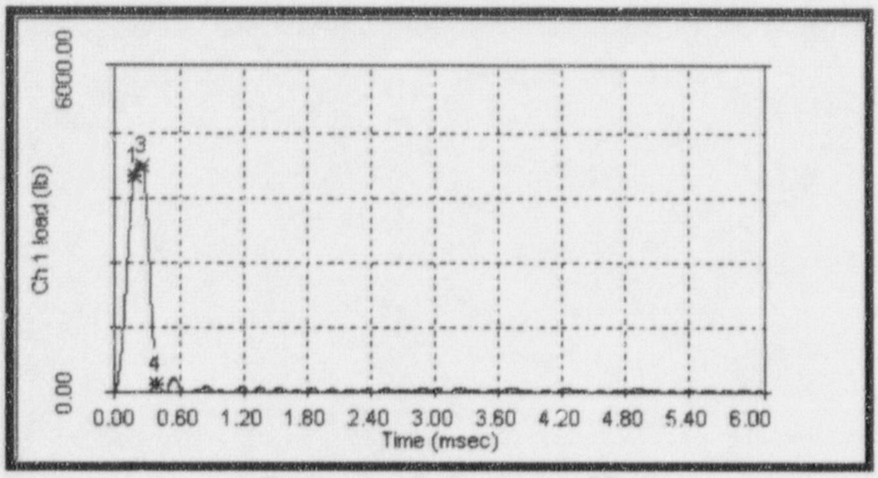


Figure A. 18 Specimen CT43

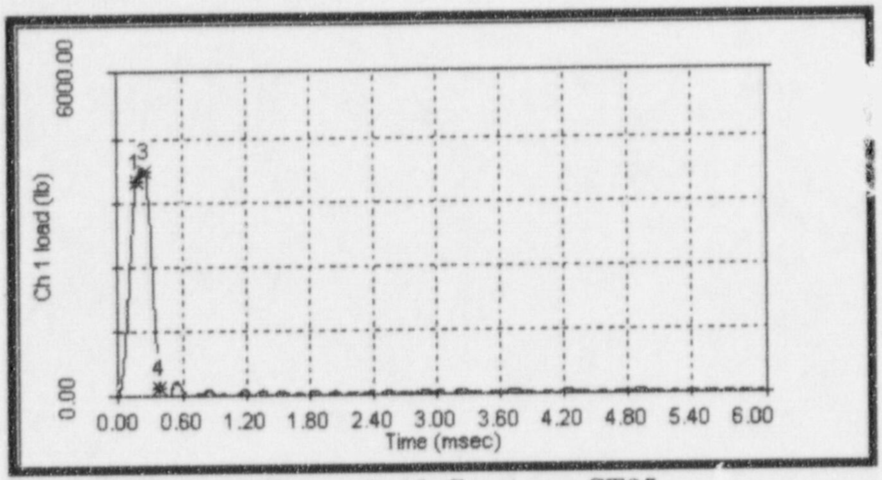


Figure A. 19 Specimen CT35

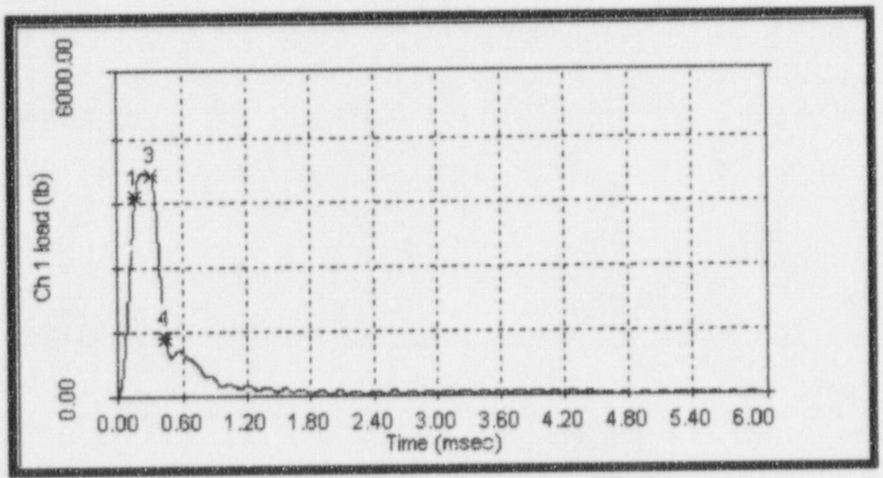


Figure A. 20 Specimen CT42

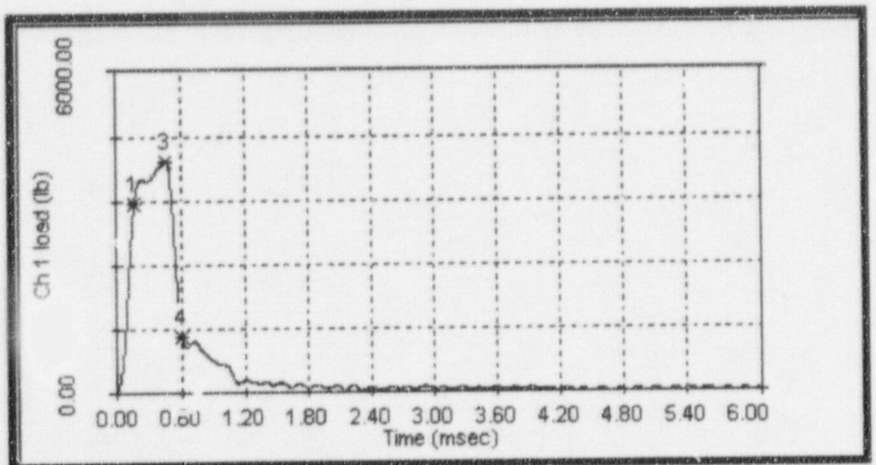


Figure A. 21 Specimen CT36

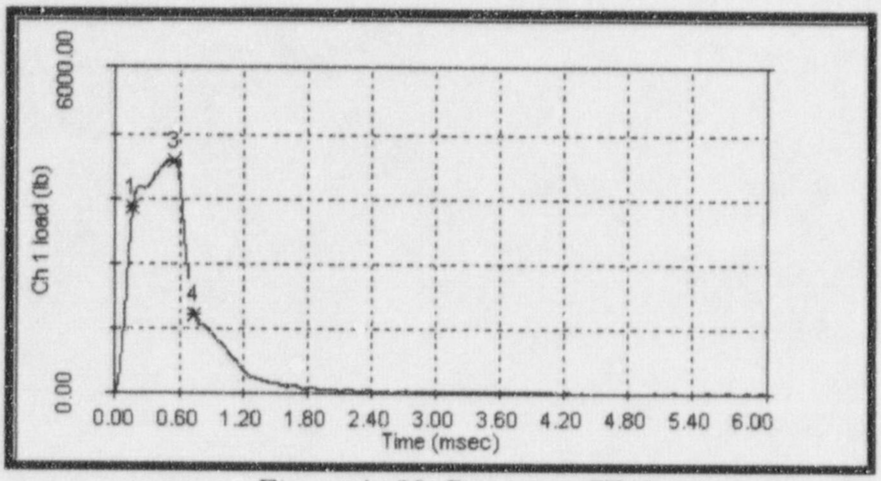


Figure A. 22 Specimen CT40

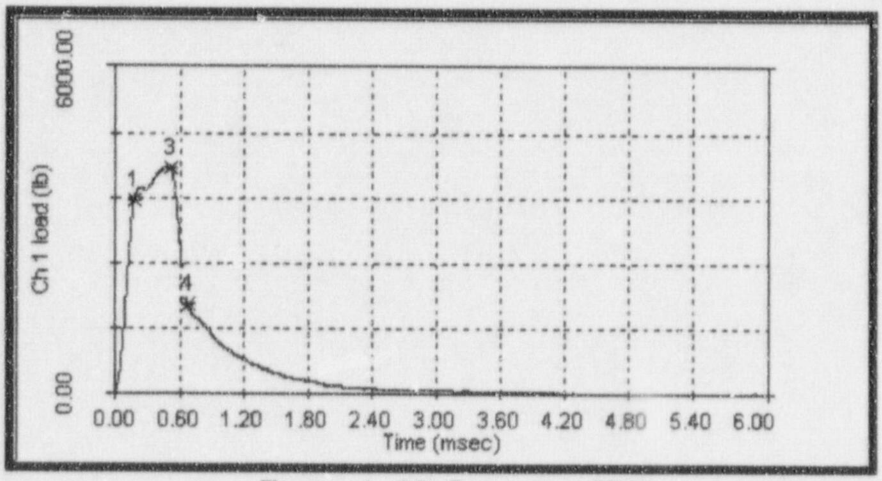


Figure A. 23 Specimen CT31

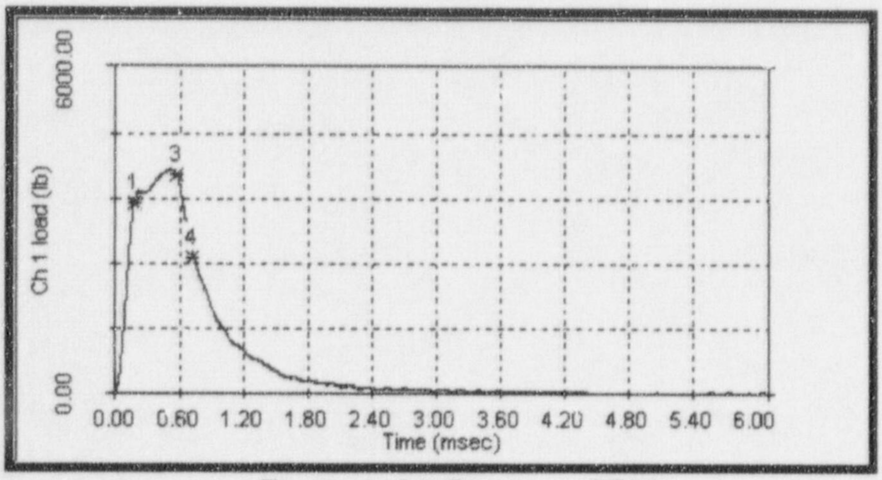


Figure A. 24 Specimen CT38

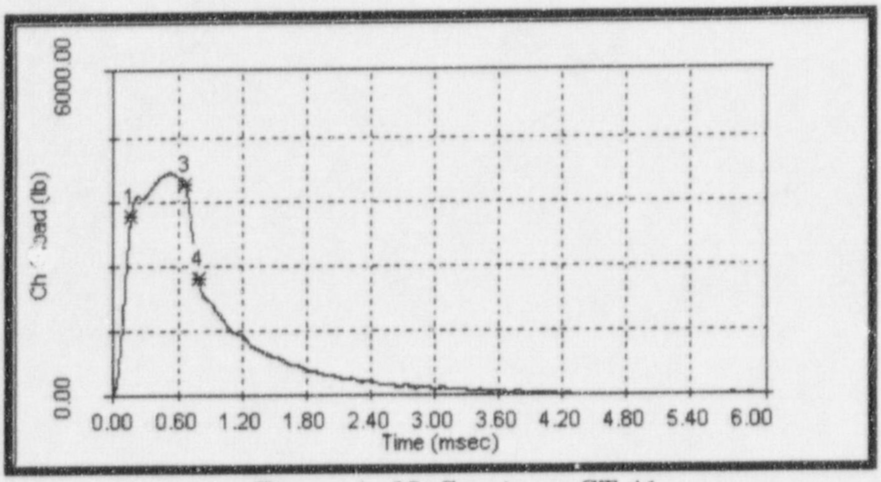


Figure A. 25 Specimen CT 41

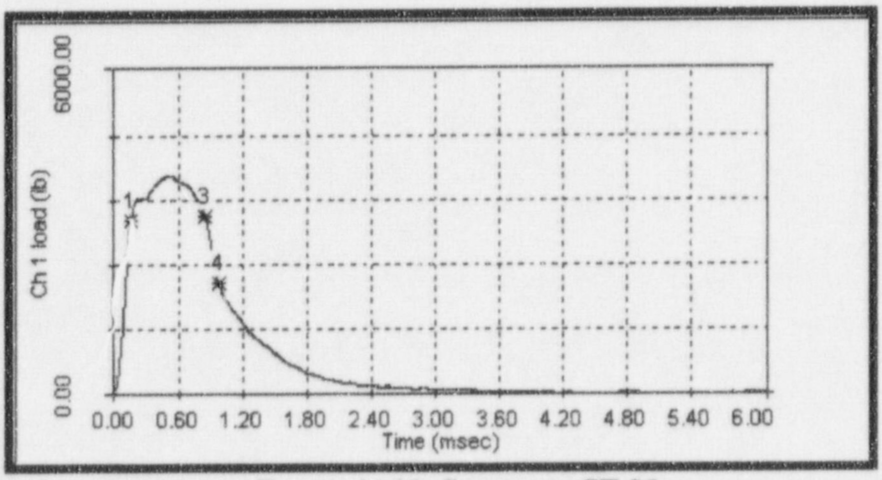


Figure A. 26 Specimen CT 32

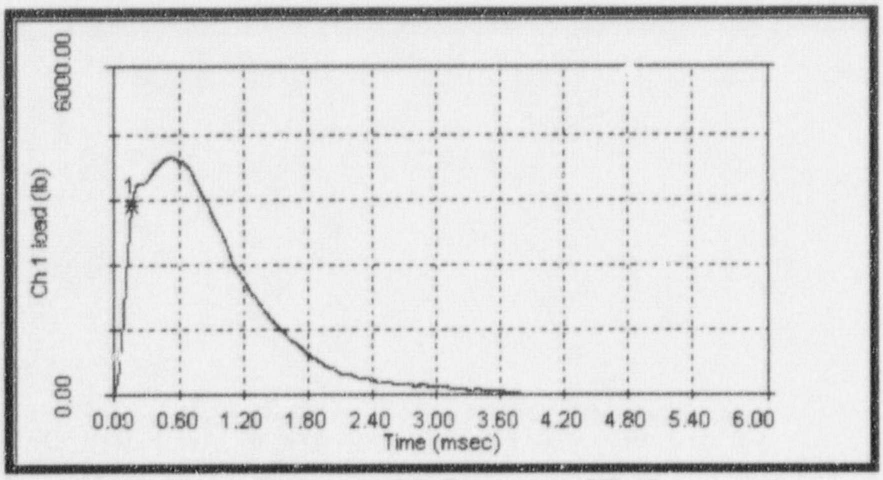


Figure A. 27 Specimen CT 45

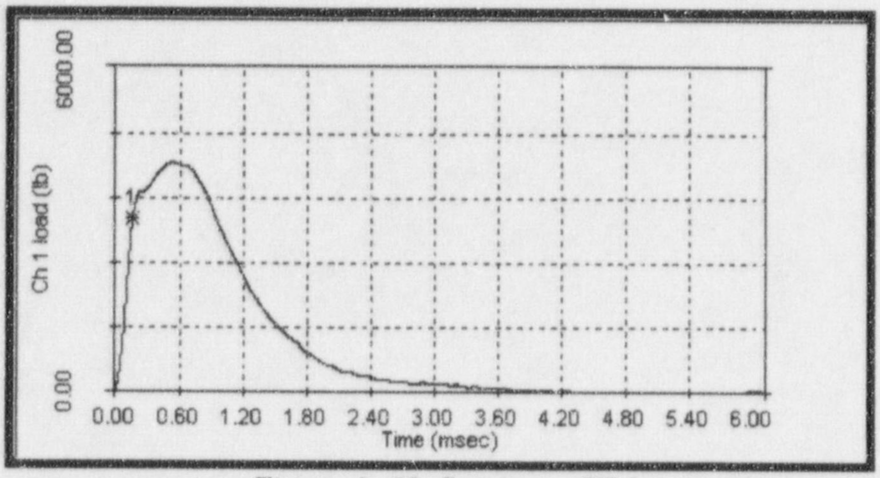


Figure A. 28 Specimen CT 34

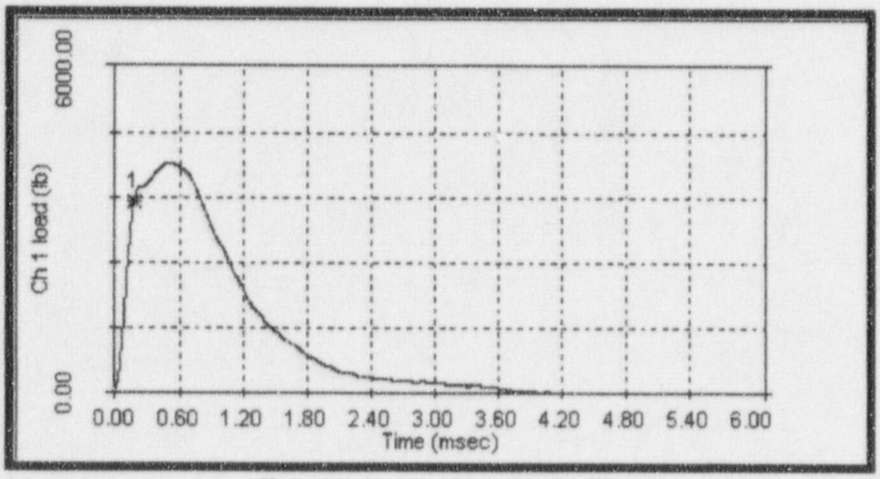


Figure A. 29 Specimen CT44

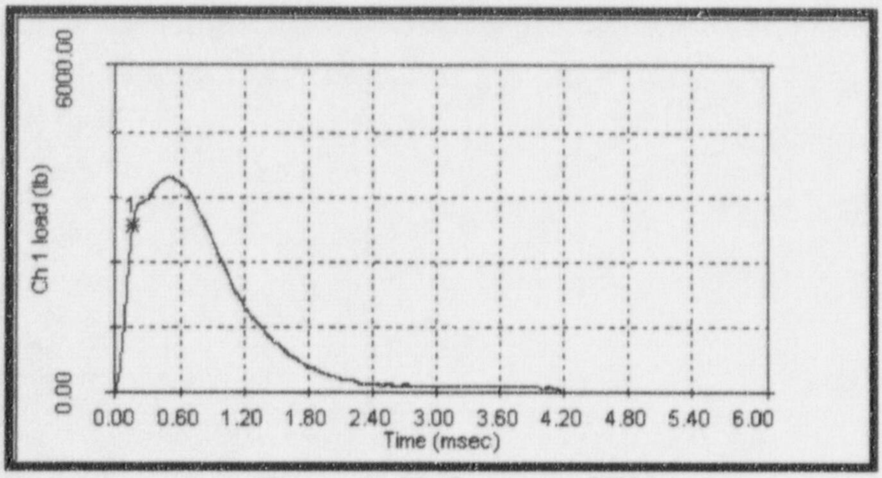


Figure A. 30 Specimen CT39

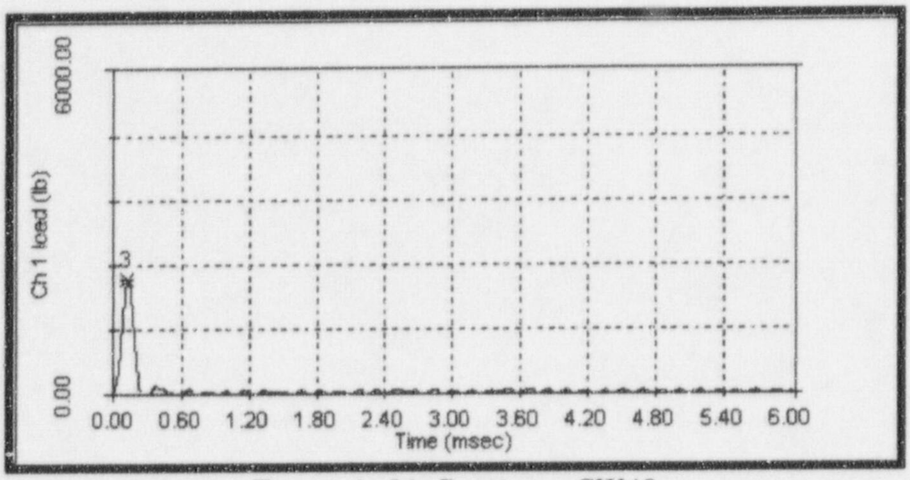


Figure A. 31 Specimen CW43

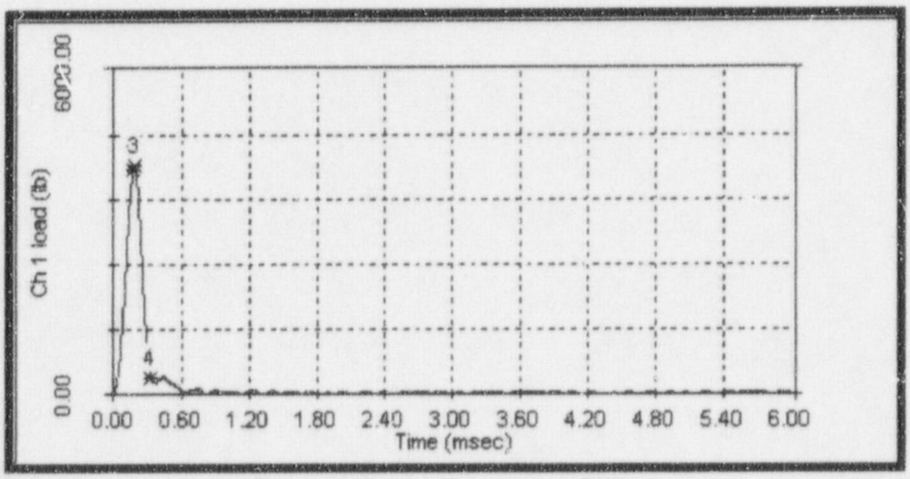


Figure A. 32 Specimen CW41

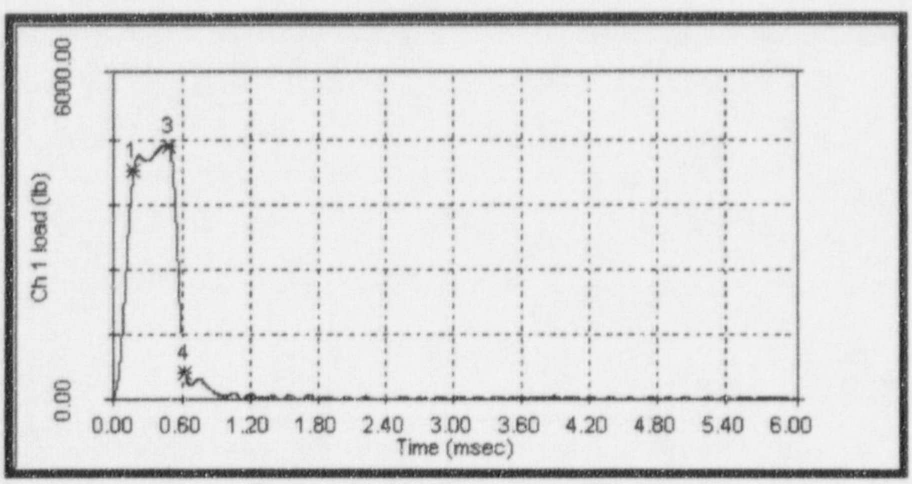


Figure A. 33 Specimen CW 35

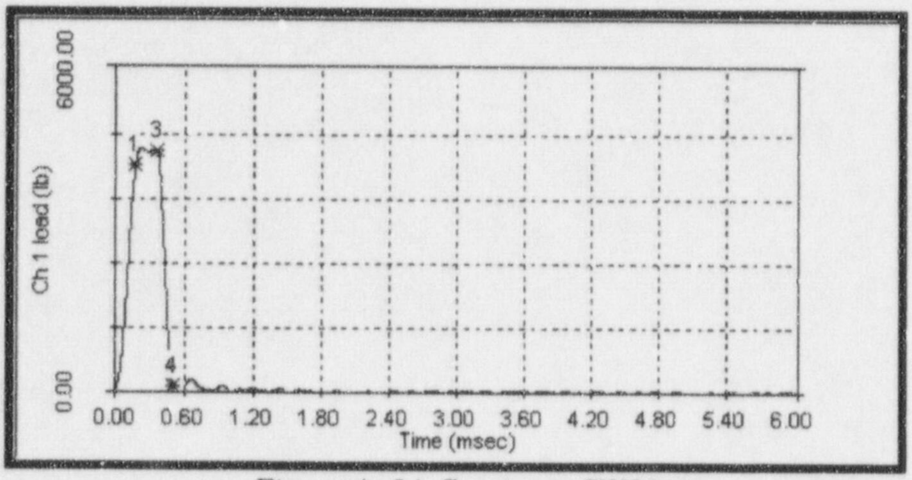


Figure A. 34 Specimen CW39

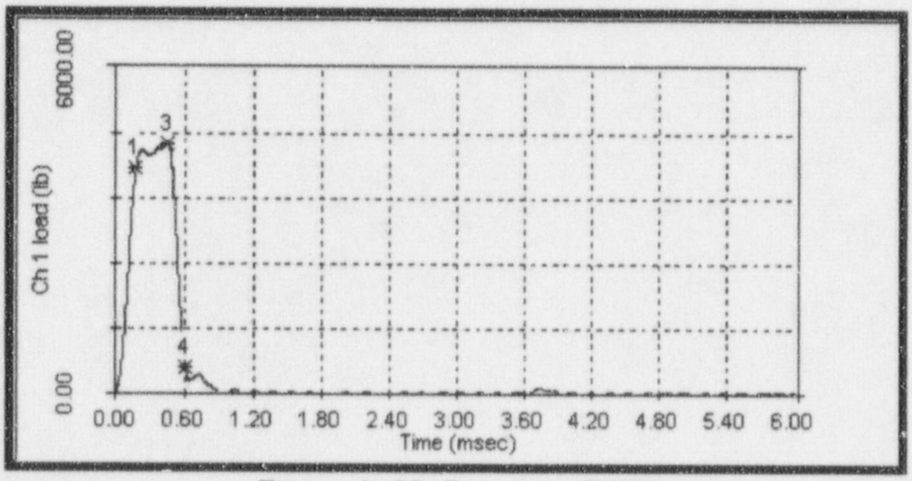


Figure A. 35 Specimen CW33

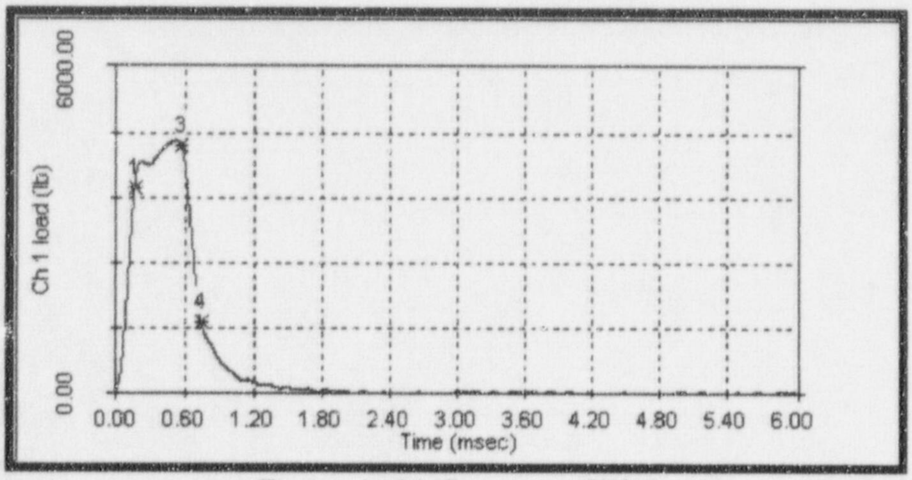


Figure A. 36 Specimen CW45

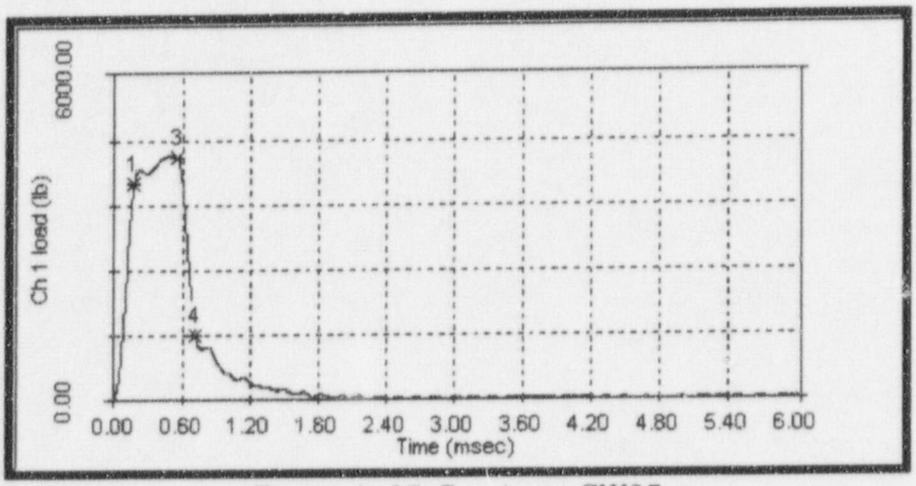


Figure A. 37 Specimen CW37

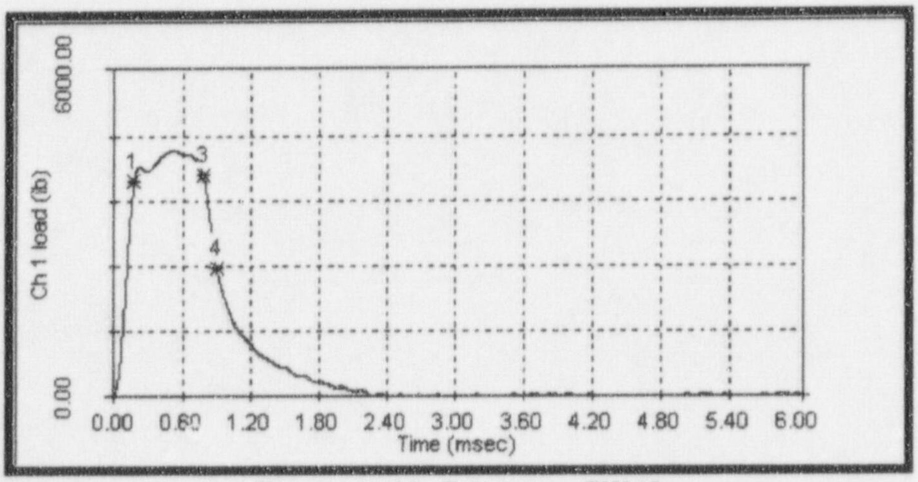


Figure A. 38 Specimen CW42

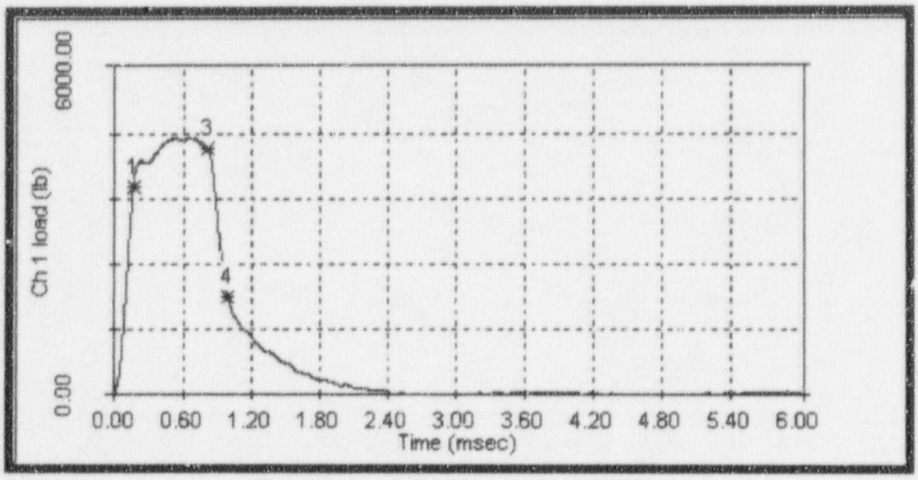


Figure A. 39 Specimen CW31

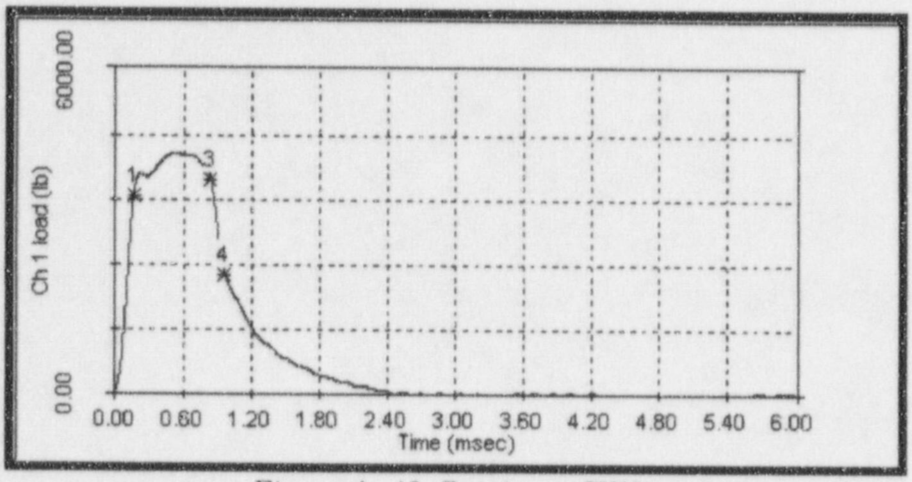


Figure A. 40 Specimen CW34

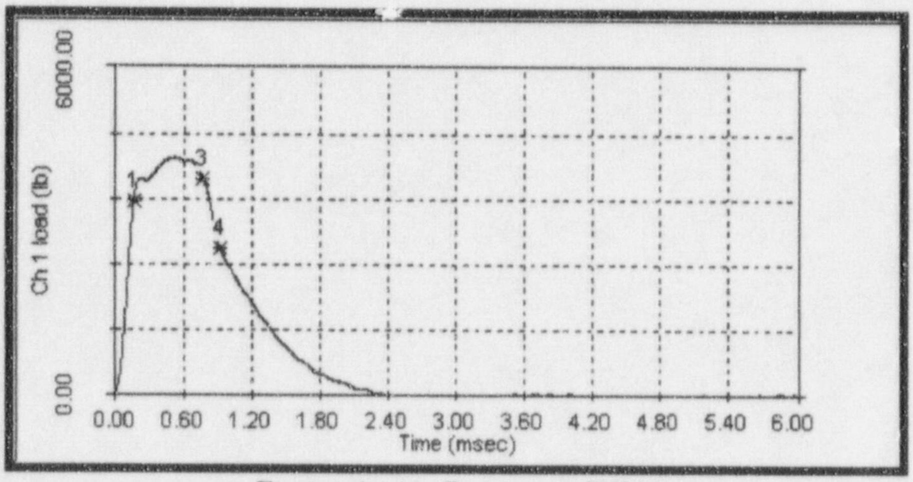


Figure A. 41 Specimen CW44

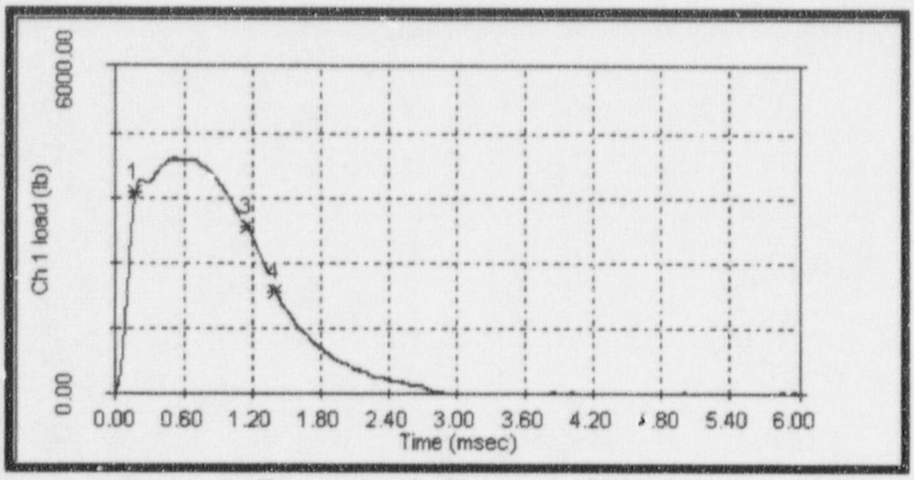


Figure A. 42 Specimen CW38

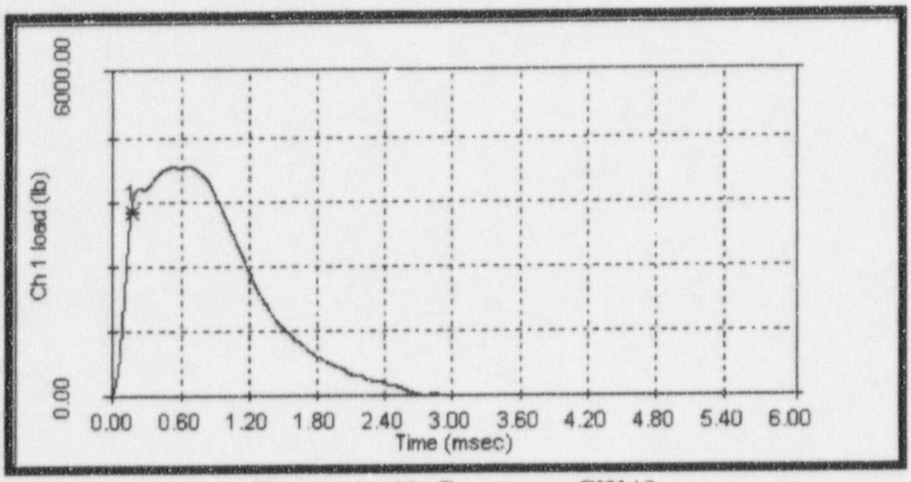


Figure A. 43 Specimen CW40

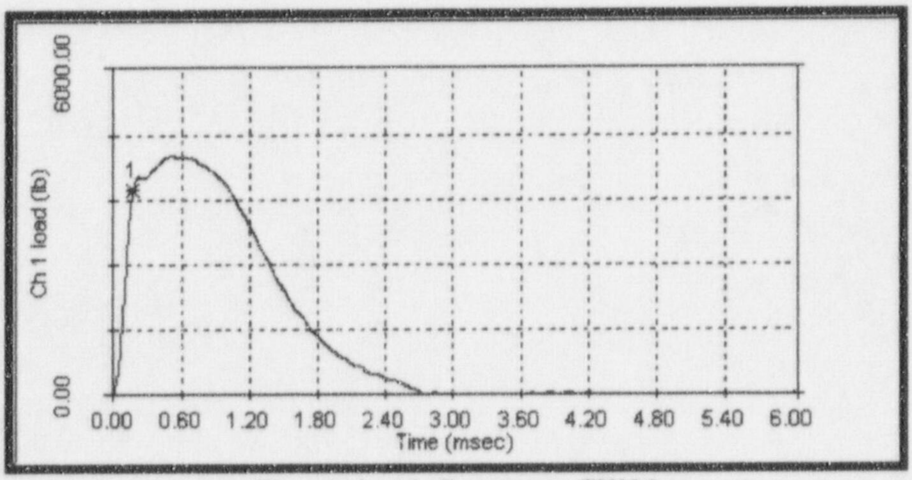


Figure A. 44 Specimen CW36

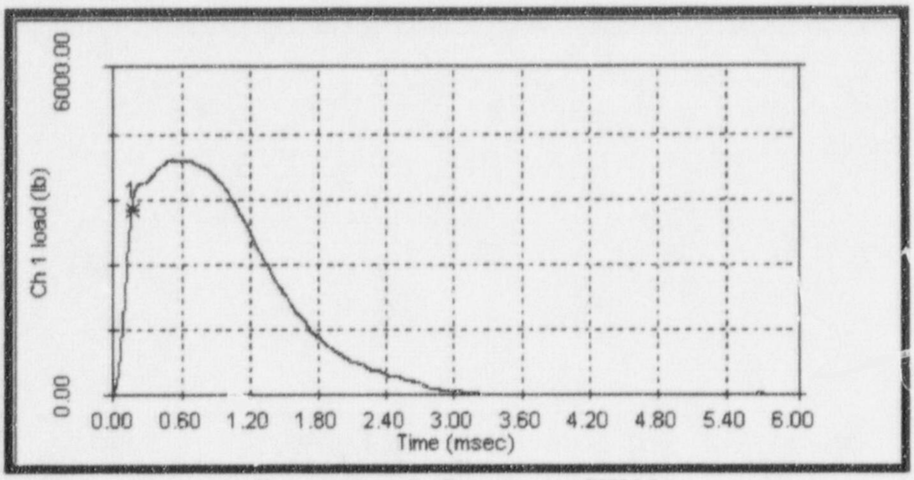


Figure A. 45 Specimen CW32

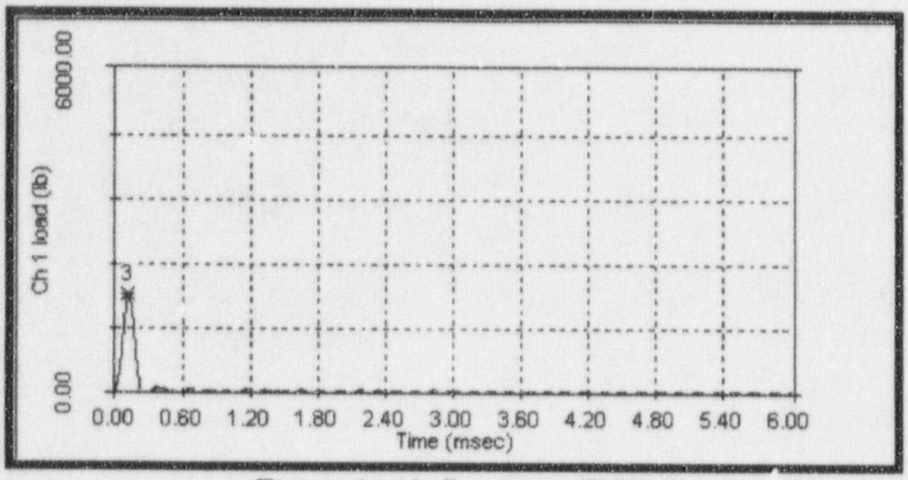


Figure A. 46 Specimen CH44

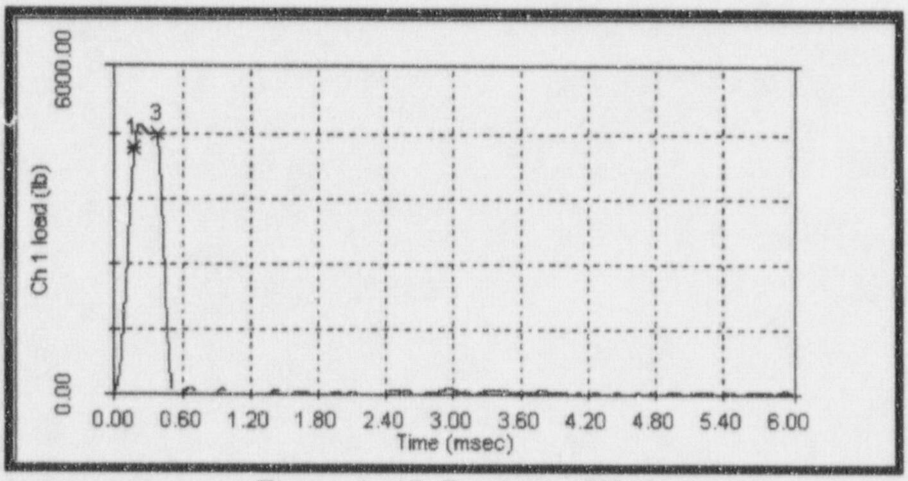


Figure A. 47 Specimen CH42

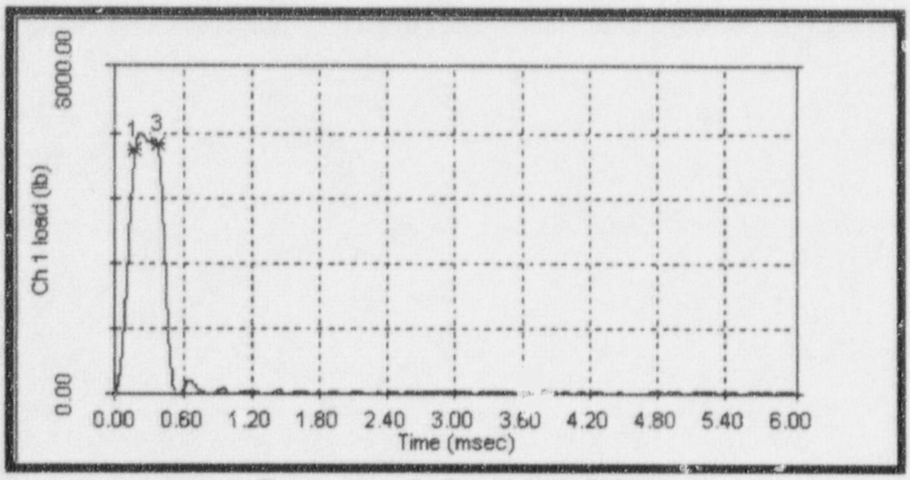


Figure A. 48 Specimen CH36

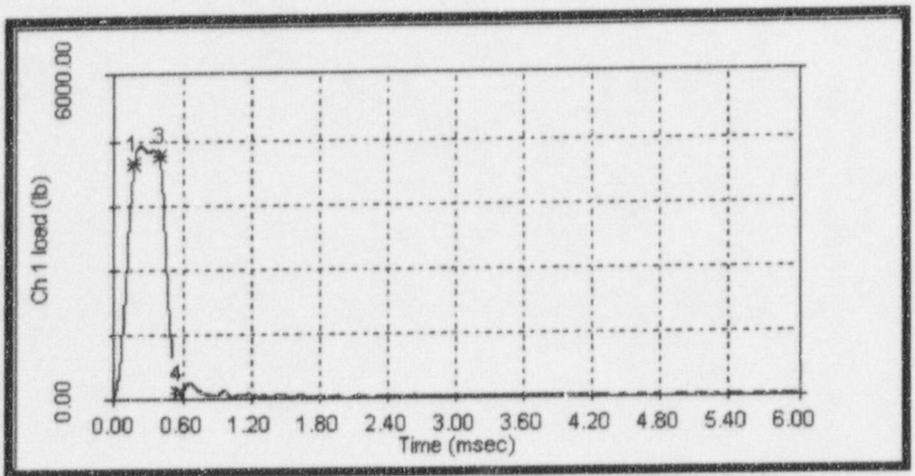


Figure A. 49 Specimen CH45

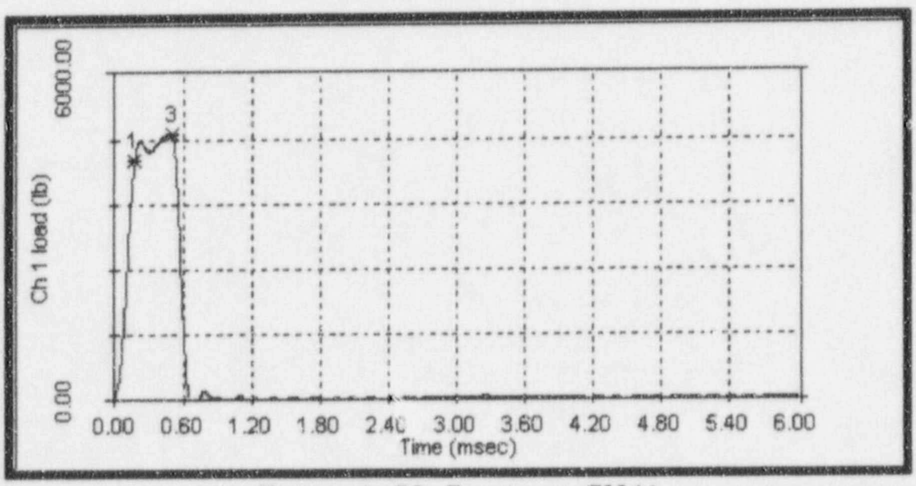


Figure A. 50 Specimen CH41

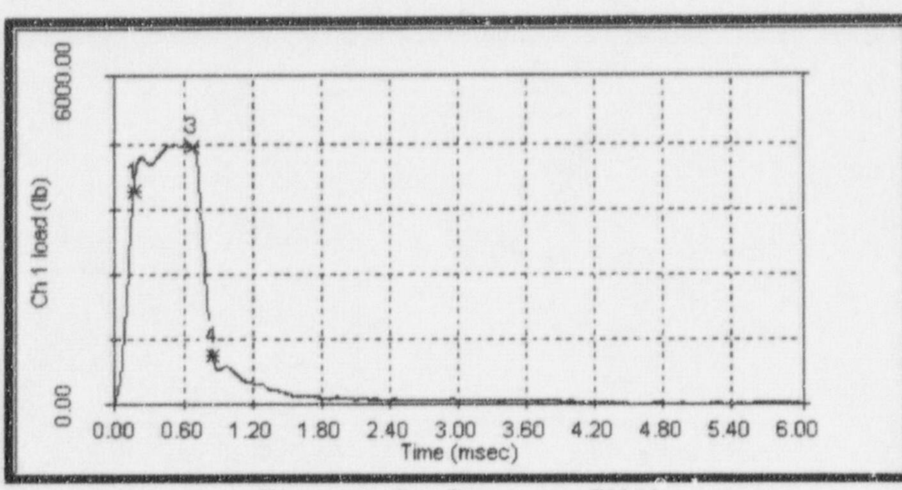


Figure A. 51 Specimen CH40

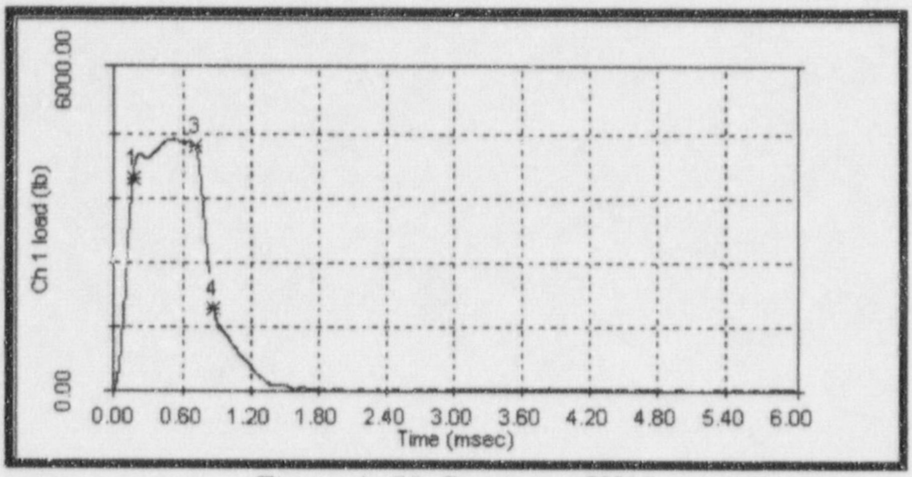


Figure A. 52 Specimen CH33

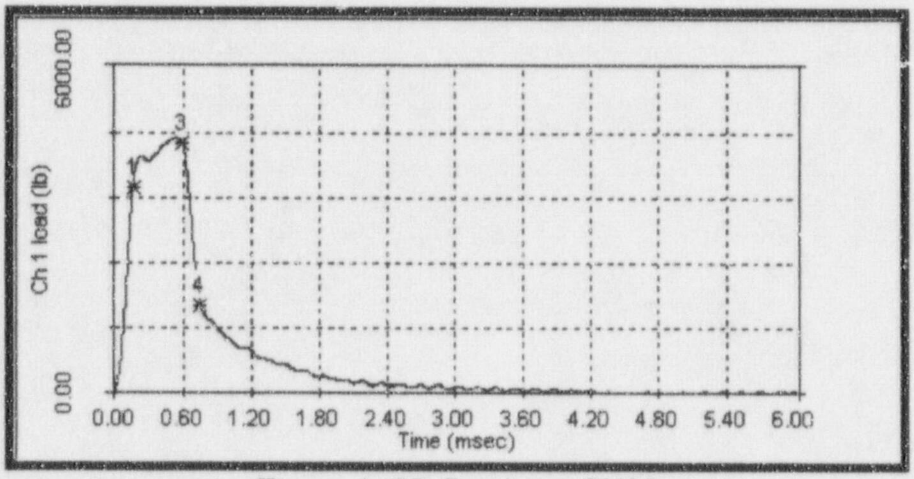


Figure A. 53 Specimen CH39

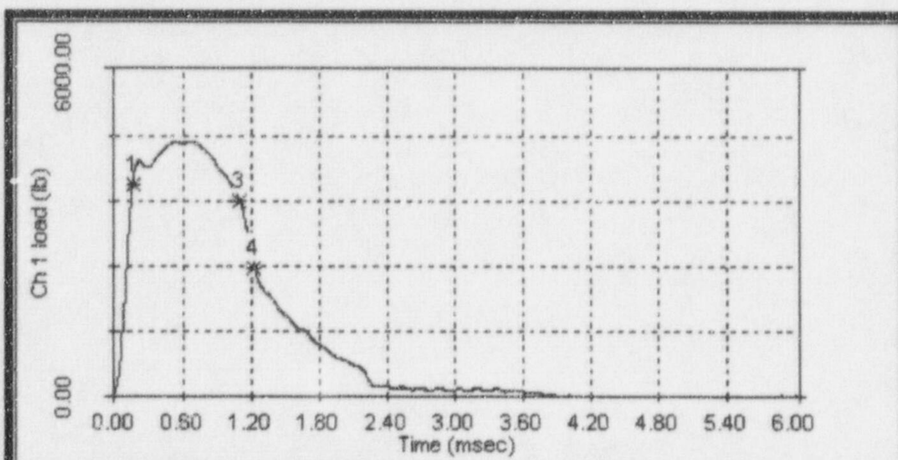


Figure A. 54 Specimen CH35

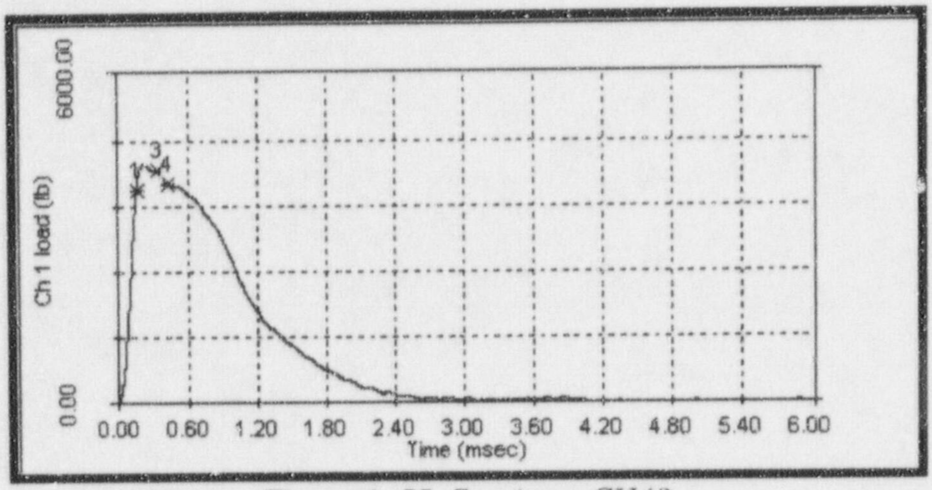


Figure A. 55 Specimen CH43

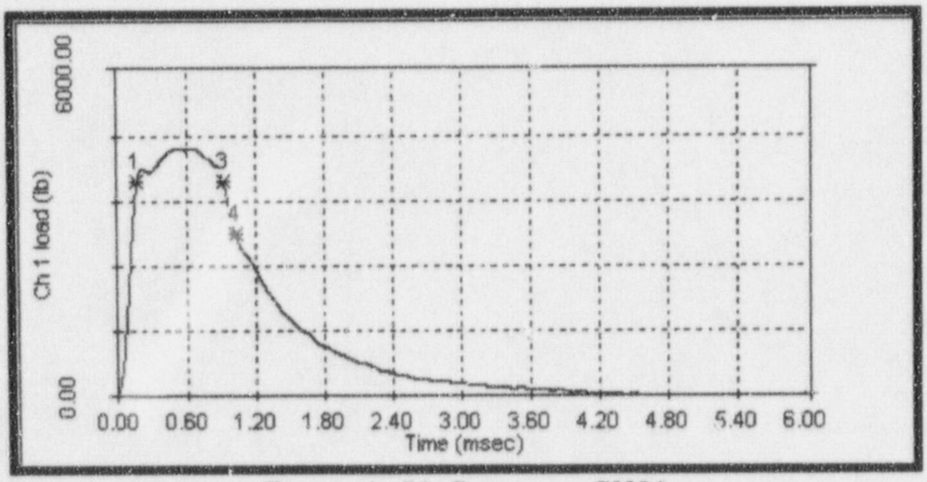


Figure A. 56 Specimen CH32

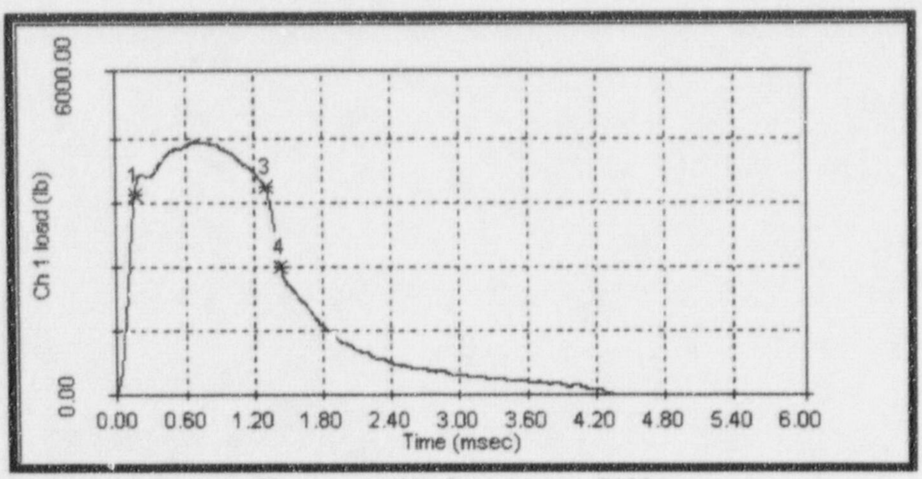


Figure A. 57 Specimen CH31

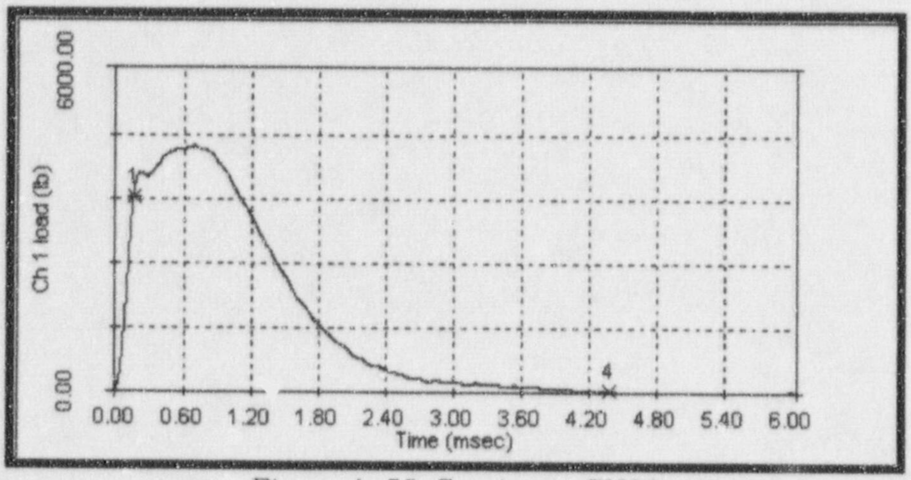


Figure A. 58 Specimen CH38

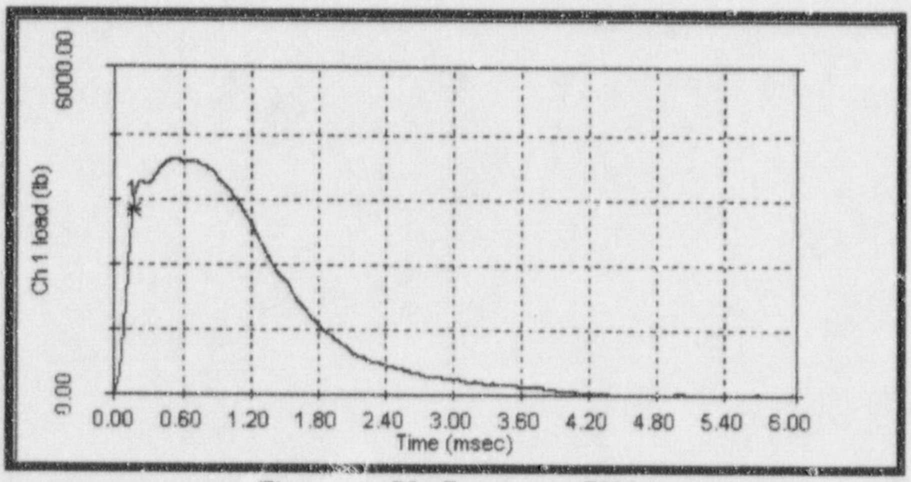


Figure A. 59 Specimen CH34

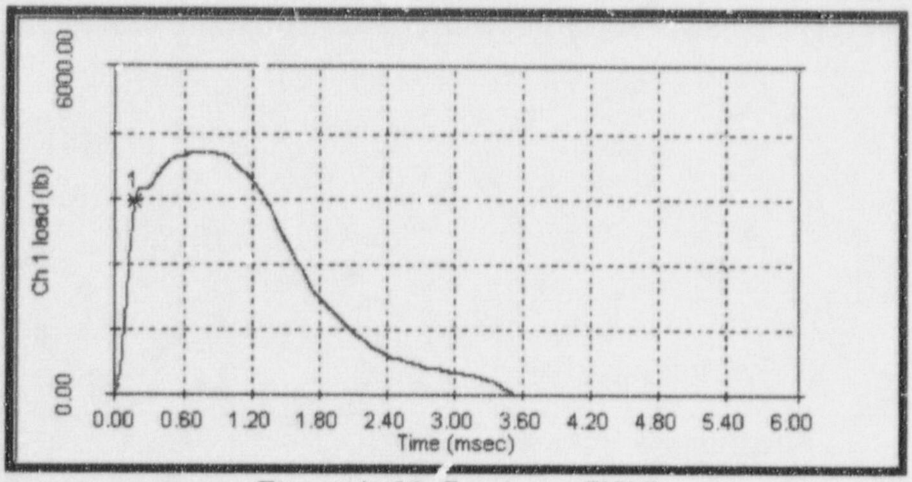


Figure A. 60 Specimen CH37

APPENDIX B

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

TABLE B-1
Changes in Average 30 ft-lb Temperatures for Intermediate Shell Plate A9154-1
(Longitudinal Orientation)
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{30}	Unirradiated	CVGRAPH Fit	ΔT_{30}
U	-20°F	20°F	40°F	-22°F	14°F	36°F
V	-25°F	35°F	60°F	-22°F	31°F	53°F
X	-25°F	25°F	50°F	-22°F	16°F	38°F
W	-25°F	- - -	- - -	-22°F	44°F	66°F

TABLE B-2
Changes in Average 50 ft-lb Temperatures for Intermediate Shell Plate A9154-1
(Longitudinal Orientation)
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{50}	Unirradiated	CVGRAPH Fit	ΔT_{50}
U	0°F	45°F	45°F	7°F	52°F	45°F
V	0°F	65°F	65°F	7°F	71°F	64°F
X	0°F	50°F	50°F	7°F	51°F	44°F
W	0°F	- - -	- - -	7°F	83°F	76°F

TABLE B-3
Changes in Average 35 mil Lateral Expansion Temperatures for Intermediate Shell Plate A9154-1
(Longitudinal Orientation)
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{35}	Unirradiated	CVGRAPH Fit	ΔT_{35}
U	0°F	40°F	40°F	4°F	48°F	44°F
V	0°F	50°F	50°F	4°F	60°F	56°F
X	0°F	50°F	50°F	4°F	54°F	50°F
W	0°F	---	---	4°F	84°F	80°F

TABLE B-4
Changes in Average Energy Absorption at Full Shear for Intermediate Shell Plate A9154-1
(Longitudinal Orientation)
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔE	Unirradiated	CVGRAPH Fit	ΔE
U	133 ft-lb	131 ft-lb	-2 ft-lb	132 ft-lb	131 ft-lb	-1 ft-lb
V	132 ft-lb	122 ft-lb	-10 ft-lb	132 ft-lb	122 ft-lb	-10 ft-lb
X	132 ft-lb	125 ft-lb	-7 ft-lb	132 ft-lb	125 ft-lb	-7 ft-lb
W	132 ft-lb	---	---	132 ft-lb	126 ft-lb	-6 ft-lb

TABLE B-5
Changes in Average 30 ft-lb Temperatures for Intermediate Shell Plate A9154-1
(Transverse Orientation)
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{30}	Unirradiated	CVGRAPH Fit	ΔT_{30}
U	25°F	55°F	30°F	28°F	43°F	15°F
V	25°F	65°F	40°F	28°F	61°F	33°F
X	25°F	60°F	35°F	28°F	54°F	26°F
W	25°F	---	---	28°F	86°F	58°F

TABLE B-6
Changes in Average 50 ft-lb Temperatures for Intermediate Shell Plate A9154-1
(Transverse Orientation)
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{50}	Unirradiated	CVGRAPH Fit	ΔT_{50}
U	70°F	105°F	35°F	71°F	94°F	23°F
V	75°F	130°F	55°F	71°F	137°F	66°F
X	75°F	105°F	30°F	71°F	112°F	41°F
W	75°F	---	---	71°F	139°F	68°F

TABLE B-7
Changes in Average 35 mil Lateral Expansion Temperatures for Intermediate Shell Plate A9154-1
(Transverse Orientation)
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{35}	Unirradiated	CVGRAPH Fit	ΔT_{35}
U	55°F	75°F	20°F	49°F	74°F	25°F
V	55°F	95°F	40°F	49°F	96°F	47°F
X	55°F	85°F	30°F	49°F	92°F	43°F
W	55°F	- - -	- - -	49°F	132°F	83°F

TABLE B-8
Changes in Average Energy Absorption at Full Shear for Intermediate Shell Plate A9154-1
(Transverse Orientation)
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔE	Unirradiated	CVGRAPH Fit	ΔE
U	75 ft-lb	75 ft-lb	0 ft-lb	75 ft-lb	75 ft-lb	0 ft-lb
V	75 ft-lb	76 ft-lb	1 ft-lb	75 ft-lb	76 ft-lb	1 ft-lb
X	75 ft-lb	73 ft-lb	-2 ft-lb	75 ft-lb	73 ft-lb	-2 ft-lb
W	75 ft-lb	- - -	- - -	75 ft-lb	74 ft-lb	-1 ft-lb

TABLE B-9
Changes in Average 30 ft-lb Temperatures for Surveillance Weld Material
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{30}	Unirradiated	CVGRAPH Fit	ΔT_{30}
U	-55°F	-25°F	30°F	-53°F	-31°F	22°F
V	-60°F	-15°F	45°F	-53°F	-6°F	47°F
X	-60°F	-25°F	35°F	-53°F	-30°F	23°F
W	-60°F	- - -	- - -	-53°F	-10°F	43°F

TABLE B-10
