Westinghouse Non-Proprietary Class 3

WCAP-15571
Revision 0

Analysis of Capsule Y from Beaver Valley Unit 1 Reactor Vessel Radiation Surveillance Program

Westinghouse Electric Company, LLC

WESTINGHOUSE NON-PROPRIETARY CLASS 3

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Analysis of Capsule Y from Beaver Valley Unit 1 Reactor Vessel Radiation Surveillance Program

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PREFACE

This report has been technically reviewed and verified by:

Reviewer:

Sections 1 through 5, 7, 8, Appendices A, B, C, D, and E	T. J. Laubham	
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EXECUTIVE SUMMARY

The purpose of this report is to document the results of the testing of surveillance capsule Y from the Beaver Valley Unit 1 reactor vessel. Capsule Y was removed at 14.3 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 14.3 EFPY of plant operation was 1.76×10^{19} n/cm^2 (E> 1.0 MeV). A brief summary of the Charpy V-notch testing results 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 Beaver Valley Unit 1 surveillance data is not credible.

1 SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance capsule Y, the fourth capsule to be removed from the Beaver Valley Unit 1 reactor pressure vessel, led to the following conclusions:

- The Charpy V-notch data presented in WCAP-8475[1], WCAP-9860[54], WCAP-10867[55], and WCAP-12005[56] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1, which is a hyperbolic tangent curve-fitting program. Appendix B presents a comparison of the Charpy V-Notch test results for each capsule based on hand fit vs. hyperbolic tangent fit. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

- Cycle 14 is projected assuming the average exposure rate of cycles 11 through 13. Cycle 15 is projected with the cycle 8 exposure rate, which represents low leakage cycles and an assumption that the hafnium is removed from the PSA assembly locations. From end of cycle 15 to 28 and 45 EFPY, the exposure projection is the cycle 8 exposure rate increased by 1.055 to allow for a "5.5 % core power uprating."

- The capsule received an average fast neutron fluence (E> 1.0 MeV) of 2.15 x 10^{19} n/cm^2 after 14.3 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel lower shell plate B6903-1 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major rolling direction (longitudinal orientation), to 2.15 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 142.18°F and a 50 ft-lb transition temperature increase of 151.29°F. This results in an irradiated 30 ft-lb transition temperature of 138.73°F and an irradiated 50 ft-lb transition temperature of 179.29°F for the longitudinal oriented specimens.

- Irradiation of the reactor vessel lower shell plate B6903-1 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major rolling direction of the plate (transverse orientation), to 2.15 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 166.93°F and a 50 ft-lb transition temperature increase of 178.61°F. This results in an irradiated 30 ft-lb transition temperature of 184.89°F and an irradiated 50 ft-lb transition temperature of 240.50°F for transverse oriented specimens.

- Irradiation of the weld metal Charpy specimens to 2.15 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 179.69°F and a 50 ft-lb transition temperature increase of 213.41°F. This results in an irradiated 30 ft-lb transition temperature of 111.96°F and an irradiated 50 ft-lb transition temperature of 169.35°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 2.15 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 18.36°F and a 50 ft-lb transition temperature increase of 62.51°F. This results in an irradiated 30 ft-lb transition temperature of –56.16°F and an irradiated 50 ft-lb transition temperature of 20.36°F.

- The average upper shelf energy of the lower shell plate B6903-1 (longitudinal orientation) resulted in an average energy decrease of 25 ft-lb after irradiation to 2.15 x 10^{19} n/cm^2 (E > 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 110 ft-lb for the longitudinal oriented specimens.

- The average upper shelf energy of the lower shell plate B6903-1 (transverse orientation) resulted in an average energy decrease of 10 ft-lb after irradiation to 2.15 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 71 ft-lb for the transverse oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted an average energy decrease of 35 ft-lb after irradiation to 2.15 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 77 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 14 ft-lb after irradiation to 2.15 x 10^{19} n/cm^2 (E> 1.0MeV). This results in an irradiated average upper shelf energy of 114 ft-lb for the weld HAZ metal.

- A comparison of the Beaver Valley Unit 1 reactor vessel beltline material test results with the Regulatory Guide 1.99, Revision 2[3] predictions (See Table 5-10) led to the following conclusions:

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

  — The measured percent decrease in upper shelf energy (USE) of all the capsule Y surveillance materials is less than the Regulatory Guide 1.99, Revision 2, predictions.

- The calculated and best estimate end-of-license (28 EFPY) neutron fluence (E> 1.0 MeV) at the core midplane for the Beaver Valley Unit 1 reactor vessel using the Regulatory Guide 1.99, Revision 2 attenuation formula (ie. Equation # 3 in the guide) is as follows:

<u>Calculated:</u> Vessel inner radius* = 3.54 x 10^{19} n/cm^2

Vessel 1/4 thickness = 2.21 x 10^{19} n/cm^2

Vessel 3/4 thickness = 8.58 x 10^{18} n/cm^2

<u>Best Estimate:</u> Vessel inner radius* = 3.42 x 10^{19} n/cm^2

Vessel 1/4 thickness = 2.13 x 10^{19} n/cm^2

Vessel 3/4 thickness = 8.29 x 10^{18} n/cm^2

*Clad/base metal interface

- The credibility evaluation of the Beaver Valley Unit 1 surveillance program presented in Appendix D of this report indicates that the surveillance results of the Beaver Valley Unit 1 surveillance program are not 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 through end of license (28 EFPY) as required by 10CFR50, Appendix G[4].

2 INTRODUCTION

This report presents the results of the examination of Capsule Y, the fourth capsule removed from the reactor in the continuing surveillance program which monitors the effects of neutron irradiation on the First Energy Beaver Valley Unit 1 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the First Energy Beaver Valley 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-8457, "Duquesne Light Company Beaver Valley Unit 1 Reactor Vessel Radiation Surveillance Program" [1]. 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"[14]. Capsule Y was removed from the reactor after 14.3 EFPY of exposure and shipped to the George Westinghouse Technology Center Hot Cell Facility, where the postirradiation mechanical testing of the Charpy V-notch impact and tensile surveillance specimens was performed.

The Charpy V-notch data presented in WCAP-8457[1], WCAP-9860[54], WCAP-10867[55], and WCAP-12005[56] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1, which is a hyperbolic tangent curve-fitting program. Appendix B presents a comparison of the Charpy V-Notch test results for each capsule based on hand fit vs. hyperbolic tangent fit. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

This report summarizes the testing of and the post-irradiation data obtained from surveillance capsule Y removed from the First Energy Beaver Valley 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 SA533 Grade B Class 1 plate (base material of the Beaver Valley 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 [6]. 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[7]) or the temperature 60°F less than the 50 ft-lb (and 35-mil lateral expansion) temperature as determined from Charpy specimens oriented normal (transverse) to the major working direction of the material. The RT_{NDT} of a given material is used to index that material to a reference stress intensity factor curve (K_{IC} curve) which appears in Appendix G to the ASME Code[6]. The K_{IC} curve is a lower bound of static fracture toughness results obtained from several heats of pressure vessel steel. When a given material is indexed to the K_{IC} 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 Beaver Valley Unit 1 reactor vessel radiation surveillance program[1], 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_{IC} 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

Eight surveillance capsules for monitoring the effects of neutron exposure on the Beaver Valley Unit 1 reactor pressure vessel core region (beltline) materials were inserted in the reactor vessel prior to initial plant start-up. The eight capsules were positioned in the reactor vessel between the thermal shield and the vessel wall as shown in Figure 4-1. The vertical center of the capsules is opposite the vertical center of the core. The capsules contain specimens made from Lower Shell Plate B6903-1 (Heat No. C6317-1), weld metal fabricated with 3/16-inch Mil B-4 weld filler wire heat number 305424 Linde 1092 flux lot number 3889, which is identical to that used in the actual fabrication of the beltline region intermediate shell longitudinal weld seams.

Capsule Y was removed after 14.3 effective full power years (EFPY) of plant operation. This capsule contained Charpy V-notch impact and tensile specimens made from Lower Shell Plate B6903-1 and submerged arc weld metal identical to the vessel intermediate shell longitudinal weld seams. In addition, this capsule contained Charpy V-notch specimens from the weld Heat-Affected-Zone (HAZ) of Intermediate Shell Plate B6607-1.

Test material obtained from Lower Shell Plate B6903-1 (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 ¼ thickness locations of the plate after performing a simulated post-weld stress-relieving treatment on the test material. All base metal Charpy V-notch impact specimens were oriented with the longitudinal axis of the specimen both normal to (transverse orientation) and parallel to (longitudinal orientation) principal working direction of the plate. Base metal tensile specimens were oriented in the transverse direction. Charpy V-notch and tensile specimens from the weld metal were oriented with the longitudinal axis of the specimens transverse to the weld direction. The wedge opening loading test specimens in Capsule Y were machined transverse to the welding direction. All WOL specimens were fatigue precracked per ASTM E399-70T. The chemical composition of the unirradiated surveillance material is presented in Table 4-1, while the results of chemical testing of charpy specimens from Capsule Y are presented in Table 4-3. The NIST standards are given in Table 4-4. The heat treatment of the surveillance materials is given in Table 4-2.

Capsule Y 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 Y is shown in Figure 4-2.

TABLE 4-1

Chemical Composition (wt%) of the Unirradiated Beaver Valley Unit 1 Reactor Vessel Surveillance Materials

Element[a]	B6903-1 Ht. C6317-1	As Deposited Weld Metal Analysis[b]	Capsule U Analysis[c]
C	0.20	0.110	0.124
Mn	1.310	1.370	1.42
P	0.010	0.018	0.008
S	0.015	0.006	0.004
Si	0.180	0.270	0.277
Ni	0.540	0.620	0.637
Mo	0.550	0.480	- - [d]
Cr	0.140	0.015	0.029
Cu	0.200	0.260	0.230
Al	0.028	0.010	0.028
Co	0.014	0.014	0.009
V	0.001	0.001	0.008
Sn	0.010	0.008	- -
N_2	0.004	0.014	- -

Notes:

a. Elements not listed are less tan 0.01 weight percent.
b. Surveillance weld used the same heat of weld wire (#305424) and flux lot (3889) as used to fabricate the intermediate shell vertical seams.
c. Analysis performed on irradiated weld metal specimen DW-63
d. Analysis not performed on this material

Table 4-2 Heat Treatment of Beaver Valley Unit 1 Reactor Vessel Surveillance Materials			
Material	**Temperature (°F)**	**Time (hrs.)**	**Coolant**
Lower Shell Plates Plate B6903-1	1550 – 1650	4	Water quenched
	1200 – 1250	4	Air cooled
	1150 – 1175	40	Furnace Cooled
Weldment	1150 ± 25	15	Furnace Cooled

TABLE 4-3 Chemical Composition of the Beaver Valley Unit 1 Charpy Specimens Removed from Surveillance Capsule Y				
Element	**Weld Metal**			**Plate B6903-1**
	DW-91	**DW-92**	**DW-96**	**DL-57**
C	0.140	0.140	0.140	0.220
S	0.009	0.005	0.007	0.016
Si	0.029	0.040	0.053	0.047
Cr	0.022	0.022	0.019	0.140
Cu	0.230	0.220	0.230	0.210
Fe	Balance	Balance	Balance	Balance
Mn	1.403	1.384	1.426	1.195
Mb	0.510	0.500	0.500	0.580
Ni	0.611	0.605	0.615	0.529
P	0.018	0.020	0.018	<0.010
V	<0.005	<0.005	<0.005	<0.005

METHOD OF ANALYSIS:

Metals – Inductiveley Coupled Plasma Spectrometry
Carbon – LECO Analyzer
Sulfur – Combustion/titration
Silicon - Gravimetric

TABLE 4-4

Chemistry Results from the Low Alloy Steel NBS Certified Reference Standards 362, 363, and 364

Element	Concentration in Weight Percent					
	NIST 362		NIST 363		NIST 364	
	Certified	Measured	Certified	Measured	Certified	Measured
C	0.160	0.162	0.620	0.620	0.870	0.870
SiO_2	0.390	0.420	0.740	0.763	0.060	0.064
Cr	0.300	0.287	1.310	1.238	0.060	0.057
Cu	0.500	0.430	0.100	0.105	0.240	0.219
Fe	95.30	98.064	94.40	93.078	96.70	94.283
Mn	1.040	0.952	1.500	1.362	0.250	0.240
Mb	0.068	0.062	0.028	0.027	0.490	0.498
Ni	0.590	0.544	0.300	0.267	0.140	0.123
P	0.041	0.041	0.020	0.017	0.010	0.011
V	0.040	0.037	0.310	0.284	0.100	0.096

Notes:
NBS 361: Certified C % = 0.383
Measured C % = 0.387

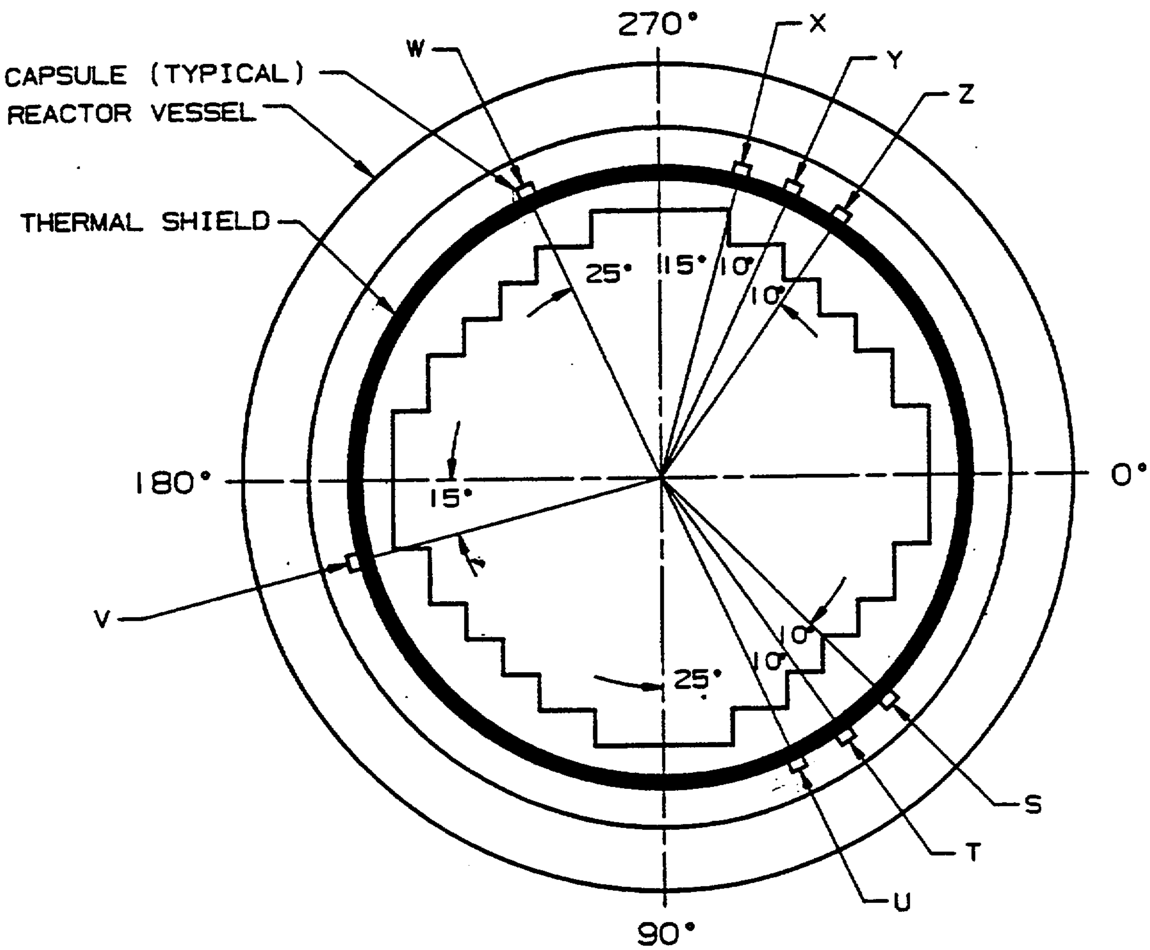


Figure 4-1 **Arrangement of Surveillance Capsules in the Beaver Valley Unit 1 Reactor Vessel**

SPECIMEN CODE:

DL LOWER SHELL PLATE B6903-1 (LONGITUDINAL DIRECTION)
DT LOWER SHELL PLATE B6903-1 (TRANSVERSE DIRECTION)
DW WELD METAL
DH HEAT-AFFECTED-ZONE MATERIAL

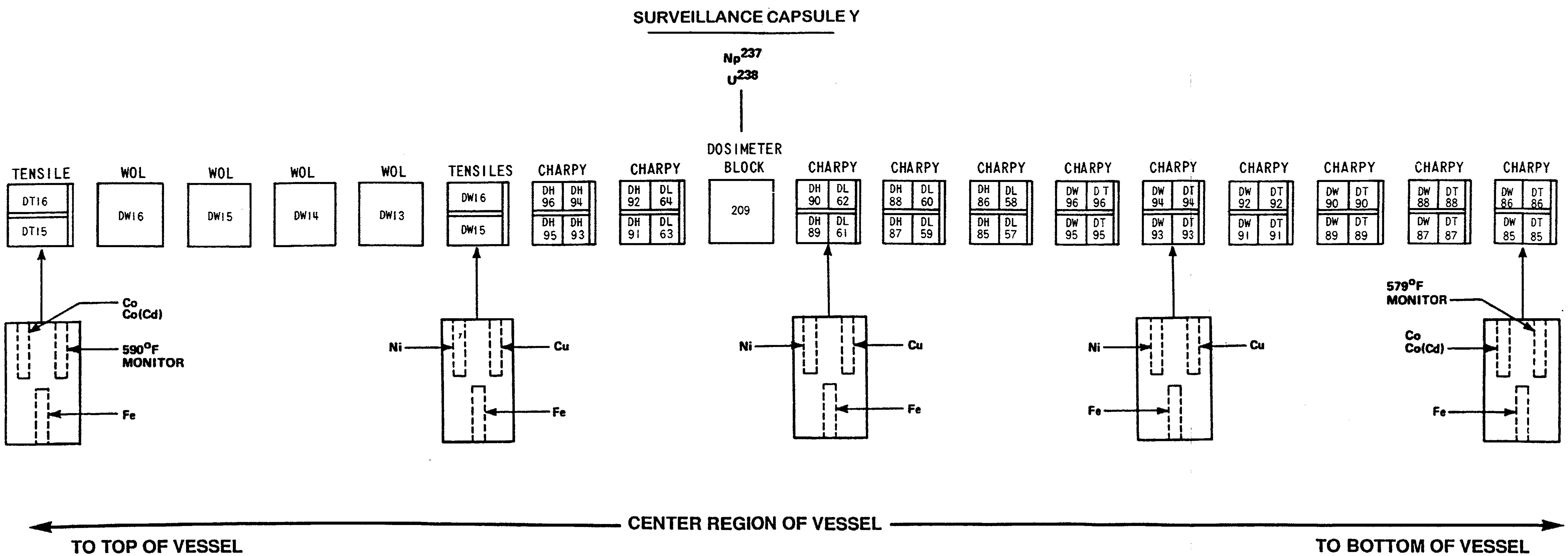


Figure 4-2 **Capsule Y Diagram Showing the Location of Specimens, Thermal Monitors, and Dosimeters.**

5 TESTING OF SPECIMENS FROM CAPSULE Y

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 George Westinghouse Technology Center. Testing was performed in accordance with 10CFR50, Appendix H[8], ASTM Specification E185-82[5], and Westinghouse Procedure MHL 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-8457[1]. 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 E23-98 [9] and Procedure RMF 8103, 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),

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

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

$$\sigma_y = 33.3 * P_{GY} \tag{3}$$

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:

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

Percent shear was determined from post-fracture photographs using the ratio-of-areas methods in compliance with ASTM E23-98[9]and A370-97[10]. 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 E8-99[11] and E21-92[12], and RMF Procedure 8102, Revision 1.

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 E83-96[13].

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.

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 Y, irradiated to a fluence of 2.15 x 10^{19} n/cm^2 (E> 1.0 MeV) in 14.3 EFPY of operation are presented in Tables 5-1 through 5-8 and are compared with unirradiated results[1] in Figures 5-1 through 5-12. The transition temperature increases and upper shelf energy decreases for the capsule Y materials are summarized in Table 5-9.

A comparison of the surveillance material 30 ft-lb transition temperature shifts and the upper shelf energy decreases with the Regulatory Guide 1.99, Revision 2, predictions is given in Table 5-10. These results led to the following conclusions:

- Irradiation of the reactor vessel lower shell plate B6903-1 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major rolling direction (longitudinal orientation), to 2.15 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 142.18°F and a 50 ft-lb transition temperature increase of 151.29°F. This results in an irradiated 30 ft-lb transition temperature of 138.73°F and an irradiated 50 ft-lb transition temperature of 179.29°F for the longitudinal oriented specimens.

- Irradiation of the reactor vessel lower shell plate B6903-1 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major rolling direction of the plate (transverse orientation), to 2.15 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 166.93°F and a 50 ft-lb transition temperature increase of 178.61°F. This results in an irradiated 30 ft-lb transition temperature of 184.89°F and an irradiated 50 ft-lb transition temperature of 240.50°F for transverse oriented specimens.

- Irradiation of the weld metal Charpy specimens to 2.15 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 179.69°F and a 50 ft-lb transition temperature increase of 213.41°F. This results in an irradiated 30 ft-lb transition temperature of 111.96°F and an irradiated 50 ft-lb transition temperature of 169.35°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 2.15 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 18.36°F and a 50 ft-lb transition temperature increase of 62.51°F. This results in an irradiated 30 ft-lb transition temperature of –56.16°F and an irradiated 50 ft-lb transition temperature of 20.36°F.

- The average upper shelf energy of the lower shell plate B6903-1 (longitudinal orientation) resulted in an average energy decrease of 25 ft-lb after irradiation to 2.15 x 10^{19} n/cm^2 (E > 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 110 ft-lb for the longitudinal oriented specimens.

- The average upper shelf energy of the lower shell plate B6903-1 (transverse orientation) resulted in an average energy decrease of 10 ft-lb after irradiation to 2.15 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 71 ft-lb for the transverse oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted an average energy decrease of 35 ft-lb after irradiation to 2.15 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 77 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 14 ft-lb after irradiation to 2.15 x 10^{19} n/cm^2 (E> 1.0MeV). This results in an irradiated average upper shelf energy of 114 ft-lb for the weld HAZ metal.

- A comparison of the Beaver Valley Unit 1 reactor vessel beltline material test results with the Regulatory Guide 1.99, Revision 2[3] predictions (See Table 5-10) led to the following conclusions:

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

  — The measured percent decrease in upper shelf energy (USE) of all the capsule Y surveillance materials is less than the Regulatory Guide 1.99, Revision 2, predictions.

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

All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are expected to maintain an upper shelf energy of no less than 50 ft-lb throughout the current license of the vessel (28 EFPY) as required by 10CFR50, Appendix G[4].

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

The Charpy V-notch data presented in WCAP-8457[1] , WCAP-9860[54], WCAP-10867[55],and WCAP-12005[56] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1, which is a hyperbolic tangent curve-fitting program. Appendix B presents a comparison of the Charpy V-Notch test results for each capsule based on hand fit vs. hyperbolic tangent fit. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

Appendix D of this report contains a credibility evaluation of the surveillance data from the Beaver Valley Unit 1 reactor vessel surveillance program. This evaluation indicates that the surveillance results are not credible.

5.3 TENSILE TEST RESULTS

The results of the tensile tests performed on the various materials contained in capsule Y irradiated to 2.15×10^{19} n/cm^2 (E> 1.0 MeV) are presented in Table 5-11 and are compared with unirradiated results[1] as shown in Figures 5-17 and 5-18.

The results of the tensile tests performed on the lower shell plate B6903-1 (transverse orientation) indicated that irradiation to 2.15×10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 26 ksi increase in the 0.2 percent offset yield strength and approximately a 15 to 20 ksi increase in the ultimate tensile strength when compared to unirradiated data[1] (Figure 5-17).

The results of the tensile tests performed on the surveillance weld metal indicated that irradiation to 2.15×10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 19 ksi increase in the 0.2 percent offset yield strength and a 15 to 20 ksi increase in the ultimate tensile strength when compared to unirradiated data[1] (Figure 5-18).

The fractured tensile specimens for the lower shell plate B6903-1 material are shown in Figure 5-19 and, while the fractured tensile specimens for the surveillance weld metal are shown in Figure 5-20. The engineering stress-strain curves for the tensile tests are shown in Figures 5-21 and 5-22.

5.4 WEDGE OPENING LOADING (WOL)

Per the surveillance capsule testing contract, the WOL Specimens were not tested and are being stored at the George Westinghouse Technology Center Hot Cell facility.

Table 5-1 Charpy V-notch Data for the Beaver Valley Unit 1 Lower Shell Plate B6903-1 Irradiated to a Fluence of 2.15 x 10^{19} n/cm^2 (E> 1.0 MeV) (Longitudinal Orientation)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	F	C	Ft-lbs	Joules	mils	Mm	%
DL62	100	38	10	14	5	0.13	10
DL58	110	43	16	22	10	0.25	15
DL63	125	52	38	52	20	0.51	20
DL59	150	66	43	58	26	0.66	25
DL61	200	93	44	60	28	0.71	35
DL64	250	121	91	123	63	1.60	75
DL57	300	149	106	144	74	1.88	95
DL60	375	191	113	153	78	1.98	100

Table 5-2 Charpy V-notch Data for the Beaver Valley Unit 1 Lower Shell Plate B6903-1 Irradiated to a Fluence of 2.15 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	%
DT95	100	38	12	16	5	0.13	10
DT90	150	66	25	34	15	0.38	15
DT89	180	82	26	35	18	0.46	20
DT87	195	91	34	46	20	0.51	25
DT88	200	93	31	42	21	0.53	25
DT91	225	107	37	50	29	0.74	40
DT96	235	113	51	69	37	0.94	60
DT93	250	121	58	79	48	1.22	0
DT92	275	135	59	80	49	1.24	95
DT94	300	149	67	91	55	1.40	95
DT85	350	177	70	95	53	1.35	100
DT86	375	191	72	98	64	1.63	100

Table 5-3 Charpy V-notch Impact Data for Beaver Valley Unit 1 Surveillance Weld Metal Irradiated to a Fluence of 2.15 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	%
DW93	0	-18	16	22	4	0.10	5
DW86	50	10	13	18	4	0.10	5
DW95	100	38	24	33	16	0.41	55
DW88	110	43	32	43	20	0.51	35
DW87	115	46	32	43	20	0.51	40
DW94	135	57	37	50	25	0.64	50
DW89	150	66	43	58	28	0.71	50
DW85	175	79	48	65	37	0.94	75
DW90	200	93	50	68	37	0.94	80
DW92	225	107	74	100	57	1.45	95
DW91	250	121	74	100	55	1.40	98
DW96	300	149	80	108	60	1.52	100

Table 5-4 Charpy V-notch Impact Data for Beaver Valley Unit 1 Representative Heat Affected Zone Material Irradiated to a Fluence of 2.15 x 10^{19} n/cm^2 (E> 1.0 MeV)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	F	C	Ft-lbs	Joules	mils	mm	%
DH86	-100	-73	19	26	9	0.23	5
DH78	-50	-46	24	33	12	0.30	20
DH88	-40	-40	28	38	13	0.33	20
DH85	-25	-32	53	72	26	0.66	35
DH94	0	-18	43	58	20	0.51	50
DH87	10	-12	46	62	12	0.30	60
DH93	50	10	54	73	30	0.76	45
DH96	72	22	81	110	49	1.24	50
DH92	125	52	68	92	41	1.04	80
DH95	175	79	86	117	54	1.37	85
DH91	225	107	106	144	68	1.73	100
DH90	300	149	107	145	62	1.57	100

Table 5-5 Instrumented Charpy Impact Test Results for the Beaver Valley Unit 1 Lower Shell Plate B6903-1 Irradiated to a Fluence of 2.15 x 10^{19} n/cm^2 (E>1.0 MeV)(Longitudinal Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2) Charpy E_D/A	Max. E_M/A	Prop. E_p/A	Yield Load P_{GY} (lb.)	Time to Yield t_{GY} (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)
DL62	100	10	81	44	36	3950	0.18	3957	0.18	3950	0	132	132
DL58	110	16	129	64	65	4116	0.17	4424	0.21	4424	0	137	142
DL63	125	38	306	251	55	3950	0.17	4856	0.53	4827	0	132	147
DL59	150	43	346	251	96	3939	0.17	4835	0.53	4764	0	131	146
DL61	200	44	355	236	119	3891	0.17	4786	0.51	4777	880	130	144
DL64	250	91	733	323	410	3611	0.17	4649	0.68	4042	2780	120	138
DL57	300	106	854	311	543	3547	0.17	4585	0.67	3653	3019	118	135
DL60	375	113	910	315	595	3422	0.17	4506	0.69	n/a	n/a	114	132

Table 5-6 Instrumented Charpy Impact Test Results for the Beaver Valley Unit 1 Lower Shell Plate B6903-1 Irradiated to a Fluence of 2.15 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 ($ft\text{-}lb/in^2$) Charpy E_D/A	Max. E_M/A	Prop. E_p/A	Yield Load P_{GY} (lb.)	Time to Yield t_{GY} (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)
DT95	100	12	97	50	47	4059	0.17	4192	0.19	4176	0	135	137
DT90	150	25	201	143	59	3817	0.17	4457	0.36	4284	0	127	138
DT89	180	26	209	115	95	3839	0.17	4214	0.31	4119	1170	128	134
DT87	195	34	274	172	102	3883	0.17	4503	0.41	4479	921	129	140
DT88	200	31	250	139	110	3790	0.17	4338	0.35	4302	1298	126	135
DT91	225	37	298	139	159	3671	0.17	4237	0.36	4184	1857	122	132
DT96	235	51	411	223	188	3685	0.17	4522	0.51	4453	2361	123	137
DT93	250	58	467	202	265	3616	0.17	4304	0.48	3486	2724	120	132
DT92	275	59	475	176	300	3586	0.17	4267	0.44	3458	2535	119	131
DT94	300	67	560	214	326	3588	0.17	4440	0.5	3367	2480	119	134
DT85	350	70	264	212	352	3566	0.17	4385	0.5	n/a	n/a	119	132
DT86	375	72	580	209	371	3447	0.17	4257	0.5	n/a	n/a	115	128

Table 5-7 Instrumented Charpy Impact Test Results for the Beaver Valley Unit 1 Surveillance Weld Metal Irradiated to a Fluence of 2.15 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								
DW93	0	16	129	73	56	4493	0.17	4860	0.22	4851	0	150	156
DW86	50	13	105	60	45	4344	0.17	4578	0.20	4578	0	145	149
DW95	100	24	193	72	122	4175	0.17	4571	0.22	4423	911	139	146
DW88	110	32	258	169	89	4139	0.17	4520	0.38	4495	363	138	144
DW87	115	32	258	175	83	3882	0.17	4642	0.54	4627	670	129	142
DW94	135	37	298	199	99	4095	0.17	4577	0.44	4544	1111	136	144
DW89	150	43	346	232	114	3914	0.17	4617	0.51	4581	1345	130	142
DW85	175	48	387	229	158	3939	0.17	4597	0.50	4363	1610	131	142
DW90	200	50	403	216	186	3945	0.17	4524	0.48	4637	625	131	141
DW92	225	74	596	226	370	3892	0.17	4539	0.50	n/a	n/a	130	140
DW91	250	74	596	218	378	3901	0.17	4571	0.48	n/a	n/a	130	141
DW96	300	80	645	224	420	3727	0.17	4427	0.51	n/a	n/a	124	136

Table 5-8 Instrumented Charpy Impact Test Results for the Beaver Valley Unit 1 Representative Heat-Affected-Zone (HAZ) Metal Irradiated to a Fluence of 2.15 x 10^{19} n/cm^2 (E>1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2) Charpy E_D/A	Max. E_M/A	Prop. E_p/A	Yield Load P_{GY} (lb.)	Time to Yield t_{GY} (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)
DH86	-100	19	153	95	58	4599	0.17	5707	0.25	5703	0	153	172
DH78	-50	24	193	85	109	4508	0.17	5160	0.23	5014	0	150	161
DH88	-40	28	226	79	147	4755	0.17	5217	0.22	5021	0	158	166
DH85	-25	53	427	260	167	4673	0.17	5216	0.50	5024	625	156	165
DH94	0	43	346	228	119	4639	0.17	5238	0.45	5196	1199	154	164
DH87	10	46	371	231	140	4473	0.17	5109	0.46	5039	1286	149	160
DH93	50	54	435	250	185	4443	0.17	5114	0.50	4999	598	148	159
DH96	72	81	653	257	395	4487	0.17	5164	0.50	4317	1544	149	161
DH92	125	68	548	237	311	4291	0.17	4830	0.49	4344	1260	143	152
DH95	175	86	693	254	469	4101	0.17	4843	0.53	4086	1828	137	149
DH91	225	106	854	344	511	4121	0.17	4859	0.68	n/a	n/a	137	150
DH90	300	107	862	322	540	3850	0.17	4612	0.67	n/a	n/a	128	141

Table 5-9 Effect of Irradiation to 2.15 x 10^{19} n/cm^2 (E>1.0 MeV) on the Notch Toughness Properties of the Beaver Valley 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[a] at Full Shear (ft-lb)		
	Unirradiated	*Irradiated*	*ΔT*	*Unirradiated*	*Irradiated*	*ΔT*	*Unirradiated*	*Irradiated*	*ΔT*	*Unirradiated*	*Irradiated*	*ΔE*
Lower Shell Plate B6903-1 (Long.)	-3.45	138.73	142.18	25.52	191.60	166.07	27.99	179.29	151.29	135	110	-25
Lower Shell Plate B6903-1 (Trans.)	17.95	184.89	166.93	43.59	230.43	186.84	61.89	240.50	178.61	81	71	-10
Weld Metal	-67.72	111.96	179.69	-48.77	169.8	218.58	-44.05	169.35	213.41	112	77	-35
HAZ Metal	-74.53	-56.16	18.36	-32.05	63.24	95.29	-42.15	20.36	62.51	128	114	-14

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 Beaver Valley 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)
Lower Shell Plate B6903-1 (Longitudinal)	V	.323	101.4	128.49	23	16
	U	.646	129.2	118.93	28	22
	W	.986	146.6	148.52	31	16
	Y	2.15	178.1	142.18	37	19
Lower Shell Plate B6903-1 (Transverse)	V	.323	101.4	137.81	23	7
	U	.646	129.2	131.84	28	4
	W	.986	146.6	179.99	31	27
	Y	2.15	178.1	166.93	37	12
Weld Metal	V	.323	125.1	159.72	31	21
	U	.646	159.4	166.32	36	26
	W	.986	180.9	187.73	40	30
	Y	2.15	219.7	179.69	44	31
HAZ Metal	V	.323	- -	0(d)	- - -	15
	U	.646	- -	49.67	- - -	18
	W	.986	- -	61.4	- - -	16
	Y	2.15	- -	18.36	- - -	11

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.

(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.

(d) The actual measured capsule Y ΔRT_{NDT} value is –8.62°F. This physically should not occur, therefore for conservatism a value of zero will be reported.

Table 5-11 Tensile Properties of the Beaver Valley Unit 1 Reactor Vessel Surveillance Materials Irradiated to 2.15 x 10^{19} n/cm^2 (E > 1.0 MeV)

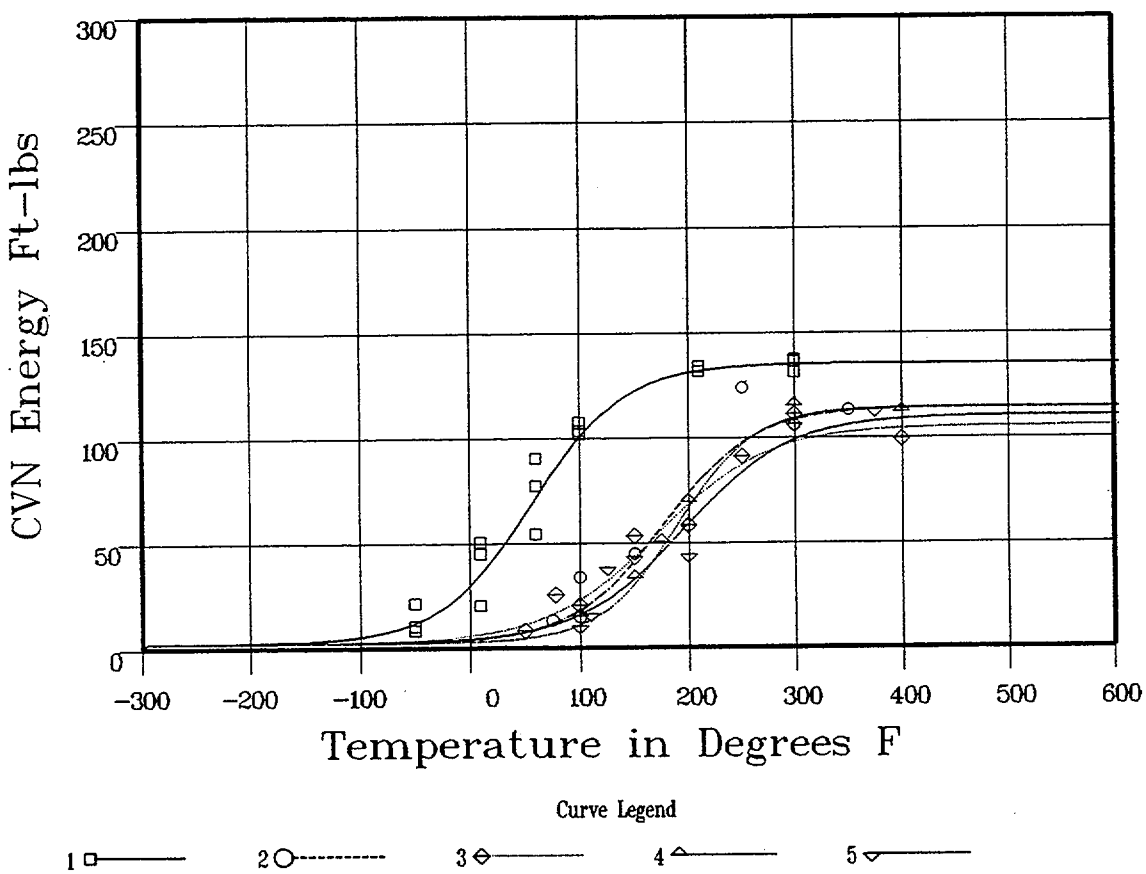
Material	Sample Number	Test Temp. (°F)	0.2% Yield Strength (ksi)	Ultimate Strength (ksi)	Fracture Load (kip)	Fracture Stress (ksi)	Fracture Strength (ksi)	Uniform Elongation (%)	Total Elongation (%)	Reduction in Area (%)
Plate B6903-1 (Transverse)	DT 15	200	81.8	100.2	3.93	185.9	80.0	10.4	19.0	57
	DT 16	550	81.0	97.6	4.11	151.3	83.7	9.3	15.5	45
Weld	DW 15	150	86.6	100.7	3.37	180.8	68.6	10.3	21.9	62
	DW 16	550	78.9	95.6	3.98	137.5	81.1	9.4	16.5	41

LOWER SHELL PLATE 6903-1 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:14:22 on 05-15-2000

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	135	0	-3.45	0	27.99	0
2	0	2.19	0	114	-21	125.04	128.49	159.3	131.3
3	0	2.19	0	105	-30	115.47	118.93	158.7	130.7
4	0	2.19	0	114	-21	145.07	148.52	174.23	146.23
5	0	2.19	0	110	-25	138.73	142.18	179.29	151.29



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV1	UNIRR	PLATE SA533B1	LT	C6317-1
2	BV1	V	PLATE SA533B1	LT	C6317-1
3	BV1	U	PLATE SA533B1	LT	C6317-1
4	BV1	W	PLATE SA533B1	LT	C6317-1
5	BV1	Y	PLATE SA533B1	LT	C6317-1

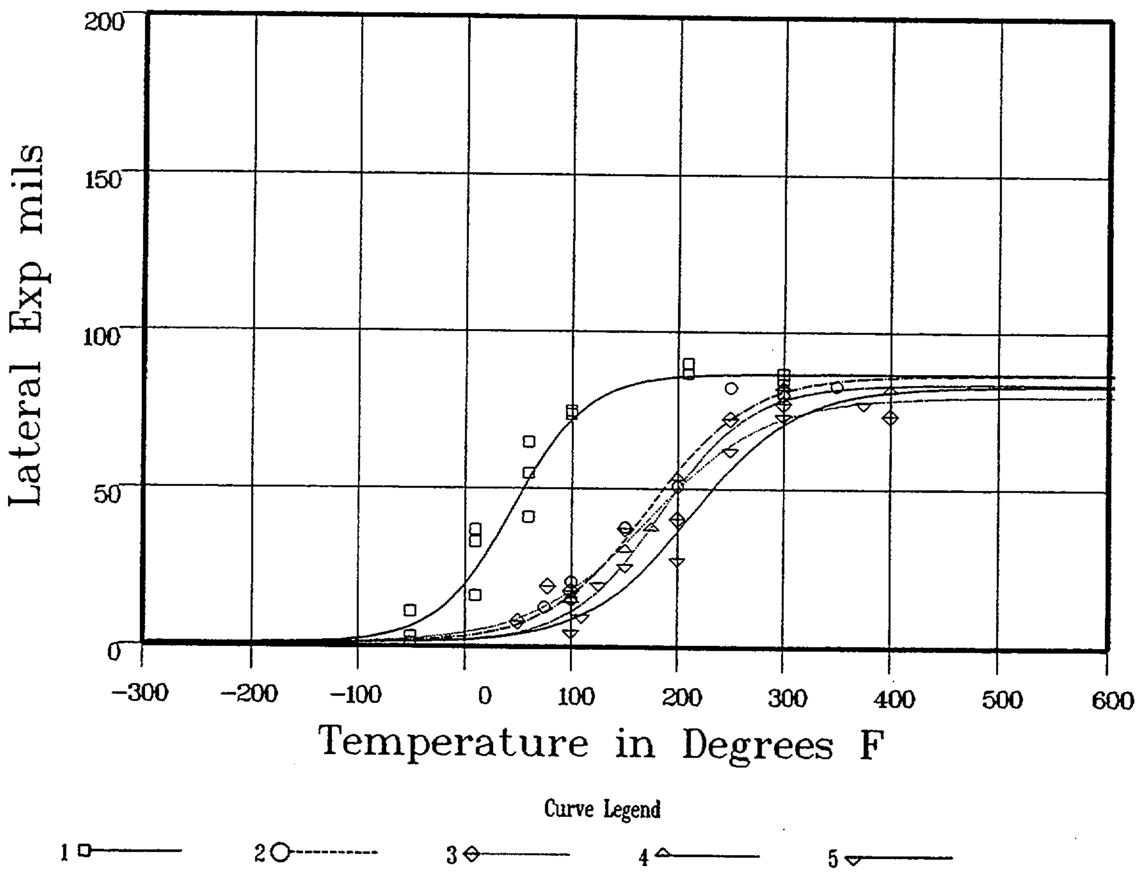
Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Beaver Valley Unit 1 Reactor Vessel Lower Shell Plate B6903-1(Longitudinal Orientation)

LOWER SHELL PLATE 6903-1 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:17:23 on 05-15-2000

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	86.85	0	25.52	0
2	0	86.69	-.16	147.9	122.37
3	0	79.79	-7.06	152.27	126.74
4	0	83.72	-3.13	163.9	138.37
5	0	83.12	-3.73	191.6	166.07



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV1	UNIRR	PLATE SA533B1	LT	C6317-1
2	BV1	V	PLATE SA533B1	LT	C6317-1
3	BV1	U	PLATE SA533B1	LT	C6317-1
4	BV1	W	PLATE SA533B1	LT	C6317-1
5	BV1	Y	PLATE SA533B1	LT	C6317-1

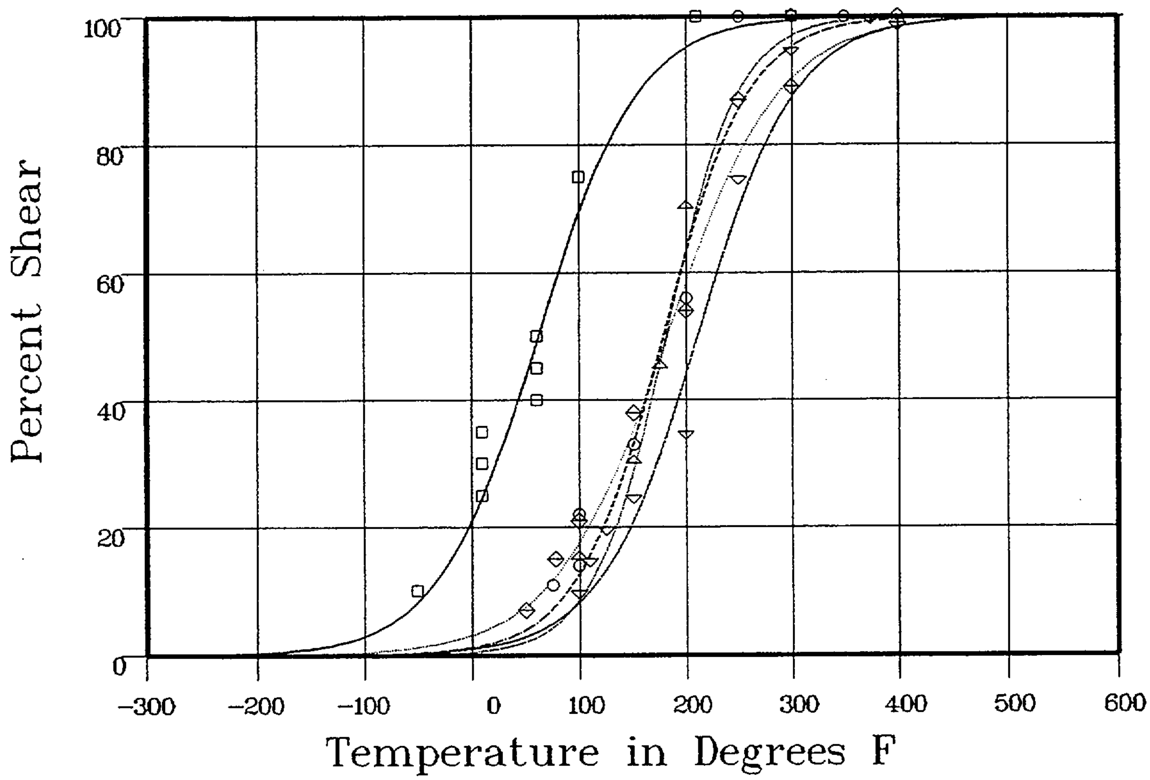
Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Beaver Valley Unit 1 Reactor Vessel Lower Shell Plate B6903-1(Longitudinal Orientation)

LOWER SHELL PLATE 6903-1 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:22:32 on 05-15-2000

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	57.18	0
2	0	173.43	116.25
3	0	177.3	120.12
4	0	176.36	119.17
5	0	206.31	149.12



Curve Legend

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

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV1	UNIRR	PLATE SA533B1	LT	C6317-1
2	BV1	V	PLATE SA533B1	LT	C6317-1
3	BV1	U	PLATE SA533B1	LT	C6317-1
4	BV1	W	PLATE SA533B1	LT	C6317-1
5	BV1	Y	PLATE SA533B1	LT	C6317-1

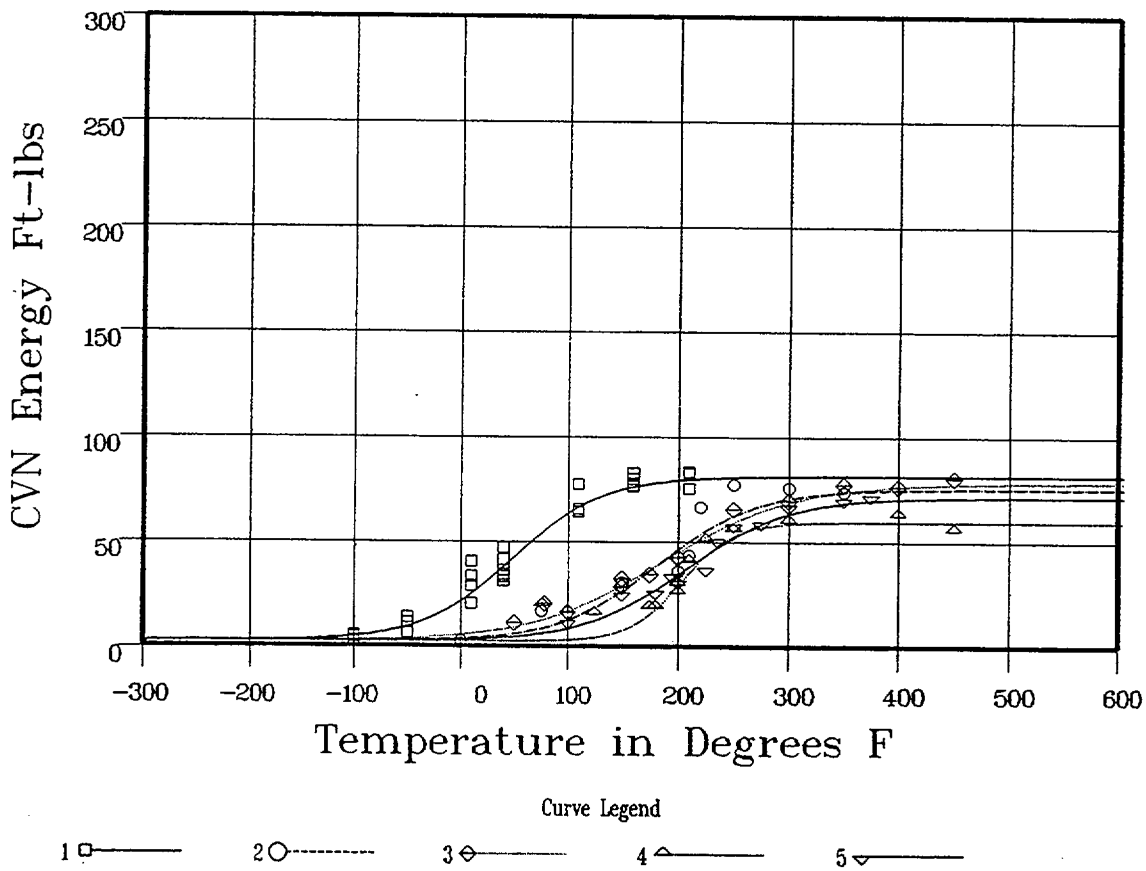
Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Beaver Valley Unit 1 Reactor Vessel Lower Shell Plate B6903-1(Longitudinal Orientation)

LOWER SHELL PLATE 6903-1 (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:29:45 on 05-15-2000

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	81	0	17.95	0	61.89	0
2	0	2.19	0	75	-6	155.77	137.81	206.14	144.25
3	0	2.19	0	78	-3	149.8	131.84	213.28	151.39
4	0	2.2	0	59	-22	197.94	179.99	237.57	175.68
5	0	2.19	0	71	-10	184.89	166.93	240.5	178.61



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV1	UNIRR	PLATE SA533B1	TL	C6317-1
2	BV1	V	PLATE SA533B1	TL	C6317-1
3	BV1	U	PLATE SA533B1	TL	C6317-1
4	BV1	W	PLATE SA533B1	TL	C6317-1
5	BV1	Y	PLATE SA533B1	TL	C6317-1

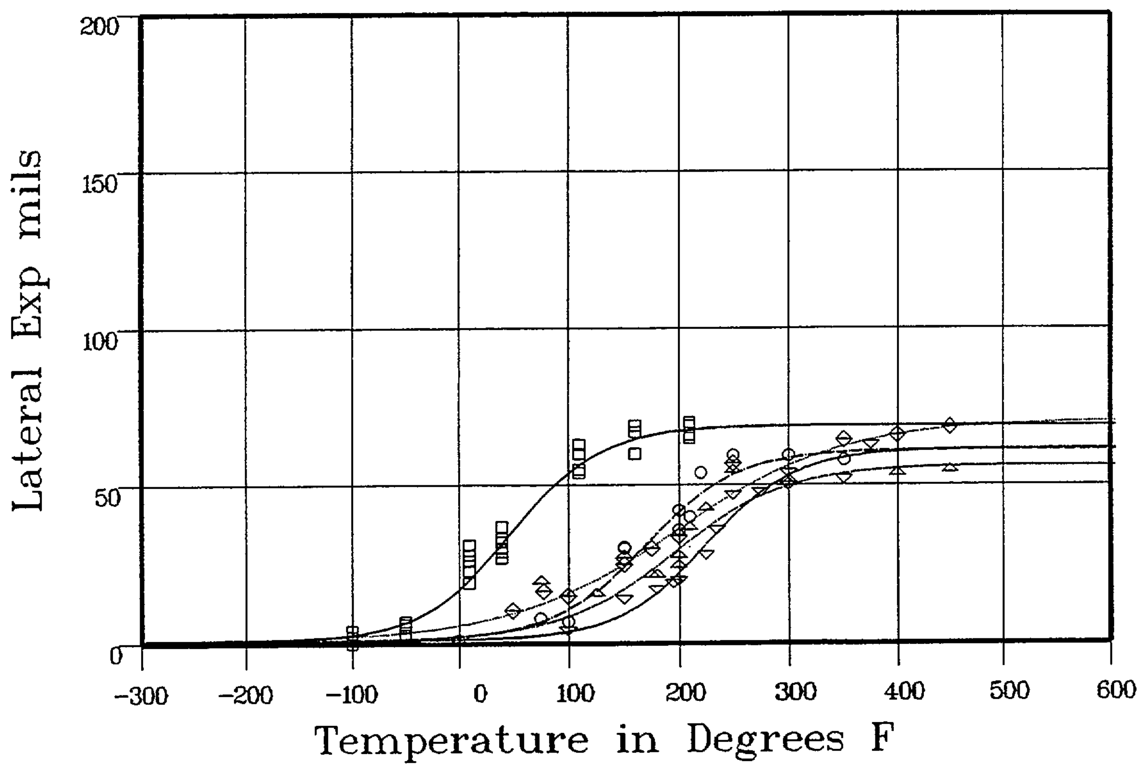
Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Beaver Valley Unit 1 Reactor Vessel Lower Shell Plate B6903-1(Transverse Orientation)

LOWER SHELL PLATE C6317-1 (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 07:30:41 on 07-10-2000

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	69.04	0	43.59	0
2	0	61.27	-7.77	175.55	131.96
3	0	70.57	1.52	189.65	146.06
4	0	56.29	-12.75	214.58	170.99
5	0	61.54	-7.49	230.43	186.84



Curve Legend

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

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV1	UNIRR	PLATE SA533B1	TL	C6317-1
2	BV1	V	PLATE SA533B1	TL	C6317-1
3	BV1	U	PLATE SA533B1	TL	C6317-1
4	BV1	W	PLATE SA533B1	TL	C6317-1
5	BV1	Y	PLATE SA533B1	TL	C6317-1

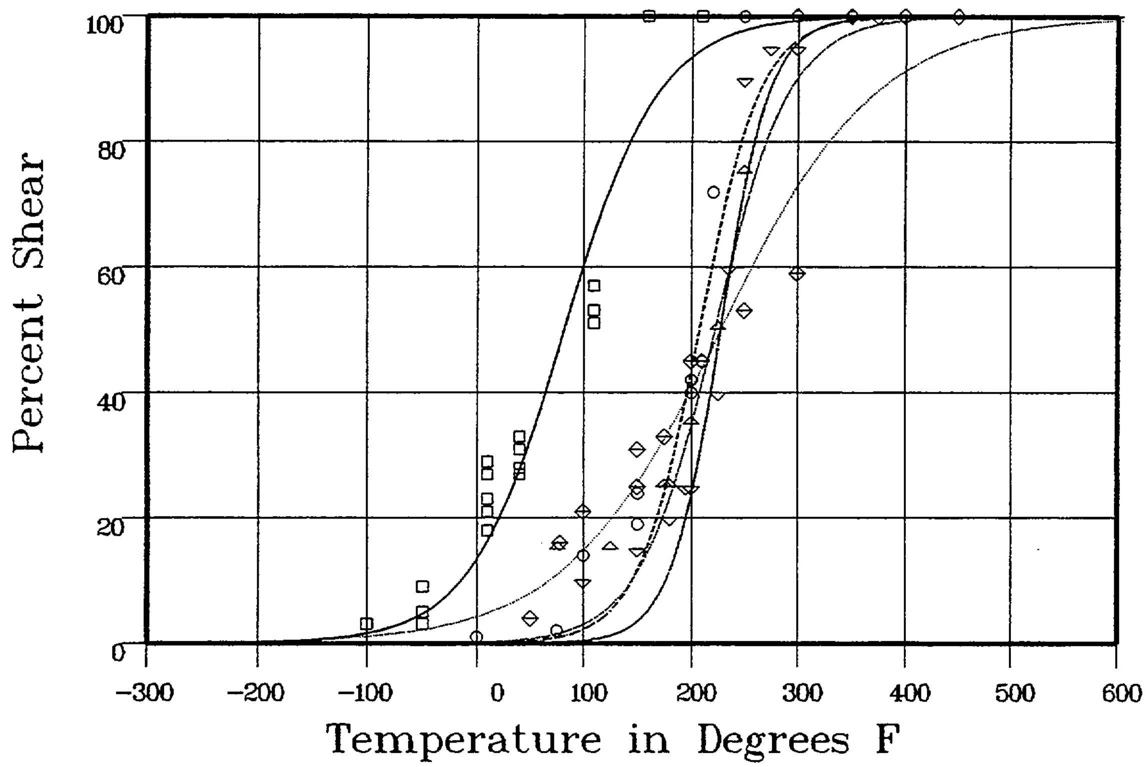
Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Beaver Valley Unit 1 Reactor Vessel Lower Shell Plate B6903-1(Transverse Orientation)

LOWER SHELL PLATE C6317-1 (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 07:27:39 on 07-10-2000

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	77.34	0
2	0	202.89	125.55
3	0	223.15	145.81
4	0	217.5	140.15
5	0	222.65	145.31



Curve Legend

1 □—— 2 ○------ 3 ◇—— 4 △—— 5 ▽——

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV1	UNIRR	PLATE SA533B1	TL	C6317-1
2	BV1	V	PLATE SA533B1	TL	C6317-1
3	BV1	U	PLATE SA533B1	TL	C6317-1
4	BV1	W	PLATE SA533B1	TL	C6317-1
5	BV1	Y	PLATE SA533B1	TL	C6317-1

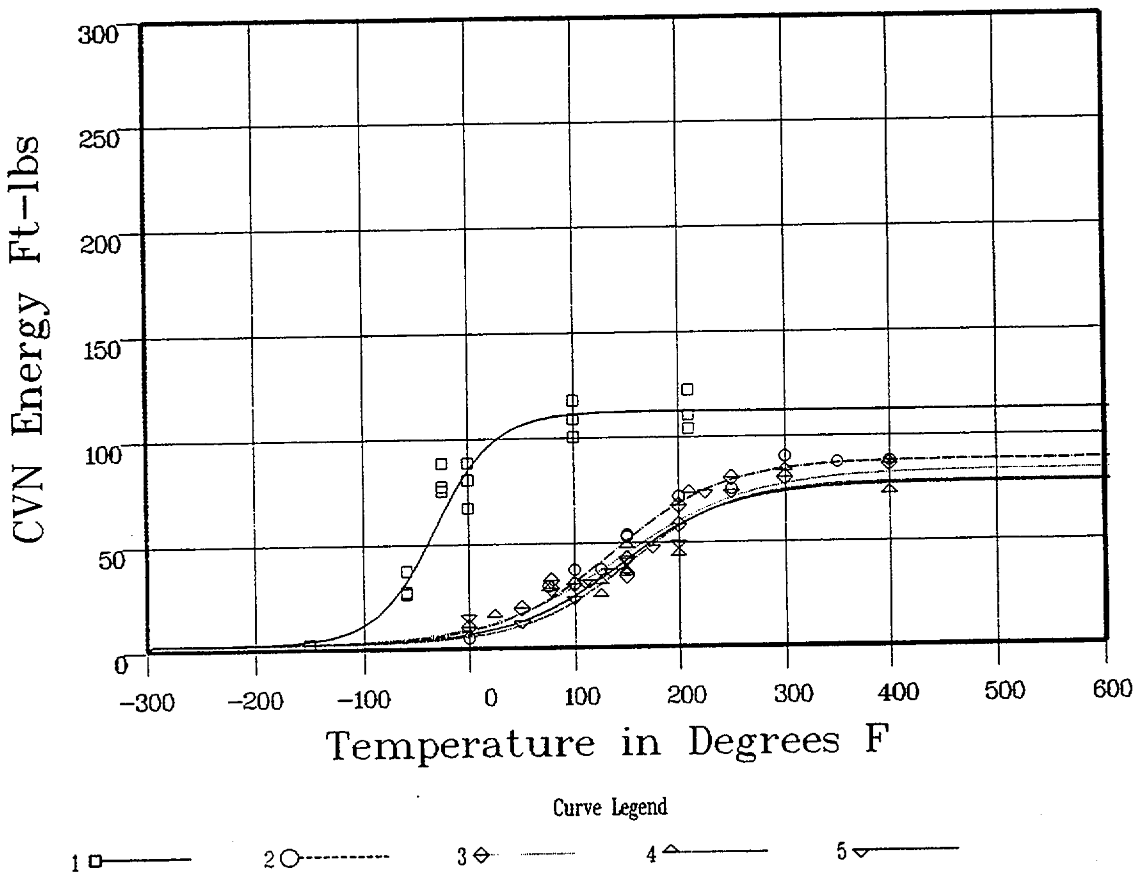
Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Beaver Valley Unit 1 Reactor Vessel Lower Shell Plate B6903-1(Transverse Orientation)

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:28:58 on 05-16-2000

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	112	0	-67.72	0	-44.05	0
2	0	2.19	0	88	-24	91.99	159.72	143.49	187.55
3	0	2.19	0	83	-29	98.59	166.32	161.52	205.58
4	0	2.19	0	78	-34	120.01	187.73	173.56	217.62
5	0	2.19	0	77	-35	111.96	179.69	169.35	213.41



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV1	UNIRR	WELD		305424
2	BV1	V	WELD		305424
3	BV1	U	WELD		305424
4	BV1	W	WELD		305424
5	BV1	Y	WELD		305424

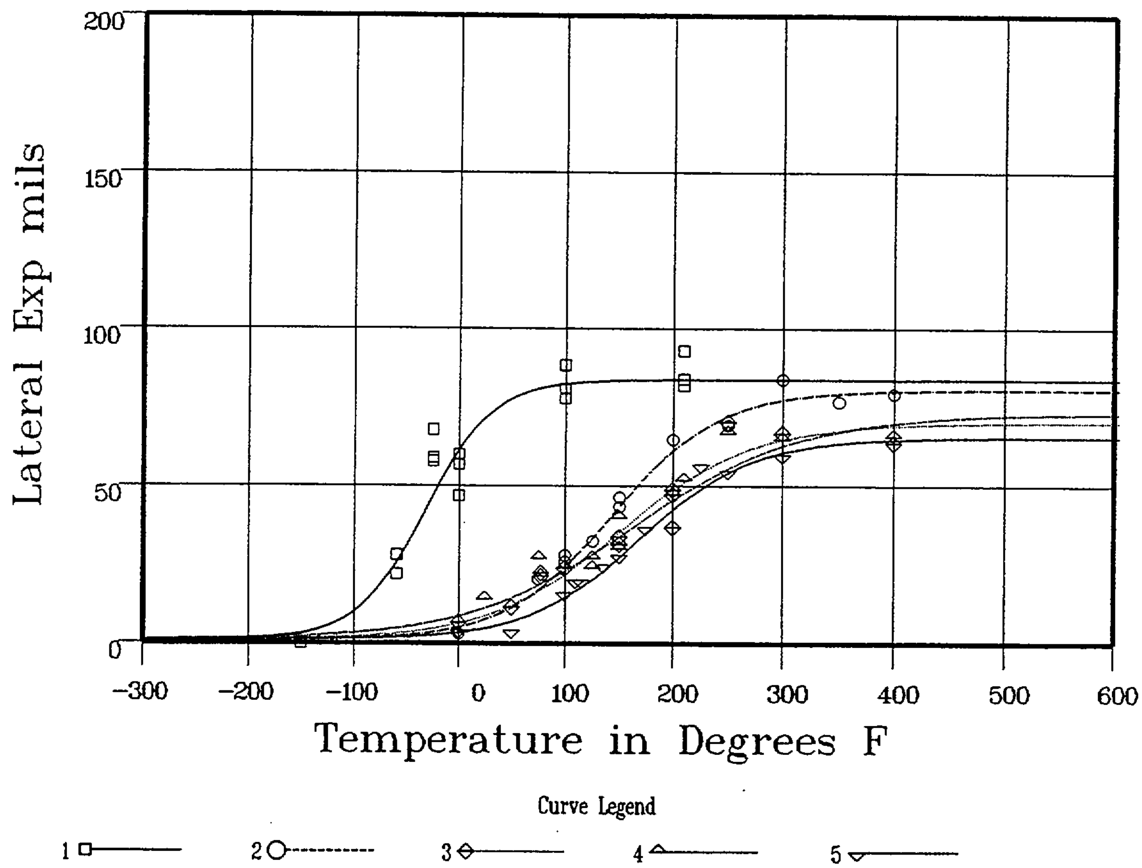
Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for Beaver Valley Unit 1 Reactor Vessel Weld Metal

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:38:21 on 05-16-2000

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	83.89	0	-48.77	0
2	0	80.7	-3.18	124.28	173.05
3	0	70.44	-13.44	143.72	192.5
4	0	73.38	-10.5	149.2	197.98
5	0	65.72	-18.16	169.8	218.58



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV1	UNIRR	WELD		305424
2	BV1	V	WELD		305424
3	BV1	U	WELD		305424
4	BV1	W	WELD		305424
5	BV1	Y	WELD		305424

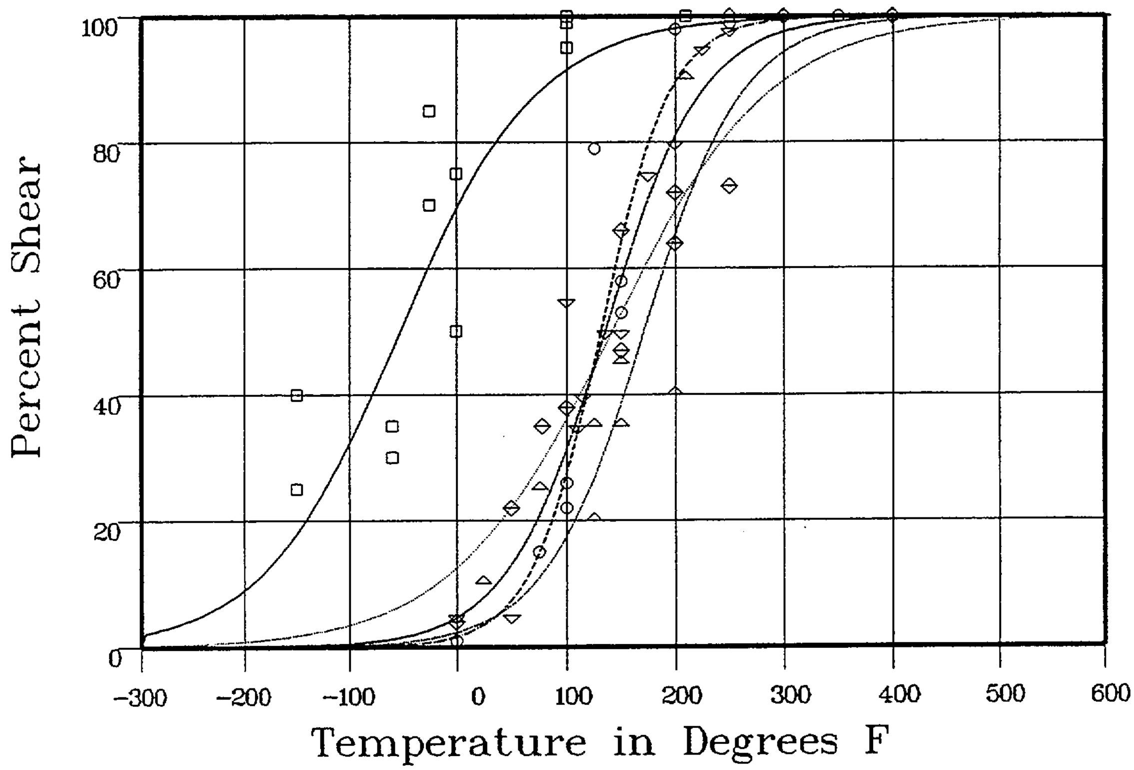
Figure 5-8 Charpy V-Notch Lateral Expansion vs. Temperature for Beaver Valley Unit 1 Reactor Vessel Weld Metal

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:41:45 on 05-16-2000

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	-57.2	0
2	0	126.56	183.76
3	0	136.81	194.02
4	0	166.4	223.61
5	0	130.37	187.57



