Westinghouse Non-Proprietary Class 3

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

Westinghouse Electric Company, LLC

WESTINGHOUSE NON-PROPRIETARY CLASS 3

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

J. H. Ledger

S. L. Anderson

J. Conermann

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

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

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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	[signature]
Section 6	G. K. Roberts	[signature]

EXECUTIVE SUMMARY

The purpose of this report is to document the results of the testing of surveillance capsule W from the Beaver Valley Unit 2 reactor vessel. Capsule W was removed at 9.77 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 9.77 EFPY of plant operation was 1.103×10^{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 C, which shows the Beaver Valley Unit 2 surveillance data is credible.

1 SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance Capsule W, the third capsule to be removed from the Beaver Valley Unit 2 reactor pressure vessel, led to the following conclusions:

- The capsule received an average fast neutron fluence (E> 1.0 MeV) of 3.625 x 10^{19} n/cm^2 after 9.77 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel intermediate shell plate B9004-2 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major rolling direction (longitudinal orientation), to 3.625 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 71.04°F and a 50 ft-lb transition temperature increase of 78.5°F. This results in an irradiated 30 ft-lb transition temperature of 106.58°F and an irradiated 50 ft-lb transition temperature of 158.82°F for the longitudinal oriented specimens.

- Irradiation of the reactor vessel intermediate shell plate B9004-2 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major rolling direction of the plate (transverse orientation), to 3.625 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 63.39°F and a 50 ft-lb transition temperature increase of 72.5°F. This results in an irradiated 30 ft-lb transition temperature of 103.1°F and an irradiated 50 ft-lb transition temperature of 163.62°F for transverse oriented specimens.

- Irradiation of the weld metal Charpy specimens to 3.625 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 6.21°F and a 50 ft-lb transition temperature increase of 20.35°F. This results in an irradiated 30 ft-lb transition temperature of –33.53°F and an irradiated 50 ft-lb transition temperature of –1.3°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 3.625 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 51.54°F and a 50 ft-lb transition temperature increase of 46.32°F. This results in an irradiated 30 ft-lb transition temperature of –35.83°F and an irradiated 50 ft-lb transition temperature of 4.55°F.

- The average upper shelf energy of the intermediate shell plate B9004-2 (longitudinal orientation) resulted in an average energy decrease of 1 ft-lb after irradiation to 3.625 x 10^{19} n/cm^2 (E > 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 94 ft-lb for the longitudinal oriented specimens.

- The average upper shelf energy of the intermediate shell plate B9004-2 (transverse orientation) resulted in an average energy decrease of 4 ft-lb after irradiation to 3.625 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 75 ft-lb for the transverse oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted an average energy decrease of 3 ft-lb after irradiation to 3.625 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 136 ft-lb for the weld metal specimens.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in no energy decrease after irradiation to 3.625 x 10^{19} n/cm^2 (E> 1.0MeV). This results in an irradiated average upper shelf energy of 104 ft-lb for the weld HAZ metal.

- A comparison of the Beaver Valley Unit 2 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 the Intermediate Shell Plate B9004-2 contained in Capsules V & W (Longitudinal) and capsule W (Transverse) is greater then the Regulatory Guide 1.99, Rev. 2 predictions. However, the shift value is less than two sigma allowance by Regulatory Guide 1.99, Rev. 2.

  — The measured 30 ft-lb shift in transition temperature of all the remaining materials contained in Capsules U, V and W are less than the Regulatory Guide 1.99, Revision 2, predictions.

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

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

  Calculated: Vessel inner radius* = 3.85 x 10^{19} n/cm^2

  Vessel 1/4 thickness = 2.40 x 10^{19} n/cm^2

  Vessel 3/4 thickness = 9.32 x 10^{18} n/cm^2

  *Clad/base metal interface

- The credibility evaluation of the Beaver Valley Unit 2 surveillance program presented in Appendix C of this report indicates that the surveillance results of the Beaver Valley Unit 2 surveillance program is 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 (32 EFPY) as required by 10CFR50, Appendix G[4].

2 INTRODUCTION

This report presents the results of the examination of Capsule W, the third capsule removed from the reactor in the continuing surveillance program which monitors the effects of neutron irradiation on the FirstEnergy Nuclear Operating Company (FENOC) Beaver Valley Unit 2 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the FENOC Beaver Valley Unit 2 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-9165, "Duquesne Light Company Beaver Valley Unit 2 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 W was removed from the reactor after 9.77 EFPY of exposure and shipped to the Westinghouse Science and Technology Center Hot Cell Facility, where the postirradiation mechanical testing of the Charpy V-notch impact and tensile surveillance specimens was performed.