Changes in Average 50 ft-lb Temperatures for Surveillance Weld Material
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{50}	Unirradiated	CVGRAPH Fit	ΔT_{50}
U	-15°F	15°F	30°F	-12°F	10°F	22°F
V	-15°F	30°F	45°F	-12°F	30°F	42°F
X	-15°F	20°F	35°F	-12°F	5°F	17°F
W	-15°F	- - -	- - -	-12°F	40°F	52°F

TABLE B-11
Changes in Average 35 mil Lateral Expansion Temperatures for Surveillance Weld Material
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{35}	Unirradiated	CVGRAPH Fit	ΔT_{35}
U	-30°F	0°F	30°F	-26°F	-4°F	22°F
V	-35°F	0°F	35°F	-26°F	7°F	33°F
X	-35°F	-15°F	20°F	-26°F	-5°F	21°F
W	-35°F	- - -	- - -	-26°F	28°F	54°F

TABLE B-12
Changes in Average Energy Absorption at Full Shear for Surveillance Weld Material
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔE	Unirradiated	CVGRAPH Fit	ΔE
U	91 ft-lb	87 ft-lb	-4 ft-lb	91 ft-lb	87 ft-lb	-4 ft-lb
V	91 ft-lb	85 ft-lb	-6 ft-lb	91 ft-lb	85 ft-lb	-6 ft-lb
X	91 ft-lb	85 ft-lb	-6 ft-lb	91 ft-lb	85 ft-lb	-6 ft-lb
W	91 ft-lb	- - -	- - -	91 ft-lb	87 ft-lb	-4 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	-85°F	-55°F	30°F	-93°F	-57°F	36°F
V	-90°F	-45°F	45°F	-93°F	-43°F	50°F
X	-90°F	-45°F	45°F	-93°F	-39°F	54°F
W	-90°F	- - -	- - -	-93°F	-33°F	60°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	-65°F	-30°F	35°F	-66°F	-28°F	38°F
V	-70°F	-15°F	55°F	-66°F	-13°F	53°F
X	-70°F	-25°F	45°F	-66°F	-4°F	62°F
W	-70°F	- - -	- - -	-66°F	4°F	70°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	-55°F	-25°F	30°F	-56°F	-28°F	28°F
V	-60°F	-15°F	45°F	-56°F	-20°F	36°F
X	-60°F	10°F	70°F	-56°F	-3°F	53°F
W	-60°F	---	---	-56°F	-15°F	71°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	136 ft-lb	121 ft-lb	-15 ft-lb	130 ft-lb	121 ft-lb	-9 ft-lb
V	130 ft-lb	111 ft-lb	-19 ft-lb	130 ft-lb	111 ft-lb	-19 ft-lb
X	130 ft-lb	117 ft-lb	-13 ft-lb	130 ft-lb	117 ft-lb	-13 ft-lb
W	130 ft-lb	---	---	130 ft-lb	103 ft-lb	-27 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 El 85-82 definition of upper shelf energy.

Table C-1 Upper Shelf Energy Values Fixed in CVGRAPH

Material	Unirradiated	Capsule U	Capsule V	Capsule X	Capsule W
Intermediate Shell Plate A9154-1 (Longitudinal Orientation)	132 ft-lb	131 ft-lb	122 ft-lb	125 ft-lb	126 ft-lb
Intermediate Shell Plate A9154-1 (Transverse Orientation)	75 ft-lb	75 ft-lb	76 ft-lb	73 ft-lb	74 ft-lb
Weld Metal (Heat # 4P4784)	91 ft-lb	87 ft-lb	85 ft-lb	85 ft-lb	87 ft-lb
HAZ Material	130 ft-lb	121 ft-lb	111 ft-lb	117 ft-lb	103 ft-lb

Unirradiated

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:40:53 on 06-23-1998

Page 1

Coefficients of Curve 1

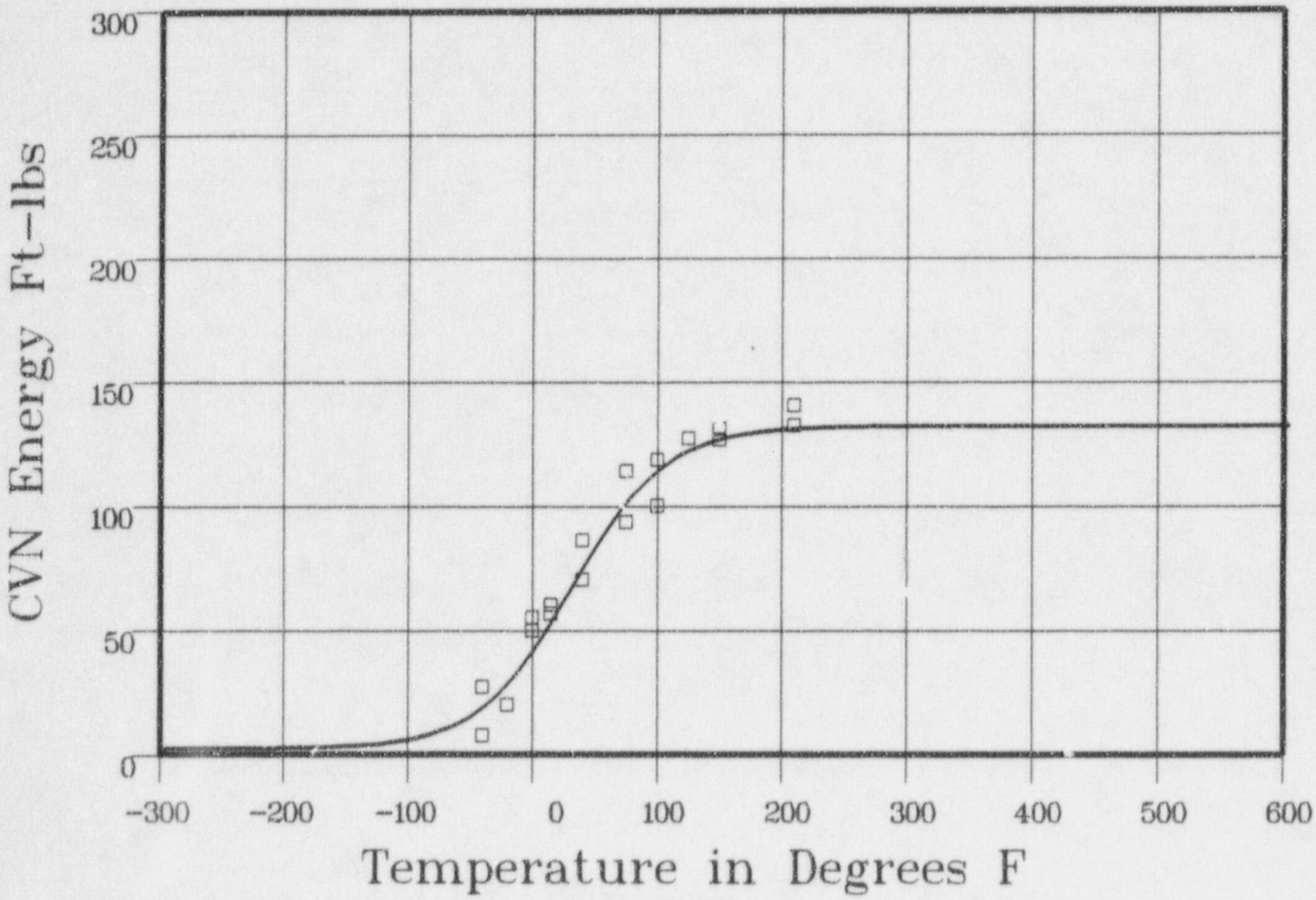
A = 67.09	B = 64.9	C = 74.97	T0 = 27.12

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

Upper Shelf Energy: 132 Fixed Temp. at 30 ft-lbs: -21.5 Temp. at 50 ft-lbs: 6.8 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: UNNIRR Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: UNNIRR Material: PLATE SA533B1 Ori.: LT Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-40	7.5	20.75	-13.25
-40	27	20.75	6.24
-20	20	30.94	-10.94
0	55	44.58	10.41
0	49.5	44.58	4.91
15	56.5	56.69	-.19
15	60	56.69	3.3
40	70	78.13	-8.13
40	86	78.13	7.86

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

Unirradiated

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: UNNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
75	114	103.69	10.3
75	93.5	103.69	-10.19
100	118.5	115.74	2.75
100	100	115.74	-15.74
125	127	123.11	3.88
150	126.5	127.28	-.78
150	131	127.28	3.71
210	140.5	131.01	9.48
210	132.5	131.01	1.48

SUM of RESIDUALS = 5.1

Capsule U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:40:53 on 06-23-1998

Page 1

Coefficients of Curve 2

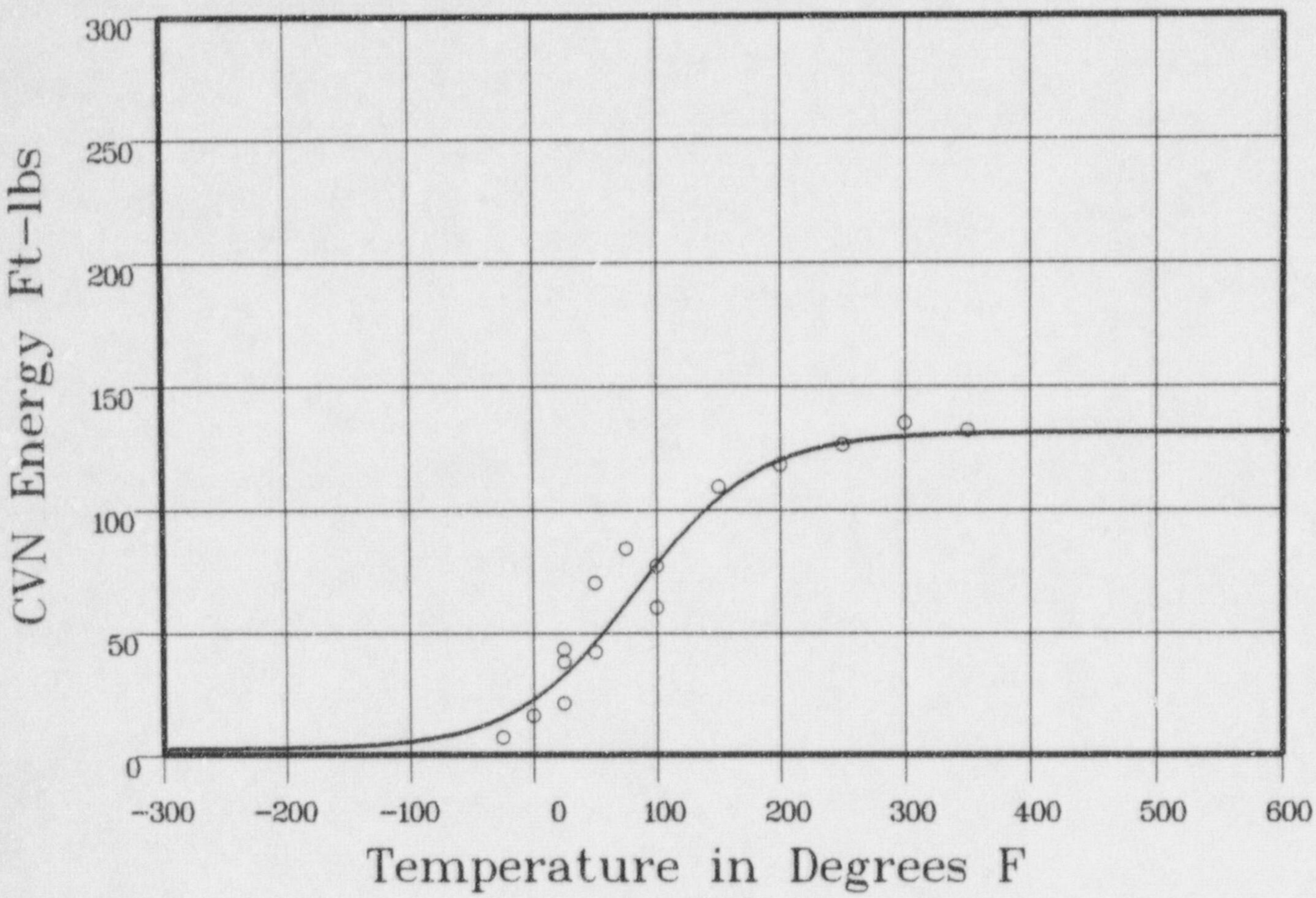
A = 66.59	B = 64.4	C = 99.03	T0 = 78.28

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

Upper Shelf Energy: 131 Fixed Temp. at 30 ft-lbs: 14.3 Temp. at 50 ft-lbs: 52.1 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: U Material: PLATE SA533B1 Ori.: LT Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	7	16.43	-9.43
0	16	24.18	-8.18
25	38	34.95	3.04
25	21	34.95	-13.95
25	43	34.95	8.04
50	42	48.69	-6.69
50	70	48.69	21.3
75	84	64.46	19.53

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

Capsule U

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
100	60	80.5	-20.5
100	77	80.5	-3.5
150	109	106.49	2.5
200	118	120.84	-2.84
250	126	127.1	-1.1
300	135	129.55	5.44
350	132	130.46	1.53

SUM of RESIDUALS = -4.78

Capsule V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:40:53 on 06-23-1998

Page 1

Coefficients of Curve 3

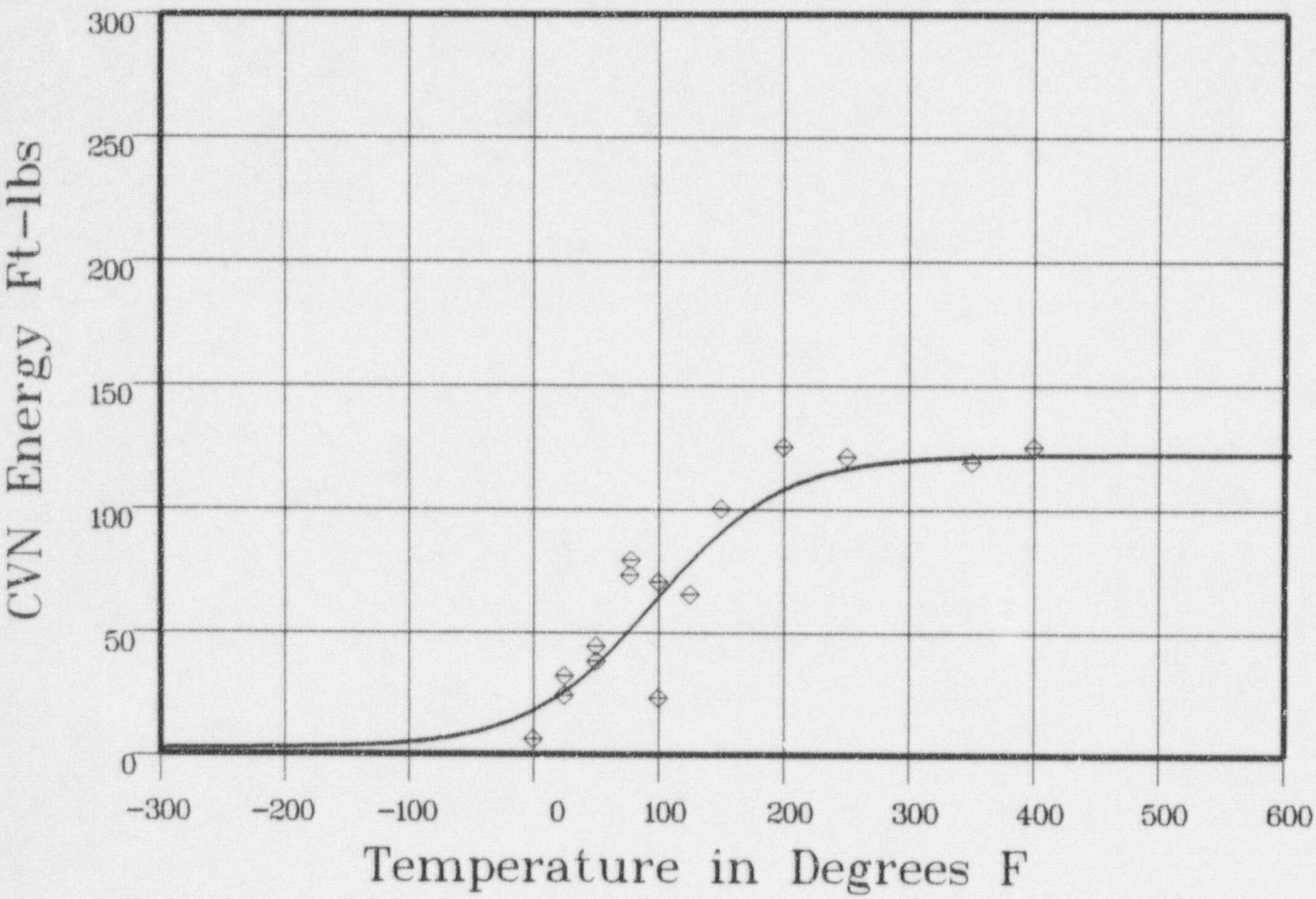
A = 62.09	B = 59.9	C = 102.49	T0 = 92.28

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

Upper Shelf Energy: 122 Fixed Temp. at 30 ft-lbs: 30.9 Temp. at 50 ft-lbs: 71.2 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: V Material: PLATE SA533B1 Ori.: LT Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	6	19.18	-13.18
25	24	27.59	-3.59
25	32	27.59	4.4
50	38	38.7	-.7
50	44	38.7	5.29
77	73	53.23	19.76
78	79	53.8	25.19
100	70	66.6	3.39

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

Capsule V

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differentiai
100	23	66.6	-43.6
125	65	80.59	-15.59
150	100	92.66	7.33
200	125	108.95	16.04
250	121	116.72	4.27
350	119	121.22	-2.22
400	125	121.7	3.29

SUM of RESIDUALS = 10.12

Capsule X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:40:53 on 06-23-1998

Page 1

Coefficients of Curve 4

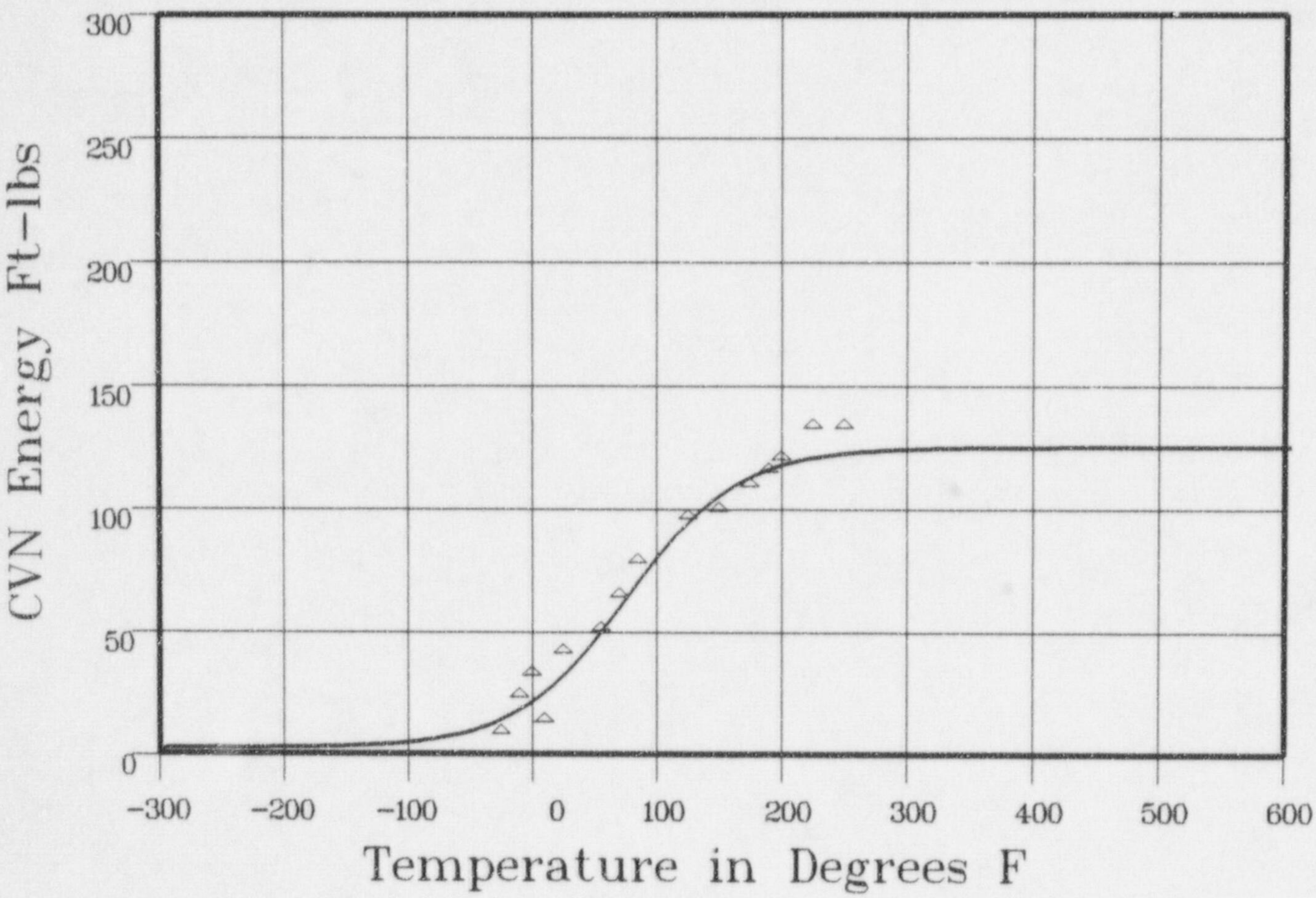
A = 63.59	B = 61.4	C = 89.77	T0 = 71.25

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

Upper Shelf Energy: 125 Fixed Temp. at 30 ft-lbs: 16 Temp. at 50 ft-lbs: 51 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: X Material: PLATE SA533B1 Ori.: LT Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	8	15.07	-7.07
-10	23	19.46	3.53
0	32	23.04	8.95
10	13	27.18	-14.18
25	41	34.49	6.5
55	50	52.6	-2.6
70	64	62.74	1.25

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

Capsule X

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: X Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
85	78	72.93	5.06
125	96	96.52	-.52
150	99	106.88	-7.88
175	109	113.92	-4.92
190	115	116.86	-1.86
200	120	118.4	1.59
225	133	121.13	11.86
250	133	122.75	10.24

SUM of RESIDUALS = 9.95

Capsule W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:40:53 on 06-23-1998