Curve Legend

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

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV1	UNIRR	WELD		305424
2	BV1	V	WELD		305424
3	BV1	U	WELD		305424
4	BV1	W	WELD		305424
5	BV1	Y	WELD		305424

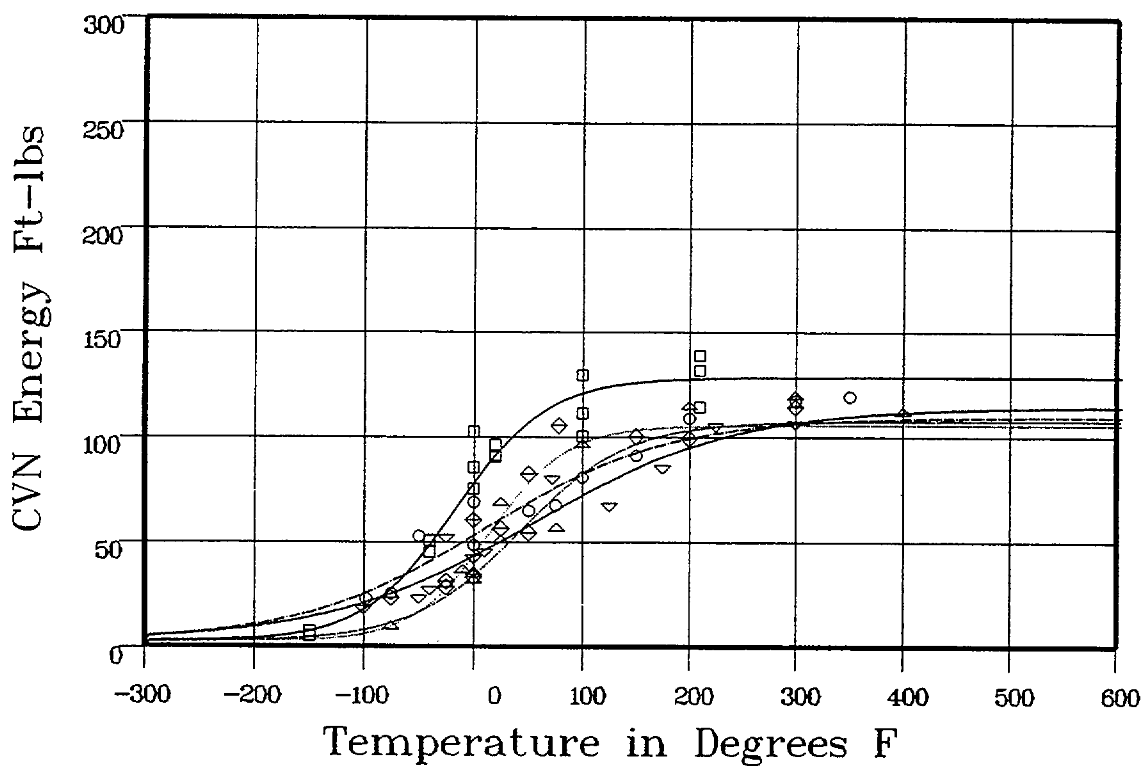
Figure 5-9 Charpy V-Notch Percent Shear vs Temperature for Beaver Valley Unit 1 Reactor Vessel Weld Metal

HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:05:43 on 05-16-2000

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	128	0	-74.53	0	-42.15	0
2	0	2.19	0	109	-19	-83.16	-8.62	-13.39	28.75
3	0	2.19	0	105	-23	-24.86	49.67	4.93	47.08
4	0	2.19	0	107	-21	-13.13	61.4	28.5	70.66
5	0	2.19	0	114	-14	-56.16	18.36	20.36	62.51



Curve Legend

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

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV1	UNIRR	HEAT AFFD ZONE		
2	BV1	V	HEAT AFFD ZONE		
3	BV1	U	HEAT AFFD ZONE		
4	BV1	W	HEAT AFFD ZONE		
5	BV1	Y	HEAT AFFD ZONE		

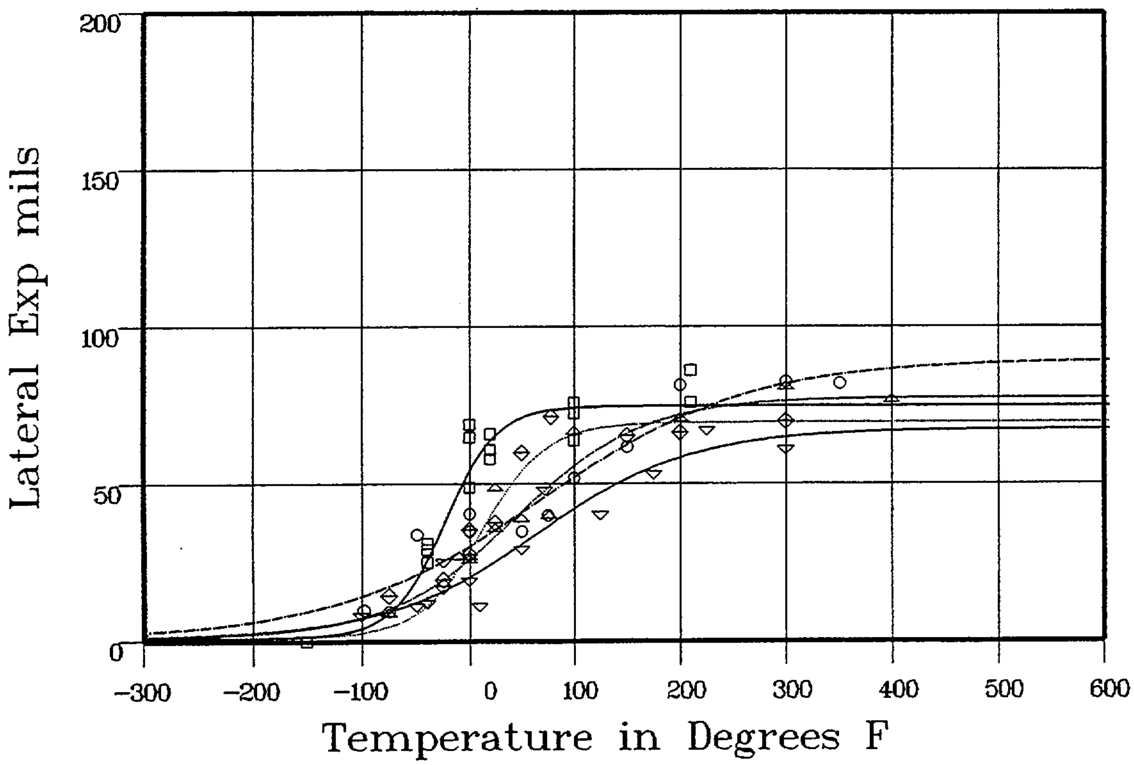
Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for Beaver Valley Unit 1 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE MATERIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 07:16:02 on 07-10-2000

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	74.88	0	-32.05	0
2	0	89.4	14.51	17.89	49.94
3	0	69.63	-5.25	6.93	38.99
4	0	77.55	2.66	25.13	57.18
5	0	67.52	-7.36	63.24	95.29



Curve Legend

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

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV1	UNIRR	HEAT AFFD ZONE		
2	BV1	V	HEAT AFFD ZONE		
3	BV1	U	HEAT AFFD ZONE		
4	BV1	W	HEAT AFFD ZONE		
5	BV1	Y	HEAT AFFD ZONE		

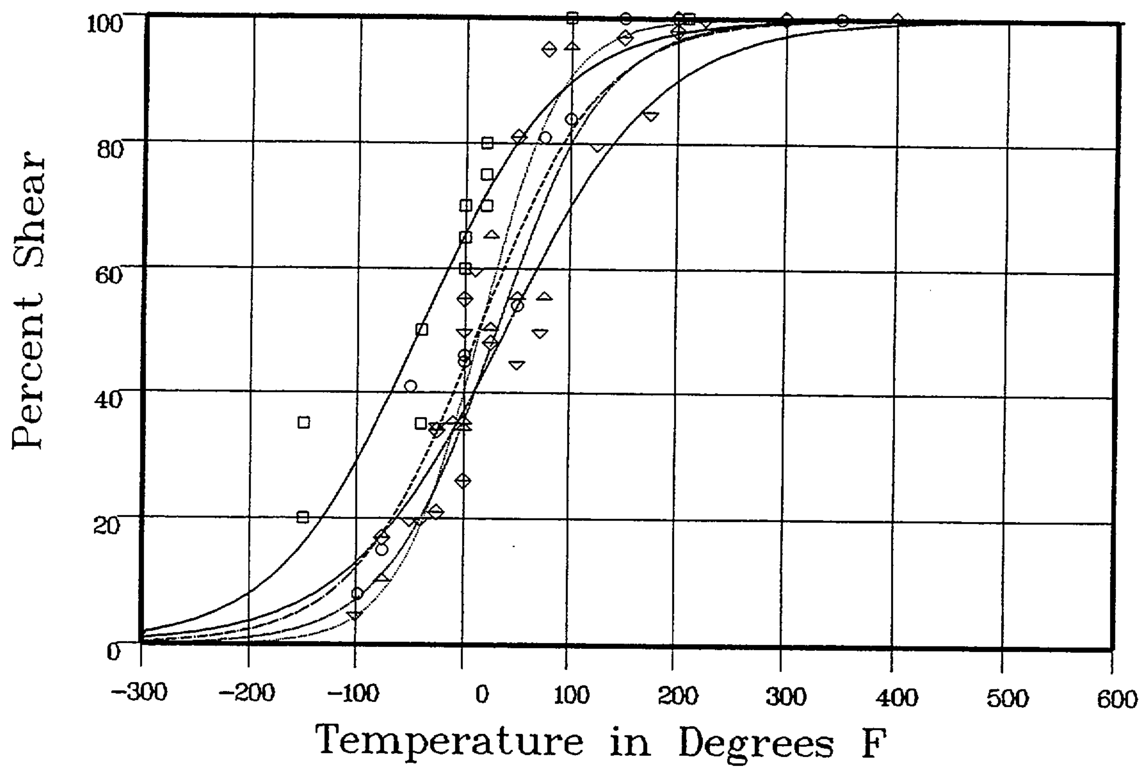
Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for Beaver Valley Unit 1 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE MATERIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 07:18:21 on 07-10-2000

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	-46.4	0
2	0	8.7	55.1
3	0	10.31	56.71
4	0	25.83	72.23
5	0	34.01	80.41



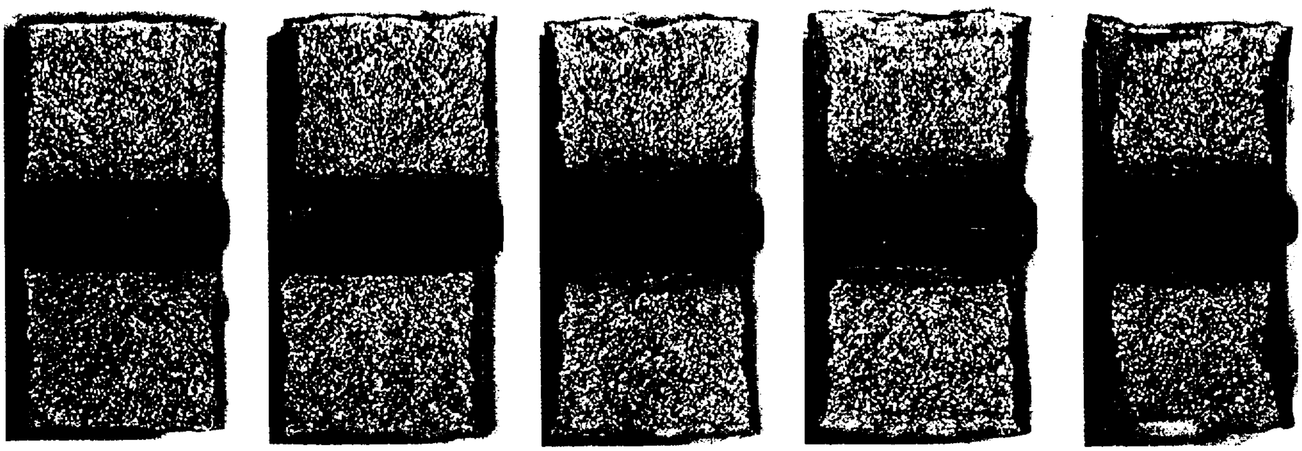
Curve Legend

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

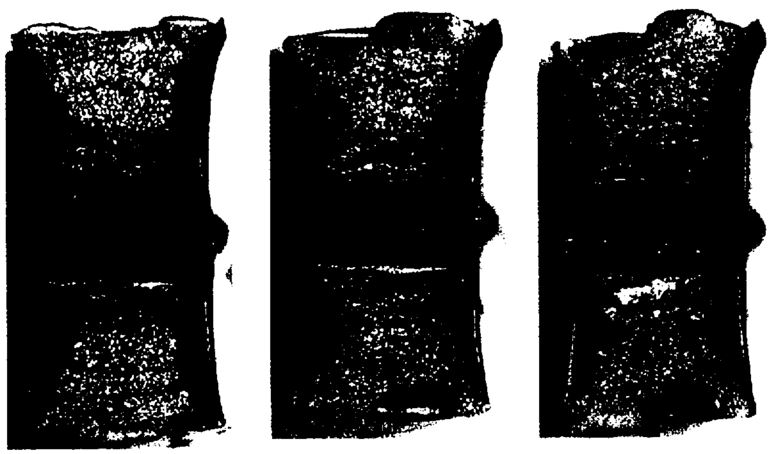
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV1	UNIRR	HEAT AFFD ZONE		
2	BV1	V	HEAT AFFD ZONE		
3	BV1	U	HEAT AFFD ZONE		
4	BV1	W	HEAT AFFD ZONE		
5	BV1	Y	HEAT AFFD ZONE		

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



DL62, 100°F   DL58, 110°F   DL63, 125°F   DL59, 150°F   DL61, 200°F



DL64, 250°F   DL57, 300°F   DL60, 375°F

Figure 5-13 Charpy Impact Specimen Fracture Surfaces for Beaver Valley Unit 1 Reactor Vessel Lower Shell Plate B6903-1(Longitudinal Orientation)

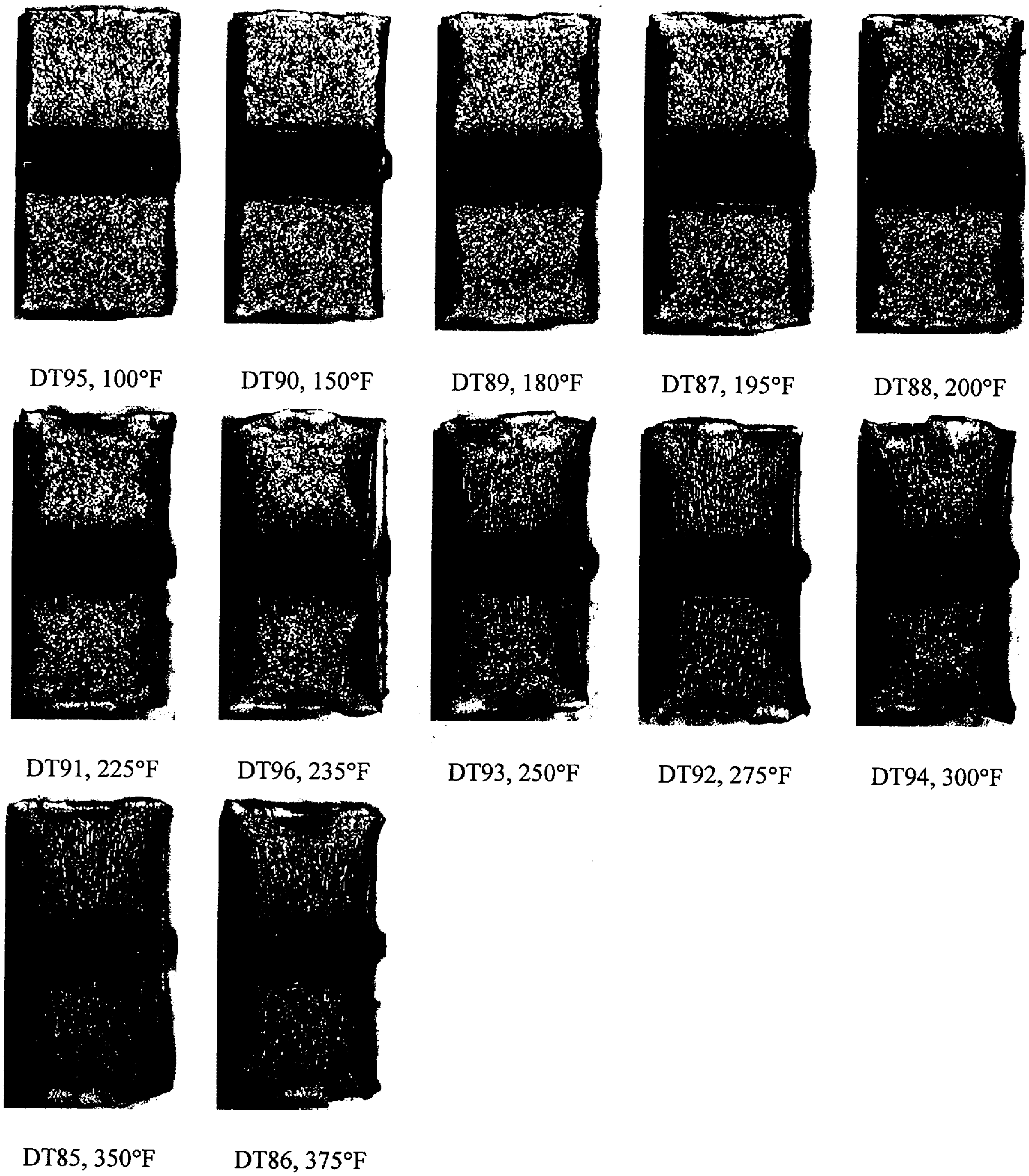


Figure 5-14 Charpy Impact Specimen Fracture Surfaces for Beaver Valley Unit 1 Reactor Vessel Lower Shell Plate B6903-1 (Transverse Orientation)

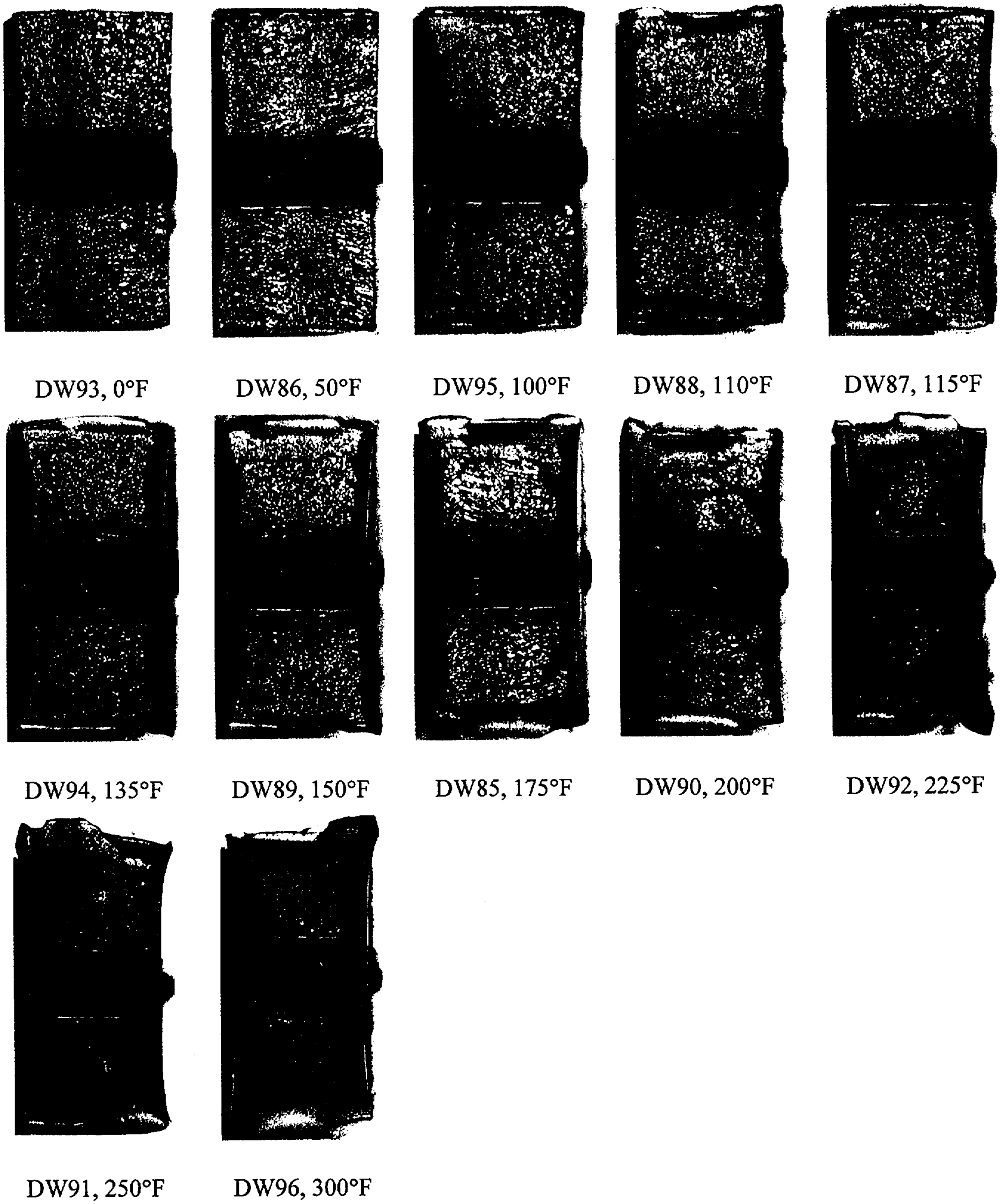


Figure 5-15 Charpy Impact Specimen Fracture Surfaces for Beaver Valley Unit 1 Reactor Vessel Weld Metal Specimen

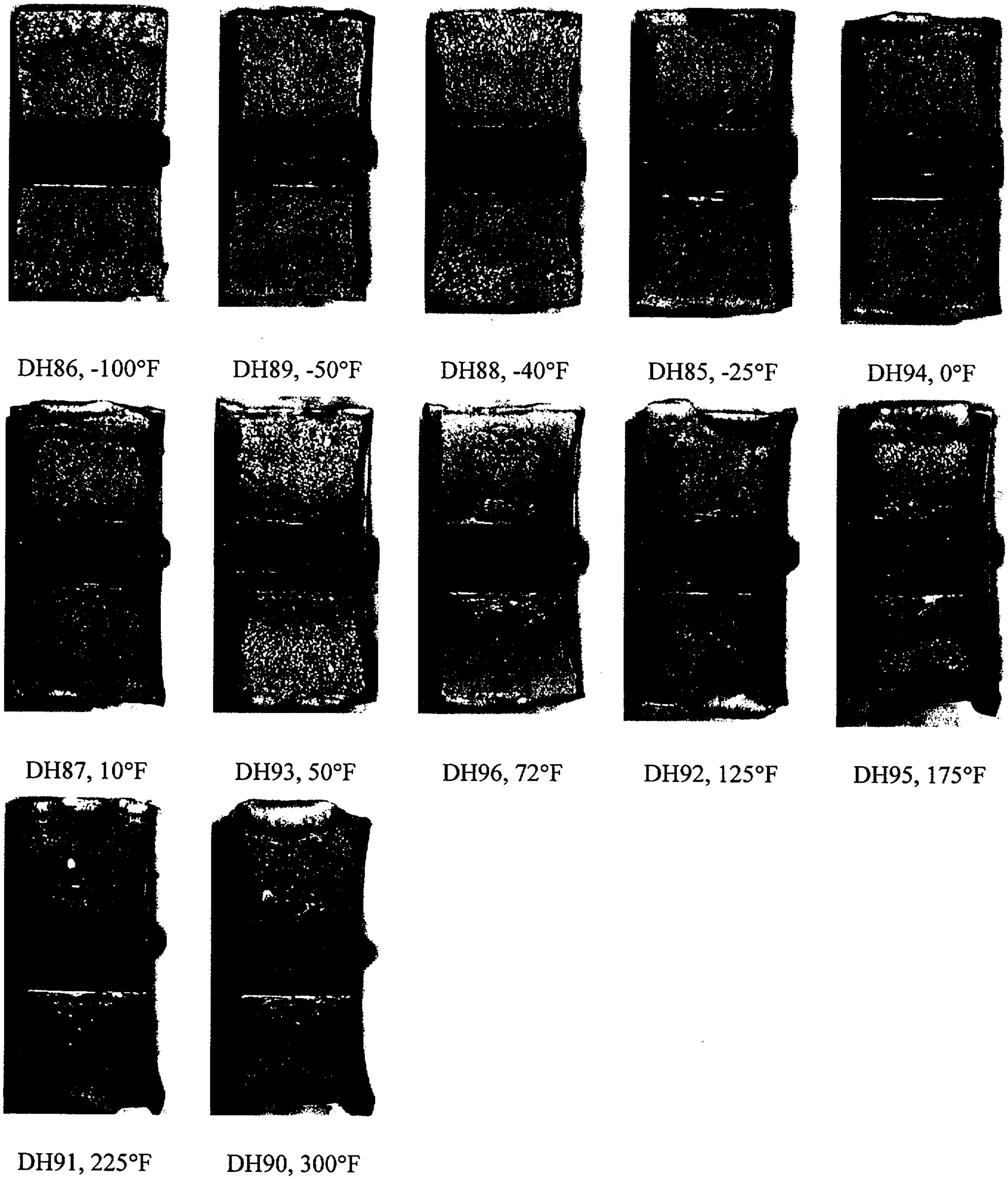


Figure 5-16 Charpy Impact Specimen Fracture Surfaces for Beaver Valley Unit 1 Reactor Vessel Heat-Affected-Zone Metal

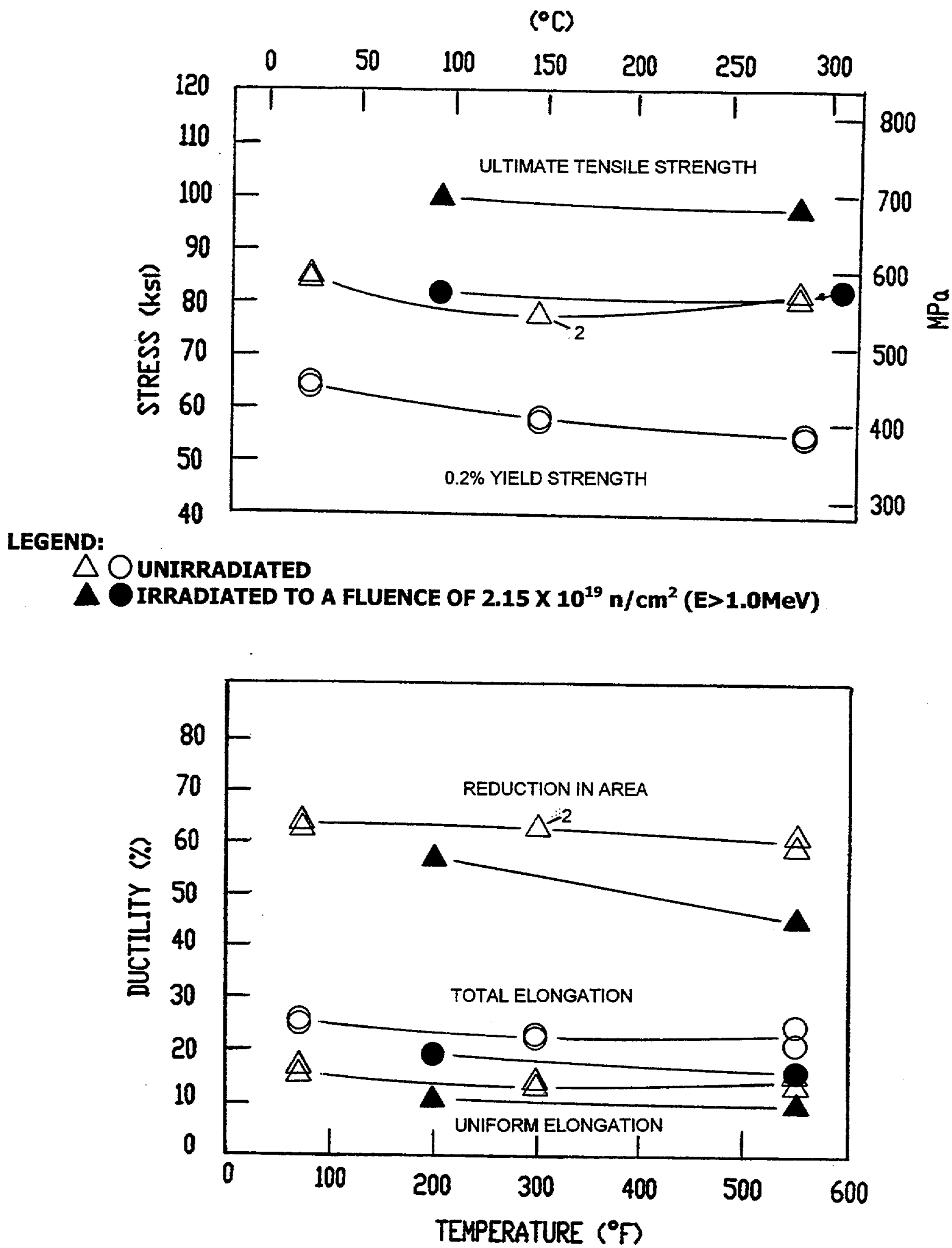


Figure 5-17 Tensile Properties for Beaver Valley Unit 1 Reactor Vessel Lower Shell Plate B6903-1 (Transverse Orientation)

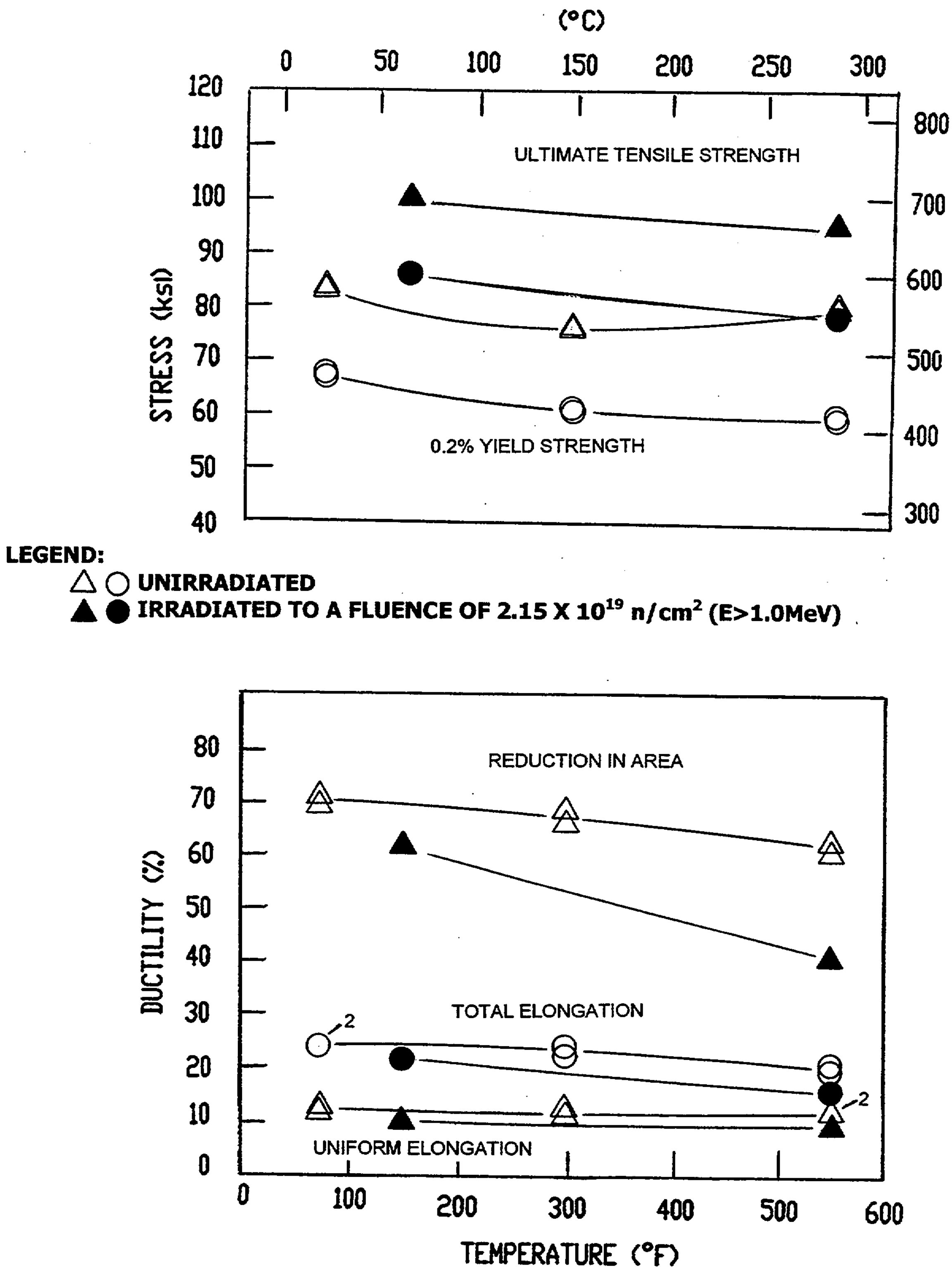
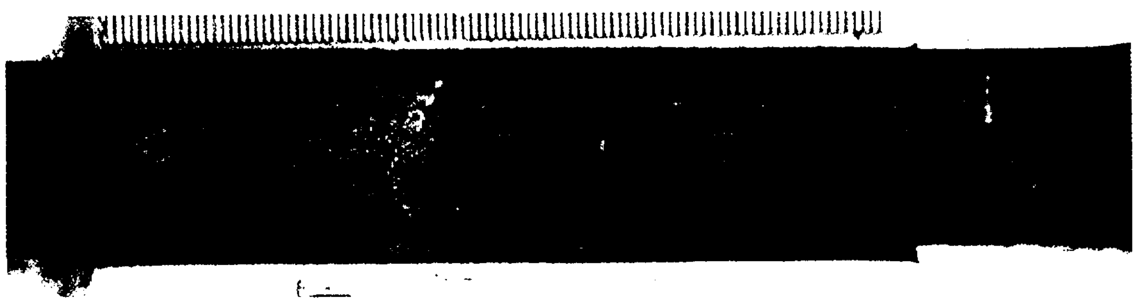
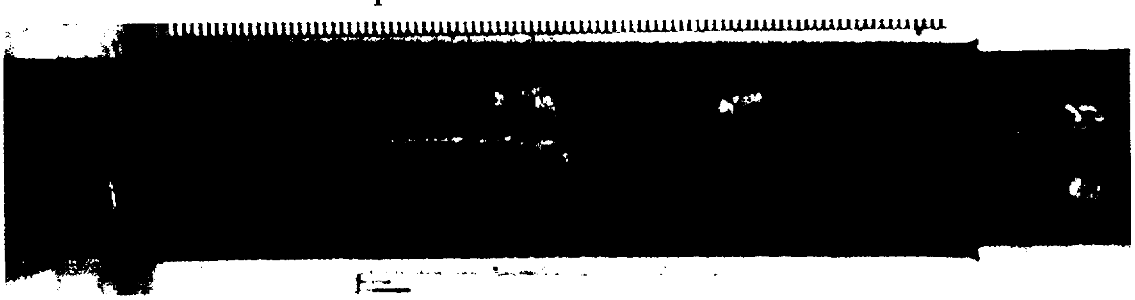


Figure 5-18 Tensile Properties for Beaver Valley Unit 1 Reactor Vessel Weld Material



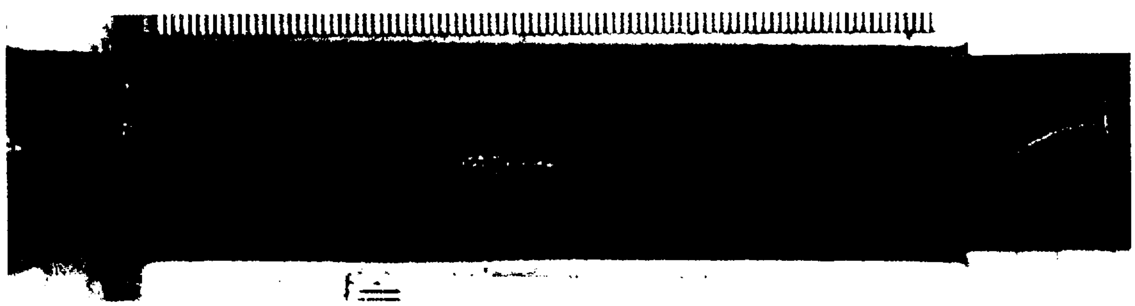
Specimen DT15 Tested at 200°F



Specimen DT16 Tested at 550°F

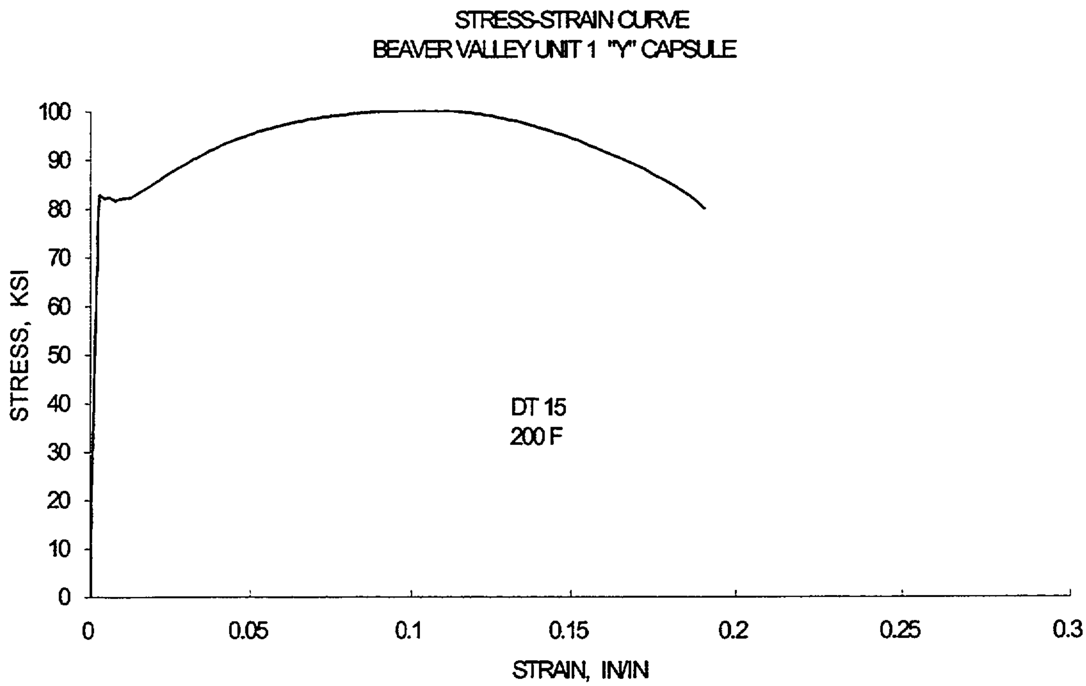
Figure 5-19 Fractured Tensile Specimens from Beaver Valley Unit 1 Reactor Vessel Lower Shell Plate B6903-1(Transverse Orientation)

Specimen DW15 Tested at 150°F



Specimen DW16 Tested at 550°F

Figure 5-20 Fractured Tensile Specimens from Beaver Valley Unit 1 Reactor Vessel Weld Metal



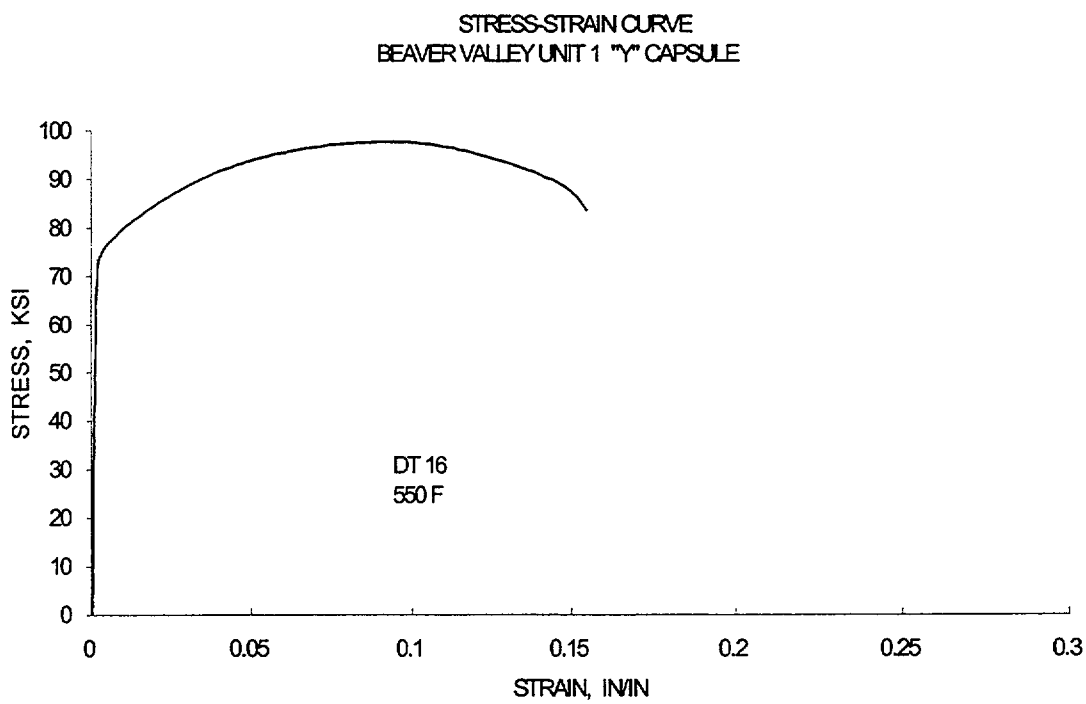
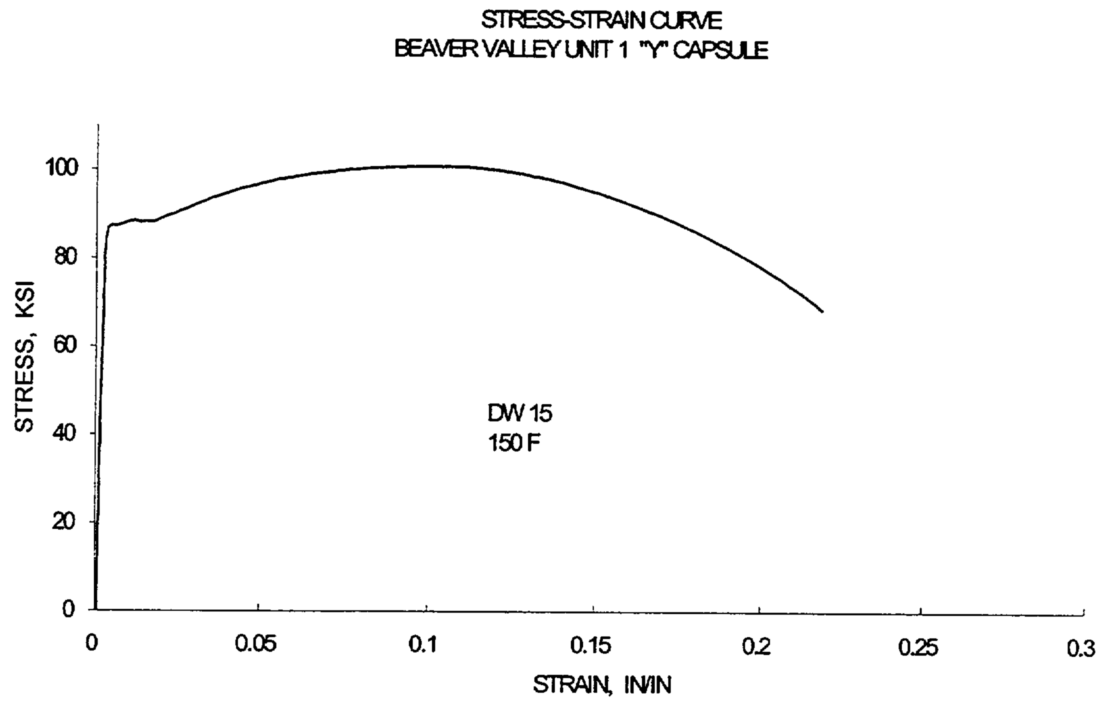


Figure 5-21 Engineering Stress-Strain Curves for Beaver Valley Unit 1 Reactor Vessel Lower Shell Plate B6903-1, Capsule Y, Transverse Tensile Specimens DT15 and DT16.



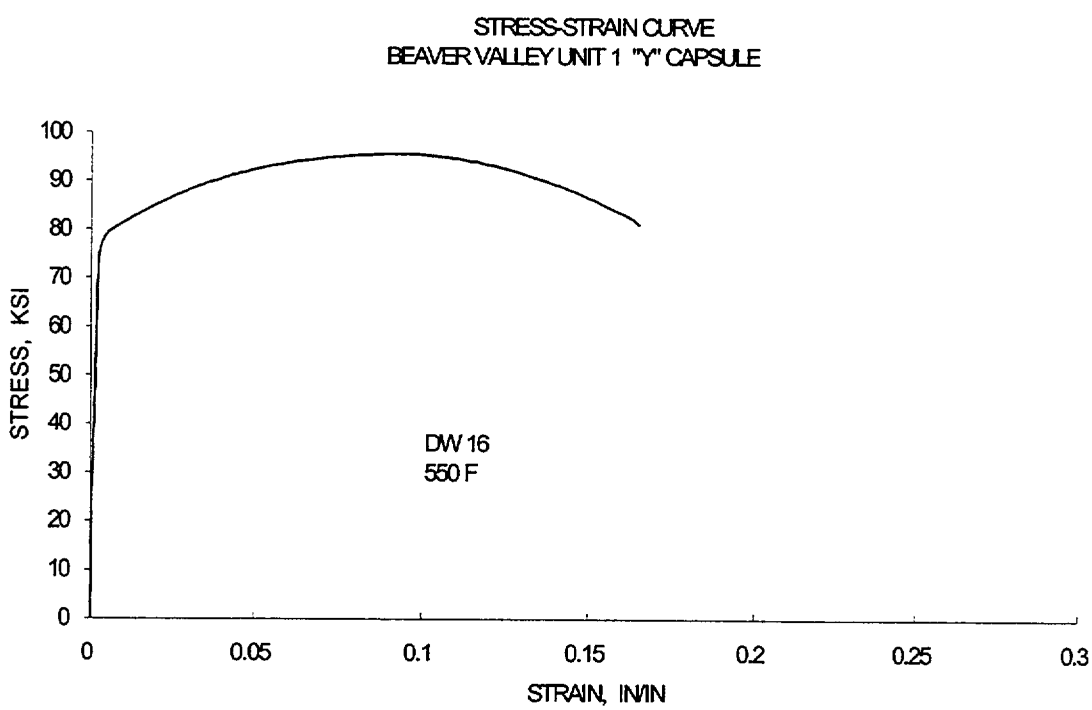


Figure 5-22 Engineering Stress-Strain Curves for Beaver Valley Unit 1 Reactor Vessel Weld Metal, Capsule Y, Tensile Specimens DW15 and DW16.

6.0 RADIATION ANALYSIS AND NEUTRON DOSIMETRY

6.1 INTRODUCTION

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

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

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

This section provides the results of the neutron dosimetry evaluations performed in conjunction with the analysis of test specimens contained in surveillance Capsules V, U, W, and Y which were withdrawn at various intervals during the first thirteen fuel cycles. This evaluation is based on current state-of-the-art methodology and nuclear data including 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 Beaver Valley 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.

All of the calculations and dosimetry evaluations presented in this section have been based on the latest available nuclear cross-section data derived from ENDF/B-VI and the latest available calculational tools and are consistent with the requirements of Draft Regulatory Guide DG-1053, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence." Additionally, the methods used to develop the best estimate pressure vessel fluence are consistent with the NRC approved methodology described in WCAP-14040-NP-A, "Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves," January 1996.

6.2 DISCRETE ORDINATES ANALYSIS

A plan view of the reactor geometry at the core midplane is shown in Figure 4-1. Eight 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 45°, 55°, 65°, 165°, 245°, 285°, 295° and 305° relative to the core cardinal axis as shown in Figure 4-1.

A plan view of a surveillance capsule holders attached to the thermal shield is shown in Figure 6-1. The stainless steel specimen containers are 1-inch square and approximately 40 inches in height. The containers are positioned axially such that the test specimens are centered on the core midplane, thus spanning the central 3.33 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 thermal shield 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 Beaver Valley Unit 1 surveillance capsules and reactor vessel, plant specific forward transport calculations were carried out using the following three-dimensional flux synthesis technique:

$$\phi(r,\theta,z) = \phi(r,\theta) * \frac{\phi(r,z)}{\phi(r)}$$

where $\phi(r,\theta,z)$ is the synthesized three-dimensional neutron flux distribution, $\phi(r,\theta)$ is the transport solution in r,θ geometry, $\phi(r,z)$ is the two-dimensional solution for a cylindrical reactor model using the actual axial core power distribution, and $\phi(r)$ is the one-dimensional solution for a cylindrical reactor model using the same source per unit height as that used in the r,θ two-dimensional calculation.

For the Beaver Valley Unit 1 analysis, all of the transport calculations were carried out using the DORT two-dimensional discrete ordinates code Version 3.1[15] and the BUGLE-96 cross–section library[16]. The BUGLE-96 library provides a 67 group coupled neutron-gamma ray cross-section data set produced specifically for light water reactor application. In these analyses, anisotropic scattering was treated with a P_5 legendre expansion and the angular discretization was modeled with an S_{16} order of angular quadrature.

The reactor core power distributions used in the plant specific transport calculations were taken from the fuel cycle design data for Beaver Valley Unit 1[17 through 29]. In performing the analyses, the spatial variation of the neutron source was obtained from a burnup weighted average of the respective power distributions from each of the individual fuel cycles. The energy distribution of the source was based on an appropriate fission split for uranium and plutonium isotopes; and, from that fission split, composite values of energy release per fission, neutron yield per fission, and fission spectrum were determined.

The absolute cycle-specific data from the synthesized transport results 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.

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 V, U, W, and Y 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 parameter [$\phi(E > 1.0 \text{ MeV})$] is given at the geometric center of the azimuthally symmetric surveillance capsule positions (15°, 25°, 35°, and 45°). The plant-specific data are meant to establish the absolute comparison of measurement with analysis. Similar data are given in Table 6-2 for the reactor vessel inner radius. The three pertinent exposure parameters [$\phi(E > 1.0 \text{ MeV})$, $\phi(E > 0.1 \text{ MeV})$, and dpa/sec] are listed. It is important to note that the data for the vessel inner 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 $\phi(E > 1.0 \text{ MeV})$, $\phi(E > 0.1 \text{ MeV})$, and dpa/sec is given in Tables 6-3, 6-4, and 6-5, respectively. The data[30] 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 $\phi(E > 1.0 \text{ MeV})$ at the ¼T depth in the reactor vessel wall along the 0° azimuth is given by:

$$\phi_{1/4T}(0°) = \phi(199.95.0°)F(204.95,0°)$$

where:

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

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

$F(204.95,0°)$ = Ratio of the neutron flux at the ¼T position to the flux at the vessel inner radius for the 0° azimuth. This data is obtained from Table 6-3.

Similar expressions apply for exposure parameters expressed in terms of $\phi(E > 0.1 \text{ MeV})$ 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 Beaver Valley 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 [$\phi(E > 1.0 \text{ MeV})$, $\phi(E > 0.1 \text{ MeV})$, 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,
- 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[31 through 44]. Following sample preparation and weighing, the activity of each monitor was determined by means of a high resolution gamma spectrometer. The irradiation history of the Beaver Valley Unit 1 reactor was obtained from data reported in NUREG-0020, "Licensed Operating Reactors Status Summary Report," for the first six cycles of operation and equivalent data supplied by Duquesne Light for cycles 7 through 13. The irradiation history applicable to the exposure of Capsules V, U, W, and Y is given in Table 6-7.

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

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

where:

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

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

In the equation describing the reaction rate calculation, the ratio $[P_j]/[P_{ref}]$ accounts for month-by-month variation of reactor core power level within any given fuel cycle as well as over multiple fuel cycles. The ratio C_j, which can be calculated for each fuel cycle using the 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 must be employed. For the irradiation history of Capsules V, U, W, and Y, the flux level term in the reaction rate calculations was set to 1.0 for Capsule U only. 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.

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.

In performing the dosimetry evaluations for the internal surveillance capsules, the sensor reaction rates measured at the locations in the capsule holder were indexed to the geometric center of the capsules prior to use in the spectrum adjustment procedure. This indexing procedure required correcting the measured reaction rates by the application of analytically determined spatial gradients. For the Beaver Valley Unit 1 surveillance capsules, the gradient correction factors for each sensor reaction were obtained from the reference forward transport calculation and were used in a multiplicative fashion to relate individual measured reaction rates to the corresponding value at the geometric center of the surveillance capsule.

Values of key fast neutron exposure parameters were derived from the measured reaction rates using the FERRET least squares adjustment code [45]. The FERRET approach used the measured reaction rate data, sensor reaction cross-sections, and the calculated spectrum as input and proceeded to adjust the group fluxes 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 calculated spectrum was converted to the FERRET 53 group structure using the SAND-II code[46]. 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[47], were also collapsed into the 53 energy group structure using the SAND-II code. In this instance, the calculated spectrum, as expanded to 620 groups, was employed as a weighting function in the cross-section collapsing procedure. Reaction cross-section uncertainties in the form of a 53 × 53 covariance matrix for each sensor reaction were also constructed from the information contained on the ENDF/B-VI data files. These matrices included energy group to energy group uncertainty correlations for each of the individual reactions. However, correlations between cross-sections for different sensor reactions were not included. The omission of this additional uncertainty information does not significantly impact the results of the adjustment.

The calculated neutron spectrum input to the FERRET evaluation was taken from the center of the surveillance capsule. While the 53 × 53 group covariance matrices applicable to the sensor reaction cross-sections were developed from the ENDF/B-VI data files, the covariance matrix for the input trial spectrum was constructed from the following relation:

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

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 correlations over a group range γ (θ specifies the strength of the latter term). The value of δ is 1 when g = g' and 0 otherwise. For the calculated spectra used in the current evaluations, a short range correlation of $\gamma = 6$ groups was used. This choice implies that neighboring groups are strongly correlated when θ is close to 1. Strong long-range correlations (or anti-correlations) were justified based on information presented by R. E. Maerker[48]. 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 Capsules U, X, Y and V dosimetry are given in Table 6-9. The data summarized in this table include fast neutron exposure evaluations in terms of $\Phi(E > 1.0 \text{ MeV})$, $\Phi(E > 0.1 \text{ MeV})$, and dpa. In general, excellent results were achieved in the fits of the best estimate spectra to the individual measured reaction rates. The measured, calculated and best estimate reaction rates for each reaction are given in Table 6-10. An examination of Table 6-10 shows that, in all cases, reaction rates calculated with the best estimate spectra match the measured reaction rates to better than 11%. 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 V, U, W, and Y are presented. The results for the Capsules V, U, W, and Y dosimetry evaluation [average BE/C ratio of 0.97 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 Beaver Valley Unit 1 reactor vessel was developed using a combination of absolute plant specific transport calculations and all available in-vessel plant specific measurement data. In the case of Beaver Valley Unit 1, this in-vessel measurement data base contains measurements from the 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 Beaver Valley Unit 1, the derived plant specific bias factors were 0.97, 0.99, and 0.98 for $\Phi(E > 1.0\ MeV)$, $\Phi(E > 0.1\ MeV)$, and dpa, respectively. Bias factors of this magnitude developed with BUGLE-96 are fully consistent with experience using the ENDF/B-VI based cross-section library.

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

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

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

The net uncertainty in the bias factor, K, is combined with the uncertainty from the analytical sensitivity study to define the overall fluence uncertainty at the reactor vessel wall. In the case of Beaver Valley 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 $\pm$ 7.8%.

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 (14.3 EFPY) exposure at the end of Cycle 13, projections are also provided for exposure periods to the end of Cycle 14 (15.7 EFPY), end of Cycle 15 (17.0 EFPY), to 28 EFPY, and to 45 EFPY. Cycle 14 is projected assuming the average exposure rate of Cycles 11 through 13. The Cycle 15 is projected with the Cycle 8 exposure rate, which represents low leakage cycles and an assumption that the hafnium is removed from the PSA assembly locations. From end of Cycle 15 to 28 and 45 EFPY, the exposure projection is the Cycle 8 exposure rate increased by 1.055 to allow for a "5.5% core power uprating".

In the derivation of best estimate and calculated exposure gradients within the reactor vessel wall for the Beaver Valley Unit 1 reactor vessel, exposure projections to 15.7, 17.0, 28, and 45 EFPY were also employed. Data based on both a $\Phi(E > 1.0\text{ MeV})$ slope and a plant-specific dpa slope through the vessel wall are provided in Table 6-14.

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

$$\phi(\tfrac{1}{4}T) = \phi(0T)\,\frac{dpa(\tfrac{1}{4}T)}{dpa(0T)} \quad \text{and} \quad \phi(\tfrac{3}{4}T) = \phi(0T)\,\frac{dpa(\tfrac{3}{4}T)}{dpa(0T)}$$

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

The calculated results applicable to the vessel inner surface are incorporated into Table 6-15 through 6-17 for exposure parameters expressed in terms of Flux (E> 1.0 MeV), Flux (E> 0.1 MeV), and dpa,

respectively. Exposure distributions through the vessel wall can be developed using these surface exposures and radial distribution functions from Section 6.2.

In Table 6-18, updated lead factors are listed for each of the Beaver Valley Unit 1 surveillance capsules which have been removed.

Table 6-19 presents the lead factors for the surveillance capsules at Beaver Valley Unit 1 which have not been removed reflecting the relocation of Capsule T from a 35° location to a 25° location and Capsule Z from a 35° location to a 15° location at the conclusion of Cycle 10. As was done for the projection of vessel fluences, Cycle 14 is projected assuming the average exposure rate of Cycles 11 through 13. Cycle 15 assumes the hafnium is removed from the PSA assembly locations and the Cycle 8, representing low leakage cycles, exposure rate applies. From end of Cycle 15 to 28 and 45 EFPY, it is assumed that there is a "5.5% core power uprating" and the exposure rate assumed is the Cycle 8 exposure rate increased by 1.055.

Figure 6-1

Surveillance Capsule Geometry

REACTOR GEOMETRY SHOWING A 45° r,θ SECTOR

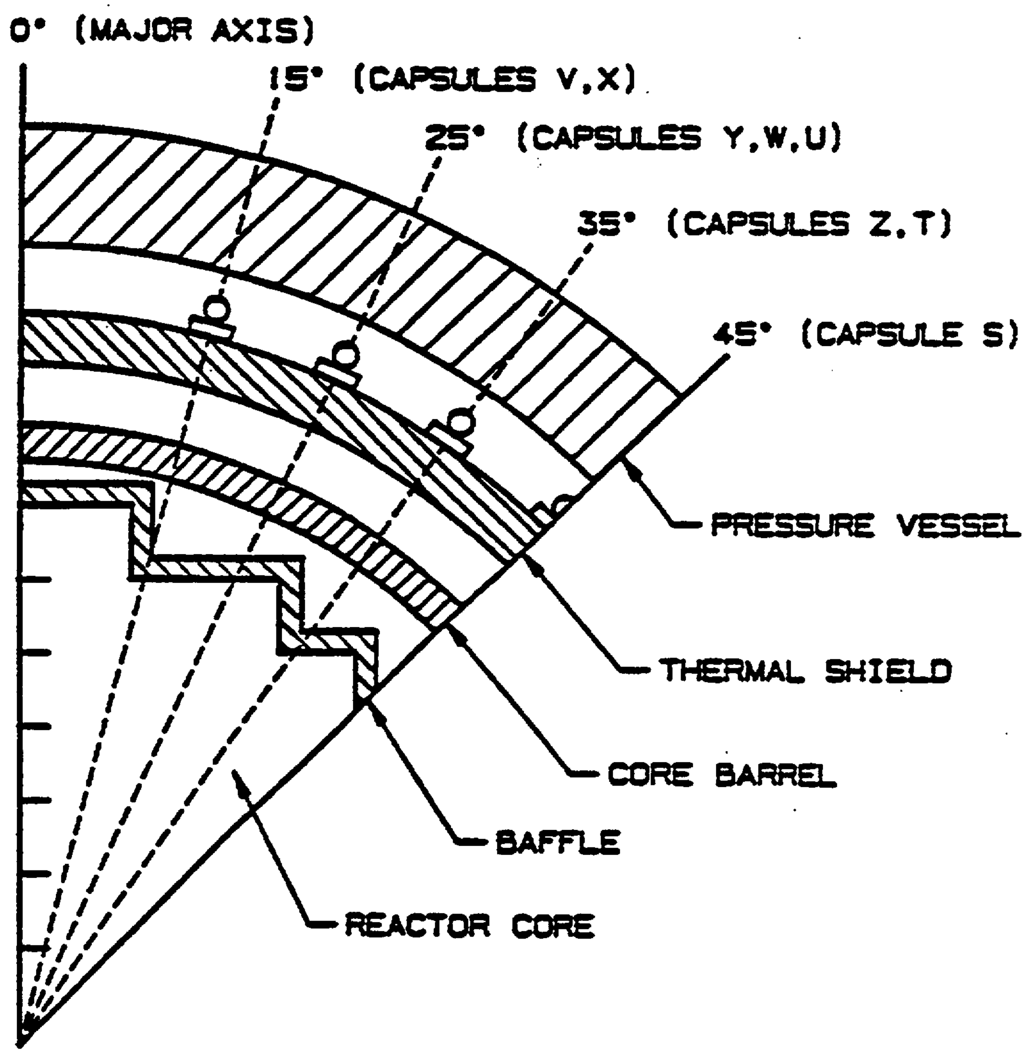


Table 6-1

Calculated Fast Neutron Exposure Rates At the Surveillance Capsule Center

	$\phi(E > 1.0\ MeV)$ $(n/cm^2\text{-sec})$			
Cycle No.	15°	25°	35°	45°
1	8.79E+10	5.70E+10	3.84E+10	2.99E+10
2	9.05E+10	5.94E+10	4.06E+10	3.16E+10
3	1.02E+11	6.53E+10	4.35E+10	3.31E+10
4	7.51E+10	4.81E+10	3.14E+10	2.41E+10
5	7.33E+10	4.64E+10	3.09E+10	2.43E+10
6	6.42E+10	4.69E+10	3.11E+10	2.38E+10
7	7.12E+10	4.53E+10	2.98E+10	2.35E+10
8	7.33E+10	4.79E+10	3.04E+10	2.33E+10
9	6.79E+10	4.70E+10	3.27E+10	2.64E+10
10	5.01E+10	3.88E+10	2.85E+10	2.28E+10
11	5.01E+10	4.09E+10	3.13E+10	2.58E+10
12	5.44E+10	4.50E+10	2.99E+10	2.23E+10
13	5.40E+10	4.17E+10	2.93E+10	2.33E+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°
1	5.50E+10	2.67E+10	1.45E+10	9.66E+09
2	5.39E+10	2.65E+10	1.47E+10	9.84E+09
3	6.30E+10	3.04E+10	1.62E+10	1.05E+10
4	4.59E+10	2.26E+10	1.19E+10	7.72E+09
5	4.48E+10	2.21E+10	1.16E+10	7.80E+09
6	3.35E+10	1.94E+10	1.18E+10	7.68E+09
7	4.12E+10	2.17E+10	1.14E+10	7.66E+09
8	4.07E+10	2.21E+10	1.17E+10	7.54E+09
9	3.64E+10	2.03E+10	1.19E+10	8.38E+09
10	2.79E+10	1.56E+10	1.05E+10	7.50E+09
11	2.59E+10	1.39E+10	1.09E+10	8.19E+09
12	2.70E+10	1.53E+10	1.13E+10	7.23E+09
13	2.76E+10	1.50E+10	1.08E+10	7.52E+09

Table 6-2 cont'd

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

Cycle No.	0°	15°	30°	45°
1	1.47E+11	7.18E+10	3.72E+10	2.42E+10
2	1.44E+11	7.13E+10	3.77E+10	2.47E+10
3	1.69E+11	8.18E+10	4.17E+10	2.64E+10
4	1.22E+11	6.03E+10	3.04E+10	1.93E+10
5	1.19E+11	5.90E+10	2.96E+10	1.95E+10
6	8.94E+10	5.12E+10	3.01E+10	1.92E+10
7	1.10E+11	5.77E+10	2.91E+10	1.91E+10
8	1.09E+11	5.86E+10	3.00E+10	1.88E+10
9	9.72E+10	5.39E+10	3.04E+10	2.09E+10
10	7.43E+10	4.13E+10	2.68E+10	1.87E+10
11	6.81E+10	3.65E+10	2.77E+10	2.04E+10
12	7.11E+10	4.00E+10	2.88E+10	1.80E+10
13	7.28E+10	3.96E+10	2.74E+10	1.87E+10

Iron Atom Displacement Rate (dpa/sec)

Cycle No.	0°	15°	30°	45°
1	8.84E-11	4.34E-11	2.33E-11	1.55E-11
2	8.66E-11	4.30E-11	2.35E-11	1.58E-11
3	1.01E-10	4.93E-11	2.60E-11	1.69E-11
4	7.38E-11	3.66E-11	1.91E-11	1.24E-11
5	7.19E-11	3.58E-11	1.86E-11	1.25E-11
6	5.39E-11	3.13E-11	1.89E-11	1.23E-11
7	6.62E-11	3.51E-11	1.83E-11	1.23E-11
8	6.54E-11	3.57E-11	1.88E-11	1.21E-11
9	5.85E-11	3.28E-11	1.91E-11	1.34E-11
10	4.49E-11	2.52E-11	1.69E-11	1.20E-11
11	4.14E-11	2.25E-11	1.74E-11	1.31E-11
12	4.32E-11	2.47E-11	1.81E-11	1.16E-11
13	4.43E-11	2.43E-11	1.72E-11	1.21E-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
204.95	0.577	0.589	0.583	0.584
209.95	0.290	0.305	0.298	0.302
214.95	0.141	0.152	0.148	0.151
219.95	0.064	0.074	0.073	0.077

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	Azimuthal Angle			
(cm)	0°	15°	30°	45°
199.95	1.000	1.000	1.000	1.000
204.95	0.850	0.885	0.872	0.880
209.95	0.621	0.673	0.657	0.674
214.95	0.413	0.467	0.457	0.477
219.95	0.228	0.285	0.287	0.313

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
204.95	0.668	0.687	0.674	0.674
209.95	0.416	0.444	0.427	0.432
214.95	0.250	0.278	0.266	0.273
219.95	0.133	0.164	0.161	0.172

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	$^{63}Cu\ (n,\alpha)$	0.6917	E > 4.7 MeV	5.271 y	
Iron	$^{54}Fe\ (n,p)$	0.0585	E > 1.0 MeV	312.3 d	
Nickel	$^{58}Ni\ (n,p)$	0.6808	E > 1.0 MeV	70.82 d	
Uranium-238	$^{238}U\ (n,f)$	0.9996	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	$^{59}Co\ (n,\gamma)$	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 Thirteen Fuel Cycles

Of The Beaver Valley Unit 1 Reactor

(Reactor Power of 2652 MWt)

Year	Month	Thermal Generation (MW-hr)	Year	Month	Thermal Generation (MW-hr)
1976	5	250	1979	1	787965
1976	6	101578	1979	2	1433040
1976	7	109048	1979	3	336146
1976	8	112413	1979	4	0
1976	9	431584	1979	5	0
1976	10	608570	1979	6	0
1976	11	199669	1979	7	0
1976	12	410132	1979	8	650167
1977	1	189115	1979	9	1419642
1977	2	0	1979	10	786544
1977	3	708513	1979	11	692354
1977	4	965179	1979	12	0
1977	5	1688148	1980	1	0
1977	6	1049724	1980	2	0
1977	7	1489440	1980	3	0
1977	8	1116291	1980	4	0
1977	9	0	1980	5	0
1977	10	40194	1980	6	0
1977	11	1030814	1980	7	0
1977	12	1828830	1980	8	0
1978	1	1570520	1980	9	0
1978	2	1672227	1980	10	0
1978	3	1903683	1980	11	216989
1978	4	1385543	1980	12	916651
1978	5	0	1981	1	1118512
1978	6	141161	1981	2	878386
1978	7	1621228	1981	3	0

Table 6-7 cont'd

Monthly Thermal Generation During The First Thirteen Fuel Cycles

Of The Beaver Valley Unit 1 Reactor

(Reactor Power of 2652 MWt)

Year	Month	Thermal Generation (MW-hr)	Year	Month	Thermal Generation (MW-hr)
1978	8	0	1981	4	915873
1978	9	0	1981	5	1453681
1978	10	0	1981	6	1874754
1978	11	0	1981	7	1080807
1978	12	504540	1981	8	1850579
			1981	9	1765793
			1981	10	1651329
			1981	11	1782396
			1981	12	1148933