This report summarizes the testing of and the post-irradiation data obtained from surveillance Capsule W removed from the FENOC Beaver Valley Unit 2 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 2 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 2 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

Six surveillance capsules for monitoring the effects of neutron exposure on the Beaver Valley Unit 2 reactor pressure vessel core region (beltline) materials were inserted in the reactor vessel prior to initial plant start-up. The six capsules were positioned in the reactor vessel between the Neutron Pads and the vessel wall as shown in Figure 4-1. The vertical center of the capsules is opposite the vertical center of the core.

Capsule W was removed after 9.77 effective full power years (EFPY) of plant operation. This capsule contained Charpy V-notch impact and tensile specimens made from Intermediate Shell Plate B9004-2, weld metal made from sections of plate B9004-2 and the adjoining lower shell plate B9005-2 (Heat No. C1408-1) using a submerged arc weld metal with 3/16-inch-diameter weld wire type B-4, heat number 83642, with Linde 0091 flux, lot number 3536, which is identical to the wire/flux combination used in the original fabrication of the core region, and heat-affected-zone specimens obtained from the weld-heat-affected zone. Additionally, tensile, bend bar, and 1/2T compact tension test specimens were included in the capsule (Figure 4-2).

Test material obtained from Intermediate Shell Plate B9004-2 (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. Specimens were machined from weld metal and the heat-affected-zone (HAZ) metal of a stress-relieved weldment joining sections of the intermediate and lower shell plates. All heat-affected-zone specimens were obtained from the weld heat-affected-zone of intermediate shell plate B9004-2.

Charpy V-notch impact specimens from intermediate shell plate B9004-2 were machined in both the longitudinal orientation (longitudinal axis of specimen parallel to major working direction) and transverse orientation (longitudinal axis of specimen perpendicular to major working direction). The core region weld Charpy impact specimens were machined from the weldment such that the long dimension of the Charpy was normal to the weld direction; the notch was machined such that the direction of crack propagation in the specimen was in the weld direction.

Capsule W also contained a bend bar specimen, machined from intermediate shell plate B9004-2 with the longitudinal axis of the specimen oriented normal to the working direction of the plate, such that the simulated crack in the specimen would propagate in the major working direction of the plate. All bend bar specimens were fatigue pre-cracked according to ASTM E399.

The compact tension test specimens from plate B9004-2 were machined in the transverse and longitudinal orientation, to obtain fracture toughness data both normal and parallel to the rolling direction of the plate. Compact tension test specimens from the weld metal were machined normal to the weld direction with the notch oriented in the direction in the direction of the weld. All specimens were fatigue pre-cracked according to ASTM E399.

The chemical composition and heat treatment of the surveillance material is presented in Tables 4-1 and 4-2. The chemical analysis reported in Table 4-1 was obtained from unirradiated material used in the surveillance program[1].

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

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

2.5% Ag, 97.5% Pb	Melting Point: 579°F (304°C)
1.75% Ag, 0.75% Sn, 97.5% Pb	Melting Point: 590°F (310°C)

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

TABLE 4-1

Chemical Composition (wt%) of the Unirradiated Beaver Valley Unit 2 Reactor Vessel Surveillance Materials

Element[(a)]	Intermediate Shell Plate B9004-2[(a)]	Weld Metal [(a,b)]
C	0.24	0.10
Al	0.047	0.001
S	0.016	0.011
N_2	0.009	0.028
Co	0.009	0.007
As	0.010	0.005
Cu	0.05	0.08
W	0.01	<0.01
Si	0.24	0.14
Sn	0.008	0.005
Mo	0.59	0.49
Zr	0.002	<0.001
Ni	0.56	0.07
P	0.010	0.008
Mn	1.32	1.17
B	0.0003	<0.001
Cr	0.08	0.07
Cb	<0.01	<0.01
V	0.003	0.002
Ti	<0.01	<0.01

Notes:

a. Analyses conducted by Combustion Engineering, Inc.
b. The surveillance weldment is a submerged arc weld fabricated using 3/16-inch diameter weld wire type B-4, heat number 83642, with a Linde 0091 type flux, lot number 3536. This weld wire/flux combination is identical to that used for the intermediate and lower shell vertical seams and the girth weld between the intermediate and lower shell plates.