Page 1

Coefficients of Curve 5

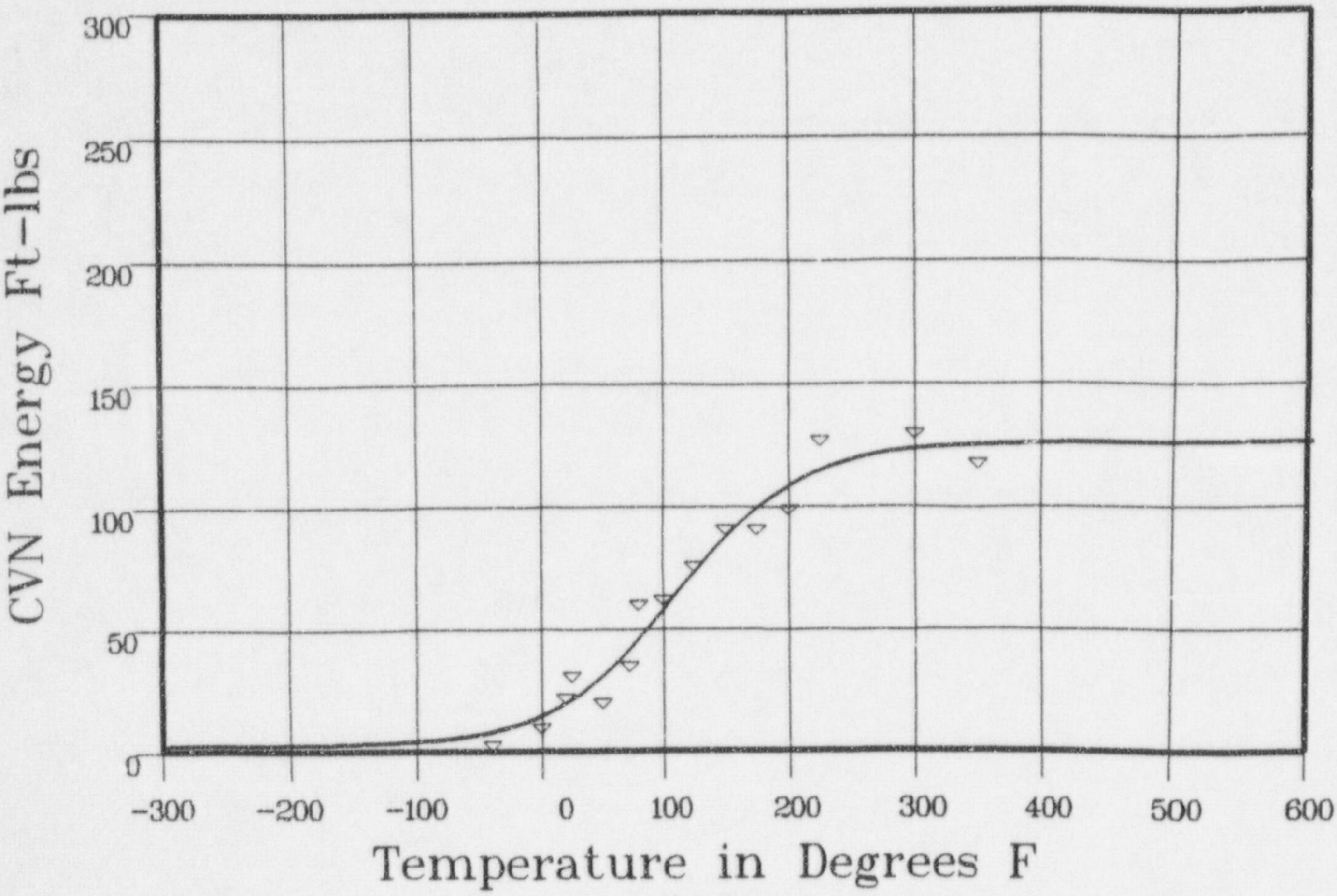
A = 64.09	B = 61.9	C = 100.05	T0 = 106.05

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

Upper Shelf Energy: 126 Fixed Temp. at 30 ft-lbs: 44 Temp. at 50 ft-lbs: 82.8 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: W Material: PLATE SA533B1 Ori.: LT Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-40	4	8.53	-4.53
0	11	15.46	-4.46
20	23	20.99	2
25	32	22.64	9.35
50	21	32.64	-11.64
72	36	43.8	-7.8

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

Capsule W

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
80	61	48.33	12.66
100	63	60.35	2.64
125	77	75.68	1.31
150	92	89.66	2.33
175	92	101.07	-9.07
200	100	109.58	-9.58
225	128	115.49	12.5
300	131	123.48	7.51
350	119	125.06	-6.06

SUM of RESIDUALS = -2.84

Unirradiated

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:52:16 on 06-23-1998

Page 1

Coefficients of Curve 1

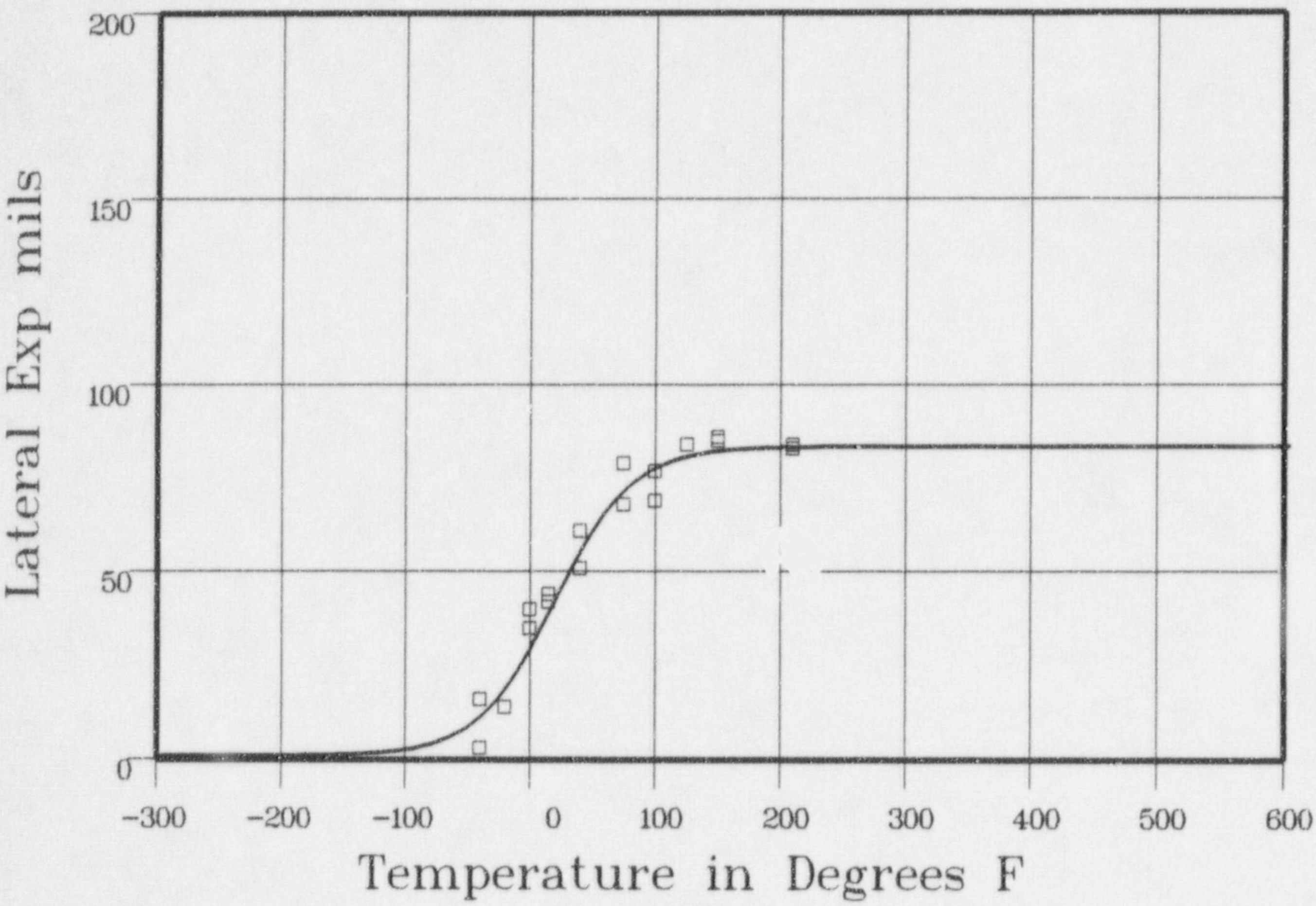
A = 42.27	B = 41.27	C = 61.86	T0 = 15.46

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

Upper Shelf L.E.: 83.55 Temperature at L.E. 35: 4.4 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: UNNIRR Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: UNNIRR Material: PLATE SA533B1 Ori.: LT Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-40	3	12.78	-9.78
-40	16	12.78	3.21
-20	14	20.9	-6.9
0	40	32.16	7.83
0	35	32.16	2.83
15	42	41.96	.03
15	44	41.96	2.03
40	51	57.84	-6.84
40	61	57.84	3.15

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

Unirradiated

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: UNNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
75	79	73.04	5.95
75	68	73.04	-5.04
100	77	78.51	-1.51
100	69	78.51	-9.51
125	84	81.23	2.76
150	86	82.5	3.49
150	85	82.5	2.49
210	84	83.4	.59
210	83	83.4	-.4

SUM of RESIDUALS = -5.59

Capsule U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:52:16 on 06-23-1998

Page 1

Coefficients of Curve 2

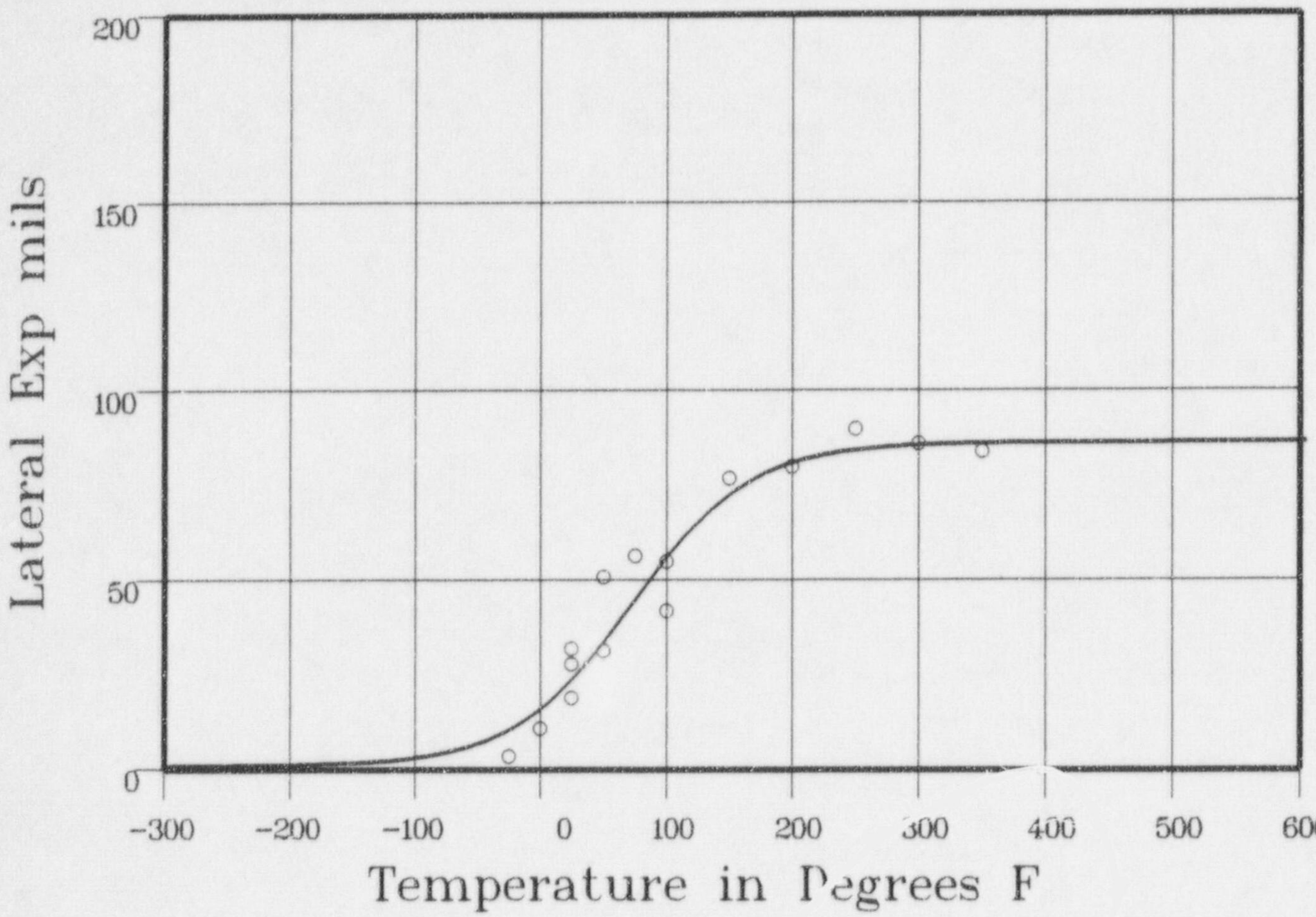
A = 43.66	B = 42.66	C = 94.12	T0 = 67.5

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

Upper Shelf L.E.: 86.33   Temperature at L.E. 35: 48.1   Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1   Heat Number: A9154-1   Orientation: LT

Capsule: U   Total Fluence:



Data Set(s) Plotted

Plant: VS1   Cap.: U   Material: PLATE SA533B1   Ori.: LT   Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	3.5	11.48	-7.98
0	11	17.42	-6.42
25	28	25.61	2.38
25	19	25.61	-6.61
25	32	25.61	6.38
50	31.5	35.82	-4.32
50	51	35.82	15.17
75	56.5	47.06	9.43

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

Capsule U

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
100	42	57.84	-15.84
100	55	57.84	-2.84
150	77	73.73	3.26
200	80	81.51	-1.51
250	90	84.6	5.39
300	86	85.73	.26
350	84	86.12	-2.12

SUM of RESIDUALS = -5.38

Capsule V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:52:16 on 06-23-1998

Page 1

Coefficients of Curve 3

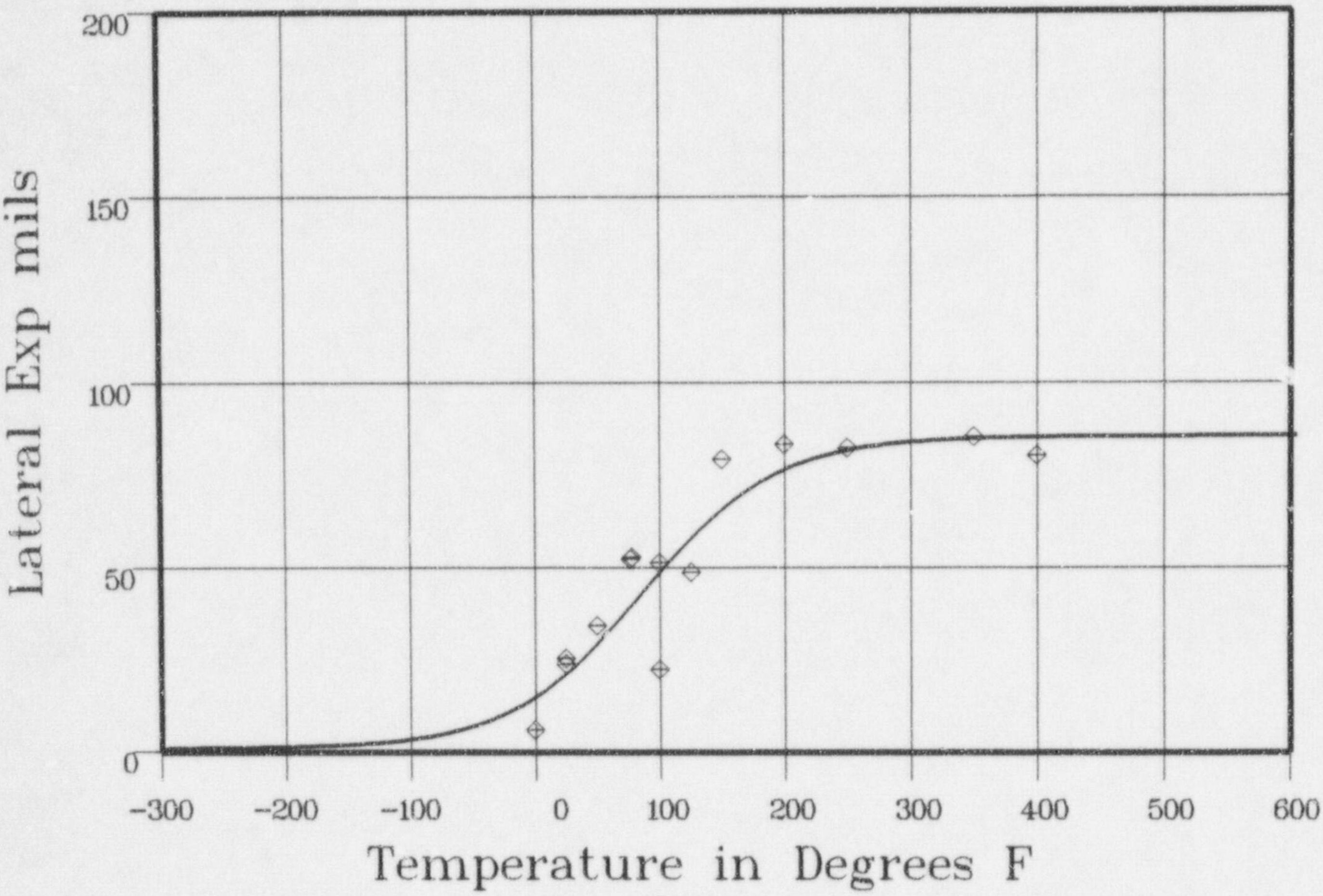
A = 43.33	B = 42.33	C = 106.58	T0 = 81.56

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

Upper Shelf L.E.: 85.67 Temperature at L.E. 35: 60.2 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: V Material: PLATE SA533B1 Ori.: LT Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	6	16.06	-10.06
25	24	22.76	1.23
25	25.5	22.76	2.73
50	34.5	31.15	3.34
50	34.5	31.15	3.34
77	52.5	41.52	10.97
78	53	41.92	11.07
100	51.5	50.58	.91

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

Capsule V

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
100	22.5	50.58	-28.08
125	49	59.69	-10.69
150	79.5	67.31	12.18
200	83.5	77.39	6.1
250	82.5	82.23	.26
350	85.5	85.13	.36
400	80.5	85.46	-4.96

SUM of RESIDUALS = -1.27

Capsule X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:52:16 on 06-23-1998

Page 1

Coefficients of Curve 4

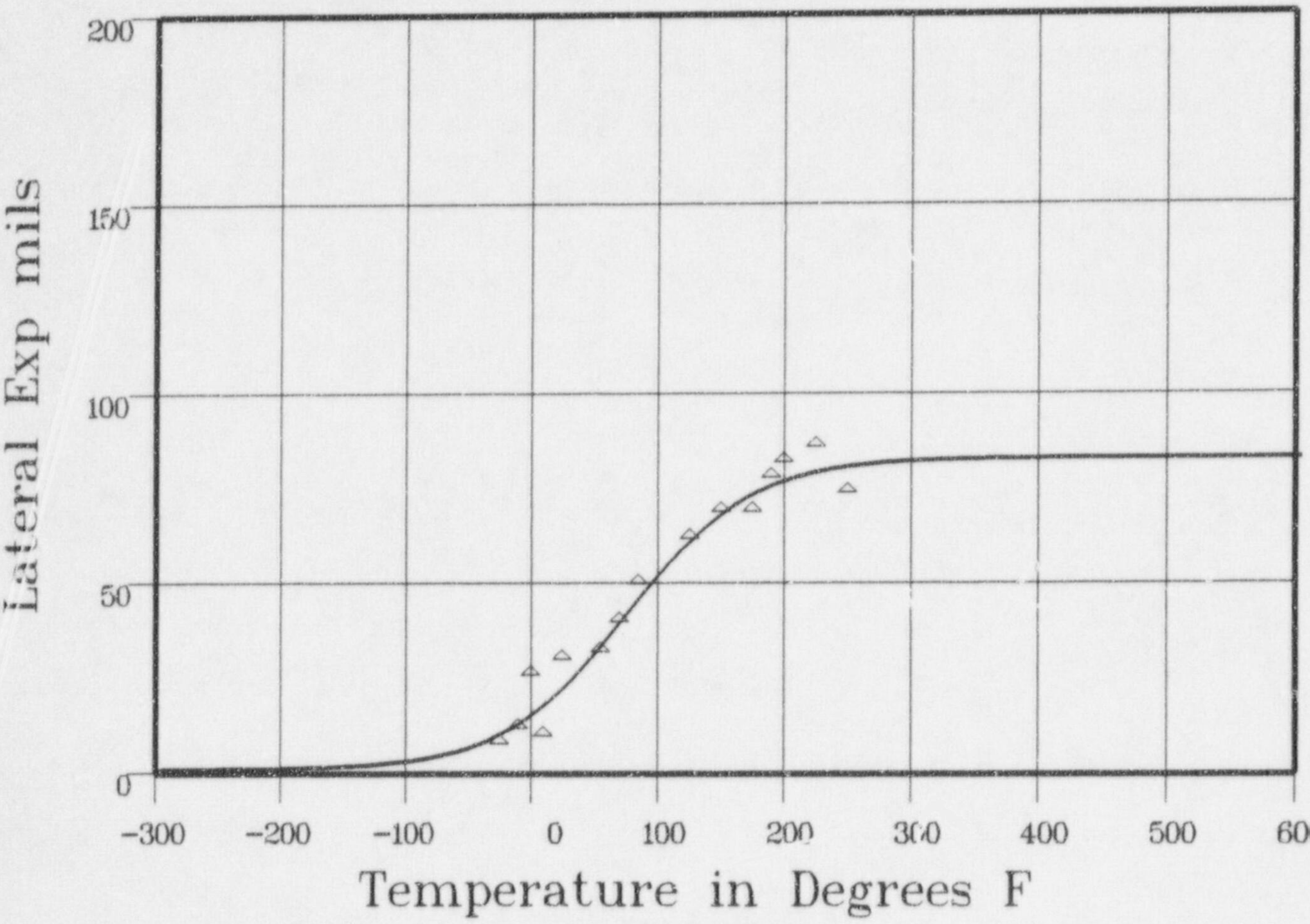
A = 42.02	B = 41.02	C = 97.97	T0 = 71.25

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

Upper Shelf L.E.: 83.05 Temperature at L.E. 35: 54.2 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: X Material: PLATE SA533B1 Ori.: LT Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	8	11.08	-3.08
-10	12	14.12	-2.12
0	26	16.53	9.46
10	10	19.27	-9.27
25	30	23.98	6.01
55	32	35.28	-3.28
70	40	41.5	-1.5

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

Capsule X

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: X Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
85	50	47.75	2.24
125	62	62.52	-.52
150	69	69.36	-.36
175	69	74.24	-5.24
190	78	76.38	1.61
200	82	77.53	4.46
225	86	79.64	6.35
250	74	80.97	-6.97

SUM of RESIDUALS = -2.22

Capsule W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:52:16 on 06-23-1998

Page 1

Coefficients of Curve 5

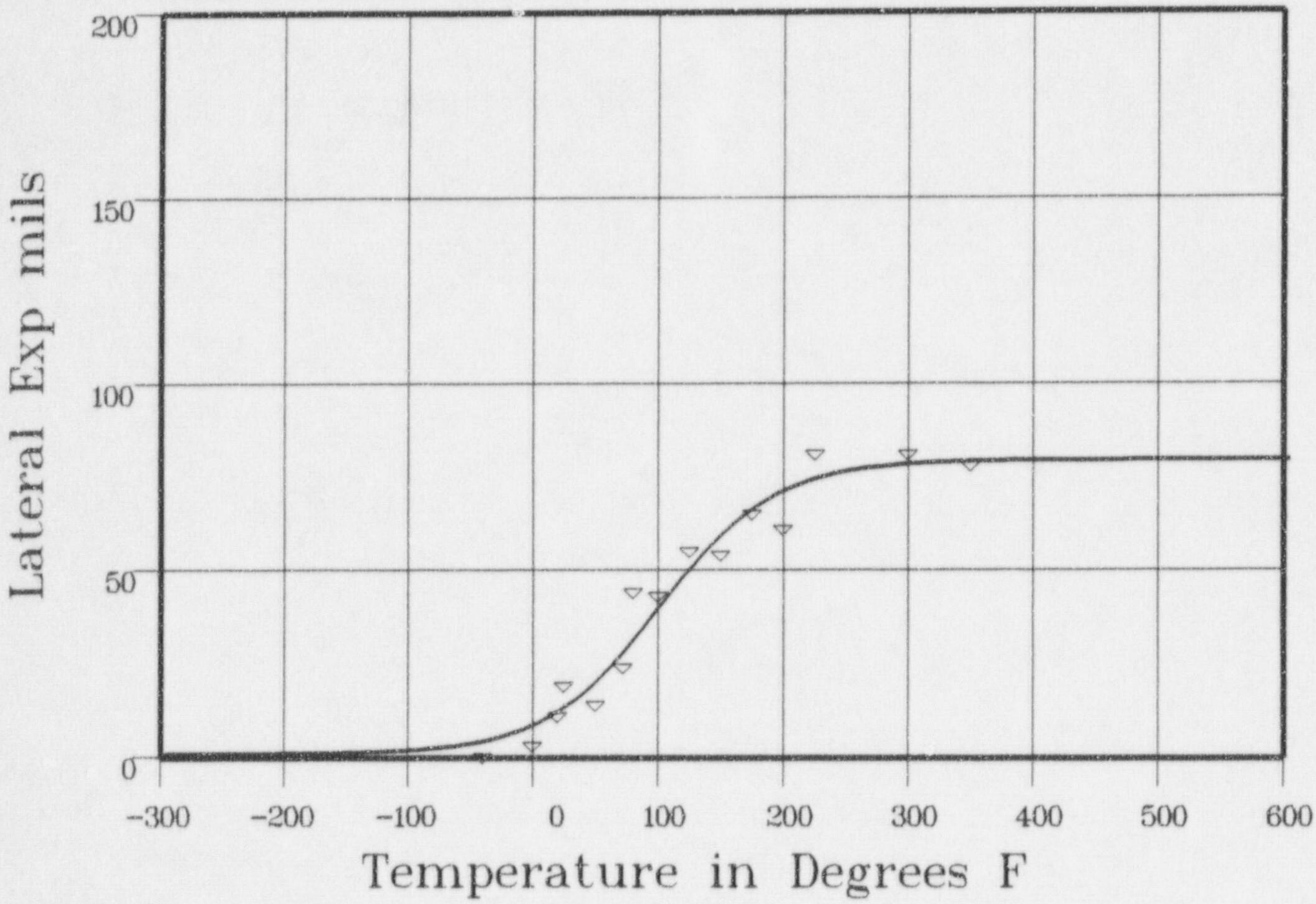
A = 40.3	B = 39.3	C = 91.79	T0 = 96.67

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

Upper Shelf L.E.: 79.6   Temperature at L.E. 35: 84.2   Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1   Heat Number: A9154-1   Orientation: LT

Capsule: W   Total Fluence:



Data Set(s) Plotted

Plant: VS1   Cap.: W   Material: PLATE SA533B1   Ori.: LT   Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-40	1	4.8	-3.8
0	4	9.52	-5.52
20	12	13.44	-1.44
25	20	14.62	5.37
50	15	21.87	-6.87
72	25	29.98	-4.98

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

Capsule W

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
80	45	33.23	11.76
100	44	41.72	2.27
125	56	52.05	3.94
150	55	60.86	-5.86
175	66	67.52	-1.52
200	62	72.11	-10.11
225	82	75.07	6.92
300	82	78.67	3.32
350	79	79.28	-.28

SUM of RESIDUALS = -6.83

Unirradiated

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:58:32 on 06-23-1998

Page 1

Coefficients of Curve 1

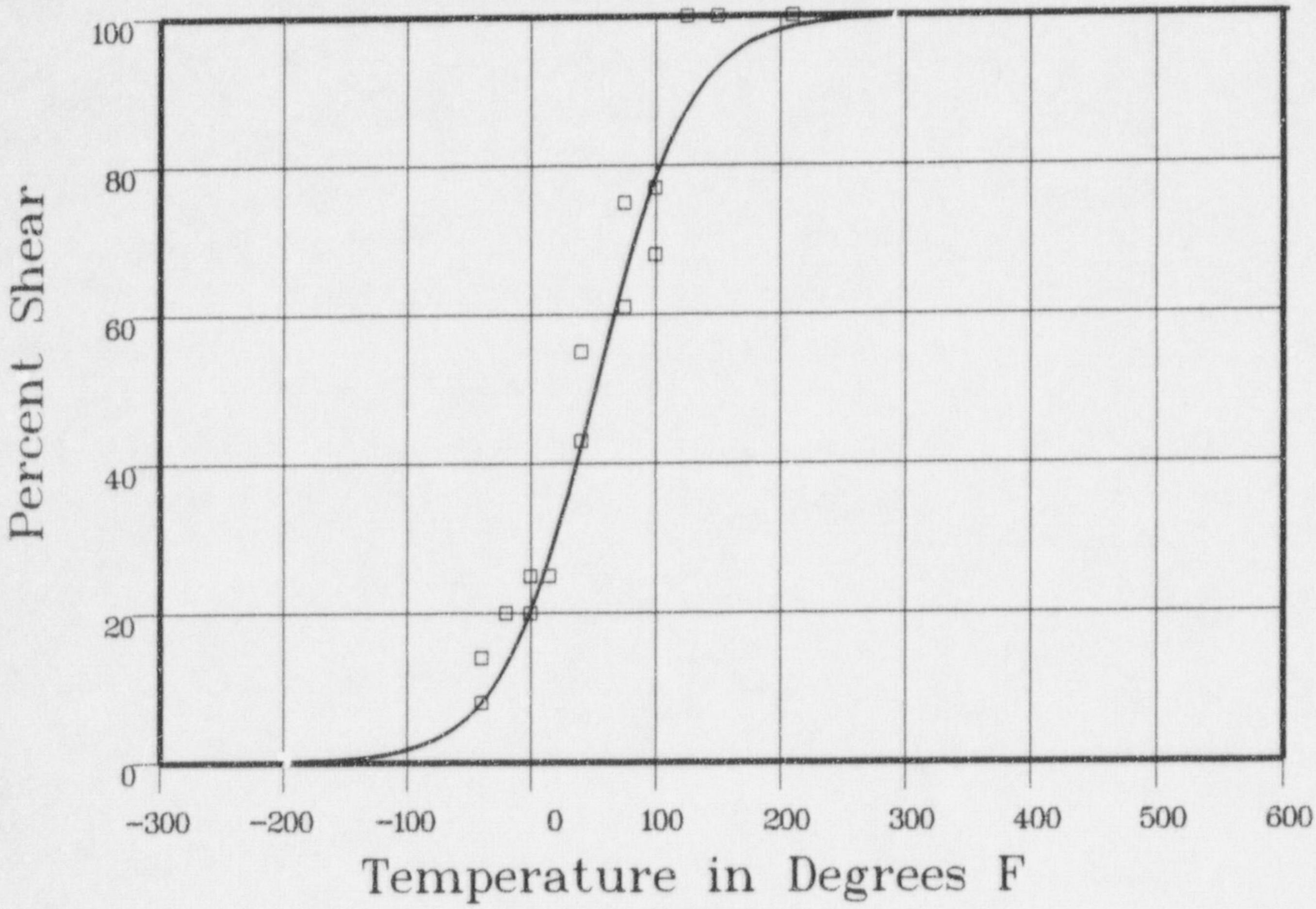
A = 50	B = 50	C = 75.34	T0 = 46.87

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

Temperature at 50% Shear: 46.8

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: UNNIRR Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: UNNIRR Material: PLATE SA533B1 Ori.: LT Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40	8	9.06	-1.06
-40	14	9.06	4.93
-20	20	14.49	5.5
0	25	22.37	2.62
0	20	22.37	-2.37
15	25	30.02	-5.02
15	25	30.02	-5.02
40	43	45.45	-2.45
40	55	45.45	9.54

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

Unirradiated

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: UNNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
75	75	67.84	7.15
75	61	67.84	-6.84
100	77	80.37	-3.37
100	68	80.37	-12.37
125	100	88.83	11.16
150	100	93.91	6.08
150	100	93.91	6.08
210	100	98.7	1.29
210	100	98.7	1.29

SUM of RESIDUALS = 17.17

Capsule U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:58:32 on 06-23-1998

Page 1

Coefficients of Curve 2

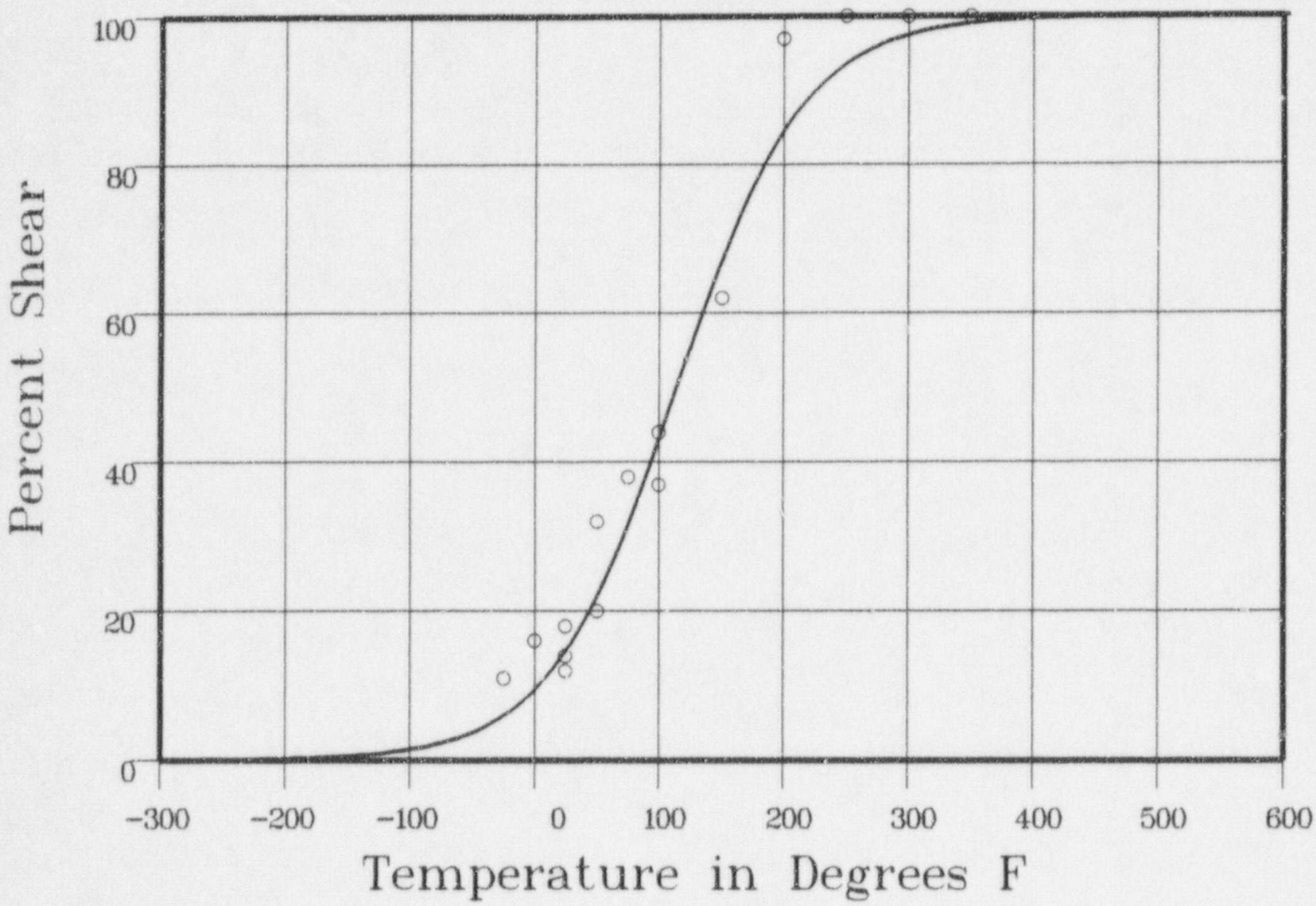
A = 50	B = 50	C = 101.16	T0 = 109.57

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

Temperature at 50% Shear: 109.5

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: U Material: PLATE SA533B1 Ori.: LT Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	11	6.53	4.46
0	16	10.28	5.71
25	18	15.81	2.18
25	12	15.81	-3.81
25	14	15.81	-1.81
50	20	23.54	-3.54
50	32	23.54	8.45
75	38	33.54	4.45

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

Capsule U

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100	37	45.28	-8.28
100	44	45.28	-1.28
150	62	68.98	-6.98
200	97	85.66	11.33
250	100	94.13	5.86
300	100	97.73	2.26
350	100	99.14	.85

SUM of RESIDUALS = 19.85

Capsule V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:58:32 on 06-23-1998

Page 1

Coefficients of Curve 3

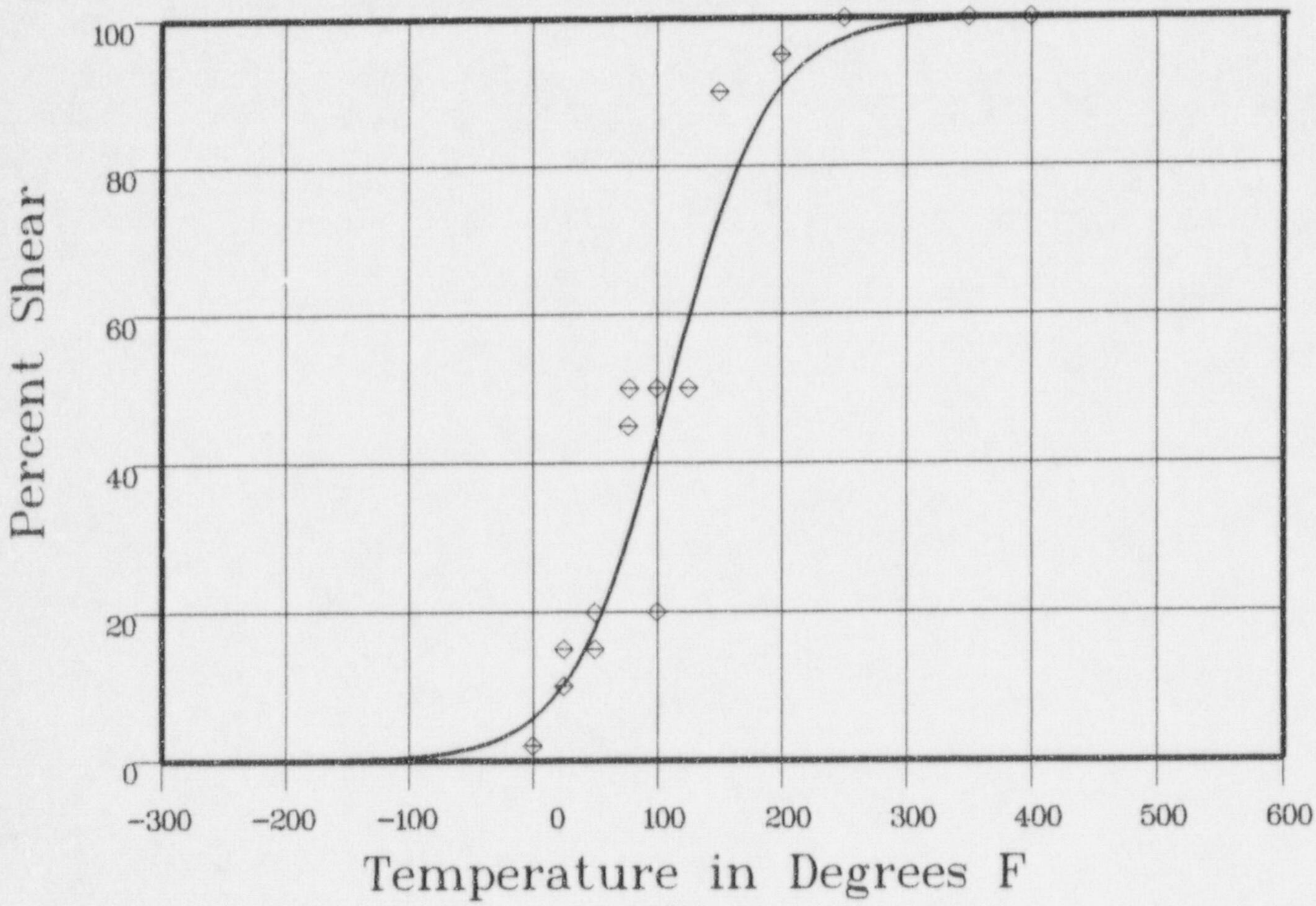
A = 50	B = 50	C = 78.9	T0 = 105.46

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

Temperature at 50% Shear: 105.4

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: V Material: PLATE SA533B1 Ori.: LT Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	2	6.45	-4.45
25	10	11.51	-1.51
25	15	11.51	3.48
50	15	19.68	-4.68
50	20	19.68	.31
77	45	32.7	12.29
78	50	33.26	16.73
100	50	46.54	3.45

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

Capsule V

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100	20	46.54	-26.54
125	50	62.12	-12.12
150	90	75.55	14.44
200	95	91.65	3.34
250	100	97.49	2.5
350	100	99.79	.2
400	100	99.94	.05

SUM of RESIDUALS = 7.51

Capsule X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:58:32 on 06-23-1998

Page 1

Coefficients of Curve 4

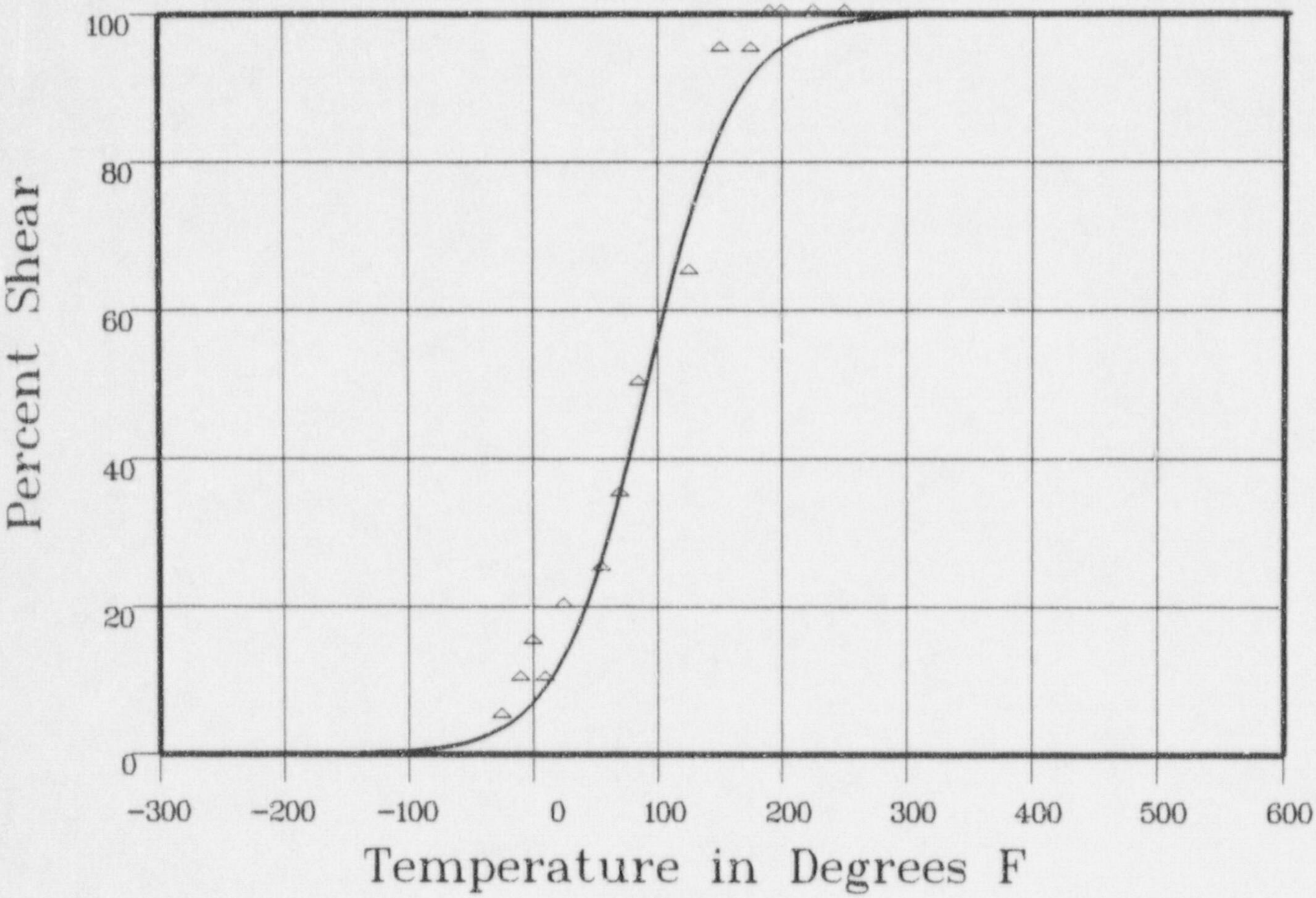
A = 50	B = 50	C = 70.63	T0 = 86.71

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

Temperature at 50% Shear: 86.7

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: X Material: PLATE SA533B1 Ori.: LT Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	5	4.05	.94
-10	10	6.07	3.92
0	15	7.9	7.09
10	10	10.22	-.22
25	20	14.83	5.16
55	25	28.94	-3.94
70	35	38.38	-3.38