Table 6-7 cont'd

Monthly Thermal Generation During The First Thirteen Fuel Cycles

Of The Beaver Valley Unit 1 Reactor

(Reactor Power of 2652 MWt)

Year	Month	Thermal Generation (MW-hr)	Year	Month	Thermal Generation (MW-hr)
1982	1	0	1985	1	1230666
1982	2	0	1985	2	1495792
1982	3	0	1985	3	1567714
1982	4	0	1985	4	1519174
1982	5	0	1985	5	1568263
1982	6	0	1985	6	1888526
1982	7	975423	1985	7	1815511
1982	8	1597914	1985	8	1799541
1982	9	994760	1985	9	1627814
1982	10	1633910	1985	10	1491565
1982	11	1868403	1985	11	1668503
1982	12	1810831	1985	12	1951848
1983	1	1734339	1986	1	1949567
1983	2	1598708	1986	2	1543257
1983	3	1939771	1986	3	1955574
1983	4	1885670	1986	4	1776190
1983	5	1732947	1986	5	825172
1983	6	585214	1986	6	0
1983	7	0	1986	7	0
1983	8	0	1986	8	170868
1983	9	233976	1986	9	1689361
1983	10	1779388	1986	10	1845418
1983	11	1695803	1986	11	1790031
1983	12	1893541	1986	12	1955537
1984	1	1552319	1987	1	1901768
1984	2	1811481	1987	2	1685908
1984	3	1263132	1987	3	1952434

Table 6-7 cont'd

Monthly Thermal Generation During The First Thirteen Cycles

Of The Beaver Valley Unit 1 Reactor

(Reactor Power of 2652 MWt)

Year	Month	Thermal Generation (MW-hr)	Year	Month	Thermal Generation (MW-hr)
1984	4	1815222	1987	4	1506172
1984	5	1812753	1987	5	20911
1984	6	1533814	1987	6	1667777
1984	7	1737076	1987	7	1886816
1984	8	1949986	1987	8	1841589
1984	9	1674388	1987	9	1752375
1984	10	658805	1987	10	1945202
1984	11	0	1987	11	1762196
1984	12	0	1987	12	469765

Table 6-7 cont'd

Monthly Thermal Generation During The First Thirteen Cycles

Of The Beaver Valley Unit 1 Reactor

(Reactor Power of 2652 MWt)

Year	Month	Thermal Generation (MW-hr)	Year	Month	Thermal Generation (MW-hr)
1988	1	0	1991	1	962970
1988	2	0	1991	2	1698024
1988	3	1677626	1991	3	1920600
1988	4	1884007	1991	4	734753
1988	5	1929940	1991	5	0
1988	6	1577195	1991	6	0
1988	7	1941312	1991	7	223412
1988	8	1816437	1991	8	1900996
1988	9	1615227	1991	9	1406382
1988	10	1541992	1991	10	1348372
1988	11	1202942	1991	11	60240
1988	12	1242361	1991	12	1967980
1989	1	1392655	1992	1	1968906
1989	2	1379326	1992	2	1839523
1989	3	1720567	1992	3	1966962
1989	4	1457829	1992	4	1821532
1989	5	1348415	1992	5	1878892
1989	6	1542116	1992	6	1902940
1989	7	1946984	1992	7	1965639
1989	8	1819779	1992	8	1604887
1989	9	43522	1992	9	1629699
1989	10	0	1992	10	494631
1989	11	0	1992	11	1620623
1989	12	82504	1992	12	1768591
1990	1	1717462	1993	1	1769550
1990	2	1766224	1993	2	1599541
1990	3	1862208	1993	3	1318121

Table 6-7 cont'd

Monthly Thermal Generation During The First Thirteen Cycles

Of The Beaver Valley Unit 1 Reactor

(Reactor Power of 2652 MWt)

Year	Month	Thermal Generation (MW-hr)	Year	Month	Thermal Generation (MW-hr)
1990	4	1546013	1993	4	0
1990	5	1751901	1993	5	0
1990	6	1871935	1993	6	522652
1990	7	1053499	1993	7	1967310
1990	8	1779924	1993	8	1899044
1990	9	1851557	1993	9	1903751
1990	10	1671278	1993	10	735881
1990	11	1899189	1993	11	779517
1990	12	1437202	1993	12	1935108

Table 6-7 cont'd

Monthly Thermal Generation During The First Thirteen Cycles

Of The Beaver Valley Unit 1 Reactor

(Reactor Power of 2652 MWt)

Year	Month	Thermal Generation (MW-hr)	Year	Month	Thermal Generation (MW-hr)
1994	1	1306074	1997	1	1957638
1994	2	1769531	1997	2	1744174
1994	3	1920450	1997	3	1153954
1994	4	1892679	1997	4	1023580
1994	5	1064786	1997	5	1963402
1994	6	39682	1997	6	1705565
1994	7	670158	1997	7	11589
1994	8	1759891	1997	8	1752251
1994	9	1902497	1997	9	1683909
1994	10	1968574	1997	10	0
1994	11	1902781	1997	11	0
1994	12	1724487	1997	12	0
1995	1	72153	1998	1	468225
1995	2	0	1998	2	0
1995	3	1225380	1998	3	0
1995	4	1903021	1998	4	0
1995	5	1967916	1998	5	0
1995	6	1900816	1998	6	0
1995	7	1961257	1998	7	0
1995	8	1381737	1998	8	973181
1995	9	1902415	1998	9	1909045
1995	10	1968103	1998	10	1974419
1995	11	1854945	1998	11	1906308
1995	12	1457253	1998	12	1968795
1996	1	1965199	1999	1	1709974
1996	2	1810977	1999	2	1019933
1996	3	1164783	1999	3	1940265

Table 6-7 cont'd

Monthly Thermal Generation During The First Thirteen Cycles

Of The Beaver Valley Unit 1 Reactor

(Reactor Power of 2652 MWt)

Year	Month	Thermal Generation (MW-hr)	Year	Month	Thermal Generation (MW-hr)
1996	4	0	1999	4	716664
1996	5	1103853	1999	5	1410478
1996	6	1767857	1999	6	1906371
1996	7	1965530	1999	7	1967597
1996	8	847659	1999	8	1958611
1996	9	1901486	1999	9	1494468
1996	10	1965965	1999	10	1951486
1996	11	1898890	1999	11	1823131
1996	12	1959481	1999	12	1970481
			2000	1	1968186
			2000	2	746198

Table 6-8

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,α) ^{60}Co	Top-Mid	4.240E+04	3.853E+05	5.620E-17
	Middle	4.420E+04	4.017E+05	5.858E-17
	Bot-Mid	4.280E+04	3.890E+05	5.673E-17
^{54}Fe (n,p) ^{54}Mn	Top	5.840E+05	3.758E+06	6.254E-15
	Top-Mid	5.350E+05	3.442E+06	5.730E-15
	Middle	5.620E+05	3.616E+06	6.019E-15
	Bot-Mid	5.320E+05	3.423E+06	5.697E-15
	Bottom	5.370E+05	3.455E+06	5.751E-15
^{58}Ni (n,p) ^{58}Co	Top-Mid	9.570E+05	4.968E+07	8.222E-15
	Mid	9.750E+05	5.061E+07	8.376E-15
	Bot-Mid	9.060E+05	4.703E+07	7.784E-15
^{59}Co (n,γ) ^{60}Co	Top	7.240E+06	6.580E+07	4.108E-12
	Bottom	7.240E+06	6.580E+07	4.108E-12
^{59}Co (n,γ) ^{60}Co (Cd)	Top	2.590E+06	2.354E+07	1.777E-12
	Bottom	2.550E+06	2.317E+07	1.749E-12
^{238}U (n,f) ^{137}Cs	Middle	1.360E+05	5.388E+06	3.539E-14
	Including ^{235}U, ^{239}Pu, and γ,fission corrections			2.952E-14
^{237}Np (n,f) ^{137}Cs	Middle	9.700E+05	3.843E+07	2.452E-13
	Including γ,fission correction			2.411E-13

Table 6-8 cont'd

Measured Sensor Activities and Reaction Rates

Surveillance Capsule U

Reaction	LOCATION	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	Top-Mid	9.440E+04	3.162E+05	4.611E-17
	Middle	1.010E+05	3.383E+05	4.934E-17
	Bot-Mid	9.300E+04	3.115E+05	4.543E-17
$^{54}Fe\ (n,p)\ ^{54}Mn$	Top	1.210E+06	2.723E+06	4.536E-15
	Top-Mid	1.130E+06	2.543E+06	4.236E-15
	Middle	1.220E+06	2.745E+06	4.573E-15
	Bot-Mid	1.160E+06	2.610E+06	4.349E-15
	Bottom	1.140E+06	2.563E+06	4.274E-15
$^{58}Ni\ (n,p)\ ^{58}Co$	Top-Mid	4.810E+06	3.529E+07	5.876E-15
	Mid	5.220E+06	3.830E+07	6.377E-15
	Bot-Mid	4.920E+06	3.610E+07	6.010E-15
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Top	1.170E+07	3.919E+07	2.444E-12
	Bottom	1.160E+07	3.885E+07	2.423E-12
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)	Top	4.270E+06	1.430E+07	1.078E-12
	Bottom	4.180E+06	1.400E+07	1.055E-12
$^{238}U\ (n,f)\ ^{137}Cs$	Middle	2.890E+05	3.816E+06	2.507E-14
	Including ^{235}U, ^{239}Pu, and γ,fission corrections			2.070E-14
$^{237}Np\ (n,f)\ ^{137}Cs$	Middle	2.140E+06	2.826E+07	1.803E-13
	Including γ,fission correction			1.775E-13

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)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	Top-Mid	1.140E+05	2.783E+05	4.059E-17
	Middle	1.200E+05	2.929E+05	4.272E-17
	Bot-Mid	1.180E+05	2.881E+05	4.201E-17
$^{54}Fe\ (n,p)\ ^{54}Mn$	Top	1.000E+06	2.474E+06	4.121E-15
	Top-Mid	9.200E+05	2.276E+06	3.792E-15
	Top-Mid	8.800E+05	2.177E+06	3.627E-15
	Middle	9.440E+05	2.335E+06	3.890E-15
	Bot-Mid	8.850E+05	2.189E+06	3.647E-15
	Bot-Mid	8.920E+05	2.206E+06	3.676E-15
	Bottom	9.190E+05	2.273E+06	3.787E-15
$^{58}Ni\ (n,p)\ ^{58}Co$	Top-Mid	2.170E+06	3.046E+07	5.071E-15
	Bot-Mid	2.200E+06	3.088E+07	5.141E-15
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Top	1.360E+07	3.320E+07	2.071E-12
	Bottom	1.400E+07	3.418E+07	2.132E-12
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)	Top	4.930E+06	1.203E+07	9.069E-13
	Bottom	4.990E+06	1.218E+07	9.179E-13
$^{238}U\ (n,f)\ ^{137}Cs$	(lost)	-	-	-
	Including ^{235}U, ^{239}Pu, and γ,fission corrections			-
$^{237}Np\ (n,f)\ ^{137}Cs$	Middle	2.570E+06	2.142E+07	1.367E-13
	Including γ,fission correction			1.346E-13

Table 6-8 cont'd

Measured Sensor Activities and Reaction Rates

Surveillance Capsule Y

Reaction	LOCATION	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	Top-Mid	1.560E+05	2.638E+05	3.847E-17
	Middle	1.670E+05	2.824E+05	4.118E-17
	Bot-Mid	1.560E+05	2.638E+05	3.847E-17
$^{54}Fe\ (n,p)\ ^{54}Mn$	Top	1.420E+06	2.335E+06	3.891E-15
	Top-Mid	1.350E+06	2.220E+06	3.699E-15
	Middle	1.430E+06	2.352E+06	3.918E-15
	Bot-Mid	1.370E+06	2.253E+06	3.754E-15
	Bottom	1.330E+06	2.187E+06	3.644E-15
$^{58}Ni\ (n,p)\ ^{58}Co$	Top-Mid	1.710E+07	3.063E+07	5.099E-15
	Middle	1.840E+07	3.296E+07	5.487E-15
	Bot-Mid	1.730E+07	3.099E+07	5.159E-15
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Top	1.810E+07	3.060E+07	1.909E-12
	Bottom	1.610E+07	2.722E+07	1.698E-12
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)	Top	6.780E+05	1.146E+07	8.638E-13
	Bottom	6.790E+06	1.148E+07	8.651E-13
$^{238}U\ (n,f)\ ^{137}Cs$	Middle	7.790E+05	3.035E+06	1.993E-14
	Including ^{235}U, ^{239}Pu, and γ,fission corrections			1.540E-14
$^{237}Np\ (n,f)\ ^{137}Cs$	Middle	5.390E+06	2.100E+07	1.340E-13
	Including γ,fission correction			1.319E-13

Table 6-9

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

Best Estimate Flux and Fluence for Capsule V

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	1σ Uncertainty
ϕ (E > 1.0 MeV)	8.355E+10	Φ (E > 1.0 MeV)	3.060E+18	6%
ϕ (E > 0.1 MeV)	2.780E+11	Φ (E > 0.1 MeV)	1.018E+19	10%
dpa/sec	1.394E-10	dpa	5.106E-03	7%
ϕ (E < 0.414 eV)	1.012E+11	Φ (E < 0.414 eV)	3.707E+18	12%

Best Estimate Flux and Fluence for Capsule U

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	1σ Uncertainty
ϕ (E > 1.0 MeV)	5.833E+10	Φ (E > 1.0 MeV)	6.604E+18	6%
ϕ (E > 0.1 MeV)	1.822E+11	Φ (E > 0.1 MeV)	2.063E+19	9%
dpa/sec	9.483E-11	dpa	1.074E-02	7%
ϕ (E < 0.414 eV)	5.910E+10	Φ (E < 0.414 eV)	6.692E+18	12%

Best Estimate Flux and Fluence for Capsule W

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	1σ Uncertainty
ϕ (E > 1.0 MeV)	4.834E+10	Φ (E > 1.0 MeV)	8.985E+18	6%
ϕ (E > 0.1 MeV)	1.502E+11	Φ (E > 0.1 MeV)	2.792E+19	10%
dpa/sec	7.873E-11	dpa	1.463E-02	7%
ϕ (E < 0.414 eV)	5.142E+10	Φ (E < 0.414 eV)	9.558E+18	12%

Best Estimate Flux and Fluence for Capsule Y

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	1σ Uncertainty
ϕ (E > 1.0 MeV)	4.697E+10	Φ (E > 1.0 MeV)	2.117E+19	6%
ϕ (E > 0.1 MeV)	1.428E+11	Φ (E > 0.1 MeV)	6.437E+19	9%
dpa/sec	7.566E-11	dpa	3.410E-02	7%
ϕ (E < 0.414 eV)	4.146E+10	Φ (E < 0.414 eV)	1.869E+19	13%

Table 6-10

Comparison of Measured, Calculated, And Best Estimate Reaction Rates At the Surveillance Capsule Center

Surveillance Capsule V

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,α)	5.72E-17	5.87E-17	5.63E-17	0.98	0.96	0.97
^{54}Fe (n,p)	5.89E-15	6.42E-15	5.99E-15	1.02	0.93	0.92
^{58}Ni (n,p)	8.13E-15	8.81E-15	8.23E-15	1.01	0.93	0.92
^{238}U (n,f) (Cd)	2.95E-14	3.10E-14	2.92E-14	0.99	0.94	0.95
^{237}Np (n,f) (Cd)	2.41E-13	2.35E-13	2.33E-13	0.97	0.99	1.03
^{59}Co (n,γ)	4.11E-12	3.85E-12	4.09E-12	1.00	1.06	1.07
^{59}Co (n,γ) (Cd)	1.76E-12	1.86E-12	1.77E-12	1.01	0.95	0.95

Surveillance Capsule U

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,α)	4.70E-17	4.41E-17	4.58E-17	0.97	1.04	1.07
^{54}Fe (n,p)	4.39E-15	4.52E-15	4.52E-15	1.03	1.00	0.97
^{58}Ni (n,p)	6.09E-15	6.15E-15	6.17E-15	1.01	1.00	0.99
^{238}U (n,f) (Cd)	2.07E-14	2.06E-14	2.09E-14	1.01	1.01	1.00
^{237}Np (n,f) (Cd)	1.77E-13	1.47E-13	1.64E-13	0.93	1.12	1.20
^{59}Co (n,γ)	2.43E-12	2.16E-12	2.42E-12	1.00	1.12	1.13
^{59}Co (n,γ) (Cd)	1.07E-12	1.05E-12	1.07E-12	1.00	1.02	1.02

Table 6-10 cont'd

Comparison of Measured, Calculated, And Best Estimate Reaction Rates At the Surveillance Capsule Center

Surveillance Capsule W

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,α)	4.18E-17	4.13E-17	4.04E-17	0.97	0.98	1.01
^{54}Fe (n,p)	3.79E-15	4.22E-15	3.87E-15	1.02	0.92	0.90
^{58}Ni (n,p)	5.11E-15	5.73E-15	5.23E-15	1.02	0.91	0.89
^{238}U (n,f) (Cd)						
^{237}Np (n,f) (Cd)	1.35E-13	1.37E-13	1.30E-13	0.96	0.95	0.99
^{59}Co (n,γ)	2.10E-12	2.00E-12	2.09E-12	1.00	1.05	1.05
^{59}Co (n,γ) (Cd)	9.12E-13	9.75E-13	9.16E-13	1.00	0.94	0.94

Surveillance Capsule Y

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,α)	3.94E-17	3.76E-17	3.88E-17	0.98	1.03	1.05
^{54}Fe (n,p)	3.78E-15	3.81E-15	3.81E-15	1.01	1.00	0.99
^{58}Ni (n,p)	5.25E-15	5.18E-15	5.20E-15	0.99	1.00	1.01
^{238}U (n,f) (Cd)	1.54E-14	1.73E-14	1.71E-14	1.11	0.99	0.89
^{237}Np (n,f) (Cd)	1.32E-13	1.23E-13	1.26E-13	0.95	1.02	1.07
^{59}Co (n,γ)	1.80E-12	1.79E-12	1.80E-12	1.00	1.01	1.01
^{59}Co (n,γ) (Cd)	8.64E-13	8.72E-13	8.65E-13	1.00	0.99	0.99

Table 6-11

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	7.086E+06	28	9.12E-03	1.327E+10
2	1.49E+01	1.522E+07	29	5.53E-03	1.375E+10
3	1.35E+01	5.617E+07	30	3.36E-03	4.324E+09
4	1.16E+01	1.549E+08	31	2.84E-03	4.182E+09
5	1.00E+01	3.595E+08	32	2.40E-03	4.150E+09
6	8.61E+00	6.324E+08	33	2.04E-03	1.264E+10
7	7.41E+00	1.551E+09	34	1.23E-03	1.294E+10
8	6.07E+00	2.400E+09	35	7.49E-04	1.258E+10
9	4.97E+00	4.929E+09	36	4.54E-04	1.083E+10
10	3.68E+00	5.658E+09	37	2.75E-04	1.206E+10
11	2.87E+00	1.058E+10	38	1.67E-04	1.245E+10
12	2.23E+00	1.324E+10	39	1.01E-04	1.262E+10
13	1.74E+00	1.709E+10	40	6.14E-05	1.260E+10
14	1.35E+00	1.696E+10	41	3.73E-05	1.254E+10
15	1.11E+00	2.901E+10	42	2.26E-05	1.235E+10
16	8.21E-01	2.910E+10	43	1.37E-05	1.203E+10
17	6.39E-01	3.109E+10	44	8.32E-06	1.160E+10
18	4.98E-01	1.969E+10	45	5.04E-06	1.119E+10
19	3.88E-01	2.708E+10	46	3.06E-06	1.103E+10
20	3.02E-01	3.312E+10	47	1.86E-06	1.060E+10
21	1.83E-01	3.080E+10	48	1.13E-06	7.854E+09
22	1.11E-01	2.135E+10	49	6.83E-07	8.237E+09
23	6.74E-02	1.930E+10	50	4.14E-07	1.670E+10
24	4.09E-02	1.142E+10	51	2.51E-07	1.722E+10
25	2.55E-02	1.149E+10	52	1.52E-07	1.762E+10
26	1.99E-02	7.043E+09	53	9.24E-08	4.967E+10
27	1.50E-02	1.262E+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 U

Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	6.092E+06	28	9.12E-03	8.088E+09
2	1.49E+01	1.304E+07	29	5.53E-03	8.339E+09
3	1.35E+01	4.731E+07	30	3.36E-03	2.612E+09
4	1.16E+01	1.287E+08	31	2.84E-03	2.529E+09
5	1.00E+01	2.961E+08	32	2.40E-03	2.519E+09
6	8.61E+00	5.123E+08	33	2.04E-03	7.651E+09
7	7.41E+00	1.247E+09	34	1.23E-03	7.789E+09
8	6.07E+00	1.874E+09	35	7.49E-04	7.629E+09
9	4.97E+00	3.686E+09	36	4.54E-04	6.579E+09
10	3.68E+00	4.082E+09	37	2.75E-04	7.259E+09
11	2.87E+00	7.541E+09	38	1.67E-04	7.562E+09
12	2.23E+00	9.245E+09	39	1.01E-04	7.612E+09
13	1.74E+00	1.169E+10	40	6.14E-05	7.583E+09
14	1.35E+00	1.142E+10	41	3.73E-05	7.527E+09
15	1.11E+00	1.916E+10	42	2.26E-05	7.393E+09
16	8.21E-01	1.887E+10	43	1.37E-05	7.188E+09
17	6.39E-01	1.984E+10	44	8.32E-06	6.923E+09
18	4.98E-01	1.260E+10	45	5.04E-06	6.661E+09
19	3.88E-01	1.707E+10	46	3.06E-06	6.552E+09
20	3.02E-01	2.086E+10	47	1.86E-06	6.290E+09
21	1.83E-01	1.922E+10	48	1.13E-06	4.654E+09
22	1.11E-01	1.326E+10	49	6.83E-07	4.875E+09
23	6.74E-02	1.192E+10	50	4.14E-07	9.837E+09
24	4.09E-02	7.034E+09	51	2.51E-07	1.010E+10
25	2.55E-02	7.009E+09	52	1.52E-07	1.031E+10
26	1.99E-02	4.295E+09	53	9.24E-08	2.886E+10
27	1.50E-02	7.684E+09			

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	5.509E+06	28	9.12E-03	6.976E+09
2	1.49E+01	1.177E+07	29	5.53E-03	7.211E+09
3	1.35E+01	4.253E+07	30	3.36E-03	2.260E+09
4	1.16E+01	1.152E+08	31	2.84E-03	2.189E+09
5	1.00E+01	2.635E+08	32	2.40E-03	2.179E+09
6	8.61E+00	4.520E+08	33	2.04E-03	6.616E+09
7	7.41E+00	1.090E+09	34	1.23E-03	6.731E+09
8	6.07E+00	1.618E+09	35	7.49E-04	6.578E+09
9	4.97E+00	3.139E+09	36	4.54E-04	5.664E+09
10	3.68E+00	3.434E+09	37	2.75E-04	6.239E+09
11	2.87E+00	6.284E+09	38	1.67E-04	6.452E+09
12	2.23E+00	7.637E+09	39	1.01E-04	6.537E+09
13	1.74E+00	9.589E+09	40	6.14E-05	6.515E+09
14	1.35E+00	9.325E+09	41	3.73E-05	6.479E+09
15	1.11E+00	1.559E+10	42	2.26E-05	6.375E+09
16	8.21E-01	1.536E+10	43	1.37E-05	6.208E+09
17	6.39E-01	1.619E+10	44	8.32E-06	5.987E+09
18	4.98E-01	1.032E+10	45	5.04E-06	5.767E+09
19	3.88E-01	1.406E+10	46	3.06E-06	5.678E+09
20	3.02E-01	1.729E+10	47	1.86E-06	5.455E+09
21	1.83E-01	1.604E+10	48	1.13E-06	4.039E+09
22	1.11E-01	1.114E+10	49	6.83E-07	4.231E+09
23	6.74E-02	1.007E+10	50	4.14E-07	8.547E+09
24	4.09E-02	5.981E+09	51	2.51E-07	8.785E+09
25	2.55E-02	5.989E+09	52	1.52E-07	8.968E+09
26	1.99E-02	3.686E+09	53	9.24E-08	2.512E+10
27	1.50E-02	6.615E+09			

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

Table 6-11 cont'd

Best Estimate Neutron Energy Spectrum at the Center of Surveillance Capsules

Capsule Y

Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	5.209E+06	28	9.12E-03	6.462E+09
2	1.49E+01	1.118E+07	29	5.53E-03	6.677E+09
3	1.35E+01	4.051E+07	30	3.36E-03	2.094E+09
4	1.16E+01	1.103E+08	31	2.84E-03	2.031E+09
5	1.00E+01	2.538E+08	32	2.40E-03	2.025E+09
6	8.61E+00	4.382E+08	33	2.04E-03	6.159E+09
7	7.41E+00	1.066E+09	34	1.23E-03	6.277E+09
8	6.07E+00	1.593E+09	35	7.49E-04	6.155E+09
9	4.97E+00	3.098E+09	36	4.54E-04	5.313E+09
10	3.68E+00	3.379E+09	37	2.75E-04	5.866E+09
11	2.87E+00	6.158E+09	38	1.67E-04	6.139E+09
12	2.23E+00	7.432E+09	39	1.01E-04	6.149E+09
13	1.74E+00	9.280E+09	40	6.14E-05	6.115E+09
14	1.35E+00	8.993E+09	41	3.73E-05	6.062E+09
15	1.11E+00	1.495E+10	42	2.26E-05	5.943E+09
16	8.21E-01	1.463E+10	43	1.37E-05	5.767E+09
17	6.39E-01	1.531E+10	44	8.32E-06	5.543E+09
18	4.98E-01	9.708E+09	45	5.04E-06	5.324E+09
19	3.88E-01	1.316E+10	46	3.06E-06	5.227E+09
20	3.02E-01	1.613E+10	47	1.86E-06	5.009E+09
21	1.83E-01	1.492E+10	48	1.13E-06	3.700E+09
22	1.11E-01	1.034E+10	49	6.83E-07	3.755E+09
23	6.74E-02	9.332E+09	50	4.14E-07	7.364E+09
24	4.09E-02	5.537E+09	51	2.51E-07	7.355E+09
25	2.55E-02	5.541E+09	52	1.52E-07	7.346E+09
26	1.99E-02	3.410E+09	53	9.24E-08	1.940E+10
27	1.50E-02	6.121E+09			

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

Table 6-12

Comparison Of Calculated And Best Estimate Integrated Neutron Exposure Of Beaver Valley Unit 1 Surveillance Capsules V, U, W, and Y

CAPSULE V

	Calculated	Best Estimate	BE/C
Φ(E > 1.0 MeV) [n/cm²]	3.23E+18	3.06E+18	0.95
Φ(E > 0.1 MeV) [n/cm²]	1.05E+19	1.02E+19	0.97
Dpa	5.31E-03	5.11E-03	0.96

CAPSULE U

	Calculated	Best Estimate	BE/C
Φ(E > 1.0 MeV) [n/cm²]	6.46E+18	6.60E+18	1.02
Φ(E > 0.1 MeV) [n/cm²]	1.96E+19	2.06E+19	1.06
Dpa	1.03E-02	1.07E-02	1.04

CAPSULE W

	Calculated	Best Estimate	BE/C
Φ(E > 1.0 MeV) [n/cm²]	9.86E+18	8.99E+18	0.91
Φ(E > 0.1 MeV) [n/cm²]	2.98E+19	2.79E+19	0.94
dpa	1.58E-02	1.46E-02	0.93

CAPSULE Y

	Calculated	Best Estimate	BE/C
Φ(E > 1.0 MeV) [n/cm²]	2.15E+19	2.12E+19	0.99
Φ(E > 0.1 MeV) [n/cm²]	6.48E+19	6.44E+20	0.99
dpa	3.44E-02	3.41E-02	0.99

AVERAGE BE/C RATIOS

	BE/C
Φ(E > 1.0 MeV) [n/cm²]	0.97
Φ(E > 0.1 MeV) [n/cm²]	0.99
Dpa	0.98

Table 6-13

Azimuthal Variations Of The Neutron Exposure Projections On The Reactor Vessel Clad/Base Metal Interface At the Elevation of Maximum Fluence

Best Estimate

	0°	15°	30°	45°
14.3 EFPY				
E>1.0 MeV	1.70E+19	8.91E+18	5.26E+18	3.55E+18
E>0.1 MeV	4.65E+19	2.43E+19	1.37E+19	9.08E+18
Dpa	2.77E-02	1.46E-02	8.54E-03	5.77E-03
15.7 EFPY				
E>1.0 MeV	1.82E+19	9.53E+18	5.72E+18	3.87E+18
E>0.1 MeV	4.95E+19	2.59E+19	1.49E+19	9.89E+18
Dpa	2.96E-02	1.56E-02	9.28E-03	6.29E-03
17.0 EFPY				
E>1.0 MeV	1.99E+19	1.05E+19	6.21E+18	4.18E+18
E>0.1 MeV	5.42E+19	2.85E+19	1.62E+19	1.07E+19
dpa	3.23E-02	1.71E-02	1.01E-02	6.80E-03
28 EFPY				
E>1.0 MeV	3.42E+19	1.83E+19	1.04E+19	6.85E+18
E>0.1 MeV	9.34E+19	4.96E+19	2.71E+19	1.75E+19
dpa	5.58E-02	2.99E-02	1.68E-02	1.11E-02
45 EFPY				
E>1.0 MeV	5.65E+19	3.03E+19	1.68E+19	1.10E+19
E>0.1 MeV	1.54E+20	8.25E+19	4.39E+19	2.81E+19
dpa	9.20E-02	4.97E-02	2.73E-02	1.78E-02

Table 6-13 cont'd

Azimuthal Variations Of The Neutron Exposure Projections On The Reactor Vessel Clad/Base Metal Interface At The Elevation of Maximum Fluence

Calculated

	0°	15°	30°	45°
14.3 EFPY				
E>1.0 MeV	1.76E+19	9.22E+18	5.44E+18	3.67E+18
E>0.1 MeV	4.69E+19	2.45E+19	1.39E+19	9.17E+18
Dpa	2.83E-02	1.49E-02	8.71E-03	5.89E-03
15.7 EFPY				
E>1.0 MeV	1.88E+19	9.86E+18	5.91E+18	4.00E+18
E>0.1 MeV	5.00E+19	2.62E+19	1.51E+19	9.99E+18
Dpa	3.02E-02	1.60E-02	9.47E-03	6.41E-03
17.0 EFPY				
E>1.0 MeV	2.05E+19	1.08E+19	6.42E+18	4.33E+18
E>0.1 MeV	5.47E+19	2.87E+19	1.64E+19	1.08E+19
dpa	3.30E-02	1.75E-02	1.03E-02	6.94E-03
28 EFPY				
E>1.0 MeV	3.54E+19	1.89E+19	1.07E+19	7.08E+18
E>0.1 MeV	9.44E+19	5.01E+19	2.73E+19	1.77E+19
dpa	5.69E-02	3.05E-02	1.72E-02	1.14E-02
45 EFPY				
E>1.0 MeV	5.85E+19	3.14E+19	1.73E+19	1.13E+19
E>0.1 MeV	1.56E+20	8.33E+19	4.43E+19	2.83E+19
dpa	9.39E-02	5.08E-02	2.78E-02	1.82E-02

Table 6-14

Neutron Exposure Values Within The

Beaver Valley Unit 1 Reactor Vessel

Best Estimate Fluence (n/cm^2) Based on E > 1.0 MeV Slope[a]

	0°	15°	30°[b]	45°
14.3 EFPY				
Surface	1.70E+19	8.91E+18	5.26E+18	3.55E+18
¼ T	9.83E+18	5.25E+18	3.06E+18	2.07E+18
¾ T	2.40E+18	1.35E+18	7.78E+17	5.36E+17
15.7 EFPY				
Surface	1.82E+19	9.53E+18	5.72E+18	3.87E+18
¼ T	1.05E+19	5.61E+18	3.33E+18	2.26E+18
¾ T	2.56E+18	1.45E+18	8.46E+17	5.84E+17
17.0 EFPY				
Surface	1.99E+19	1.05E+19	6.21E+18	4.18E+18
¼ T	1.15E+19	6.16E+18	3.62E+18	2.44E+18
¾ T	2.80E+18	1.59E+18	9.18E+17	6.31E+17
28 EFPY				
Surface	3.42E+19	1.83E+19	1.04E+19	6.85E+18
¼ T	1.98E+19	1.08E+19	6.03E+18	4.00E+18
¾ T	4.83E+18	2.78E+18	1.53E+18	1.03E+18
45 EFPY				
Surface	5.65E+19	3.03E+19	1.68E+19	1.10E+19
¼ T	3.26E+19	1.79E+19	9.78E+18	6.41E+18
¾ T	7.97E+18	4.61E+18	2.48E+18	1.66E+18

Note:

a) The ¼T and ¾T values were determined using the calculational methods described in Section 6.2 and not by the empirical relation described in Regulatory Guide 1.99, Rev. 2.

Table 6-14 cont'd

Neutron Exposure Values Within The

Beaver Valley Unit 1 Reactor Vessel

Best Estimate Fluence (n/cm2) Based on dpa Slope[a]

	0°	15°	30°	45°
14.3 EFPY				
Surface	1.70E+19	8.91E+18	5.26E+18	3.55E+18
¼ T	1.14E+19	6.12E+18	3.54E+18	2.39E+18
¾ T	4.26E+18	2.48E+18	1.40E+18	9.69E+17
15.7 EFPY				
Surface	1.82E+19	9.53E+18	5.72E+18	3.87E+18
¼ T	1.21E+19	6.55E+18	3.85E+18	2.61E+18
¾ T	4.54E+18	2.65E+18	1.52E+18	1.06E+18
17.0 EFPY				
Surface	1.99E+19	1.05E+19	6.21E+18	4.18E+18
¼ T	1.33E+19	7.18E+18	4.18E+18	2.82E+18
¾ T	4.96E+18	2.91E+18	1.65E+18	1.14E+18
28 EFPY				
Surface	3.42E+19	1.83E+19	1.04E+19	6.85E+18
¼ T	2.29E+19	1.25E+19	6.98E+18	4.61E+18
¾ T	8.56E+18	5.08E+18	2.75E+18	1.87E+18
45 EFPY				
Surface	5.65E+19	3.03E+19	1.68E+19	1.10E+19
¼ T	3.78E+19	2.08E+19	1.13E+19	7.39E+18
¾ T	1.41E+19	8.44E+18	4.46E+18	3.00E+18

Note:

a) The ¼T and ¾T values were determined using the calculational methods described in Section 6.2 and not by the empirical relation described in Regulatory Guide 1.99, Rev. 2.

Table 6-14 cont'd

Neutron Exposure Values Within The

Beaver Valley Unit 1 Reactor Vessel

Calculated Fluence (n/cm2) Based on E > 1.0 MeV Slope[a]

	0°	15°	30°	45°
14.3 EFPY				
Surface	1.76E+19	9.22E+18	5.44E+18	3.67E+18
¼ T	1.02E+19	5.43E+18	3.17E+18	2.14E+18
¾ T	2.48E+18	1.40E+18	8.05E+17	5.54E+17
15.7 EFPY				
Surface	1.88E+19	9.86E+18	5.91E+18	4.00E+18
¼ T	1.08E+19	5.81E+18	3.45E+18	2.34E+18
¾ T	2.65E+18	1.50E+18	8.75E+17	6.04E+17
17.0 EFPY				
Surface	2.05E+19	1.08E+19	6.42E+18	4.33E+18
¼ T	1.19E+19	6.37E+18	3.74E+18	2.53E+18
¾ T	2.90E+18	1.64E+18	9.50E+17	6.53E+17
28 EFPY				
Surface	3.54E+19	1.89E+19	1.07E+19	7.08E+18
¼ T	2.04E+19	1.11E+19	6.24E+18	4.14E+18
¾ T	4.99E+18	2.87E+18	1.58E+18	1.07E+18
45 EFPY				
Surface	5.85E+19	3.14E+19	1.73E+19	1.13E+19
¼ T	3.37E+19	1.85E+19	1.01E+19	6.63E+18
¾ T	8.24E+18	4.77E+18	2.57E+18	1.71E+18

Note:

a) The ¼T and ¾T values were determined using the calculational methods described in Section 6.2 and not by the empirical relation described in Regulatory Guide 1.99, Rev. 2.

Table 6-14 cont'd

Neutron Exposure Values Within The

Beaver Valley Unit 1 Reactor Vessel

Calculated Fluence (n/cm2) Based on dpa Slope[a]

	0°	15°	30°	45°
14.3 EFPY				
Surface	1.76E+19	9.22E+18	5.44E+18	3.67E+18
¼ T	1.18E+19	6.33E+18	3.66E+18	2.47E+18
¾ T	4.41E+18	2.56E+18	1.45E+18	1.00E+18
15.7 EFPY				
Surface	1.88E+19	9.86E+18	5.91E+18	4.00E+18
¼ T	1.25E+19	6.77E+18	3.98E+18	2.70E+18
¾ T	4.70E+18	2.74E+18	1.57E+18	1.09E+18
17.0 EFPY				
Surface	2.05E+19	1.08E+19	6.42E+18	4.33E+18
¼ T	1.37E+19	7.43E+18	4.33E+18	2.92E+18
¾ T	5.14E+18	3.01E+18	1.71E+18	1.18E+18
28 EFPY				
Surface	3.54E+19	1.89E+19	1.07E+19	7.08E+18
¼ T	2.37E+19	1.30E+19	7.22E+18	4.77E+18
¾ T	8.86E+18	5.25E+18	2.85E+18	1.93E+18
45 EFPY				
Surface	5.85E+19	3.14E+19	1.73E+19	1.13E+19
¼ T	3.91E+19	2.16E+19	1.17E+19	7.65E+18
¾ T	1.46E+19	8.73E+18	4.61E+18	3.10E+18

Note:

a) The ¼T and ¾T values were determined using the calculational methods described in Section 6.2 and not by the empirical relation described in Regulatory Guide 1.99, Rev. 2.

Table 6-15

Calculated Fast Neutron Fluence (E>1.0 MeV) for

Materials Comprising the Beltline Region of the Reactor Vessel

Operating Time (EFPY)	Lower Shell Plates	Lower Shell Long. Weld	Circ. Weld	Int. Shell Plates	Int. Shell Long. Weld
14.3	1.76E+19	3.67E+18	1.75E+19	1.76E+19	3.67E+18
15.7	1.88E+19	4.00E+18	1.87E+19	1.88E+19	4.00E+18
17.0	2.05E+19	4.33E+18	2.05E+19	2.05E+19	4.33E+18
28.00	3.54E+19	7.08E+18	3.53E+19	3.54E+19	7.08E+18
45.00	5.85E+19	1.13E+19	5.82E+19	5.85E+19	1.13E+19

Table 6-16

Calculated Fast Neutron Fluence (E>0.1 MeV) for

Materials Comprising the Beltline Region of the Reactor Vessel

Operating Time (EFPY)	Lower Shell Plates	Lower Shell Long. Weld	Circ. Weld	Int. Shell Plates	Int. Shell Long. Weld
14.3	4.69E+19	9.17E+18	4.68E+19	4.69E+19	9.17E+18
15.7	5.00E+19	9.99E+18	4.99E+19	5.00E+19	9.99E+18
17.0	5.47E+19	1.08E+19	5.45E+19	5.47E+19	1.08E+19
28.00	9.43E+19	1.77E+19	9.41E+19	9.43E+19	1.77E+19
45.00	1.56E+20	2.83E+19	1.55E+20	1.56E+20	2.83E+19

Table 6-17

Calculated Iron Atom Displacements for

Materials Comprising the Beltline Region of the Reactor Vessel

Operating Time (EFPY)	Lower Shell Plates	Lower Shell Long. Weld	Circ. Weld	Int. Shell Plates	Int. Shell Long. Weld
14.3	2.83E-02	5.89E-03	2.82E-02	2.83E-02	5.89E-03
15.7	3.02E-02	6.41E-03	3.01E-02	3.02E-02	6.41E-03
17.0	3.30E-02	6.94E-03	3.29E-02	3.30E-02	6.94E-03
28.00	5.69E-02	1.14E-02	5.67E-02	5.69E-02	1.14E-02
45.00	9.39E-02	1.82E-02	9.36E-02	9.39E-02	1.82E-02

Table 6-18

Updated Lead Factors For Beaver Valley Unit 1

Surveillance Capsules Which Have Been Removed

Capsule	Lead Factor
V[a]	1.60
U[b]	1.05
W[c]	1.09
Y[d]	1.22

[a] - Withdrawn at the end of Cycle 1.

[b] - Withdrawn at the end of Cycle 4.

[c] - Withdrawn at the end of Cycle 6.

[d] - Withdrawn at the end of Cycle 13.

The surveillance capsule lead factor is defined by:

$$\frac{\Phi^{Surveillance\ Capsule}_{Calculated}}{\Phi^{Clad\ /\ Base\ Metal\ Interface\ Axial\ Peak}_{Calculated}}$$

where Φ is the neutron fluence ($E > 1.0$ MeV) at the time of the capsule withdrawal.

Table 6-19

Projected Lead Factors for Beaver Valley Unit 1

Surveillance Capsules Which Have Not Been Removed

		Location/Capsule [a]			
		15°	25°	15°	45°
EFPY	Cycle	X	T	Z	S
10.8	10	1.72	0.77	0.77	0.60
11.8	11	1.73	0.81	0.83	0.62
12.9	12	1.75	0.86	0.90	0.63
14.3	13	1.76	0.91	0.97	0.65
15.7	14	1.77	0.95	1.03	0.66
17.0	15	1.78	0.97	1.10	0.66
28		1.79	1.05	1.39	0.62
45		1.79	1.10	1.55	0.60

[a] The projected factors assume Capsule T is relocated to a 25° position and Capsule Z is relocated to a 15° position after Cycle 10.

The surveillance capsule lead factor is defined by:

$$\frac{\Phi^{Surveillance\ Capsule}_{Calculated}}{\Phi^{Clad\ /\ Base\ Metal\ Interface\ Axial\ Peak}_{Calculated}}$$

where Φ is the neutron fluence (E > 1.0 MeV) at the projected time.

7 SURVEILLANCE CAPSULE REMOVAL SCHEDULE

The following surveillance capsule removal schedule meets the requirements of ASTM E185-82 and is recommended for future capsules to be removed from the Beaver Valley Unit 1 reactor vessel. This recommended removal schedule is applicable to 28 EFPY of operation.

Table 7-1 Beaver Valley 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)]
V	165°	1.60	1.16	3.23×10^{18} (c)
U	65°	1.05	3.59	6.46×10^{18} (c)
W	245°	1.09	5.89	9.86×10^{18} (c)
Y	295°	1.22	14.3	2.15×10^{19} (c)
X	285°	1.76	25.7	5.82×10^{19} (f)
T	55°	(d)	Standby	---
Z	305°	(e)	Standby	---
S	45°	0.63	Standby	---

Notes:

(a) Updated in Capsule Y dosimetry analysis, see Section 6 of this report.
(b) Effective Full Power Years (EFPY) from plant startup.
(c) Plant specific evaluation.
(d) Capsule T was moved to the capsule U location at the end of cycle 10 (10.8 EFPY). The lead factor was approximately 0.77 through the first 10 cycles. The average lead factor for cycle 11 and higher is 0.95 (Reference Table 6-19).
(e) Capsule Z was moved to the capsule V location at the end of cycle 10 (10.8 EFPY). The lead factor was approximately 0.77 through the first 10 cycles. The average lead factor for cycle 11 and higher is 1.11 (Reference Table 6-19).
(f) Vessel clad/base metal interface fluence at a license renewal of 45 EFPY (i.e. 20 year life extension).

8 REFERENCES

1. WCAP-8475, *Duquesne Light Company Beaver Valley Unit No. 1 Reactor Vessel Radiation Surveillance Program*, J. A. Davidson, October, 1974.

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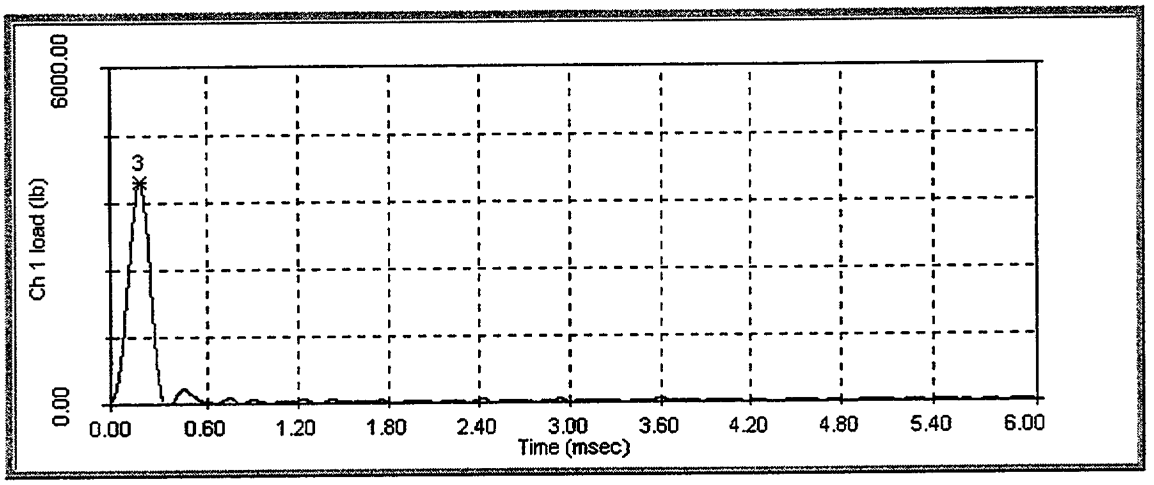
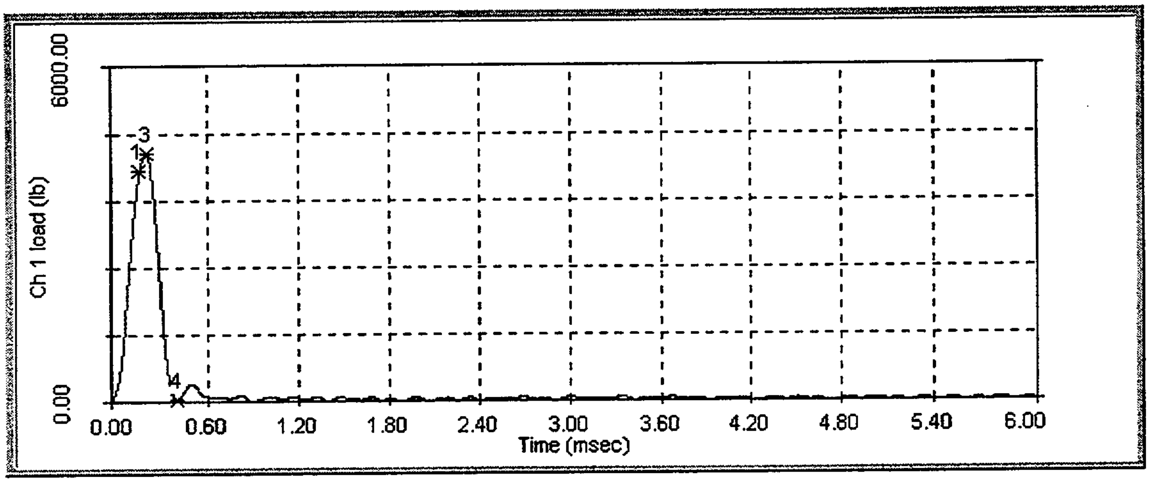
APPENDIX A

LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS



DL62, 100°F



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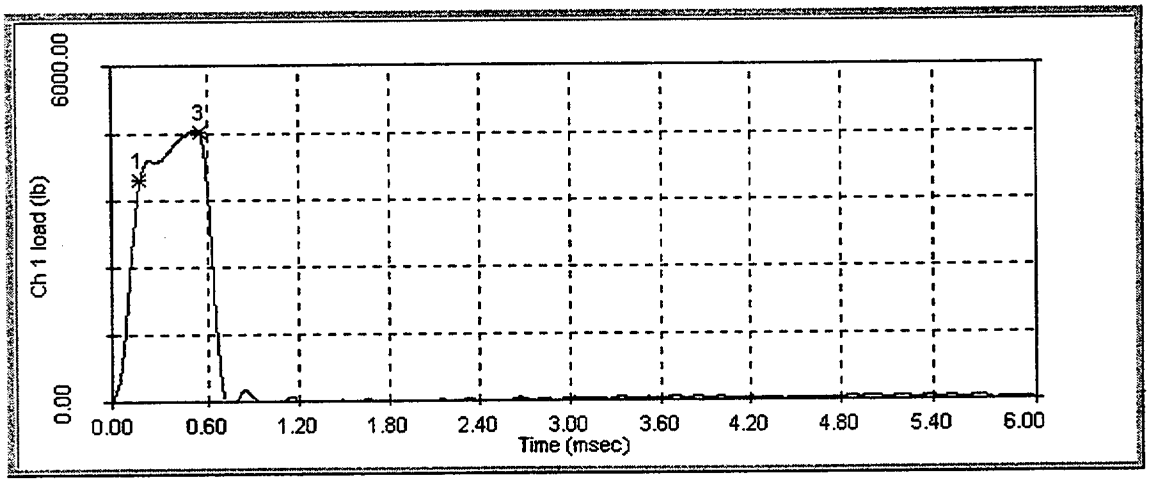

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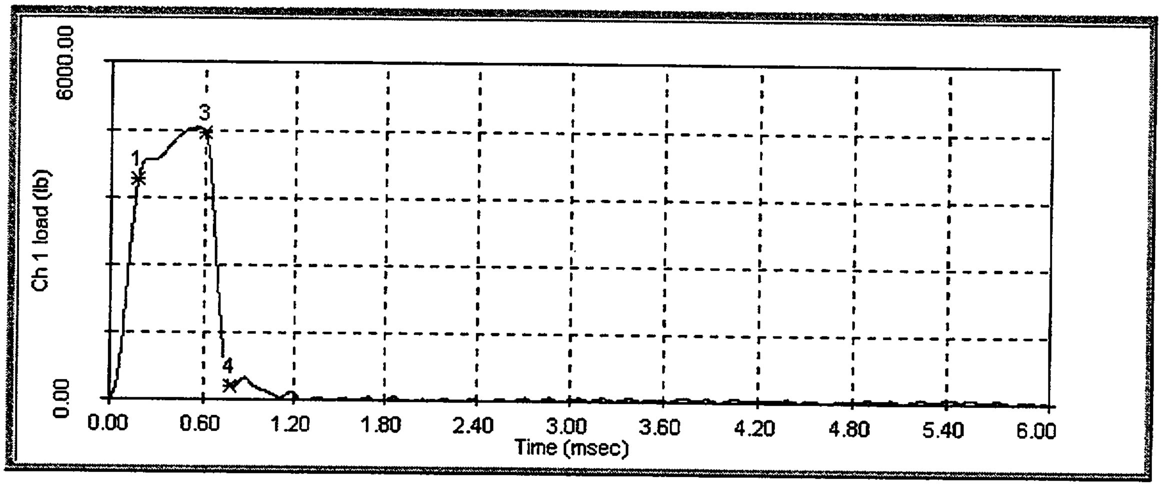

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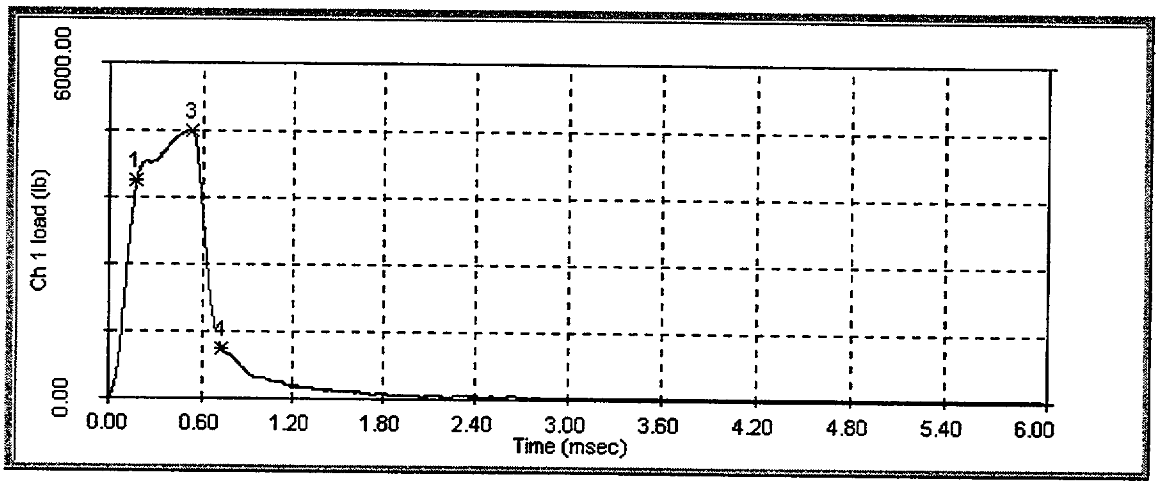
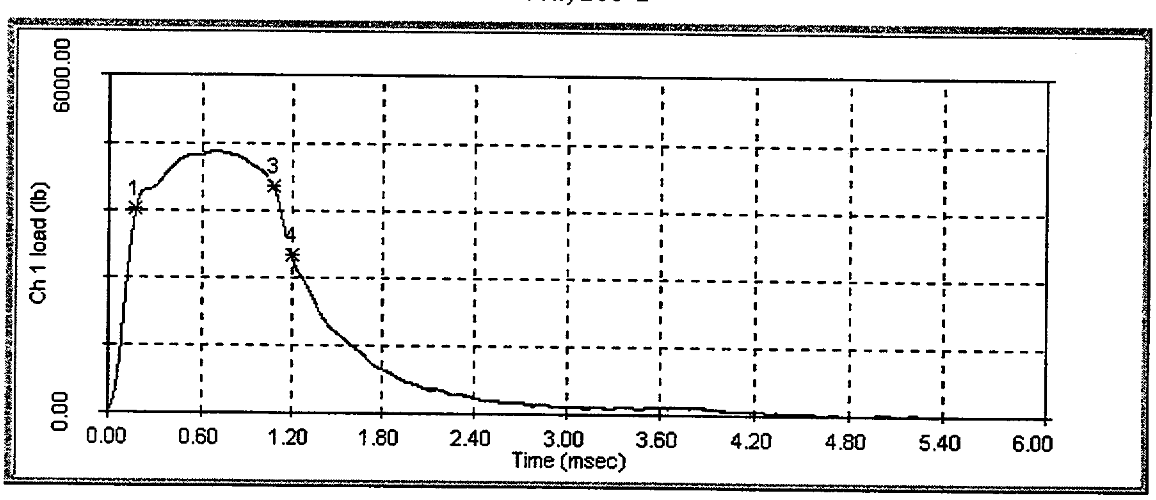


DL61, 200°F



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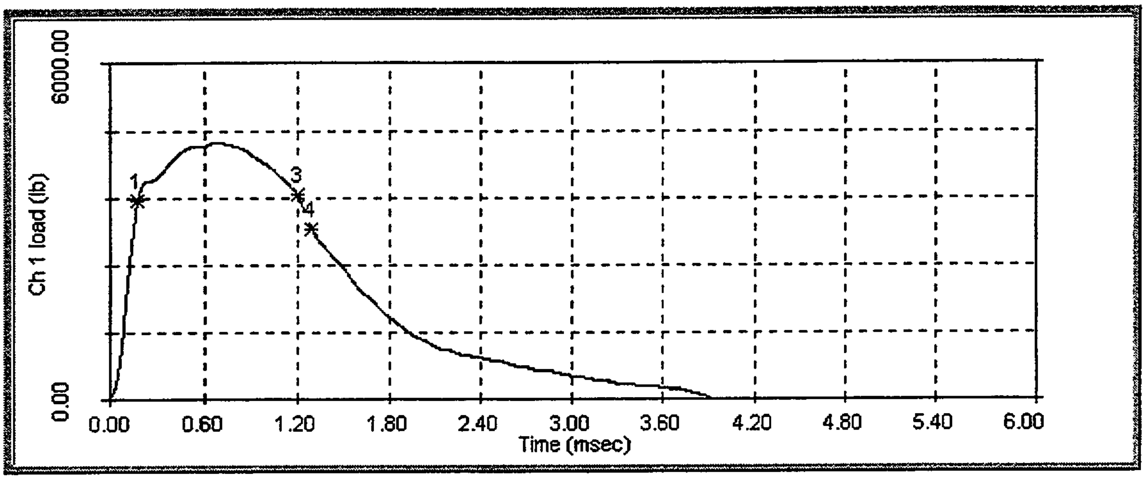
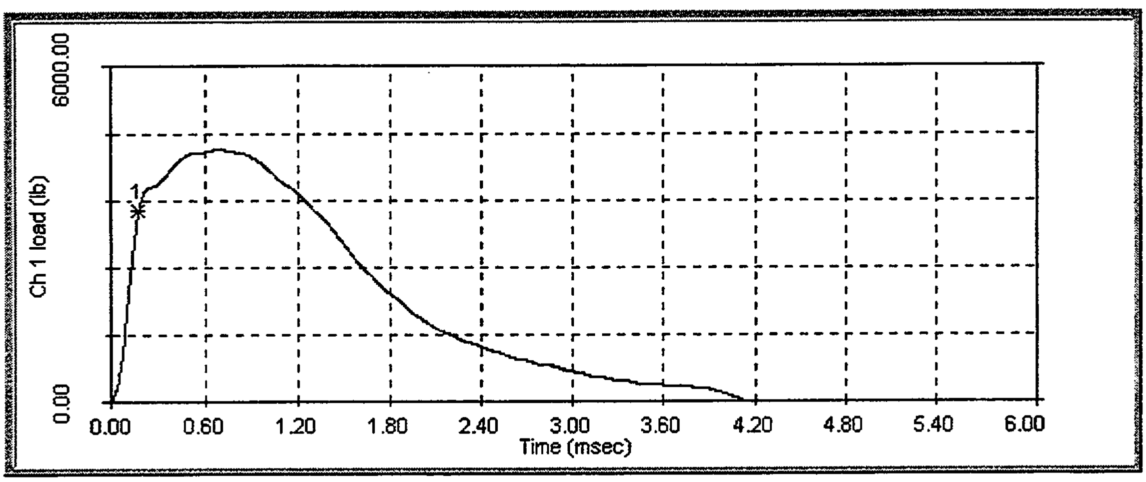


DL57, 300°F



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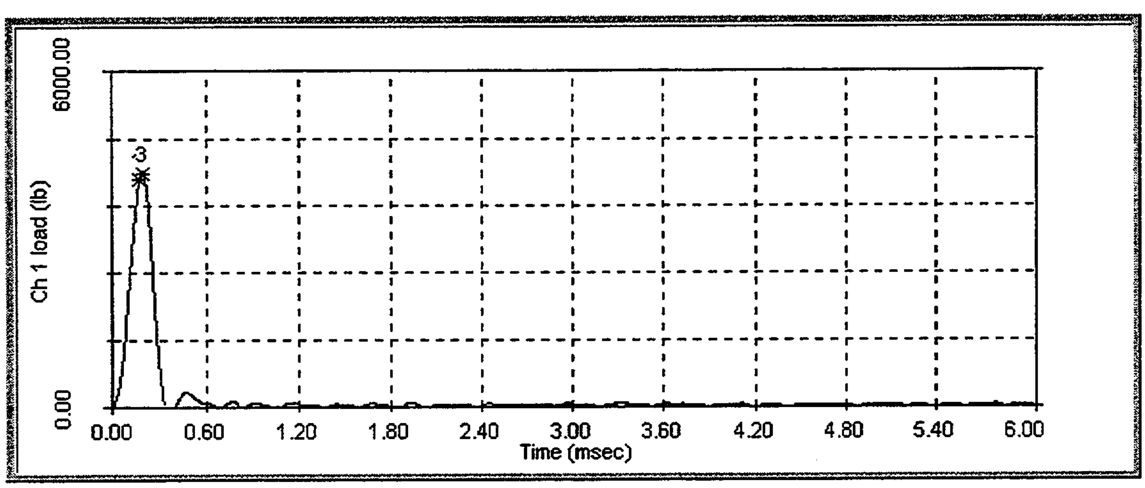

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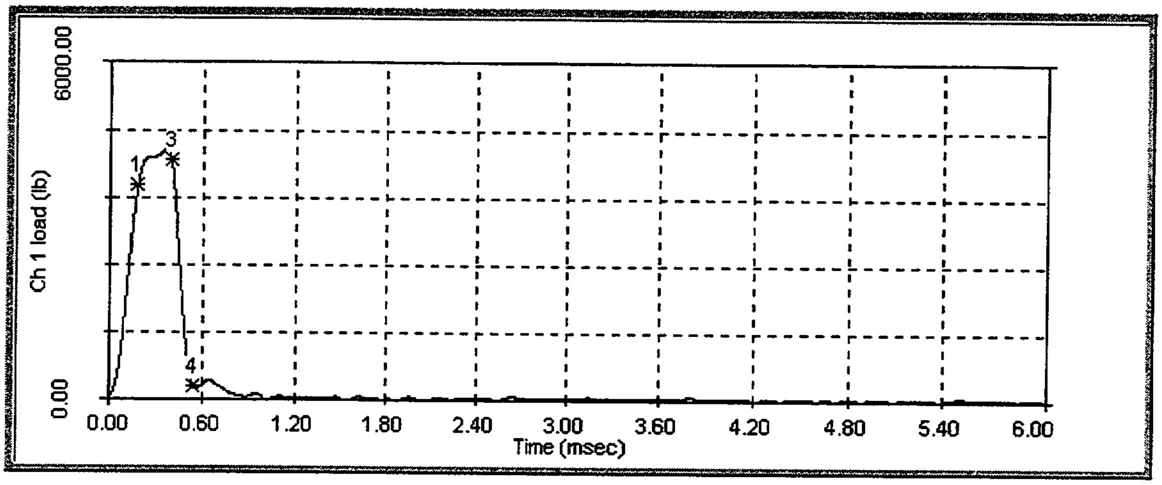

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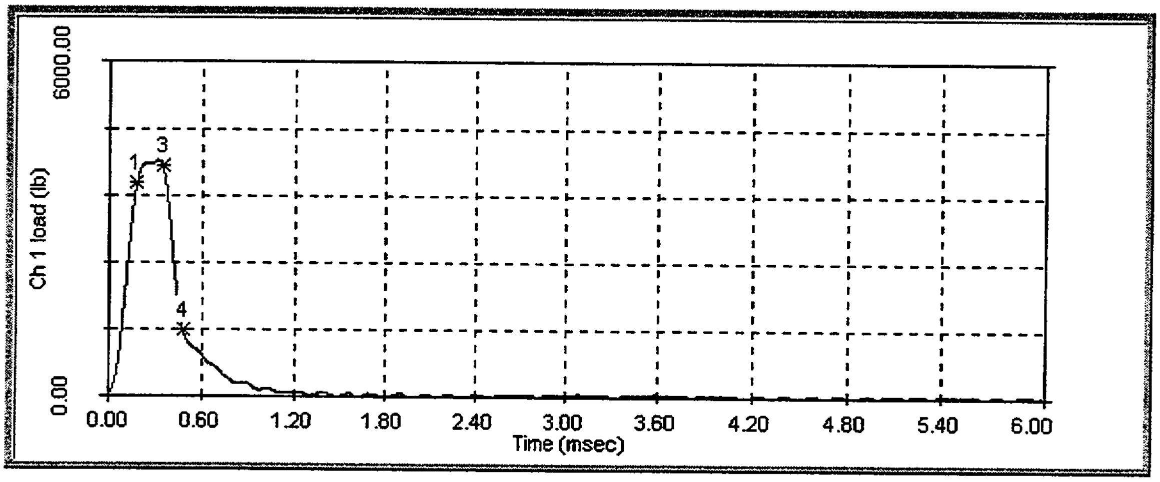

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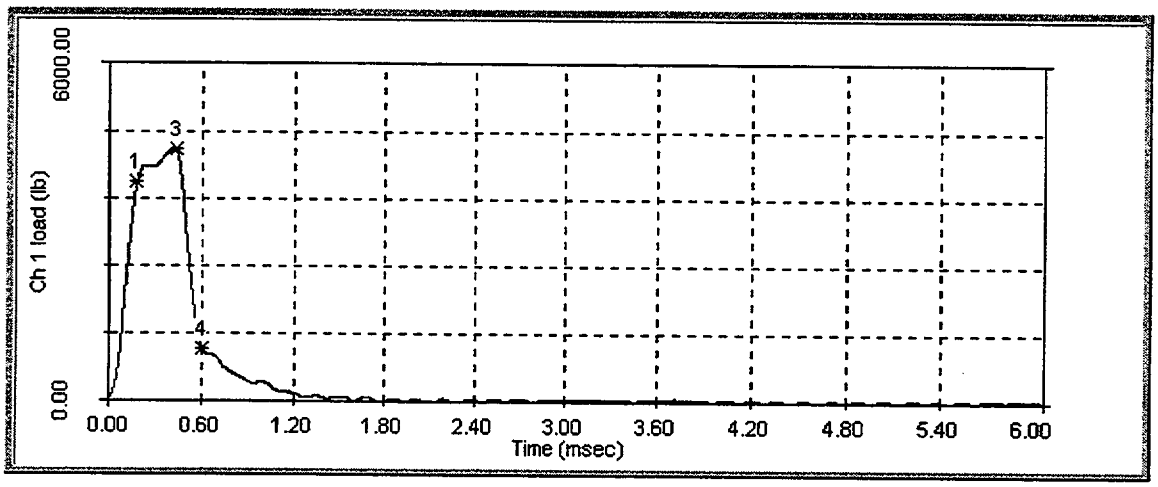

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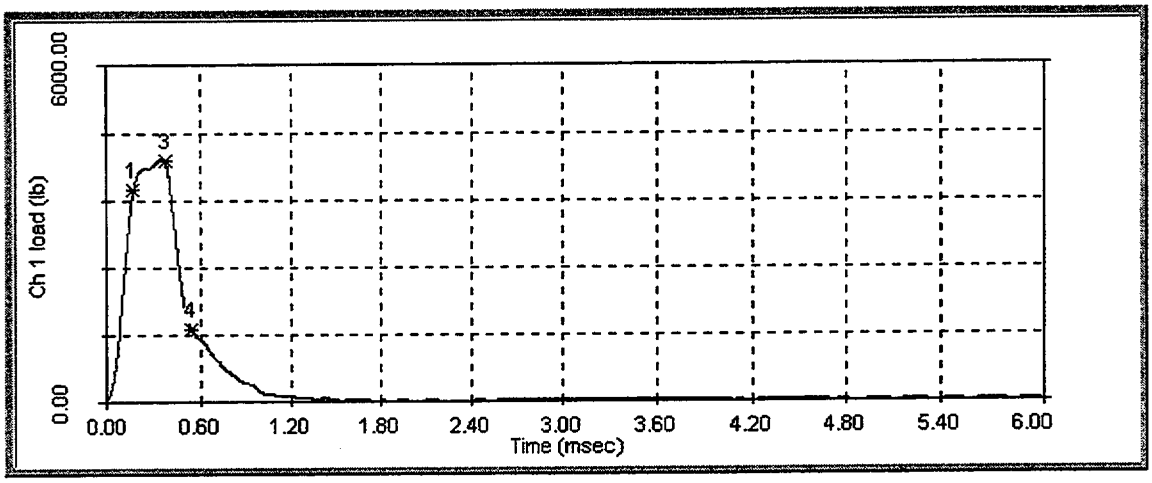

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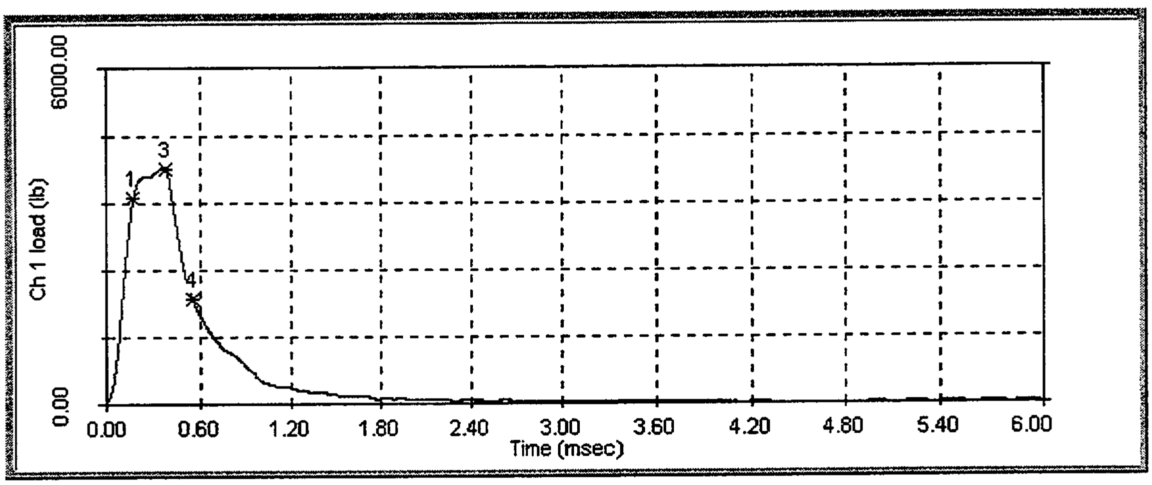