Table 4-2

Heat Treatment of Beaver Valley Unit 2 Reactor Vessel Surveillance Materials[1]

Material	Temperature (°F)	Time (hrs.)	Coolant
Intermediate Shell Plate B9004-2	1600 ± 25	4	Water quenched
	1225 ± 25	4	Air cooled
	1140 ± 25	30	Furnace Cooled
Weldment	1150 ± 25	13 ½	Furnace Cooled

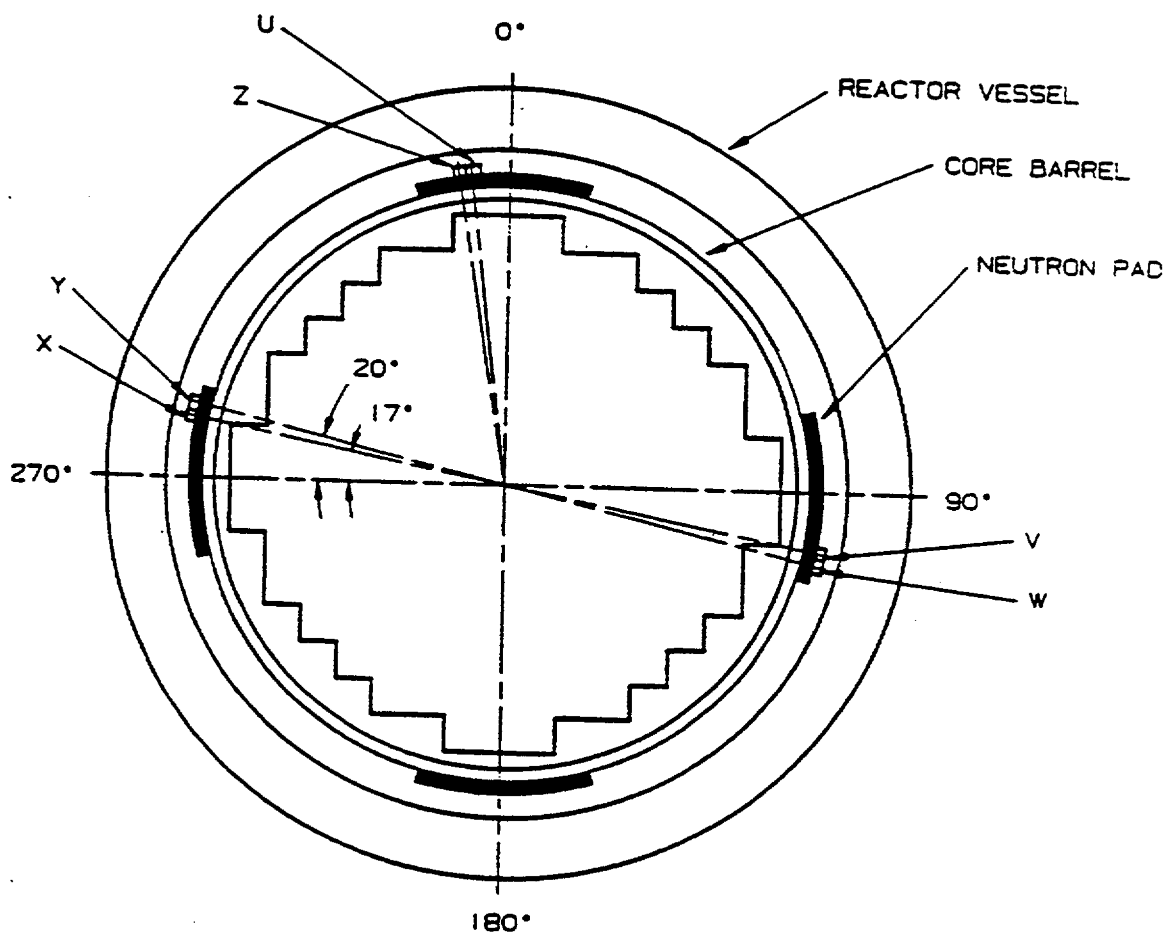


Figure 4-1 Arrangement of Surveillance Capsules in the Beaver Valley Unit 2 Reactor Vessel

LEGEND:

WL - INTERMEDIATE PLATE B9004-2 (LONGITUDINAL)
WT - INTERMEDIATE PLATE B9004-2 (TRANSVERSE)
WW – WELD METAL
WH – HEAT - AFFECTED - ZONE METAL

CAPSULE W

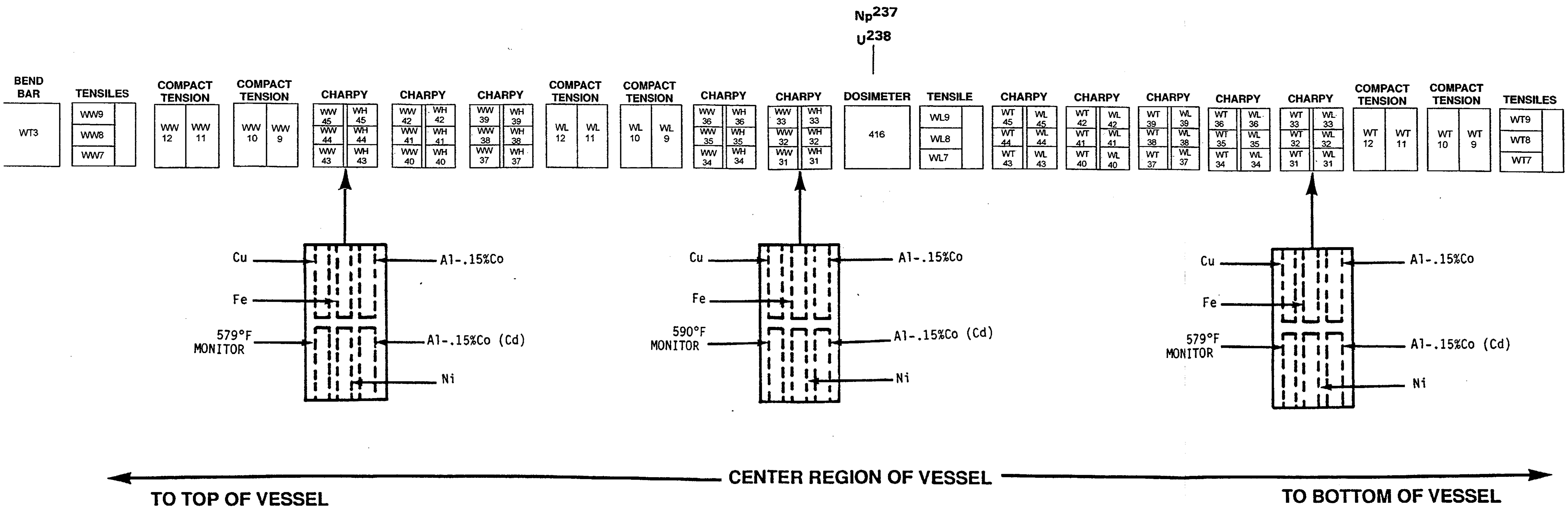


Figure 4-2 Capsule W Diagram Showing the Location of Specimens, Thermal Monitors, and Dosimeters.

5 TESTING OF SPECIMENS FROM CAPSULE W

5.1 OVERVIEW

The post-irradiation mechanical testing of the Charpy V-notch impact specimens and tensile specimens was performed in the Remote Metallographic Facility (RMF) at the Westinghouse Science and Technology Center (STC). 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-9165[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 $\phi = 45°$ and $\rho = 0.010$ inch, Equation 1 is valid with C = 1.21. Therefore, (for L = 4W),

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

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

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

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

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

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

Percent shear was determined from post-fracture photographs using the ratio-of-areas methods in compliance with ASTM 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 W, irradiated to a fluence of 3.625 x 10^{19} n/cm^2 (E> 1.0 MeV) in 9.77 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 W 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 intermediate shell plate B9004-2 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major rolling direction (longitudinal orientation), to 3.625 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 71.04°F and a 50 ft-lb transition temperature increase of 78.5°F. This results in an irradiated 30 ft-lb transition temperature of 106.58°F and an irradiated 50 ft-lb transition temperature of 158.82°F for the longitudinal oriented specimens.

- Irradiation of the reactor vessel intermediate shell plate B9004-2 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major rolling direction of the plate (transverse orientation), to 3.625 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 63.39°F and a 50 ft-lb transition temperature increase of 72.5°F. This results in an irradiated 30 ft-lb transition temperature of 103.1°F and an irradiated 50 ft-lb transition temperature of 163.62°F for transverse oriented specimens.