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

Capsule X

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: X Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
85	50	48.78	1.21
125	65	74.72	-9.72
150	95	85.71	9.28
175	95	92.41	2.58
190	100	94.9	5.09
200	100	96.11	3.88
225	100	98.04	1.95
250	100	99.02	.97

SUM of RESIDUALS = 24.84

Capsule W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:58:32 on 06-23-1998

Page 1

Coefficients of Curve 5

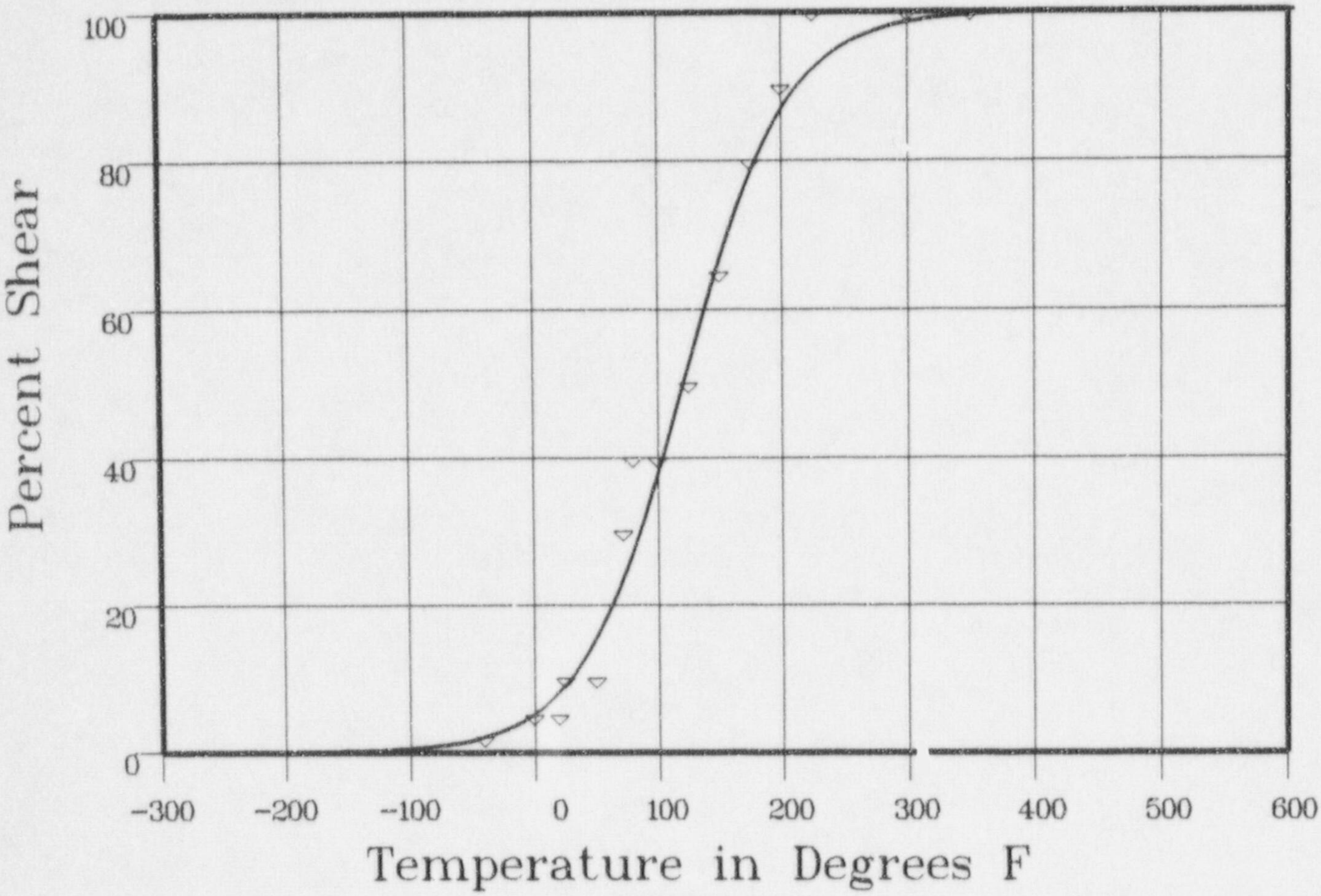
A = 50	B = 50	C = 83.57	T0 = 116.14

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

Temperature at 50% Shear: 116.1

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: W Material: PLATE SA533B1 Ori.: LT Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40	2	2.32	-.32
0	5	5.84	-.84
20	5	9.1	-4.1
25	10	10.14	-.14
50	10	17.03	-7.03
72	30	25.79	4.2

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

Capsule W

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: LT

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
80	40	29.62	10.37
100	40	40.45	-.45
125	50	55.27	-5.27
150	65	69.21	-4.21
175	80	80.35	-.35
200	90	88.14	1.85
225	100	93.11	6.88
300	100	98.78	1.21
350	100	99.63	.36

SUM of RESIDUALS = 2.12

Unirradiated

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:05:32 on 06-23-1998

Page 1

Coefficients of Curve 1

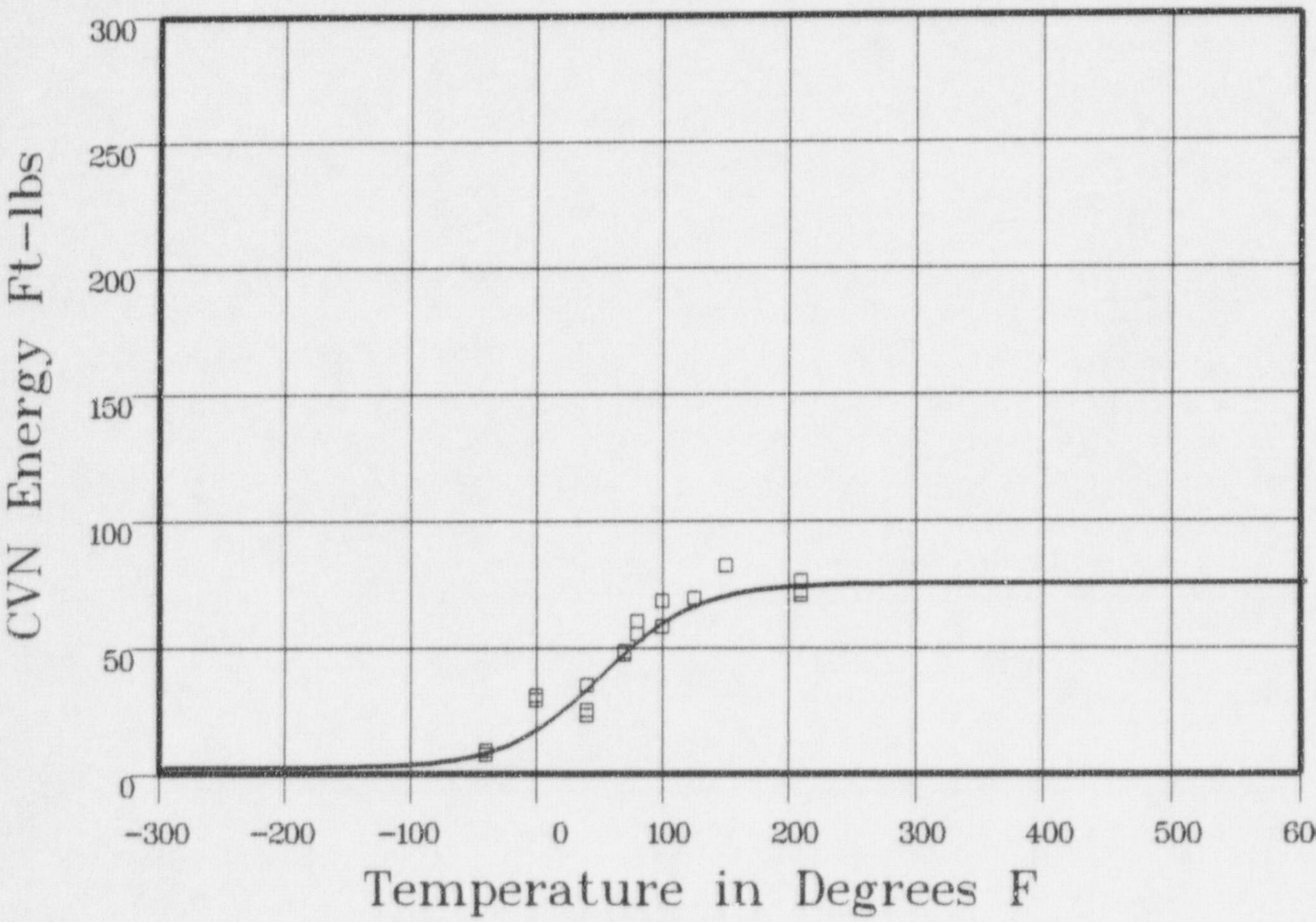
A = 38.59	B = 36.4	C = 75.63	T0 = 46.4

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

Upper Shelf Energy: 75 Fixed Temp. at 30 ft-lbs: 28.1 Temp. at 50 ft-lbs: 70.9 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: UNNIRR Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: UNNIRR Material: PLATE SA533B1 Ori.: TL Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-40	9	8.92	.07
-40	7.5	8.92	-1.42
0	29	18.7	10.29
0	31	18.7	12.29
40	35	35.52	-.52
40	23	35.52	-12.52
40	25	35.52	-10.52
70	48	49.59	-1.59
70	47	49.59	-2.59

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

Unirradiated

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: UNNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
80	60	53.78	6.21
80	55	53.78	1.21
100	68	60.79	7.2
100	58	60.79	-2.79
125	69	66.9	2.09
150	82	70.58	11.41
210	70.5	74.04	-3.54
210	76	74.04	1.95
210	72	74.04	-2.04

SUM of RESIDUALS = 15.18

Capsule U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:05:32 on 06-23-1998

Page 1

Coefficients of Curve 2

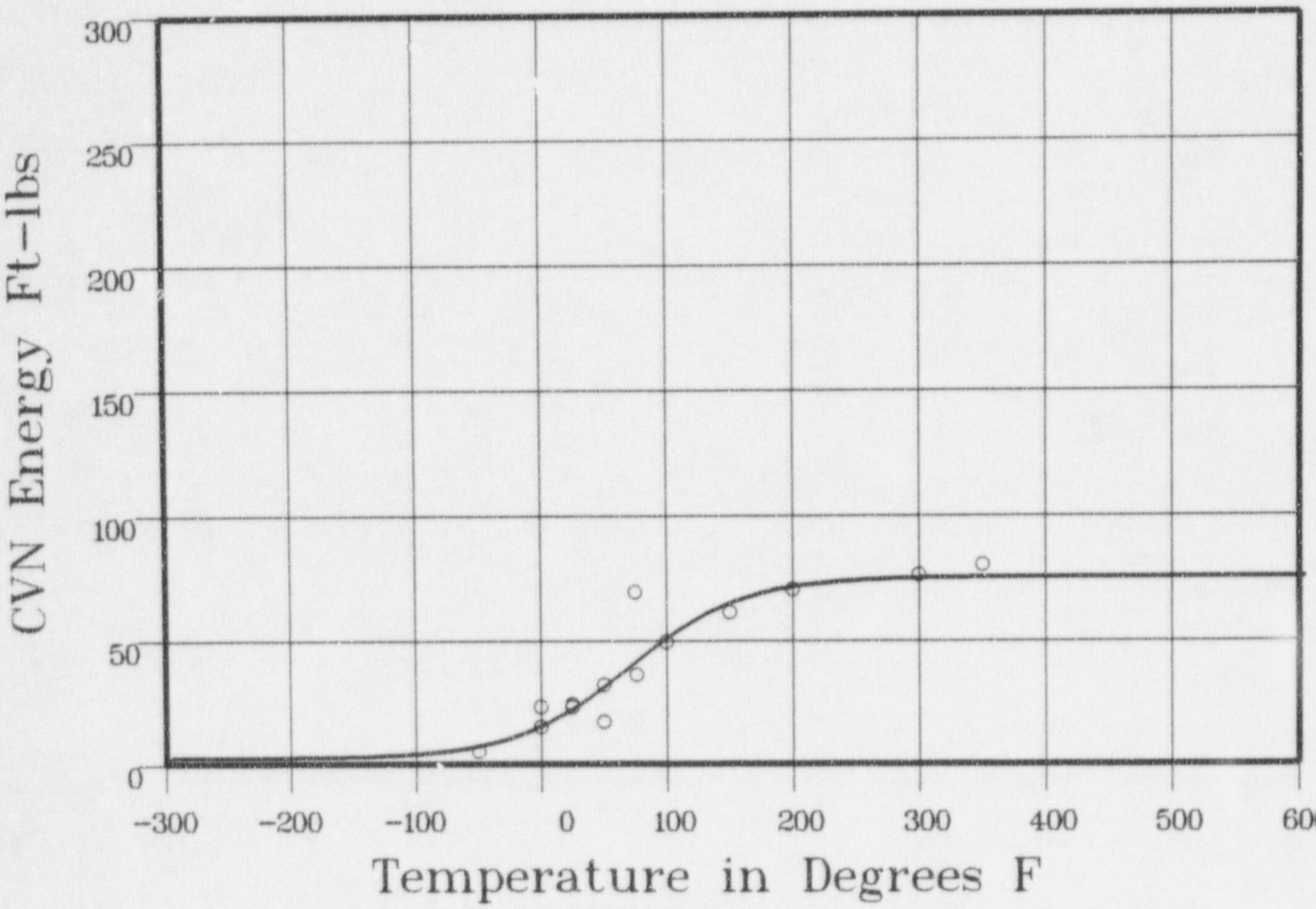
A = 38.59	B = 36.4	C = 90.43	T0 = 64.43

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

Upper Shelf Energy: 75 Fixed Temp. at 30 ft-lbs: 42.6 Temp. at 50 ft-lbs: 93.7 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	5	7.56	-2.56
0	23	16.31	6.68
0	15	16.31	-1.31
25	24	23.66	.33
25	23	23.66	-.66
50	32	32.83	-.83
50	17	32.83	-15.83
75	69	42.83	26.16

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

Capsule U

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
76	36	43.22	-7.22
100	49	52.21	-3.21
150	61	65.46	-4.46
200	70	71.54	-1.54
300	76	74.6	1.39
350	80	74.86	5.13

SUM of RESIDUALS = 2.03

Capsule V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:05:32 on 06-23-1998

Page 1

Coefficients of Curve 3

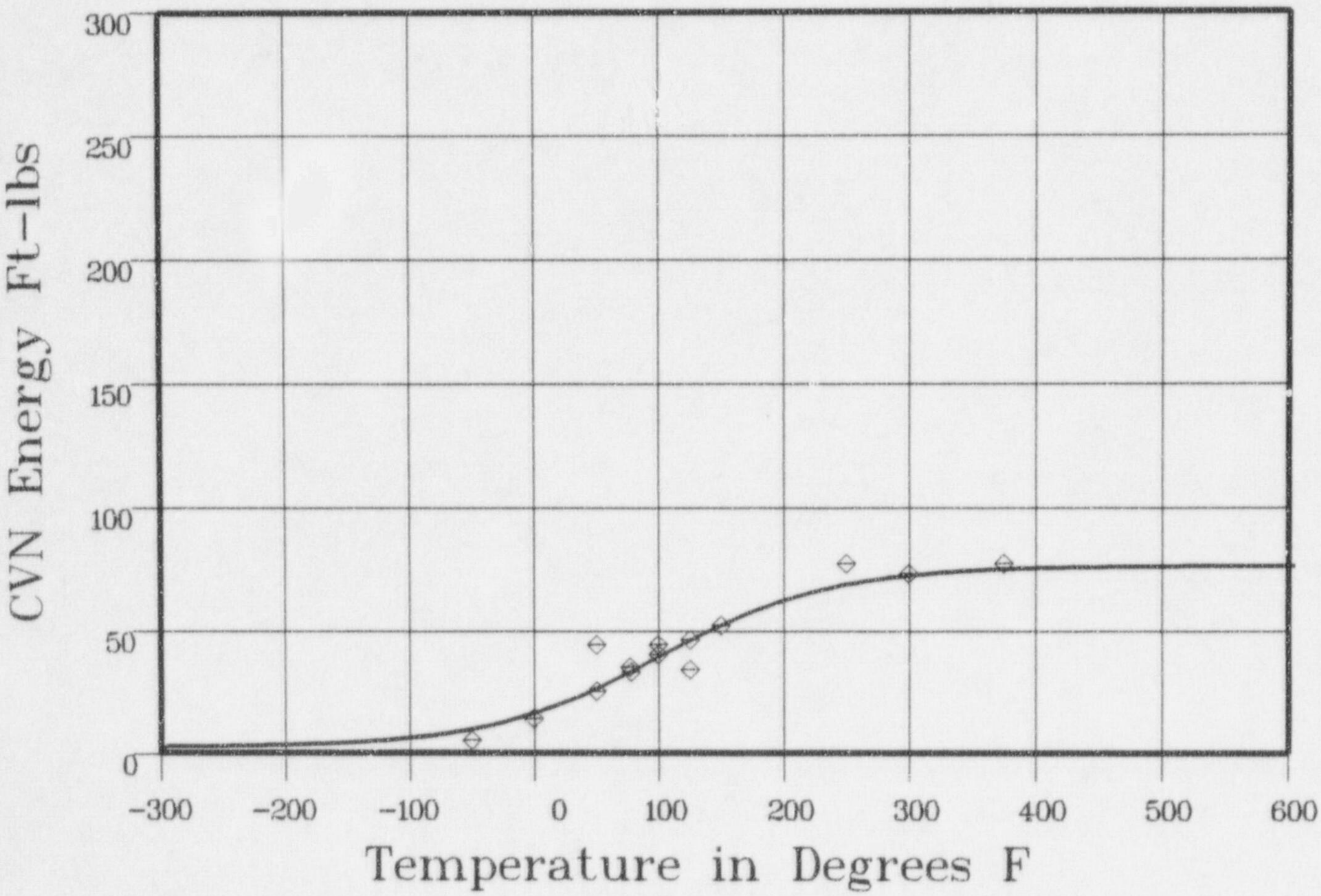
A = 39.09	B = 36.9	C = 137.45	T0 = 95.15

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

Upper Shelf Energy: 76 Fixed Temp. at 30 ft-lbs: 60.5 Temp. at 50 ft-lbs: 137 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: V Material: PLATE SA533B1 Ori.: TL Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	5	10.16	-5.16
0	14	16.98	-2.98
50	25	27.39	-2.39
50	44	27.39	16.6
77	35	34.25	.74
78	33	34.51	-1.51
100	44	40.39	3.6
100	40	40.39	-.39

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

Capsule V

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
125	34	46.98	-12.98
125	46	46.98	-.98
150	52	53.08	-1.08
250	77	68.98	8.01
300	73	72.43	.56
375	77	74.76	2.23

SUM of RESIDUALS = 4.24

CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:05:48 on 09-24-1998

Page 1

Coefficients of Curve 4

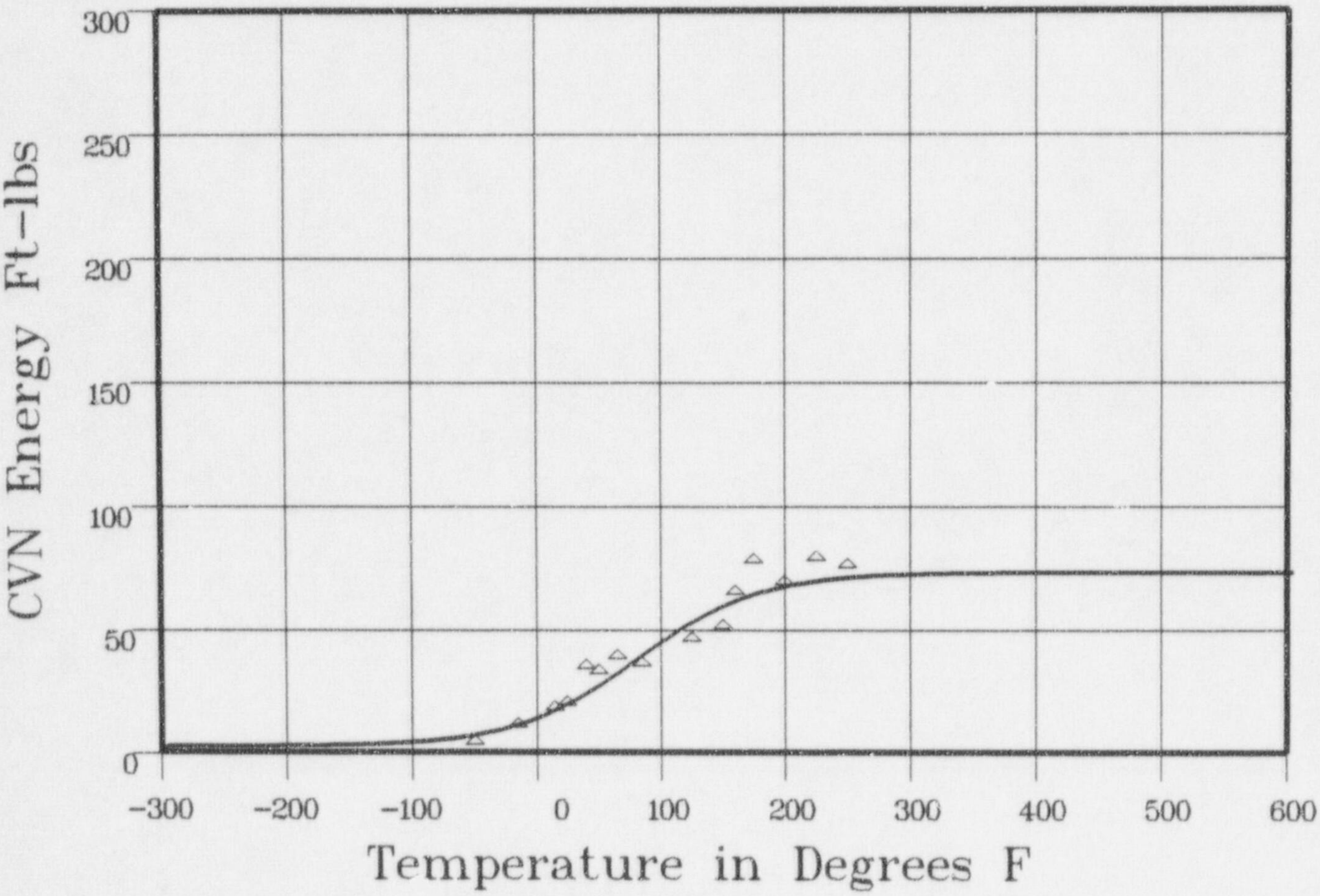
A = 37.59	B = 35.4	C = 98.28	T0 = 75.64

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

Upper Shelf Energy: 73 Fixed Temp. at 30 ft-lbs: 54.2 Temp. at 50 ft-lbs: 111.5 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: X Material: PLATE SA533B1 Ori.: TL Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	3	7.29	-4.29
-15	10	11.86	-1.86
15	17	18.16	-1.16
25	19	20.82	-1.82
40	34	25.29	8.7
50	32	28.56	3.43
65	38	33.78	4.21

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

CAPSULE X

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: X Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
85	35	40.96	-5.96
125	45	54.01	-9.01
150	50	60.22	-10.22
160	64	62.21	1.78
175	77	64.72	12.27
200	68	67.77	22
225	78	69.76	8.23
250	75	71.01	3.98

SUM of RESIDUALS = 8.49

Capsule W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:05:32 on 06-23-1998

Page 1

Coefficients of Curve 5

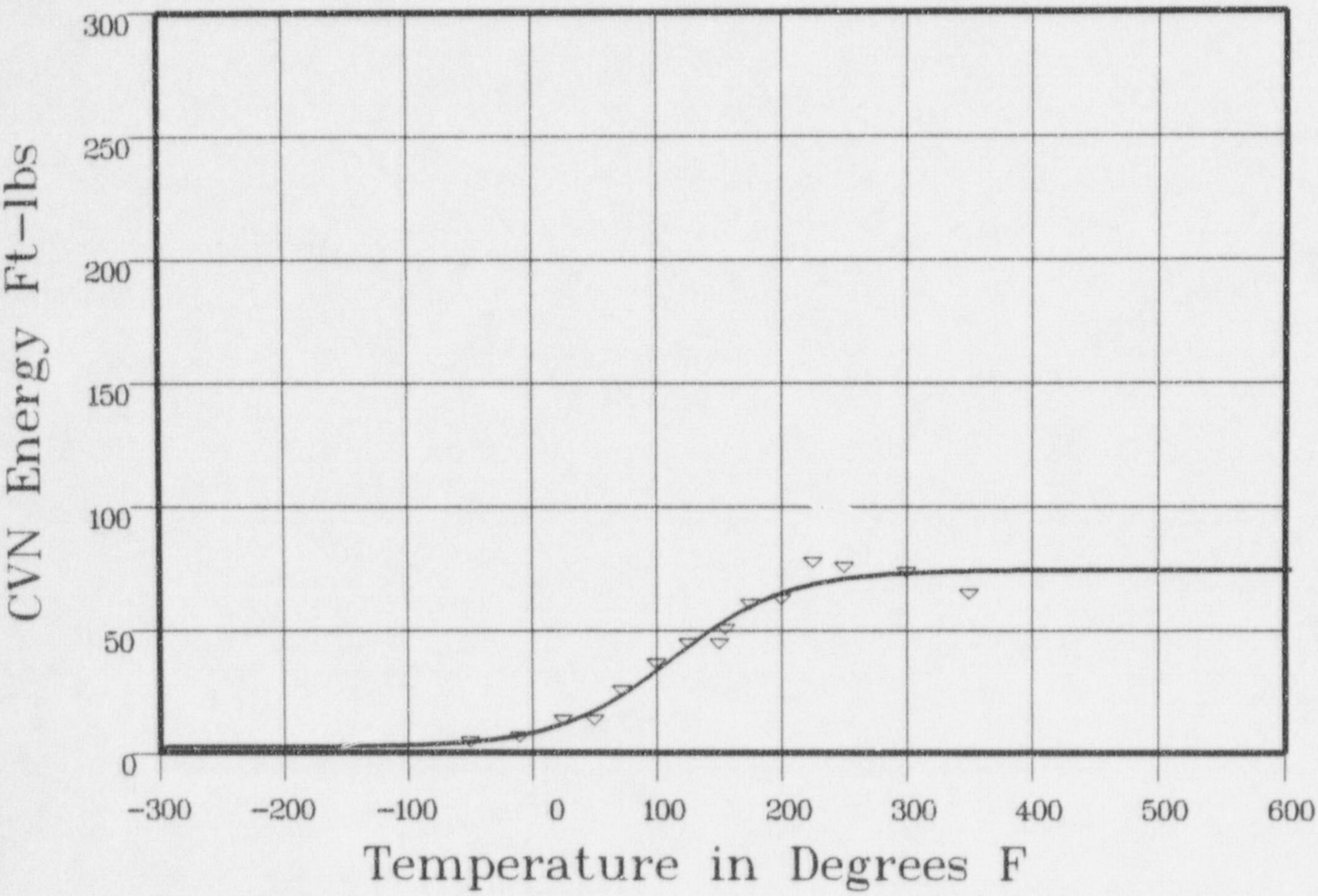
A = 38.09	B = 35.9	C = 92.47	T0 = 107.22

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

Upper Shelf Energy: 74 Fixed Temp. at 30 ft-lbs: 85.9 Temp. at 50 ft-lbs: 139 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: W Material: PLATE SA533B1 Ori.: TL Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	6	4.51	1.48
-10	8	7.47	.52
25	15	12.57	2.42
50	15	18.34	-3.34
72	27	25.04	1.95
100	38	35.3	2.69

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

Capsule W

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
125	46	44.91	1.08
150	46	53.61	-7.61
155	52	55.15	-3.15
175	62	60.53	1.46
200	64	65.49	-1.49
225	79	68.78	10.21
250	77	70.86	6.13
300	75	72.9	2.09
350	66	73.62	-7.62

SUM of RESIDUALS = 6.84

Unirradiated

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:21:51 on 06-23-1998

Page 1

Coefficients of Curve 1

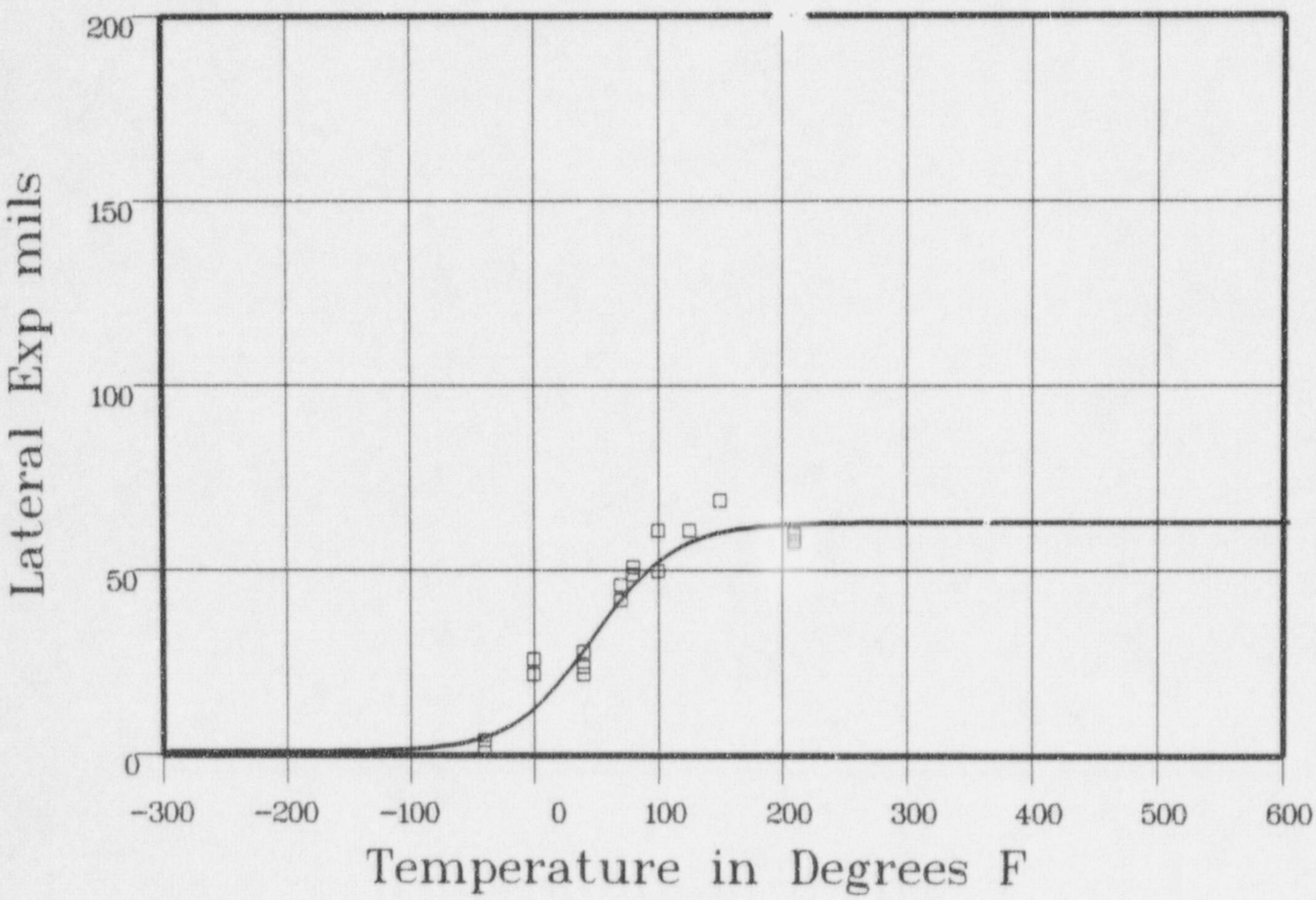
A = 32.07	B = 31.07	C = 65.97	T0 = 43.12

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

Upper Shelf L.E.: 63.15 Temperature at L.E. 35: 49.3 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: UNNIRR Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: UNNIRR Material: PLATE SA533B1 Ori.: TL Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-40	4	5.62	-1.62
-40	2	5.62	-3.62
0	22	14.23	7.76
0	26	14.23	11.76
40	28	30.6	-2.6
40	22	30.6	-8.6
40	24	30.6	-6.6
70	46	44.07	1.92
70	42	44.07	-2.07

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

Unirradiated

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: UNNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
80	51	47.83	3.16
80	49	47.83	1.16
100	61	53.74	7.25
100	50	53.74	-3.74
125	61	58.35	2.64
150	69	60.8	8.19
210	58	62.75	-4.75
210	60	62.75	-2.75
210	58	62.75	-4.75

SUM of RESIDUALS = 2.68

Capsule U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:21:51 on 06-23-1998

Page 1

Coefficients of Curve 2

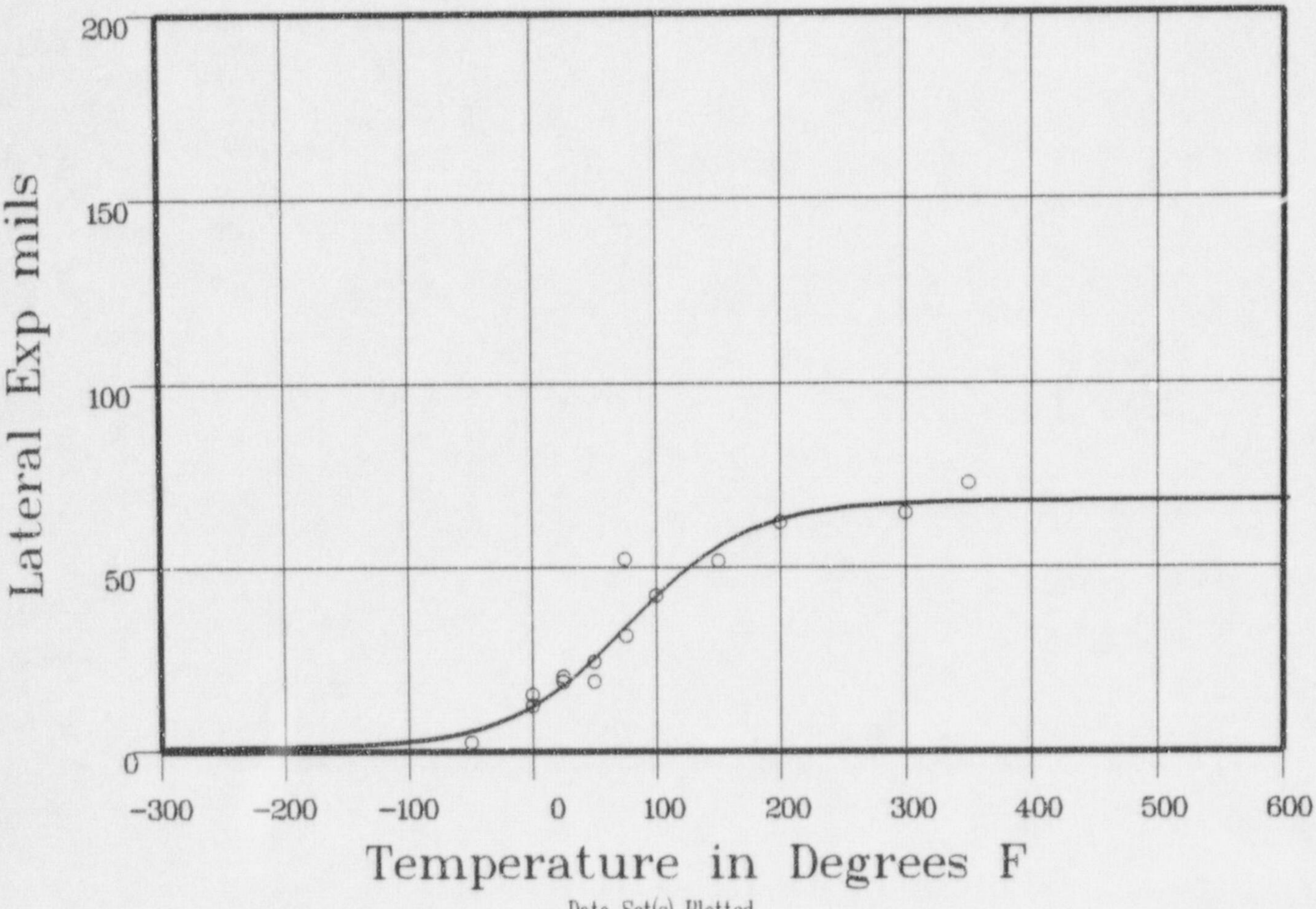
A = 34.57	B = 33.57	C = 97.16	T0 = 72.55

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

Upper Shelf L.E.: 68.14 Temperature at L.E. 35: 73.7 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	2.5	5.98	-3.48
0	15.5	13.31	2.18
0	12.5	13.31	-.81
25	19	19.33	-.33
25	20.5	19.33	1.16
50	24.5	26.91	-2.41
50	19	26.91	-7.91
75	52.5	35.41	17.08

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

Capsule U

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
76	31.5	35.76	-4.26
100	42.5	43.81	-1.31
150	52	56.81	-4.81
200	62.5	63.6	-1.1
300	65	67.52	-2.52
350	73	67.92	5.07

SUM of RESIDUALS = -3.49

Capsule V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:21:51 on 06-23-1998

Page 1

Coefficients of Curve 3

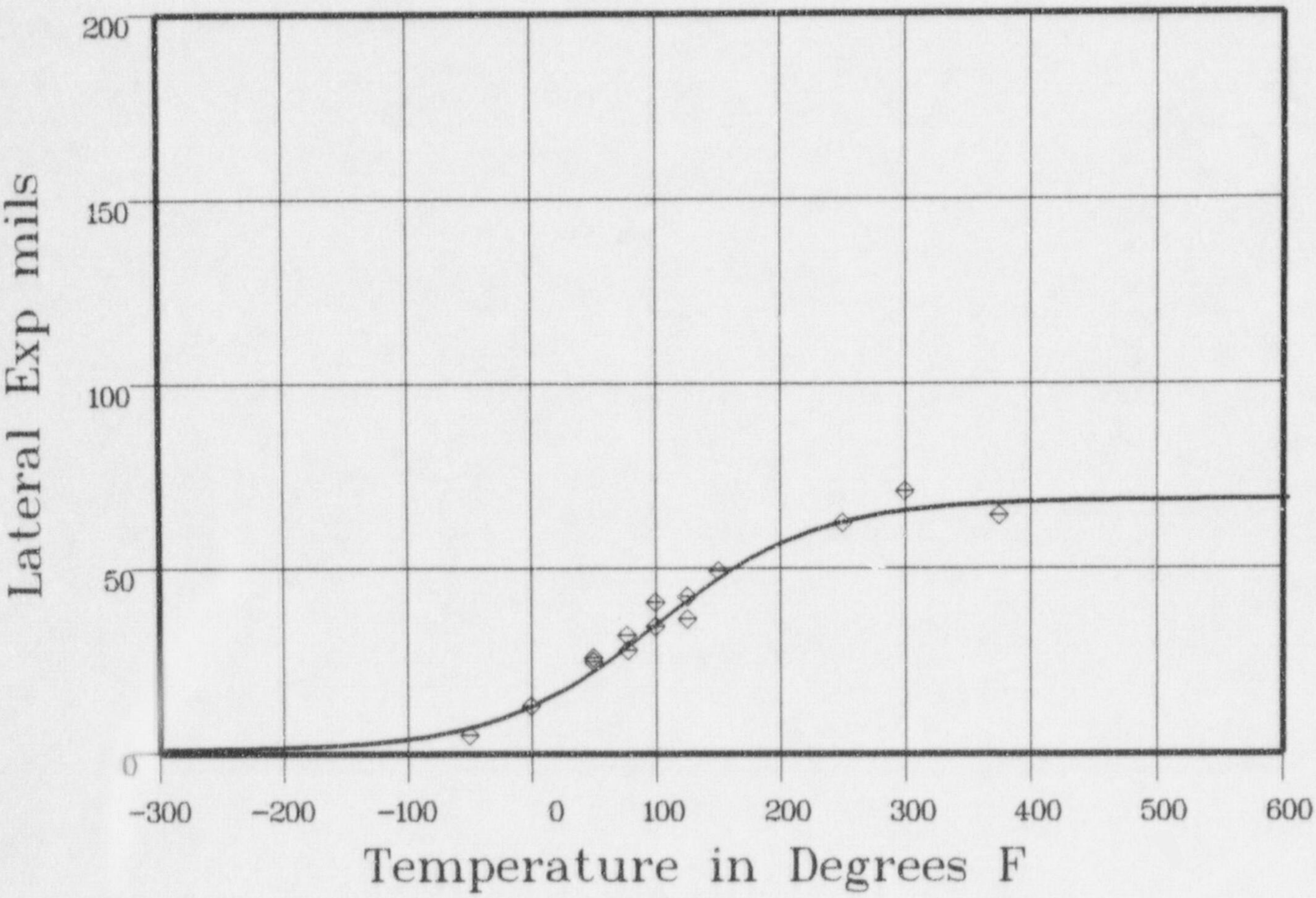
A = 34.84	B = 33.84	C = 128.88	T0 = 94.92

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

Upper Shelf L.E.: 68.68 Temperature at L.E. 35: 95.5 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: V Material: PLATE SA533B1 Ori.: TL Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	5	7.46	-2.46
0	13	13.62	-.62
50	26	23.5	2.49
50	25	23.5	1.49
77	32	30.16	1.83
78	28	30.42	-2.42
100	34.5	36.17	-1.67
100	41	36.17	4.82

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

Capsule V

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
125	36.5	42.6	-6.1
125	42.5	42.6	-.1
150	49.5	48.48	1.01
250	62.5	63.09	-.59
300	71	65.99	5
375	64.5	67.82	-3.32

SUM of RESIDUALS = -.64

Capsule X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:21:51 on 06-23-1998

Page 1

Coefficients of Curve 4

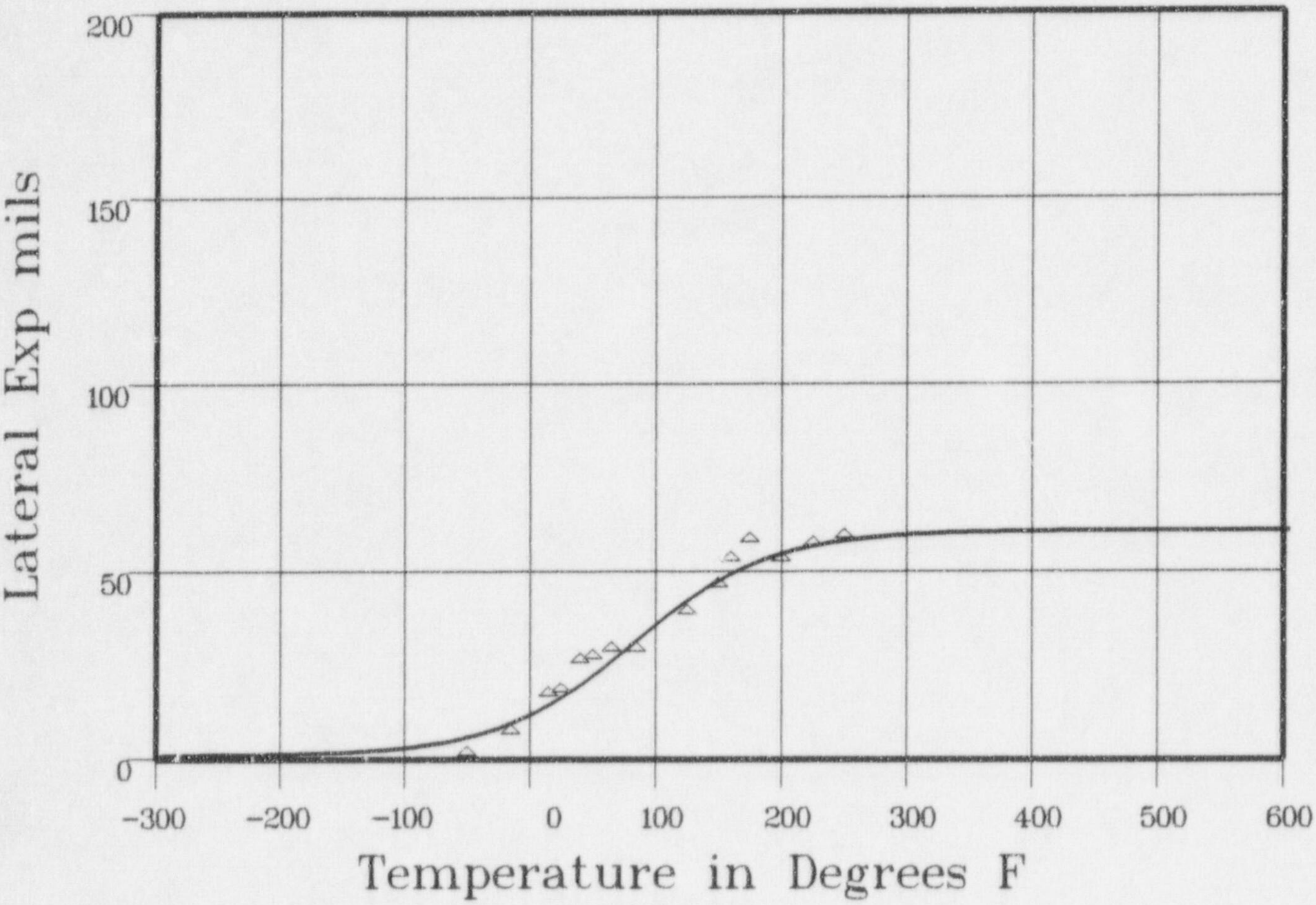
A = 30.98	B = 29.98	C = 108.5	T0 = 76.87