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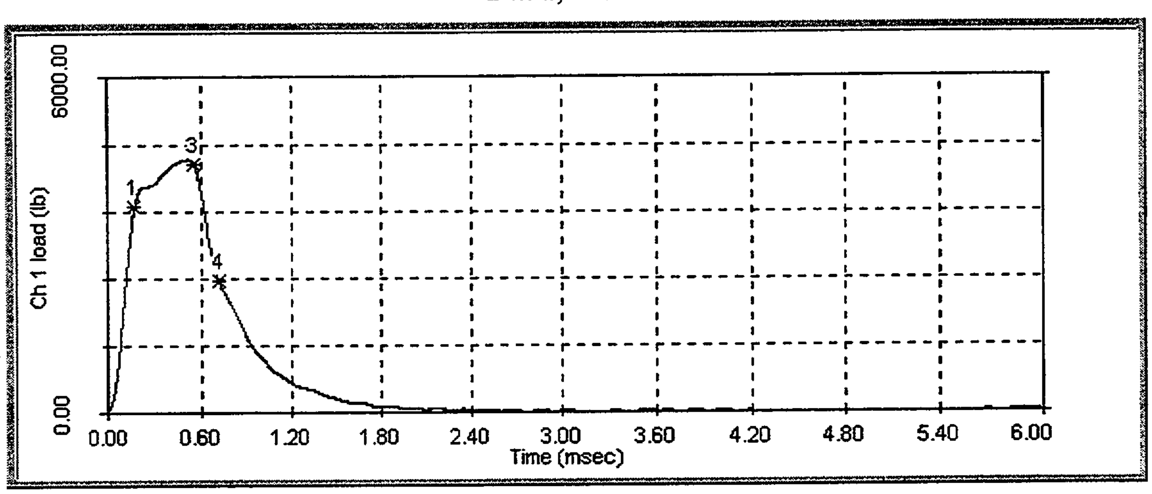

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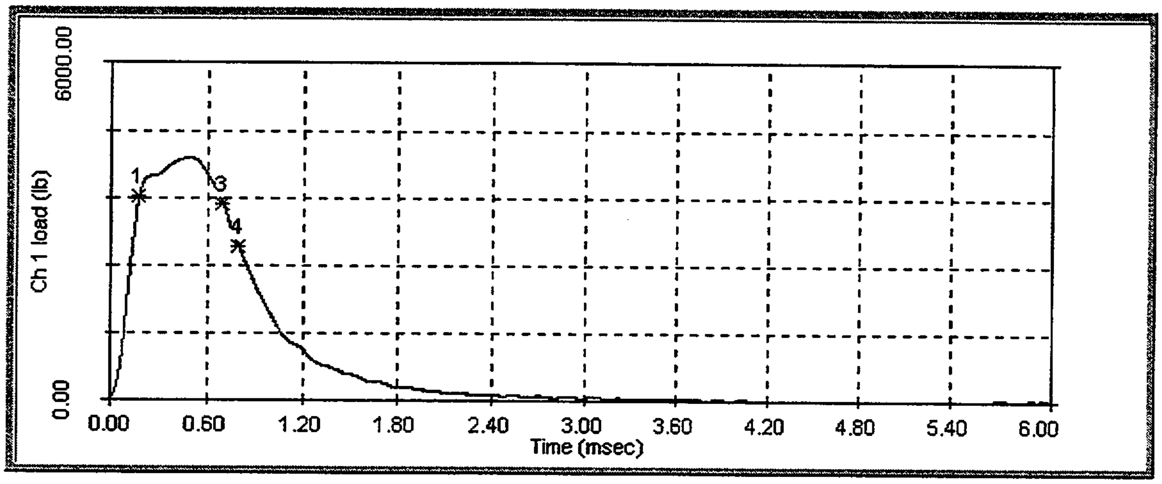

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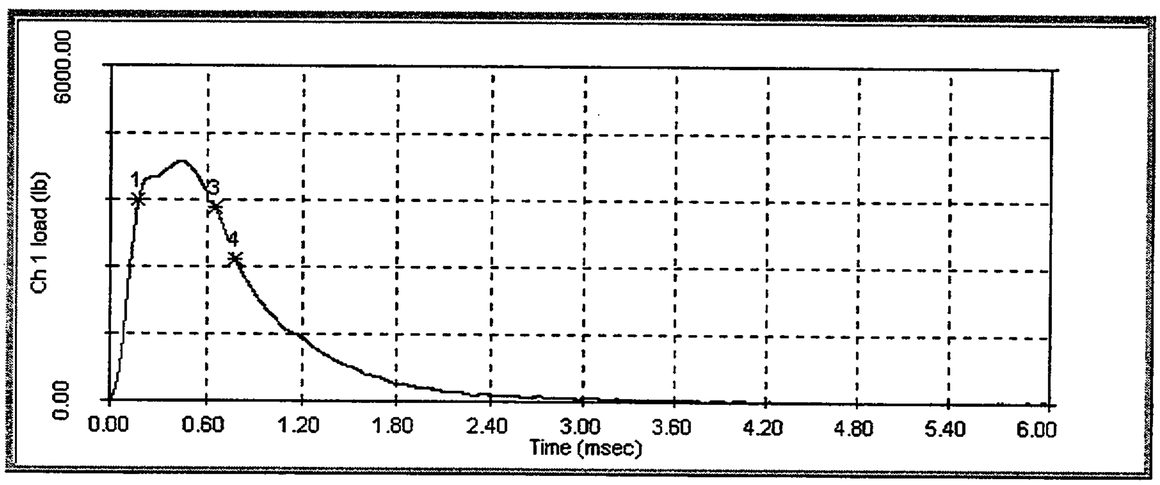

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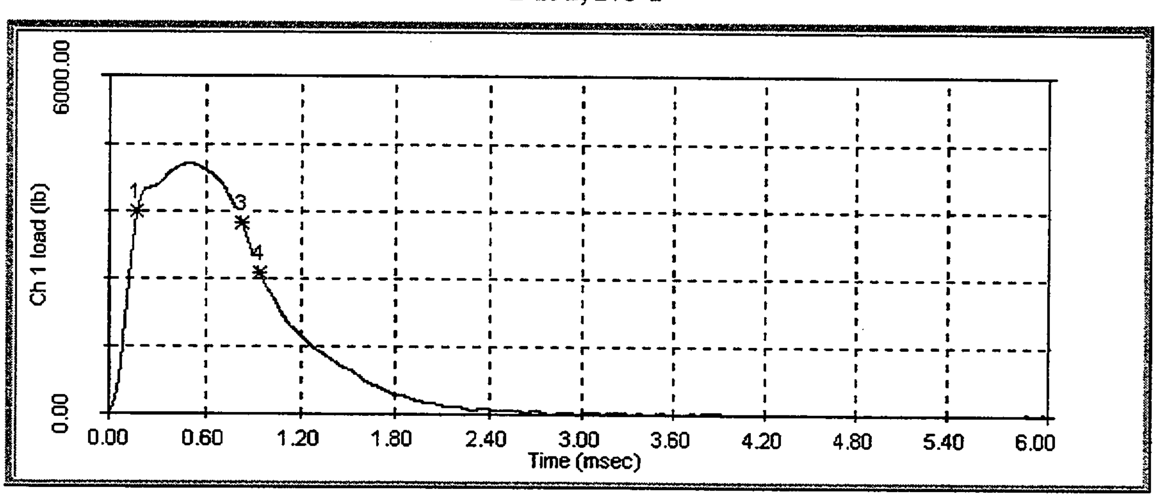

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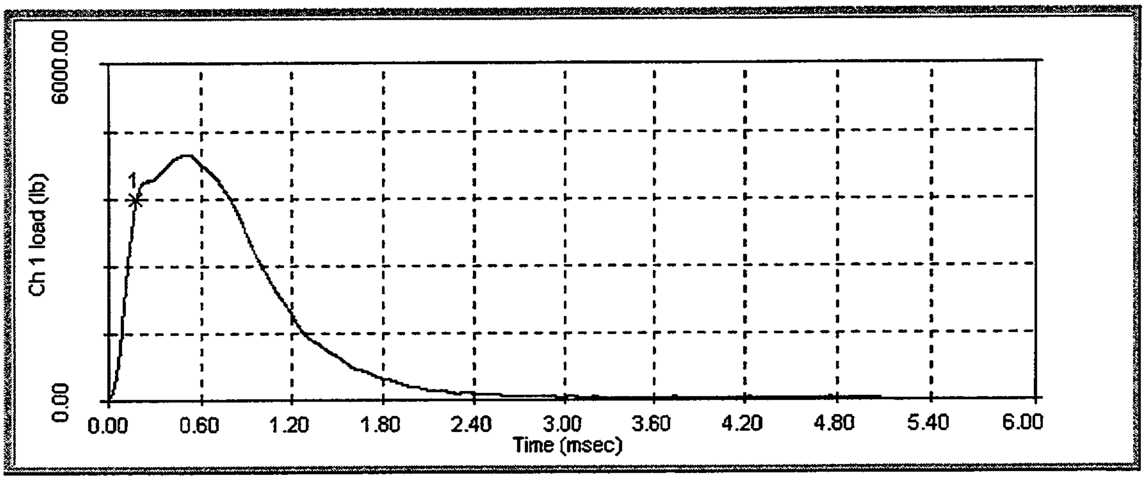
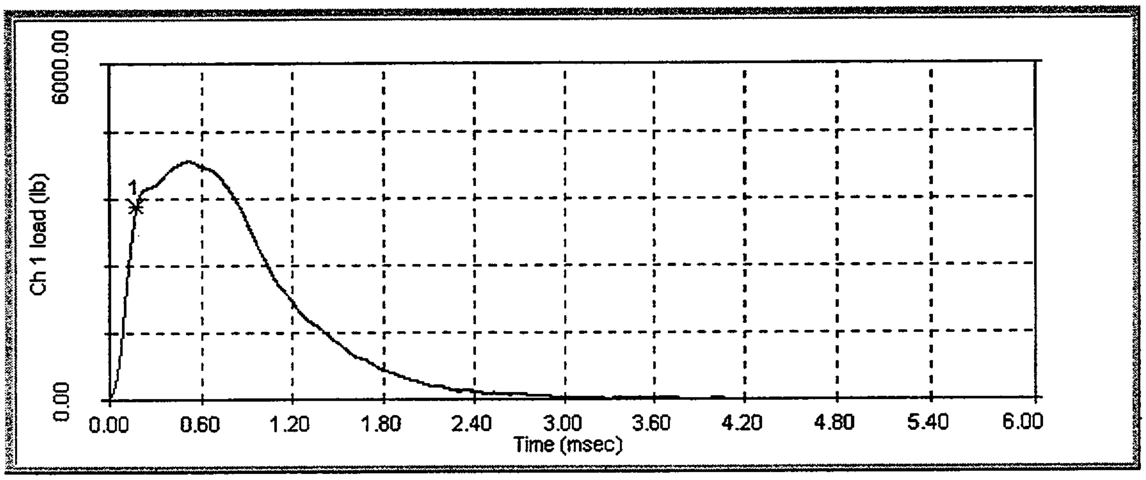
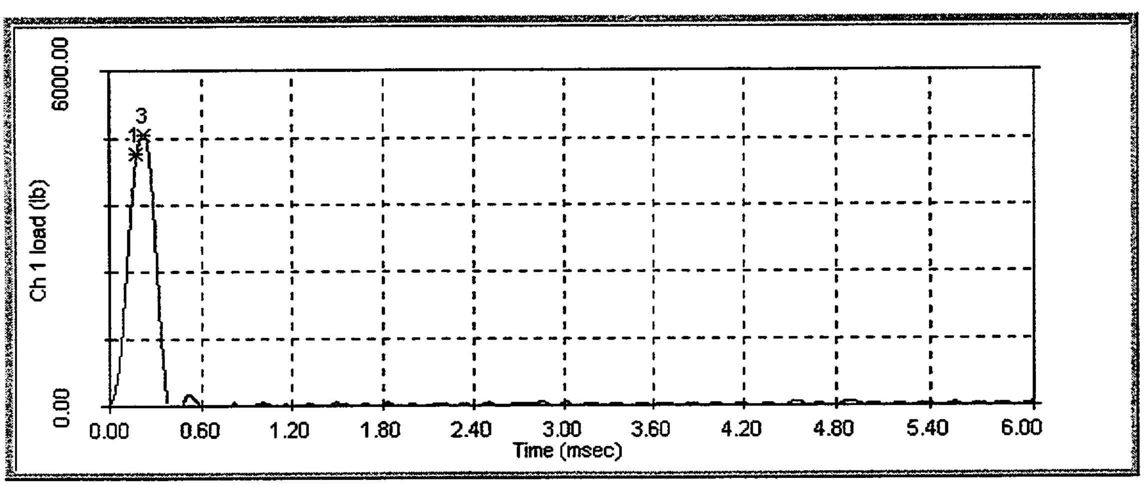


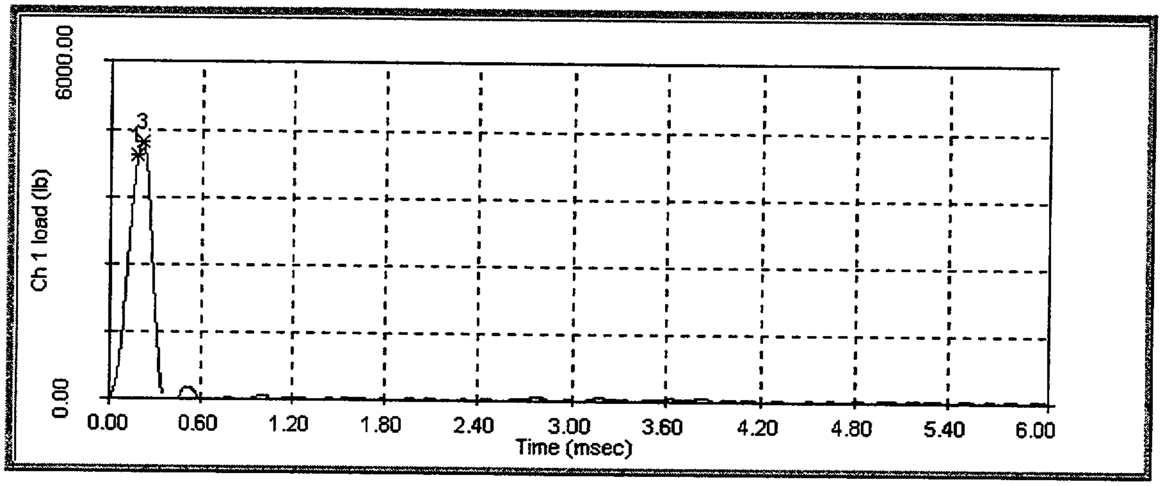
DT85, 350°F



DT86, 375°F



DW93, 0°F



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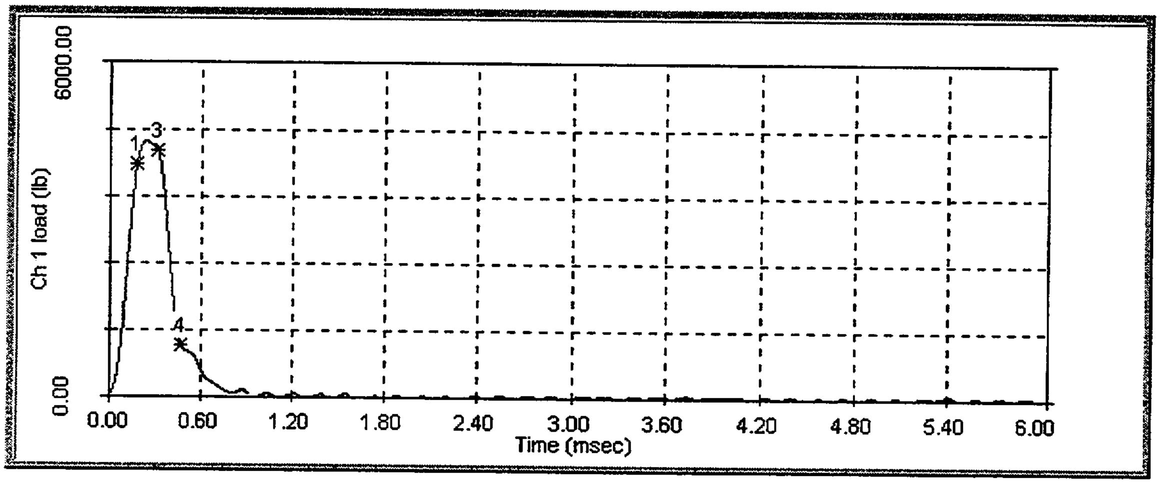
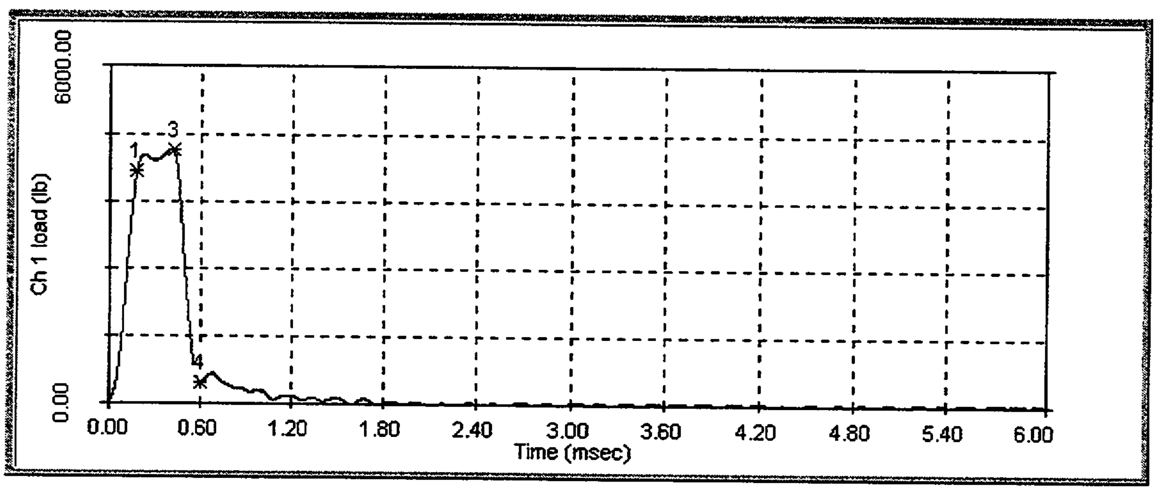


DW95, 100°F



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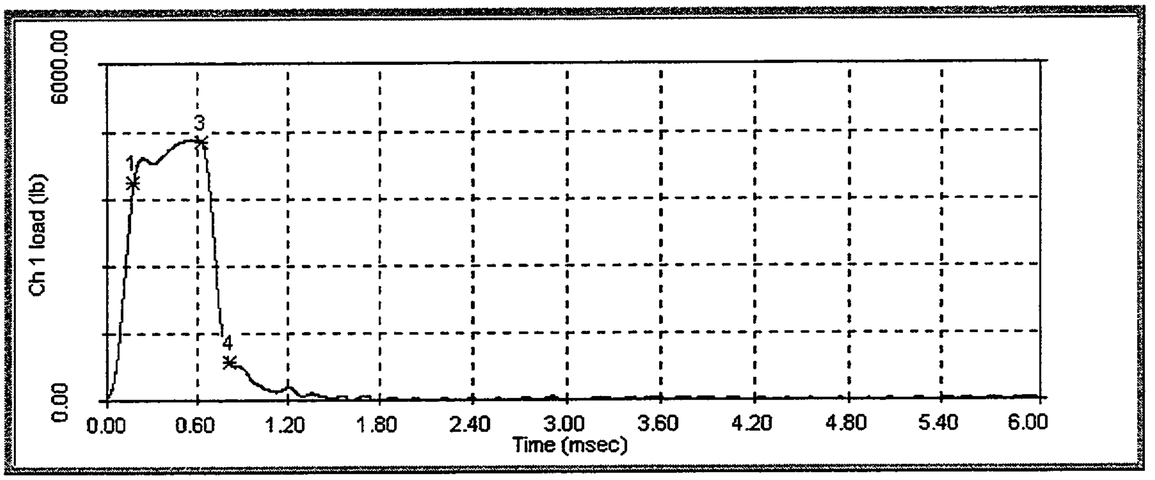

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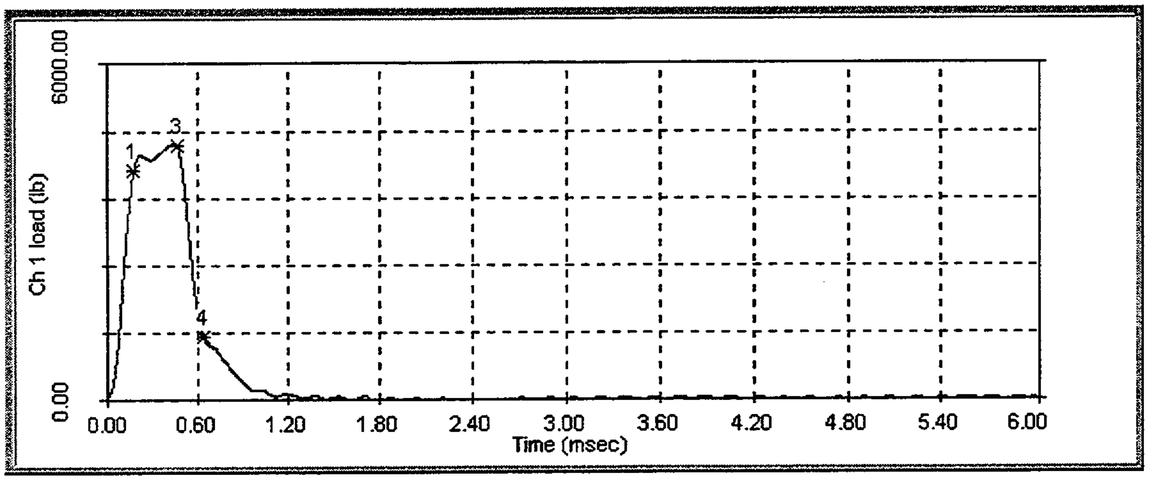

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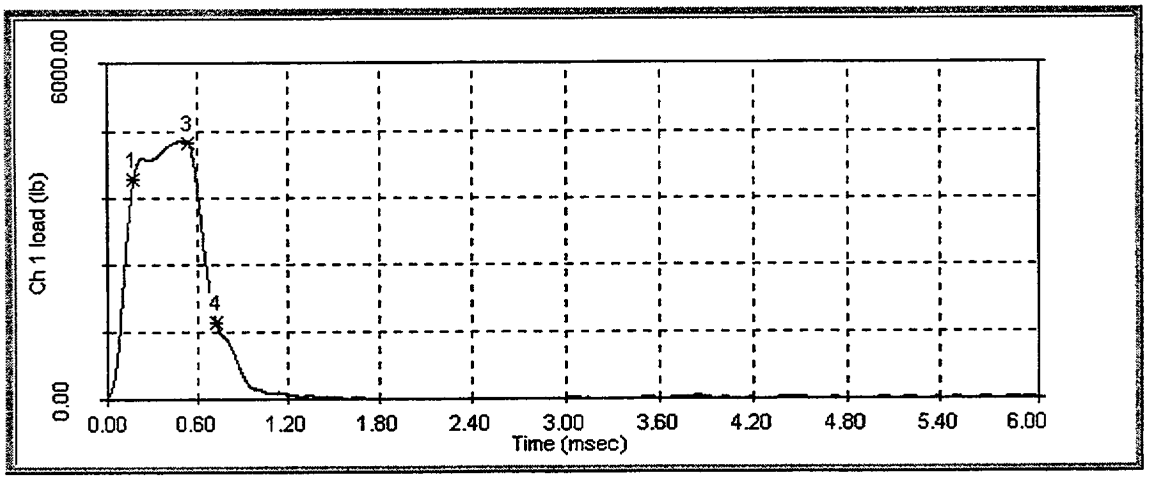

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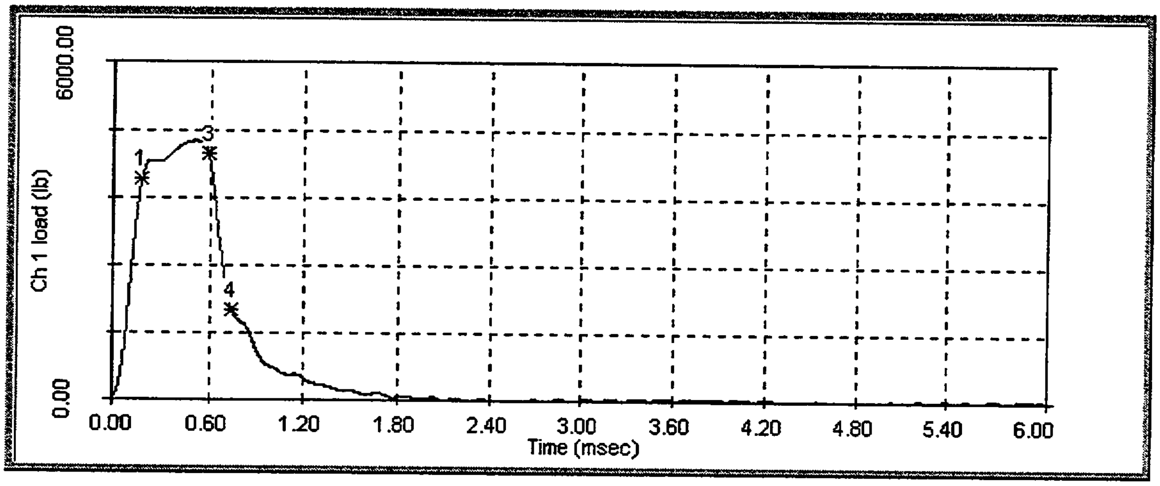
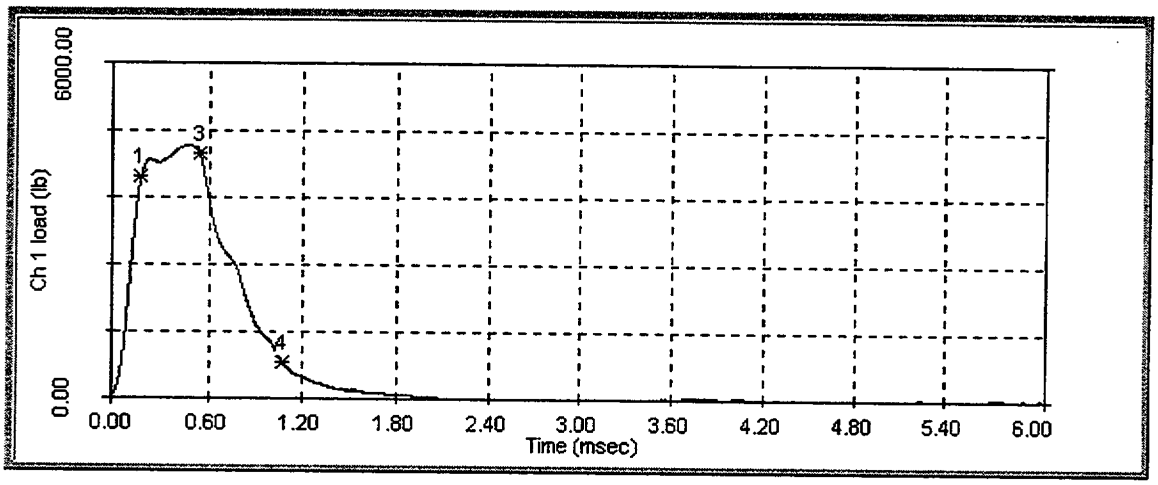


DW85, 175°F



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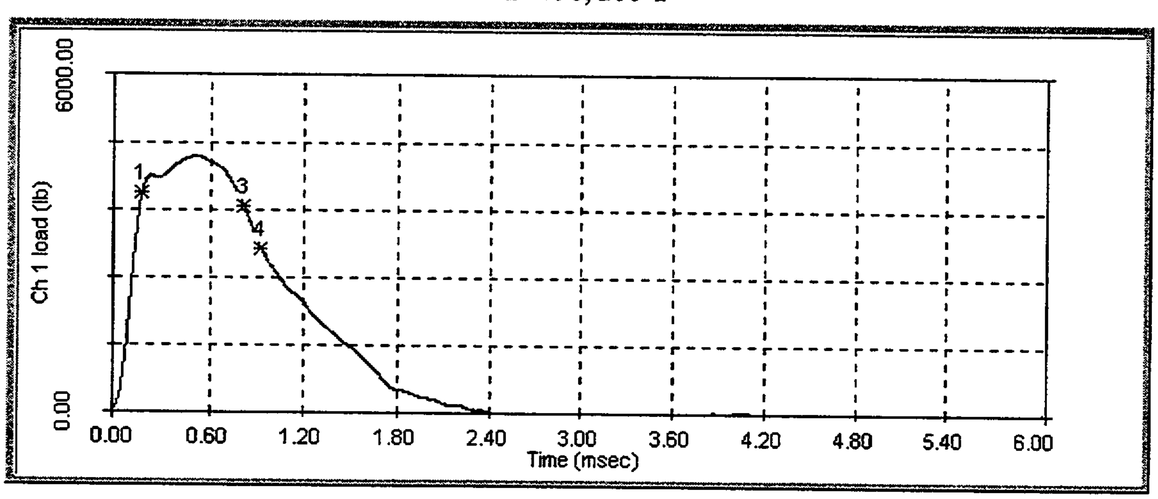

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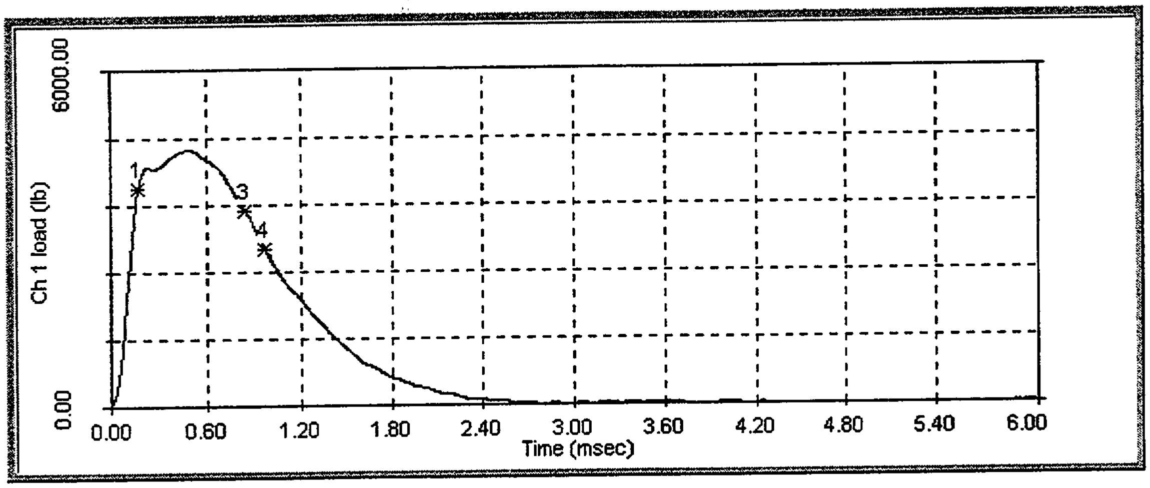

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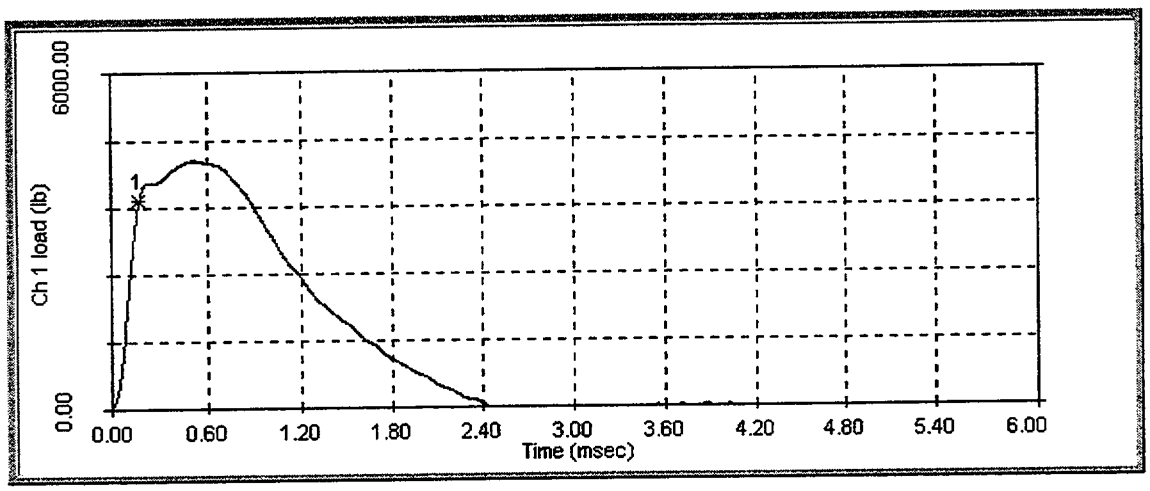

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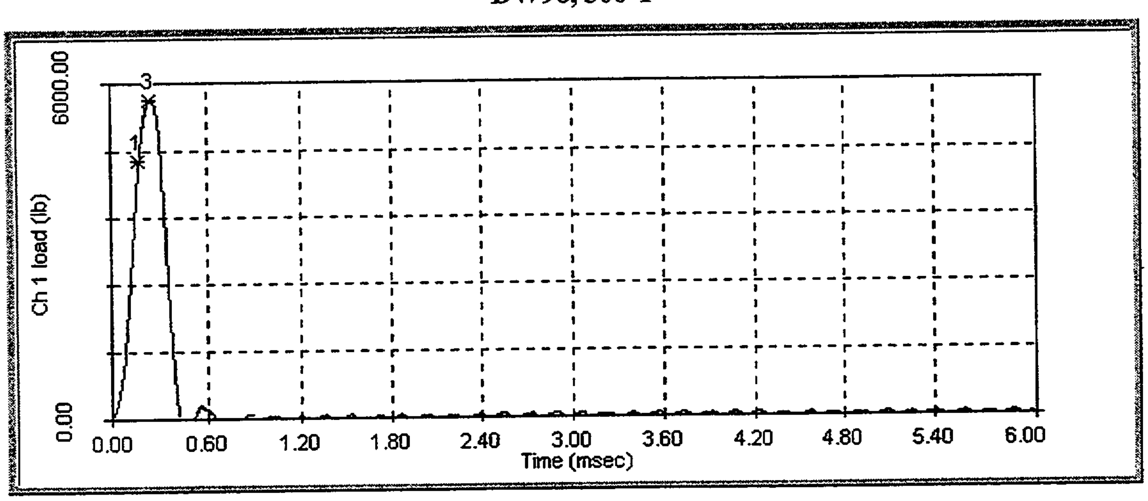

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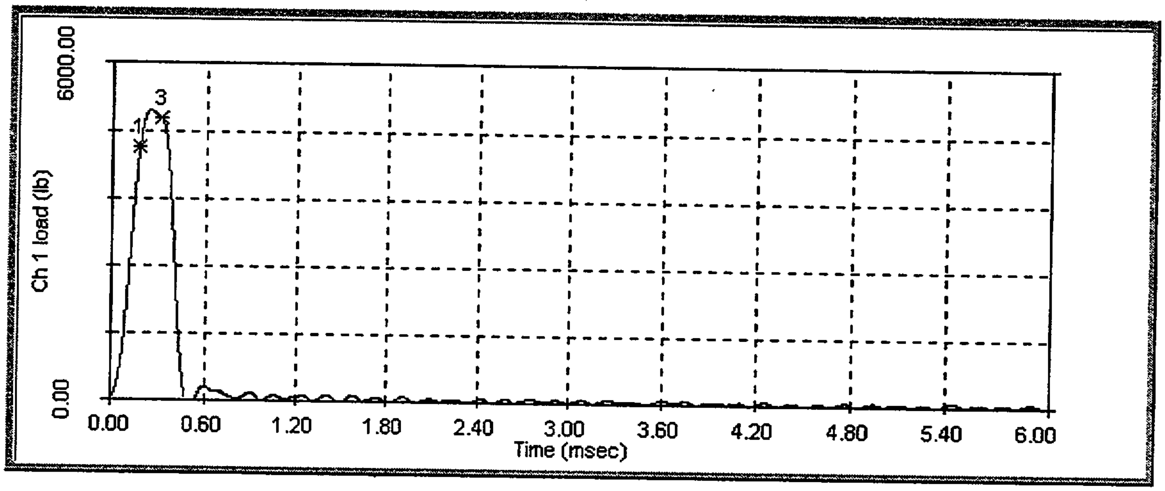

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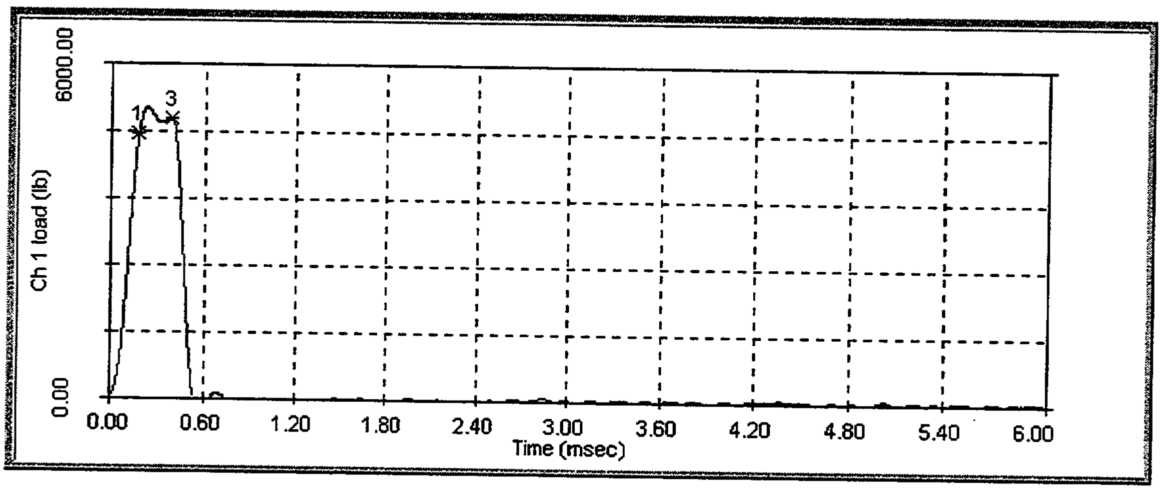

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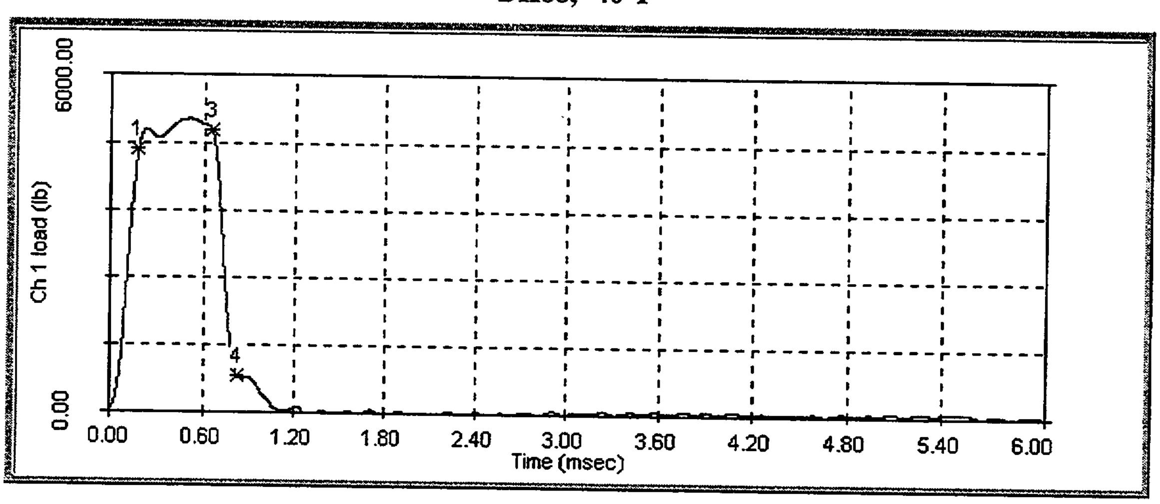

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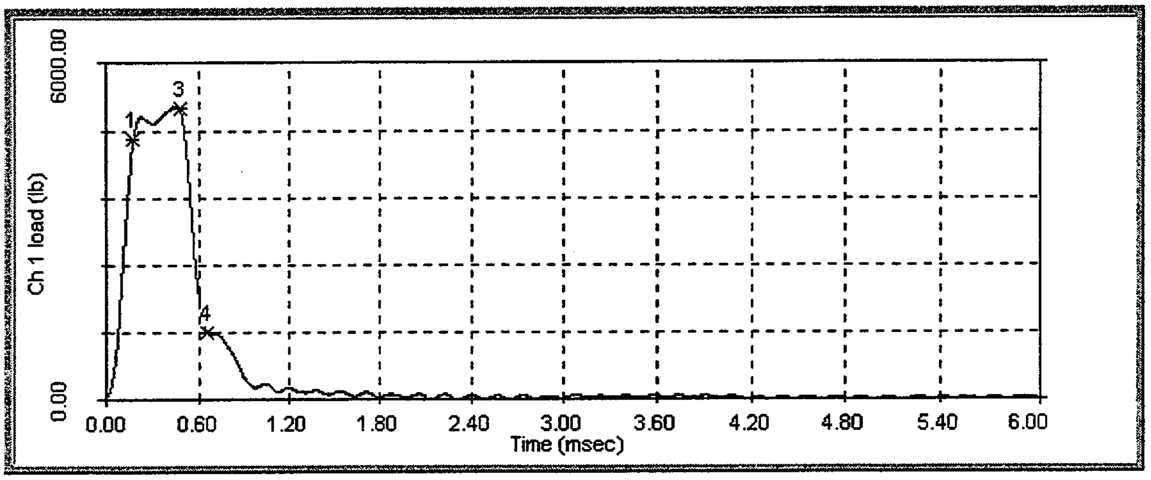

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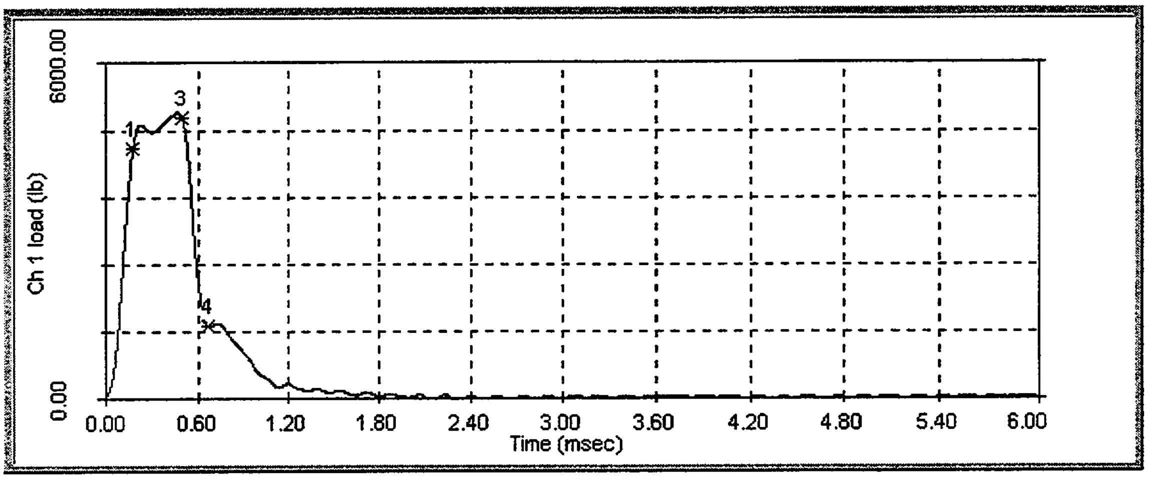

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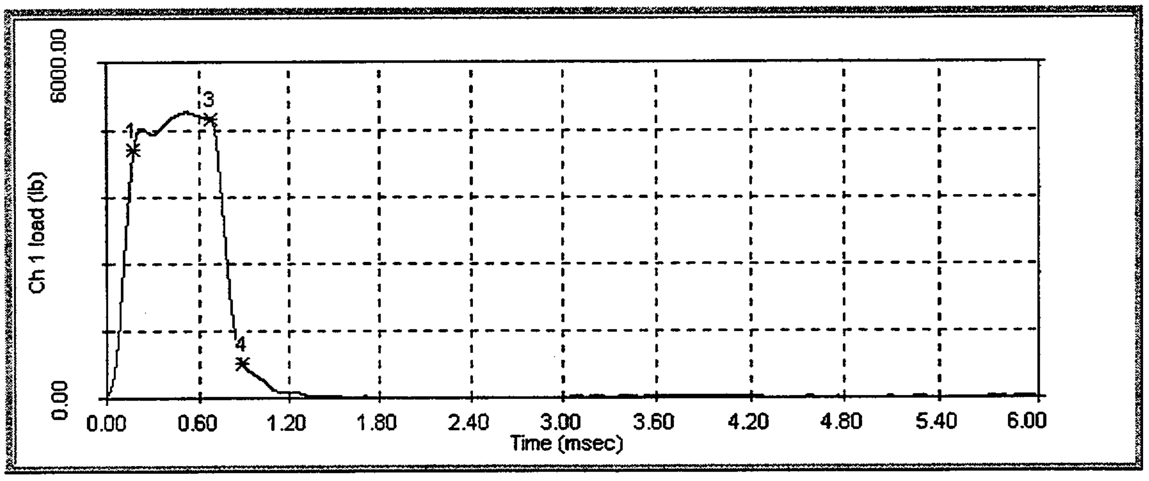

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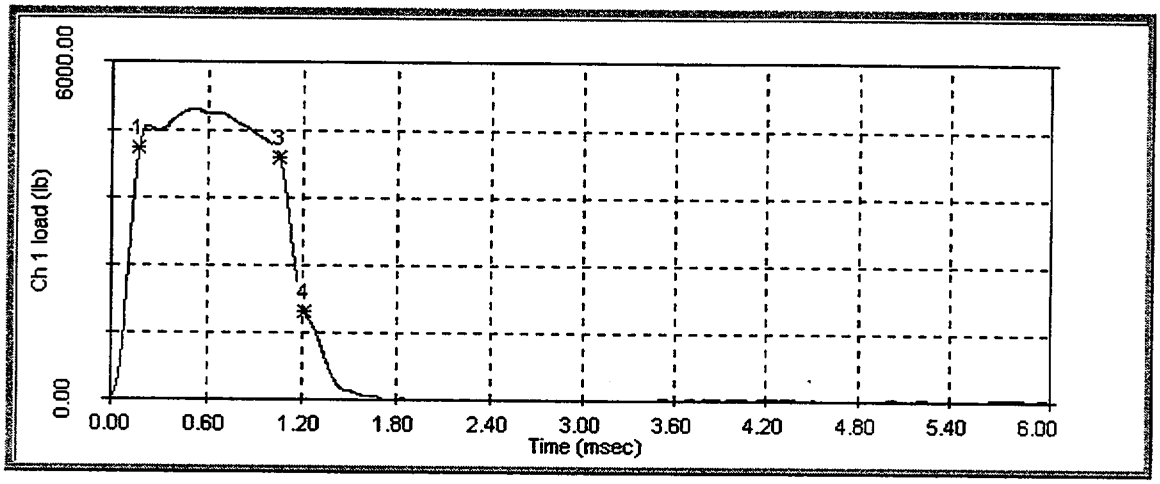

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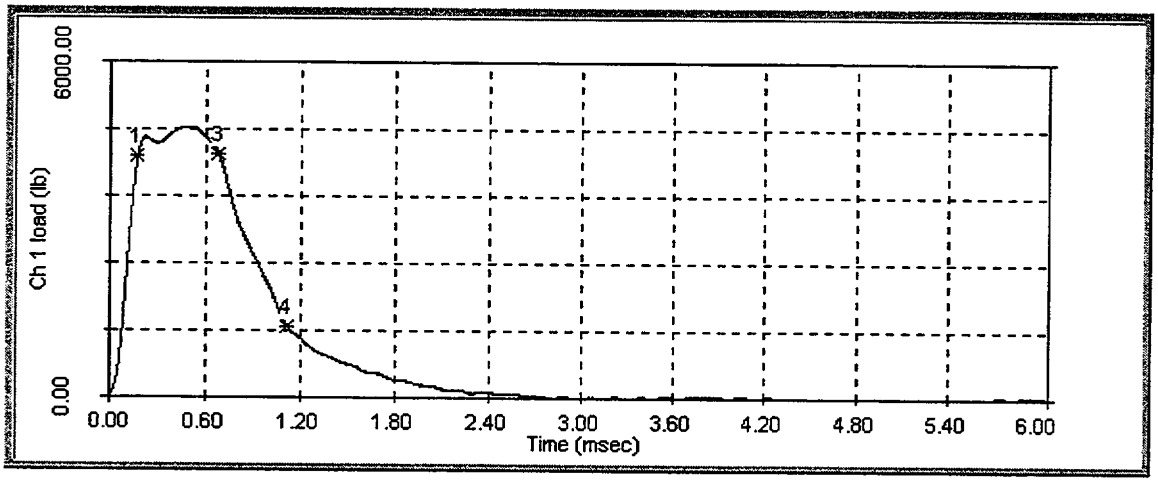

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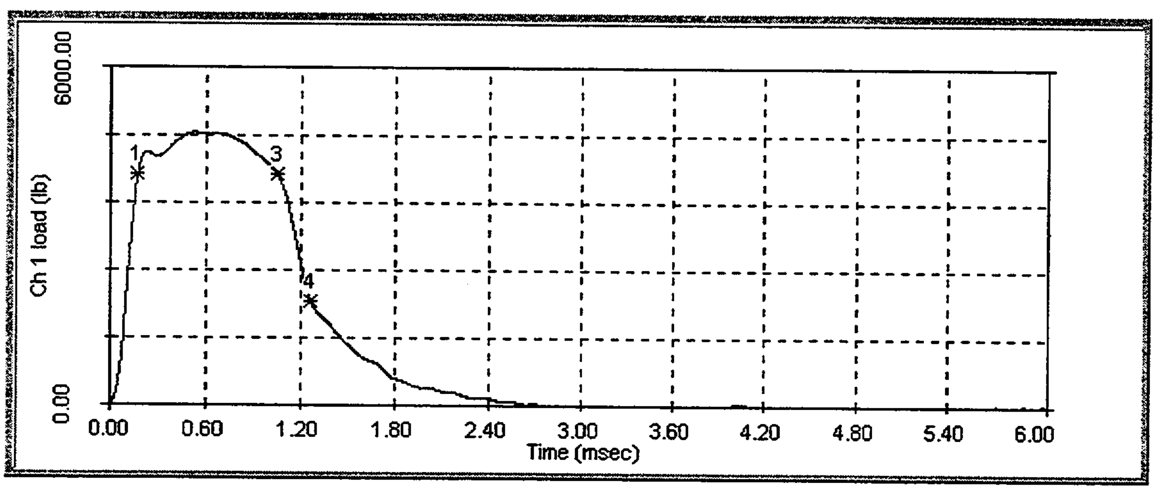

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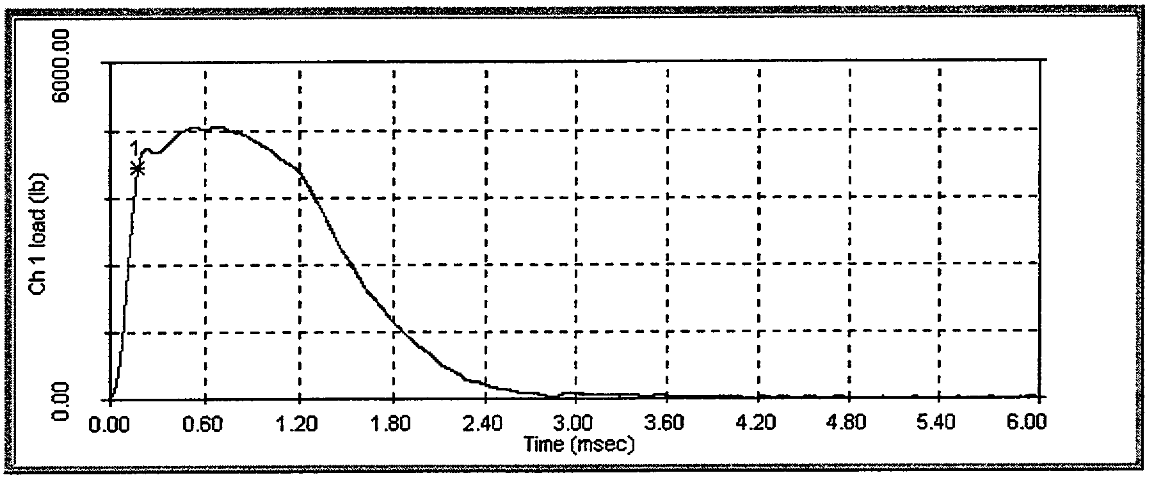

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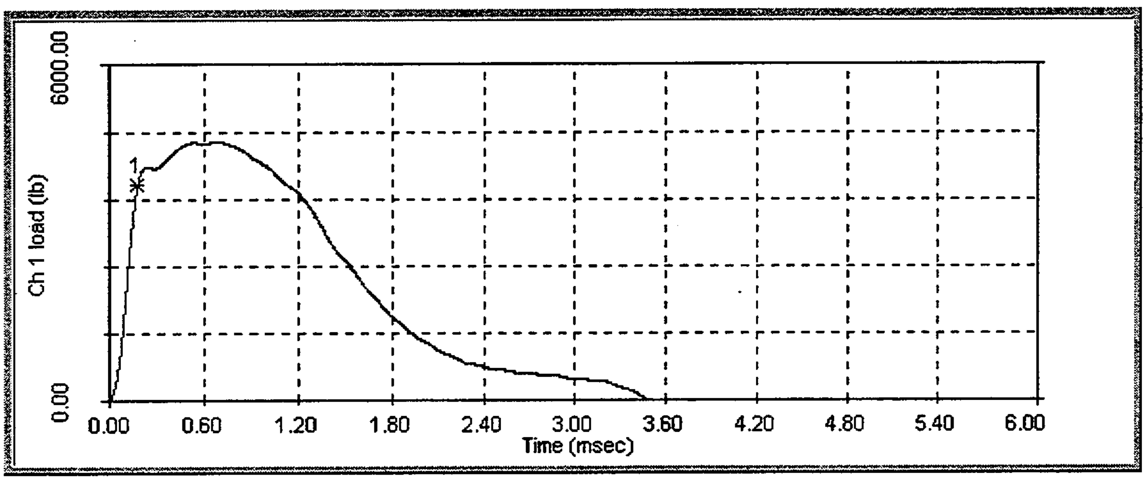


DH90, 300°F

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 Lower Shell Plates B6903-1

(Longitudinal Orientation) Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{30}	Unirradiated	CVGRAPH Fit	ΔT_{30}
V	-5	125	130	-3.45	125.0	128.5
U	-5	115	120	-3.45	115.5	118.9
W	-5	145	150	-3.45	145.1	148.5
Y	-5	---	---	-3.45	138.7	142.2

TABLE B-2

Changes in Average 50 ft-lb Temperatures for Lower Shell Plates B6903-1

(Longitudinal Orientation) Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{50}	Unirradiated	CVGRAPH Fit	ΔT_{50}
V	25	160	135	27.99	159.3	131.3
U	25	110	135	27.99	158.7	130.7
W	25	175	150	27.99	174.2	146.2
Y	25	---	---	27.99	179.3	151.3

TABLE B-3

Changes in Average 35 mil Lateral Expansion Temperatures for Shell Lower Shell Plates B6903-1 (Longitudinal Orientation) Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{35}	Unirradiated	CVGRAPH Fit	ΔT_{35}
V	25	150	125	25.52	147.9	122.4
U	25	150	125	25.52	152.3	126.7
W	25	165	140	25.52	163.9	138.4
Y	25	---	---	25.52	191.6	166.1

TABLE B-4

Changes in Average Energy Absorption at Full Shear for Shell Lower Shell Plates B6903-1 (Longitudinal Orientation) Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔE	Unirradiated	CVGRAPH Fit	ΔE
V	134	114	-20	135	114	-21
U	134	99	-35	135	105	-30
W	134	114	-20	135	114	-21
Y	134	---	---	135	110	-25

TABLE B-5

Changes in Average 30 ft-lb Temperatures for Shell Lower Shell Plates B6903-1

(Transverse Orientation) Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{30}	Unirradiated	CVGRAPH Fit	ΔT_{30}
V	20	160	140	17.95	155.8	137.8
U	20	155	135	17.95	149.7	131.8
W	20	205	185	17.95	197.9	180.0
Y	20	---	---	17.95	184.9	166.9

TABLE B-6

Changes in Average 50 ft-lb Temperatures for Lower Shell Plates B6903-1

(Transverse Orientation) Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{50}	Unirradiated	CVGRAPH Fit	ΔT_{50}
V	65	215	150	61.89	206.1	144.3
U	65	225	160	61.89	213.3	151.4
W	65	230	165	61.89	237.6	175.7
Y	65	---	---	61.89	240.5	178.6

TABLE B-7

Changes in Average 35 mil Lateral Expansion Temperatures for Lower Shell Plates B6903-1

(Transverse Orientation) Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{35}	Unirradiated	CVGRAPH Fit	ΔT_{35}
V	45	180	135	43.54	175.6	131.1
U	45	200	155	43.54	189.7	145.2
W	45	215	170	43.54	214.6	170.1
Y	45	---	---	43.54	230.4	186.0

TABLE B-8

Changes in Average Energy Absorption at Full Shear for Lower Shell Plates B6903-1

(Transverse Orientation) Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔE	Unirradiated	CVGRAPH Fit	ΔE
V	80	75	-5	81	75	-6
U	80	78	-2	81	78	-3
W	80	59	-20	81	59	-22
Y	80	---	---	81	71	-10

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}
V	-60	90	150	-67.72	91.99	159.7
U	-60	95	155	-67.72	98.59	166.3
W	-60	125	185	-67.72	120.0	187.7
Y	-60	---	---	-67.72	112.0	179.7

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}
V	-35	145	180	-44.05	143.5	187.6
U	-35	165	200	-44.05	161.5	205.6
W	-35	175	210	-44.05	173.6	217.6
Y	-35	---	---	-44.05	169.4	213.4

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}
V	-45	125	170	-48.77	124.3	173.1
U	-45	160	205	-48.77	143.7	192.5
W	-45	145	190	-48.77	149.2	198.0
Y	-45	---	---	-48.77	169.8	218.6

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
V	112	88	-24	112	88	-24
U	112	83	-29	112	83	-29
W	112	78	-34	112	78	-34
Y	112	---	---	112	77	-35

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}
V	-65	-65	0	-74.53	-83.16	-8.62
U	-65	-30	35	-74.53	-24.86	49.67
W	-65	-5	60	-74.53	-13.13	61.40
Y	-65	---	---	-74.53	-56.16	18.36

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}
V	-40	-10	30	-42.15	-13.39	28.75
U	-40	5	45	-42.15	4.93	47.08
W	-40	25	65	-42.15	28.5	70.66
Y	-40	---	---	-42.15	20.36	62.51

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}
V	-30	25	55	-32.05	17.89	49.94
U	-30	10	40	-32.05	6.93	38.99
W	-30	30	60	-32.05	25.13	57.18
Y	-30	---	---	-32.05	63.24	95.29

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
V	128	115	-13	128	109	-19
U	128	105	-23	128	105	-23
W	128	114	-14	128	107	-21
Y	128	---	---	128	117	-14

APPENDIX C

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

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

TABLE C-1
Upper Shelf Energy Values Fixed in CVGRAPH

Material	Unirradiated	Capsule V	Capsule U	Capsule W	Capsule Y
Lower Shell Plate B6903-1 (Longitudinal Orientation)	135	114	105	114	110
Lower Shell Plate B6903-1 (Transverse Orientation)	81	75	78	59	71
Weld Metal (Heat # 305424)	112	88	83	78	77
HAZ Material	128	109	105	107	114

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:09:04 on 05-15-2000

Page 1

Coefficients of Curve 1

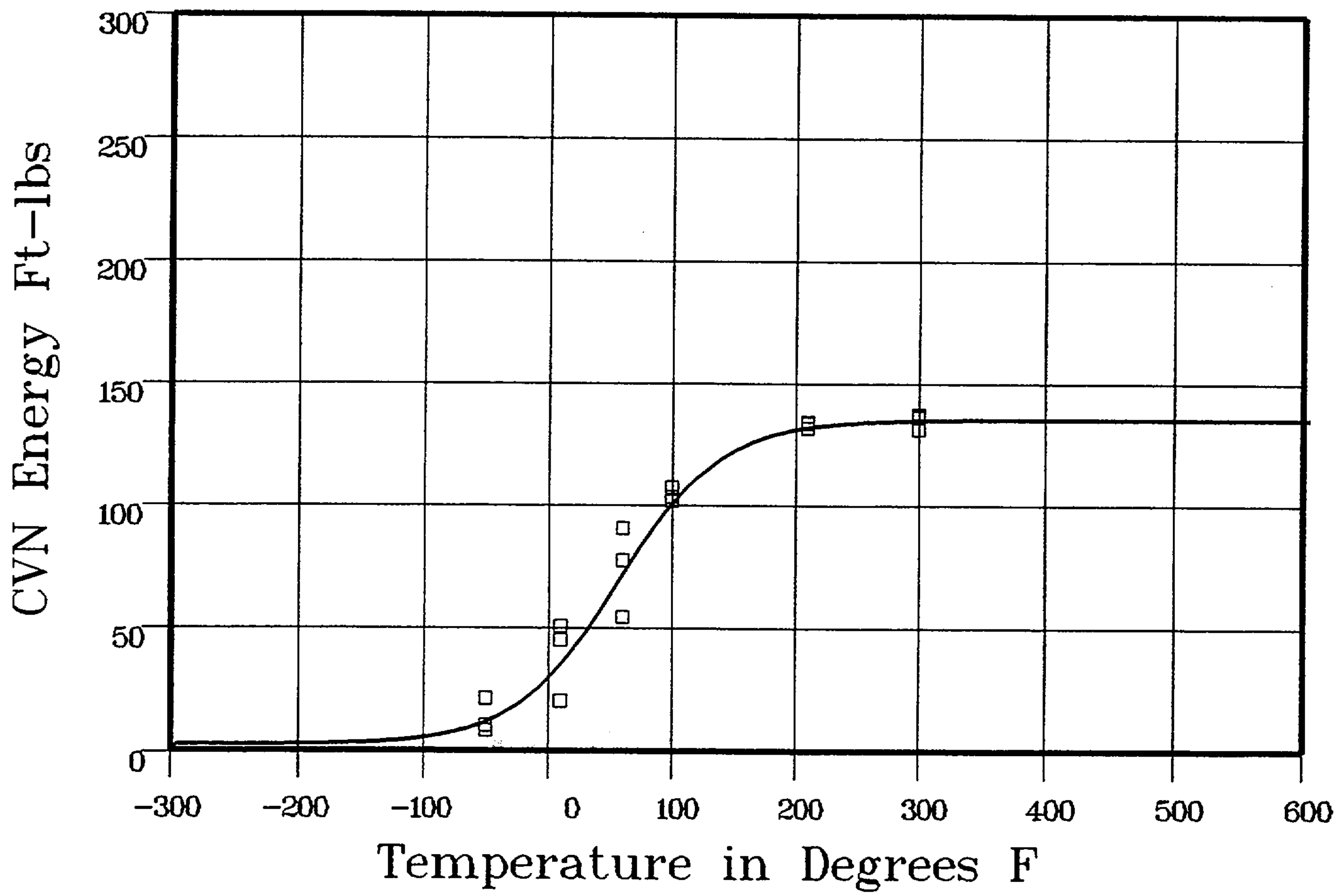
A = 68.59	B = 66.4	C = 83.49	T0 = 52.03

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

Upper Shelf Energy: 135 Fixed Temp. at 30 ft-lbs: -3.4 Temp. at 50 ft-lbs: 27.9 Lower Shelf Energy: 2.19 Fixed

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

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	21	12.8	8.19
-50	10	12.8	-2.8
-50	8	12.8	-4.8
10	20	37.73	-17.73
10	44.5	37.73	6.76
10	50	37.73	12.26
60	54	74.91	-20.91
60	77	74.91	2.08
60	90	74.91	15.08

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

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2

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

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
100	107	103.03	3.96
100	101.5	103.03	-1.53
100	103	103.03	-.03
210	134	132.04	1.95
210	133.5	132.04	1.45
210	131.5	132.04	-.54
300	137	134.65	2.34
300	136	134.65	1.34
300	131	134.65	-3.65

SUM of RESIDUALS = 3.39

CAPSULE V (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:09:04 on 05-15-2000

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Coefficients of Curve 2

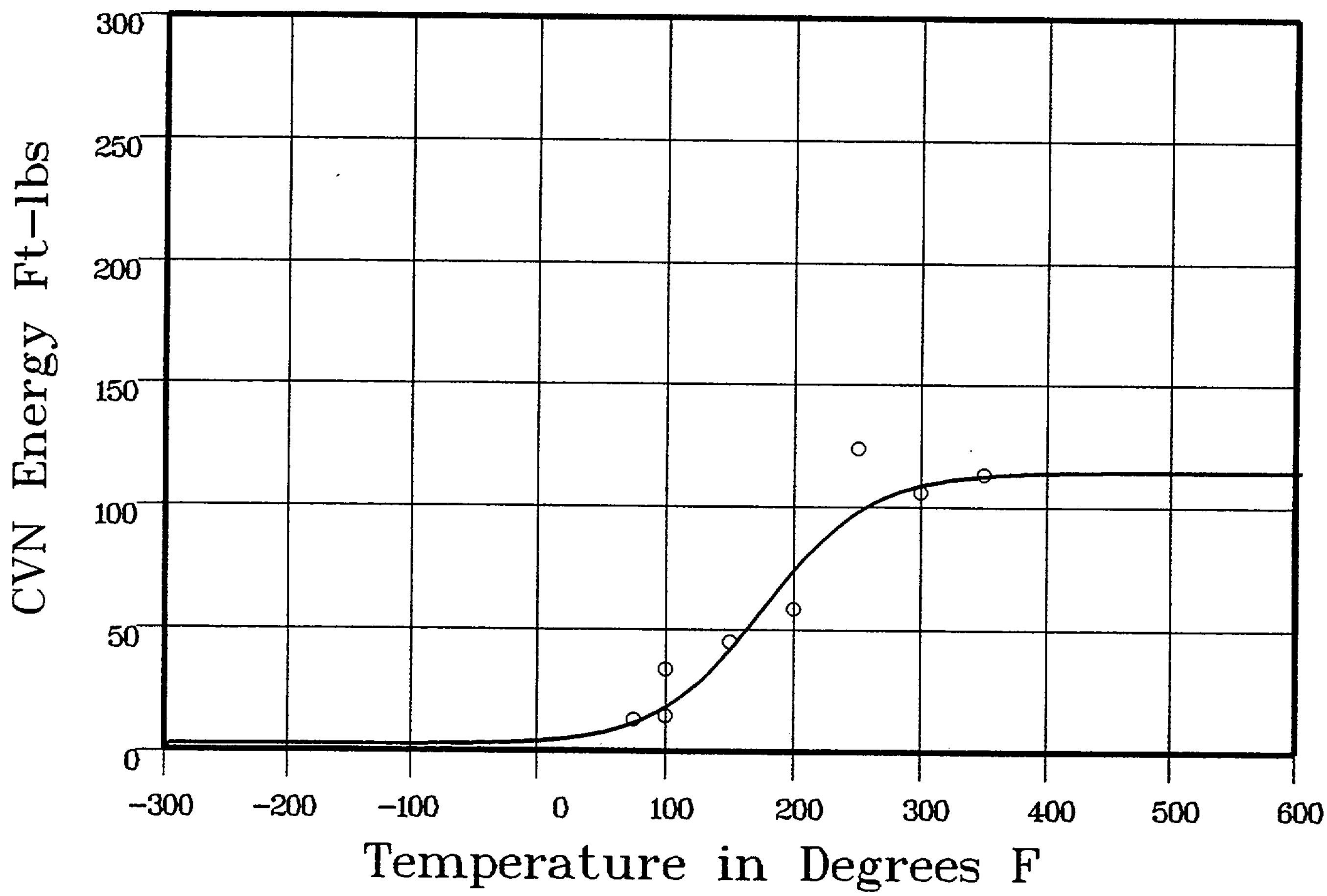
A = 58.09	B = 55.9	C = 84.19	T0 = 171.59