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

Upper Shelf L.E.: 60.96   Temperature at L.E. 35: 91.5   Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1   Heat Number: A9154-1   Orientation: TL

Capsule: X   Total Fluence:



Data Set(s) Plotted

Plant: VS1   Cap.: X   Material: PLATE SA533B1   Ori.: TL   Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	1	6.27	-5.27
-15	7	10.31	-3.31
15	17	15.52	1.47
25	18	17.64	.35
40	26	21.16	4.83
50	27	23.7	3.29
65	29	27.71	1.28

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

Capsule X

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: X Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
85	29	33.22	-4.22
125	39	43.47	-4.47
150	46	48.59	-2.59
160	53	50.31	2.68
175	58	52.52	5.47
200	53	55.34	-2.34
225	57	57.29	-.29
250	59	58.59	.4

SUM of RESIDUALS = -2.71

Capsule W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:21:51 on 06-23-1998

Page 1

Coefficients of Curve 5

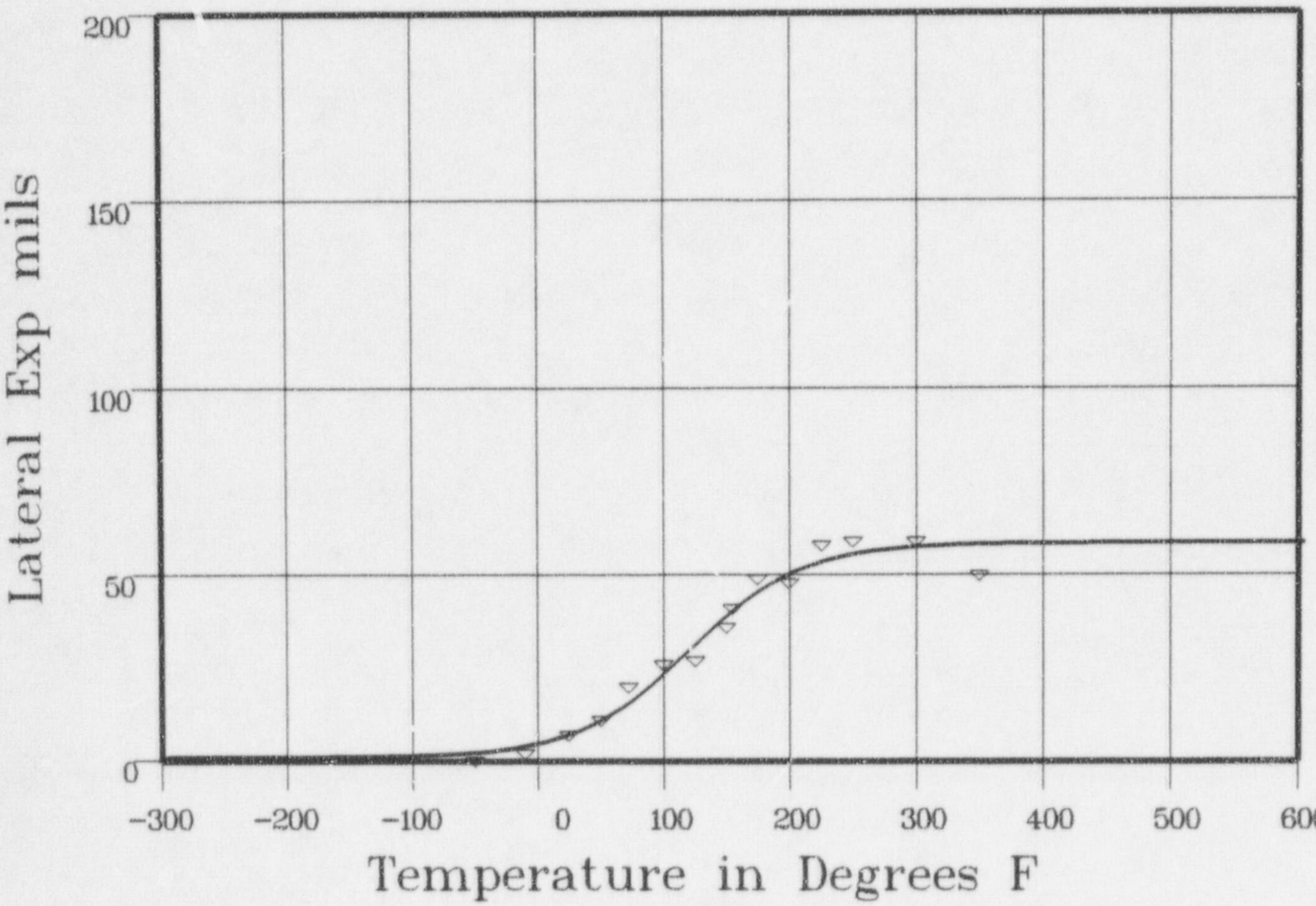
A = 29.85	B = 28.85	C = 89.75	T0 = 115.31

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

Upper Shelf L.E.: 58.7 Temperature at L.E. 35: 131.5 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: W Material: PLATE SA533B1 Ori.: TL Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	1	2.41	-1.41
-10	3	4.33	-1.33
25	8	7.8	.19
50	12	11.91	.08
72	21	16.91	4.08
100	27	24.97	2.02

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

Capsule W

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
125	28	32.95	-4.95
150	37	40.47	-3.47
155	42	41.83	.16
175	50	46.63	3.36
200	49	51.1	-2.1
225	59	54.09	4.9
250	60	55.96	4.03
300	60	57.77	2.22
350	51	58.39	-7.39

SUM of RESIDUALS = .39

Unirradiated

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:29:00 on 06-23-1998

Page 1

Coefficients of Curve 1

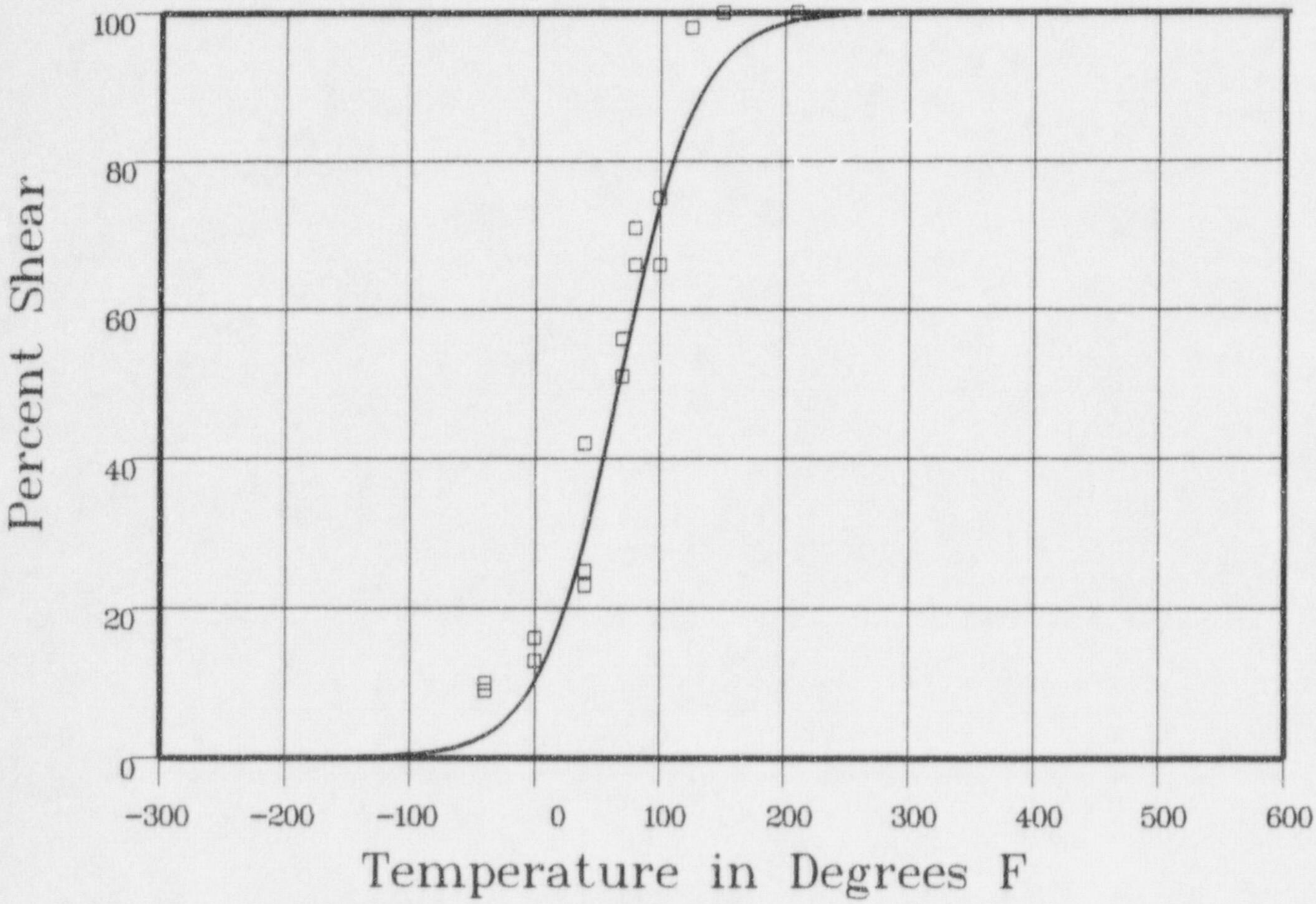
A = 50	B = 50	C = 62.33	T0 = 62.81

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

Temperature at 50% Shear: 62.8

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: UNNIRR Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: UNNIRR Material: PLATE SA533B1 Ori.: TL Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40	10	3.56	6.43
-40	9	3.56	5.43
0	13	11.75	1.24
0	16	11.75	4.24
40	23	32.47	-9.47
40	25	32.47	-7.47
40	42	32.47	9.52
70	56	55.73	.26
70	51	55.73	-4.73

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

Unirradiated

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: UNNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
80	71	63.44	7.55
80	66	63.44	2.55
100	75	76.73	-1.73
100	66	76.73	-10.73
125	98	88.03	9.96
150	100	94.25	5.74
210	100	99.11	.88
210	100	99.11	.88
210	100	99.11	.88

SUM of RESIDUALS = 21.45

Capsule U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:29:00 on 06-23-1998

Page 1

Coefficients of Curve 2

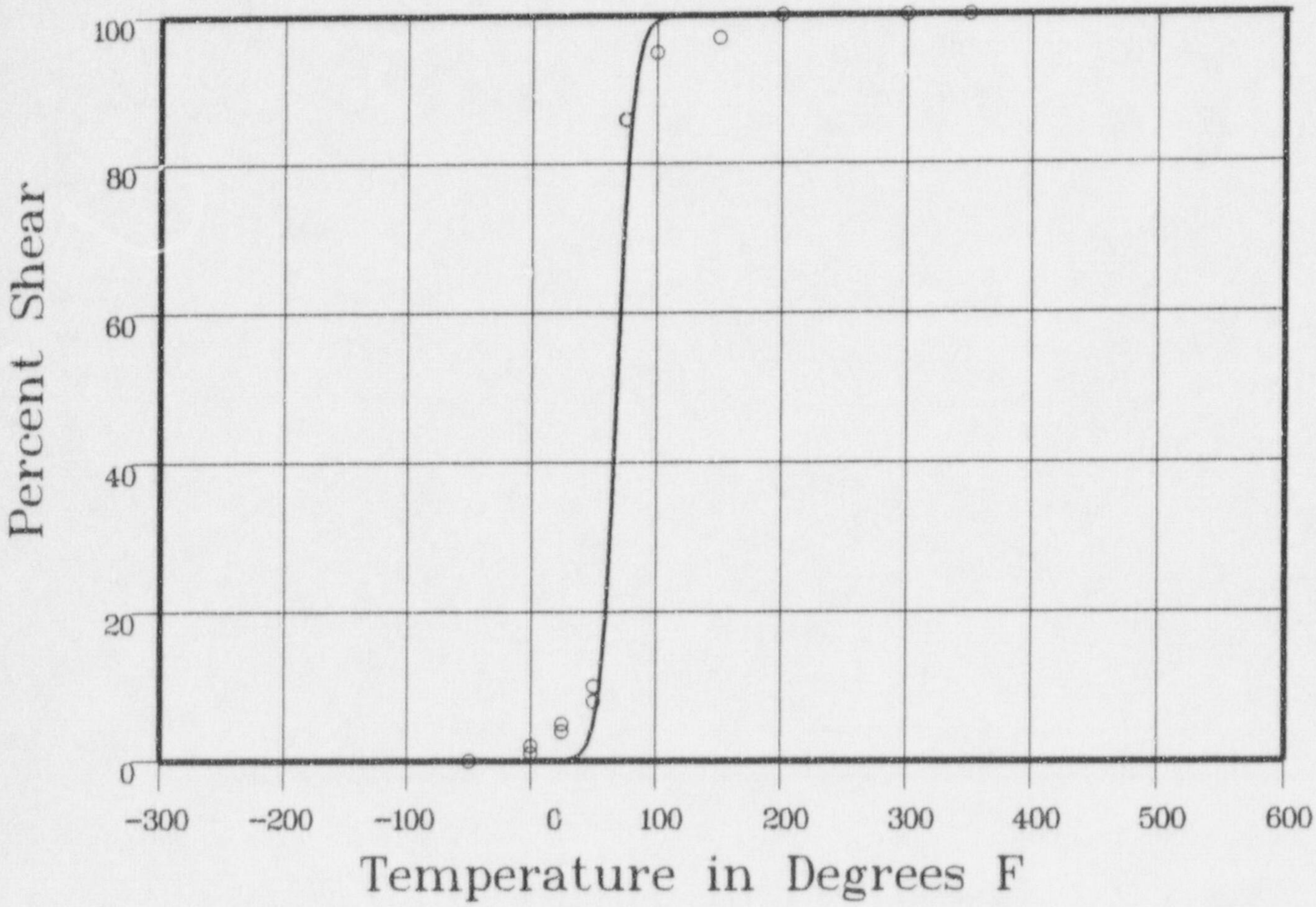
A = 50	B = 50	C = 12.6	T0 = 64.16

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

Temperature at 50% Shear: 64.1

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	0	0	0
0	2	0	1.99
0	1	0	.99
25	5	.19	4.8
25	4	.19	3.8
50	10	9.56	.43
50	8	9.56	-1.56
75	86	84.81	1.18

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

Capsule U

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
76	86	86.74	-.74
100	95	99.66	-4.66
150	97	99.99	-2.99
200	100	100	0
300	100	100	0
350	100	100	0

SUM of RESIDUALS = 3.24

Capsule V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:29:00 on 06-23-1998

Page 1

Coefficients of Curve 3

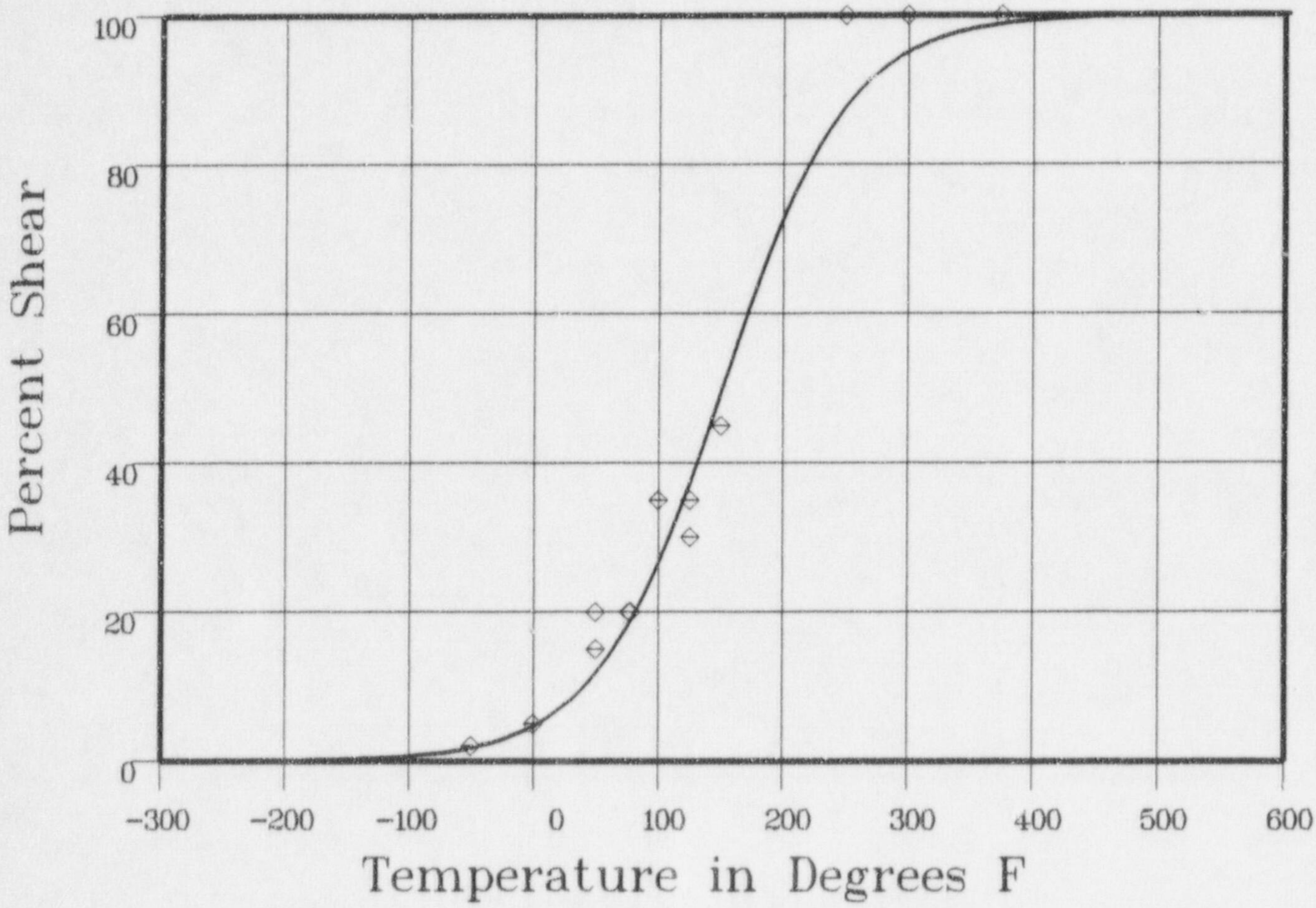
A = 50	B = 50	C = 100.54	T0 = 146.48

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

Temperature at 50% Shear: 146.4

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: V Material: PLATE SA533B1 Ori.: TL Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	2	1.96	.03
0	5	5.14	-.14
50	15	12.79	2.2
50	20	12.79	7.2
77	20	20.06	-.06
78	20	20.38	-.38
100	35	28.4	6.59
100	35	28.4	6.59

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

Capsule V

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
125	30	39.47	-9.47
125	35	39.47	-4.47
150	45	51.74	-6.74
250	100	88.68	11.31
300	100	95.49	4.5
375	100	98.94	1.05

SUM of RESIDUALS = 18.21

Capsule X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:29:00 on 06-23-1998

Page 1

Coefficients of Curve 4

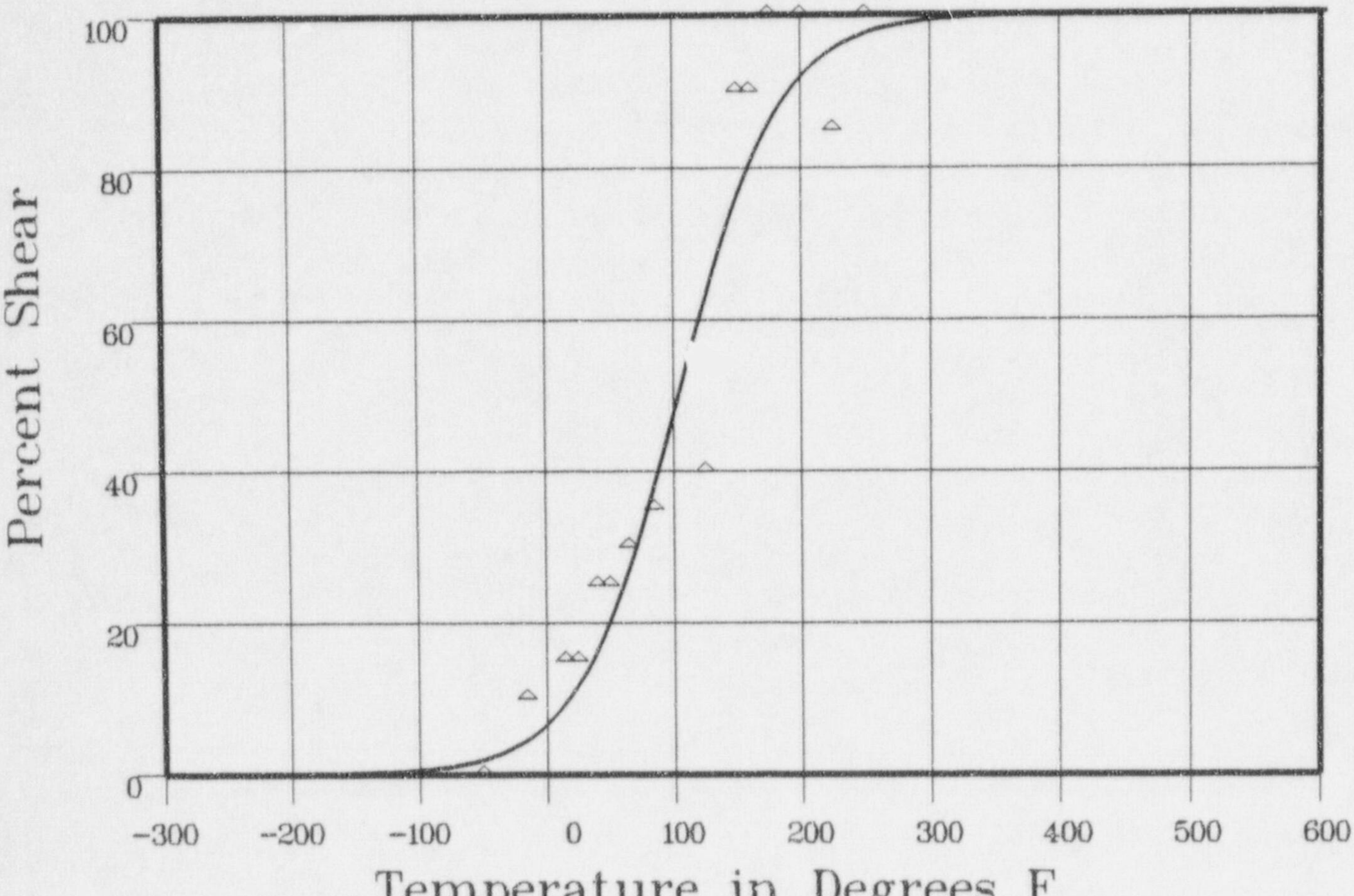
A = 50	B = 50	C = 78.81	T0 = 99.51

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

Temperature at 50% Shear: 99.5

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: X Material: PLATE SA533B1 Ori.: TL Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	0	2.2	-2.2
-15	10	5.18	4.81
15	15	10.48	4.51
25	15	13.11	1.88
40	25	18.09	6.9
50	25	22.16	2.83
65	30	29.4	.59

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

Capsule X

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: X Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
85	35	40.89	-5.89
125	40	65.62	-25.62
150	90	78.26	11.73
160	90	82.27	7.72
175	100	87.16	12.83
200	100	92.75	7.24
225	85	96.02	-11.02
250	100	97.85	2.14

SUM of RESIDUALS = 18.49

Capsule W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:58:39 on 08-19-1998

Page 1

Coefficients of Curve 5

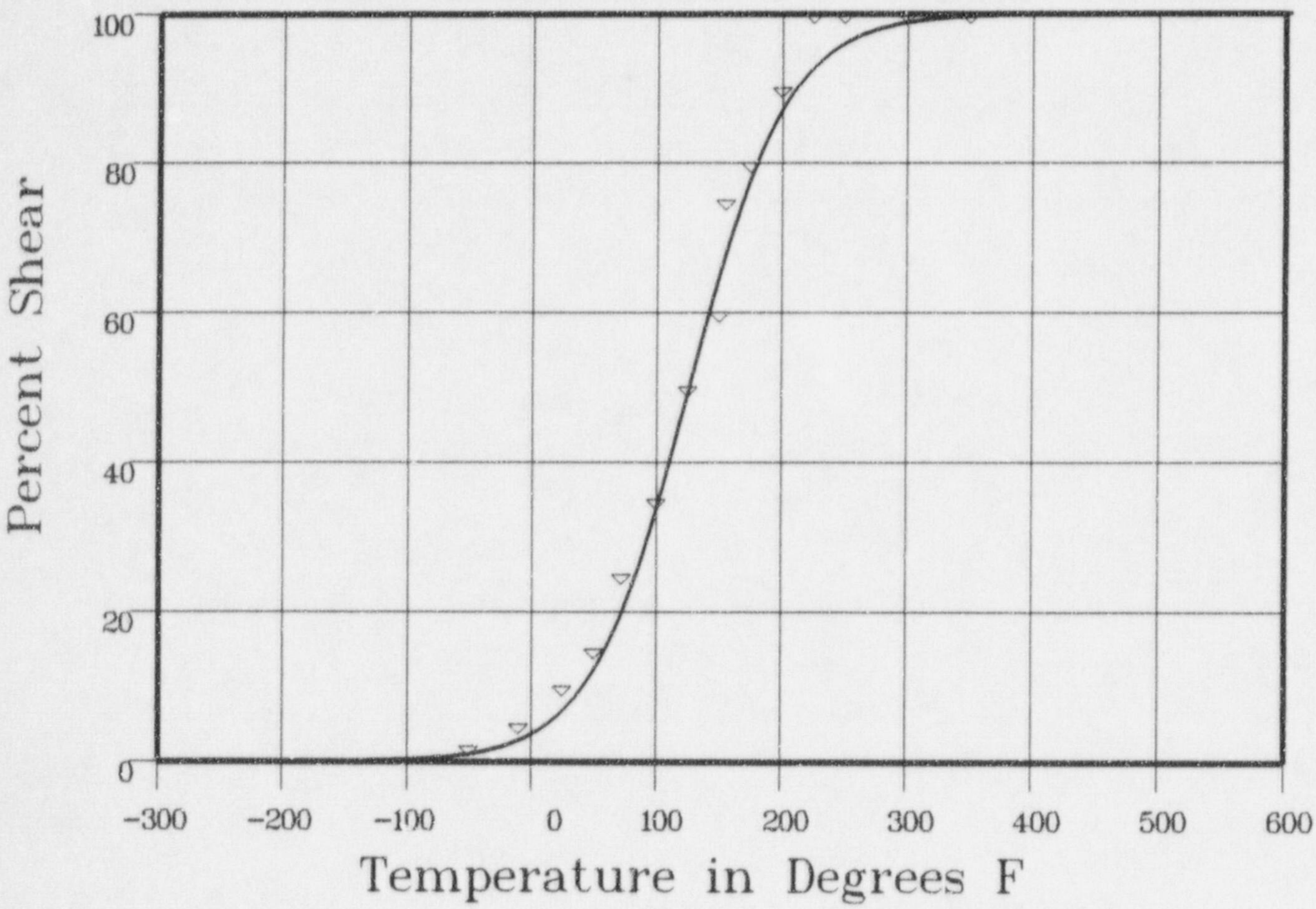
A = 50	B = 50	C = 77.52	T0 = 121.58

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

Temperature at 50% Shear: 121.5

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: W Material: PLATE SA533B1 Ori.: TL Heat #: A9154-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	2	1.18	.81
-10	5	3.24	1.75
25	10	7.64	2.35
50	15	13.62	1.37
72	25	21.77	3.22
100	35	36.43	-1.43

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

Capsule W

Page 2

Material: PLATE SA533B1 Heat Number: A9154-1 Orientation: TL

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
125	50	52.2	-2.2
150	60	67.54	-7.54
155	75	70.31	4.68
175	80	79.86	.13
200	90	88.31	1.68
225	100	93.51	6.48
250	100	96.48	3.51
300	100	99	.99
350	100	99.72	.27

SUM of RESIDUALS = 16.11

Unirradiated

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:36:21 on 06-23-1998

Page 1

Coefficients of Curve 1

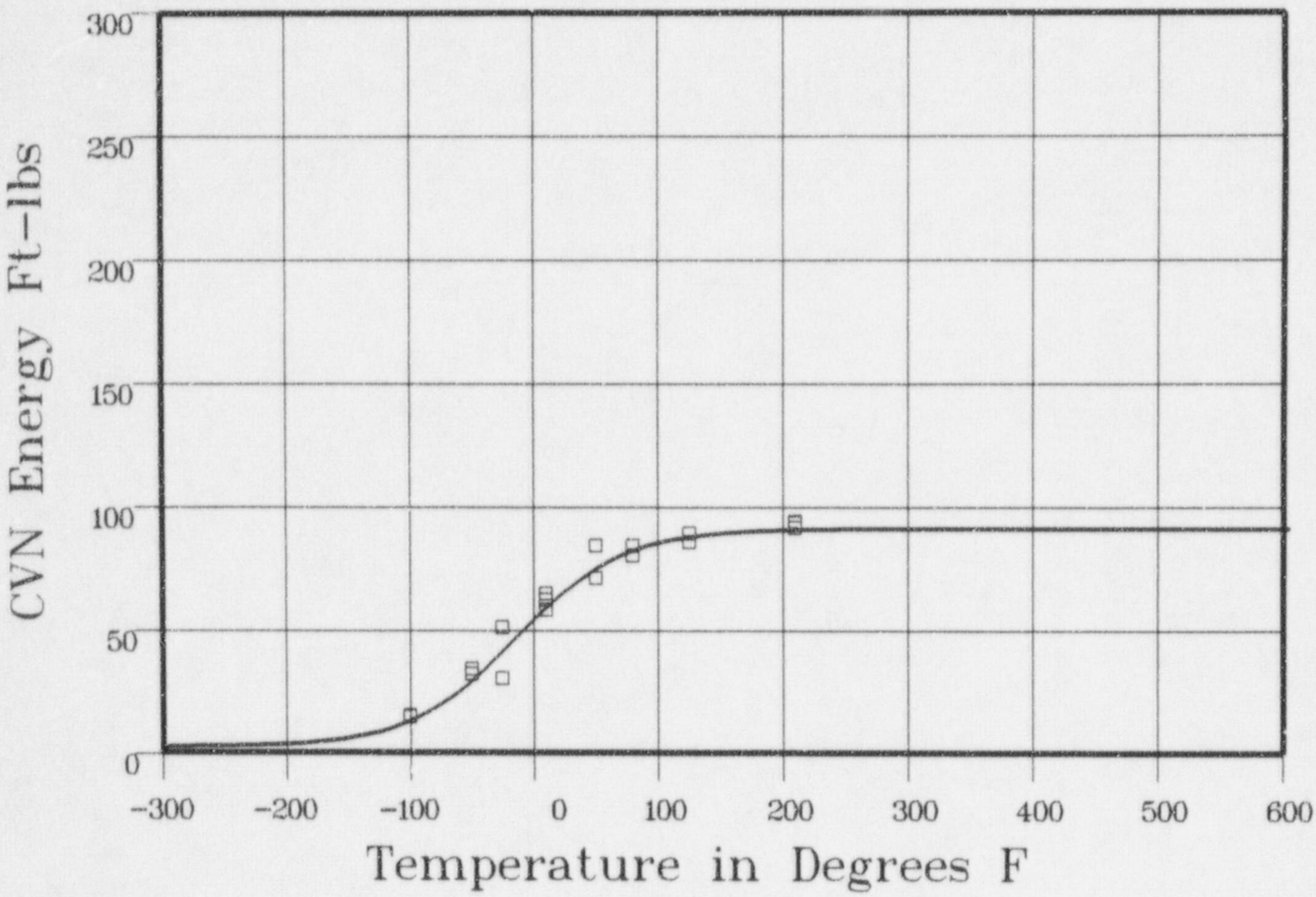
A = 46.59	B = 44.4	C = 86.19	T0 = -18.91

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

Upper Shelf Energy: 91 Fixed Temp. at 30 ft-lbs: -52.7 Temp. at 50 ft-lbs: -12.3 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 4P47841 Orientation:

Capsule: UNNIRR Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: UNNIRR Material: WELD Ori.: Heat #: 4P47841

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	15	13.94	1.05
-100	14.5	13.94	.55
-50	34	31.24	2.75
-50	32	31.24	.75
-25	51	43.47	7.52
-25	30	43.47	-13.47
10	62	60.96	1.03
10	64.5	60.96	3.53
10	58	60.96	-2.96

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

Unirradiated

Page 2

Material: WELD Heat Number: 4P4784I Orientation:

Capsule: UNNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	84	76.07	7.92
50	71	76.07	-5.07
80	84	82.87	1.12
80	80	82.87	-2.87
125	85.5	87.95	-2.45
125	89	87.95	1.04
210	94	90.56	3.43
210	93.5	90.56	2.93
210	91.5	90.56	.93

SUM of RESIDUALS = 7.78

Capsule U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:36:21 on 06-23-1998

Page 1

Coefficients of Curve 2

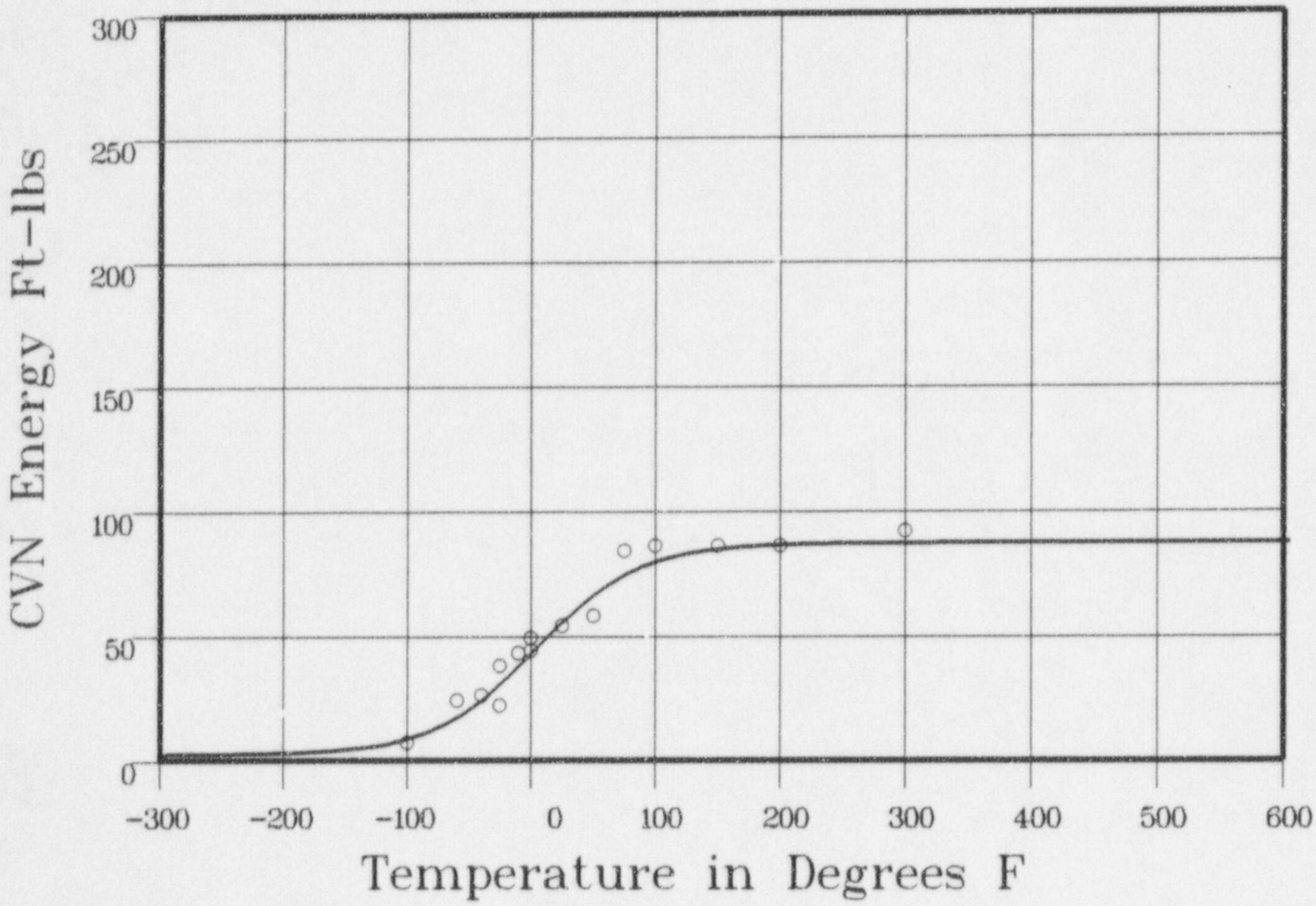
A = 44.59	B = 42.4	C = 82.56	T0 = -.93

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

Upper Shelf Energy: 87 Fixed   Temp. at 30 ft-lbs: -30.5   Temp. at 50 ft-lbs: 9.6   Lower Shelf Energy: 2.19 Fixed

Material: WELD   Heat Number: 4P4784   Orientation:

Capsule: U   Total Fluence:



Data Set(s) Plotted

Plant: VS1   Cap.: U   Material: WELD   Ori.:   Heat #: 4P4784

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	7	9.25	-2.25
-60	24	18.56	5.43
-40	26	25.91	.08
-25	22	32.58	-10.58
-25	38	32.58	5.41
-10	43	39.96	3.03
0	49	45.08	3.91
0	44	45.08	-1.08

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

Capsule U

Page 2

Material: WELD   Heat Number: 4P4784   Orientation:

Capsule: U   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
25	54	57.49	-3.49
50	58	67.87	-9.87
75	84	75.37	8.62
100	86	80.23	5.76
150	86	84.86	1.13
200	86	86.35	-.35
300	92	86.94	5.05

SUM of RESIDUALS = 10.83

Capsule V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:36:21 on 06-23-1998

Page 1

Coefficients of Curve 3

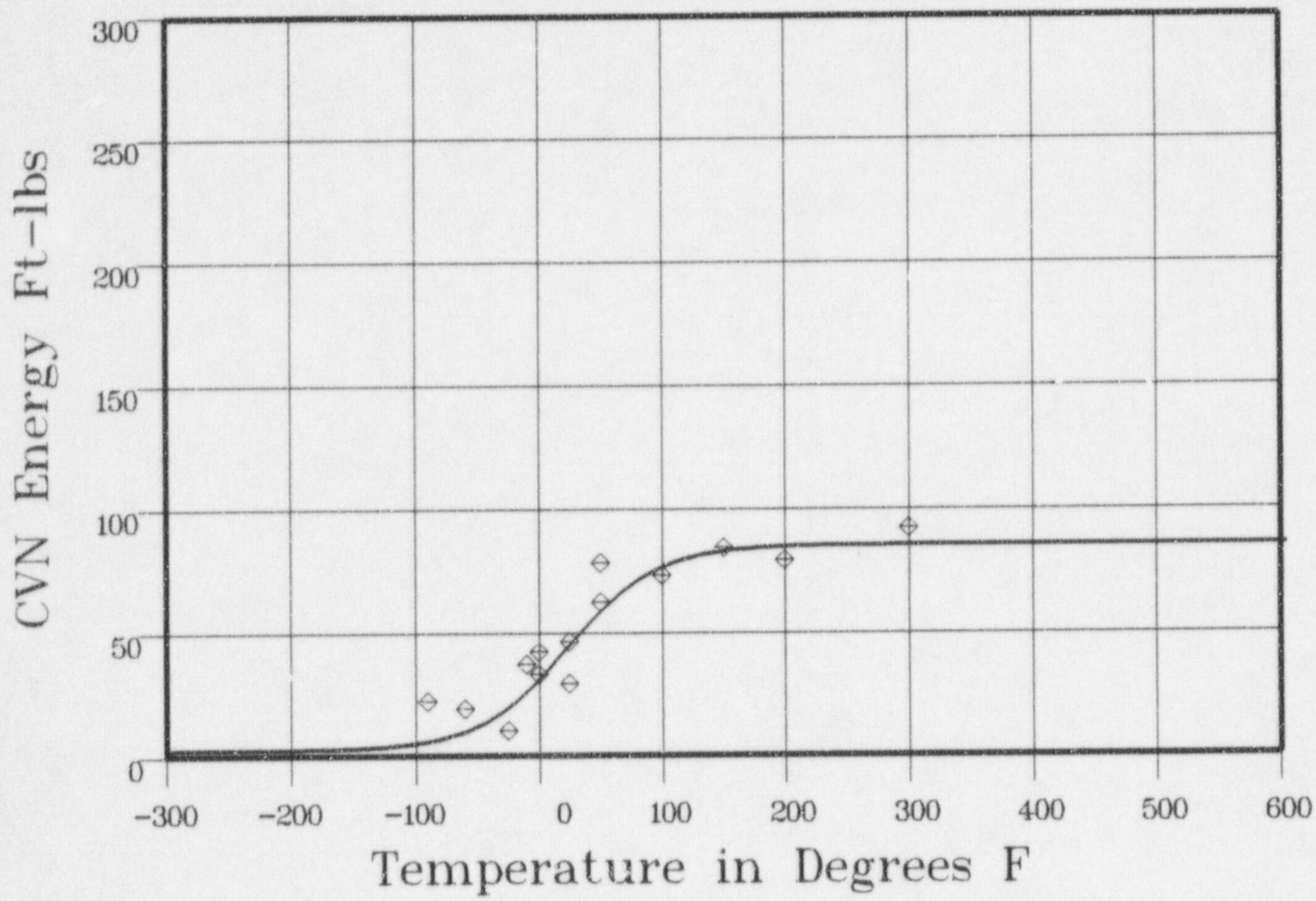
A = 43.59	B = 41.4	C = 72.07	T0 = 18.28

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

Upper Shelf Energy: 85 Fixed   Temp. at 30 ft-lbs: -6.3   Temp. at 50 ft-lbs: 29.5   Lower Shelf Energy: 2.19 Fixed

Material: WELD   Heat Number: 4P4784   Orientation:

Capsule: V   Total Fluence:



Data Set(s) Plotted

Plant: VS1   Cap.: V   Material: WELD   Ori.:   Heat #: 4P4784

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-90	22	6.11	15.88
-60	19	10.66	8.33
-25	10	21.35	-11.35
-25	10	21.35	-11.35
-10	37	28.14	8.85
0	33	33.31	-.31
0	42	33.31	8.68
25	29	47.44	-18.44

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

Capsule V

Page 2

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
25	46	47.44	-1.44
50	62	60.72	1.27
50	78	60.72	17.27
100	73	77.22	-4.22
150	84	82.91	1.08
200	79	84.46	-5.46
300	92	84.96	7.03

SUM of RESIDUALS = 15.8

Capsule X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:36:21 on 06-23-1998