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

Upper Shelf Energy: 114 Fixed   Temp. at 30 ft-lbs: 125   Temp. at 50 ft-lbs: 159.3   Lower Shelf Energy: 2.19 Fixed

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

Capsule: V   Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
75	13	12.43	.56
100	33.5	19.45	14.04
100	14.5	19.45	-4.95
150	44.5	44.06	.43
200	58	76.27	-18.27
250	123.5	98.97	24.52
300	105.5	108.94	-3.44
350	113	112.4	.59

SUM of RESIDUALS = 13.46

CAPSULE U (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:09:04 on 05-15-2000

Page 1

Coefficients of Curve 3

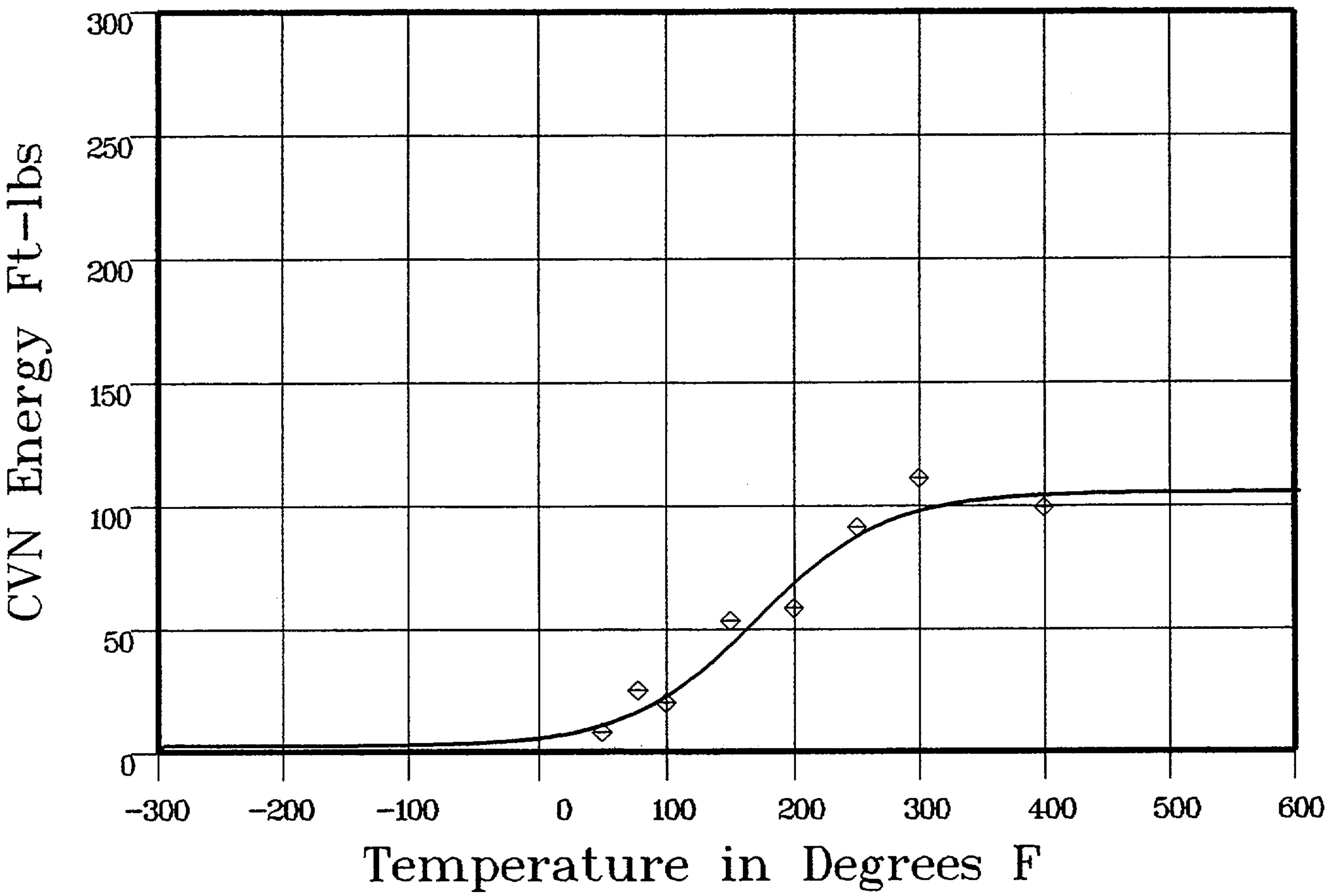
A = 53.59	B = 51.4	C = 101.44	T0 = 165.82

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

Upper Shelf Energy: 105 Fixed   Temp. at 30 ft-lbs: 115.4   Temp. at 50 ft-lbs: 158.7   Lower Shelf Energy: 2.19 Fixed

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

Capsule: U   Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	8	11.71	-3.71
78	25	17.66	7.33
100	20	24.25	-4.25
150	53	45.64	7.35
200	58	70.29	-12.29
250	91	88.57	2.42
300	111	98.18	12.81
400	99	103.99	-4.99

SUM of RESIDUALS = 4.67

CAPSULE W (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:09:04 on 05-15-2000

Page 1

Coefficients of Curve 4

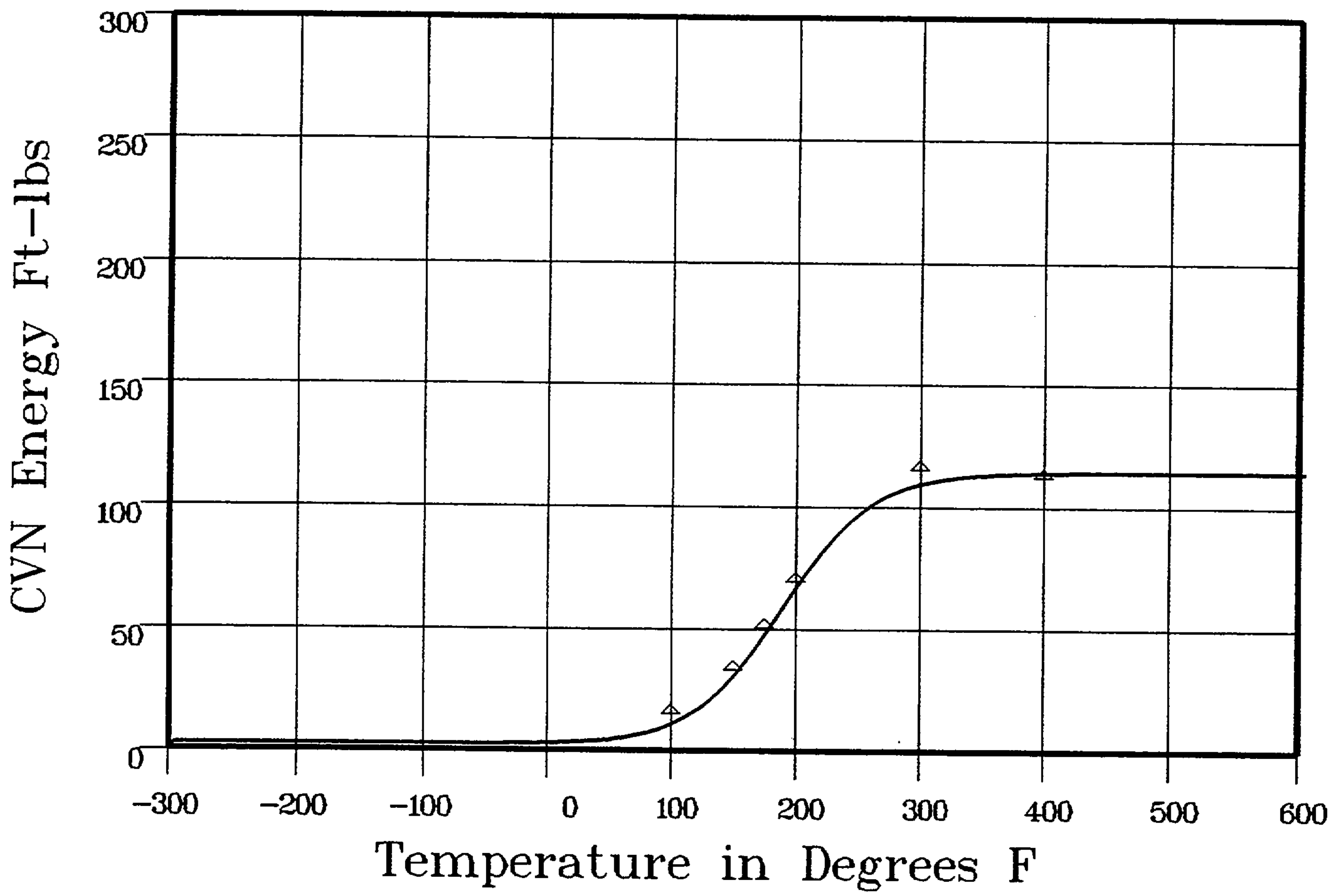
A = 58.09	B = 55.9	C = 71.64	T0 = 184.68

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

Upper Shelf Energy: 114 Fixed   Temp. at 30 ft-lbs: 145   Temp. at 50 ft-lbs: 174.2   Lower Shelf Energy: 2.19 Fixed

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

Capsule: W   Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
100	15	11.81	3.18
150	33	32.97	.02
175	50	50.58	-.58
200	69	69.86	-.86
300	115	109.69	5.3
400	112	113.72	-1.72

SUM of RESIDUALS = 5.33

CAPSULE Y (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:09:04 on 05-15-2000
Page 1
Coefficients of Curve 5

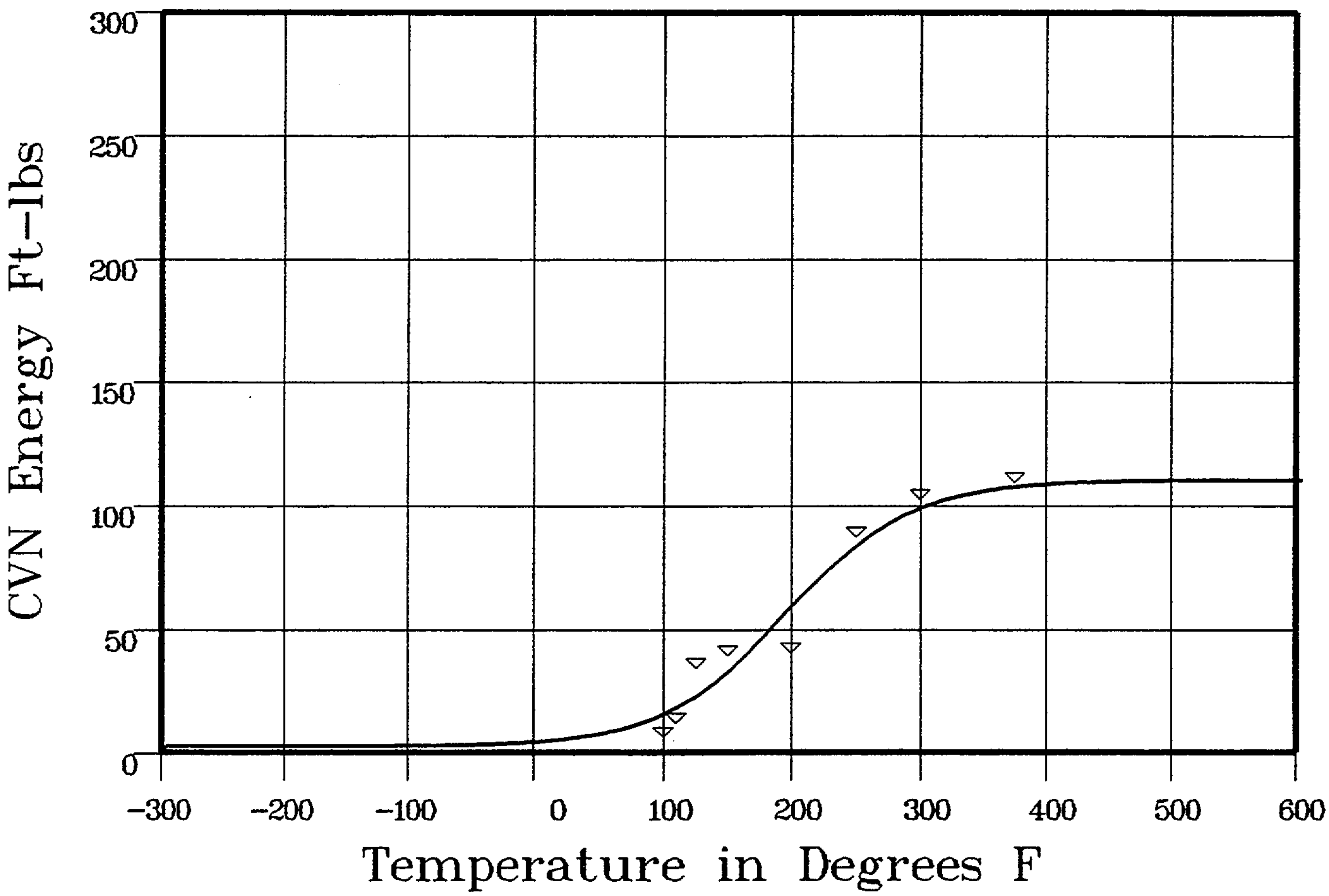
A = 56.09	B = 53.9	C = 97.76	T0 = 190.4

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

Upper Shelf Energy: 110 Fixed   Temp. at 30 ft-lbs: 138.7   Temp. at 50 ft-lbs: 179.2   Lower Shelf Energy: 2.19 Fixed

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

Capsule: Y   Total Fluence:



Data Set(s) Plotted
Plant: BV1   Cap.: Y   Material: PLATE SA533B1   Ori.: LT   Heat #: C6317-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
100	10	16.85	-6.85
110	16	19.64	-3.64
125	38	24.6	13.39
150	43	35.01	7.98
200	44	61.37	-17.37
250	91	85.41	5.58

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

CAPSULE Y (LONGITUDINAL ORIENTATION)

Page 2

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

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
300	106	99.64	6.35
375	113	107.58	5.41

SUM of RESIDUALS = 10.87

UNIRRADIATED (LONTIDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:19:13 on 05-15-2000

Page 1

Coefficients of Curve 1

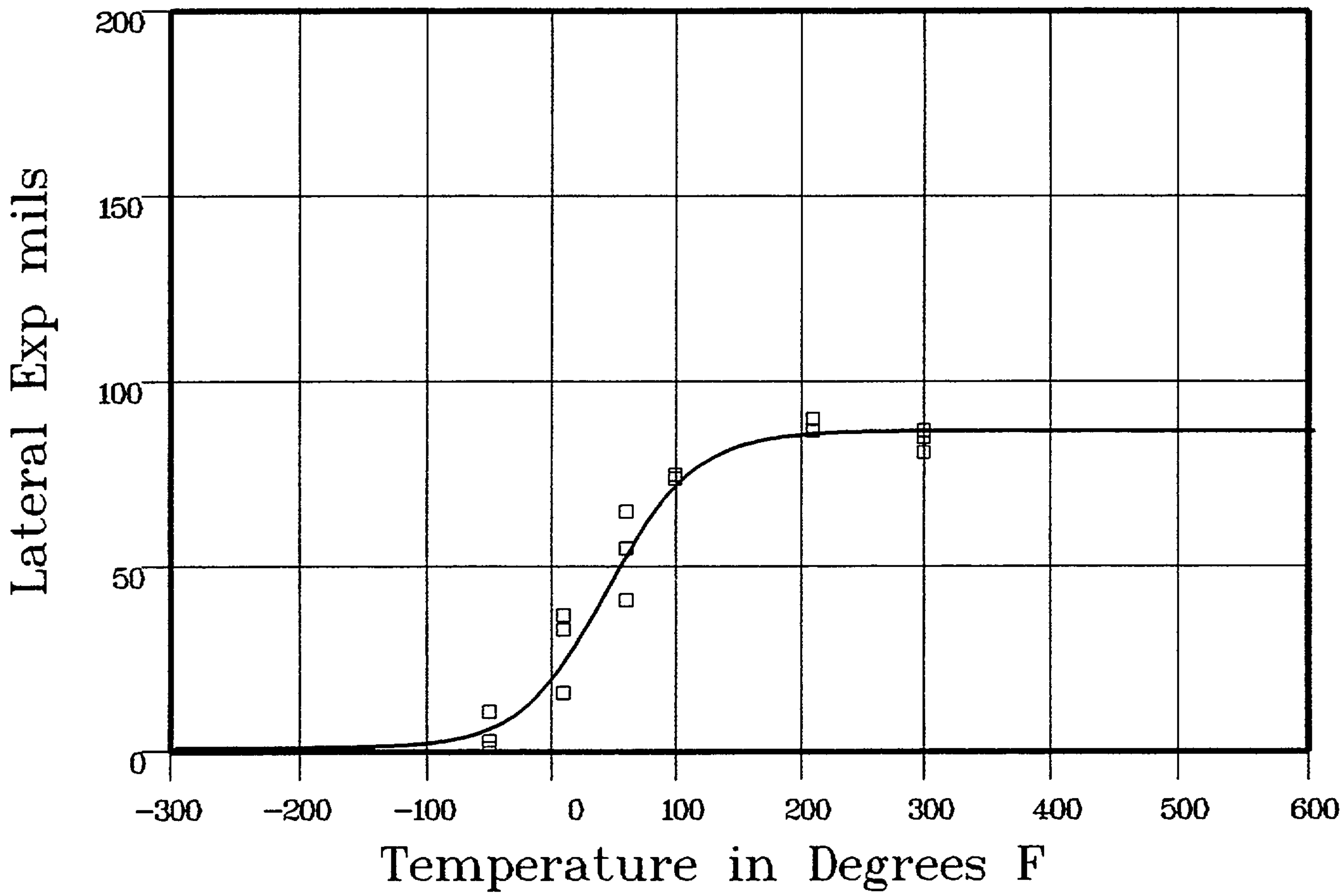
A = 43.88	B = 42.88	C = 70.27	T0 = 40.31

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

Upper Shelf L.E.: 86.77 Temperature at L.E. 35: 25.5 Lower Shelf L.E.: 1 Fixed

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

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	3	7.09	-4.09
-50	1	7.09	-6.09
-50	11	7.09	3.9
10	33	26.45	6.54
10	37	26.45	10.54
10	16	26.45	-10.45
60	55	55.59	-.59
60	65	55.59	9.4
60	41	55.59	-14.59

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

UNIRRADIATED (LONTIDINAL ORIENTATION)

Page 2

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

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
100	75	73.51	1.48
100	75	73.51	1.48
100	74	73.51	.48
210	87	86.09	.9
210	87	86.09	.9
210	90	86.09	3.9
300	87	86.72	.27
300	85	86.72	-1.72
300	81	86.72	-5.72

SUM of RESIDUALS = -3.44

CAPSULE V (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:17:23 on 05-15-2000

Page 1

Coefficients of Curve 2

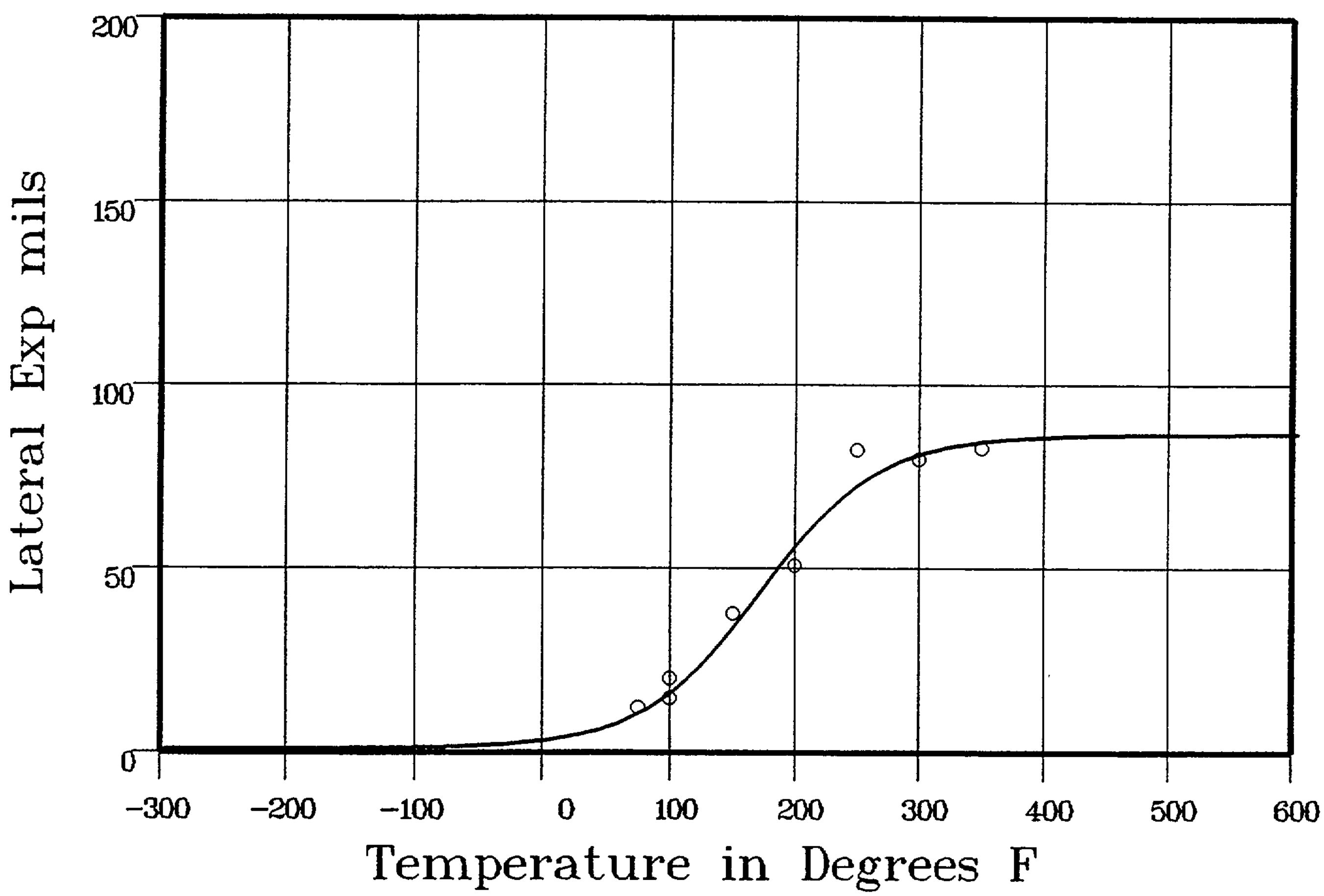
A = 43.84	B = 42.84	C = 95.33	T0 = 167.87

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

Upper Shelf L.E.: 86.69 Temperature at L.E. 35: 147.9 Lower Shelf L.E.: 1 Fixed

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

Capsule: V Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
75	12.5	11.68	.81
100	20.5	17.62	2.87
100	15	17.62	-2.62
150	38	35.9	2.09
200	51	57.76	-6.76
250	82.5	73.71	8.78
300	80	81.65	-1.65
350	83	84.85	-1.85

SUM of RESIDUALS = 1.65

CAPSULE U (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:17:23 on 05-15-2000
Page 1
Coefficients of Curve 3

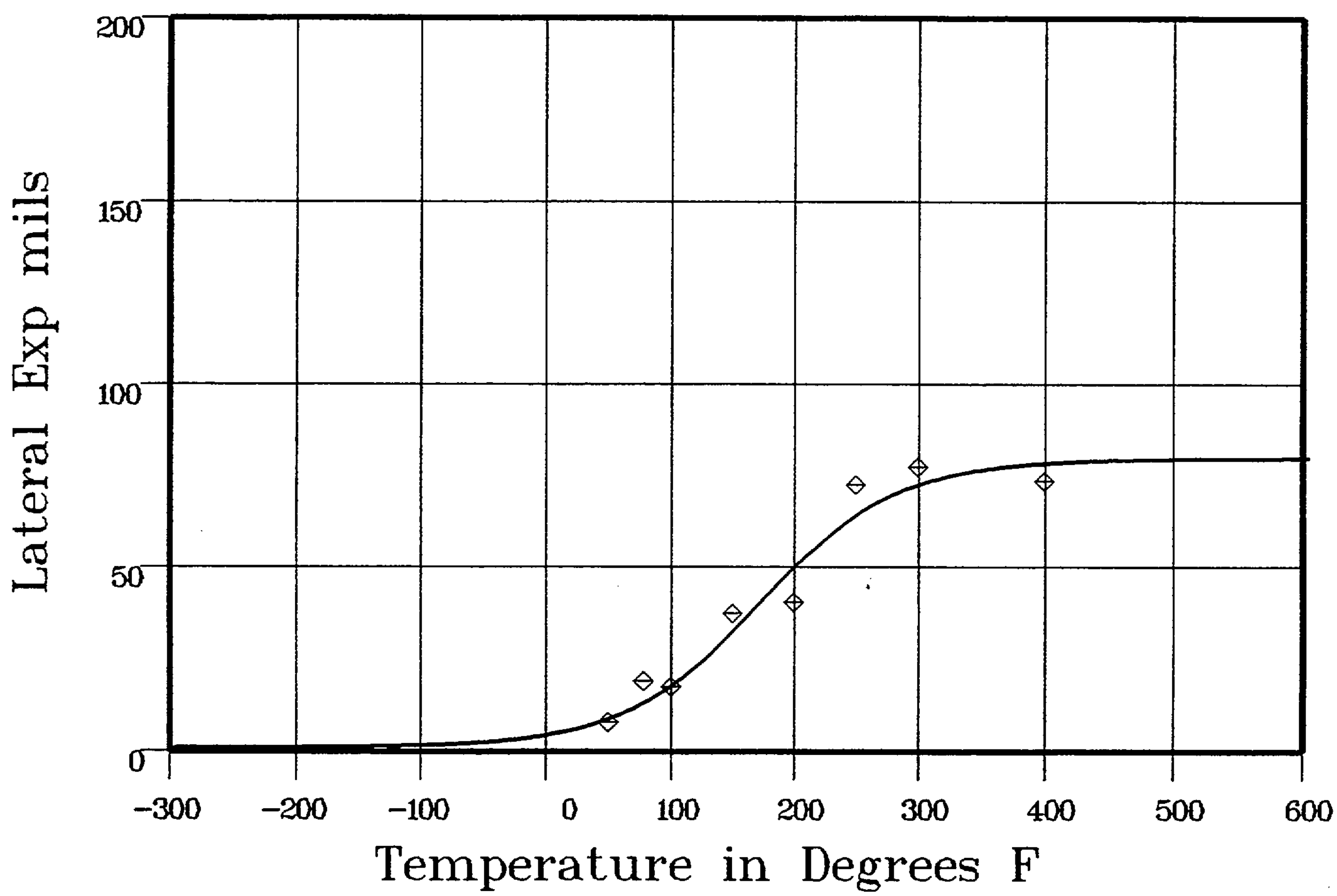
A = 40.39	B = 39.39	C = 111.02	T0 = 167.57

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

Upper Shelf L.E.: 79.79   Temperature at L.E. 35: 152.2   Lower Shelf L.E.: 1 Fixed

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

Capsule: U   Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
50	8	9.45	-1.45
78	19	14.08	4.91
100	17.5	18.99	-1.49
150	37.5	34.21	3.28
200	40.5	51.58	-11.08
250	72.5	65.24	7.25
300	77.5	73.15	4.34
400	73.59	78.61	-5.01

SUM of RESIDUALS = .74

CAPSULE W (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:17:23 on 05-15-2000

Page 1

Coefficients of Curve 4

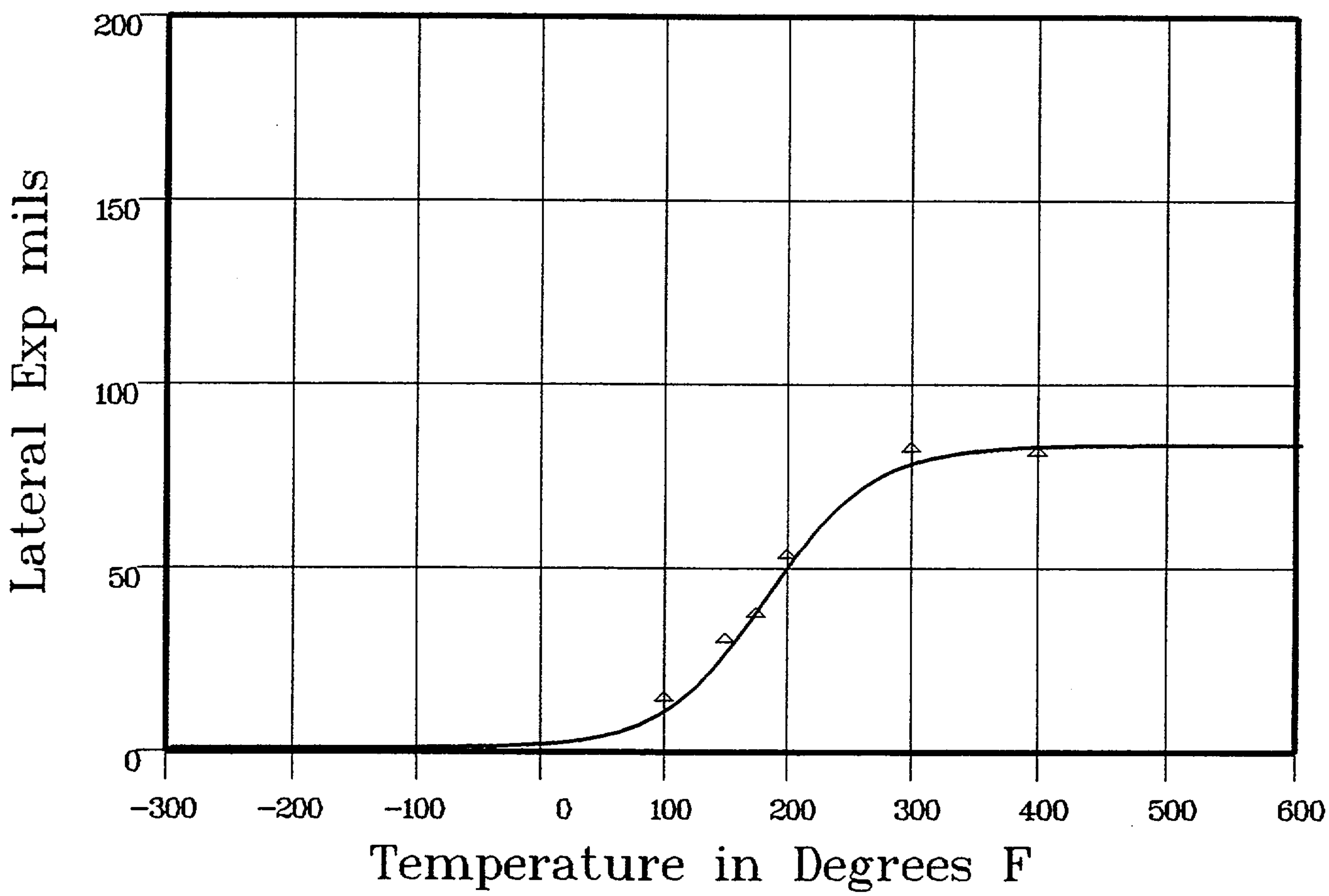
A = 42.36	B = 41.36	C = 85.53	T0 = 179.29

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

Upper Shelf L.E.: 83.72   Temperature at L.E. 35: 163.9   Lower Shelf L.E.: 1 Fixed

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

Capsule: W   Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
100	14	12.19	1.8
150	30	28.72	1.27
175	37	40.28	-3.28
200	53	52.18	.81
300	82	79.08	2.91
400	81	83.25	-2.25

SUM of RESIDUALS = 1.26

CAPSULE Y (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:17:23 on 05-15-2000

Page 1

Coefficients of Curve 5

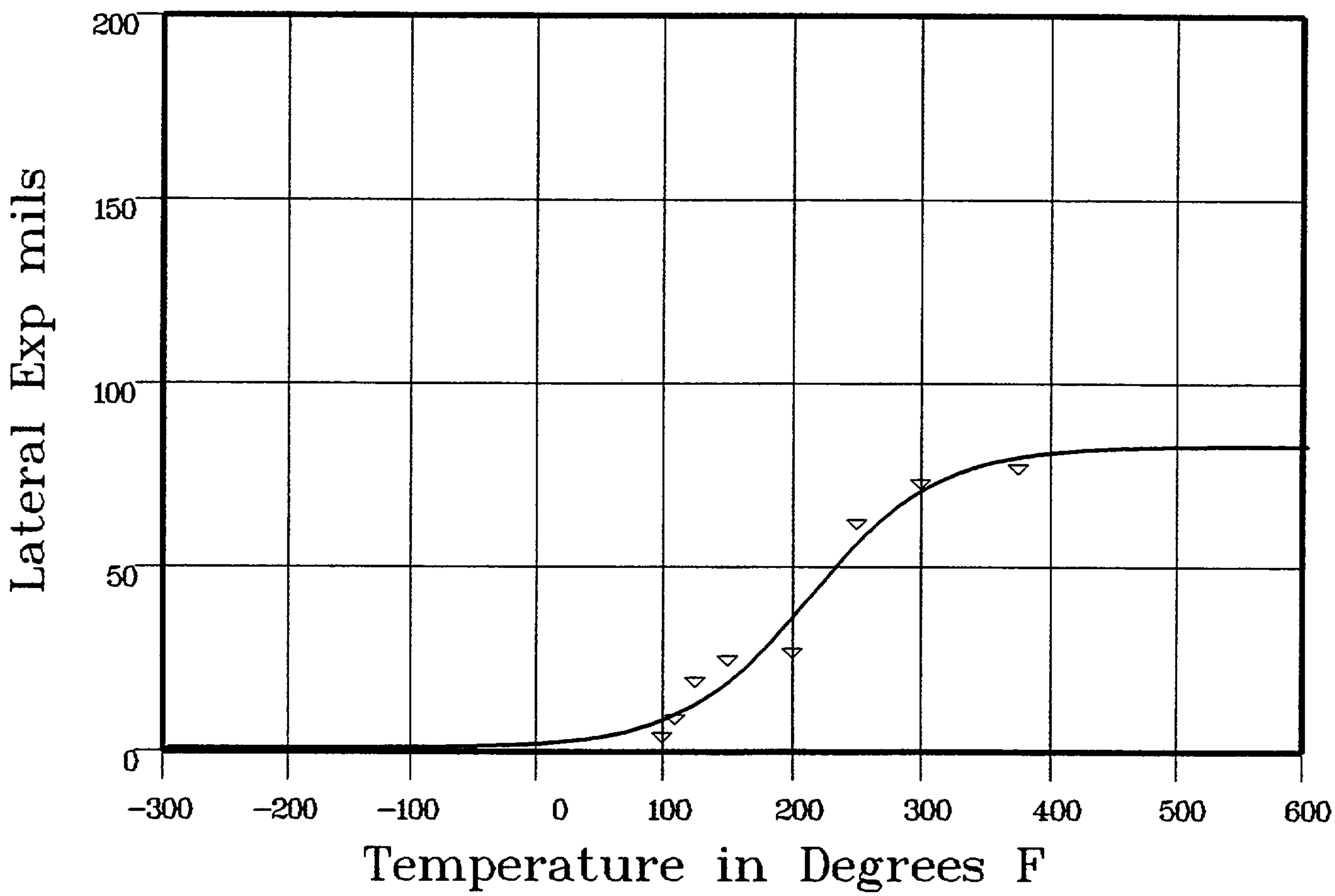
A = 42.06	B = 41.06	C = 99.48	T0 = 208.88

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

Upper Shelf L.E.: 83.12 Temperature at L.E. 35: 191.6 Lower Shelf L.E.: 1 Fixed

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

Capsule: Y Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
100	5	9.27	-4.27
110	10	10.89	-.89
125	20	13.83	6.16
150	26	20.24	5.75
200	28	38.4	-10.4
250	63	58.12	4.87

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

CAPSULE Y (LONGITUDINAL ORIENTATION)

Page 2

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

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
300	74	71.79	2.2
375	78	80.31	-2.31
		SUM of RESIDUALS =	1.11

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:22:32 on 05-15-2000

Page 1

Coefficients of Curve 1

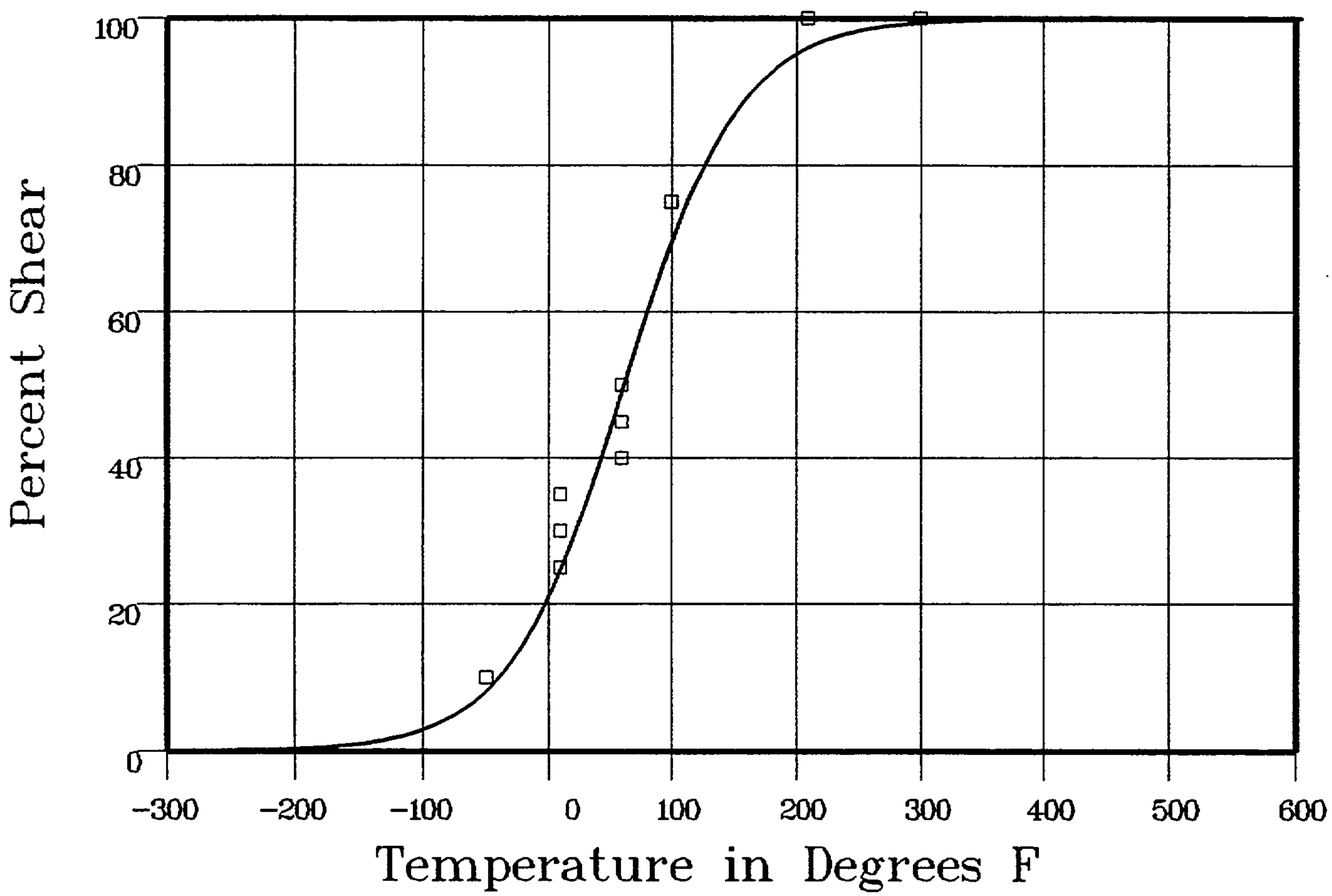
A = 50	B = 50	C = 92.73	T0 = 57.18

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

Temperature at 50% Shear: 57.1

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

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	10	9.01	.98
-50	10	9.01	.98
-50	10	9.01	.98
10	25	26.54	-1.54
10	35	26.54	8.45
10	30	26.54	3.45
60	40	51.51	-11.51
60	45	51.51	-6.51
60	50	51.51	-1.51

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

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2

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

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100	75	71.57	3.42
100	75	71.57	3.42
100	75	71.57	3.42
210	100	96.42	3.57
210	100	96.42	3.57
210	100	96.42	3.57
300	100	99.47	.52
300	100	99.47	.52
300	100	99.47	.52

SUM of RESIDUALS = 16.34

CAPSULE V (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:22:32 on 05-15-2000

Page 1

Coefficients of Curve 2

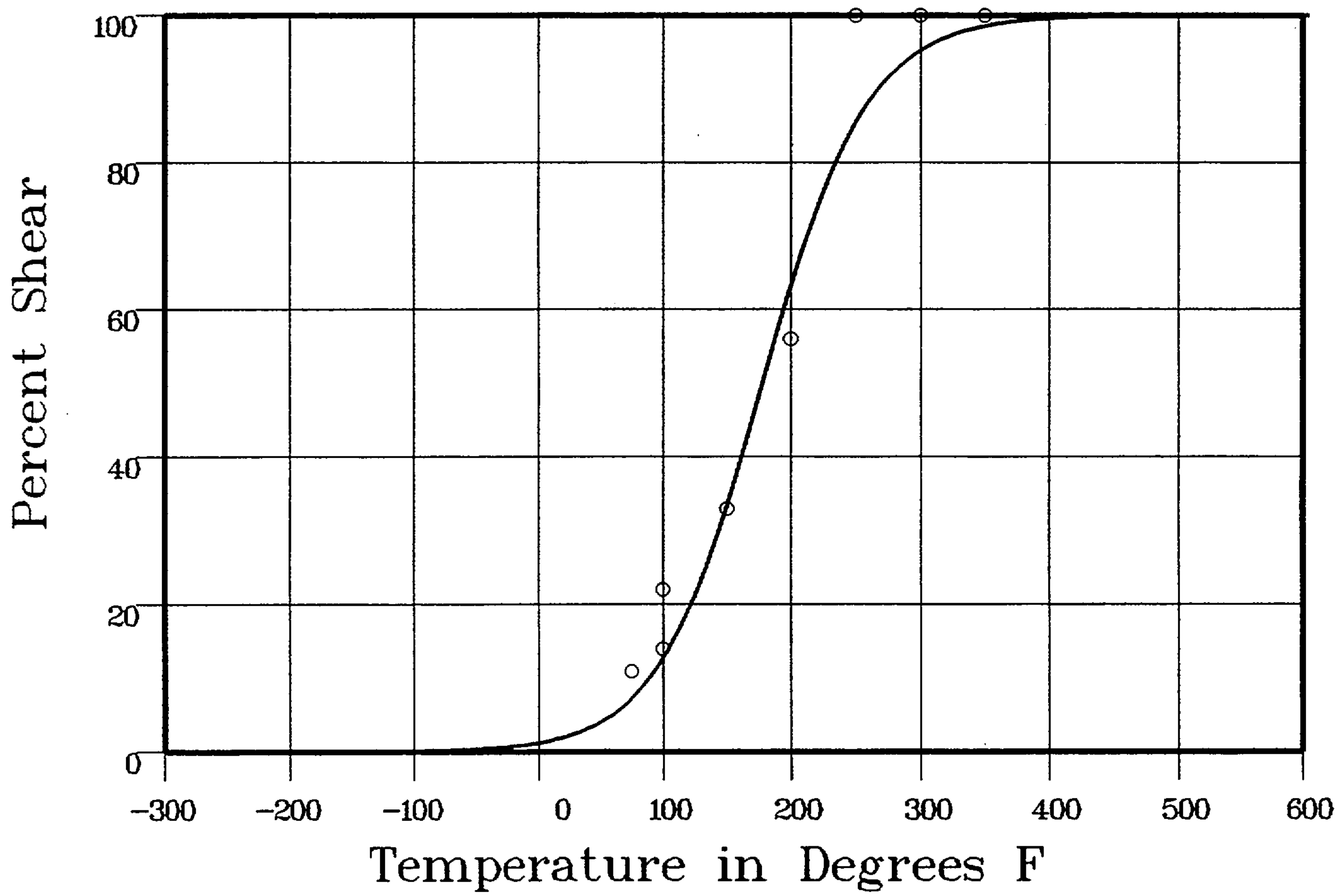
A = 50	B = 50	C = 80.97	T0 = 173.43

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

Temperature at 50% Shear: 173.4

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

Capsule: V Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
75	11	8.08	2.91
100	14	14.01	-.01
100	22	14.01	7.98
150	33	35.91	-2.91
200	56	65.83	-9.83
250	100	86.88	13.11
300	100	95.79	4.2
350	100	98.73	1.26

SUM of RESIDUALS = 16.7

CAPSULE U (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:22:32 on 05-15-2000

Page 1

Coefficients of Curve 3

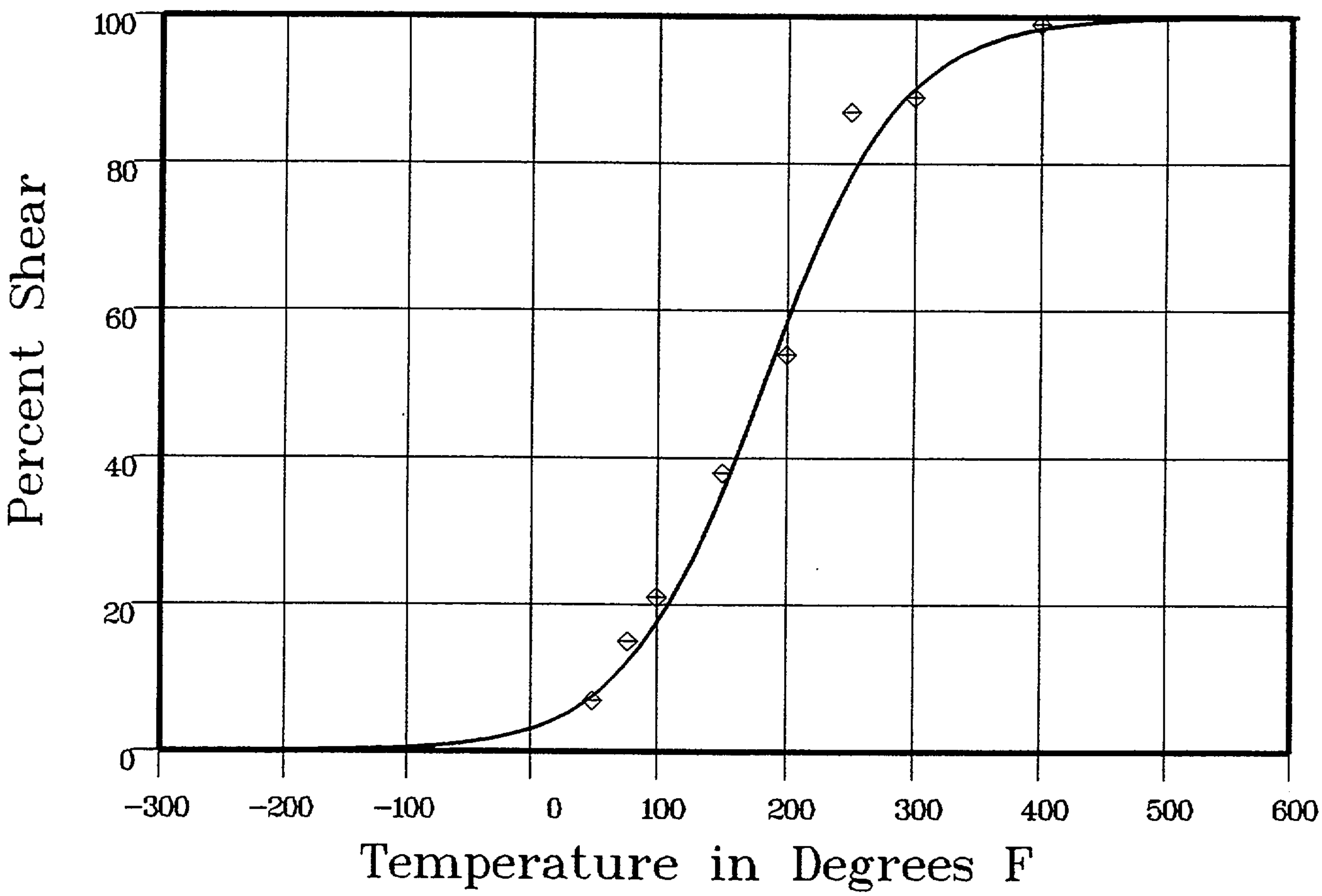
A = 50	B = 50	C = 106.01	T0 = 177.3

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

Temperature at 50% Shear: 177.3

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

Capsule: U Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50	7	8.3	-1.3
78	15	13.31	1.68
100	21	18.86	2.13
150	38	37.39	.6
200	54	60.54	-6.54
250	87	79.76	7.23
300	89	91	-2
400	99	98.52	.47

SUM of RESIDUALS = 2.28

CAPSULE W (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:22:32 on 05-15-2000

Page 1

Coefficients of Curve 4

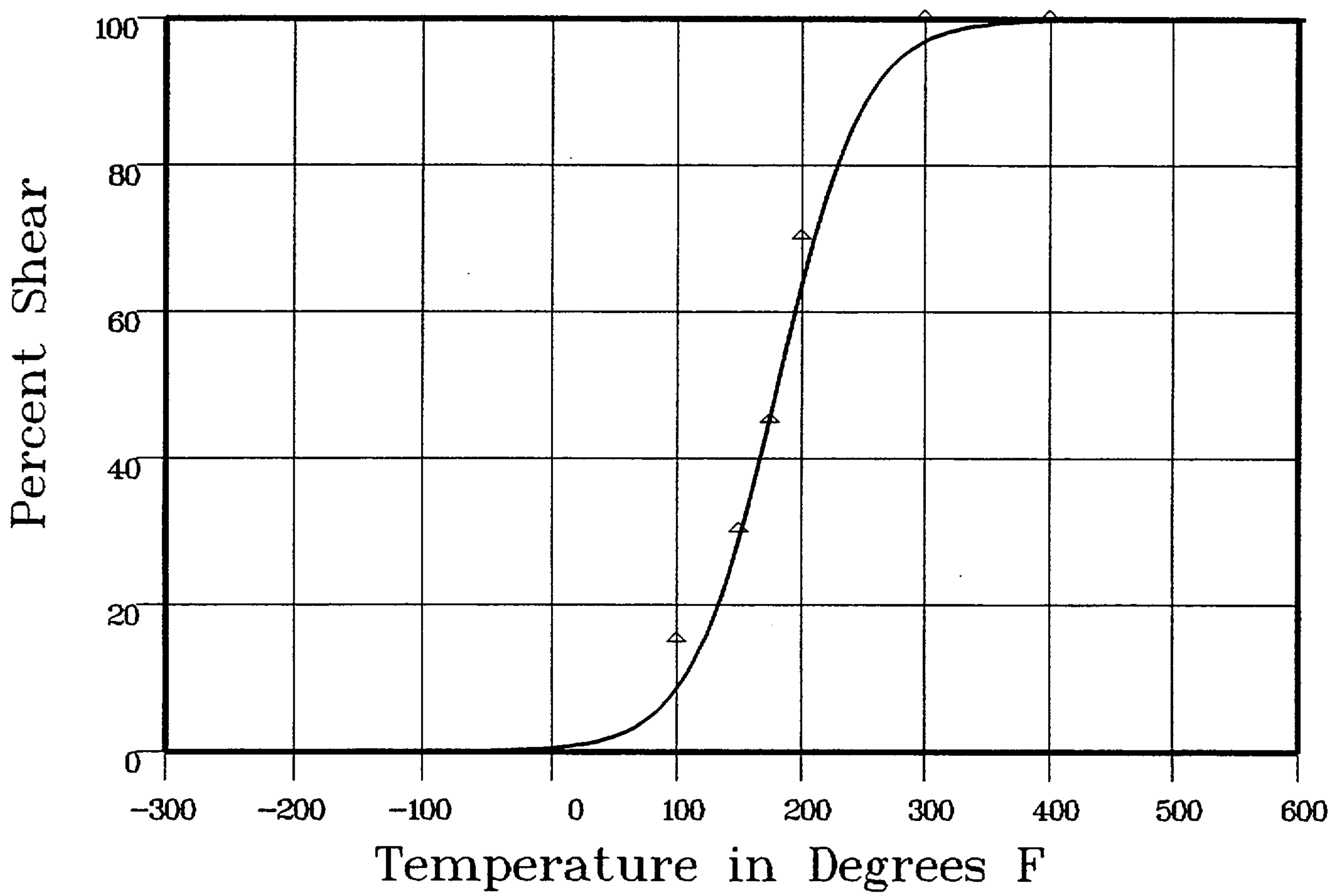
A = 50	B = 50	C = 68.56	T0 = 176.36

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

Temperature at 50% Shear: 176.3

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

Capsule: W Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100	15	9.72	5.27
150	30	31.66	-1.66
175	45	49	-4
200	70	66.58	3.41
300	100	97.35	2.64
400	100	99.85	.14

SUM of RESIDUALS = 5.8

CAPSULE Y (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:22:32 on 05-15-2000

Page 1

Coefficients of Curve 5

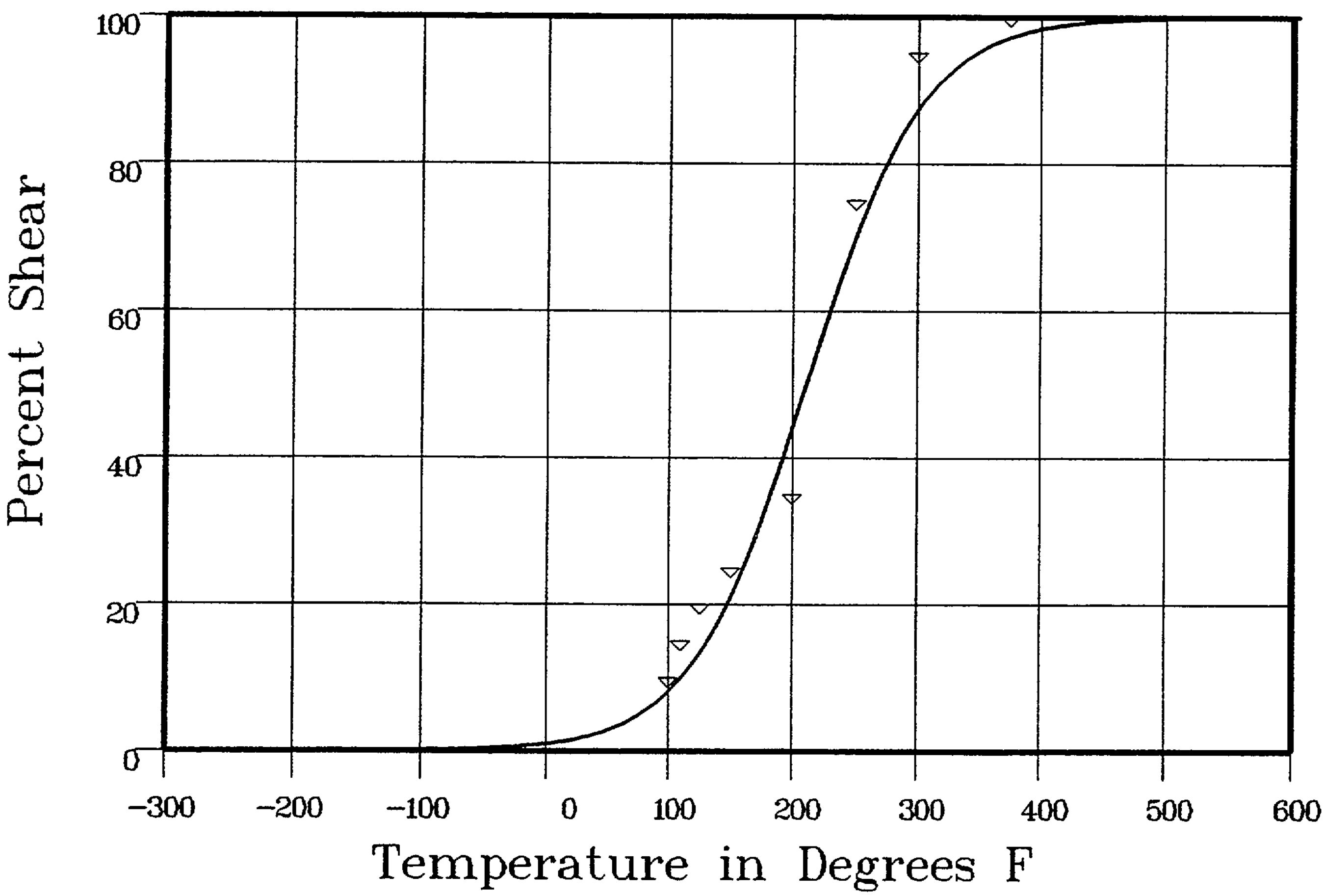
A = 50	B = 50	C = 92.13	T0 = 206.31

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

Temperature at 50% Shear: 206.3

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

Capsule: Y Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100	10	9.04	.95
110	15	11	3.99
125	20	14.61	5.38
150	25	22.75	2.24
200	35	46.57	-11.57
250	75	72.07	2.92

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

CAPSULE Y (LONGITUDINAL ORIENTATION)

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

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
300	95	88.42	6.57
375	100	97.49	2.5
		SUM of RESIDUALS =	13

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:29:45 on 05-15-2000

Page 1

Coefficients of Curve 1

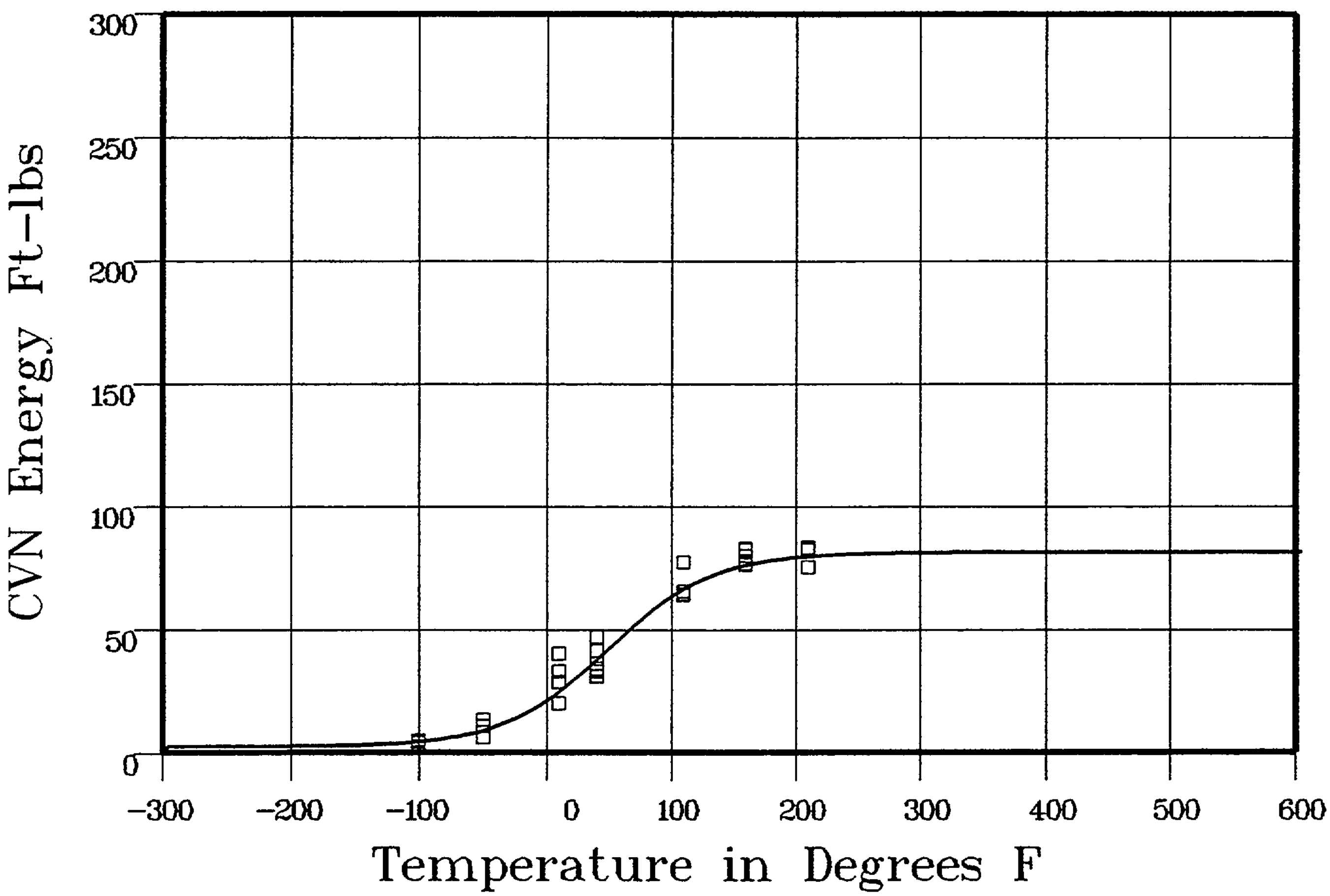
A = 41.59	B = 39.4	C = 84.5	T0 = 43.59

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

Upper Shelf Energy: 81 Fixed Temp. at 30 ft-lbs: 17.9 Temp. at 50 ft-lbs: 61.8 Lower Shelf Energy: 2.19 Fixed

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

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	5	4.74	.25
-100	4.5	4.74	-.24
-100	4	4.74	-.74
-100	2.5	4.74	-2.24
-50	11	9.95	1.04
-50	11	9.95	1.04
-50	13.5	9.95	3.54
-50	6	9.95	-3.95
-50	11	9.95	1.04

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

UNIRRADIATED (TRANSVERSE ORIENTATION)

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

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
10	20	26.71	-6.71
10	28.5	26.71	1.78
10	33	26.71	6.28
10	40	26.71	13.28
10	28.5	26.71	1.78
40	34	39.92	-5.92
40	36	39.92	-3.92
40	31	39.92	-8.92
40	33	39.92	-6.92
40	46.5	39.92	6.57
40	41	39.92	1.07
110	64	67.44	-3.44
110	77	67.44	9.55
110	63.5	67.44	-3.94
110	65	67.44	-2.44
160	79.5	76.28	3.21
160	76.5	76.28	.21
160	76	76.28	-.28
160	82.5	76.28	6.21
160	82	76.28	5.71
210	82	79.49	2.5
210	83	79.49	3.5
210	82.5	79.49	3
210	75	79.49	-4.49

SUM of RESIDUALS = 17.4

CAPSULE V (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:29:45 on 05-15-2000

Page 1

Coefficients of Curve 2

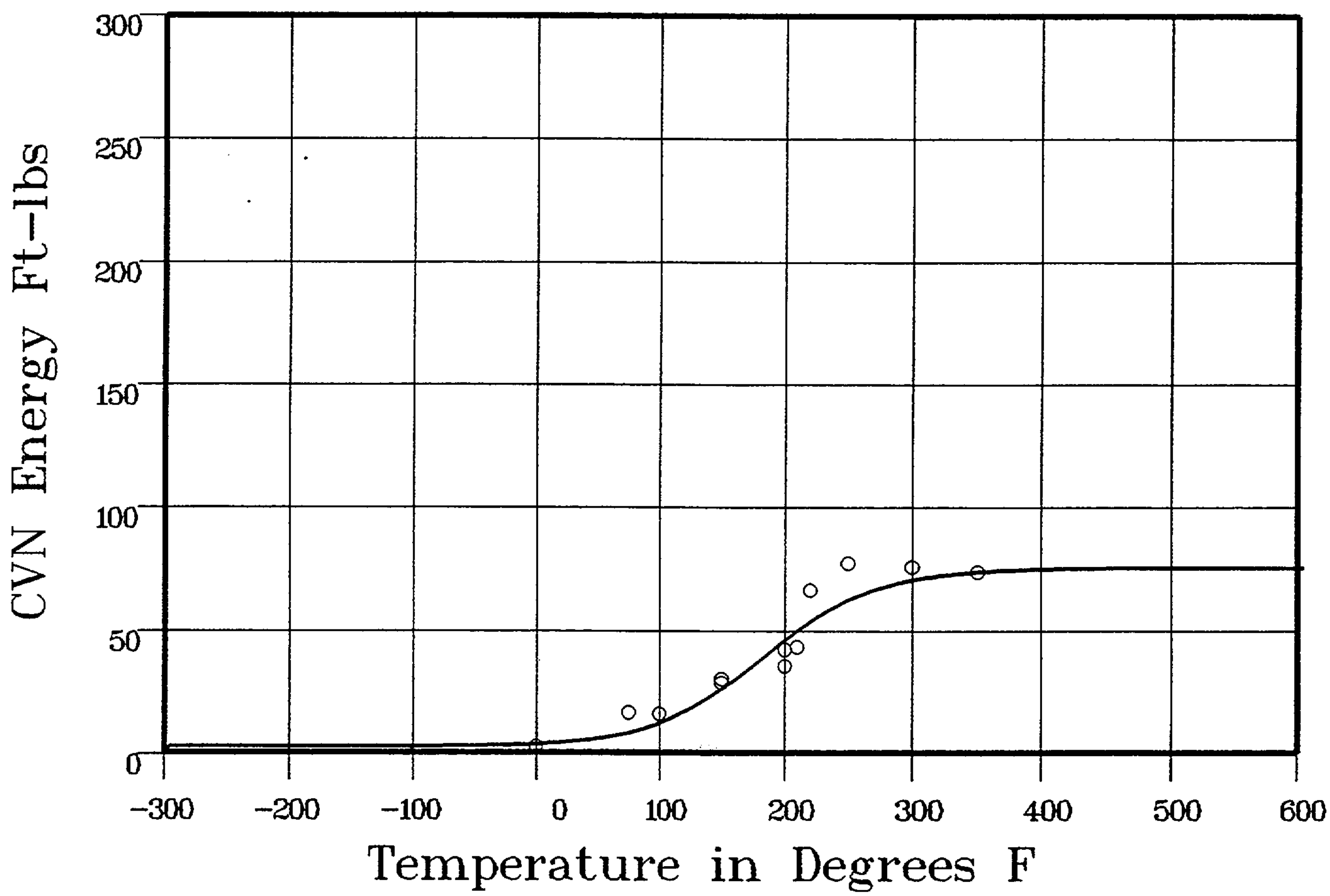
A = 38.59	B = 36.4	C = 89.17	T0 = 177.24

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

Upper Shelf Energy: 75 Fixed Temp. at 30 ft-lbs: 155.7 Temp. at 50 ft-lbs: 206.1 Lower Shelf Energy: 2.19 Fixed

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

Capsule: V Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	2.5	3.54	-1.04
75	16.5	8.87	7.62
100	16	13.13	2.86
150	28.5	27.81	.68
150	30	27.81	2.18
200	35.5	47.69	-12.19
200	42	47.69	-5.69
210	43	51.39	-8.39

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

CAPSULE V (TRANSVERSE ORIENTATION)

Page 2

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

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
220	66	54.82	11.17
250	77	63.09	13.9
300	75.5	70.63	4.86
350	73.5	73.51	-.01

SUM of RESIDUALS = 15.96

CAPSULE U (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:29:45 on 05-15-2000

Page 1

Coefficients of Curve 3

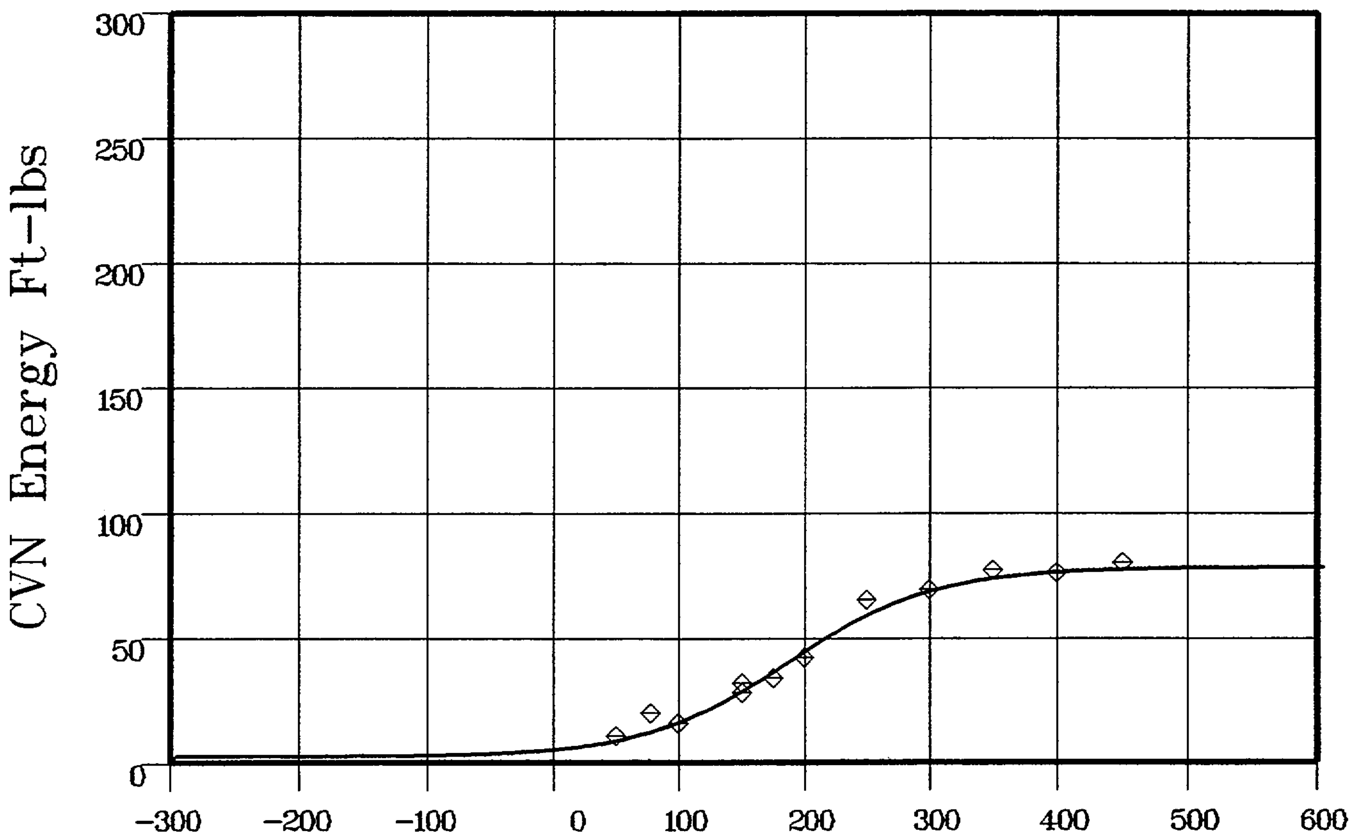
A = 40.09	B = 37.9	C = 117.44	T0 = 181.87

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

Upper Shelf Energy: 78 Fixed Temp. at 30 ft-lbs: 149.8 Temp. at 50 ft-lbs: 213.2 Lower Shelf Energy: 2.19 Fixed

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

Capsule: U Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	11	9.45	1.54
78	20	13.24	6.75
100	16	17.26	-1.26
150	28	30.05	-2.05
150	32	30.05	1.94
175	34	37.88	-3.88
200	42	45.9	-3.9
250	65	59.91	5.08

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

CAPSULE U (TRANSVERSE ORIENTATION)

Page 2

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

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
300	69	69.05	-.05
350	77	73.9	3.09
400	76	76.19	-.19
450	80	77.21	2.78

SUM of RESIDUALS = 9.84

CAPSULE W (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:29:45 on 05-15-2000

Page 1

Coefficients of Curve 4

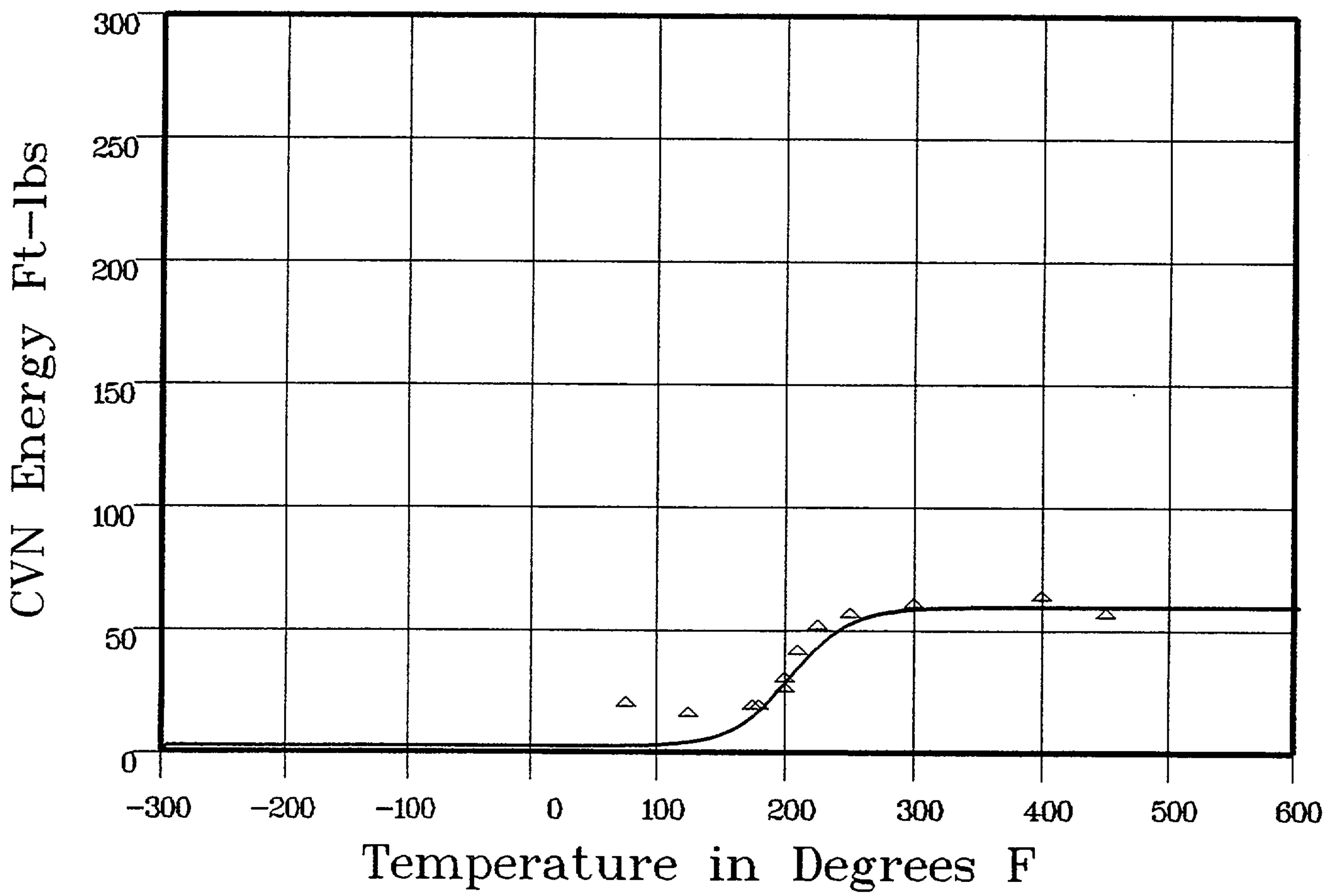
A = 30.6	B = 28.39	C = 46.28	T0 = 198.92

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

Upper Shelf Energy: 59 Fixed   Temp. at 30 ft-lbs: 197.9   Temp. at 50 ft-lbs: 237.5   Lower Shelf Energy: 2.2 Fixed

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

Capsule: W   Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
76	19	2.47	16.52
125	15	4.43	10.56
175	18	17.1	.89
180	18	19.59	-1.59
200	29	31.25	-2.25
200	25	31.25	-6.25
210	40	37.26	2.73

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

CAPSULE W (TRANSVERSE ORIENTATION)

Page 2

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

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
225	50	45.09	4.9
250	55	53.36	1.63
300	59	58.28	.71
400	62	58.99	3
450	55	58.99	-3.99

SUM of RESIDUALS = 26.85

CAPSULE Y (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:29:45 on 05-15-2000

Page 1

Coefficients of Curve 5

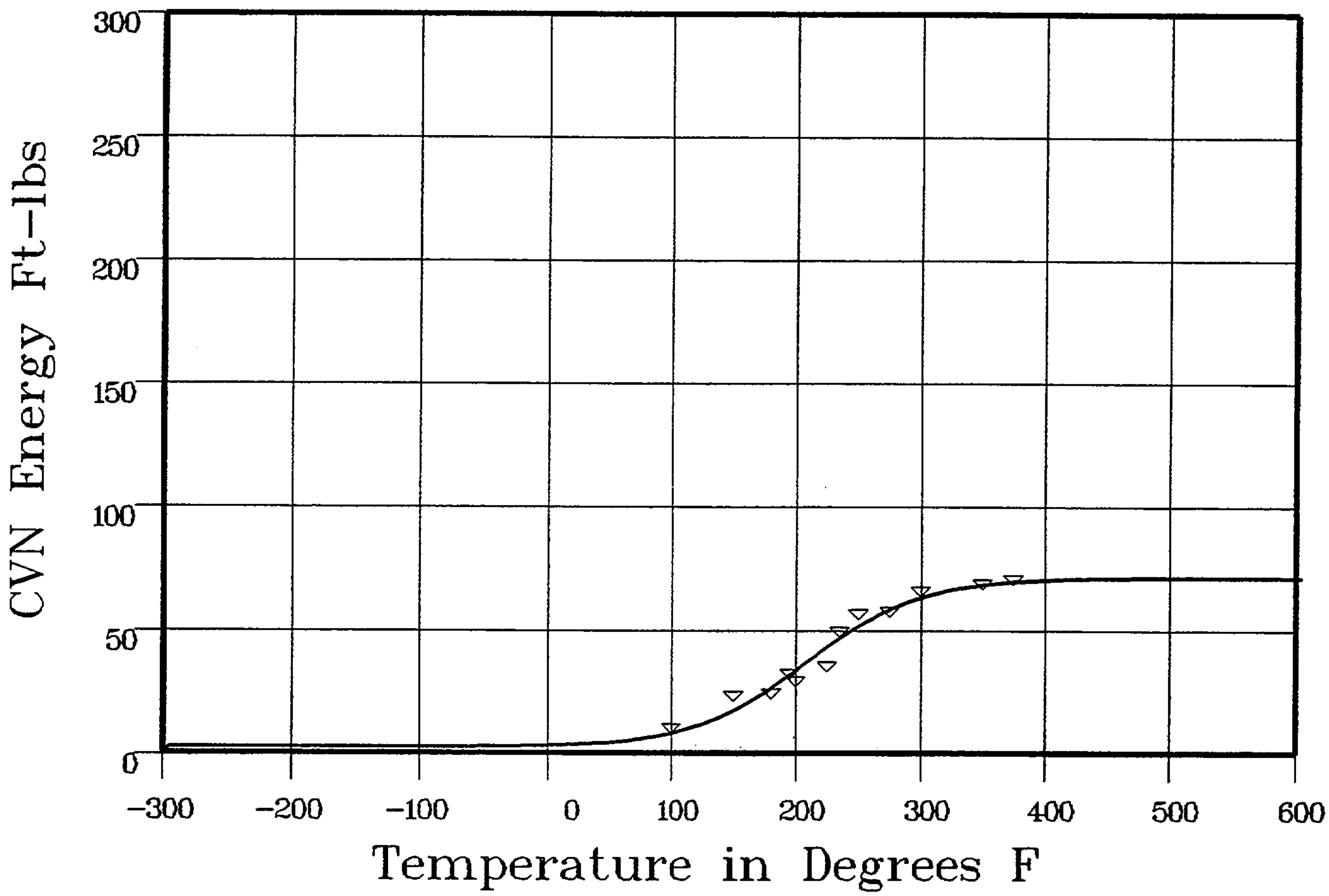
A = 36.59	B = 34.4	C = 91.85	T0 = 202.73

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

Upper Shelf Energy: 71 Fixed Temp. at 30 ft-lbs: 184.8 Temp. at 50 ft-lbs: 240.5 Lower Shelf Energy: 2.19 Fixed

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

Capsule: Y Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
100	12	8.83	3.16
150	25	18.76	6.23
180	26	28.25	-2.25
195	34	33.71	.28
200	31	35.57	-4.57
225	37	44.77	-7.77

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

CAPSULE Y (TRANSVERSE ORIENTATION)

Page 2

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

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
235	51	48.21	2.78
250	58	52.88	5.11
275	59	59.18	-.18
300	67	63.61	3.38
350	70	68.32	1.67
375	72	69.42	2.57

SUM of RESIDUALS = 10.43

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:35:19 on 07-07-2000

Page 1

Coefficients of Curve 2

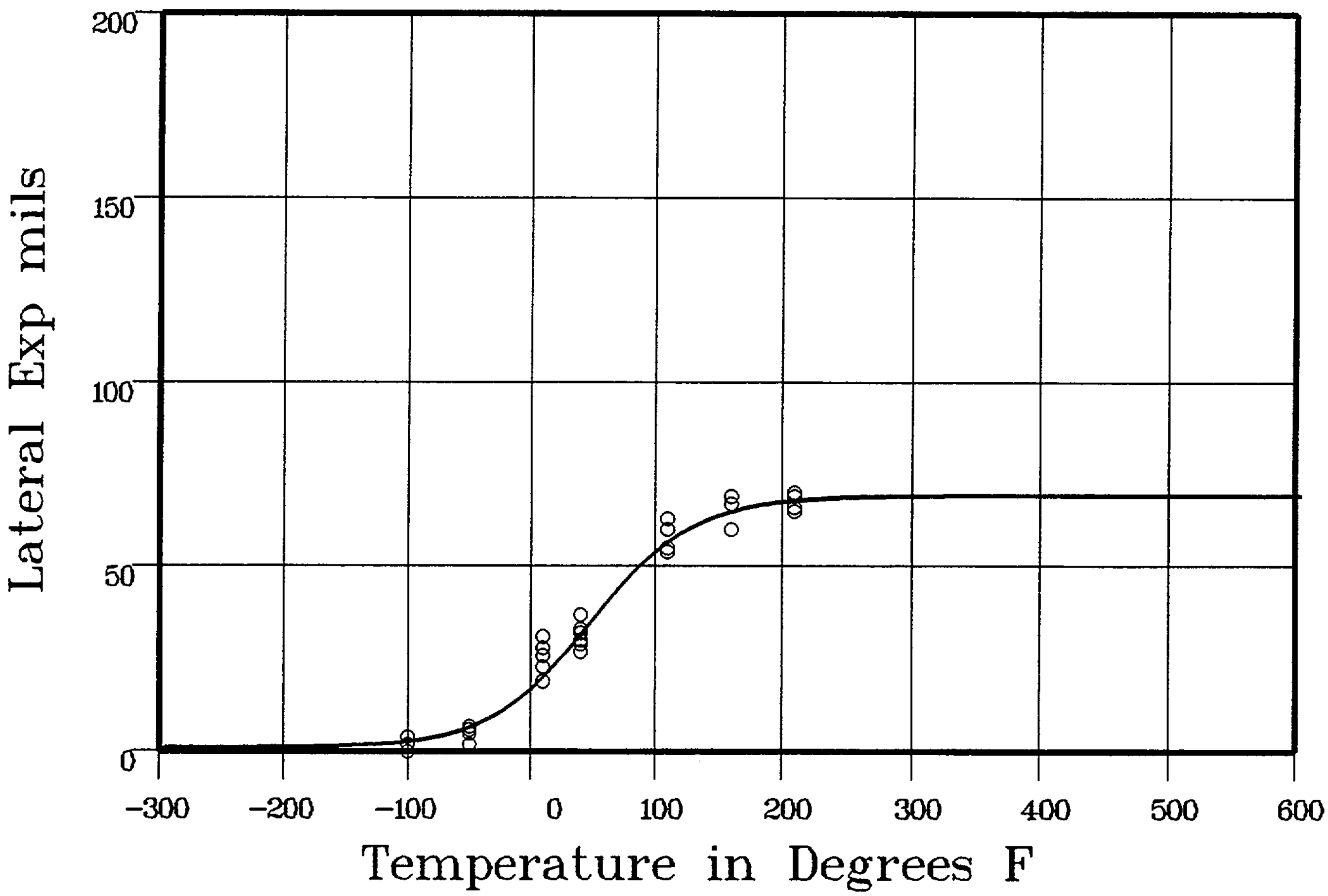
A = 35.09	B = 34.09	C = 82.52	T0 = 44.06

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

Upper Shelf L.E.: 69.19 Temperature at L.E. 35: 43.8 Lower Shelf L.E.: 1 Fixed

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

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	2	3.01	-1.01
-100	4	3.01	.98
-100	0	3.01	-3.01
-100	0	3.01	-3.01
-50	5	7.33	-2.33
-50	2	7.33	-5.33
-50	6	7.33	-1.33
-50	7	7.33	-.33

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

UNIRRADIATED (TRANSVERSE ORIENTATION)

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

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	7	7.33	-.33
10	28	21.77	6.22
10	31	21.77	9.22
10	26	21.77	4.22
10	19	21.77	-2.77
10	23	21.77	1.22
40	30	33.42	-3.42
40	37	33.42	3.57
40	33	33.42	-.42
40	32	33.42	-1.42
40	29	33.42	-4.42
40	27	33.42	-6.42
110	63	57.72	5.27
110	54	57.72	-3.72
110	55	57.72	-2.72
110	60	57.72	2.27
160	67	65.32	1.67
160	67	65.32	1.67
160	69	65.32	3.67
160	60	65.32	-5.32
160	67	65.32	1.67
210	66	67.99	-1.99
210	65	67.99	-2.99
210	69	67.99	1
210	70	67.99	2

SUM of RESIDUALS = -7.62

CAPSULE V (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:54:39 on 05-15-2000

Page 1

Coefficients of Curve 2

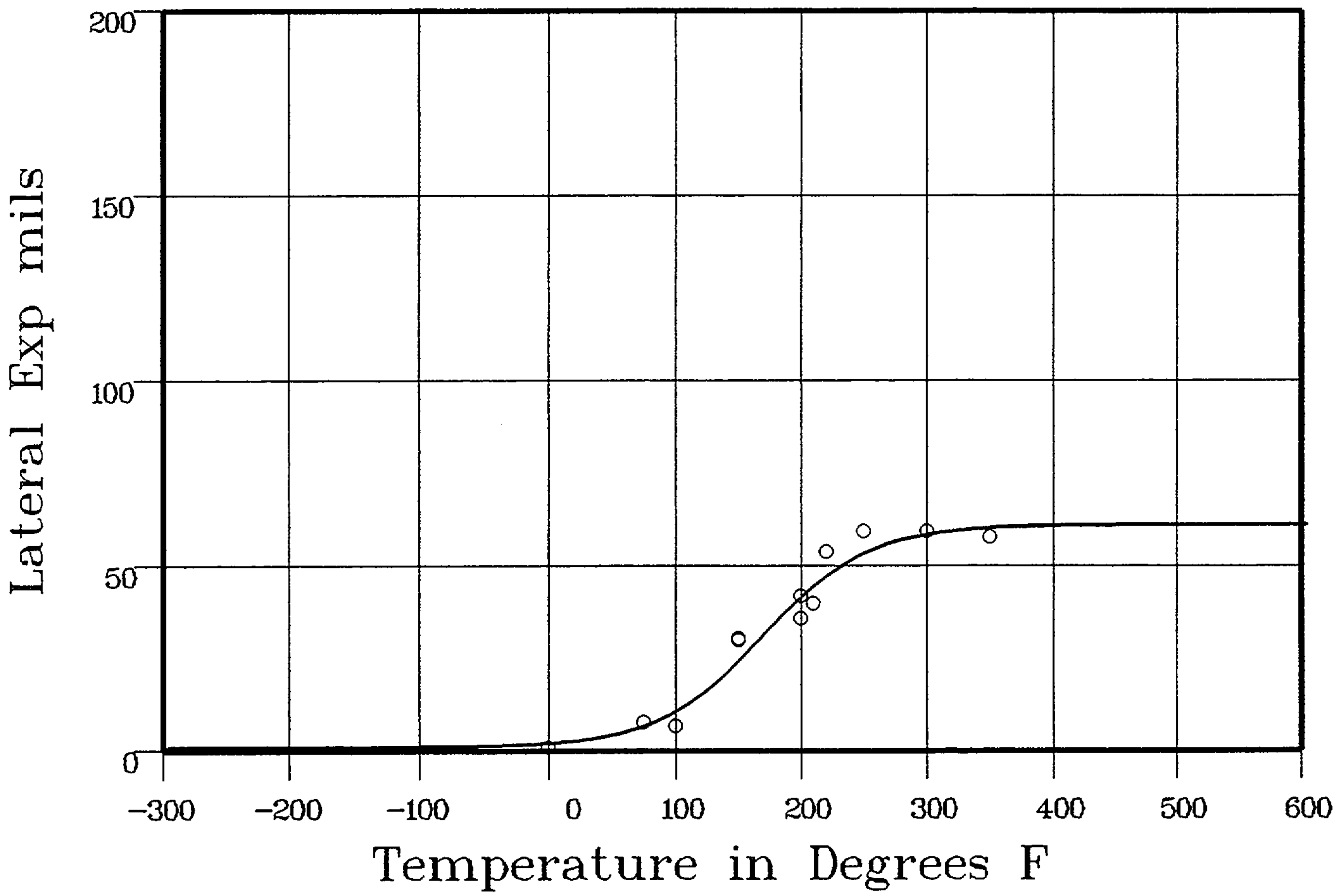
A = 31.13	B = 30.13	C = 84.6	T0 = 164.64

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

Upper Shelf L.E.: 61.27 Temperature at L.E. 35: 175.5 Lower Shelf L.E.: 1 Fixed

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

Capsule: V Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	1	2.2	-1.2
75	8	7.46	.53
100	7	11.74	-4.74
150	30.5	25.96	4.53
150	30	25.96	4.03
200	36	43.04	-7.04
200	42	43.04	-1.04
210	40	45.9	-5.9

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

CAPSULE V (TRANSVERSE ORIENTATION)

Page 2

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

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
220	54	48.44	5.55
250	59.5	54.19	5.3
300	59.5	58.9	.59
350	58	60.52	-2.52

SUM of RESIDUALS = -1.91

CAPSULE U (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:54:39 on 05-15-2000

Page 1

Coefficients of Curve 3

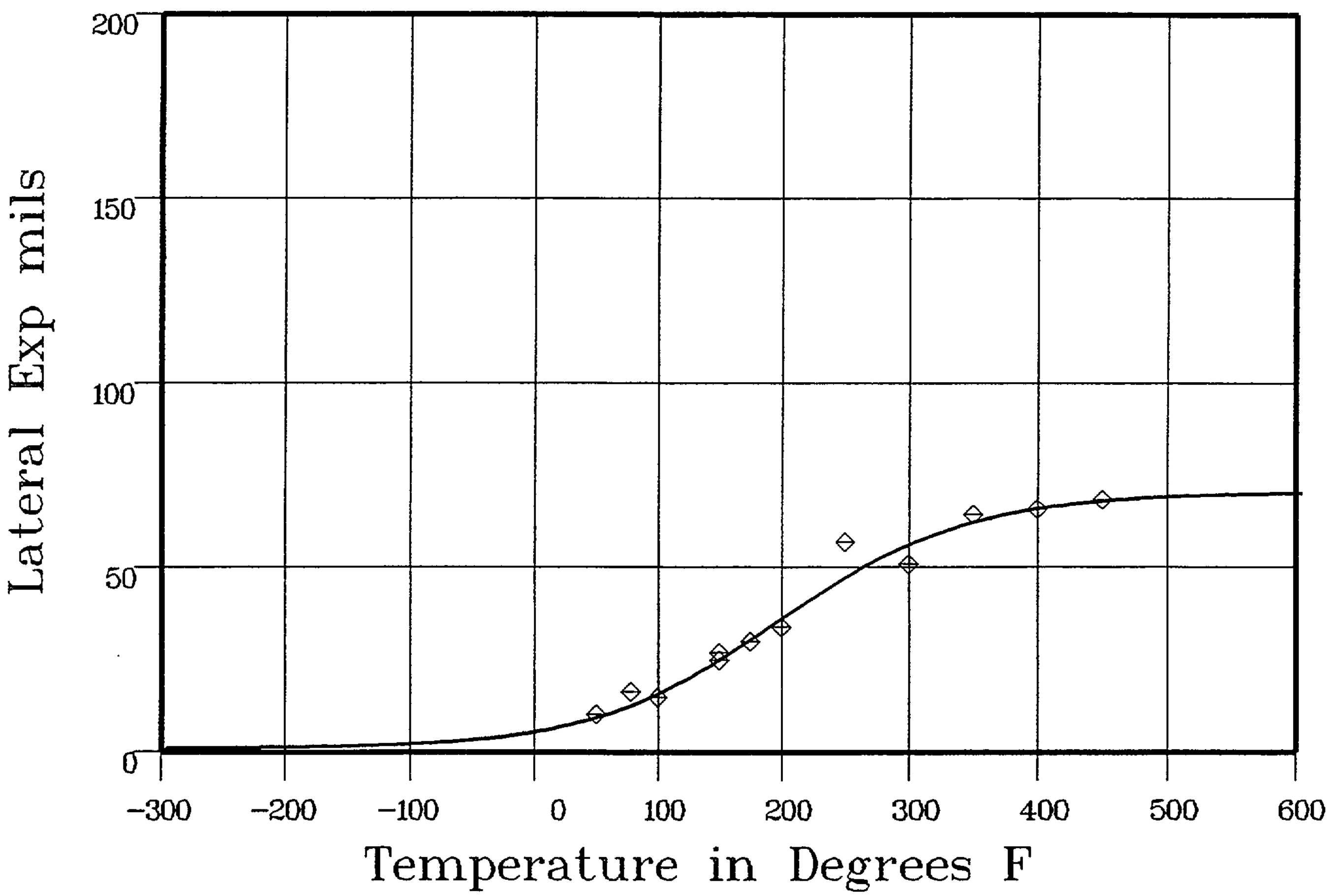
A = 35.78	B = 34.78	C = 151.04	T0 = 193.06

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

Upper Shelf L.E.: 70.57 Temperature at L.E. 35: 189.6 Lower Shelf L.E.: 1 Fixed

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

Capsule: U Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
50	10.5	10.09	.4
78	16.5	13.44	3.05
100	15	16.7	-1.7
150	25	26.12	-1.12
150	27	26.12	.87
175	30	31.64	-1.64
200	34	37.38	-3.38
250	57	48.31	8.68

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

CAPSULE U (TRANSVERSE ORIENTATION)

Page 2

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

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
300	51	56.98	-5.98
350	64.5	62.83	1.66
400	66	66.35	-.35
450	68.5	68.32	.17

SUM of RESIDUALS = .65

CAPSULE W (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:54:39 on 05-15-2000

Page 1

Coefficients of Curve 4

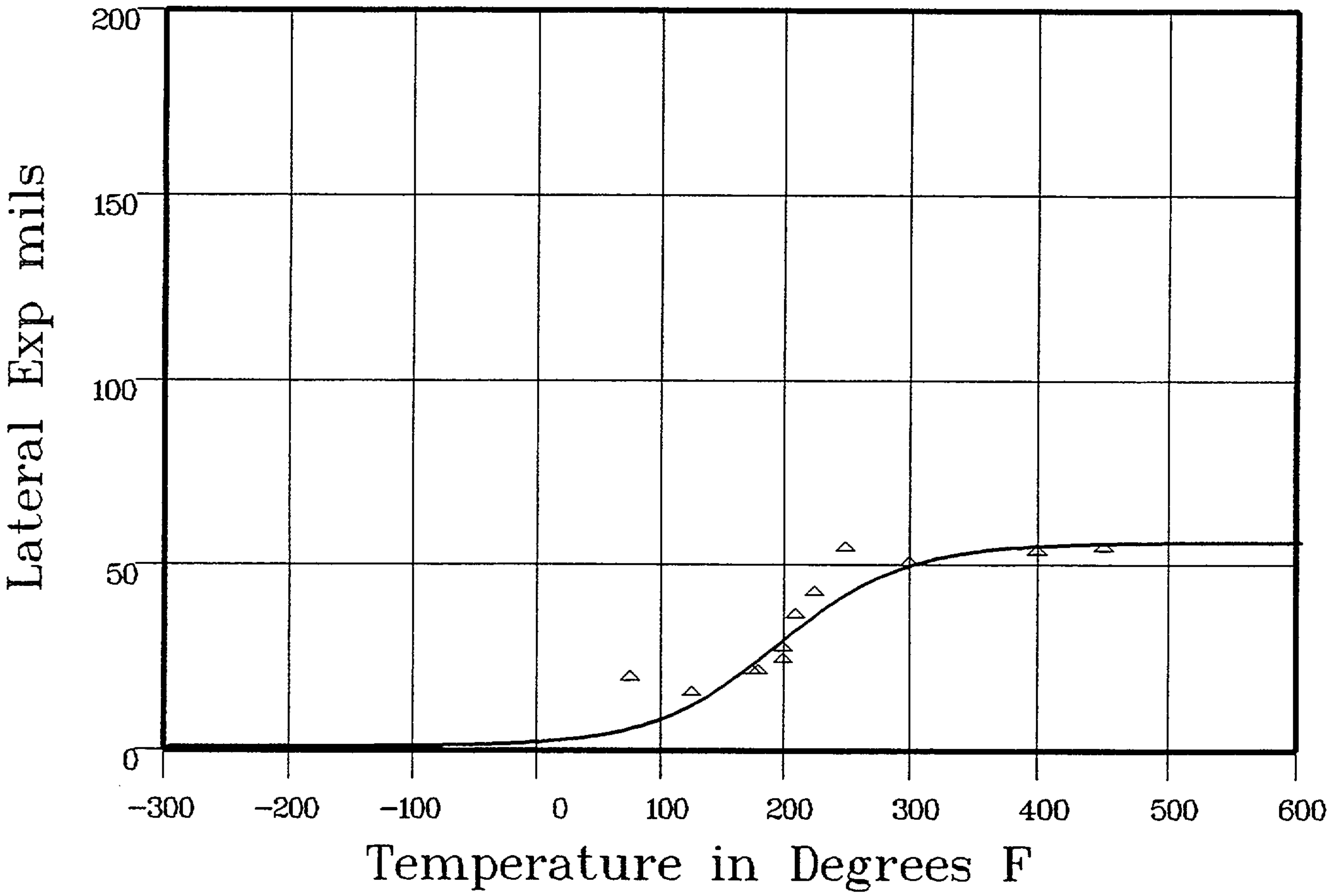
A = 28.64	B = 27.64	C = 103.24	T0 = 190.42

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

Upper Shelf L.E.: 56.29   Temperature at L.E. 35: 214.5   Lower Shelf L.E.: 1 Fixed

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

Capsule: W   Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
76	19	6.43	12.56
125	15	13.14	1.85
175	21	24.54	-3.54
180	21	25.86	-4.86
200	24	31.2	-7.2
200	27	31.2	-4.2
210	36	33.82	2.17

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

CAPSULE W (TRANSVERSE ORIENTATION)

Page 2

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

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed LE	Differential
225	42	37.57	4.42
250	54	43.03	10.96
300	50	50.38	-.38
400	53	55.35	-2.35
450	54	55.93	-1.93

SUM of RESIDUALS = 7.5

CAPSULE Y (TRANSVERSE ORIENTAITON)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:54:39 on 05-15-2000

Page 1

Coefficients of Curve 5

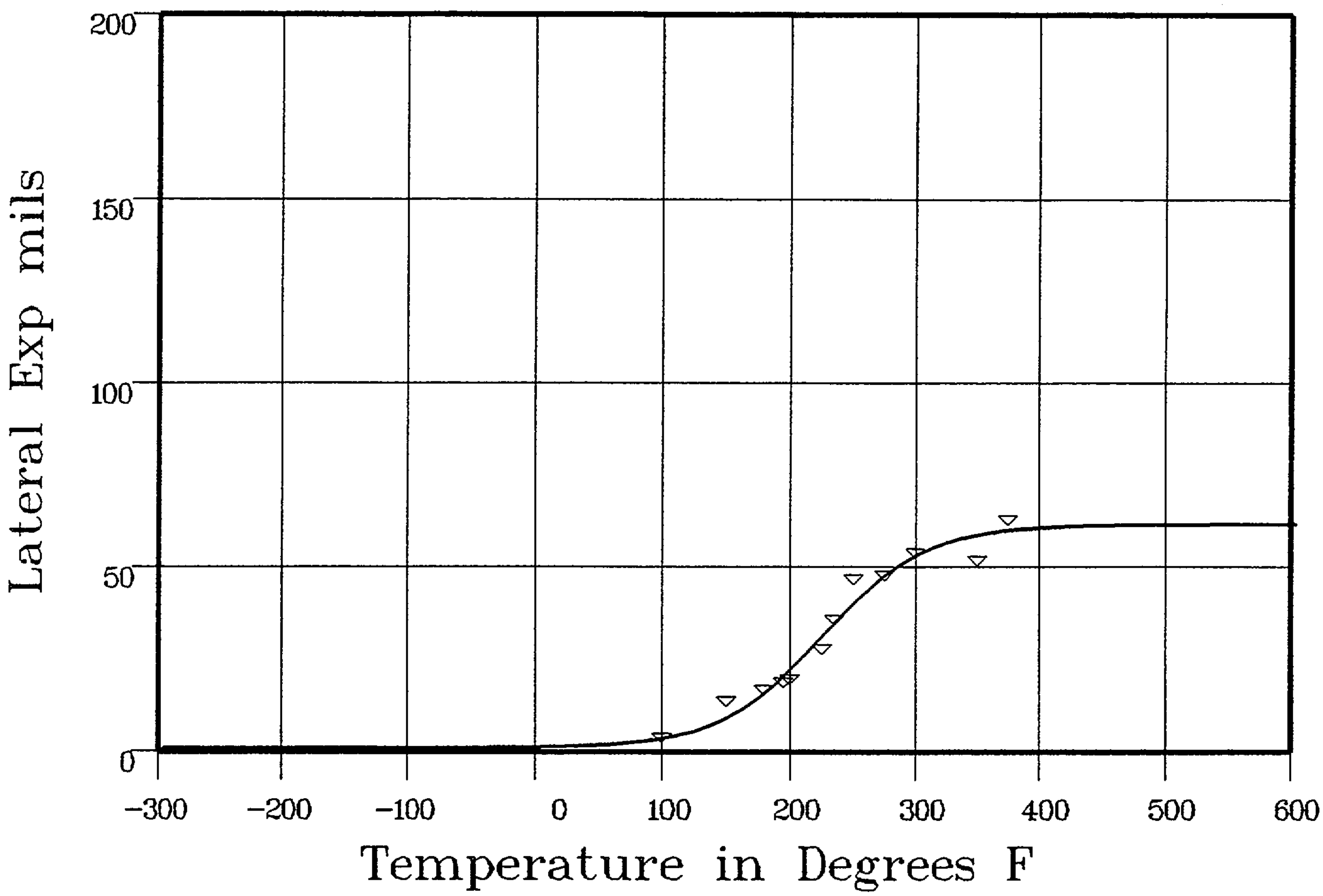
A = 31.27	B = 30.27	C = 81.88	T0 = 220.31

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

Upper Shelf L.E.: 61.54 Temperature at L.E. 35: 230.4 Lower Shelf L.E.: 1 Fixed

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

Capsule: Y Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
100	5	4.04	.95
150	15	10.21	4.78
180	18	17.46	.53
195	20	22.2	-2.2
200	21	23.91	-2.91
225	29	33	-4

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

CAPSULE Y (TRANSVERSE ORIENTAITON)

Page 2

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

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
235	37	36.64	.35
250	48	41.79	6.2
275	49	48.94	.05
300	55	53.98	1.01
350	53	59.1	-6.1
375	64	60.19	3.8

SUM of RESIDUALS = 2.47

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:36:36 on 07-07-2000

Page 1

Coefficients of Curve 2

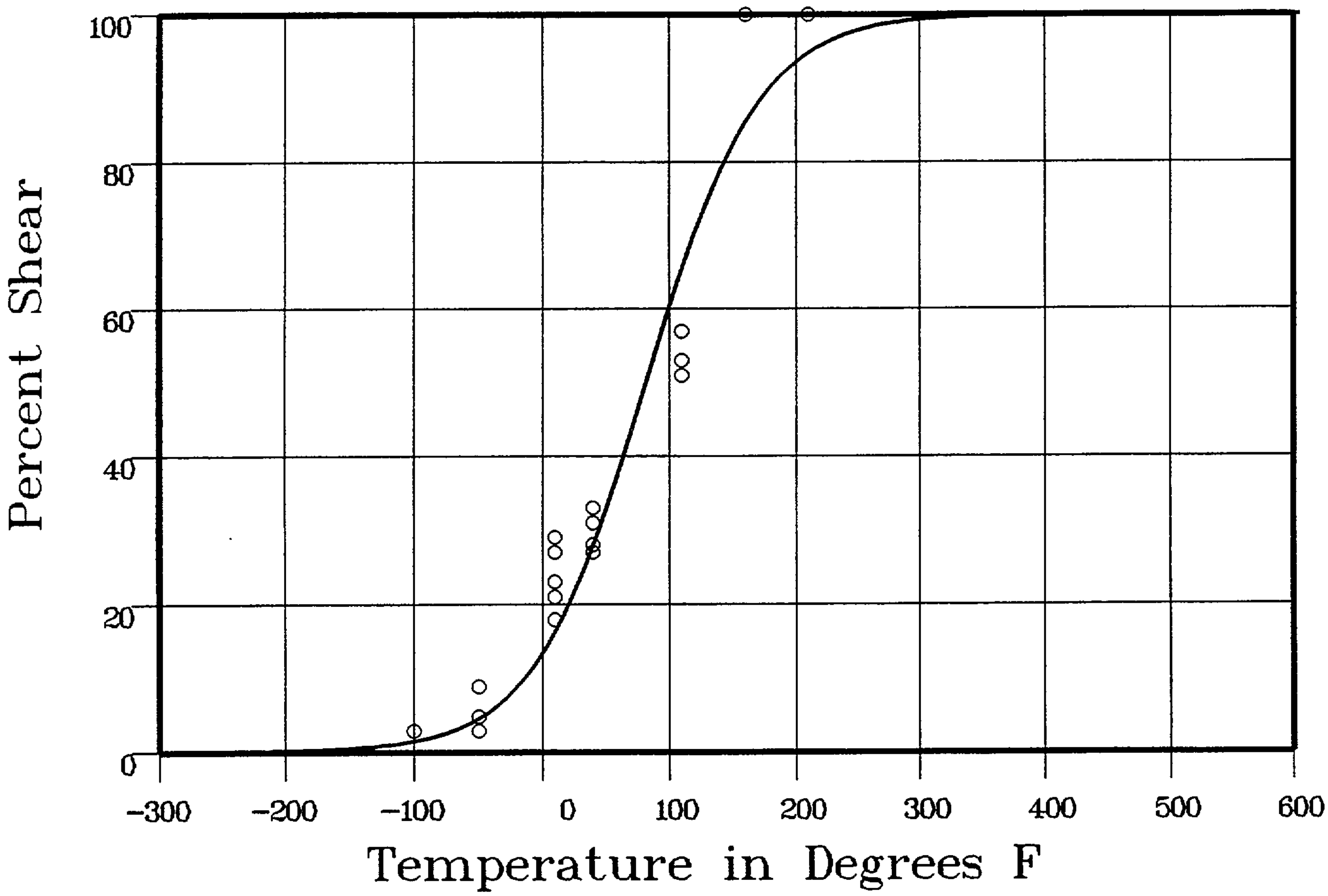
A = 50	B = 50	C = 88.02	T0 = 77.34

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

Temperature at 50% Shear: 77.3

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

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	3	1.74	1.25
-100	3	1.74	1.25
-100	3	1.74	1.25
-100	3	1.74	1.25
-50	5	5.24	-.24
-50	3	5.24	-2.24
-50	9	5.24	3.75
-50	5	5.24	-.24

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

UNIRRADIATED (TRANSVERSE ORIENTATION)

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

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	5	5.24	-.24
10	27	17.79	9.2
10	29	17.79	11.2
10	21	17.79	3.2
10	18	17.79	.2
10	23	17.79	5.2
40	28	29.97	-1.97
40	33	29.97	3.02
40	33	29.97	3.02
40	31	29.97	1.02
40	28	29.97	-1.97
40	27	29.97	-2.97
110	57	67.74	-10.74
110	51	67.74	-16.74
110	51	67.74	-16.74
110	53	67.74	-14.74
160	100	86.73	13.26
160	100	86.73	13.26
160	100	86.73	13.26
160	100	86.73	13.26
160	100	86.73	13.26
210	100	95.32	4.67
210	100	95.32	4.67
210	100	95.32	4.67
210	100	95.32	4.67

SUM of RESIDUALS = 60.98

CAPSULE V (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:03:15 on 05-15-2000

Page 1

Coefficients of Curve 2

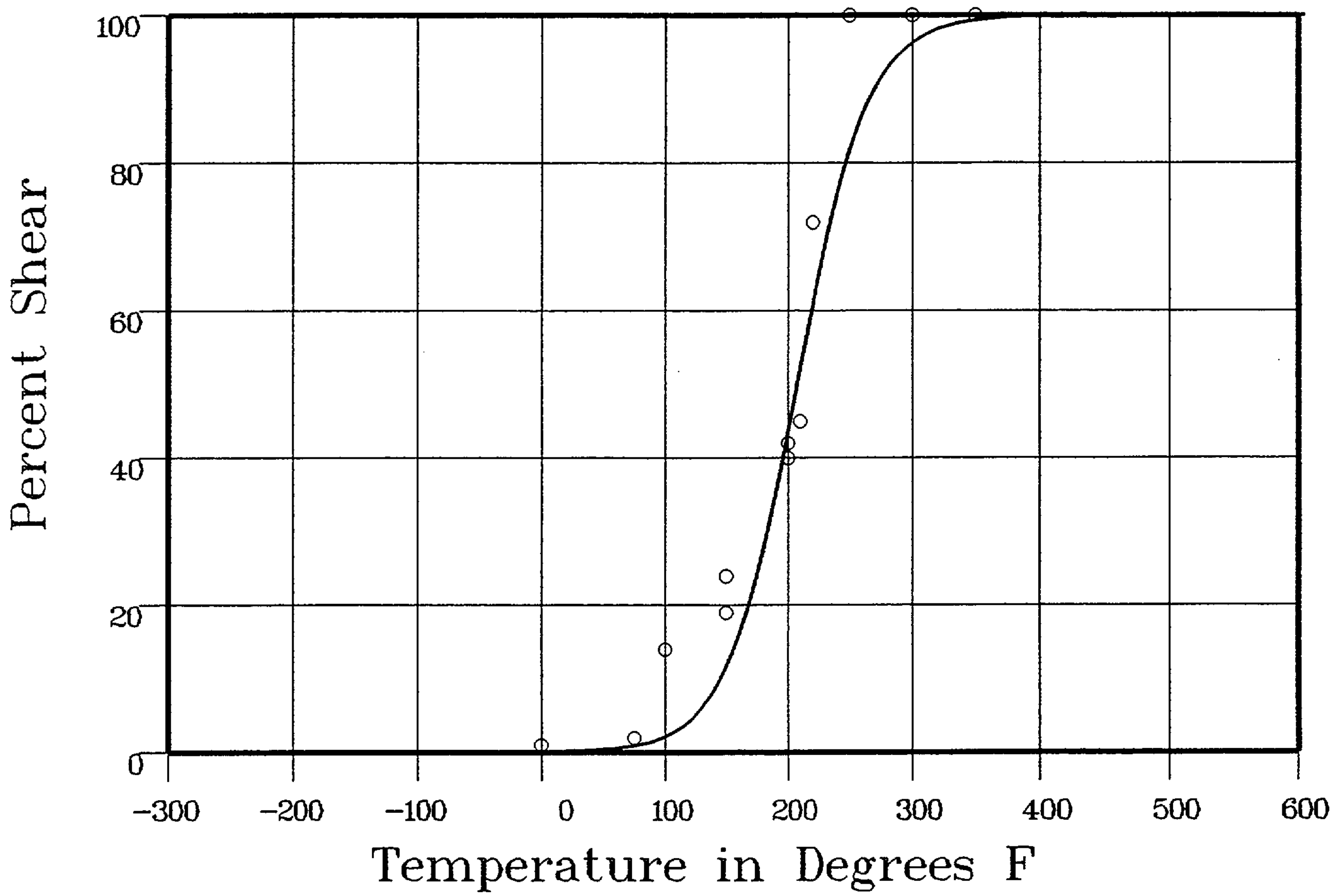
A = 50	B = 50	C = 56.81	T0 = 202.89

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

Temperature at 50% Shear: 202.8

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

Capsule: V Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	1	.07	.92
75	2	1.09	.9
100	14	2.6	11.39
150	19	13.44	5.55
150	24	13.44	10.55
200	40	47.45	-7.45
200	42	47.45	-5.45
210	45	56.22	-11.22

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

CAPSULE V (TRANSVERSE ORIENTATION)

Page 2

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

Capsule: V   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
220	72	64.61	7.38
250	100	83.99	16
300	100	96.82	3.17
350	100	99.43	.56

SUM of RESIDUALS = 32.32

CAPSULE U (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:03:15 on 05-15-2000
Page 1
Coefficients of Curve 3

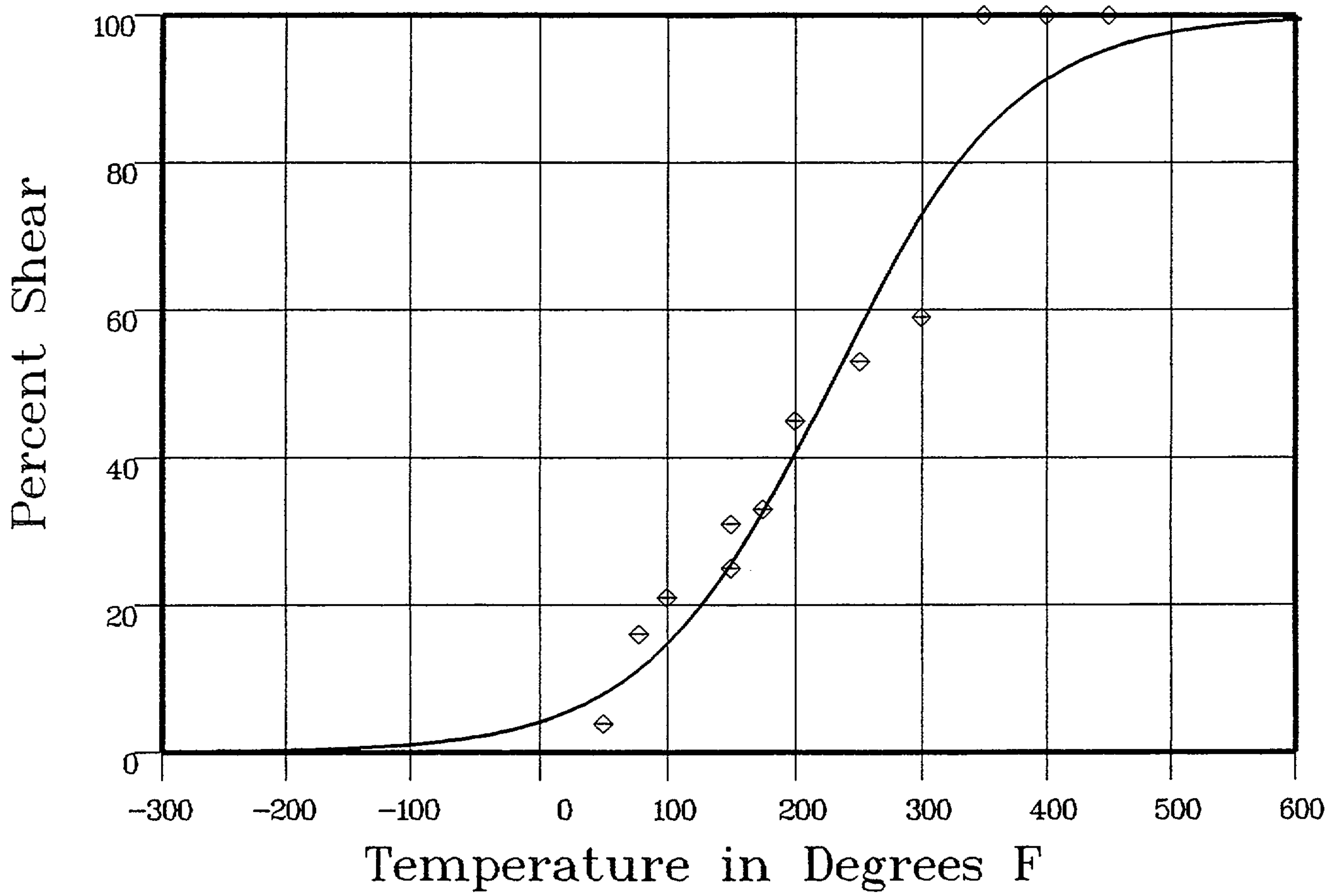
A = 50	B = 50	C = 145.97	T0 = 223.15

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

Temperature at 50% Shear: 223.1

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

Capsule: U Total Fluence:



Data Set(s) Plotted
Plant: BV1 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: C6317-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50	4	8.53	-4.53
78	16	12.03	3.96
100	21	15.61	5.38
150	25	26.84	-1.84
150	31	26.84	4.15
175	33	34.07	-1.07
200	45	42.13	2.86
250	53	59.09	-6.09

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

CAPSULE U (TRANSVERSE ORIENTATION)

Page 2

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

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
300	59	74.13	-15.13
350	100	85.04	14.95
400	100	91.85	8.14
450	100	95.72	4.27

SUM of RESIDUALS = 15.06

CAPSULE W (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:03:15 on 05-15-2000

Page 1

Coefficients of Curve 4

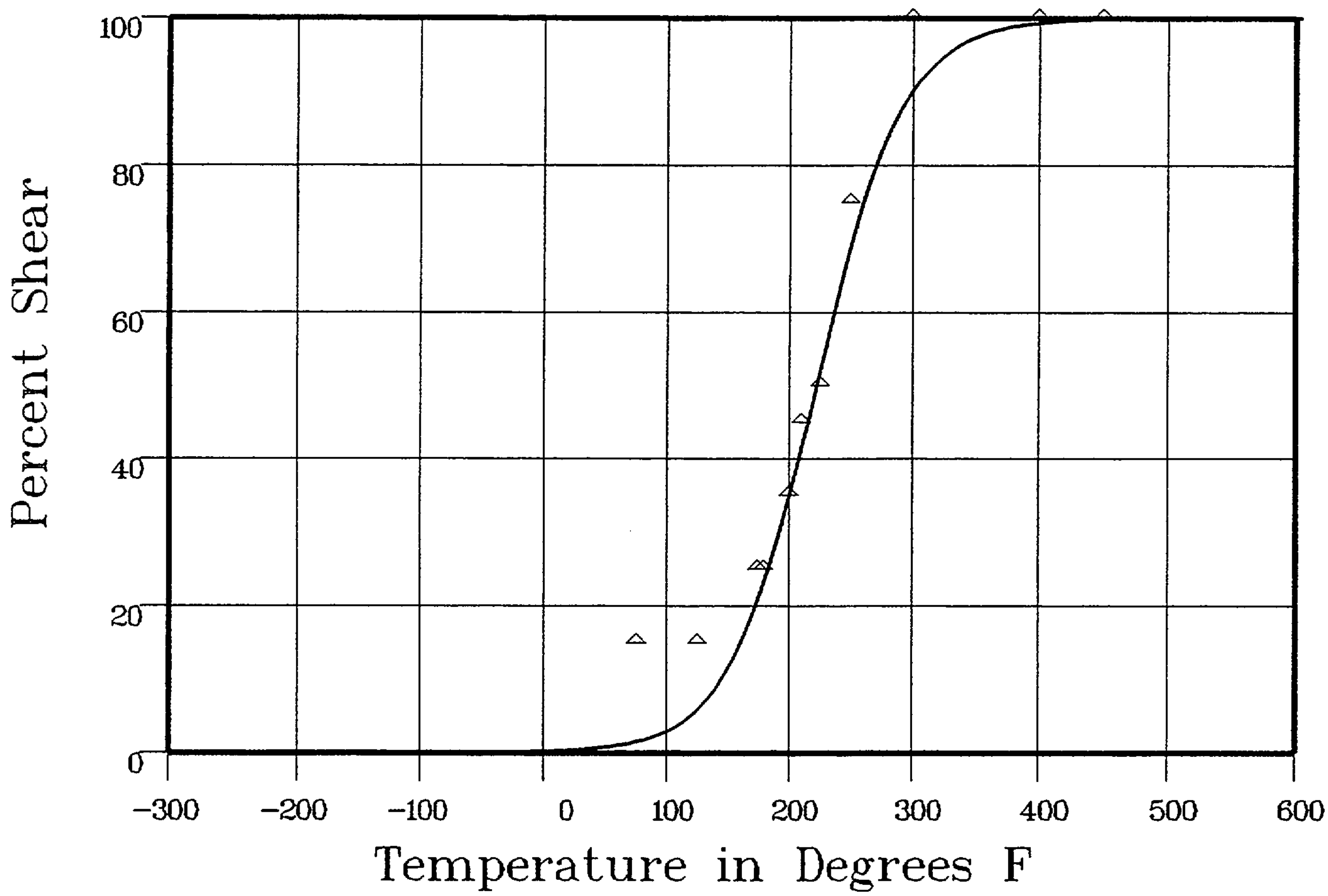
A = 50	B = 50	C = 70.29	T0 = 217.5

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

Temperature at 50% Shear: 217.5

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

Capsule: W Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
76	15	1.75	13.24
125	15	6.71	8.28
175	25	22.98	2.01
180	25	25.59	-.59
200	35	37.8	-2.8
200	35	37.8	-2.8
210	45	44.68	.31

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

CAPSULE W (TRANSVERSE ORIENTATION)

Page 2

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

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
225	50	55.31	-5.31
250	75	71.6	3.39
300	100	91.27	8.72
400	100	99.44	.55
450	100	99.86	.13

SUM of RESIDUALS = 25.16

CAPSULE Y (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:03:15 on 05-15-2000

Page 1

Coefficients of Curve 5

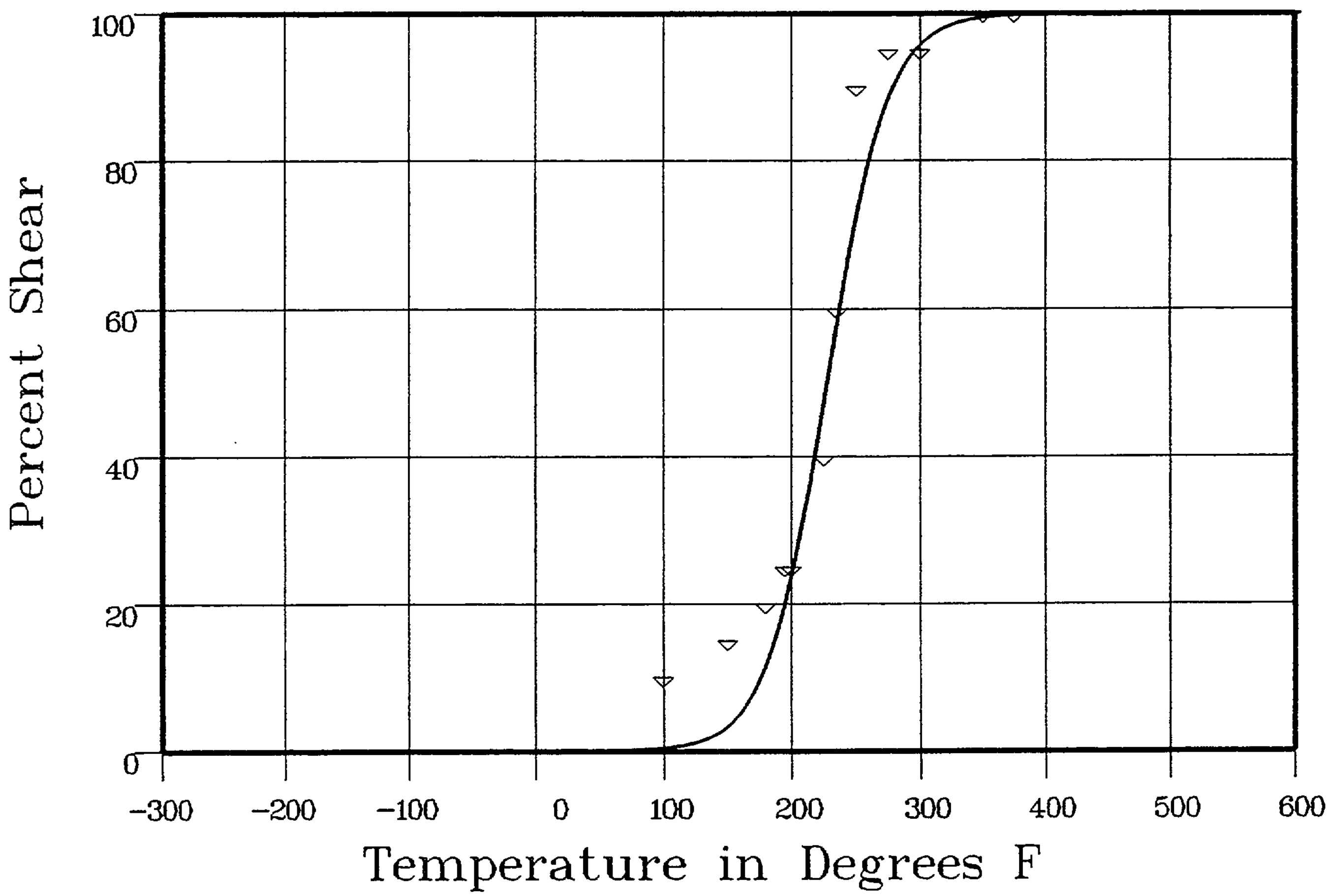
A = 50	B = 50	C = 46.55	T0 = 222.65

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

Temperature at 50% Shear: 222.6

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

Capsule: Y Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100	10	.51	9.48
150	15	4.22	10.77
180	20	13.79	6.2
195	25	23.35	1.64
200	25	27.42	-2.42
225	40	52.51	-12.51

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

CAPSULE Y (TRANSVERSE ORIENTATION)

Page 2

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

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
235	60	62.95	-2.95
250	90	76.39	13.6
275	95	90.45	4.54
300	95	96.52	-1.52
350	100	99.58	.41
375	100	99.85	.14

SUM of RESIDUALS = 27.4

UNIRRADIATED (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:28:58 on 05-16-2000

Page 1

Coefficients of Curve 1

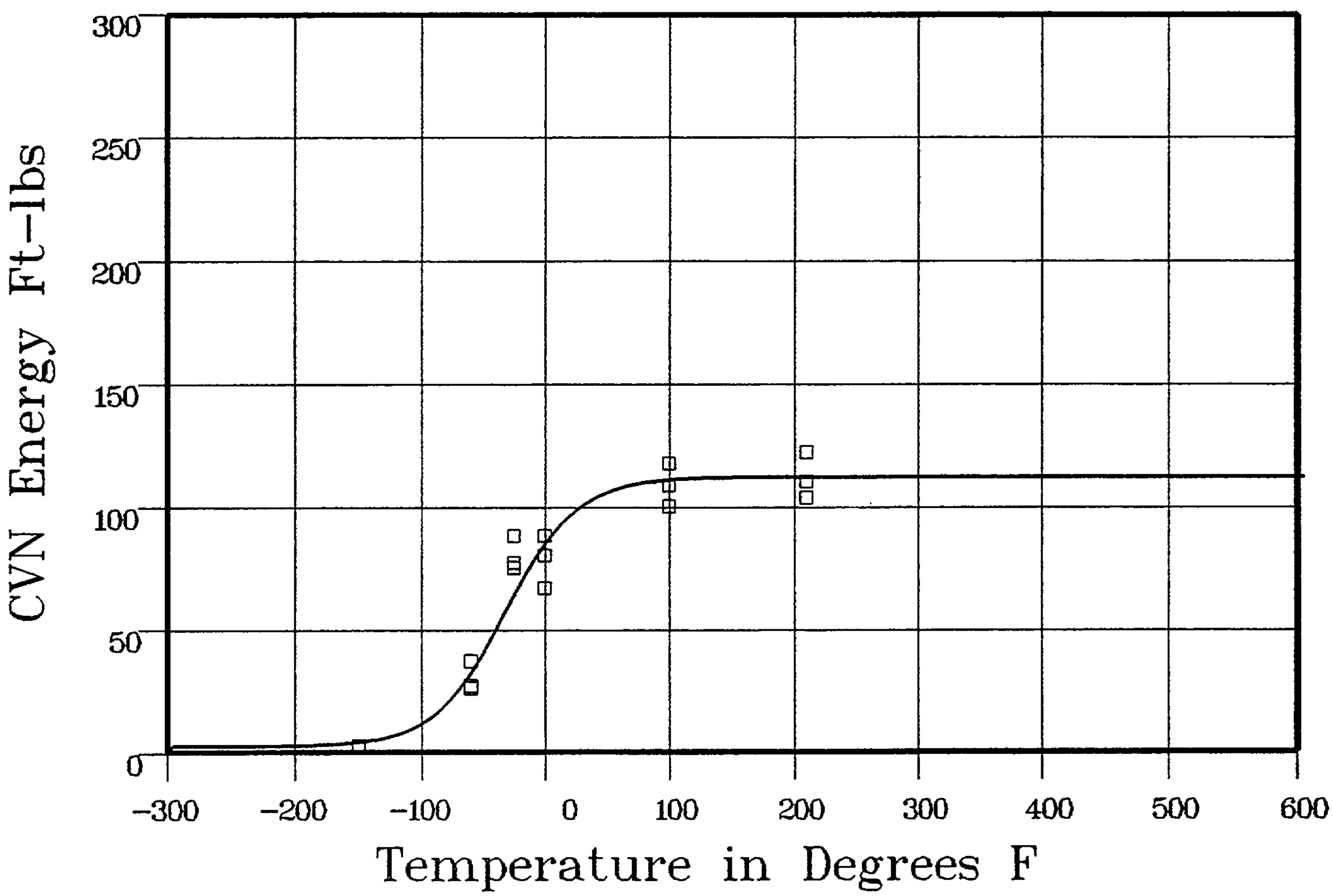
A = 57.09	B = 54.9	C = 57.62	T0 = -36.56

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

Upper Shelf Energy: 112 Fixed Temp. at 30 ft-lbs: -67.7 Temp. at 50 ft-lbs: -44 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 305424 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-150	2	4.3	-2.3
-150	2.5	4.3	-1.8
-60	27	35.92	-8.92
-60	26	35.92	-9.92
-60	37	35.92	1.07
-25	77	67.97	9.02
-25	75	67.97	7.02
-25	88	67.97	20.02
0	80	87.9	-7.9

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

UNIRRADIATED (WELD)

Page 2

Material: WELD   Heat Number: 305424   Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	88	87.9	.09
0	66.5	87.9	-21.4
100	117.5	111.04	6.45
100	108.5	111.04	-2.54
100	100	111.04	-11.04
210	103.5	111.97	-8.47
210	122	111.97	10.02
210	110	111.97	-1.97

SUM of RESIDUALS = -22.59

CAPSULE V (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:28:58 on 05-16-2000

Page 1

Coefficients of Curve 2

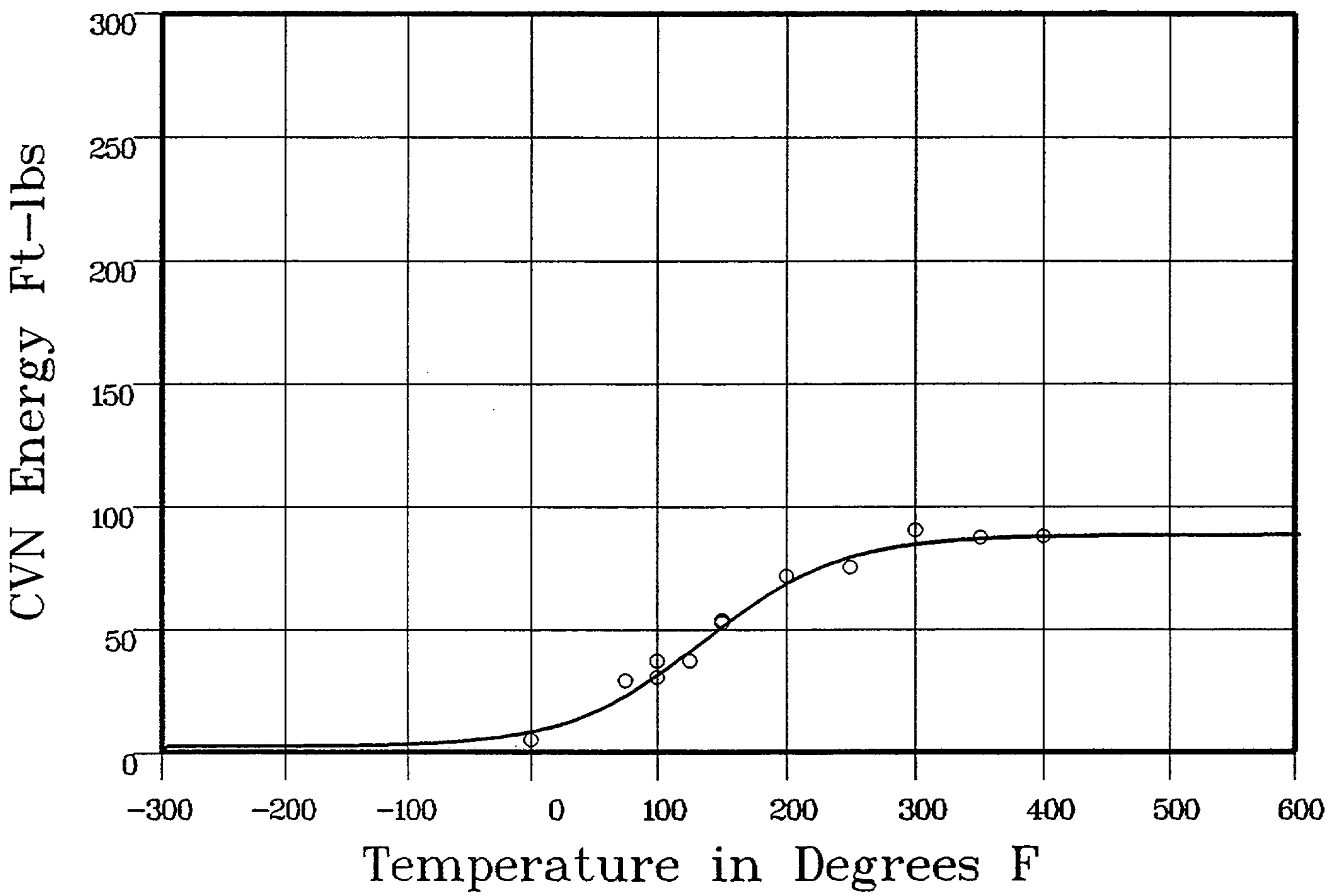
A = 45.09	B = 42.9	C = 106.75	T0 = 131.25

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

Upper Shelf Energy: 88 Fixed Temp. at 30 ft-lbs: 91.9 Temp. at 50 ft-lbs: 143.4 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 305424 Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	5	8.95	-3.95
75	29	24.37	4.62
100	37	32.88	4.11
100	30.5	32.88	-2.38
125	37	42.59	-5.59
150	52.5	52.55	-.05
150	53.5	52.55	.94
200	71.5	69.45	2.04

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

CAPSULE V (WELD)

Page 2

Material: WELD   Heat Number: 305424   Orientation:

Capsule: V   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
250	75	79.63	-4.63
300	90	84.51	5.48
350	87	86.59	.4
400	87.5	87.44	.05

SUM of RESIDUALS = 1.03

CAPSULE U (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:28:58 on 05-16-2000
Page 1
Coefficients of Curve 3

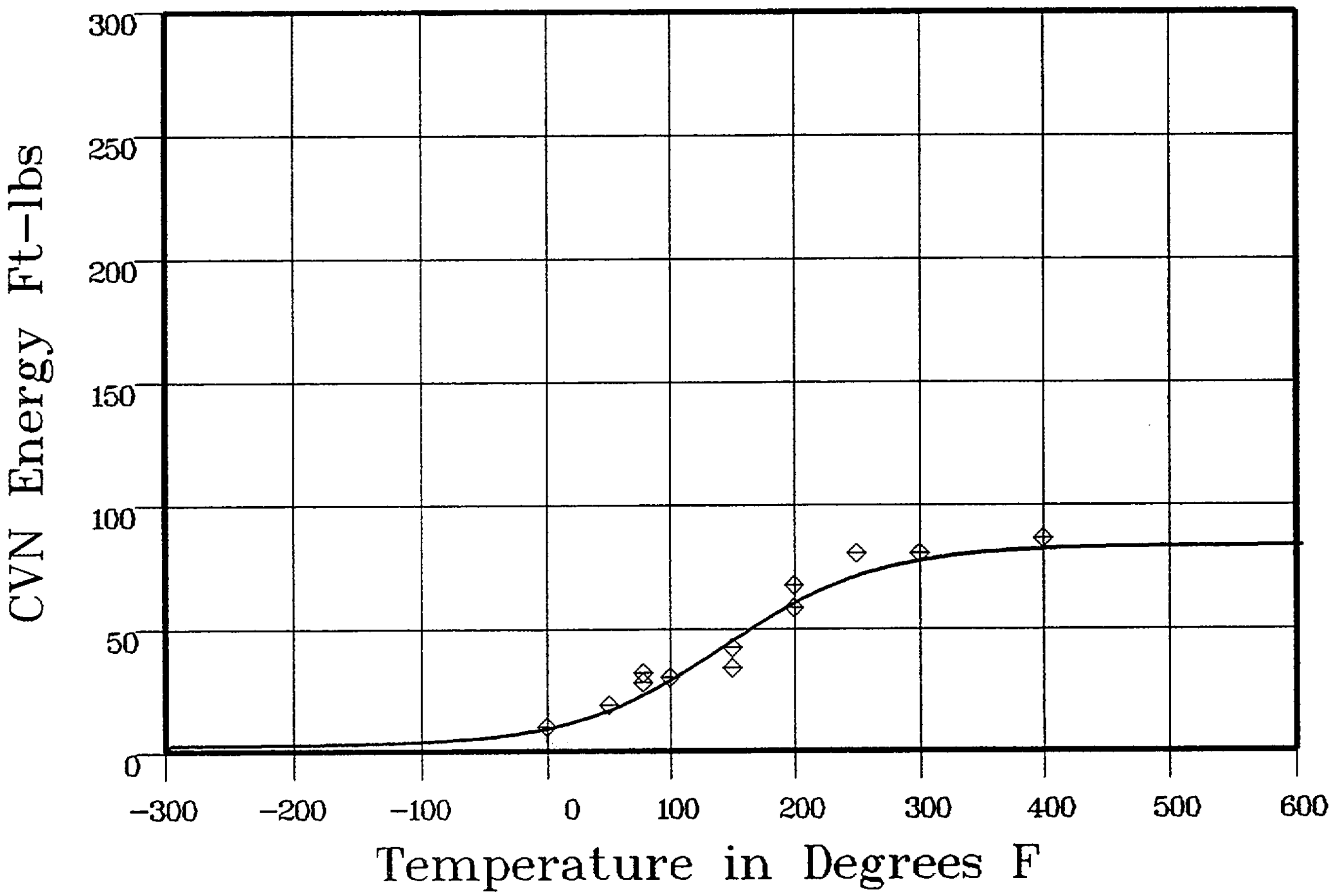
A = 42.59	B = 40.4	C = 123.9	T0 = 138.57