Page 1

Coefficients of Curve 4

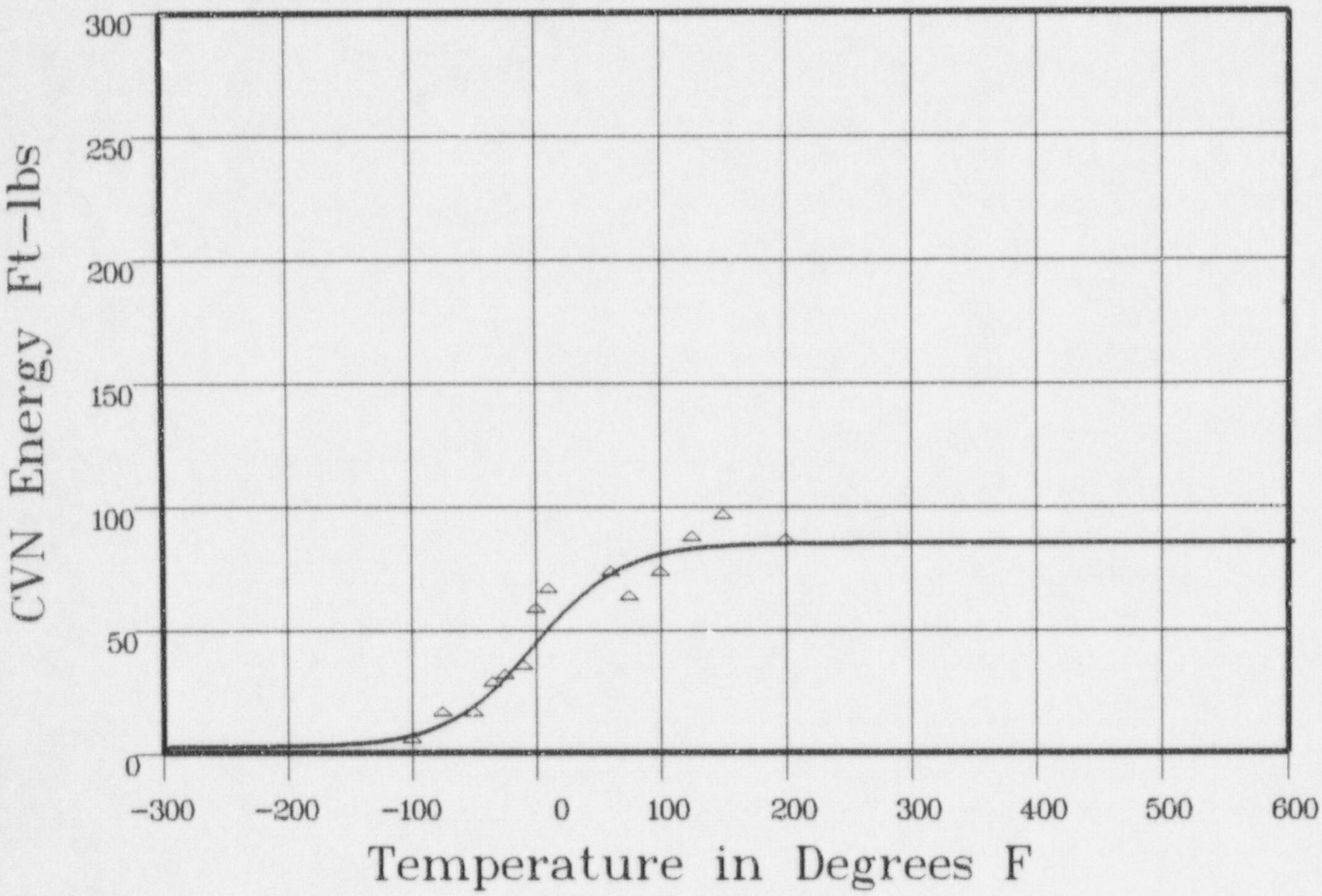
A = 43.59	B = 41.4	C = 71.06	T0 = -6.09

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

Upper Shelf Energy: 85 Fixed Temp. at 30 ft-lbs: -30.3 Temp. at 50 ft-lbs: 4.9 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: X Material: WELD Ori.: Heat #: 4P4784

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	4	7.7	-3.7
-75	15	12.61	2.38
-50	15	20.84	-5.84
-35	27	27.63	-.63
-25	30	32.83	-2.83
-10	34	41.32	-7.32
0	57	47.14	9.85

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

Capsule X

Page 2

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: X Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
10	65	52.81	12.18
60	72	73.84	-1.84
75	62	77.33	-15.33
100	72	81.01	-9.01
125	86	82.98	3.01
150	95	83.98	11.01
200	85	84.75	.24

SUM of RESIDUALS = -7.83

Capsule W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:36:21 on 06-23-1998

Page 1

Coefficients of Curve 5

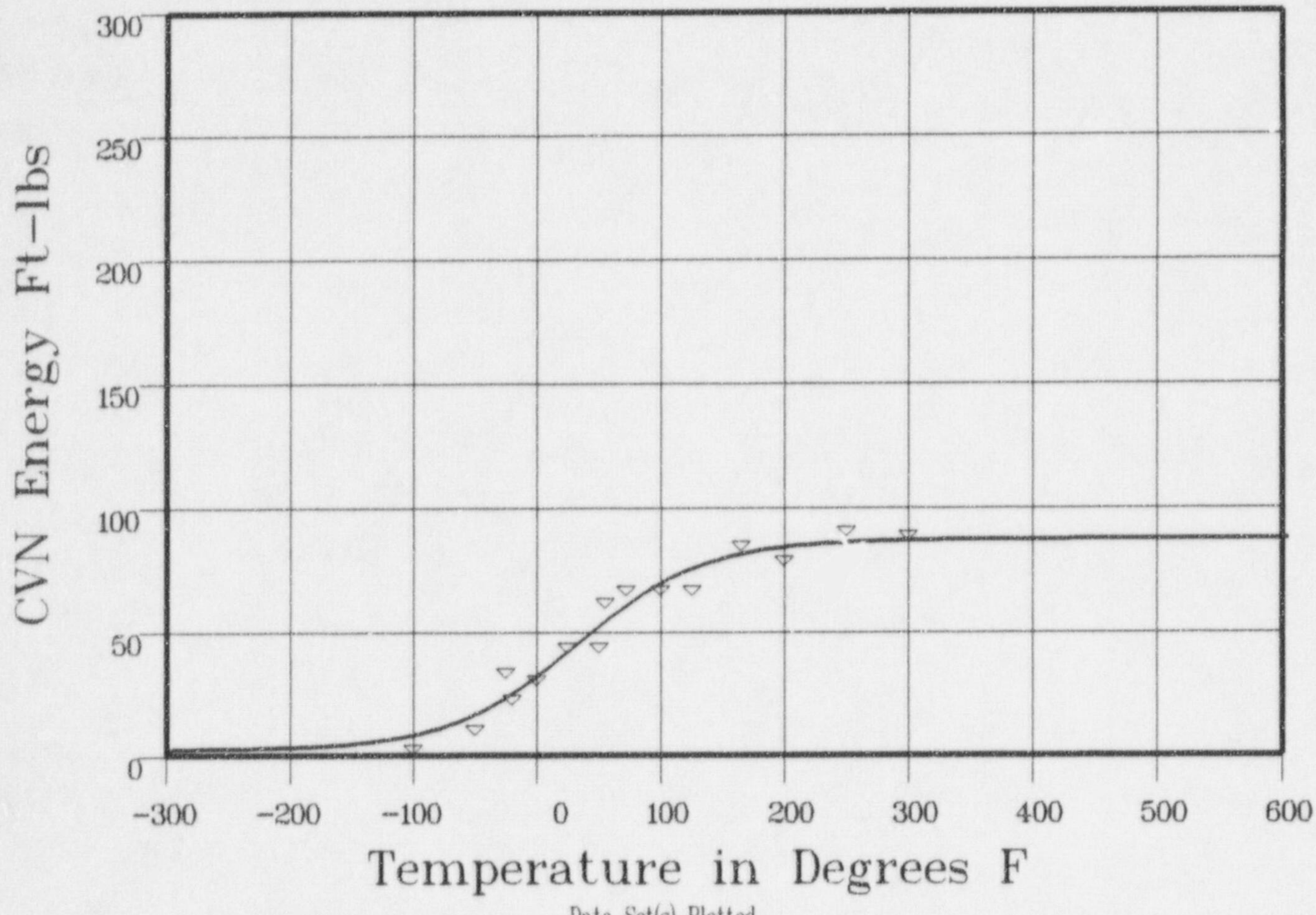
A = 44.59	B = 42.4	C = 102.38	T0 = 27.18

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

Upper Shelf Energy: 87 Fixed Temp. at 30 ft-lbs: -9.5 Temp. at 50 ft-lbs: 40.2 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: W Material: WELD Ori.: Heat #: 4P4784

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	4	8.72	-4.72
-50	12	17.57	-5.57
-25	35	24.68	10.31
-20	24	26.33	-2.33
0	32	33.59	-1.59
25	45	43.69	1.3

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

Capsule W

Page 2

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	45	53.89	-8.89
55	63	55.84	7.15
72	68	62.05	5.94
100	68	70.52	-2.52
125	68	76.06	-8.06
165	86	81.61	4.38
200	80	84.19	-4.19
250	92	85.92	6.07
300	90	86.59	3.4

SUM of RESIDUALS = .67

Unirradiated

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:46:24 on 06-23-1998

Page 1

Coefficients of Curve 1

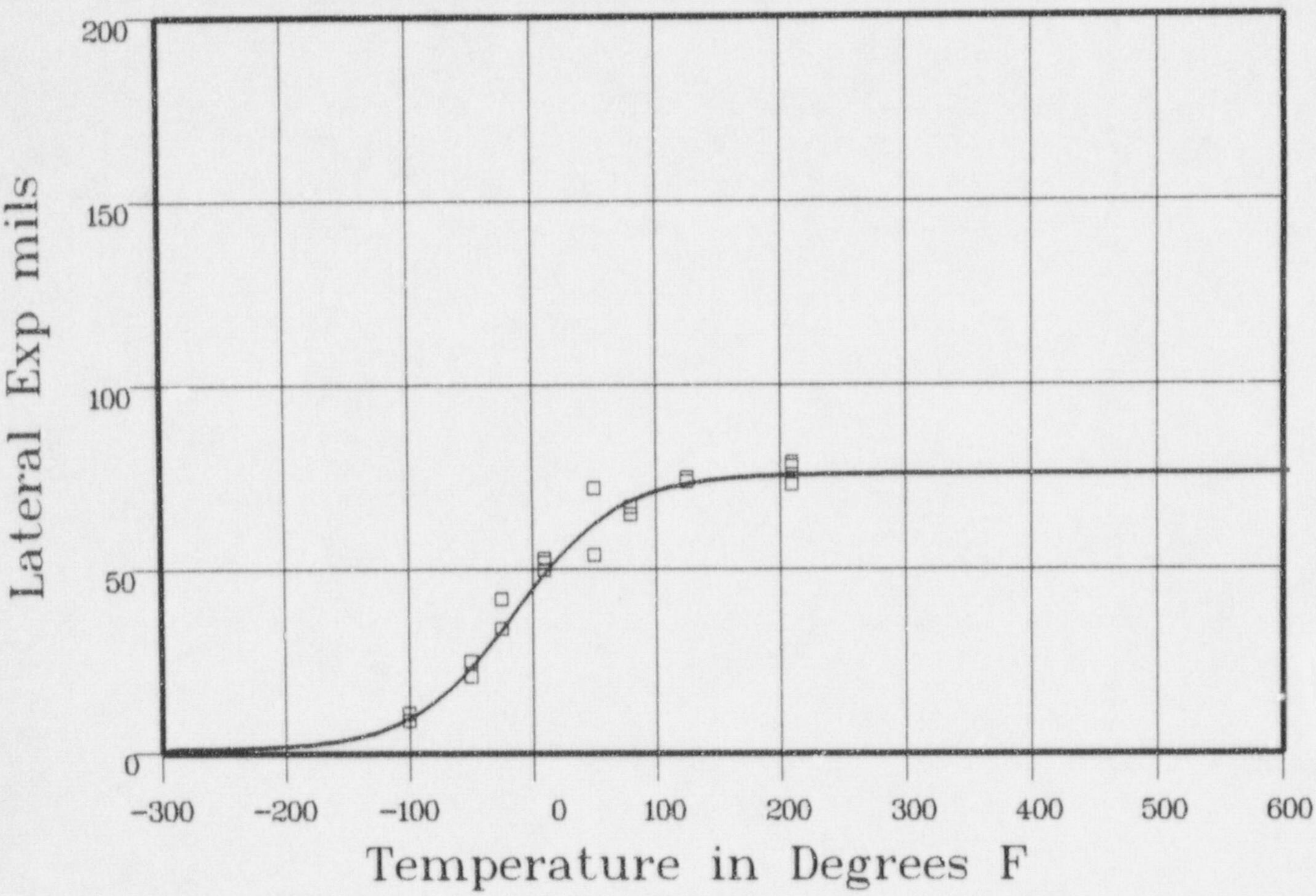
A = 38.47	B = 37.47	C = 84.19	T0 = -18.75

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

Upper Shelf L.E.: 75.94 Temperature at L.E. 35: -26.5 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 4P47841 Orientation:

Capsule: UNNIRR Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: UNNIRR Material: WELD Ori.: Heat #: 4P47841

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	11	10.49	.5
-100	9	10.49	-1.49
-50	25	25.16	-.16
-50	21	25.16	-4.16
-25	42	35.69	6.3
-25	34	35.69	-1.69
10	50	50.78	-.78
10	52	50.78	1.21
10	53	50.78	2.21

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

Unirradiated

Page 2

Material: WELD Heat Number: 4P47841 Orientation:

Capsule: UNNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
50	72	63.69	8.3
50	54	63.69	-9.69
80	65	69.38	-4.38
80	67	69.38	-2.38
125	75	73.55	1.44
125	74	73.55	.44
210	79	75.61	3.38
210	78	75.61	2.38
210	73	75.61	-2.61

SUM of RESIDUALS = -1.2

Capsule U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:42:29 on 06-23-1998

Page 1

Coefficients of Curve 2

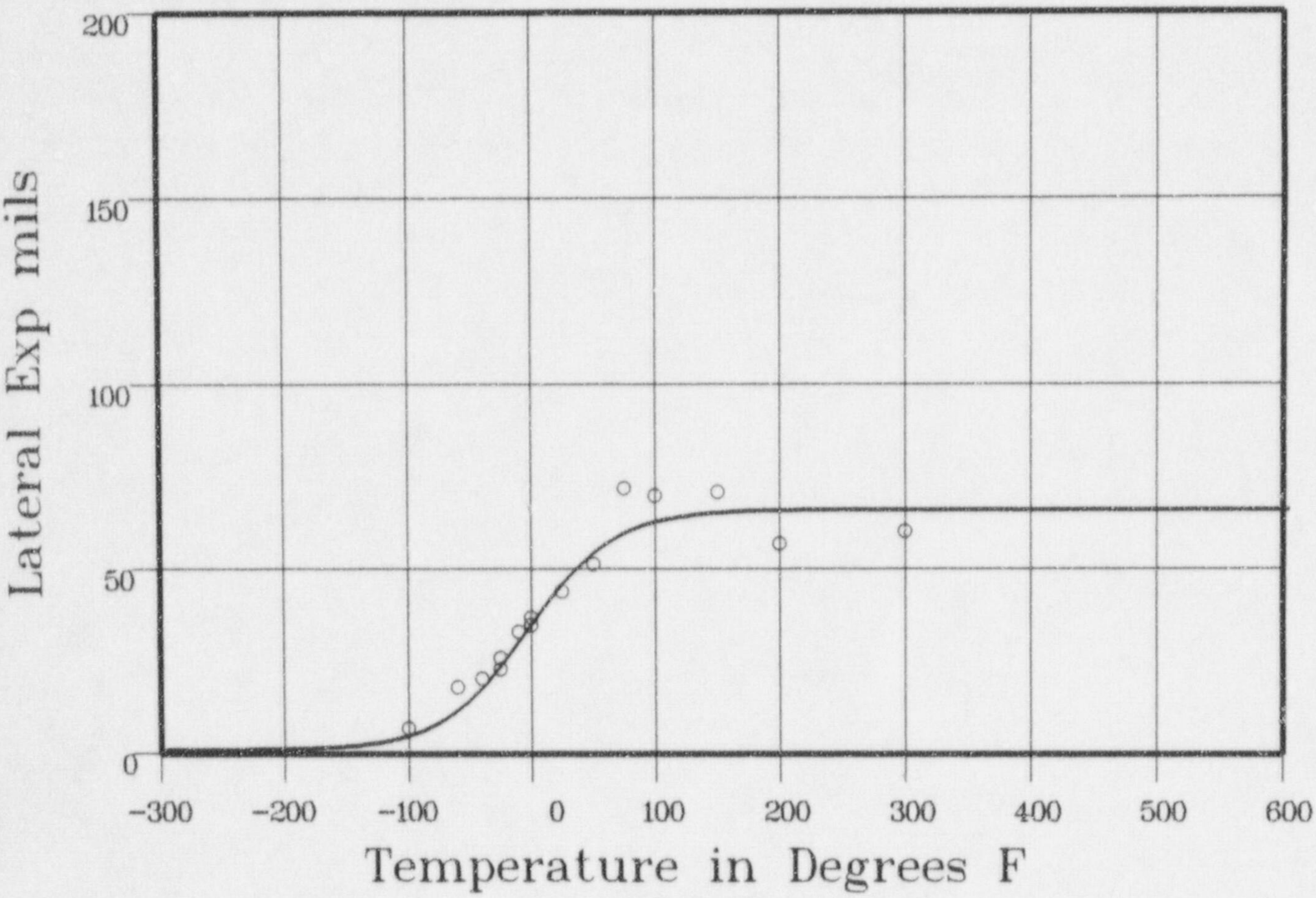
A = 33.6	B = 32.6	C = 70.1	T0 = -7.5

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

Upper Shelf L.E.: 66.21 Temperature at L.E. 35: -4.5 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: U Material: WELD Ori.: Heat #: 4P4784

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	7	5.34	1.65
-60	18	12.92	5.07
-40	20.5	19.49	1
-25	23	25.63	-2.63
-25	26	25.63	.36
-10	33	32.44	.55
0	37	37.08	-.08
0	35	37.08	-2.08

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

Capsule U

Page 2

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
25	44	47.72	-3.72
50	51.5	55.62	-4.12
75	72	60.55	11.44
100	70	63.31	6.68
150	71	65.49	5.5
200	57	66.04	-9.04
300	60.5	66.2	-5.7

SUM of RESIDUALS = 4.87

Capsule V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:42:29 on 06-23-1998

Page 1

Coefficients of Curve 3

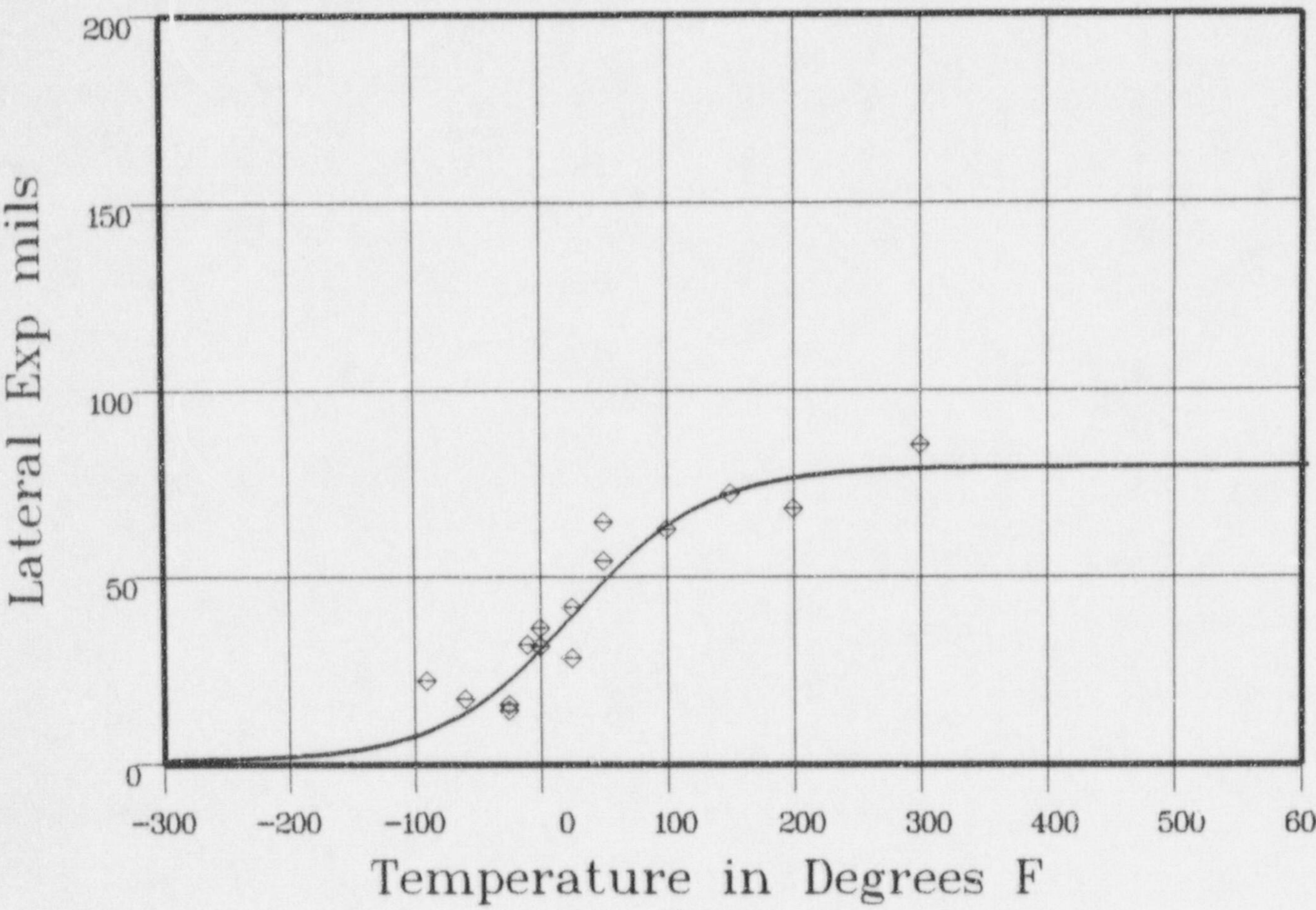
A = 40.31	B = 39.31	C = 105.8	T0 = 21.56

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

Upper Shelf L.E.: 79.62 Temperature at L.E. 35: 7.1 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: V Material: WELD Ori.: Heat #: 4P4784

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-90	22.5	9.51	12.98
-60	17.5	14.86	2.63
-25	16	24.04	-8.04
-25	14.5	24.04	-9.54
-10	32	28.92	3.07
0	31.5	32.4	-.9
0	36.5	32.4	4.09
25	28.5	41.58	-13.08

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

Capsule V

Page 2

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
25	42	41.58	.41
50	54.5	50.62	3.87
50	65	50.62	14.37
100	63	65.07	-2.07
150	72.5	73.24	-.74
200	68.5	77.01	-8.51
300	85.5	79.21	6.28

SUM of RESIDUALS = 4.8

Capsule X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:42:29 on 06-23-1998

Page 1

Coefficients of Curve 4

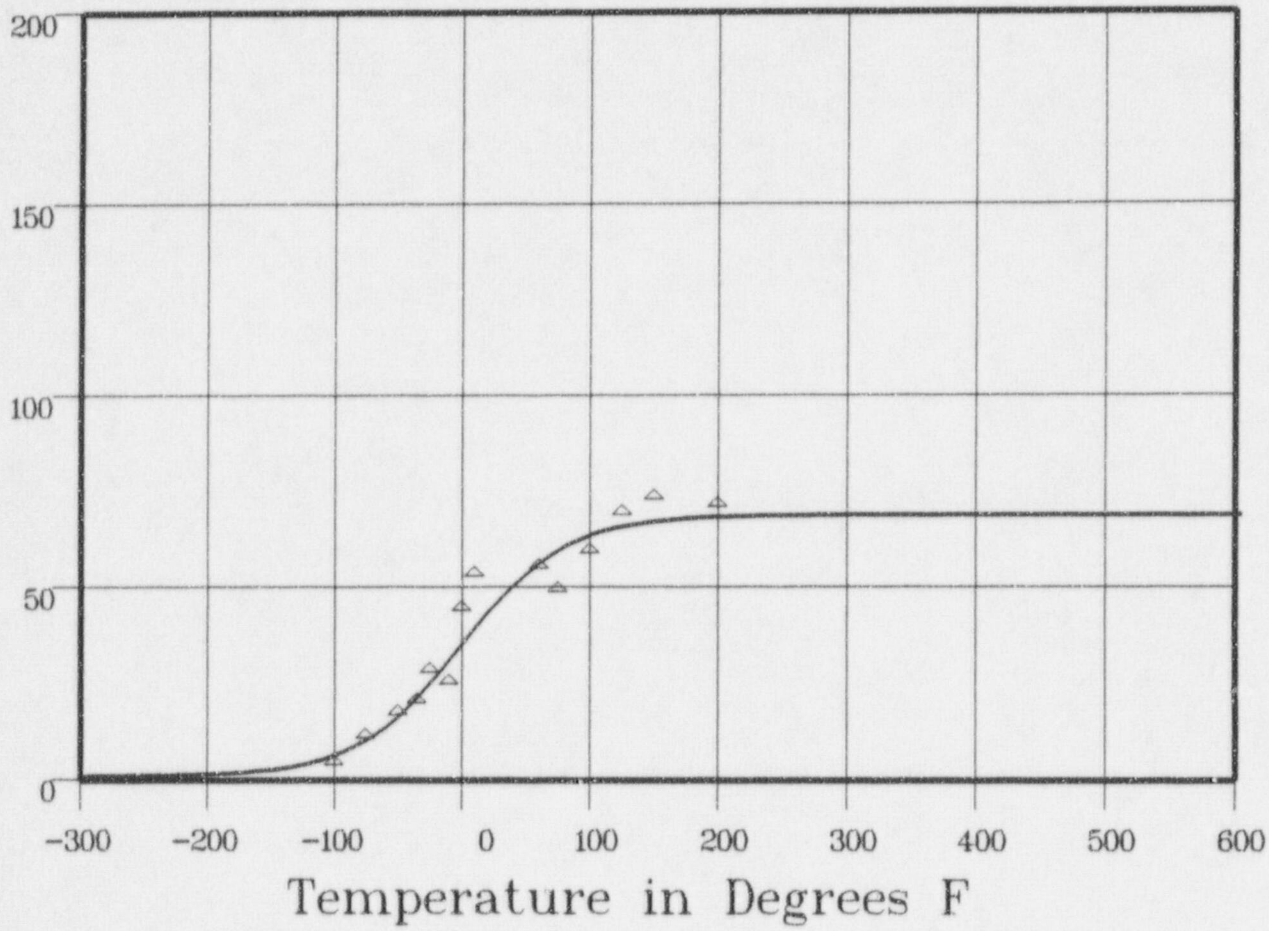
A = 34.92	B = 33.92	C = 81.61	T0 = -5.15

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

Upper Shelf L.E.: 68.85   Temperature at L.E. 35: -4.9   Lower Shelf L.E.: 1 Fixed

Material: WELD   Heat Number: 4P4784   Orientation:

Capsule: X   Total Fluence:



Data Set(s) Plotted

Plant: VS1   Cap.: X   Material: WELD   Ori.:   Heat #: 4P4784

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	4	7.04	-3.04
-75	11	11.38	-.38
-50	17	17.96	-.96
-35	20	23.04	-3.04
-25	28	26.83	1.16
-10	25	32.91	-7.91
0	44	37.06	6.93

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

Capsule X

Page 2

Material: WELD   Heat Number: 4P4784   Orientation:

Capsule: X   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
10	53	41.15	11.84
60	55	57.42	-2.42
75	49	60.5	-11.5
100	59	64.06	-5.06
125	69	66.17	2.82
150	73	67.37	5.62
200	71	68.41	2.58

SUM of RESIDUALS = -3.37

Capsule W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:42:29 on 06-23-1998

Page 1

Coefficients of Curve 5

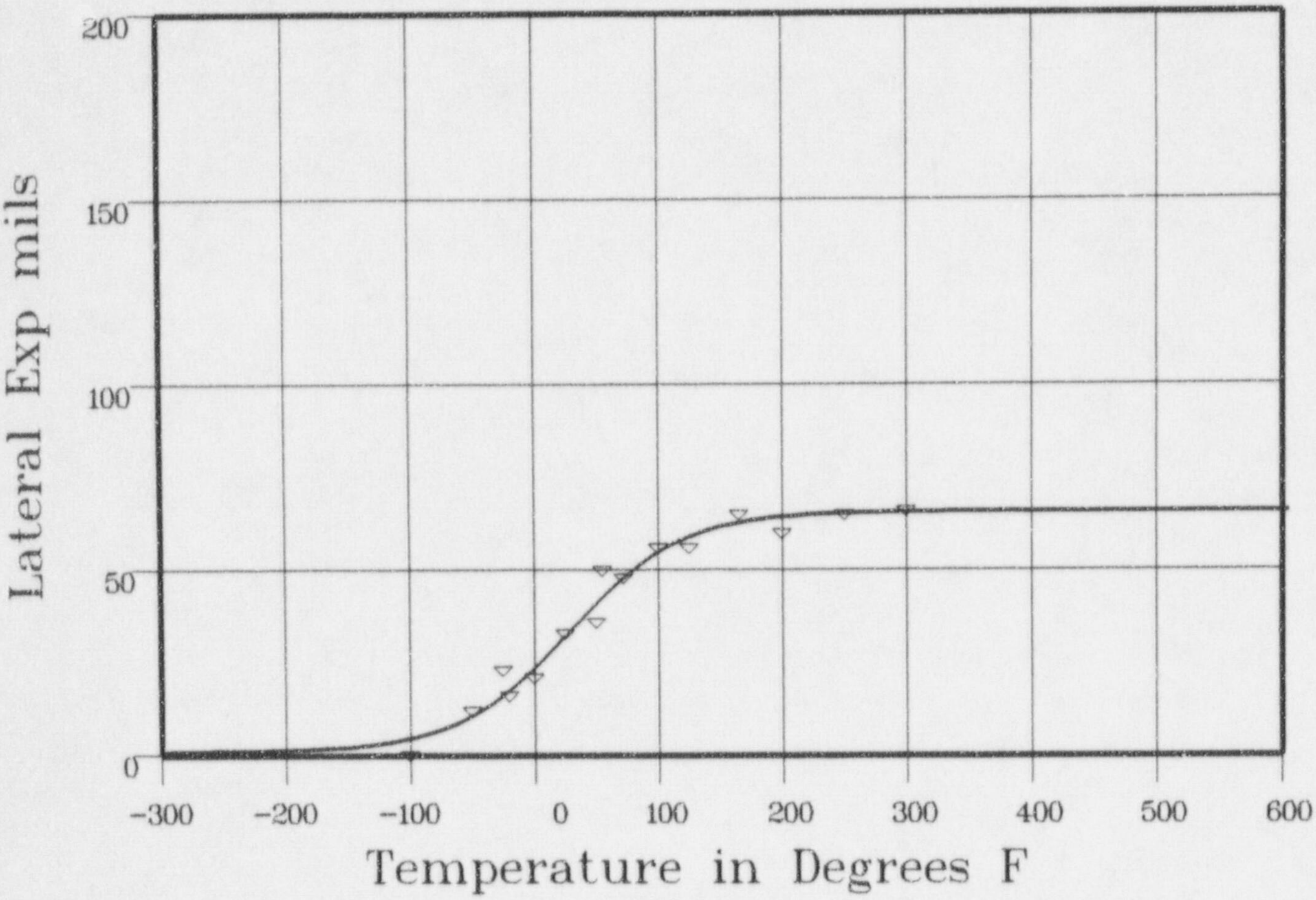
A = 33.4	B = 32.4	C = 90.12	T0 = 23.43

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

Upper Shelf L.E.: 65.81 Temperature at L.E. 35: 27.8 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: W Material: WELD Ori.: Heat #: 4P4784

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	1	4.93	-3.93
-50	13	11.62	1.37
-25	24	17.49	6.5
-20	17	18.89	-1.89
0	22	25.16	-3.16
25	34	33.97	.02

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

Capsule W

Page 2

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
50	37	42.69	-5.69
55	51	44.31	6.68
72	49	49.35	-.35
100	57	55.79	1.2
125	57	59.65	-2.65
165	66	63.13	2.86
200	61	64.55	-3.55
250	66	65.39	.6
300	67	65.67	1.32

SUM of RESIDUALS = -.68

Unirradiated

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:50:44 on 06-23-1998

Page 1

Coefficients of Curve 1

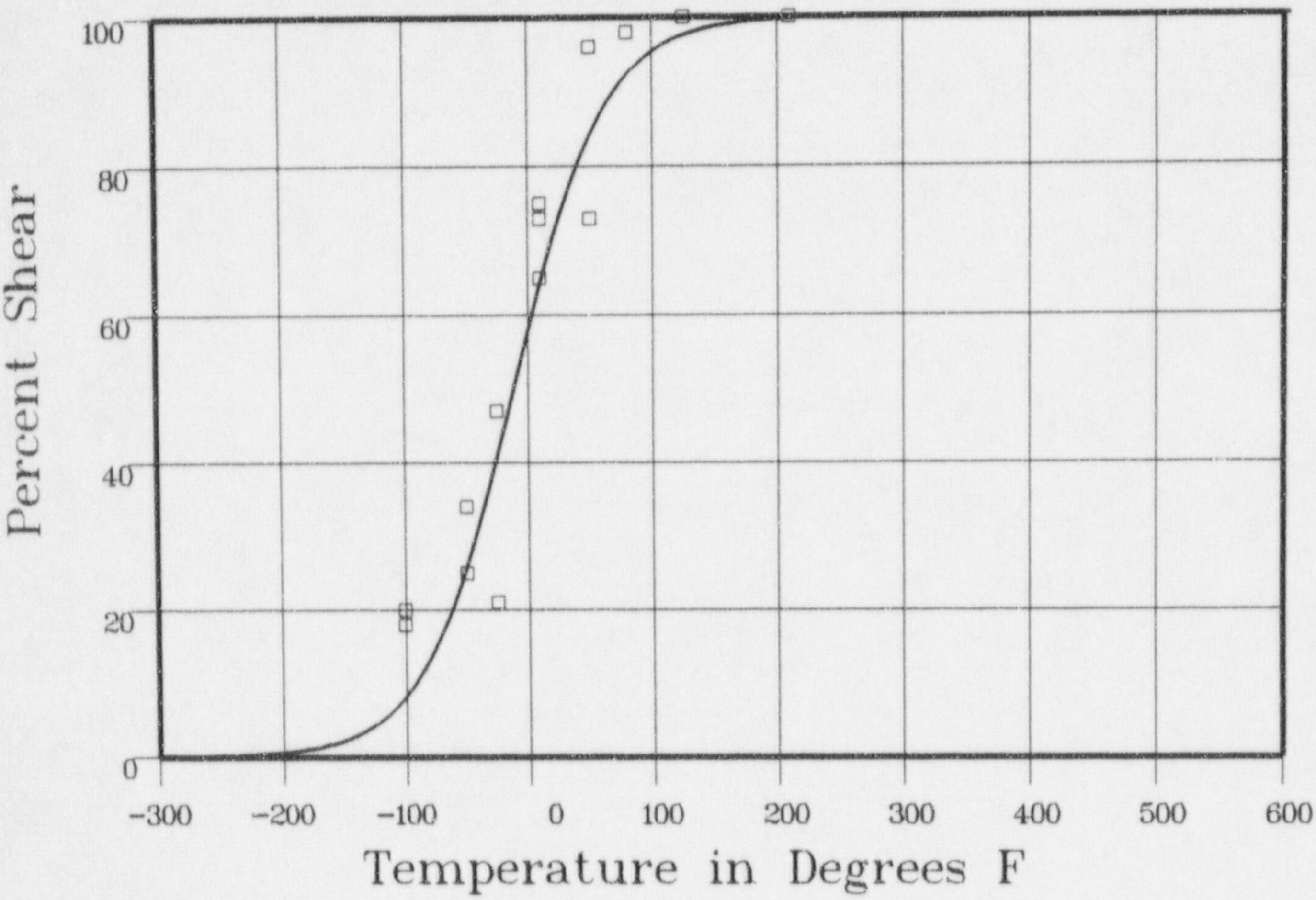
A = 50	B = 50	C = 73.33	T0 = -16.14

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

Temperature at 50% Shear: -16.1

Material: WELD Heat Number: 4P47841 Orientation:

Capsule: UNNIRR Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: UNNIRR Material: WELD Ori.: Heat #: 4P47841

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	20	9.22	10.77
-100	18	9.22	8.77
-50	25	28.43	-3.43
-50	34	28.43	5.56
-25	47	43.99	3
-25	21	43.99	-22.99
10	65	67.1	-2.1
10	73	67.1	5.89
10	75	67.1	7.89

ata continued on next page ****

Unirradiated

Page 2

Material: WELD   Heat Number: 4P47841   Orientation:

Capsule: UNNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50	96	85.86	10.13
50	73	85.86	-12.86
80	98	93.22	4.77
80	98	93.22	4.77
125	100	97.91	2.08
125	100	97.91	2.08
210	100	99.79	2
210	100	99.79	2
210	100	99.79	2

SUM of RESIDUALS = 24.98

Capsule U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:50:44 on 06-23-1998

Page 1

Coefficients of Curve 2

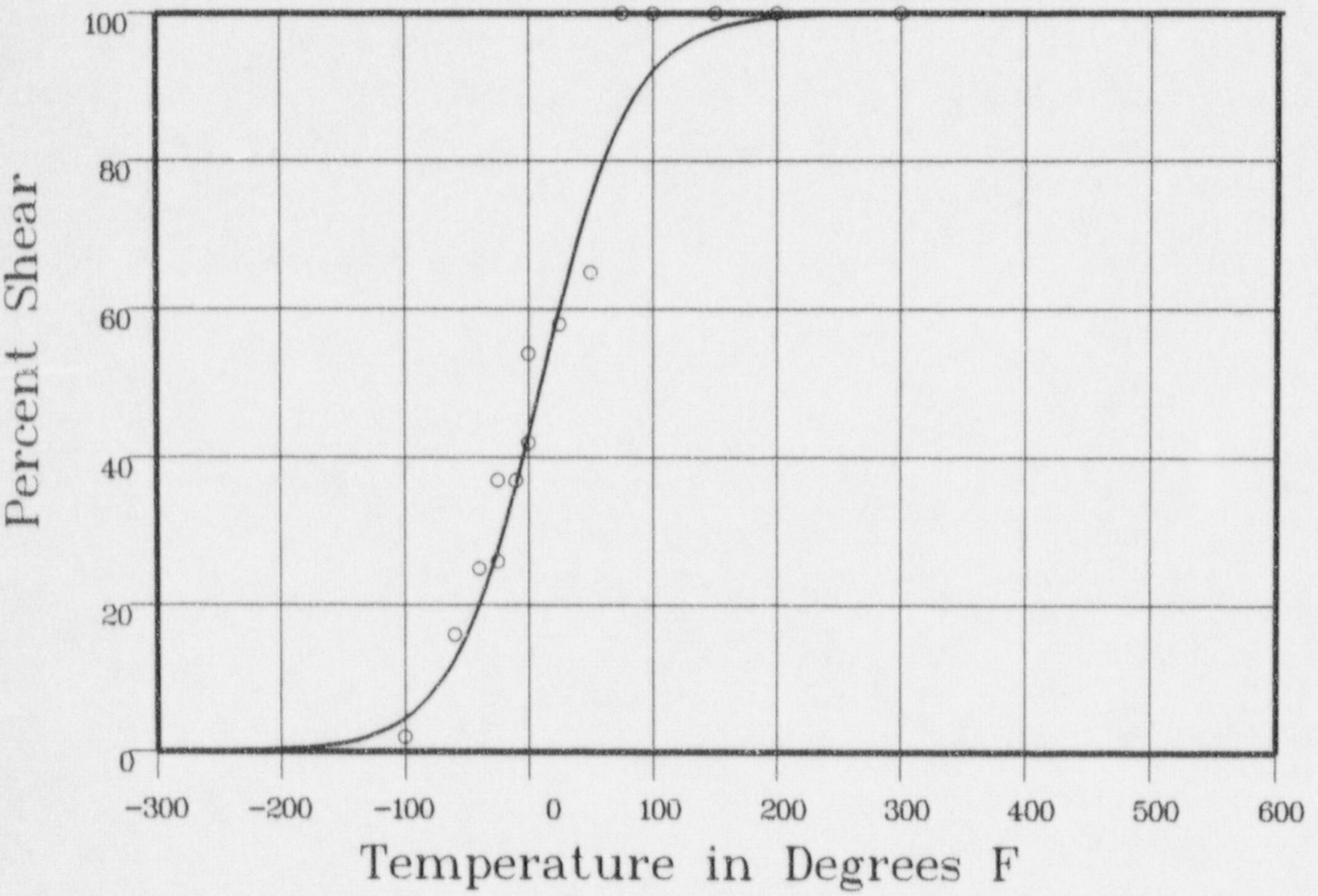
A = 50	B = 50	C = 72.64	T0 = 5.6

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

Temperature at 50% Shear: 5.6

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap: U Material: WELD Ori.: Heat #: 4P4784

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	2	5.17	-3.17
-60	16	14.1	1.89
-40	25	22.17	2.82
-25	37	30.09	6.9
-25	26	30.09	-4.09
-10	37	39.42	-2.42
0	54	46.15	7.84
0	42	46.15	-4.15

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

Capsule U

Page 2

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25	58	63.04	-5.04
50	65	77.24	-12.24
75	100	87.1	12.89
100	100	93.07	6.92
150	100	98.15	1.84
200	100	99.52	.47
300	100	99.96	.03

SUM of RESIDUALS = 10.47

Capsule V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:50:44 on 06-23-1998

Page 1

Coefficients of Curve 3

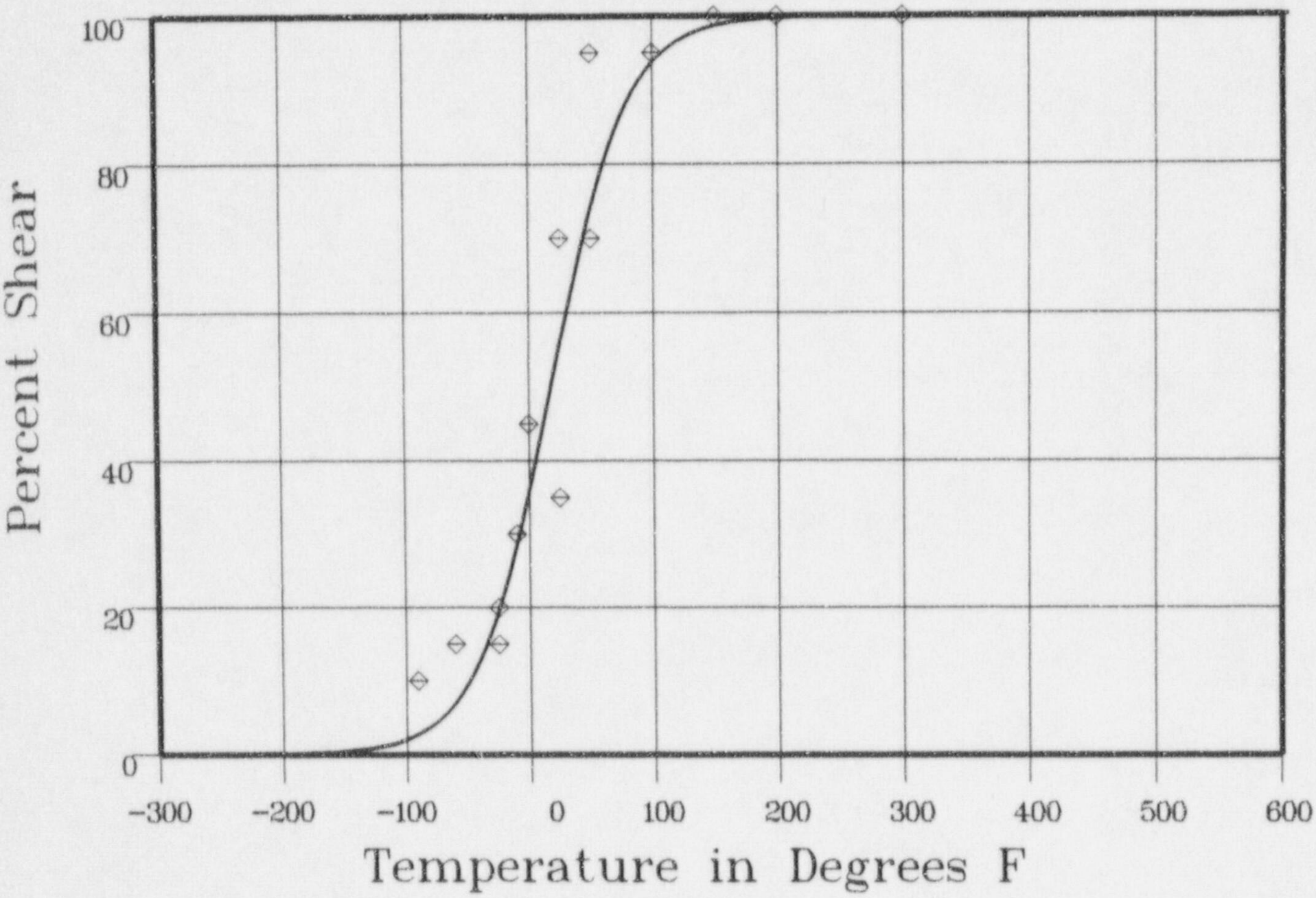
A = 50	B = 50	C = 60.84	T0 = 13.12

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

Temperature at 50% Shear: 13.1

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: V Material: WELD Ori.: Heat #: 4P4784