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

Upper Shelf Energy: 83 Fixed Temp. at 30 ft-lbs: 98.5 Temp. at 50 ft-lbs: 161.5 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 305424 Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted
Plant: BV1 Cap.: U Material: WELD Ori.: Heat #: 305424

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	10	9.99	0
50	19	17.8	1.19
78	32	24.28	7.71
78	28	24.28	3.71
100	30	30.41	-.41
150	34	46.31	-12.31
150	42	46.31	-4.31
200	58	61.13	-3.13

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

CAPSULE U (WELD)

Page 2

Material: WELD　　Heat Number: 305424　　Orientation:

Capsule: U　　Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
200	67	61.13	5.86
250	80	71.52	8.47
300	80	77.44	2.55
400	86	81.82	4.17

SUM of RESIDUALS = 13.51

CAPSULE W (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:28:58 on 05-16-2000
Page 1
Coefficients of Curve 4

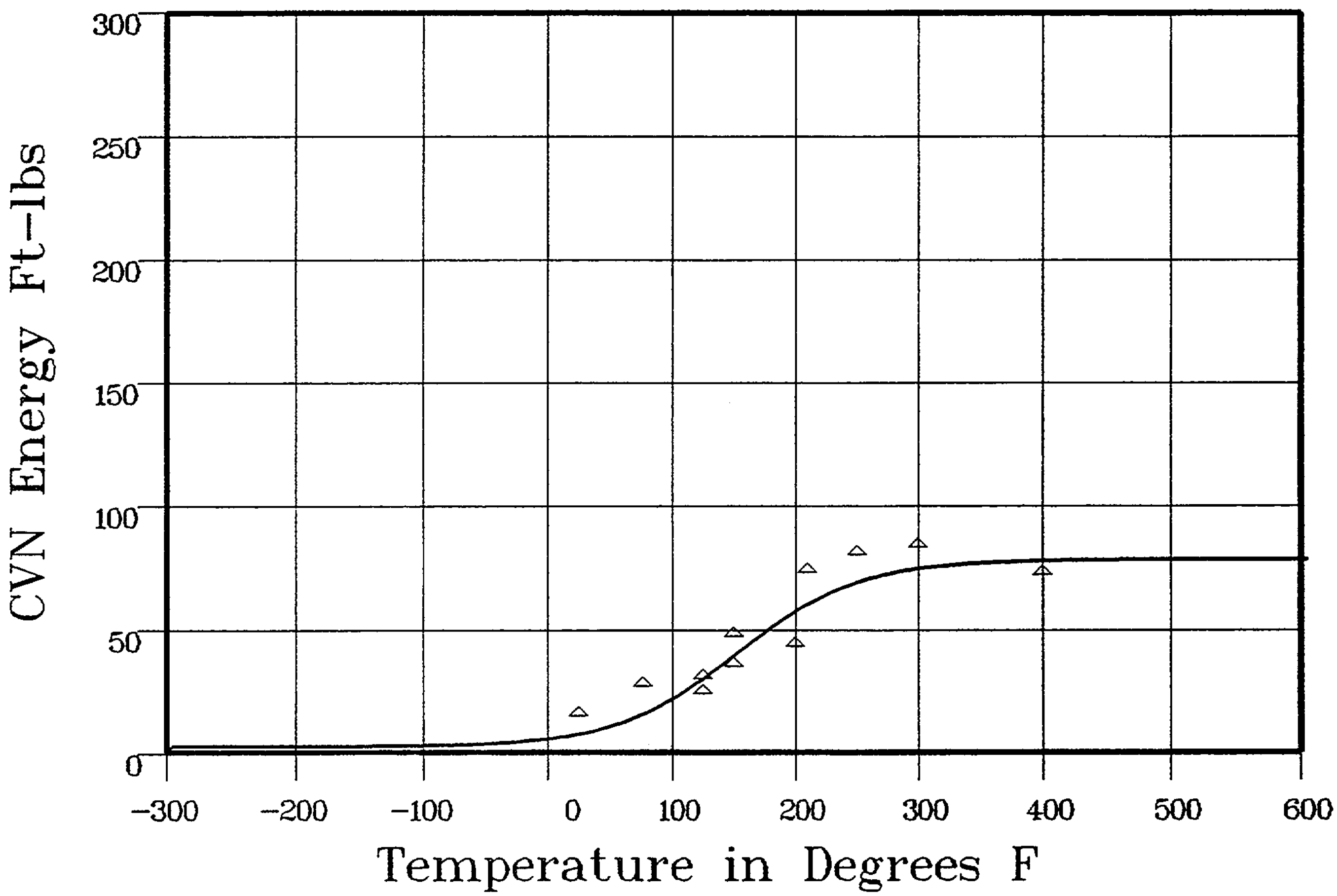
A = 40.09	B = 37.9	C = 99.08	T0 = 147.07

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

Upper Shelf Energy: 78 Fixed Temp. at 30 ft-lbs: 120 Temp. at 50 ft-lbs: 173.5 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 305424 Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted
Plant: BV1 Cap.: W Material: WELD Ori.: Heat #: 305424

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
25	15	8.14	6.85
76	27	16.78	10.21
125	30	31.79	-1.79
125	24	31.79	-7.79
150	35	41.22	-6.22
150	47	41.22	5.77
200	43	58.61	-15.61

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

CAPSULE W (WELD)

Page 2

Material: WELD   Heat Number: 305424   Orientation:

Capsule: W   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
210	73	61.38	11.61
250	80	69.56	10.43
300	83	74.69	8.3
400	72	77.54	-5.54

SUM of RESIDUALS = 16.24

CAPSULE Y (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:28:58 on 05-16-2000

Page 1

Coefficients of Curve 5

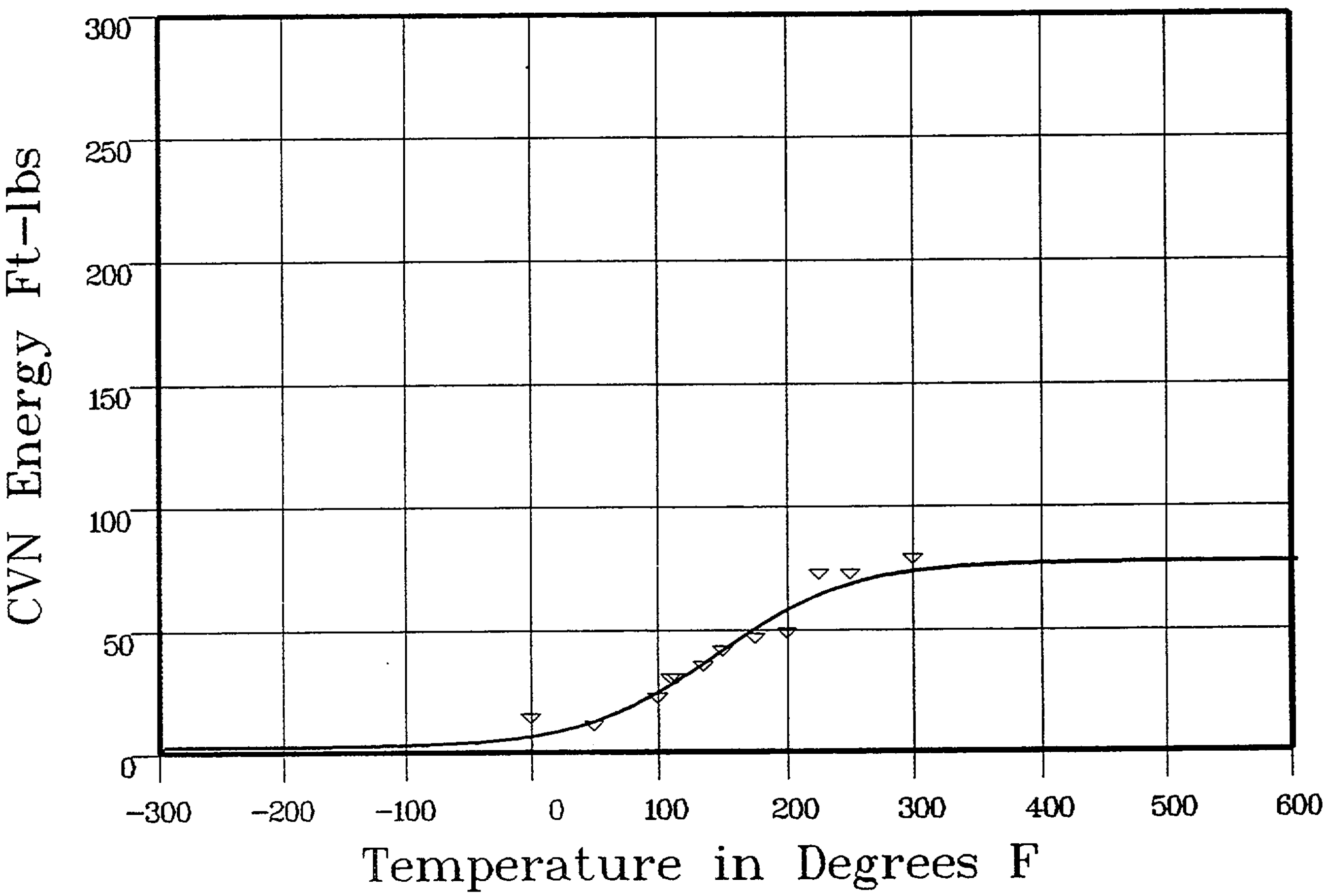
A = 39.59	B = 37.4	C = 104.69	T0 = 139.45

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

Upper Shelf Energy: 77 Fixed Temp. at 30 ft-lbs: 111.9 Temp. at 50 ft-lbs: 169.3 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 305424 Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	16	7.07	8.92
50	13	13.66	-.66
100	24	26.13	-2.13
110	32	29.34	2.65
115	32	31.02	.97
135	37	38.01	-1.01

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

CAPSULE Y (WELD)

Page 2

Material: WELD Heat Number: 305424 Orientation:

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
150	43	43.35	-.35
175	48	51.83	-3.83
200	50	59.1	-9.1
225	74	64.78	9.21
250	74	68.92	5.07
300	80	73.67	6.32

SUM of RESIDUALS = 16.07

UNIRRADIATED (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:38:21 on 05-16-2000

Page 1

Coefficients of Curve 1

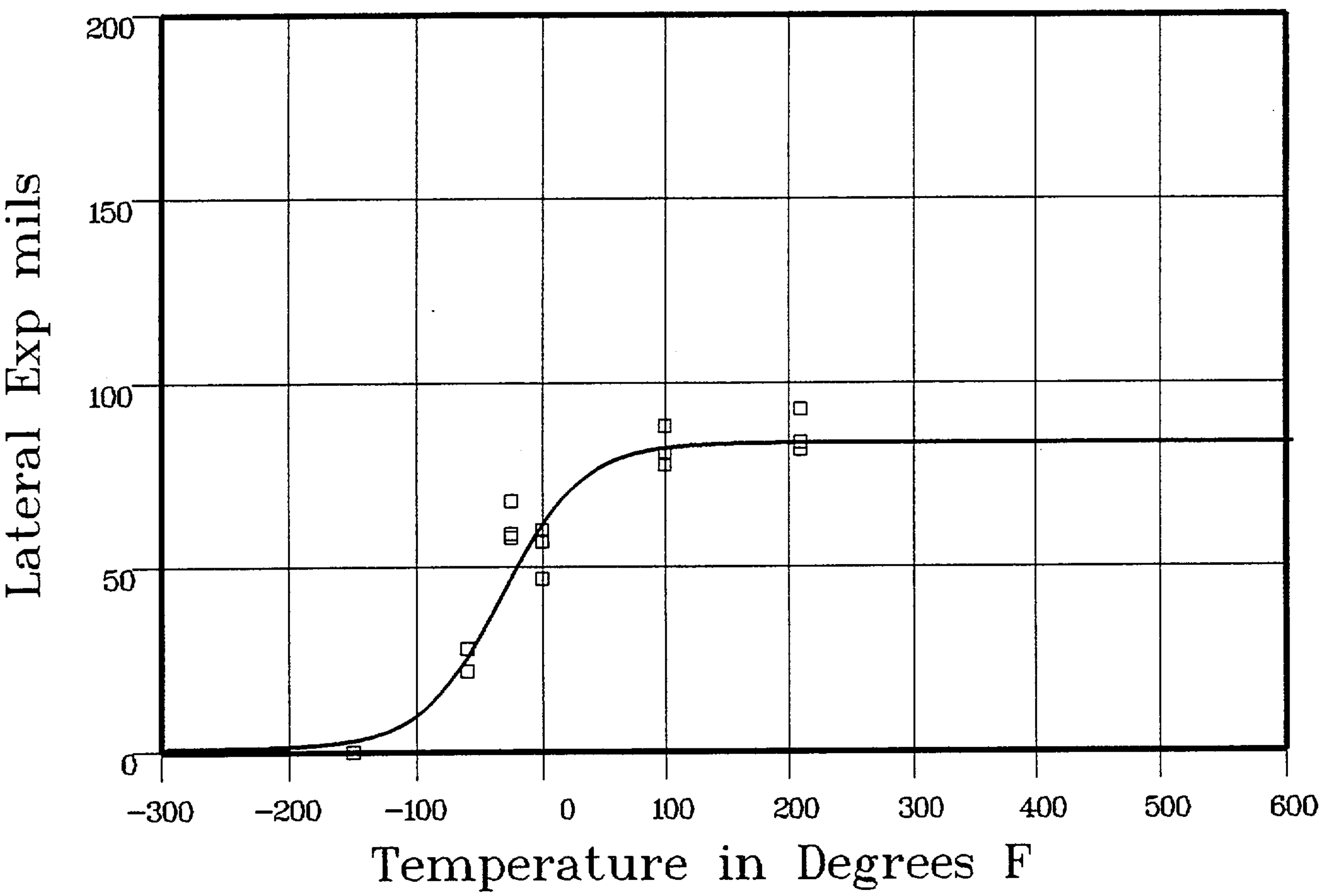
A = 42.44	B = 41.44	C = 64.67	T0 = -37.03

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

Upper Shelf L.E.: 83.89 Temperature at L.E. 35: -48.7 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 305424 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-150	0	3.44	-3.44
-150	0	3.44	-3.44
-60	22	28.31	-6.31
-60	22	28.31	-6.31
-60	28	28.31	-.31
-25	58	50.06	7.93
-25	59	50.06	8.93
-25	68	50.06	17.93
0	57	63.88	-6.88

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

UNIRRADIATED (WELD)

Page 2

Material: WELD Heat Number: 305424 Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	60	63.88	-3.88
0	47	63.88	-16.88
100	88.5	82.71	5.78
100	81	82.71	-1.71
100	78	82.71	-4.71
210	82	83.85	-1.85
210	93	83.85	9.14
210	84	83.85	.14

SUM of RESIDUALS = -5.89

CAPSULE V (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:38:21 on 05-16-2000

Page 1

Coefficients of Curve 2

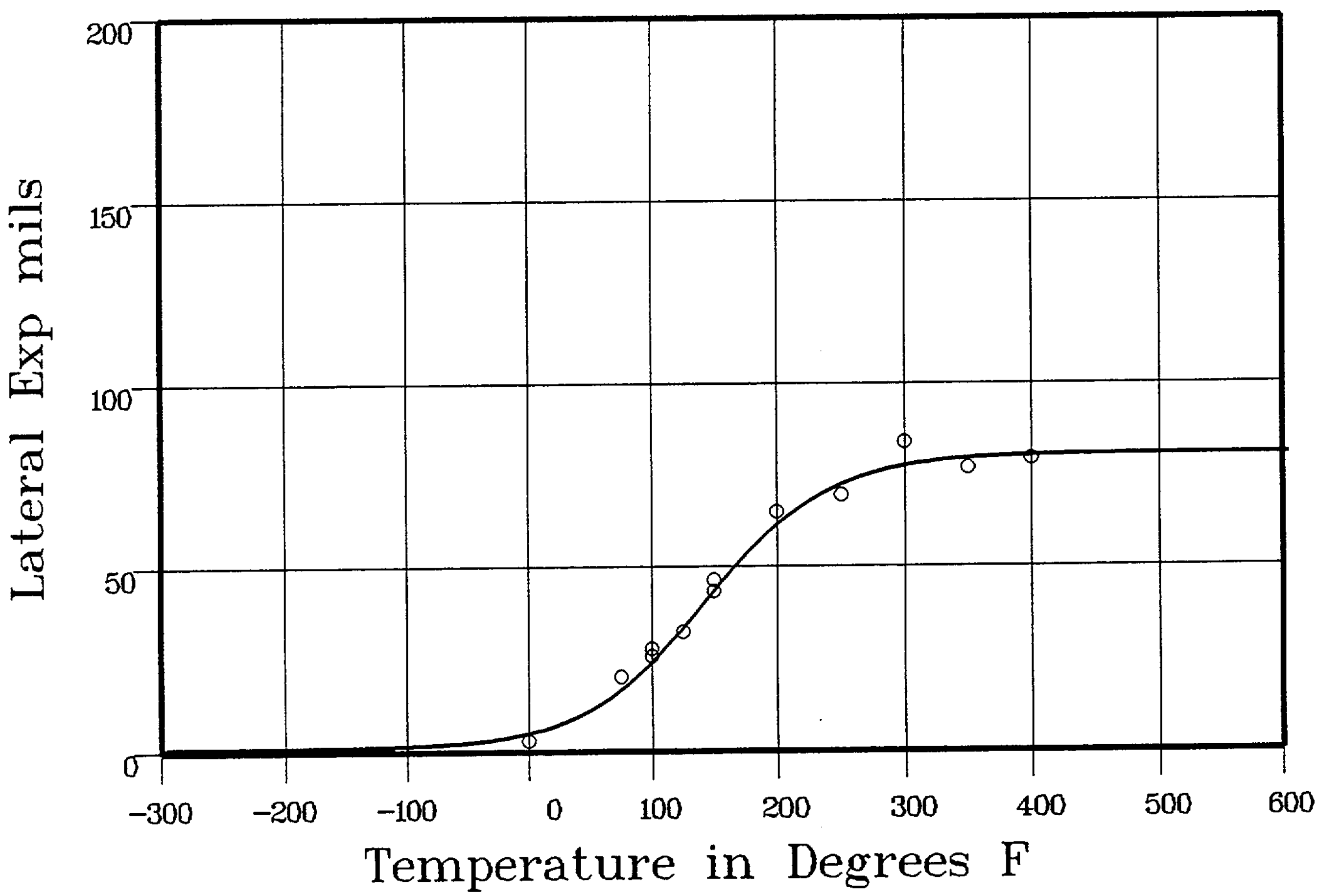
A = 40.85	B = 39.85	C = 98.58	T0 = 138.86

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

Upper Shelf L.E.: 80.7 Temperature at L.E. 35: 124.2 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 305424 Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	3	5.49	-2.49
75	20.5	18.12	2.37
100	28	25.9	2.09
100	26	25.9	.09
125	32.5	35.28	-2.78
150	46.5	45.33	1.16
150	43.5	45.33	-1.83
200	65	62.82	2.17

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

CAPSULE V (WELD)

Page 2

Material: WELD   Heat Number: 305424   Orientation:

Capsule: V   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
250	69.5	73.14	-3.64
300	84	77.78	6.21
350	77	79.62	-2.62
400	79.5	80.31	-.81

SUM of RESIDUALS = -.08

CAPSULE U (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:38:21 on 05-16-2000

Page 1

Coefficients of Curve 3

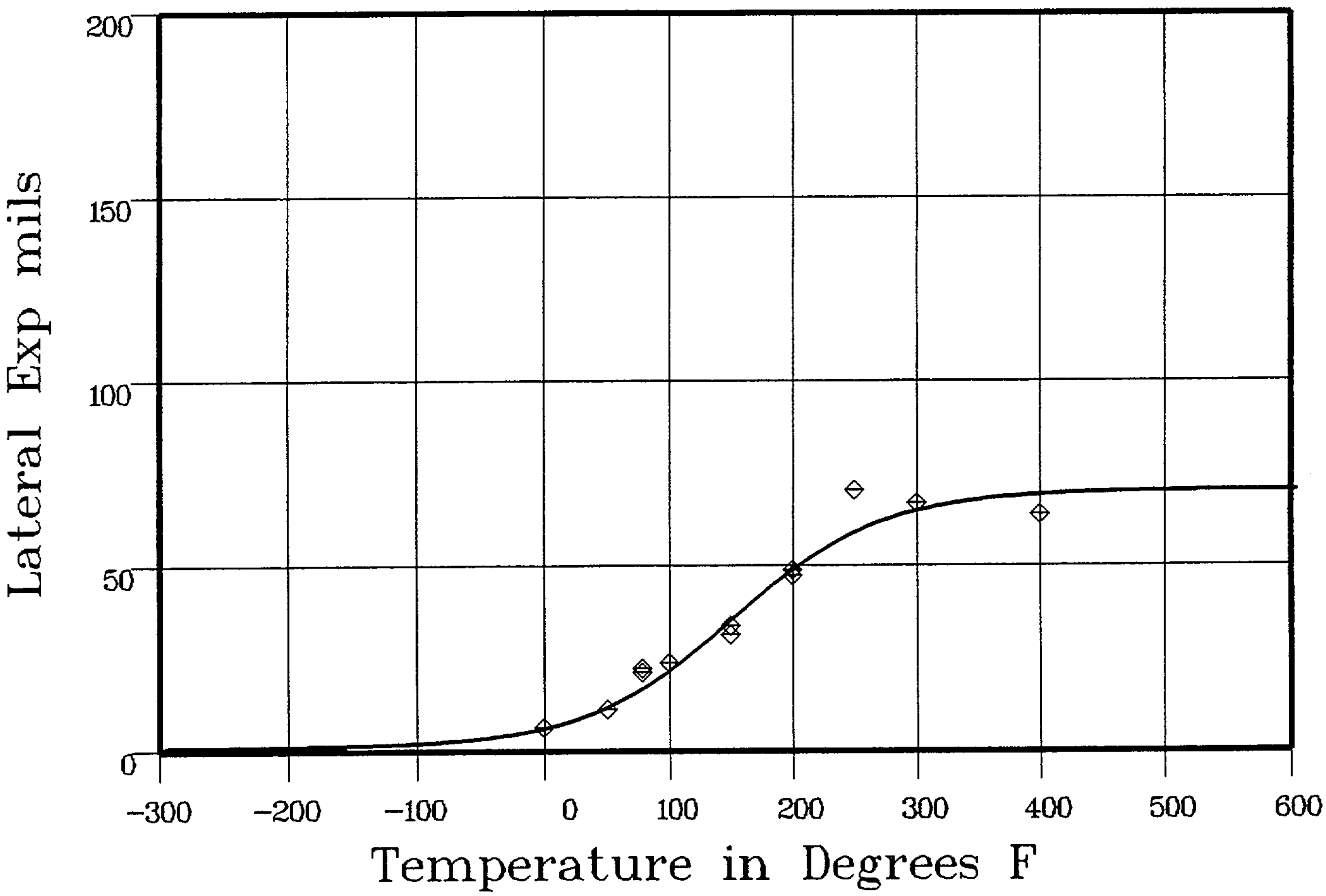
A = 35.72	B = 34.72	C = 121.16	T0 = 146.25

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

Upper Shelf L.E.: 70.44   Temperature at L.E. 35: 143.7   Lower Shelf L.E.: 1 Fixed

Material: WELD   Heat Number: 305424   Orientation:

Capsule: U   Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	6.5	6.7	-.2
50	11.5	12.77	-1.27
78	22.5	17.99	4.5
78	21.5	17.99	3.5
100	24	23.07	.92
150	31.5	36.79	-5.29
150	34	36.79	-2.79
200	49	50.18	-1.18

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

CAPSULE U (WELD)

Material: WELD Heat Number: 305424 Orientation:

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
200	47.5	50.18	-2.68
250	70.5	59.83	10.66
300	67	65.35	1.64
400	64	69.4	-5.4

SUM of RESIDUALS = 2.38

CAPSULE W (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:38:21 on 05-16-2000

Page 1

Coefficients of Curve 4

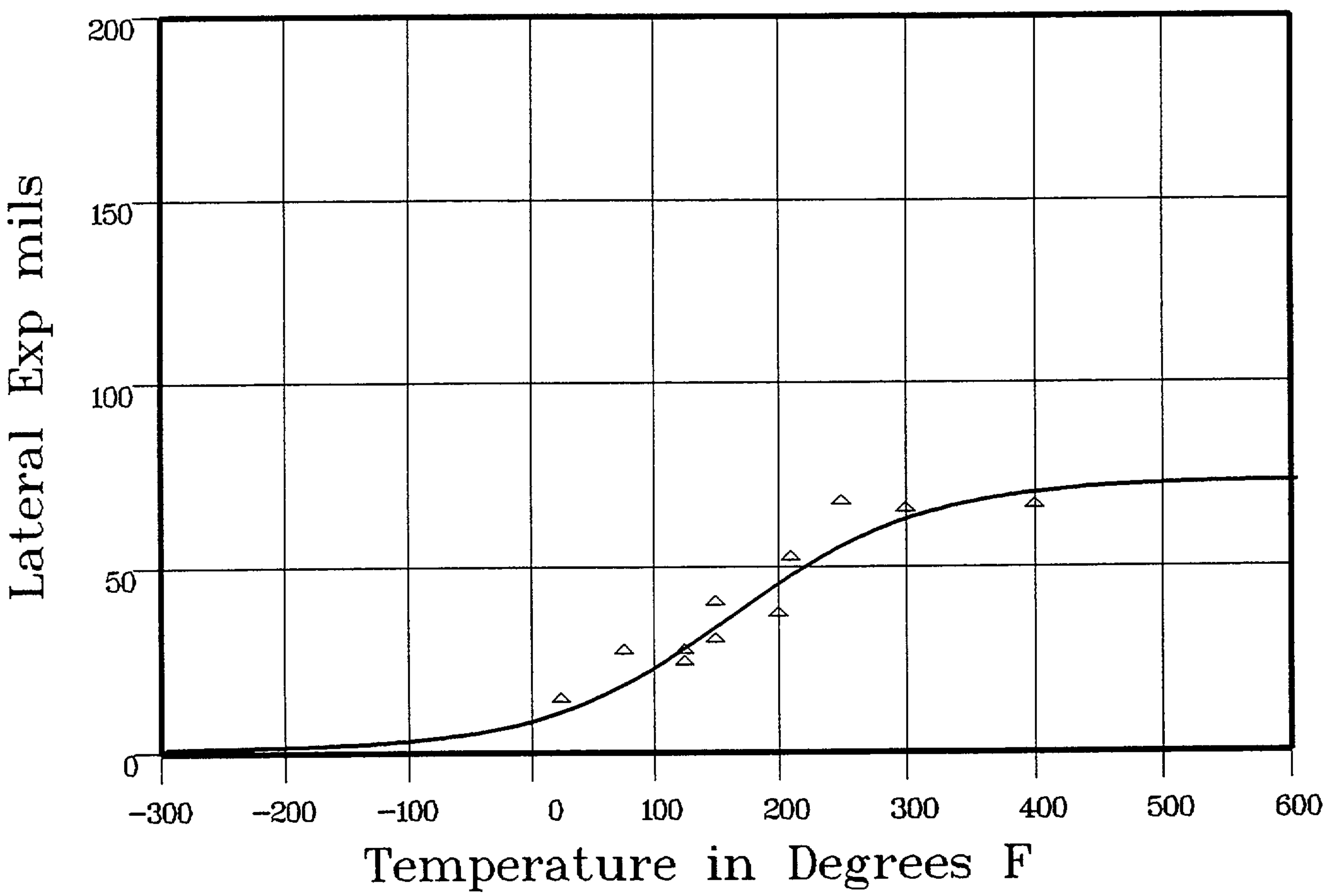
A = 37.19	B = 36.19	C = 153.04	T0 = 158.49

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

Upper Shelf L.E.: 73.38 Temperature at L.E. 35: 149.2 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 305424 Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
25	14	11.76	2.23
76	27	19.37	7.62
125	27	29.39	-2.39
125	24	29.39	-5.39
150	30	35.18	-5.18
150	40	35.18	4.81
200	37	46.77	-9.77

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

CAPSULE W (WELD)

Page 2

Material: WELD   Heat Number: 305424   Orientation:

Capsule: W   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
210	52	48.93	3.06
250	67	56.57	10.42
300	65	63.54	1.45
400	66	70.43	-4.43

SUM of RESIDUALS = 2.41

CAPSULE Y (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:38:21 on 05-16-2000

Page 1

Coefficients of Curve 5

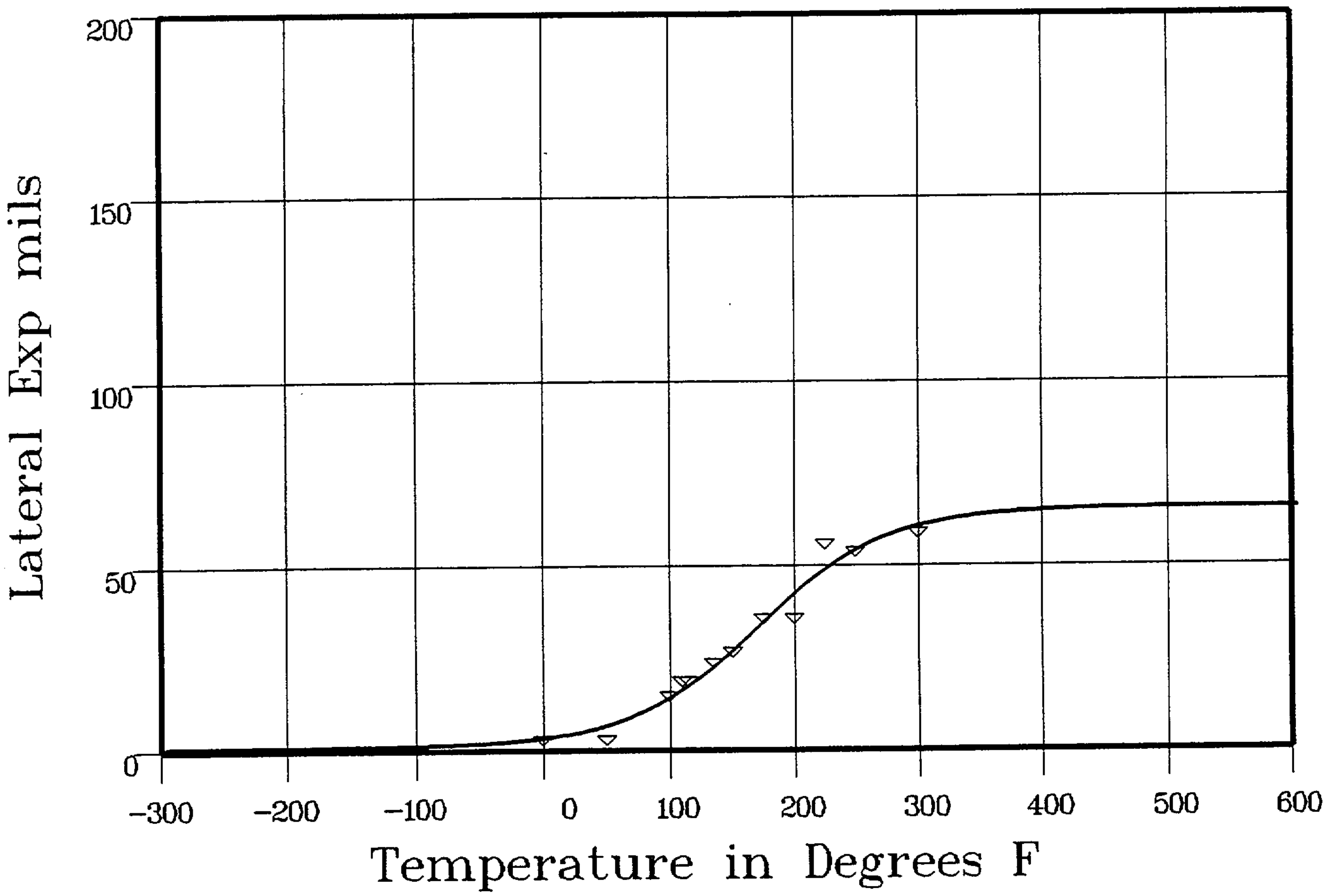
A = 33.36	B = 32.36	C = 104.04	T0 = 164.53

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

Upper Shelf L.E.: 65.72 Temperature at L.E. 35: 169.8 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 305424 Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	4	3.62	.37
50	4	7.44	-3.44
100	16	15.52	.47
110	20	17.8	2.19
115	20	19.02	.97
135	25	24.41	.58

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

CAPSULE Y (WELD)

Page 2

Material: WELD Heat Number: 305424 Orientation:

Capsule: Y Total Fluence:

Charpy V–Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
150	28	28.87	-.87
175	37	36.6	.39
200	37	43.98	-6.98
225	57	50.3	6.69
250	55	55.23	-.23
300	60	61.26	-1.26

SUM of RESIDUALS = -1.1

UNIRRADIATED (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:41:45 on 05-16-2000

Page 1

Coefficients of Curve 1

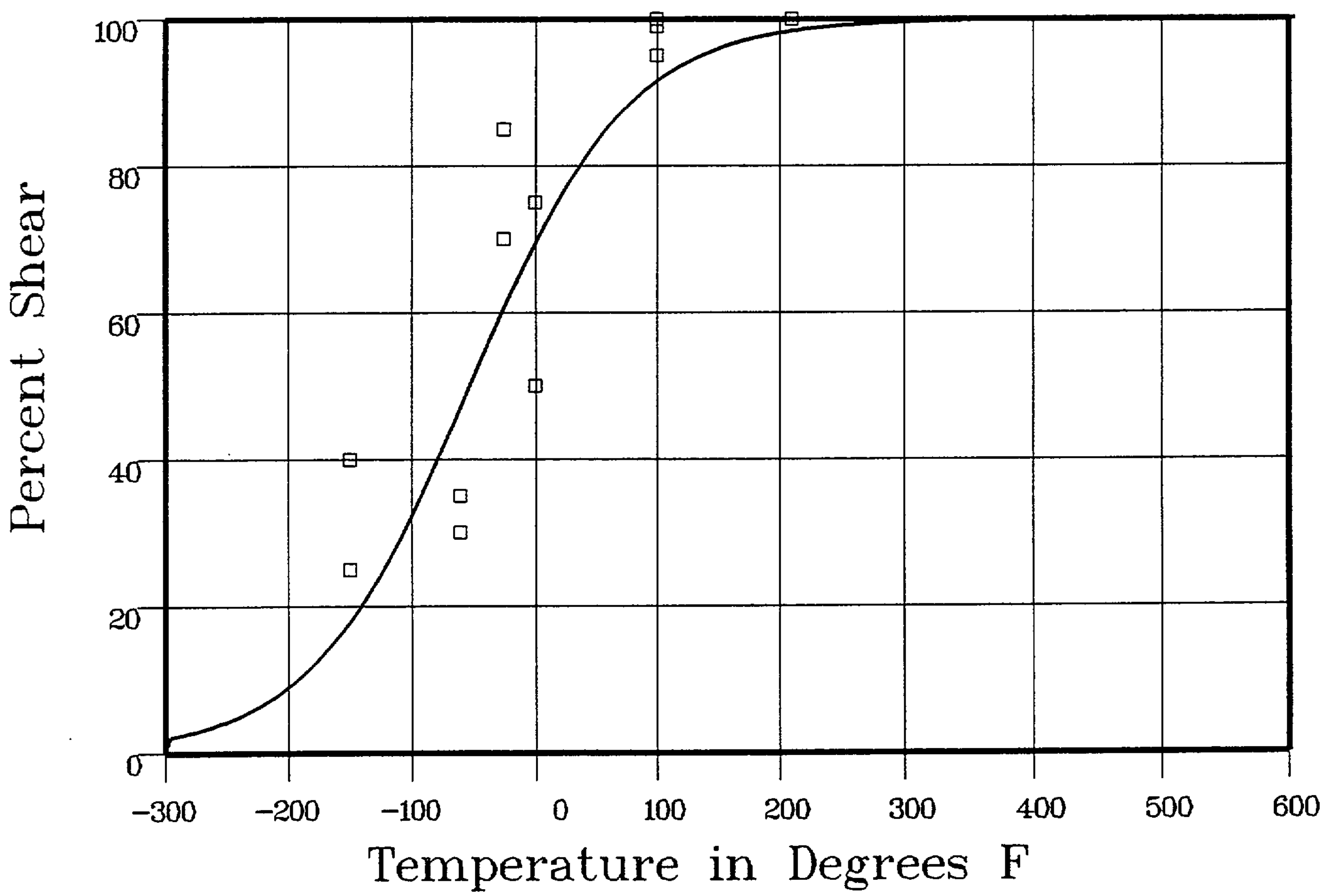
A = 50	B = 50	C = 127.74	T0 = -57.2

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

Temperature at 50% Shear: -57.2

Material: WELD Heat Number: 305424 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-150	25	18.95	6.04
-150	40	18.95	21.04
-60	35	48.9	-13.9
-60	30	48.9	-18.9
-60	35	48.9	-13.9
-25	70	62.34	7.65
-25	70	62.34	7.65
-25	85	62.34	22.65
0	75	71	3.99

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

UNIRRADIATED (WELD)

Page 2

Material: WELD   Heat Number: 305424   Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	75	71	3.99
0	50	71	-21
100	100	92.13	7.86
100	99	92.13	6.86
100	95	92.13	2.86
210	100	98.49	1.5
210	100	98.49	1.5
210	100	98.49	1.5

SUM of RESIDUALS = 27.4

CAPSULE V (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:41:45 on 05-16-2000

Page 1

Coefficients of Curve 2

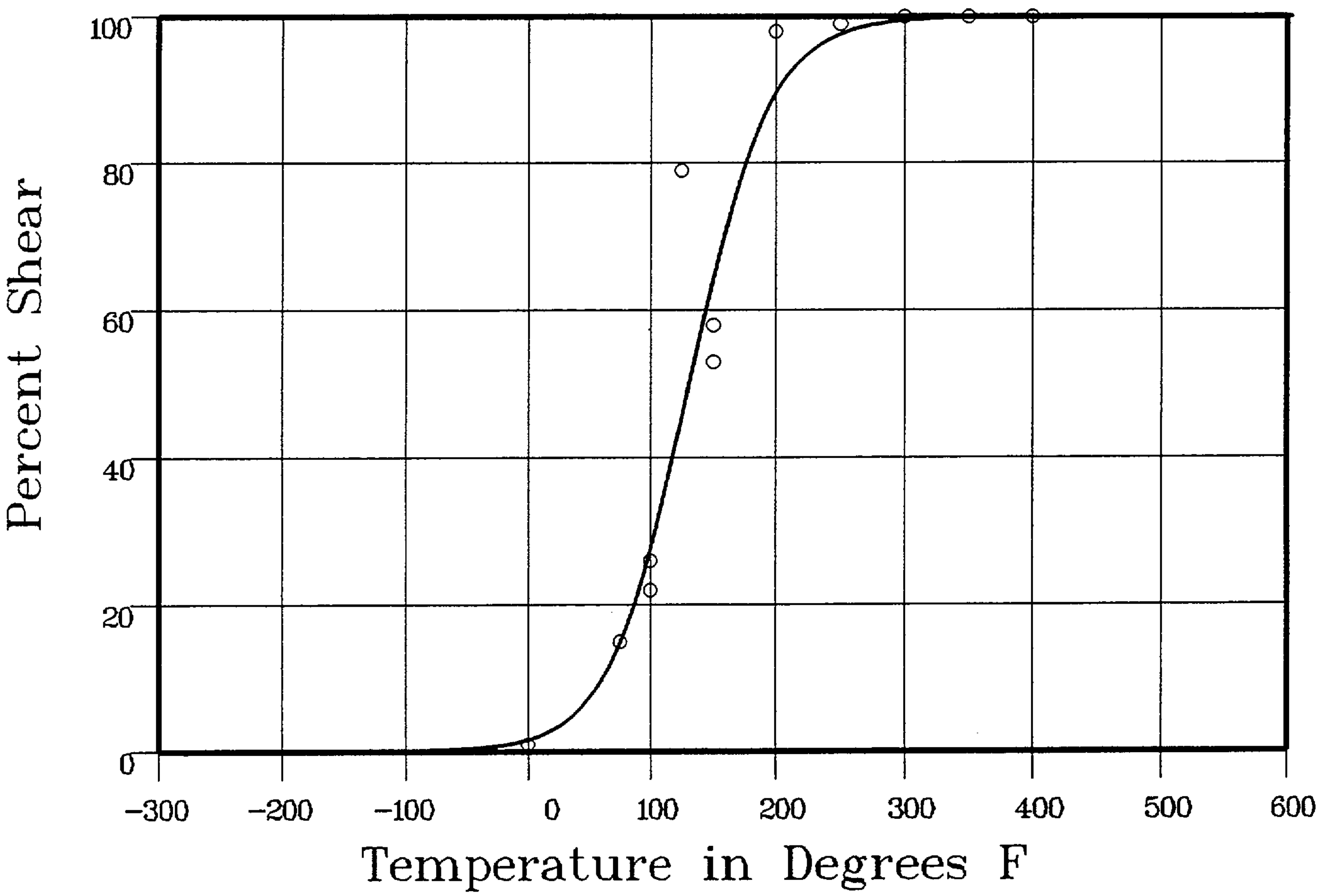
A = 50	B = 50	C = 64.21	T0 = 126.56

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

Temperature at 50% Shear: 126.5

Material: WELD Heat Number: 305424 Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	1	1.9	-.9
75	15	16.71	-1.71
100	22	30.42	-8.42
100	26	30.42	-4.42
125	79	48.78	30.21
150	53	67.48	-14.48
150	58	67.48	-9.48
200	98	90.78	7.21

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

CAPSULE V (WELD)

Page 2

Material: WELD Heat Number: 305424 Orientation:

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
250	99	97.9	1.09
300	100	99.55	.44
350	100	99.9	.09
400	100	99.97	.02

SUM of RESIDUALS = -.32

CAPSULE U (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:41:45 on 05-16-2000

Page 1

Coefficients of Curve 3

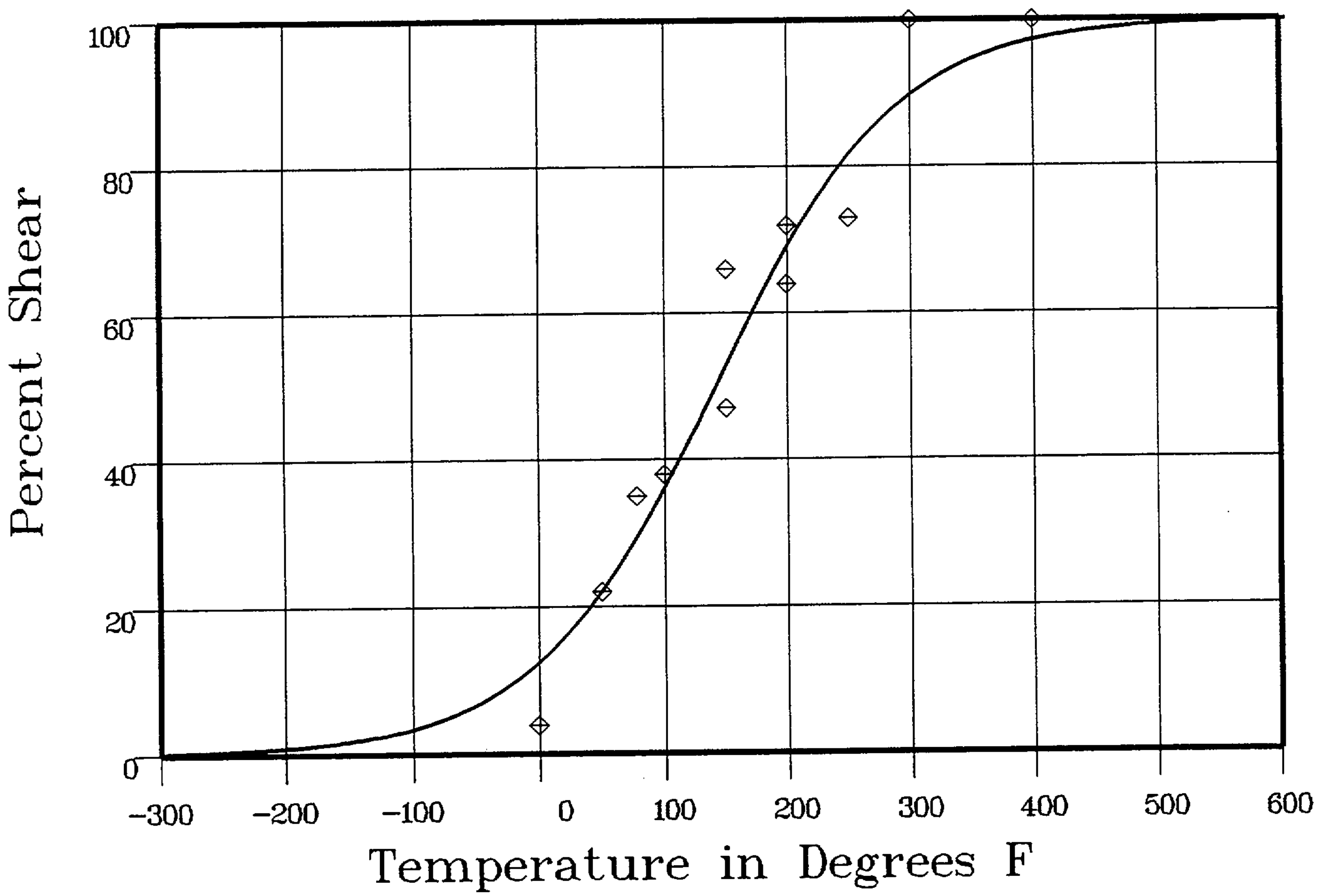
A = 50	B = 50	C = 145.42	T0 = 136.81

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

Temperature at 50% Shear: 136.8

Material: WELD Heat Number: 305424 Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	4	13.22	-9.22
50	22	23.25	-1.25
78	35	30.81	4.18
78	35	30.81	4.18
100	38	37.6	.39
150	47	54.52	-7.52
150	66	54.52	11.47
200	64	70.45	-6.45

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

CAPSULE U (WELD)

Page 2

Material: WELD   Heat Number: 305424   Orientation:

Capsule: U   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
200	72	70.45	1.54
250	73	82.58	-9.58
300	100	90.41	9.58
400	100	97.39	2.6

SUM of RESIDUALS = -.04

CAPSULE W (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:41:45 on 05-16-2000
Page 1
Coefficients of Curve 4

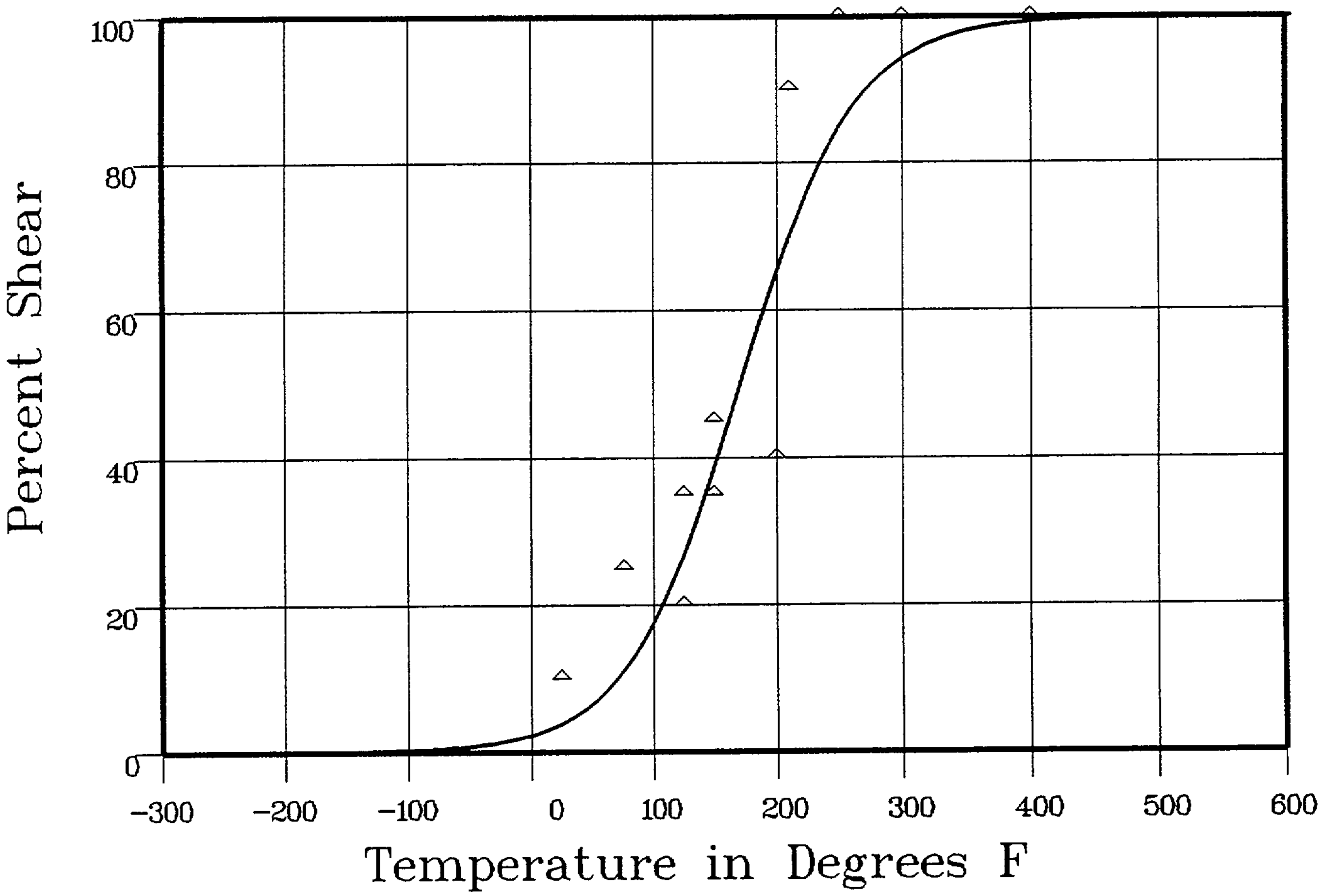
A = 50	B = 50	C = 91.53	T0 = 166.4

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

Temperature at 50% Shear: 166.4

Material: WELD Heat Number: 305424 Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted
Plant: BV1 Cap.: W Material: WELD Ori.: Heat #: 305424

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25	10	4.35	5.64
76	25	12.18	12.81
125	35	28.8	6.19
125	20	28.8	-8.8
150	35	41.13	-6.13
150	45	41.13	3.86
200	40	67.56	-27.56

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

CAPSULE W (WELD)

Page 2

Material: WELD Heat Number: 305424 Orientation:

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
210	90	72.16	17.83
250	100	86.13	13.86
300	100	94.87	5.12
400	100	99.39	.6

SUM of RESIDUALS = 23.44

CAPSULE Y (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:41:45 on 05-16-2000

Page 1

Coefficients of Curve 5

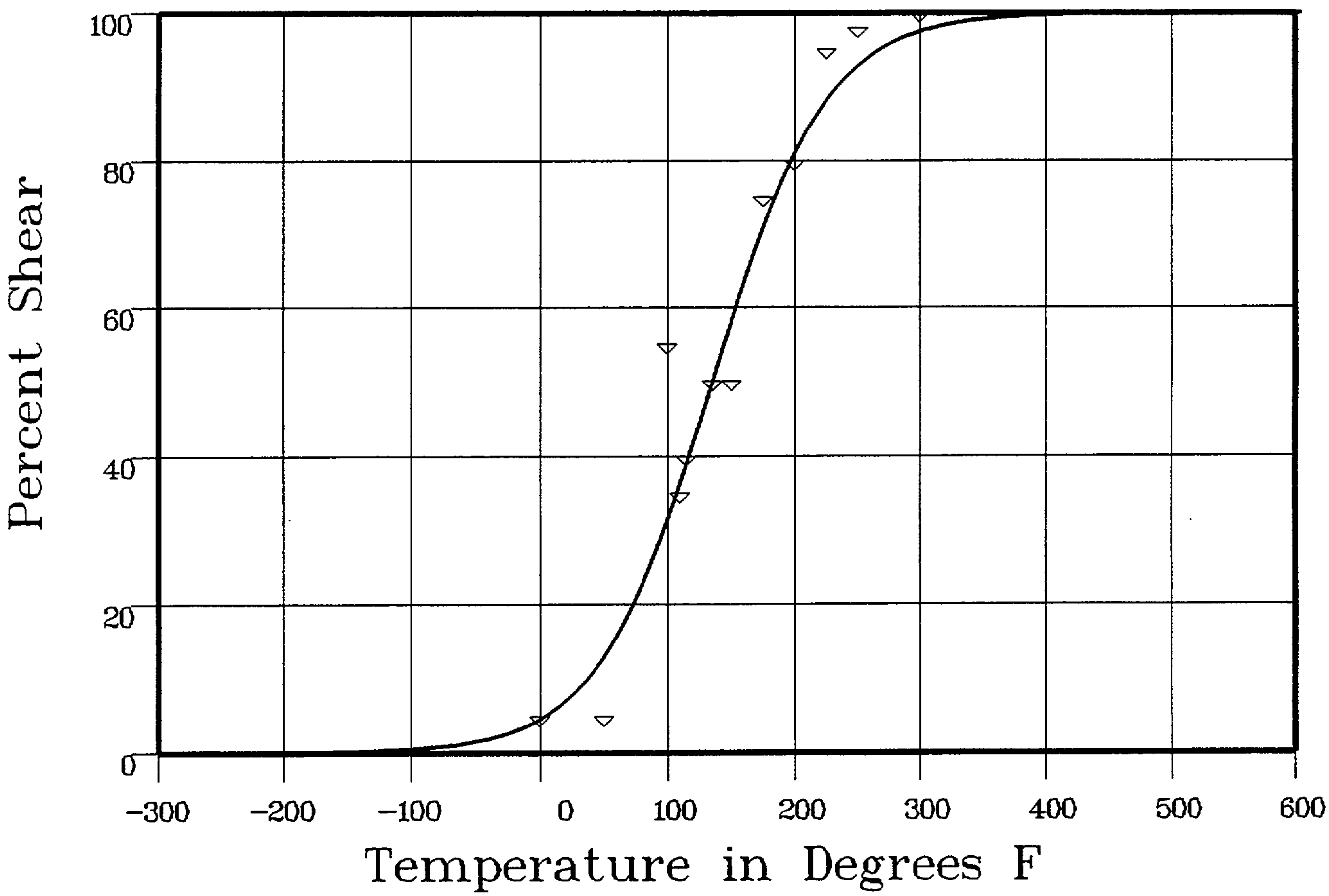
A = 50	B = 50	C = 89.54	T0 = 130.37

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

Temperature at 50% Shear: 130.3

Material: WELD Heat Number: 305424 Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

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

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	5	5.15	-.15
50	5	14.24	-9.24
100	55	33.66	21.33
110	35	38.81	-3.81
115	40	41.5	-1.5
135	50	52.58	-2.58

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

CAPSULE Y (WELD)

Page 2

Material: WELD   Heat Number: 305424   Orientation:

Capsule: Y   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
150	50	60.78	-10.78
175	75	73.04	1.95
200	80	82.56	-2.56
225	95	89.22	5.77
250	98	93.53	4.46
300	100	97.78	2.21

SUM of RESIDUALS = 5.09

UNIRRADIATED (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:05:43 on 05-16-2000

Page 1

Coefficients of Curve 1

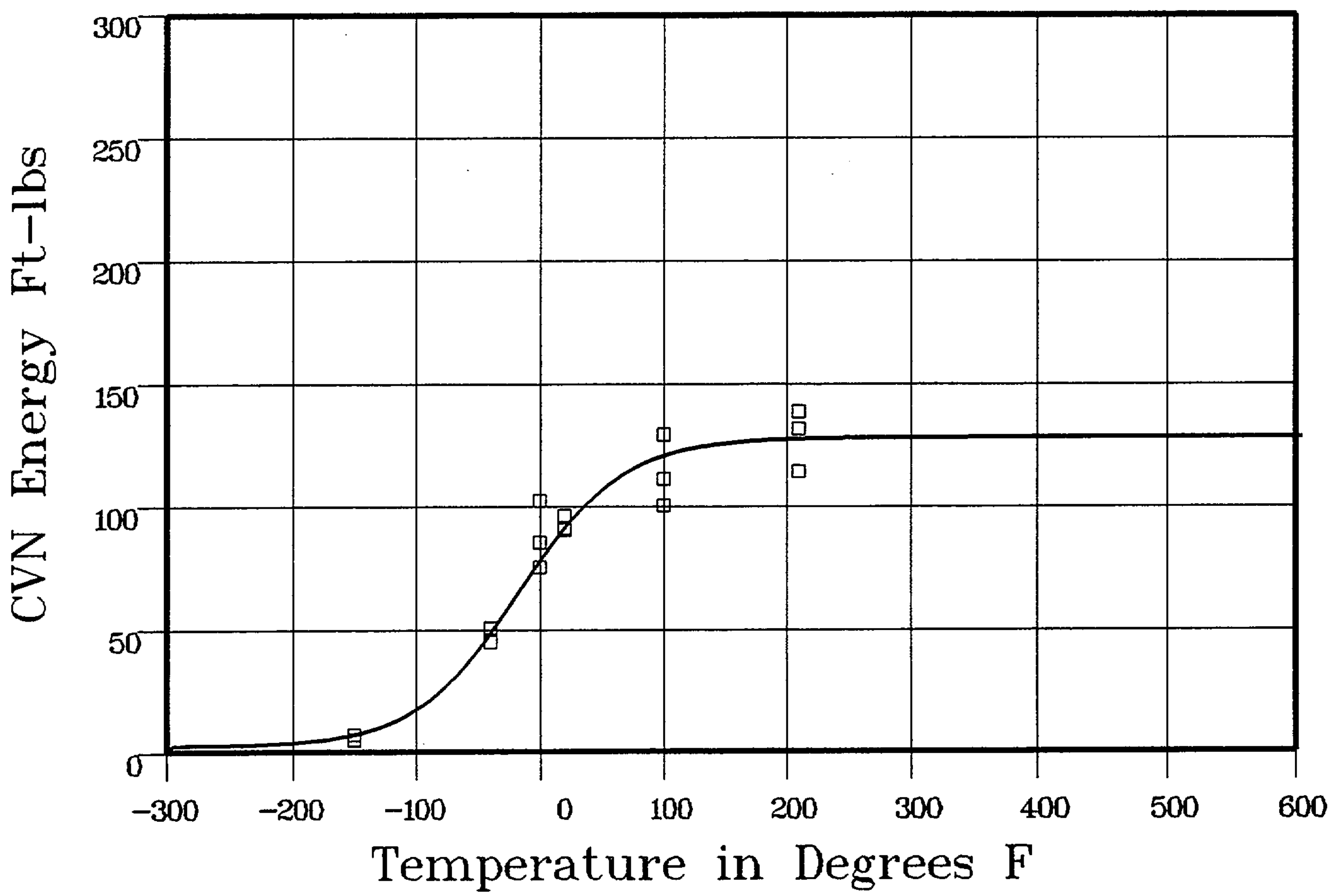
A = 65.09	B = 62.9	C = 84.09	T0 = -21.56

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

Upper Shelf Energy: 128 Fixed Temp. at 30 ft-lbs: -74.5 Temp. at 50 ft-lbs: -42.1 Lower Shelf Energy: 2.19 Fixed

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

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: BV1 Cap.: UNIRR Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-150	7	7.86	-.86
-150	4.5	7.86	-3.36
-150	5	7.86	-2.86
-40	44.5	51.52	-7.02
-40	50	51.52	-1.52
-40	50.5	51.52	-1.02
0	85	80.88	4.11
0	75	80.88	-5.88
0	102	80.88	21.11

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

UNIRRADIATED (HAZ)

Page 2

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
20	91	93.88	-2.88
20	90	93.88	-3.88
20	96	93.88	2.11
100	129	121.38	7.61
100	100	121.38	-21.38
100	111	121.38	-10.38
210	131.5	127.49	4
210	138.5	127.49	11
210	114	127.49	-13.49

SUM of RESIDUALS =-24.59

CAPSULE V (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:05:43 on 05-16-2000

Page 1

Coefficients of Curve 2

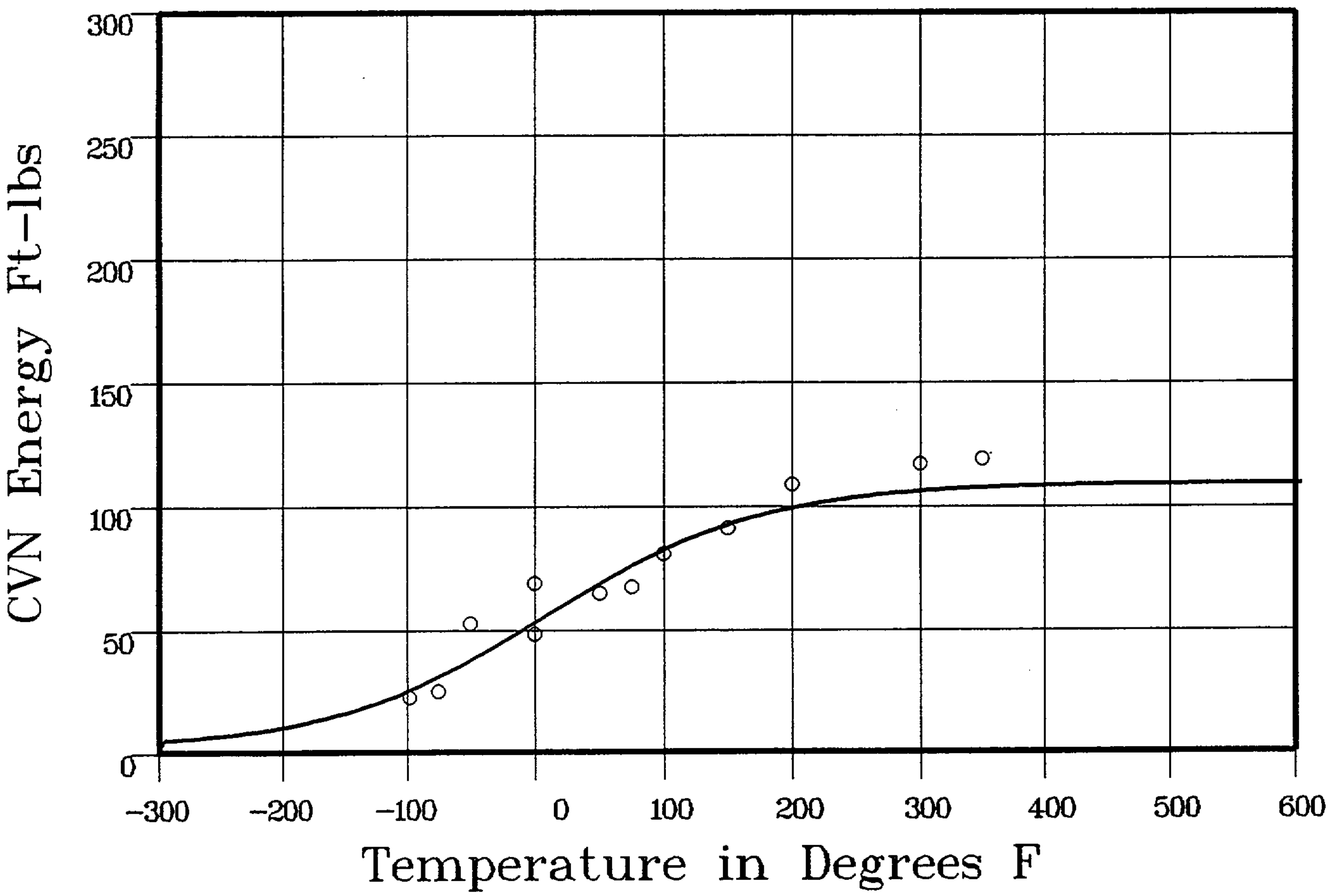
A = 55.59	B = 53.4	C = 167.33	T0 = 4.21

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

Upper Shelf Energy: 109 Fixed Temp. at 30 ft-lbs: -83.1 Temp. at 50 ft-lbs: -13.3 Lower Shelf Energy: 2.19 Fixed

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

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: BV1 Cap.: V Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-98	22.5	26.51	-4.01
-75	25	32.05	-7.05
-50	52.5	38.87	13.62
0	68.5	54.25	14.24
0	48	54.25	-6.25
50	64.5	69.85	-5.35
75	67	76.93	-9.93
100	80.5	83.21	-2.71

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

CAPSULE V (HAZ)

Page 2

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: V   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
150	91	93.08	-2.08
200	108.5	99.61	8.88
300	117	105.97	11.02
350	119	107.31	11.68

SUM of RESIDUALS = 22.05

CAPSULE U (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:05:43 on 05-16-2000

Page 1

Coefficients of Curve 3

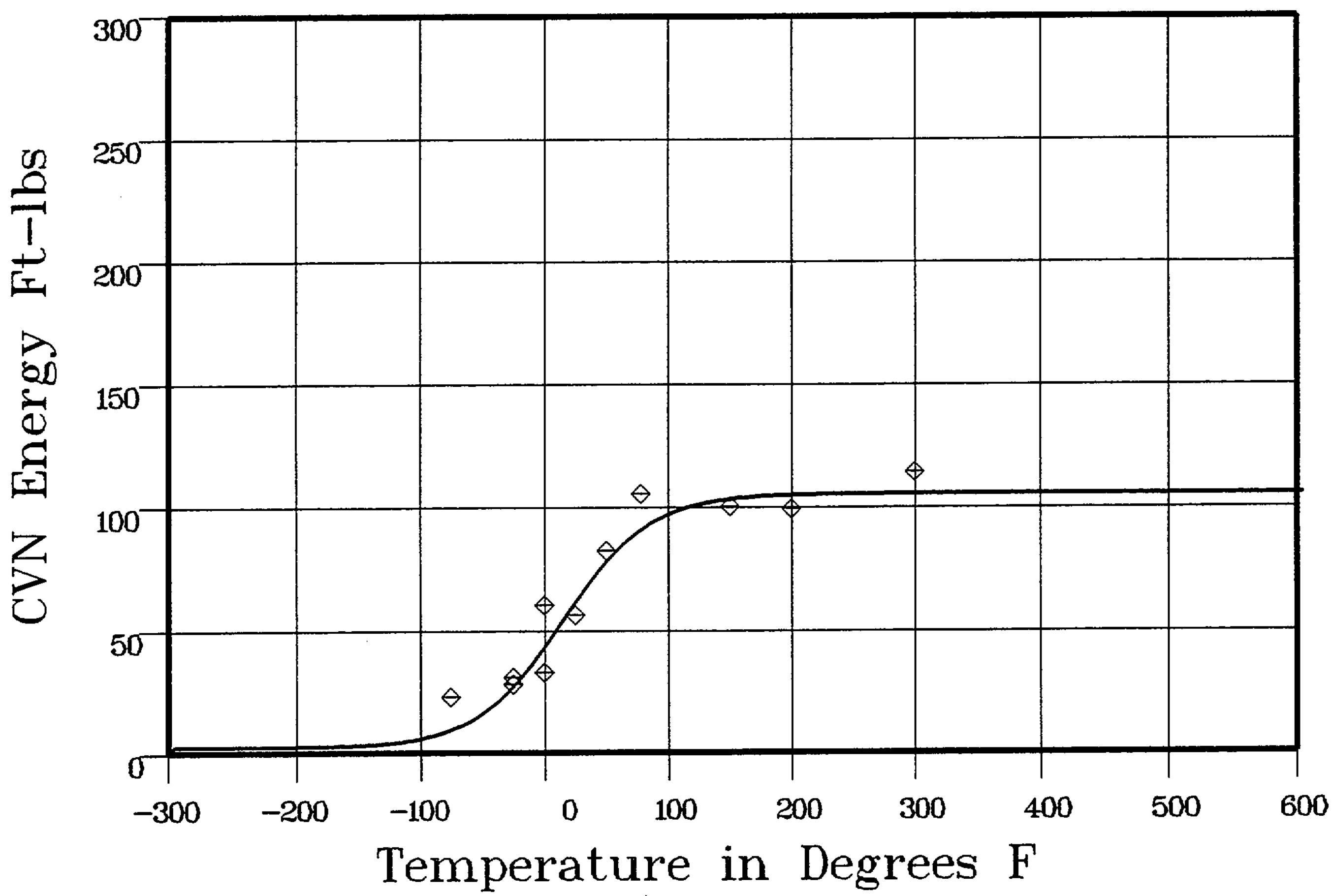
A = 53.59	B = 51.4	C = 69.94	T0 = 9.84

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

Upper Shelf Energy: 105 Fixed Temp. at 30 ft-lbs: -24.8 Temp. at 50 ft-lbs: 4.9 Lower Shelf Energy: 2.19 Fixed

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

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: BV1 Cap.: U Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-75	23	10.54	12.45
-25	28	29.92	-1.92
-25	31	29.92	1.07
-25	28	29.92	-1.92
0	33	46.41	-13.41
0	60	46.41	13.58
25	56	64.56	-8.56
50	82	80.24	1.75

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

CAPSULE U (HAZ)

Page 2

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: U   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
78	105	92.18	12.81
150	100	103.16	-3.16
200	99	104.55	-5.55
300	114	104.97	9.02

SUM of RESIDUALS = 16.17

CAPSULE W (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:05:43 on 05-16-2000

Page 1

Coefficients of Curve 4

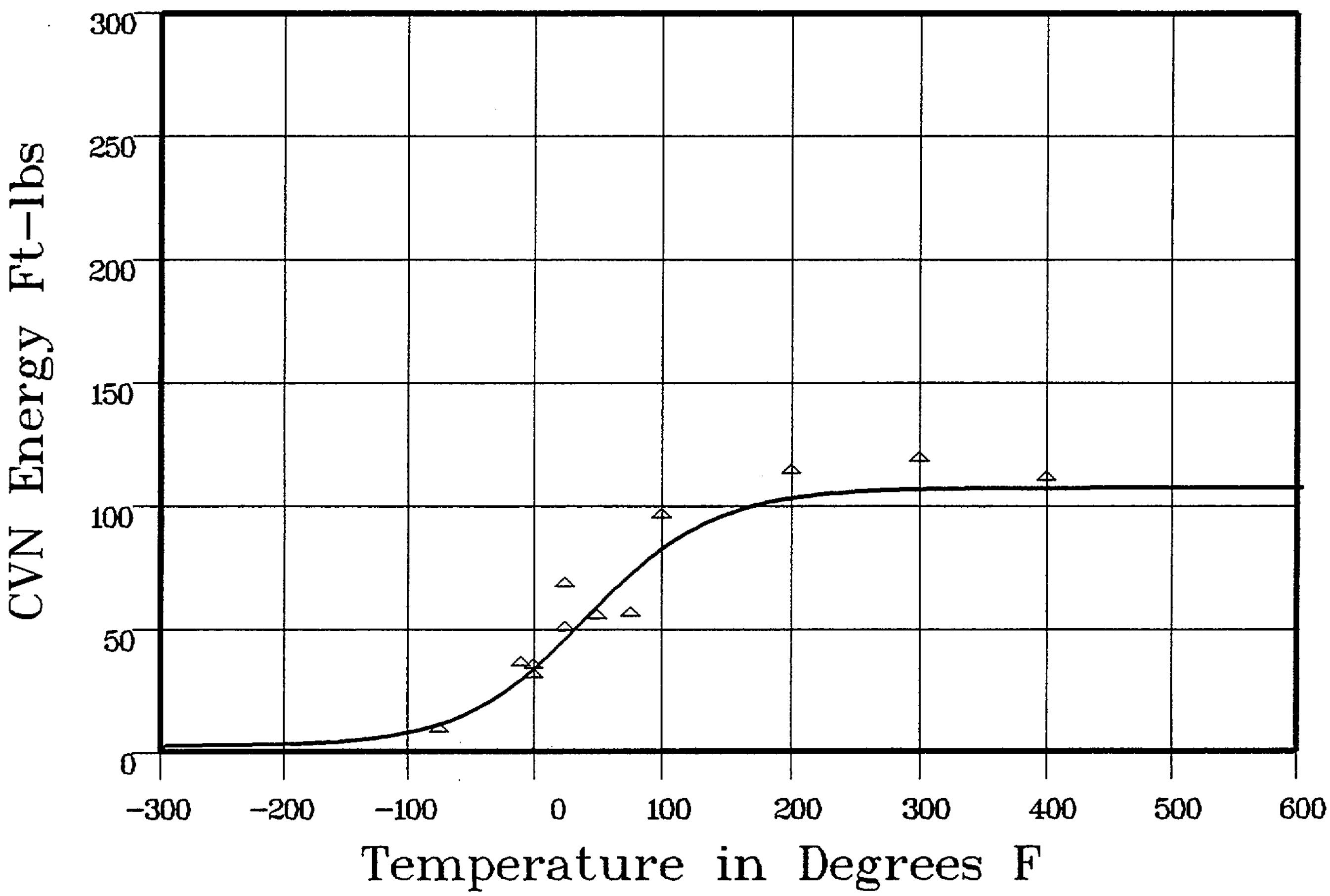
A = 54.59	B = 52.4	C = 98.82	T0 = 37.2

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

Upper Shelf Energy: 107 Fixed Temp. at 30 ft-lbs: -13.1 Temp. at 50 ft-lbs: 28.5 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: BV1 Cap.: W Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-75	8	12	-4
-10	35	31.31	3.68
0	30	35.75	-5.75
0	34	35.75	-1.75
25	67	48.16	18.83
25	49	48.16	.83
50	54	61.34	-7.34

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

CAPSULE W (HAZ)

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
76	55	74.17	-19.17
100	95	84.03	10.96
200	113	103.25	9.74
300	118	106.48	11.51
400	110	106.93	3.06

SUM of RESIDUALS = 20.62

CAPSULE Y (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:05:43 on 05-16-2000

Page 1

Coefficients of Curve 5

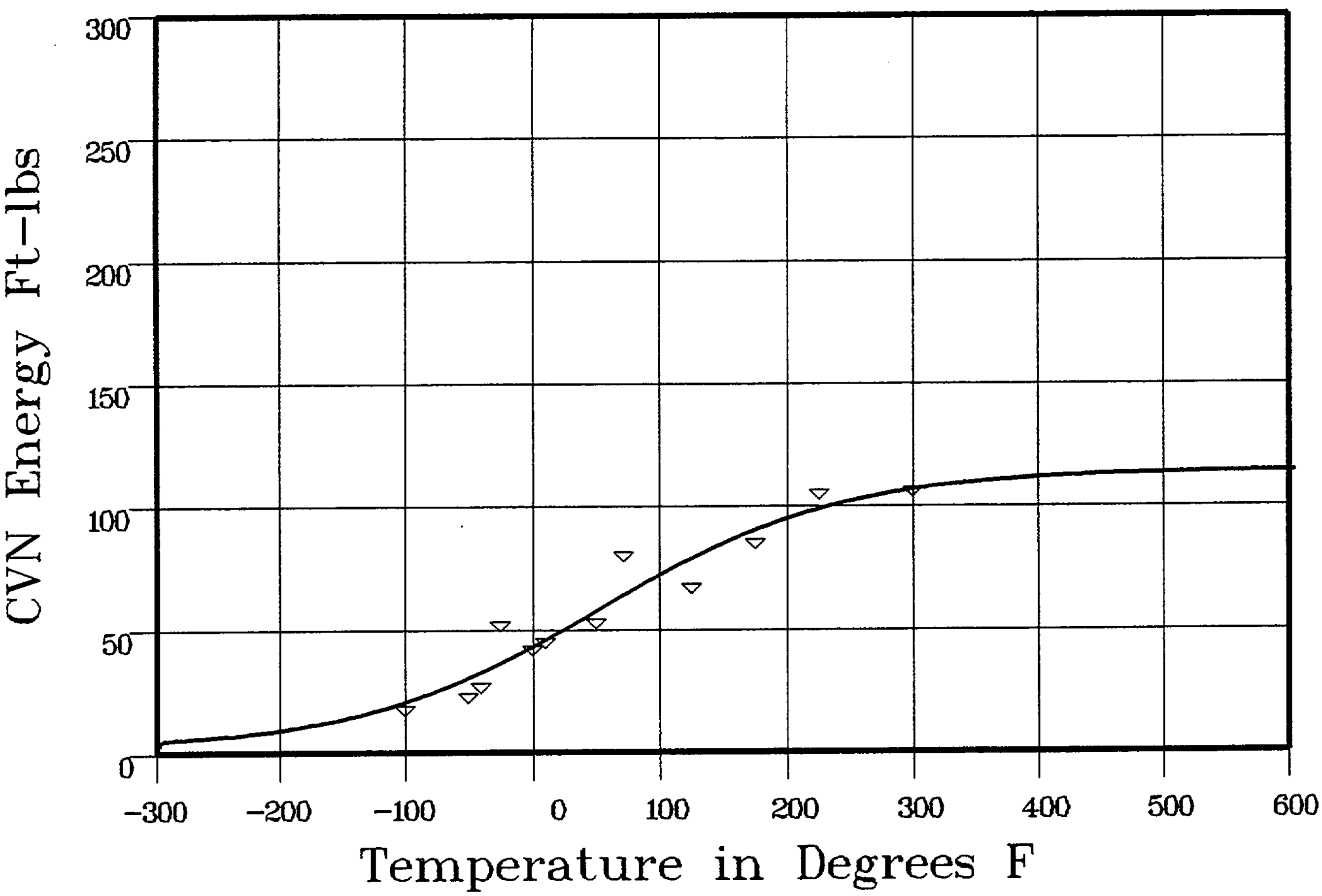
A = 58.09	B = 55.9	C = 188.07	T0 = 47.81

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

Upper Shelf Energy: 114 Fixed Temp. at 30 ft-lbs: -56.1 Temp. at 50 ft-lbs: 20.3 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: BV1 Cap.: Y Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	19	21.42	-2.42
-50	24	31.39	-7.39
-40	28	33.74	-5.74
-25	53	37.47	15.52
0	43	44.18	-1.18
10	46	47.01	-1.01

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

CAPSULE Y (HAZ)

Page 2

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: Y   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	54	58.75	-4.75
72	81	65.24	15.75
125	68	79.83	-11.83
175	86	91.03	-5.03
225	106	99.25	6.74
300	107	106.83	.16

SUM of RESIDUALS = -1.19

UNIRRADIATED (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:44:18 on 07-07-2000

Page 1

Coefficients of Curve 2

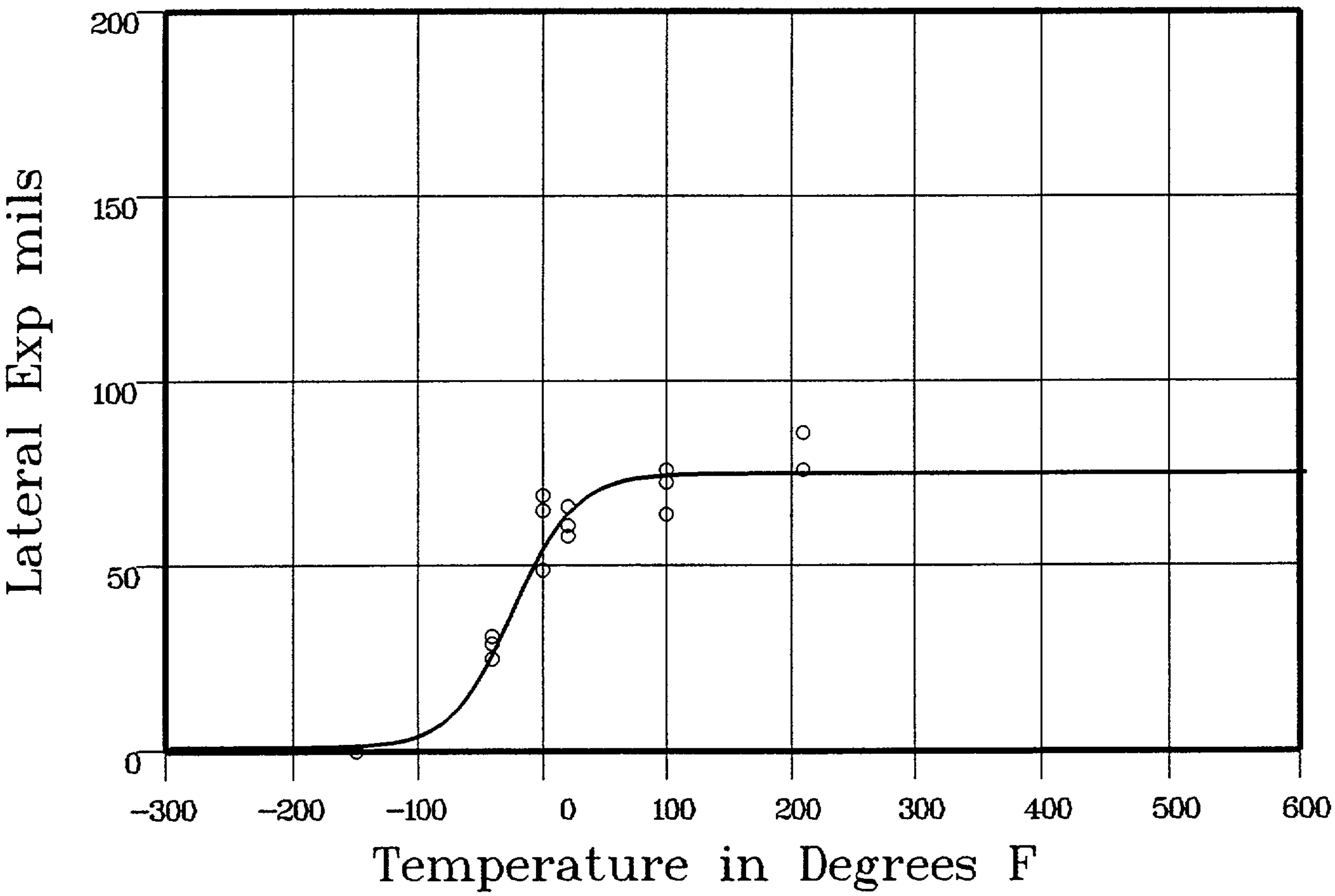
A = 37.94	B = 36.94	C = 49.19	T0 = -28.12

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

Upper Shelf L.E.: 74.88 Temperature at L.E. 35: -32 Lower Shelf L.E.: 1 Fixed

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

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: BV1 Cap.: UNIRR Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-150	0	1.51	-1.51
-150	0	1.51	-1.51
-150	0	1.51	-1.51
-40	25	29.19	-4.19
-40	29	29.19	-.19
-40	31	29.19	1.8
0	69	57.02	11.97
0	49	57.02	-8.02

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

UNIRRADIATED (HAZ)

Page 2

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	65	57.02	7.97
20	61	65.73	-4.73
20	58	65.73	-7.73
20	66	65.73	.26
100	64	74.48	-10.48
100	76	74.48	1.51
100	72.5	74.48	-1.98
210	76	74.88	1.11
210	76	74.88	1.11
210	86	74.88	11.11

SUM of RESIDUALS = -5.06

CAPSULE V (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve   Printed at 08:10:00 on 05-16-2000

Page 1

Coefficients of Curve 2

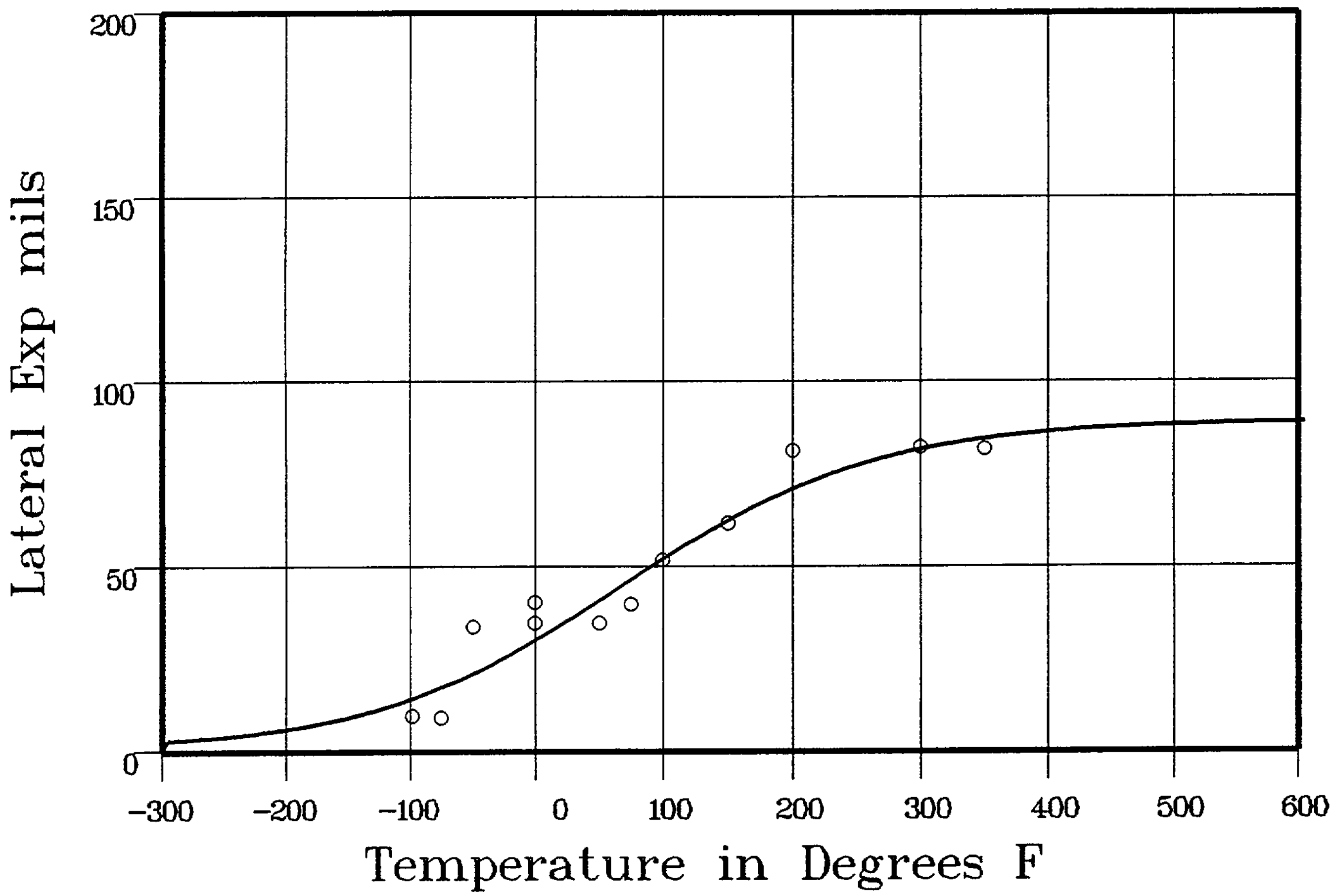
A = 45.2	B = 44.2	C = 195.07	T0 = 63.75

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

Upper Shelf L.E.: 89.4   Temperature at L.E. 35: 17.8   Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: V   Total Fluence:



Data Set(s) Plotted

Plant: BV1   Cap.: V   Material: HEAT AFFD ZONE   Ori.:   Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-98	10	15.14	-5.14
-75	9.5	18.17	-8.67
-50	34	22	11.99
0	40.5	31.25	9.24
0	35	31.25	3.74
50	35	42.09	-7.09
75	40	47.75	-7.75
100	52	53.32	-1.32

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

CAPSULE V (HAZ)

Page 2

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: V   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
150	62	63.56	-1.56
200	81.5	71.87	9.62
300	82.5	82.2	.29
350	82	84.94	-2.94

SUM of RESIDUALS = .41

CAPSULE U (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:10:00 on 05-16-2000

Page 1

Coefficients of Curve 3

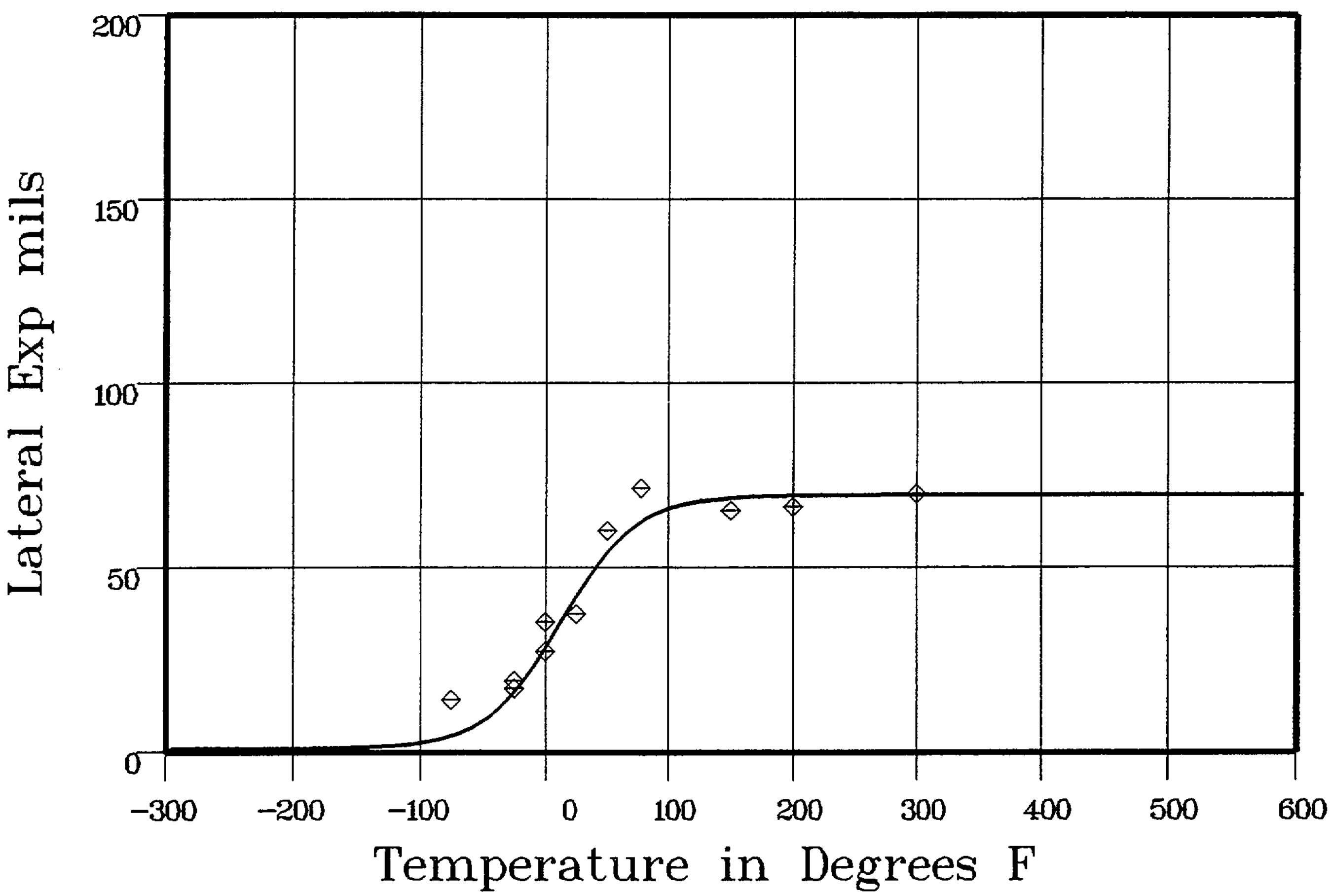
A = 35.31	B = 34.31	C = 60.93	T0 = 7.5

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

Upper Shelf L.E.: 69.63 Temperature at L.E. 35: 6.9 Lower Shelf L.E.: 1 Fixed

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

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: BV1 Cap.: U Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-75	14.5	5.29	9.2
-25	17.5	18.57	-1.07
-25	19.5	18.57	.92
-25	17.5	18.57	-1.07
0	27.5	31.11	-3.61
0	35.5	31.11	4.38
25	37.7	44.91	-7.21
50	60	56	3.99

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

CAPSULE U (HAZ)

Page 2

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: U   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
78	71.5	63.45	8.04
150	65.5	69	-3.5
200	66.5	69.51	-3.01
300	70	69.62	.37

SUM of RESIDUALS = 7.44

CAPSULE W (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:10:00 on 05-16-2000

Page 1

Coefficients of Curve 4

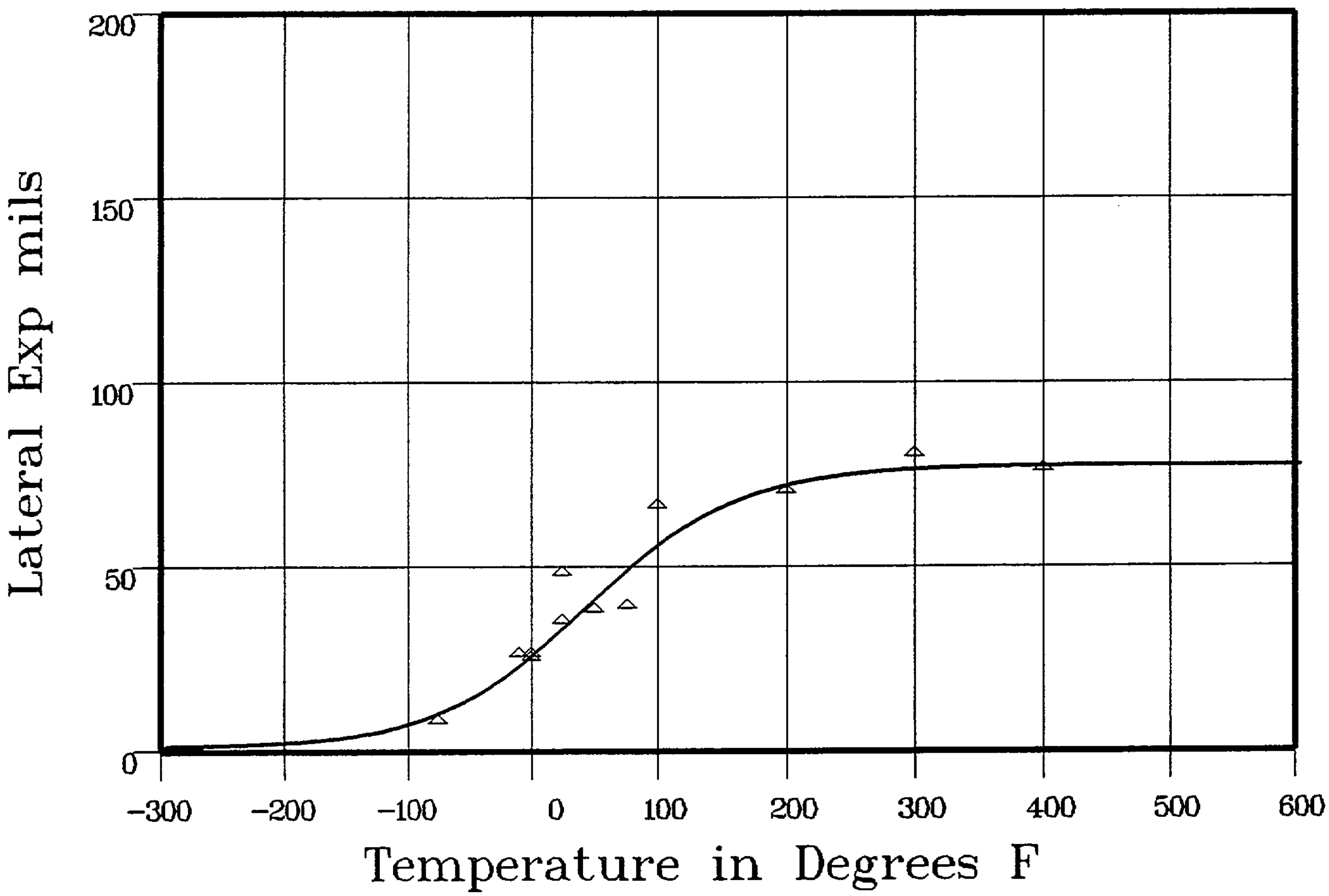
A = 39.27	B = 38.27	C = 121.3	T0 = 38.73

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

Upper Shelf L.E.: 77.55 Temperature at L.E. 35: 25.1 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: BV1 Cap.: W Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-75	8	11.17	-3.17
-10	26	24.67	1.32
0	25	27.45	-2.45
0	26	27.45	-1.45
25	48	34.95	13.04
25	35	34.95	.04
50	38	42.81	-4.81

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

CAPSULE W (HAZ)

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
76	39	50.67	-11.67
100	66	57.11	8.88
200	70	72.54	-2.54
300	80	76.53	3.46
400	76	77.35	-1.35

SUM of RESIDUALS = -.71

CAPSULE Y (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:10:00 on 05-16-2000

Page 1

Coefficients of Curve 5

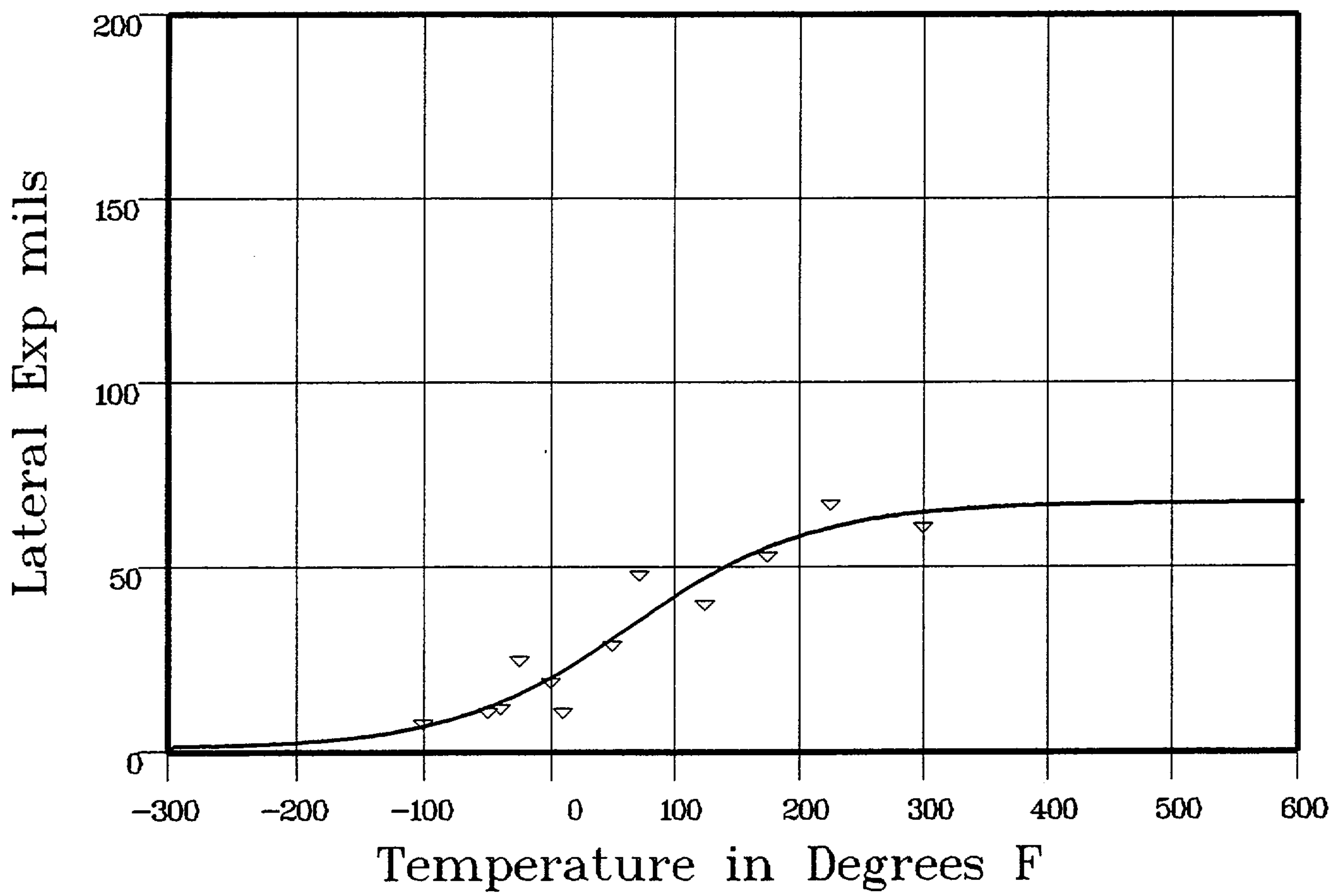
A = 34.26	B = 33.26	C = 145.99	T0 = 60

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

Upper Shelf L.E.: 67.52 Temperature at L.E. 35: 63.2 Lower Shelf L.E.: 1 Fixed

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

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: BV1 Cap.: Y Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	9	7.68	1.31
-50	12	13.06	-1.06
-40	13	14.48	-1.48
-25	26	16.82	9.17
0	20	21.31	-1.31
10	12	23.29	-11.29

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

CAPSULE Y (HAZ)

Page 2

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

Capsule: Y   Total Fluence:

Charpy V–Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
50	30	31.98	−1.98
72	49	36.98	12.01
125	41	48.16	−7.16
175	54	56.11	−2.11
225	68	61.23	6.76
300	62	65.12	−3.12

SUM of RESIDUALS = −.29

UNIRRADIATED (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:49:32 on 07-07-2000

Page 1

Coefficients of Curve 2

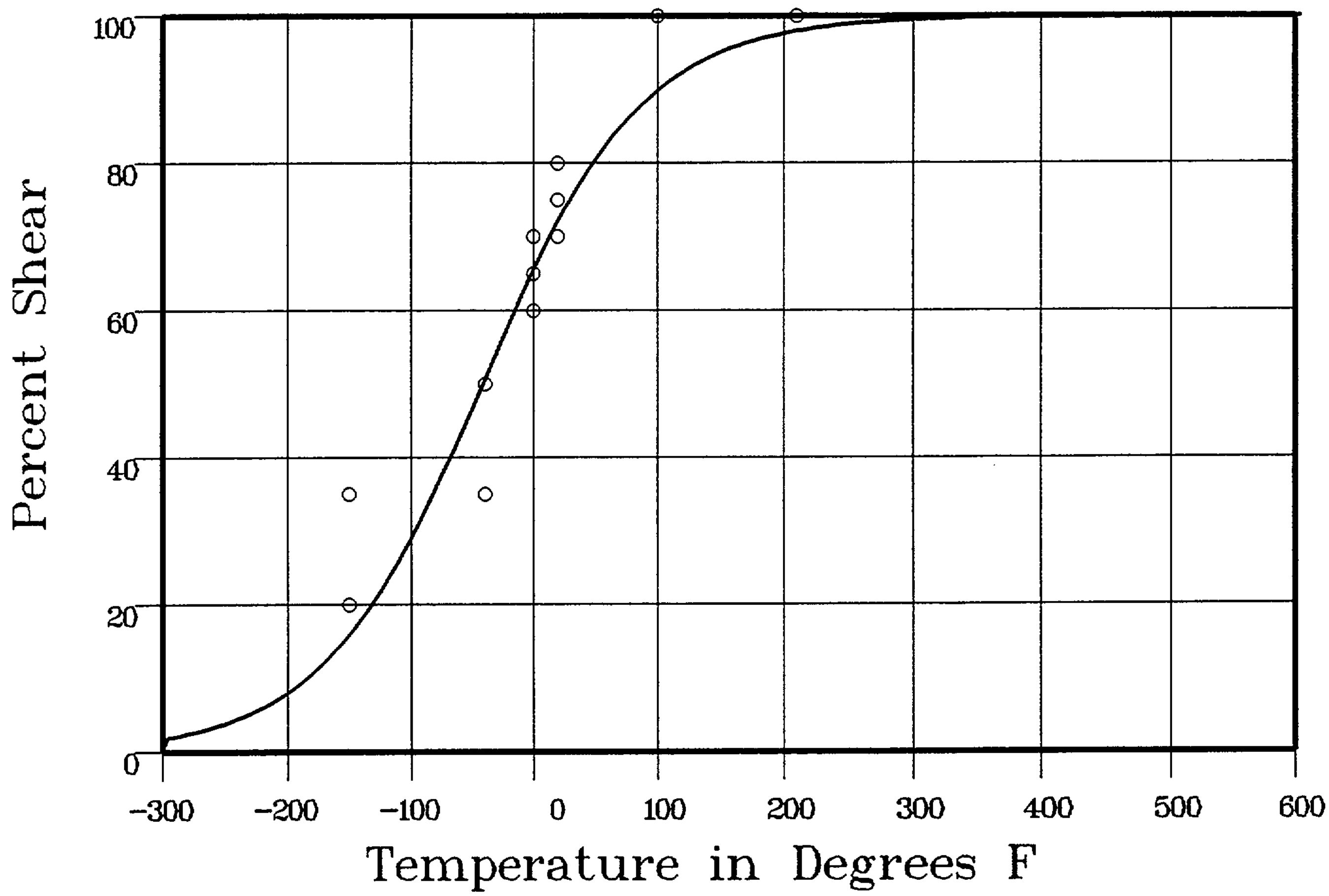
A = 50	B = 50	C = 130.16	T0 = -46.4

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

Temperature at 50% Shear: -46.4

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: BV1 Cap.: UNIRR Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-150	35	16.91	18.08
-150	20	16.91	3.08
-150	20	16.91	3.08
-40	50	52.45	-2.45
-40	35	52.45	-17.45
-40	50	52.45	-2.45
0	70	67.1	2.89
0	60	67.1	-7.1

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

UNIRRADIATED (HAZ)

Page 2

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	65	67.1	-2.1
20	70	73.5	-3.5
20	75	73.5	1.49
20	80	73.5	6.49
100	100	90.46	9.53
100	100	90.46	9.53
100	100	90.46	9.53
210	100	98.09	1.9
210	100	98.09	1.9
210	100	98.09	1.9

SUM of RESIDUALS = 34.39

CAPSULE V (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:13:31 on 05-16-2000

Page 1

Coefficients of Curve 2

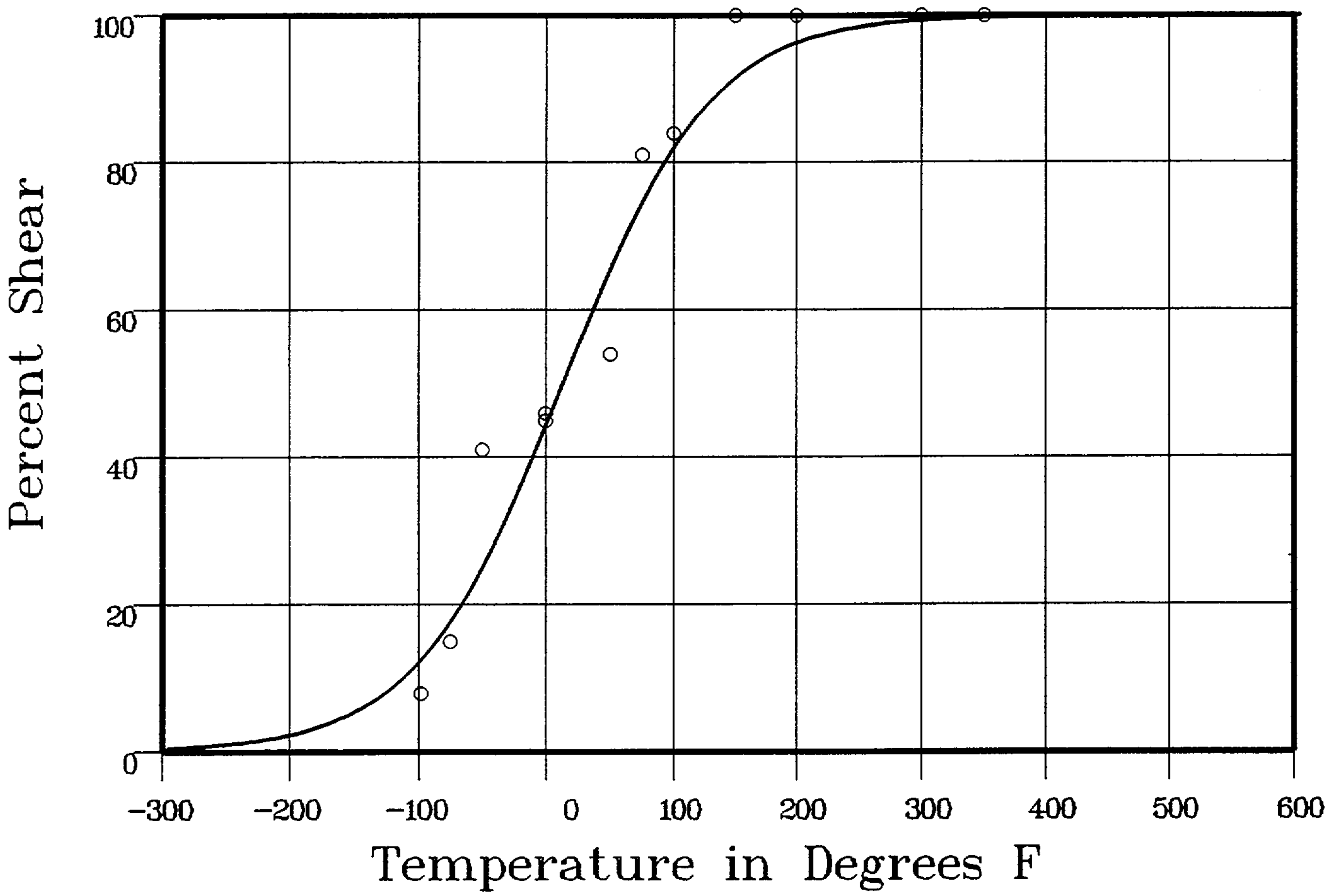
A = 50	B = 50	C = 114.68	T0 = 8.7

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

Temperature at 50% Shear: 8.7

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

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: BV1 Cap.: V Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-98	8	13.46	-5.46
-75	15	18.85	-3.85
-50	41	26.43	14.56
0	46	46.21	-.21
0	45	46.21	-1.21
50	54	67.26	-13.26
75	81	76.06	4.93
100	84	83.09	.9

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

CAPSULE V (HAZ)

Page 2

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

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
150	100	92.15	7.84
200	100	96.56	3.43
300	100	99.38	.61
350	100	99.74	.25

SUM of RESIDUALS = 8.56

CAPSULE U (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:13:31 on 05-16-2000
Page 1
Coefficients of Curve 3

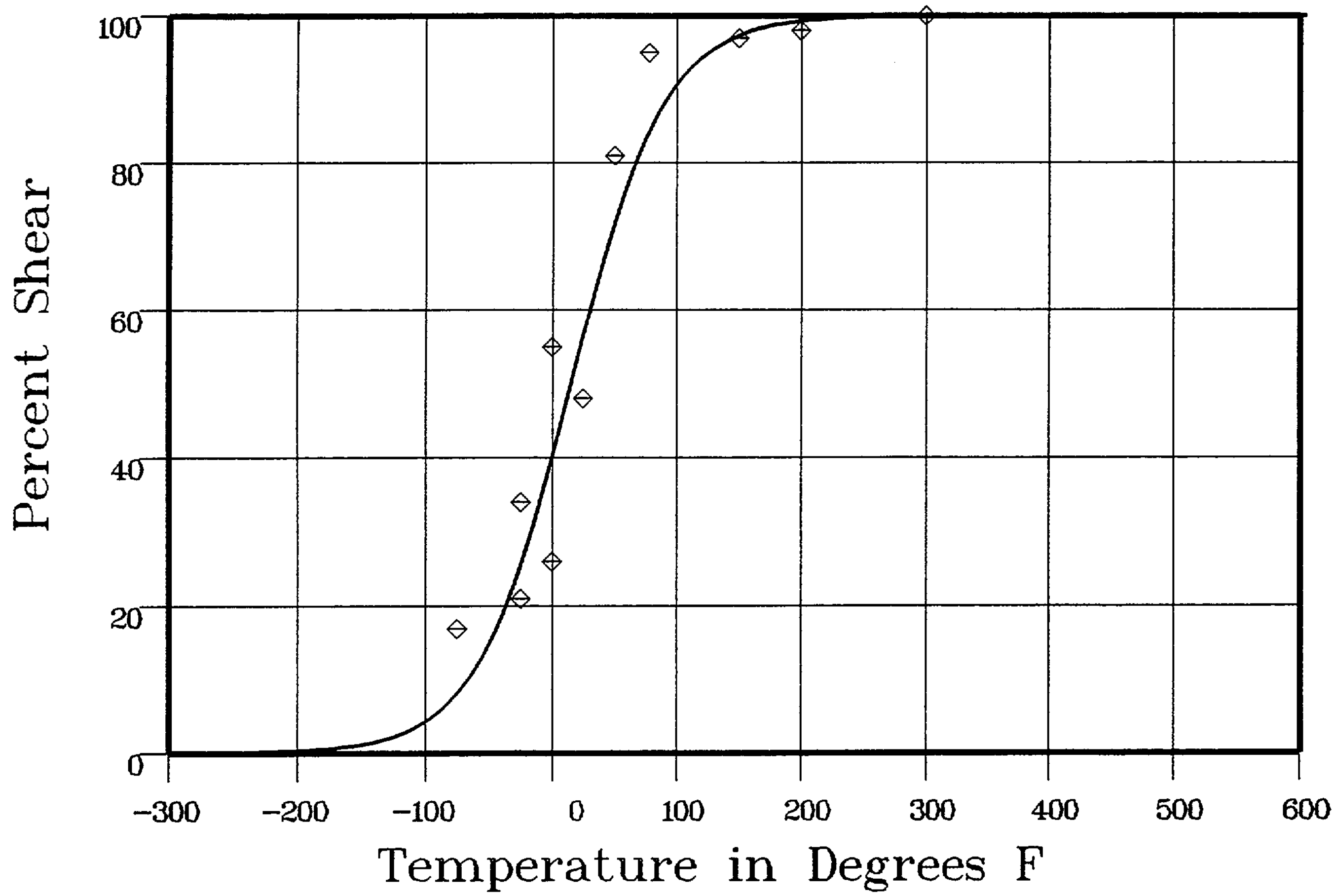
A = 50	B = 50	C = 74.88	T0 = 10.31

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

Temperature at 50% Shear: 10.3

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

Capsule: U Total Fluence:



Data Set(s) Plotted
Plant: BV1 Cap.: U Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75	17	9.29	7.7
-25	34	28.02	5.97
-25	21	28.02	-7.02
-25	34	28.02	5.97
0	26	43.15	-17.15
0	55	43.15	11.84
25	48	59.68	-11.68
50	81	74.26	6.73

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

CAPSULE U (HAZ)

Page 2

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

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
78	95	85.91	9.08
150	97	97.65	-.65
200	98	99.37	-1.37
300	100	99.95	.04

SUM of RESIDUALS = 9.46

CAPSULE W (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:13:31 on 05-16-2000

Page 1

Coefficients of Curve 4

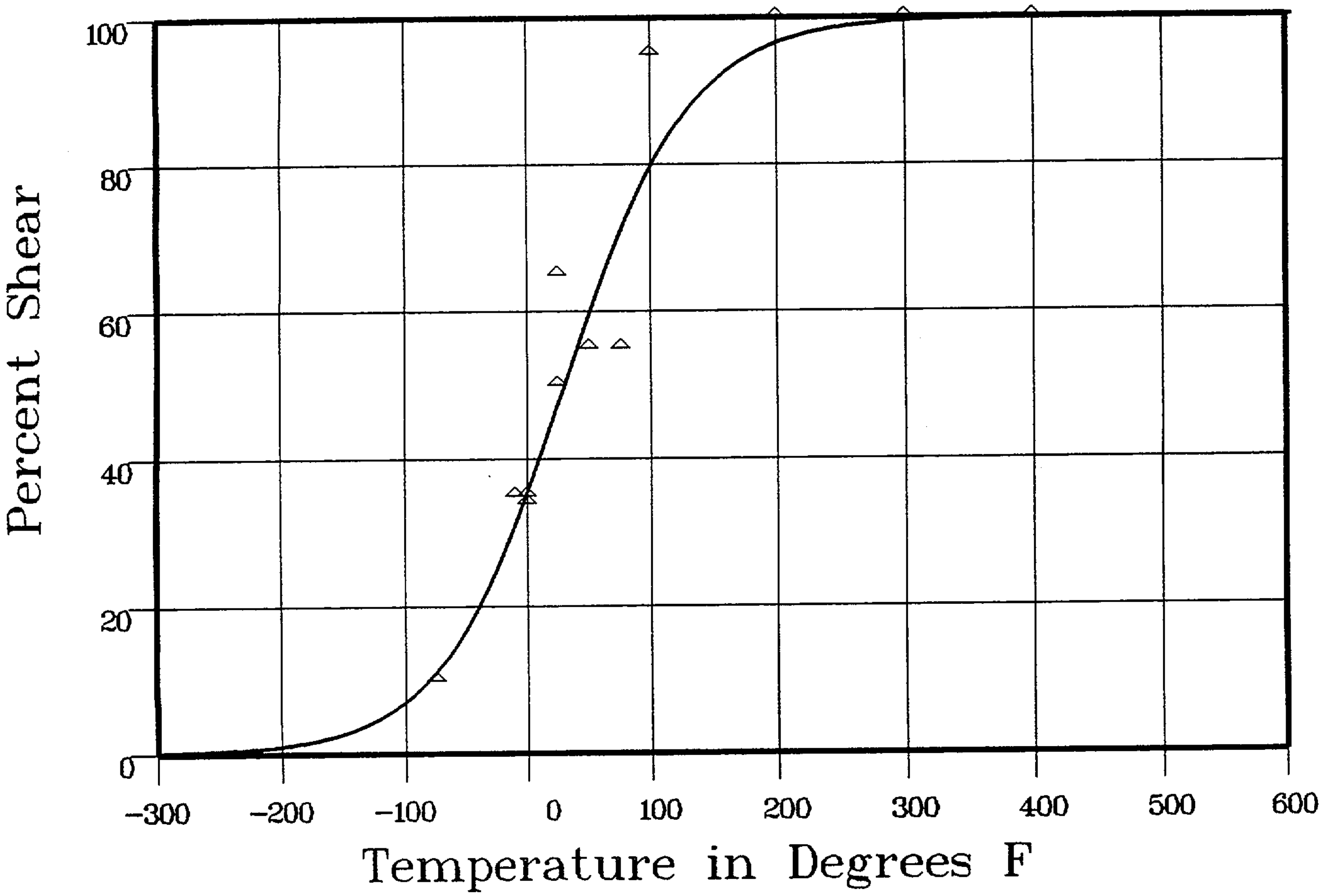
A = 50	B = 50	C = 101.61	T0 = 25.83

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

Temperature at 50% Shear: 25.8

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: BV1 Cap.: W Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75	10	12.08	-2.08
-10	35	33.06	1.93
0	35	37.55	-2.55
0	34	37.55	-3.55
25	65	49.58	15.41
25	50	49.58	.41
50	55	61.67	-6.67

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

CAPSULE W (HAZ)

Page 2

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
76	55	72.85	-17.85
100	95	81.14	13.85
200	100	96.85	3.14
300	100	99.54	.45
400	100	99.93	.06

SUM of RESIDUALS = 2.54

CAPSULE Y (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:13:31 on 05-16-2000

Page 1

Coefficients of Curve 5

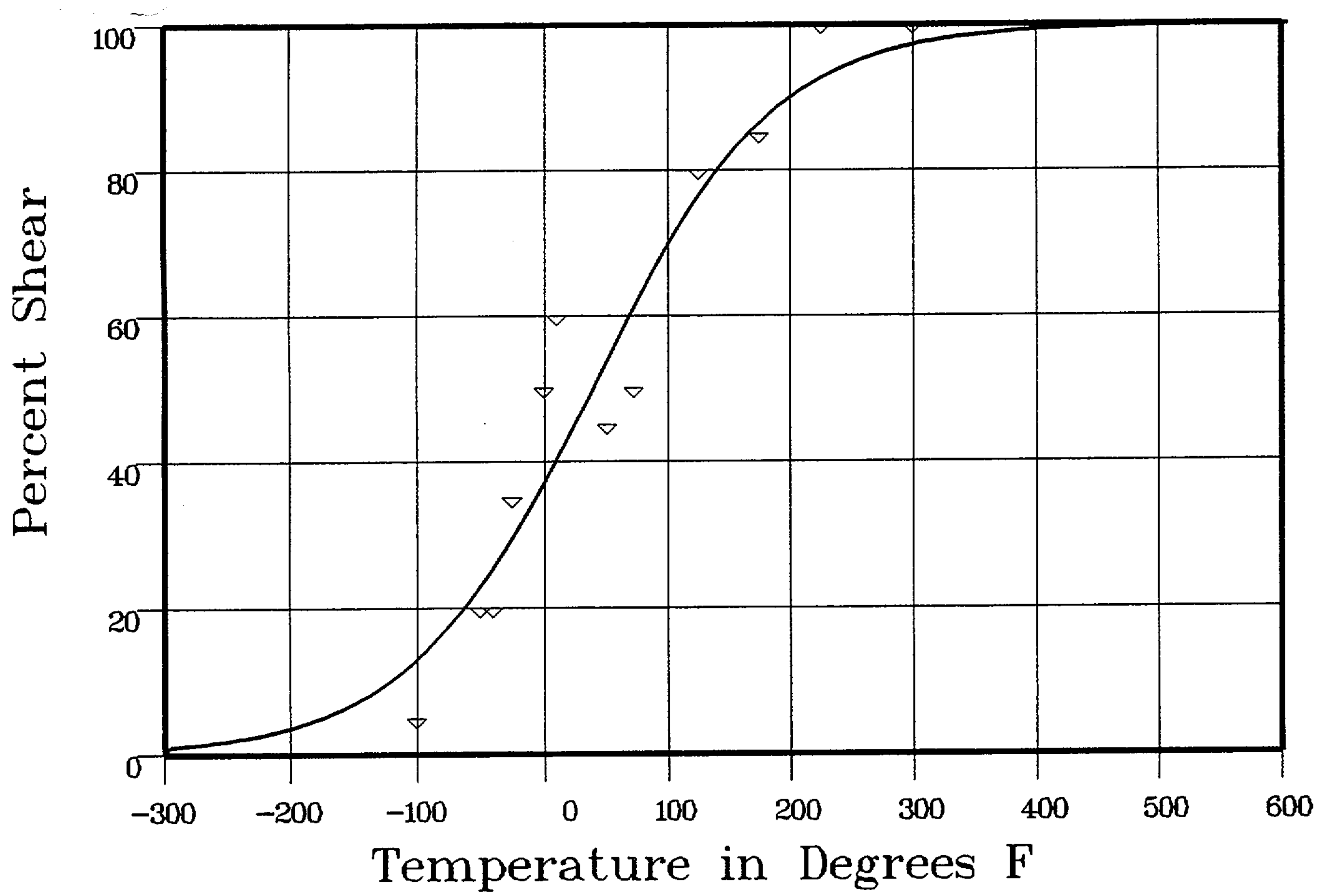
A = 50	B = 50	C = 146.29	T0 = 34.01

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

Temperature at 50% Shear: 34

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: BV1 Cap.: Y Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	5	13.79	-8.79
-50	20	24.07	-4.07
-40	20	26.66	-6.66
-25	35	30.85	4.14
0	50	38.58	11.41
10	60	41.86	18.13

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

CAPSULE Y (HAZ)

Page 2

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: Y   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50	45	55.44	-10.44
72	50	62.69	-12.69
125	80	77.62	2.37
175	85	87.29	-2.29
225	100	93.15	6.84
300	100	97.43	2.56

SUM of RESIDUALS = .5

APPENDIX D

BEAVER VALLEY UNIT 1 SURVEILLANCE PROGRAM CREDIBILITY ANALYSIS

INTRODUCTION:

Regulatory Guide 1.99, Revision 2 and 10 CFR Part 50.61, describe 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 and 10 CFR Part 50.61, describe the method for calculating the adjusted reference temperature and Charpy upper-shelf energy of reactor vessel beltline materials using surveillance capsule data. These methods can only be applied when two or more credible surveillance data sets become available from the reactor in question.

To date there has been four surveillance capsules removed from the Beaver Valley 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 and/or 10 CFR Part 50.61, 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 to the Beaver Valley Unit 1 reactor vessel surveillance data and determine if the Beaver Valley Unit 1 surveillance data is credible.

EVALUATION:

Criterion 1: The materials in the surveillance capsules must be those which are the controlling materials with regard to radiation embrittlement.

The beltline region of the reactor vessel is defined in Appendix G to 10 CFR Part 50, "Fracture Toughness Requirements", as follows:

> "the reactor vessel (shell material including welds, heat affected zones, and plates or forgings) that directly surrounds the effective height of the active core and adjacent regions of the reactor vessel that are predicted to experience sufficient neutron radiation damage to be considered in the selection of the most limiting material with regard to radiation damage."

The Beaver Valley Unit 1 reactor vessel consists of the following beltline region materials:

- Intermediate Shell Plate B6607-1 (Heat # C4381-1)
- Intermediate Shell Plate B6607-2 (Heat # C4381-2)
- Lower Shell Plate B6903-1 (Heat # C6317-1)
- Lower Shell Plate B7203-2 (Heat # C6293-2)
- Intermediate Shell Longitudinal Weld Seams 19-714 A & B
  (Wire Heat 305424, Linde 1092, Flux Lot NO. 3889)
- Intermediate to Lower Shell Circumferential Weld Seam 11-714
  (Wire Heat 90136, Linde 0091, Flux Lot NO. 3977 & 3998)
- Lower Shell Longitudinal Weld Seams 20-714 A & B
  (Wire Heat 305414, Linde 1092, Flux Lot NO. 3947)

The Beaver Valley Unit 1 surveillance program was based on ASTM E185-73 and utilizes test specimens from lower shell plate B6903-1 and weld metal fabricated with wire heat # 305424, linde 1092, flux lot no. 3889.

In ASTM E185-73, Annex A1, "surveillance material selection procedures," the number one criteria for selecting the surveillance program material is the initial RT_{NDT} value of the material. However, in ASTM E185-73, Section 4.1 – Test Materials, "the base metal and weld metal to be included in the program should represent the material that may limit the operation of the reactor during its lifetime."

An evaluation of the limiting intermediate shell plate B6607-2 and limiting lower shell plate B6903-1 was performed to determine which plate would be limiting during the reactor vessel's lifetime. This evaluation shows that at fluences greater than 1.727 x 10^{19} n/cm^2 (E > 1.0 MeV), the lower shell plate B6903-1 is limiting. The EOL fluence was projected to be greater than 1.727 x 10^{19} n/cm^2 (E > 1.0 MeV). Hence, lower shell plate B6903-1 was utilized in the surveillance program.

At the time the surveillance capsule program was developed, the initial RT_{NDT} of the weld metal was not known and is based on a generic value. Hence, all weld metal IRT_{NDT} values were –56°F and considered equivalent. The weld wire used in the intermediate shell longitudinal weld seams 19-714 A & B had one of the highest weight %'s of Cu and the highest weight % of P. In addition, USE values for the weld metals were not available. Hence, weld wire heat # 305424, linde 1092, flux lot no. 3889 was utilized in the surveillance program and is identical to the intermediate shell longitudinal weld seams.

Based on the above discussion and the methodology in use at the time the program was developed, the Beaver Valley Unit 1 surveillance program meets this criterion.

Criterion 2: Scatter in the plots of Charpy energy versus temperature for the irradiated and unirradiated conditions should be small enough to permit the determination of the 30 ft-lb temperature and upper shelf energy unambiguously.

Plots of Charpy energy versus temperature for the unirradiated and irradiated condition are presented Appendix C of this report.

Based on engineering judgment, 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 Beaver Valley Unit 1 surveillance materials unambiguously. Hence, the Beaver Valley 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.

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 the plate data and to determine if the scatter of the measured plate ΔRT_{NDT} values about this best fit line is less than 28°F for welds and less than 17°F for plates.

The Beaver Valley Unit 1 surveillance weld metal was also used in the St. Lucie Unit 1 lower shell longitudinal weld seam and in the circ. weld of the LaSalle Unit 1 vessel. However, the only source of surveillance data for the weld wire is the Beaver Valley Unit 1 surveillance program. Hence, no adjustment will be made to the data for this credibility evaluation.

In addition, the Beaver Valley Unit 1 circ. weld seam wire is in the St. Lucie Unit 1 surveillance program and per reference 30, the St. Lucie Unit 1 surveillance weld data is credible. Therefore, it will be applied to the Beaver Valley Unit 1 vessel when determining CF's following the guideline provided by the NRC in the February 12, 1998 workshop.

The Beaver Valley Unit 1 lower shell longitudinal weld seam wire is in the Fort Calhoun Unit 1 surveillance program. Therefore, it will be checked for credibility and applied to the Beaver Valley unit 1 vessel.

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

Calculation of Chemistry Factors using Beaver Valley Unit 1 Surveillance Capsule Data

Material	Capsule	Capsule f(a)	FF(b)	ΔRT_{NDT}(c)	FF*ΔRT_{NDT}	FF^2
Lower Shell Plate B6903-1 (Longitudinal)	V	.323	.689	128.49	88.53	.475
	U	.646	.878	118.93	104.42	.771
	W	.986	.996	148.52	147.93	.992
	Y	2.15	1.21	142.18	172.04	1.464
Lower Shell Plate B6903-1 (Transverse)	V	.323	.689	137.81	94.95	.475
	U	.646	.878	131.84	115.76	.771
	W	.986	.996	179.99	179.27	.992
	Y	2.15	1.21	166.93	201.99	1.464
				SUM:	1104.89	7.404
	CF = Σ(FF * RT_{NDT}) ÷ Σ(FF^2) = (1104.89) ÷ (7.404) = **149.2 °F**					
Surveillance Weld Metal 19-714A/B (Heat 305424)	V	.323	.689	159.72	110.05	.475
	U	.646	.878	166.32	146.03	.771
	W	.986	.996	187.73	186.98	.992
	Y	2.15	1.21	179.69	217.42	1.464
				SUM:	660.48	3.702
CF = Σ(FF * RT_{NDT}) ÷ Σ(FF^2) = (660.48) ÷ (3.702) = **178.4°F**						

Notes:
(a) f = Measured fluence from capsule Y dosimetry analysis results (x 10^{19} n/cm^2, E > 1.0 MeV). (See Section 6 of this report.)
(b) FF = fluence factor = $f^{(0.28 - 0.1*\log f)}$.
(c) ΔRT_{NDT} values are the measured 30 ft-lb shift values (Appendix B & C) and do not include the adjustment ratio procedure of Reg. Guide 1.99 Revision 2, Position 2.1, since this calculation is based on the actual surveillance weld metal measured shift values.

TABLE D-2
Best Fit Evaluation for Beaver Valley Unit 1 Surveillance Materials

Material	Capsule	CF[a] ($Slope_{best\ fit}$)	FF[b]	ΔRT_{NDT}[c]	Best Fit ΔRT_{NDT} (°F)	Scatter ΔRT_{NDT} (°F)	<17°F (Base Metals) <28°F (Weld)
Lower Shell Plate B6903-1 (Longitudinal)	V	149.2	.689	128.49	102.8	-25.7	NO
	U	149.2	.878	118.93	131.0	12.1	YES
	W	149.2	.996	148.52	148.6	0.1	YES
	Y	149.2	1.21	142.18	180.5	38.3	NO
Lower Shell Plate B6903-1 (Transverse)	V	149.2	.689	137.81	102.8	-35.0	NO
	U	149.2	.878	131.84	131.0	-0.8	YES
	W	149.2	.996	179.99	148.6	-31.4	NO
	Y	149.2	1.21	166.93	180.5	13.6	YES
Surveillance Weld Metal 19-4A/B (Heat 305424)	V	178.4	.689	159.72	122.9	-36.8	NO
	U	178.4	.878	166.32	156.6	-9.7	YES
	W	178.4	.996	187.73	177.7	-10.0	YES
	Y	178.4	1.21	179.69	215.9	36.2	NO

Notes:
(a) f = Measured fluence from capsule Y dosimetry analysis results (x 10^{19} n/cm^2, E > 1.0 MeV). Ref. 16
(b) FF = fluence factor = $f^{(0.28 - 0.1*\log f)}$.
(c) ΔRT_{NDT} values are the measured 30 ft-lb shift values (Appendix B & C) and do not include the adjustment ratio procedure of Reg. Guide 1.99 Revision 2, Position 2.1, since this calculation is based on the actual surveillance weld metal measured shift values.

$$\text{Best Fit } \Delta RT_{NDT} = (Slope_{best\ fit}) * (\text{Fluence Factor})$$

From Table D-2 above, the Beaver Valley Unit 1 Plate Data has four out of eight data points outside the 17°F scatter band. The surveillance weld has two out of four data points outside the 28°F scatter band.

Hence, the surveillance data is not credible.

Determination of CF:

Since the data are not credible, evaluate whether CF should be determined from the tables. The table of CF for plate B6903-1 (0.21% Cu & 0.54% Ni) is:

$$\frac{(CF - 155)}{(129 - 155)} = \frac{(.54 - .6)}{(.4 - .6)} \Rightarrow CF = 147.2$$

The CF based on the surveillance data is 149.2°F and is greater than the CF from the tables. Per the February 12, 1998 NRC Industry Meeting, the NRC recommended that surveillance data be used along with a full σ_Δ of 17°F for further calculations, such as PTS or determination of adjusted reference temperature, if it is greater than the table value.

Contained in Table D-3 is the determination of the weld CF using the ratio procedure adjustment.

D-3
CF Based on Measure Data

Material	Capsule	Capsule f	FF	ΔRT_{NDT}*	FFxΔRT_{NDT}	FF^2
Surveillance Weld Metal 19-714A/B (Heat 305424)	V	.323	.689	169.3	116.7	.475
	U	.646	.878	176.3	154.8	.771
	W	.986	.996	199.0	198.2	.992
	Y	2.15	1.21	189.4	229.2	1.464
				SUM:	698.8	3.702
CF = Σ(FF x RT_{NDT}) ÷ Σ(FF^2) = (698.8) ÷ (3.702) = **188.8°F**						

*Ratio adjusted by 1.06 (191.7/181.6).

The table CF 191.7°F is conservative and will be used along with a full σ_Δ for calculations in the calc note.

The next step will be to determine if the St. Lucie and Fort Calhoun Unit 1 surveillance welds are credible when applied to the Beaver Valley Unit 1 circ weld.

Table D-4
St. Lucie Unit 1 Surveillance Weld Data*

Material	Capsule	Cu	Ni	Irradiated Temperature °F	Fluence 10^{19} n/cm^2	Measured ΔRT_{NDT}
Surveillance Weld Metal Heat 90136	97°	0.2291	0.0699	546.7	0.627	72.3
	104°	0.2291	0.0699	546.7	0.909	67.4
	284°	0.2291	0.0699	546.7	1.41	68.0

*The data contained in this table was obtained from reference 51 and 52.

Based on the average of cycle 4-7, the inlet temperatures of cycles 8 and 9, the Beaver Valley Unit 1 operation temperature is 544.1°F

The best estimate Cu & Ni weight % for weld heat 90136 is:

0.27 Cu and 0.07 Ni ⇒ table CF_{vw} = 124.3°F

A credibility evaluation of the St. Lucie Unit 1 surveillance weld data was performed in reference 51 and weld data has been shown to be credible. Hence, this data will be adjusted for temperature and chemistry and will be used in this calc note.

Based on the data provided in TR-0-MCM-001[49] and the CEOG Report CE-NPSD-1039, Rev. 02[53], the best estimate Cu and Ni weight percent values for the Fort Calhoun Unit 1 surveillance weld (Heat 305414) are:

$$\% \text{ Cu} = 0.3092 \approx 0.31\%$$
$$\% \text{ Ni} = 0.6042 \approx 0.60\%$$

Per B&W Report BAW-2226-00 (BWNT Document No. 77-2226-00)[50], the measured ΔT_{30} and fluence values for the first 3 capsules removed from the Fort Calhoun Unit 1 vessel (weld metal) are:

Table D-5
Ft. Calhoun Unit 1 Surveillance Weld Data

Material	Capsule	Cu[49]	Ni[49]	Irradiated Temperature °F[2]	Fluence 10^{19} n/cm^{2}*	Measured ΔRT_{NDT}*
Surveillance Weld Metal Heat 90136	W-225	0.35	0.60	527	5.53	238
	W-265	0.35	0.60	534	7.71	221
	W-275	0.35	0.60	538	1.28	219

*The data obtained from references 50.