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-90	10	3.26	6.73
-60	15	8.28	6.71
-25	15	22.21	-7.21
-25	20	22.21	-2.21
-10	30	31.86	-1.86
0	45	39.37	5.62
0	45	39.37	5.62
25	35	59.63	-24.63

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

Capsule V

Page 2

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25	70	59.63	10.36
50	70	77.06	-7.06
50	95	77.06	17.93
100	95	94.56	.43
150	100	98.9	1.09
200	100	99.78	.21
300	100	99.99	0

SUM of RESIDUALS = 11.75

Capsule X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:50:44 on 06-23-1998

Page 1

Coefficients of Curve 4

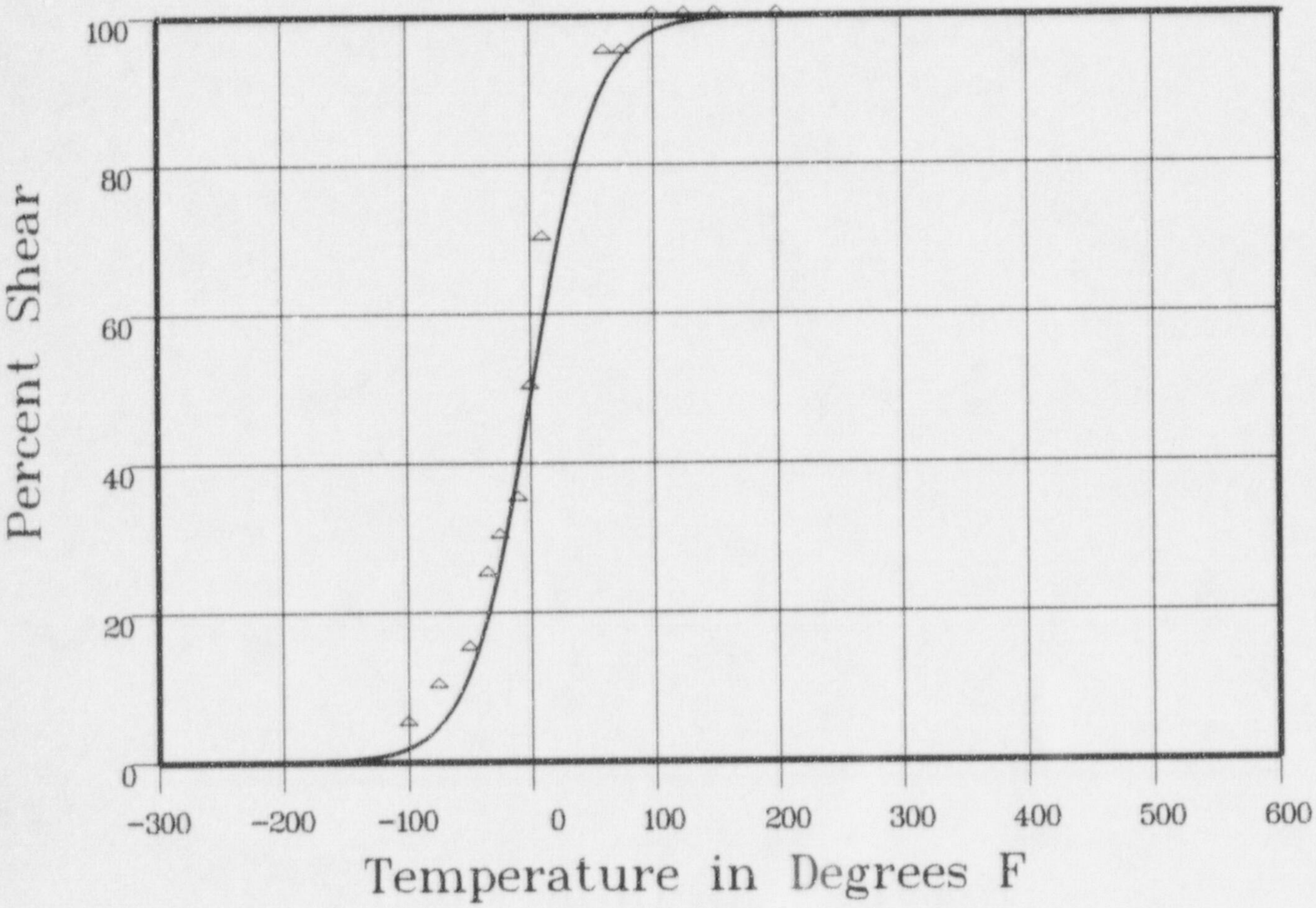
A = 50	B = 50	C = 51.09	T0 = -3.28

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

Temperature at 50% Shear: -3.2

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: X Material: WELD Ori.: Heat #: 4P4784

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	5	2.21	2.78
-75	10	5.69	4.3
-50	15	13.83	1.16
-35	25	22.41	2.58
-25	30	29.93	.06
-10	35	43.46	-8.46
0	50	53.2	-3.2

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

Capsule X

Page 2

Material: WELD   Heat Number: 4P4784   Orientation:

Capsule: X   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
10	70	62.71	7.28
60	95	92.25	2.74
75	95	95.53	-.53
100	100	98.27	1.72
125	100	99.34	.65
150	100	99.75	.24
200	100	99.96	.03

SUM of RESIDUALS = 11.38

Capsule W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:50:44 on 06-23-1998

Page 1

Coefficients of Curve 5

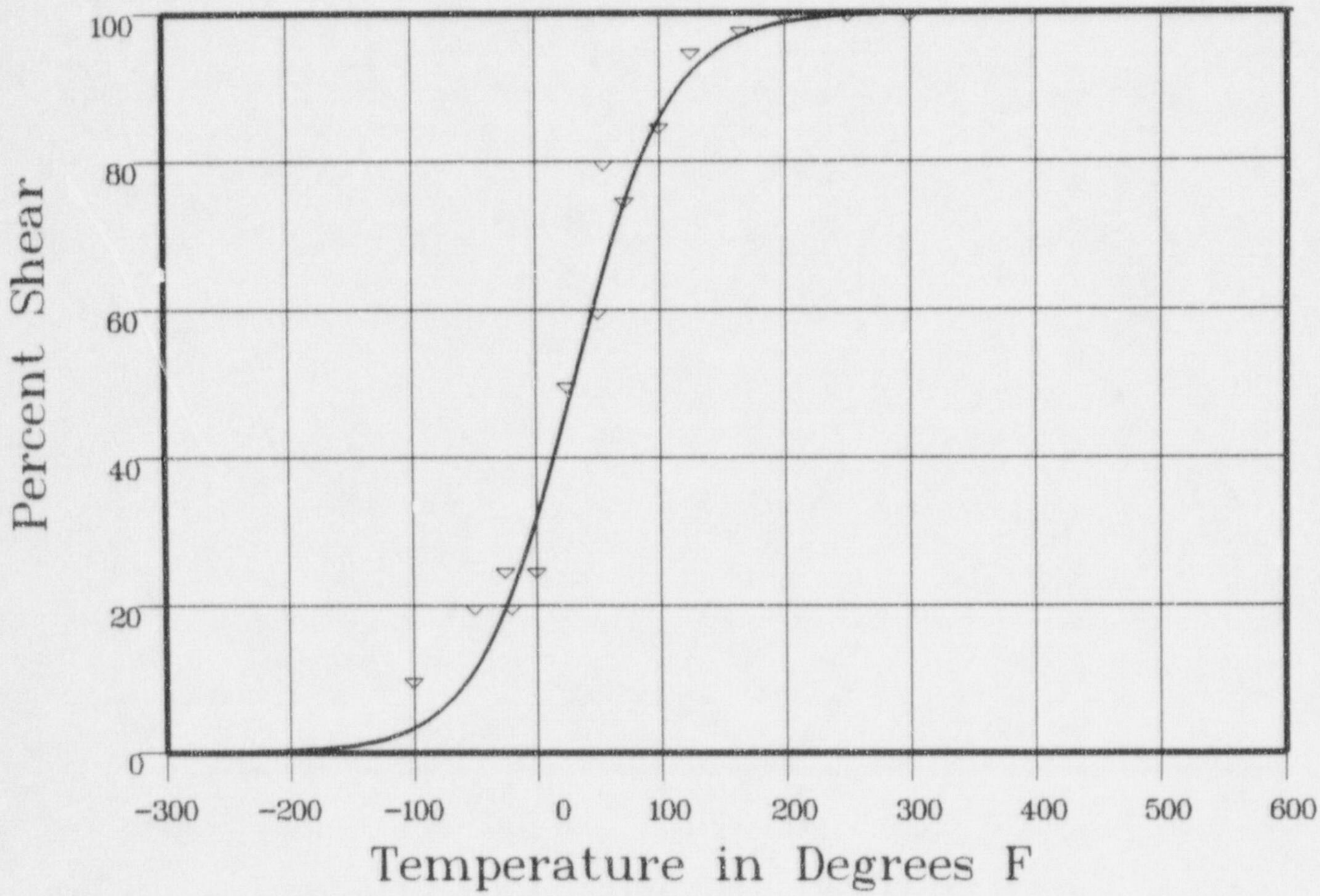
A = 50	B = 50	C = 77.83	T0 = 25.37

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

Temperature at 50% Shear: 25.3

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: W Material: WELD Ori.: Heat #: 4P4784

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	10	3.83	6.16
-50	20	12.59	7.4
-25	25	21.51	3.48
-20	20	23.75	-3.75
0	25	34.25	-9.25
25	50	49.75	.24

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

Capsule W

Page 2

Material: WELD Heat Number: 4P4784 Orientation:

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50	60	65.3	-5.3
55	80	68.15	11.84
72	75	76.81	-1.81
100	85	87.18	-2.18
125	95	92.82	2.17
165	98	97.3	.69
200	100	98.88	1.11
250	100	99.68	.31
300	100	99.91	.08

SUM of RESIDUALS = 11.19

Unirradiated

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:59:34 on 06-23-1998

Page 1

Coefficients of Curve 1

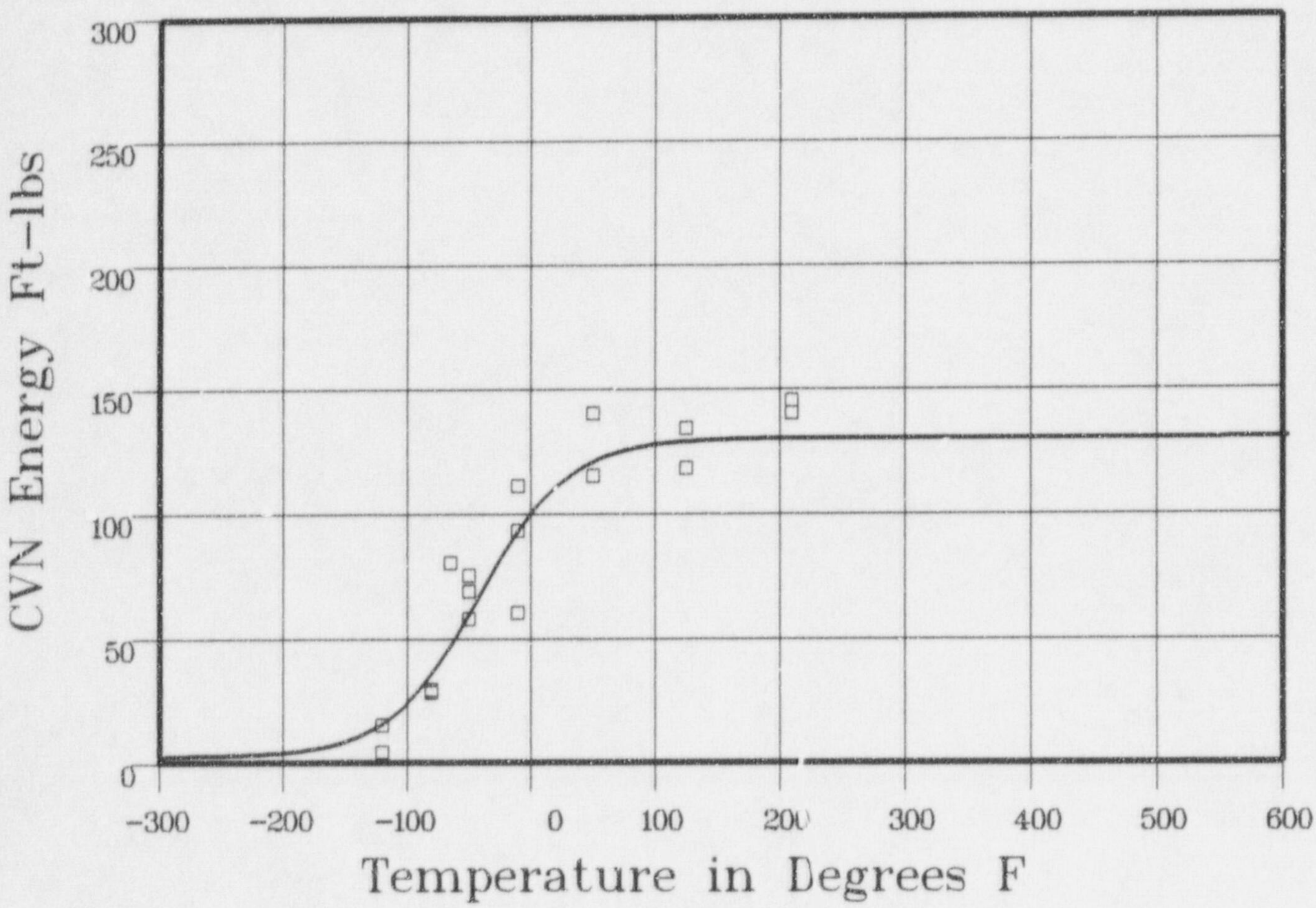
A = 66.09	B = 63.9	C = 72.62	T0 = -46.87

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

Upper Shelf Energy: 130 Fixed Temp. at 30 ft-lbs: -93.3 Temp. at 50 ft-lbs: -65.5 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: UNNIRR Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: UNNIRR Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-120	15	17.25	-2.25
-120	4	17.25	-13.25
-80	28	38.82	-10.82
-80	29	38.82	-9.82
-65	80	50.47	29.52
-50	57.5	63.35	-5.85
-50	75	63.35	11.64
-50	68.5	63.35	5.14
-10	60	96.01	-36.01

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

Unirradiated

Page 2

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

Capsule: UNNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-10	111	96.01	14.98
-10	93	96.01	-3.01
50	115	121.7	-6.7
50	140	121.7	18.29
125	134	128.88	5.11
125	118	128.88	-10.88
210	140	129.89	10.1
210	140	129.89	10.1
210	145	129.89	15.1

SUM of RESIDUALS = 21.41

Capsule U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:59:34 on 06-23-1998

Page 1

Coefficients of Curve 2

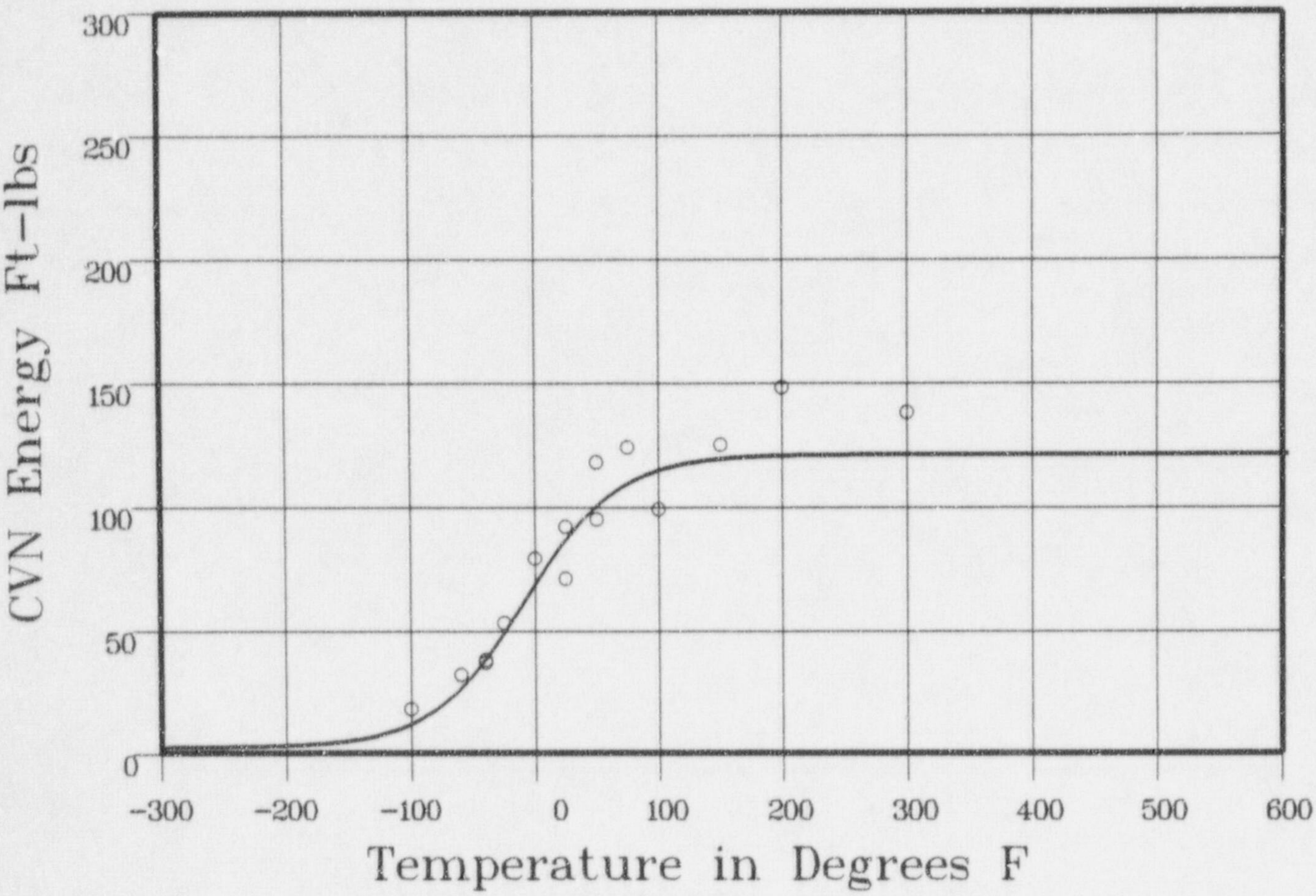
A = 61.59	B = 59.4	C = 75.28	T0 = -13.12

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

Upper Shelf Energy: 121 Fixed Temp. at 30 ft-lbs: -57.7 Temp. at 50 ft-lbs: -28 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: U Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	18	12.94	5.05
-60	32	28.75	3.24
-40	38	41.25	-3.25
-40	37	41.25	-4.25
-25	53	52.3	.69
0	79	71.85	7.14
25	71	89.34	-18.34
25	92	89.34	2.65

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

Capsule U

Page 2

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

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	95	102.28	-7.28
50	118	102.28	15.71
75	124	110.57	13.42
100	99	115.39	-16.39
150	125	119.46	5.53
200	148	120.58	27.41
300	138	120.97	17.02

SUM of RESIDUALS = 48.37

Capsule V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:59:34 on 06-23-1998

Page 1

Coefficients of Curve 3

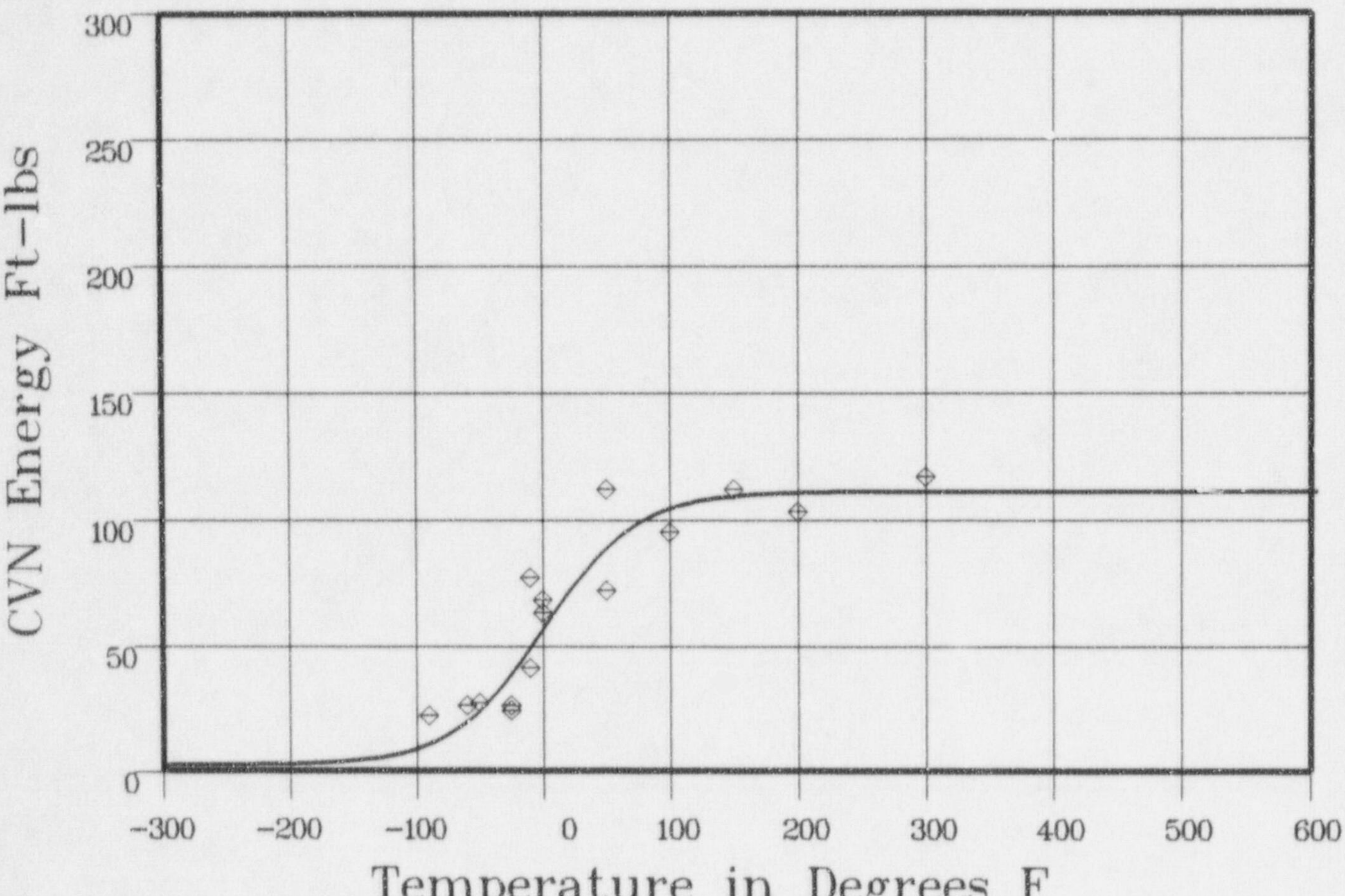
A = 56.59	B = 54.4	C = 73.06	T0 = -4.21

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

Upper Shelf Energy: 111 Fixed Temp. at 30 ft-lbs: -43.2 Temp. at 50 ft-lbs: -13.1 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: V Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-90	22	11.68	10.31
-60	26	21.61	4.38
-50	27	26.36	.63
-25	24	41.53	-17.53
-25	26	41.53	-15.53
-10	77	52.3	24.69
-10	41	52.3	-11.3
0	68	59.73	8.26

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

Capsule V

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
0	63	59.73	3.26
50	72	90.89	-18.89
50	112	90.89	21.1
100	95	105.06	-10.06
150	112	109.42	2.57
200	103	110.59	-7.59
300	117	110.97	6.02

SUM of RESIDUALS = .33

Capsule X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:59:34 on 06-23-1998

Page 1

Coefficients of Curve 4

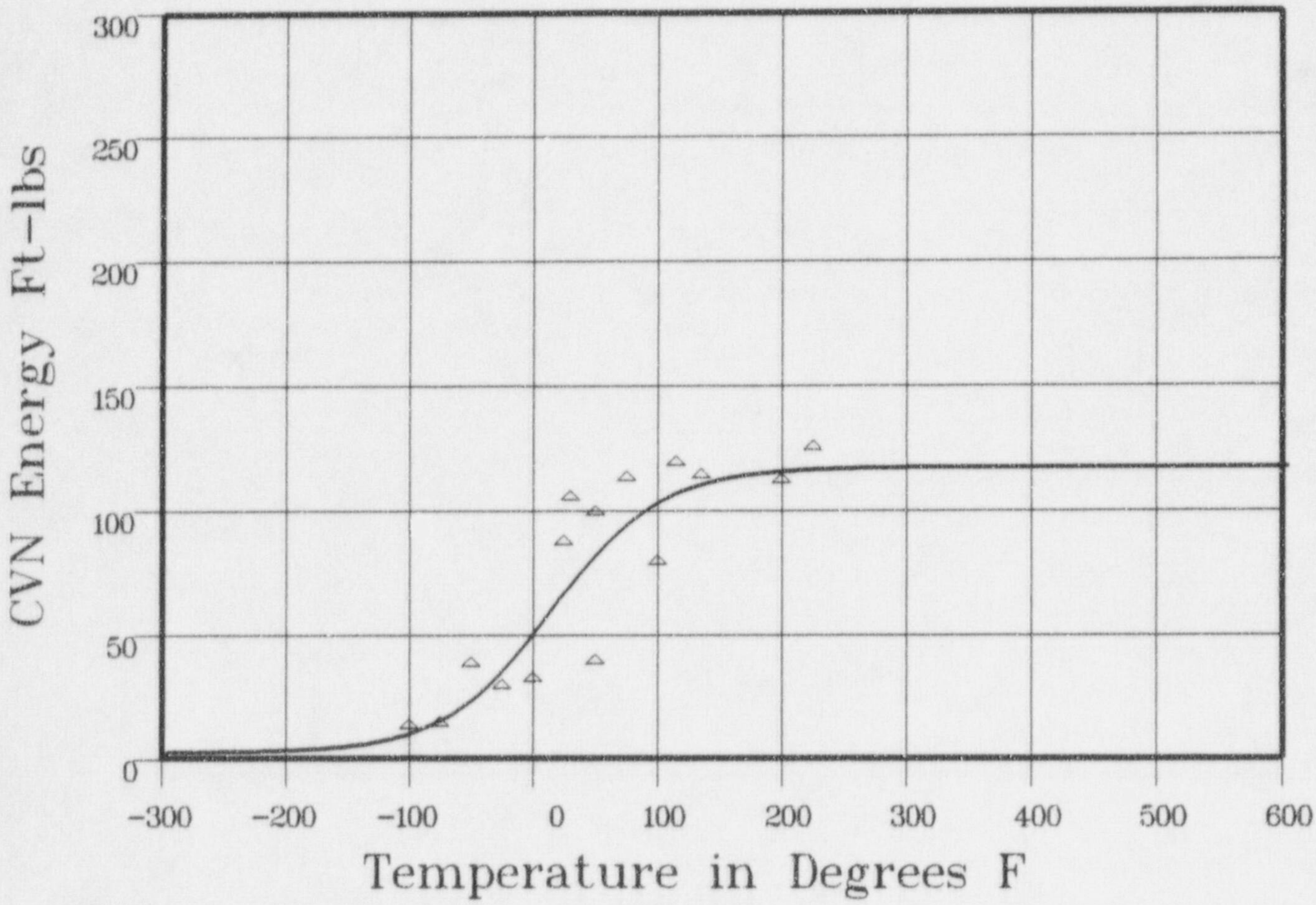
A = 59.59	B = 57.4	C = 86.85	T0 = 10.31

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

Upper Shelf Energy: 117 Fixed   Temp. at 30 ft-lbs: -39.2   Temp. at 50 ft-lbs: -4.3   Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: X   Total Fluence:



Data Set(s) Plotted

Plant: VS1   Cap.: X   Material: HEAT AFFD ZONE   Ori.:   Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	12	10.58	1.41
-75	13	16.31	-3.31
-50	37	25.11	11.88
-25	28	37.46	-9.46
0	31	52.81	-21.81
25	86	69.21	16.78
30	104	72.39	31.6

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

Capsule X

Page 2

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

Capsule: X Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	38	84.14	-46.14
50	98	84.14	13.85
75	112	95.87	16.12
100	78	104.08	-26.08
115	118	107.54	10.45
135	113	110.84	2.15
200	111	115.56	-4.56
225	124	116.18	7.81

SUM of RESIDUALS = .69

Capsule W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:59:34 on 06-23-1998

Page 1

Coefficients of Curve 5

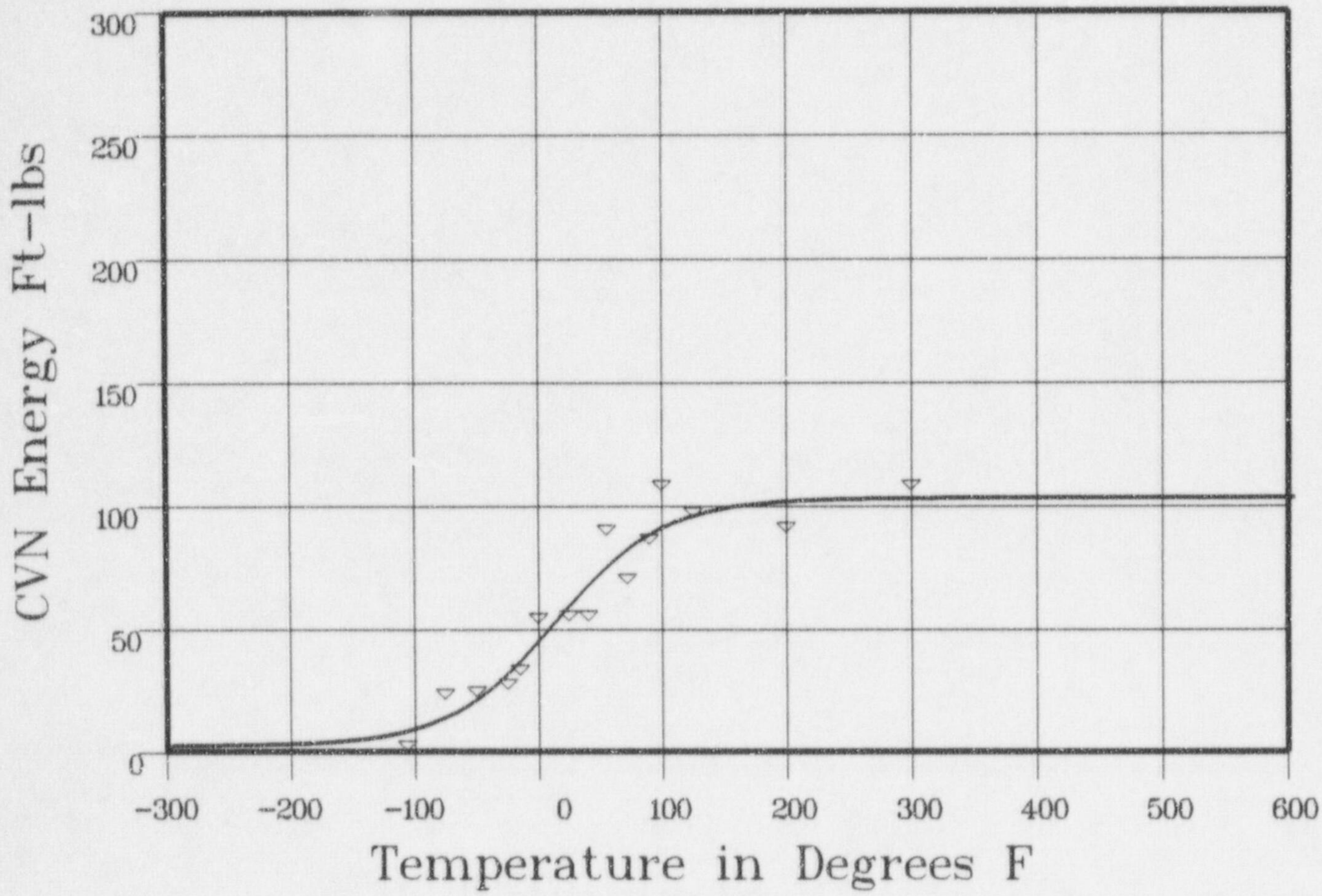
A = 52.59	B = 50.4	C = 86.85	T0 = 8.9

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

Upper Shelf Energy: 103 Fixed   Temp. at 30 ft-lbs: -33   Temp. at 50 ft-lbs: 4.4   Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: W   Total Fluence:



Data Set(s) Plotted

Plant: VS1   Cap.: W   Material: HEAT AFFD ZONE   Ori.:   Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-106	4	8.87	-4.87
-75	25	14.95	10.04
-50	26	22.84	3.15
-25	29	33.86	-4.86
-15	35	39.06	-4.06
0	56	47.44	8.55

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

Capsule W

Page 2

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

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
25	57	61.83	-4.83
40	57	69.91	-12.91
55	92	77.09	14.9
72	72	83.89	-11.89
90	88	89.5	-1.5
100	110	91.98	18.01
125	99	96.49	2.5
200	93	101.77	-8.77
300	110	102.87	7.12

SUM of RESIDUALS = 10.57

Unirradiated

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:09:45 on 06-23-1998

Page 1

Coefficients of Curve 1

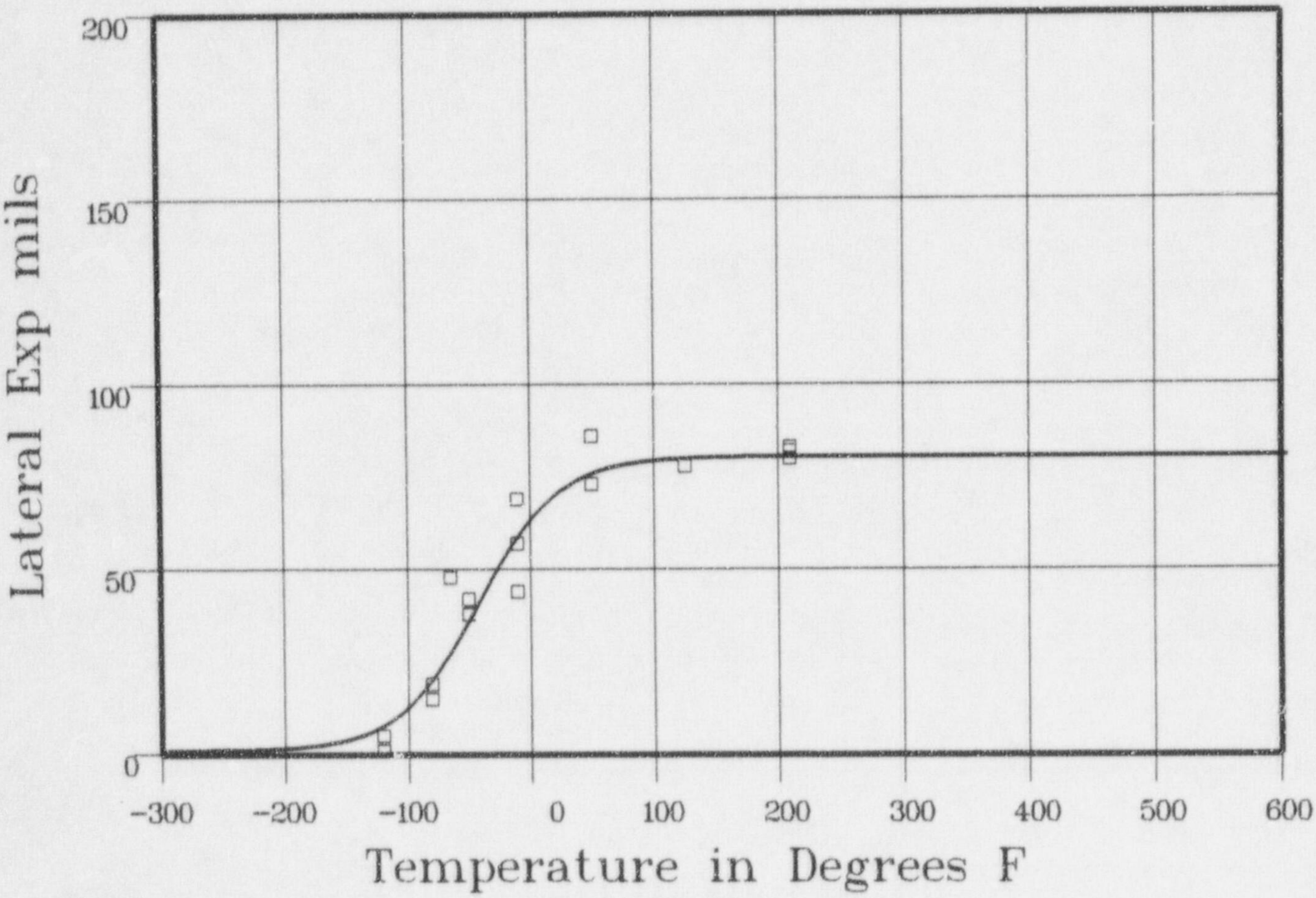
A = 40.77	B = 39.77	C = 65.93	T0 = -46.88

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

Upper Shelf L.E.: 80.55 Temperature at L.E. 35: -56.5 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: UNNIRR Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: UNNIRR Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-120	5	8.8	-3.8
-120	1	8.8	-7.8
-80	15	22.32	-7.32
-80	19	22.32	-3.32
-65	48	30.11	17.88
-50	38	38.89	-.89
-50	42	38.89	3.1
-50	42	38.89	3.1
-10	44	60.96	-16.96

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

Unirradiated

Page 2

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

Capsule: UNNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-10	69	60.96	8.03
-10	57	60.96	-3.96
50	73	76.56	-3.56
50	86	76.56	9.43
125	78	80.12	-2.12
125	78	80.12	-2.12
210	80	80.52	-.52
210	83	80.52	2.47
210	82	80.52	1.47

SUM of RESIDUALS = -6.94

Capsule U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:05:58 on 06-23-1998

Page 1

Coefficients of Curve 2

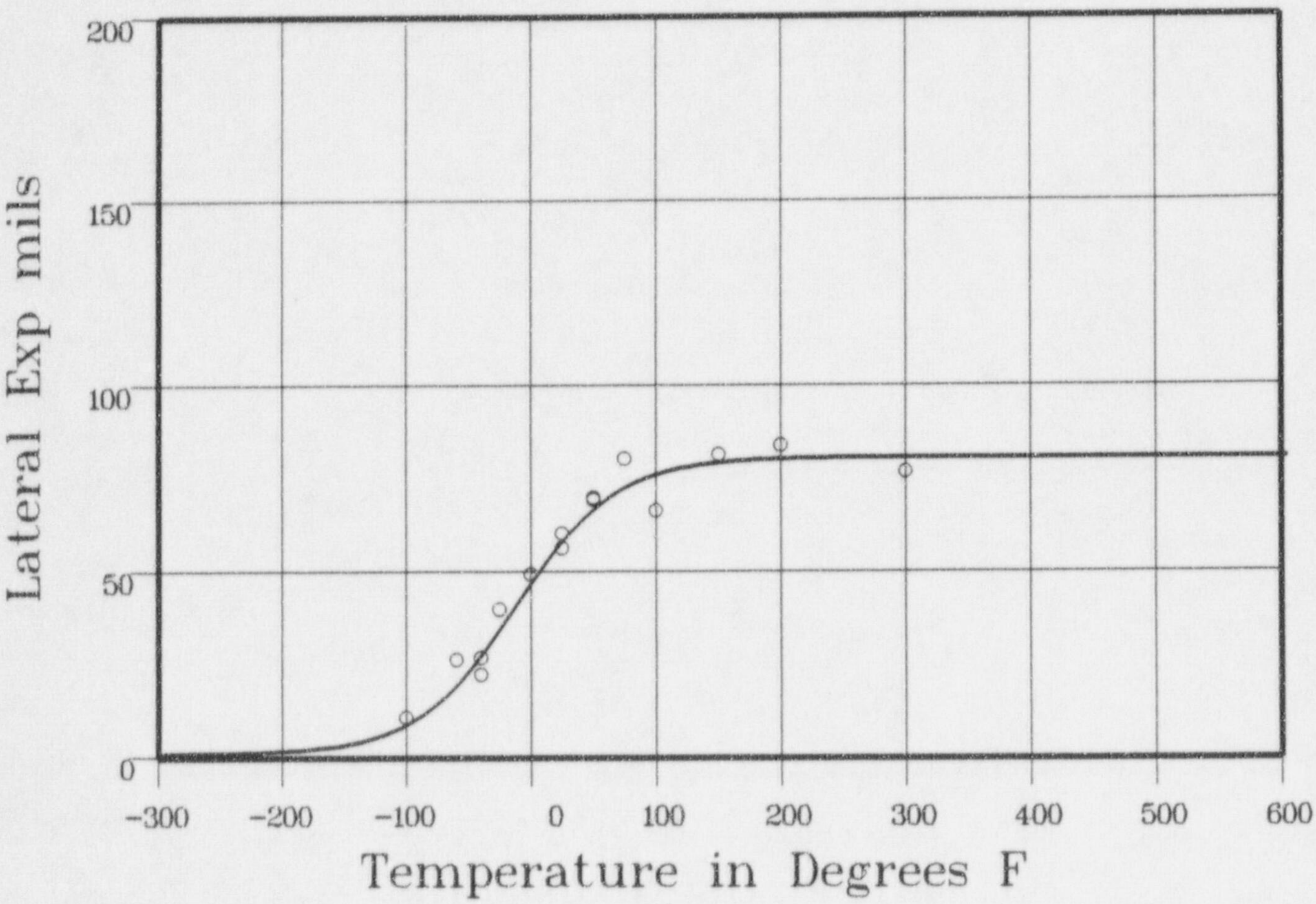
A = 40.87	B = 39.87	C = 79.76	T0 = -16.34

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

Upper Shelf L.E.: 80.74 Temperature at L.E. 35: -28.1 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: U Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	11	9.71	1.28
-60	26.5	20.99	5.5
-40	27	29.38	-2.38
-40	22.5	29.38	-6.88
-25	40	36.56	3.43
0	49.5	48.93	.56
25	56.5	59.87	-3.37
25	60.5	59.87	.62

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

Capsule U

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
50	70	68.04	1.95
50	69.5	68.04	1.45
75	80.5	73.42	7.07
100	66.5	76.65	-10.15
150	81.5	79.53	1.96
200	84	80.4	3.59
300	77	80.72	-3.72

SUM of RESIDUALS = .93

Capsule V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:05:58 on 06-23-1998

Page 1

Coefficients of Curve 3

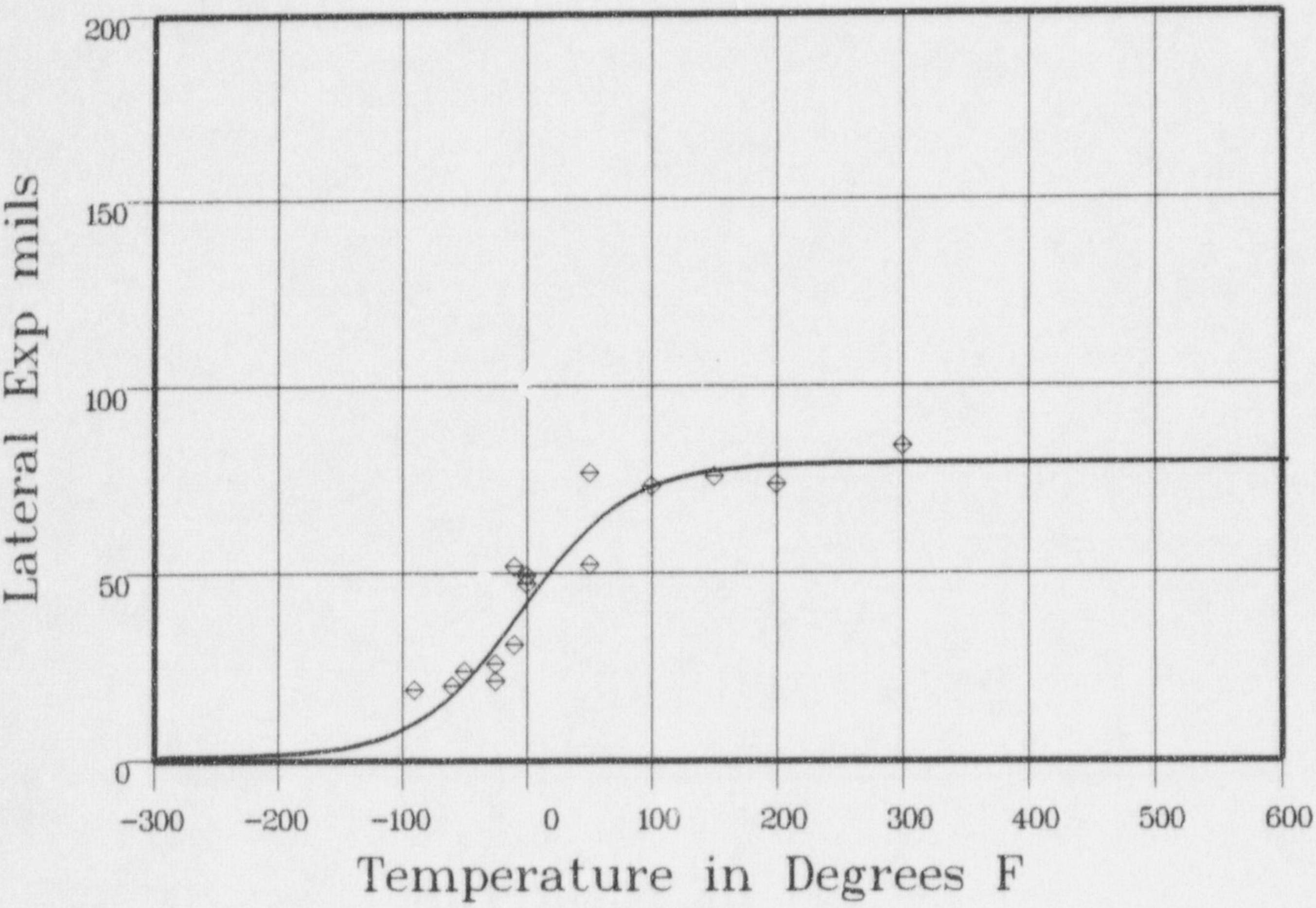
A = 40.24	B = 39.24	C = 84.8	T0 = -8.9

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

Upper Shelf L.E.: 79.49 Temperature at L.E. 35: -20.3 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: V Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-90	19	11.1	7.89
-60	20	19.09	.9
-50	24	22.58	1.41
-25	21.5	32.88	-11.38
-25	26	32.88	-6.88
-10	52	39.73	12.26
-10	31	39.73	-8.73
0	49.5	44.35	5.14

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

Capsule V

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
0	47.5	44.35	3.14
50	52.5	63.82	-11.32
50	77	63.82	13.17
100	73.5	73.9	-.4
150	76	77.68	-1.68
200	74	78.92	-4.92
300	84	79.43	4.56

SUM of RESIDUALS = 3.15

Capsule X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:05:58 on 06-23-1998

Page 1

Coefficients of Curve 4

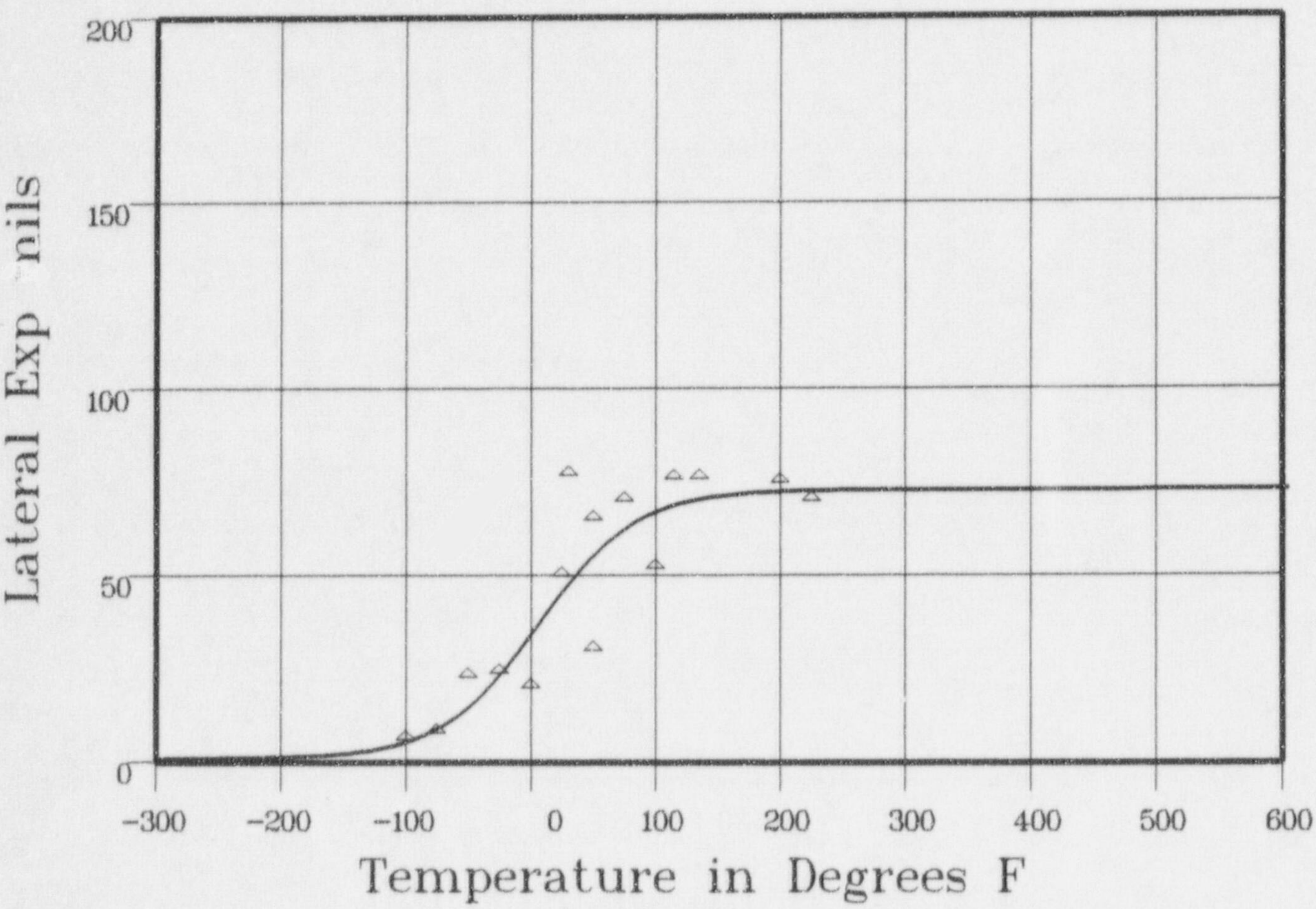
A = 36.99	B = 35.99	C = 77.81	T0 = 1.4

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

Upper Shelf L.E: 72.99 Temperature at L.E. 35: -2.9 Lower Shelf L.E: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: X Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	6	5.94	.05
-75	8	9.85	-1.85
-50	23	16.16	6.83
-25	24	25.22	-1.22
0	20	36.34	-16.34
25	50	47.58	2.41
30	77	49.66	27.33

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

Capsule X

Page 2

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

Capsule: X Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
50	30	56.94	-26.94
50	65	56.94	8.05
75	70	63.55	6.44
100	52	67.7	-15.7
115	76	69.3	6.69
135	76	70.74	5.25
200	75	72.56	2.43
225	70	72.76	-2.76

SUM of RESIDUALS = .65

Capsule W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:05:58 on 06-23-1998

Page 1

Coefficients of Curve 5

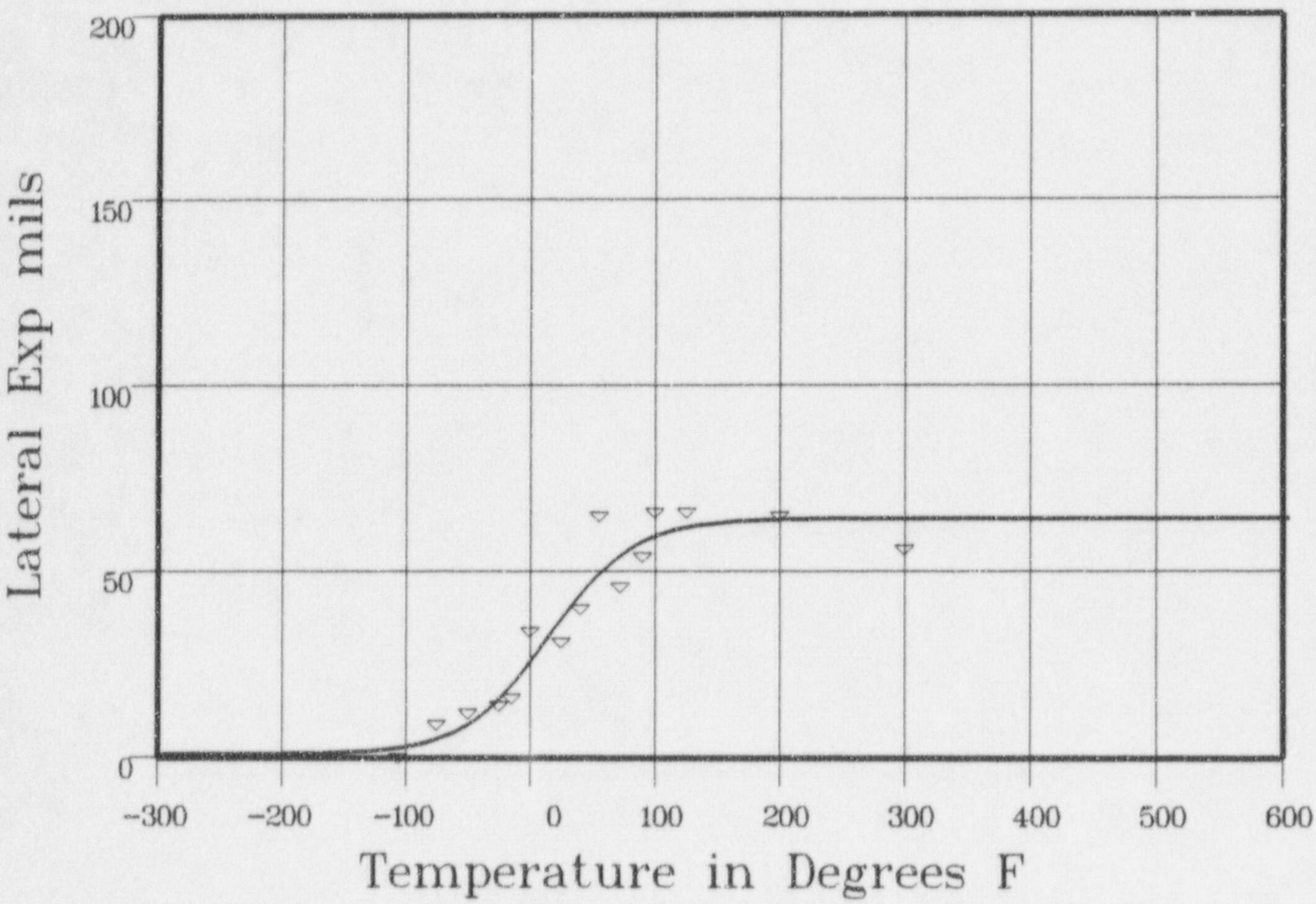
A = 32.67	B = 31.67	C = 67.61	T0 = 10.31

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

Upper Shelf L.E.: 64.34 Temperature at L.E. 35: 15.2 Lower Shelf L.E.: 1 Fixed

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

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: W Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-106	1	2.96	-1.96
-75	10	5.7	4.29
-50	13	10.11	2.88
-25	15	17.48	-2.48
-15	17	21.34	-4.34
0	35	27.88	7.11

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

Capsule W

Page 2

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
25	32	39.44	-7.44
40	41	45.75	-4.75
55	66	51.01	14.98
72	47	55.55	-8.55
90	55	58.86	-3.86
100	67	60.17	6.8[illegible]
125	67	62.28	4.71
200	66	64.11	1.88
300	57	64.33	-7.33

SUM of RESIDUALS = 1.96

Unirradiated

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:14:12 on 06-23-1998

Page 1

Coefficients of Curve 1

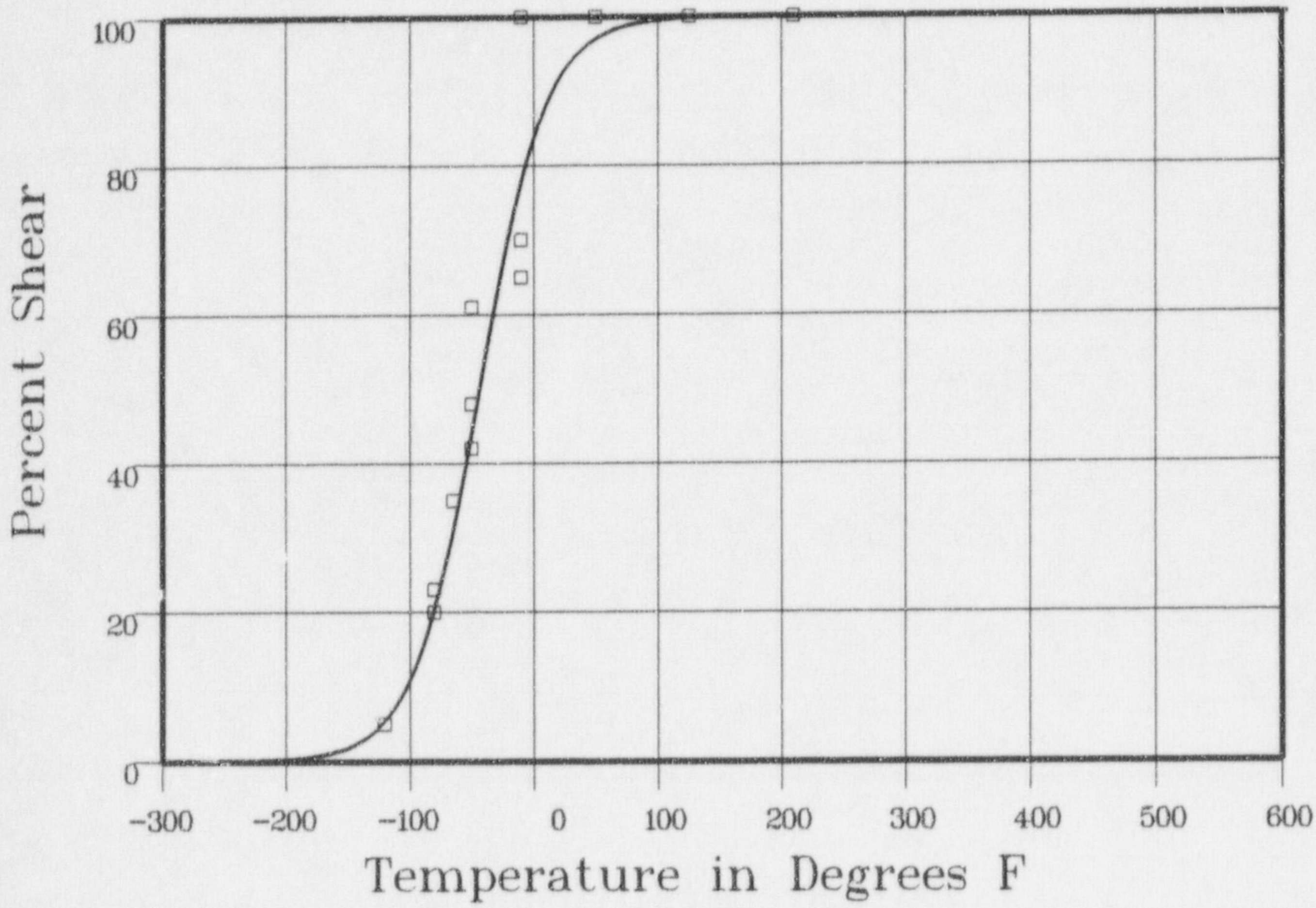
A = 50	B = 50	C = 53.5	T0 = -48.18

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

Temperature at 50% Shear: -48.1

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: UNNIRR Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: UNNIRR Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-120	5	6.39	-1.39
-120	5	6.39	-1.39
-80	20	23.34	-3.34
-80	23	23.34	-.34
-65	35	34.78	.21
-50	42	48.3	-6.3
-50	61	48.3	12.69
-50	45	48.3	-3
-10	65	80.64	-15.64

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

Unirradiated

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

Capsule: UNNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-10	100	80.64	19.35
-10	70	80.64	-10.64
50	100	97.51	2.48
50	100	97.51	2.48
125	100	99.84	.15
125	100	99.84	.15
210	100	99.99	0
210	100	99.99	0
210	100	99.99	0

SUM of RESIDUALS = -1.81

Capsule U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:14:12 on 06-23-1998

Page 1

Coefficients of Curve 2

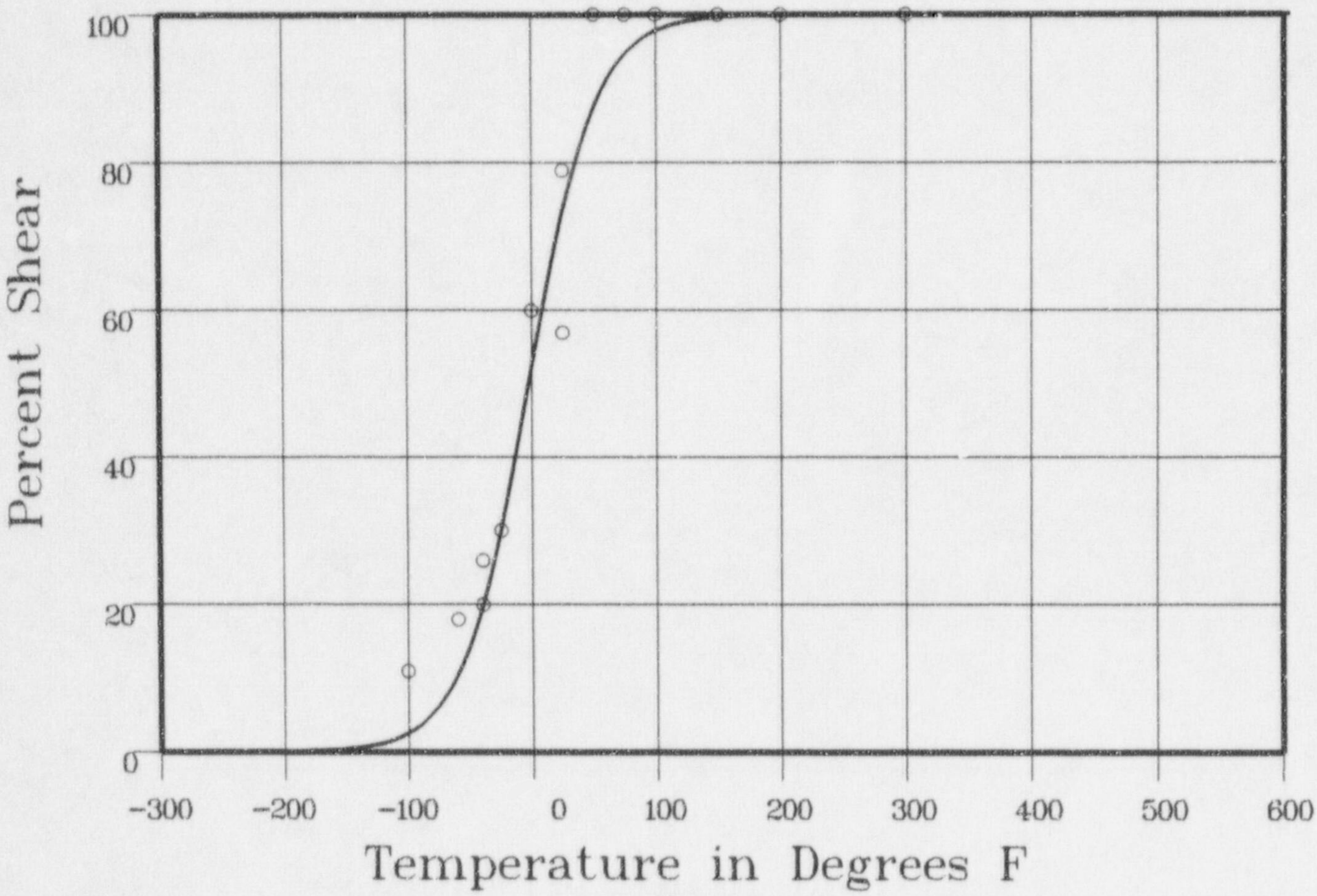
A = 50	B = 50	C = 53.74	T0 = -7

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

Temperature at 50% Shear: -7

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap: U Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	11	3.04	7.95
-60	18	12.21	5.78
-40	26	22.65	3.34
-40	20	22.65	-2.65
-25	30	33.85	-3.85
0	60	56.47	3.52
25	57	76.69	-19.69
25	79	76.69	2.3

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

Capsule U

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
50	100	89.29	10.7
50	100	89.29	10.7
75	100	95.48	4.51
100	100	98.16	1.83
150	100	99.71	.28
200	100	99.95	.04
300	100	99.99	0

SUM of RESIDUALS = 24.8

Capsule V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:14:12 on 06-23-1998

Page 1

Coefficients of Curve 3

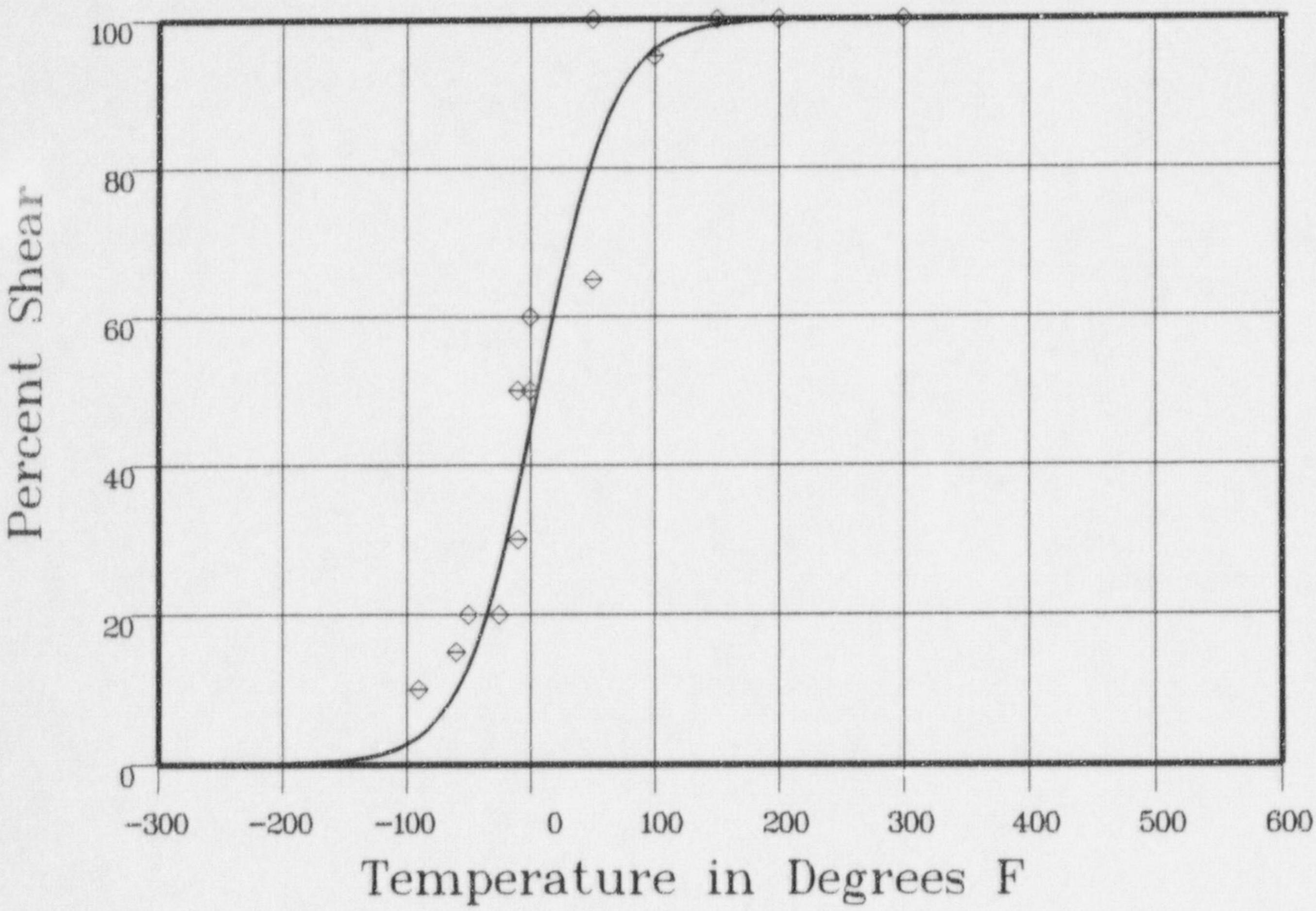
A = 50	B = 50	C = 59.43	T0 = 1.4

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

Temperature at 50% Shear: 1.4

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

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: V Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-90	10	4.41	5.58
-60	15	11.24	3.75
-50	20	15.05	4.94
-25	20	29.13	-9.13
-25	20	29.13	-9.13
-10	50	40.52	9.47
-10	30	40.52	-10.52
0	60	48.81	11.18

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

Capsule V

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
0	50	48.81	1.18
50	65	83.68	-18.68
50	100	83.68	16.31
100	95	96.5	-1.5
150	100	99.33	.66
200	100	99.87	.12
300	100	99.99	0

SUM of RESIDUALS = 4.25

Capsule X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:14:12 on 06-23-1998

Page 1

Coefficients of Curve 4

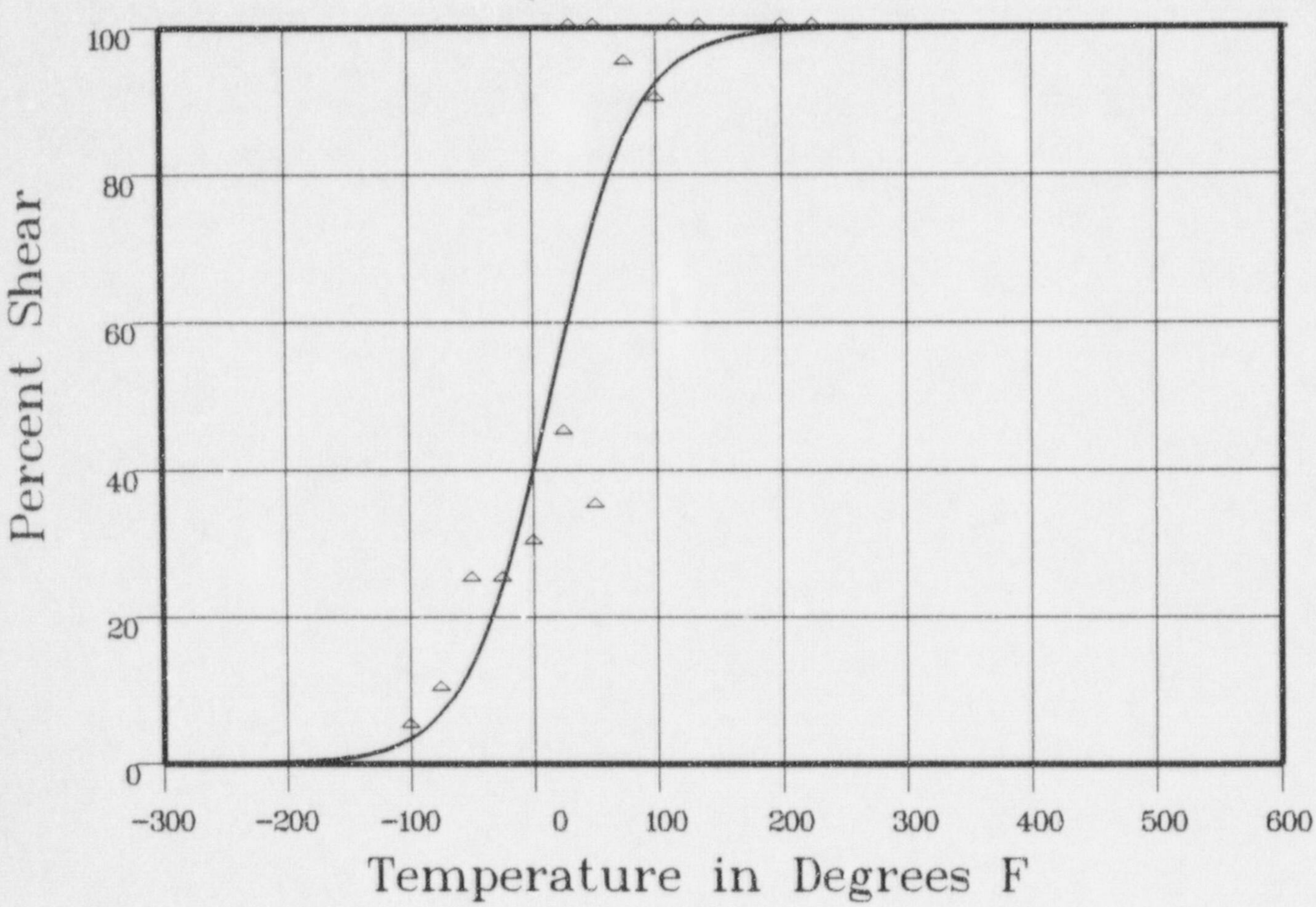
A = 50	B = 50	C = 68.77	T0 = 9.37

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

Temperature at 50% Shear: 9.3

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: X Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	5	3.98	1.01
-75	10	7.91	2.08
-50	25	15.1	9.89
-25	25	26.9	-1.9
0	30	43.22	-13.22
25	45	61.16	-16.16
30	100	64.56	35.43

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

Capsule X

Page 2

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

Capsule: X   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50	35	76.52	-41.52
50	100	76.52	23.47
75	95	87.08	7.91
100	90	93.31	-3.31
115	100	95.57	4.42
135	100	97.47	2.52
200	100	99.61	.38
225	100	99.81	.18

SUM of RESIDUALS = 11.23

Capsule W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:14:12 on 06-23-1998

Page 1

Coefficients of Curve 5

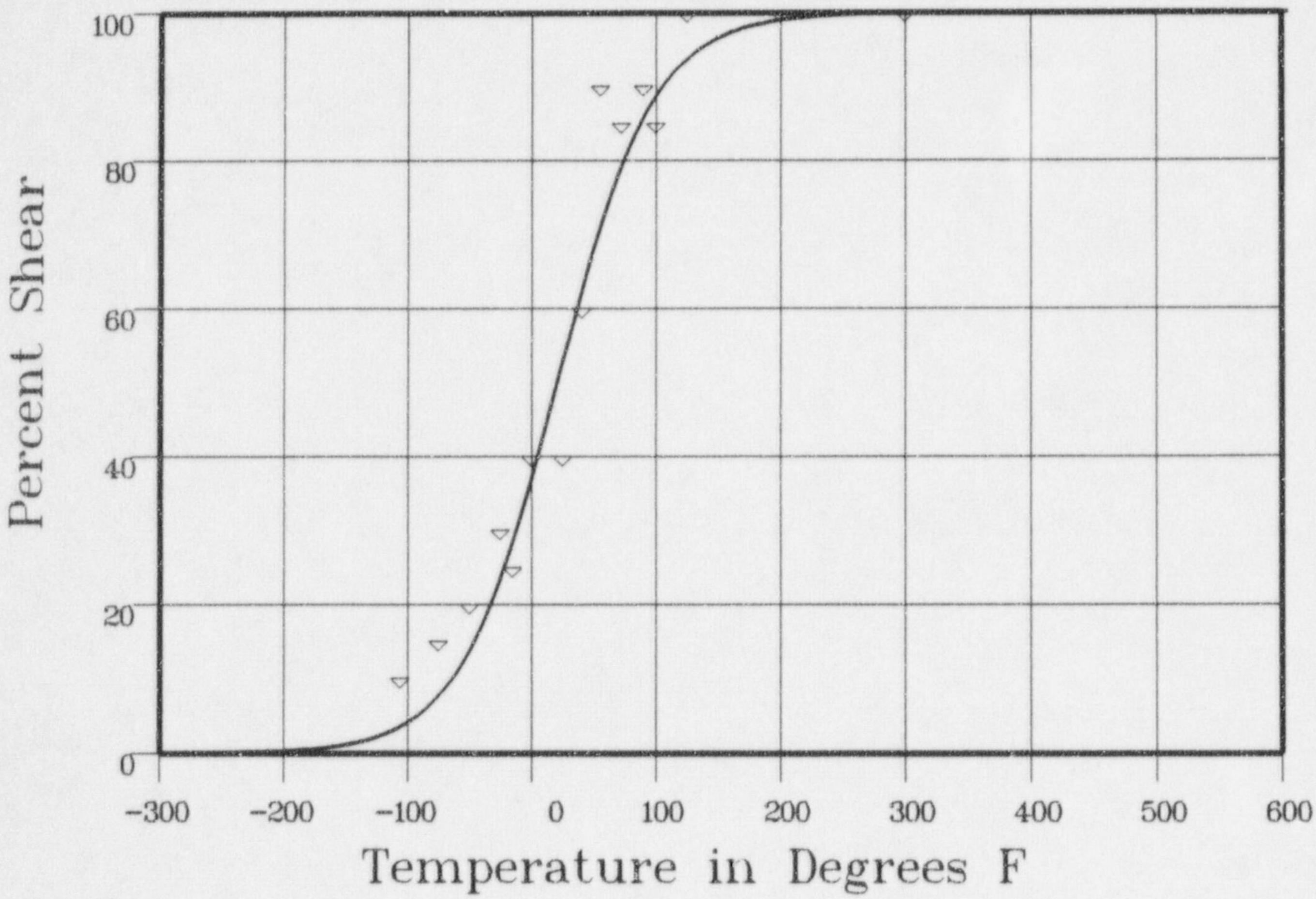
A = 50	B = 50	C = 77.11	T0 = 15.93

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

Temperature at 50% Shear: 15.9

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: VS1 Cap.: W Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-106	10	4.06	5.93
-75	15	8.63	6.36
-50	20	15.31	4.68
-25	30	25.69	4.3
-15	25	30.95	-5.95
0	40	39.81	.18

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

Capsule W

Page 2

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

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25	40	55.84	-15.84
40	60	65.11	-5.11
55	90	73.36	16.63
72	85	81.06	3.93
90	90	87.22	2.77
100	85	89.84	-4.84
125	100	94.41	5.58
200	100	99.16	.83
300	100	99.93	.06

SUM of RESIDUALS = 19.54

APPENDIX D

V.C. SUMMER 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 becomes available from the reactor in question.

To date there has been four surveillance capsules removed from the V.C. Summer 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 V.C. Summer Unit 1 reactor vessel surveillance data and determine if the V.C. Summer 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 embrittlements.

The beltline region of the reactor vessel is defined in Appendix G to 10CFR Part 50, "Frature 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 V.C. Summer Unit 1 reactor vessel consists of the following beltline region materials:

- *Intermediate Shell Plate 11-1 and 11-2 (Heat Nos. A9154-1 and A9153-2)*
- *Lower Shell Plate 10-1 and 10-2 (Heat Nos. C9923-2 and C9923-1)*
- *Intermediate Shell Longitudinal Weld Seams BC & BD, Lower Shell Longitudinal Weld Seams BA & BB and Girth Weld Seam A5.*

The V.C. Summer Unit 1 surveillance program utilizes longitudinal and transverse test specimens from the intermediate shell plate A9154-1. The surveillance weld metal was fabricated with weld wire heat number 4P4784, Linde 124 Flux, Lot 3930, which is the same as all the welds in the beltline region.

At the time 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. Intermediate shell plate A9154-1 had the highest initial RT_{NDT} and one of the lowest initial USE of all the plate materials in the beltline region. In addition, intermediate shell plate A9154-1 had the highest content of copper and phosphorus of all beltline plate materials. Therefore, based on having the highest initial RT_{NDT} and one of the lowest USE of all the plate materials, the intermediate shell plate A9154-1 was chosen for the surveillance program. The weld, on the other hand, represents all of the beltline welds.

Based on the above discussion, the V.C. Summer Unit 1 surveillance material meets 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 the Charpy energy versus temperature for the unirradiated and irradiated condition are presented in Section 5 and Appendix C of this Report.

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 V.C. Summer Unit 1 surveillance materials unambiguously. Therefore, the V.C. Summer 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 fails 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.

TABLE D-1: V.C. Summer Unit 1 Surveillance Capsule Data Chemistry Factor Calculation

Material	Capsule	Capsule f[(a)]	FF[(b)]	ΔRT_{NDT}[(c)]	FF * ΔRT_{NDT}	FF^2
Intermediate Shell Plate A9154-1	U	0.654	0.881	36.0	31.7	0.776
	V	1.538	1.119	52.6	58.9	1.252
	X	2.543	1.250	37.7	47.1	1.563
(Longitudinal)	W	4.664	1.388	65.7	91.2	1.927
Intermediate Shell Plate A9154-1	U	0.654	0.881	14.5	12.8	0.776
	V	1.538	1.119	32.4	36.3	1.252
	X	2.543	1.250	26.0	32.5	1.563
(Transverse)	W	4.664	1.388	57.8	80.2	1.927
				SUM:	390.7	11.036
	$CF_{A9154-1} = \Sigma(FF*RT_{NDT}) \div \Sigma(FF^2) = (390.7) \div (11.036) = 35.4°F$					
Surveillance Weld Material	U	0.654	0.881	22.2	19.6	0.776
	V	1.538	1.119	46.5	52.0	1.252
	X	2.543	1.250	22.4	28.0	1.563
	W	4.664	1.388	43.2	60.0	1.927
				SUM:	159.6	5.518
	$CF_{Weld} = \Sigma(FF*RT_{NDT}) \div \Sigma(FF^2) = (159.6) \div (5.518) = 28.9°F$					

NOTES:

(a) f = Measured fluence from Capsule V dosimetry analysis results per Section 6 (x 10^{19} n/cm², E > 1.0 MeV).

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

(c) ΔRT_{NDT} values are the measured 30 ft-lb shift values (See Section 5 and Appendix C) and does not include an adjustment per the ratio procedure of Reg. Guide 1.99 Rev. 2, Position 2.1, since this calculation is based on the actual surveillance base and 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: Best-Fit Evaluation for V.C. Summer Unit 1 Surveillance Materials

Base Material	**CF (°F)**	**FF**	**Measured ΔRT_{NDT} (30 ft-lb) (°F)**	**Best-Fit [a] ΔRT_{NDT} (°F)**	**Scatter of ΔRT_{NDT} (°F)[c] (BF - Meas.)**	**< 17°F (Base Metals) < 28°F (Weld Metals)**
Intermediate Shell	35.4	0.881	36.0	31.2	-4.8	Yes
Plate A9154-1	35.4	1.119	52.6	39.6	-13.0	Yes
	35.4	1.250	37.7	44.3	6.6	Yes
(Longitudinal)	35.4	1.388	65.7	49.1	-16.6	Yes
Intermediate Shell	35.4	0.881	14.5	31.2	16.5	Yes
Plate A9154-1	35.4	1.119	32.4	39.6	7.2	Yes
	35.4	1.250	26.0	44.3	18.3	Yes[b]
(Transverse)	35.4	1.388	57.8	49.1	-8.7	Yes
Surveillance Weld	28.9	0.881	22.2	25.5	3.3	Yes
Metal	28.9	1.119	46.5	32.3	-14.2	Yes
	28.9	1.250	22.4	36.1	13.7	Yes
	28.9	1.388	43.2	40.1	-3.1	Yes

NOTES:

(a) Best-fit Line Per Equation 2 of Reg. Guide 1.99, Rev. 2, Position 1.1.

(b) See Discussion Below.

(c) + Numbers indicate over prediction by the best-fit line.

From Table D-2 above, it can be seen that one of eight points for the surveillance plate material falls outside the scatter band (+/- 17°F) on the low side, meaning that the Reg. Guide 1.99, Revision 2 over predicted ΔRT_{NDT}. Based on guidance from the NRC, when only one point out of six or more is outside the scatter band (especially on the low side), then it should be considered credible. As for the weld material, Table D-2 indicates all the scatter is within the acceptable range for credible data.

Based on this discussion the V.C. Summer Unit 1 surveillance materials meet this criteria.

Figure D-1

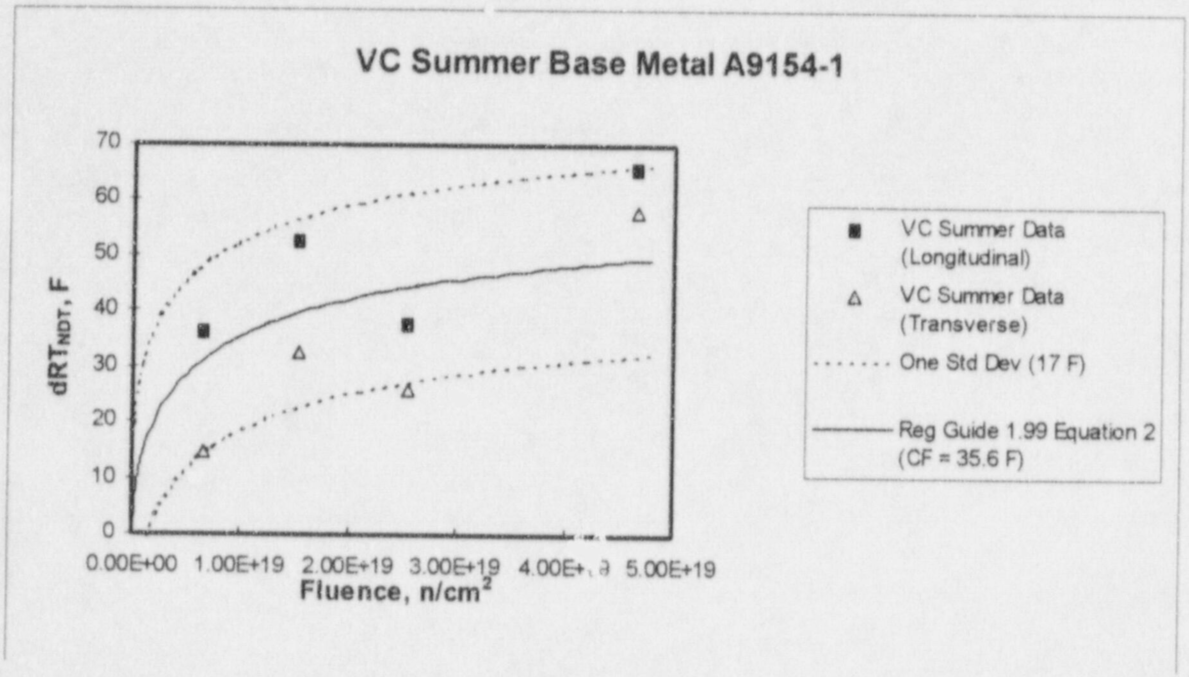
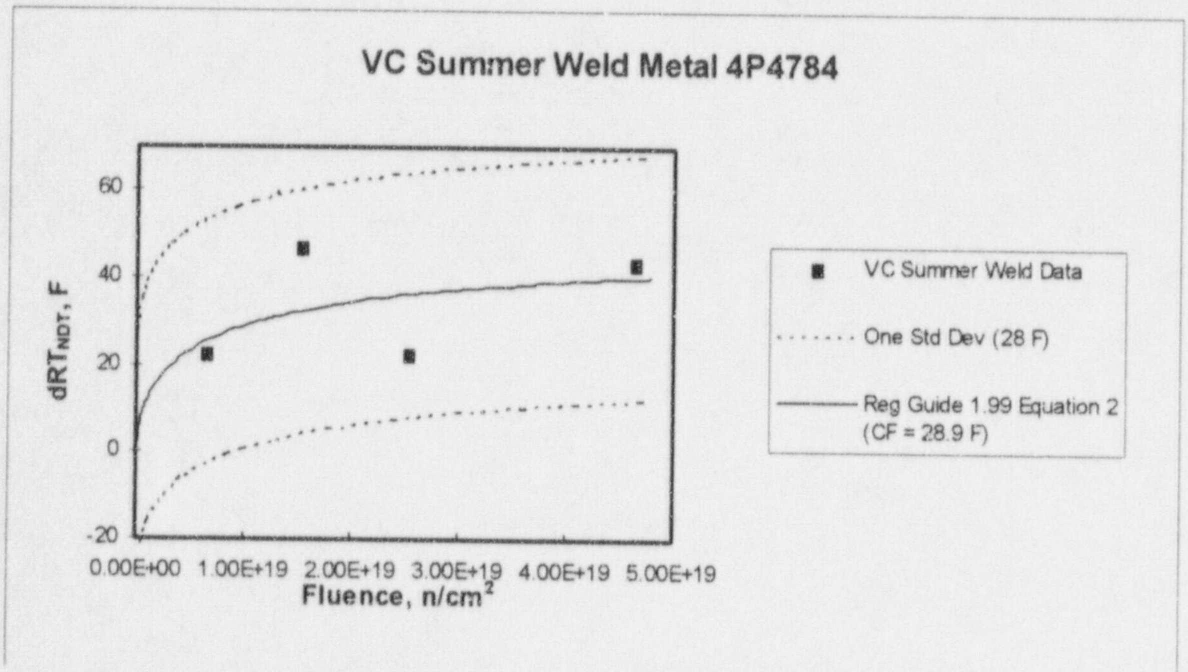


Figure D-2



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 core barrel 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 temperature 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 V.C. Summer Unit 1 surveillance program does not contain correlation monitor material. Therefore, this criterion is not applicable to the V.C. Summer Unit 1 surveillance program.

CONCLUSION:

Based on the preceding responses to all five criteria of Regulatory Guide 1.99, Revision 2, Section B and 10CFR 50.61, the V.C. Summer Unit 1 surveillance data is Credible.