- Irradiation of the weld metal Charpy specimens to 3.625 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 6.21°F and a 50 ft-lb transition temperature increase of 20.35°F. This results in an irradiated 30 ft-lb transition temperature of –33.53°F and an irradiated 50 ft-lb transition temperature of –1.3°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 3.625 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 51.54°F and a 50 ft-lb transition temperature increase of 46.32°F. This results in an irradiated 30 ft-lb transition temperature of –35.83°F and an irradiated 50 ft-lb transition temperature of 4.55°F.

- The average upper shelf energy of the intermediate shell plate B9004-2 (longitudinal orientation) resulted in an average energy decrease of 1 ft-lb after irradiation to 3.625 x 10^{19} n/cm^2 (E > 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 94 ft-lb for the longitudinal oriented specimens.

- The average upper shelf energy of the intermediate shell plate B9004-2 (transverse orientation) resulted in an average energy decrease of 4 ft-lb after irradiation to 3.625 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 75 ft-lb for the transverse oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted an average energy decrease of 3 ft-lb after irradiation to 3.625 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 136 ft-lb for the weld metal specimens.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in no energy decrease after irradiation to 3.625 x 10^{19} n/cm^2 (E> 1.0MeV). This results in an irradiated average upper shelf energy of 104 ft-lb for the weld HAZ metal.

- A comparison of the Beaver Valley Unit 2 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 the Intermediate Shell Plate B9004-2 contained in Capsules V & W (Longitudinal) and capsule W (Transverse) is greater then the Regulatory Guide 1.99, Rev. 2 predictions. However, the shift value is less than two sigma allowance by Regulatory Guide 1.99, Rev. 2.

  — The measured 30 ft-lb shift in transition temperature of all the remaining materials contained in Capsules U, V and W are less than the Regulatory Guide 1.99, Revision 2, predictions.

  — The measured percent decrease in upper shelf energy (USE) of all the Capsules U, V and W 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 W 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 (32 EFPY) as required by 10CFR50, Appendix G[4].

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

Appendix C of this report contains a credibility evaluation of the surveillance data from the Beaver Valley Unit 2 reactor vessel surveillance program. This evaluation indicates that the surveillance results are credible.

5.3 TENSILE TEST RESULTS

The results of the tensile tests performed on the various materials contained in Capsule W irradiated to 3.625 x 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 through 5-19.

The results of the tensile tests performed on the intermediate shell plate B9004-2 (longitudinal orientation) indicated that irradiation to 3.625 x 10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 10 ksi increase in the 0.2 percent offset yield strength and approximately a 8 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 intermediate shell plate B9004-2 (transverse orientation) indicated that irradiation to 3.625 x 10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 8 to 10 ksi increase in the 0.2 percent offset yield strength and approximately a 10 to 15 ksi increase in the ultimate tensile strength when compared to unirradiated data[1] (Figure 5-18).

The results of the tensile tests performed on the surveillance weld metal indicated that irradiation to 3.625 x 10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 5 to 10 ksi increase in the 0.2 percent offset yield strength and a 5 to 10 ksi increase in the ultimate tensile strength when compared to unirradiated data[1] (Figure 5-19).

The fractured tensile specimens for the intermediate shell plate B9004-2 material are shown in Figures 5-20 and 5-21, while the fractured tensile specimens for the surveillance weld metal are shown in Figure 5-22. The engineering stress-strain curves for the tensile tests are shown in Figures 5-23 through 5-28.

5.4 BEND BAR AND 1/2T COMPACT TENSION SPECIMENS

Per the surveillance capsule testing contract with the First Energy Company, bend bar and 1/2T compact tension specimens will not be tested. The specimens will be stored at the Westinghouse Science and Technology Center Hot Cell.

Table 5-1 Charpy V-notch Data for the Beaver Valley Unit 2 Intermediate Shell Plate B9004-2 Irradiated to a Fluence of 3.625 x 10^{19} n/cm^2 (E> 1.0 MeV) (Longitudinal Orientation)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	Ft-lbs	Joules	mils	Mm	%
WL40	-50	-46	6	8	0	0.00	2
WL42	0	-18	9	12	2	0.05	5
WL37	50	10	24	33	11	0.28	10
WL44	100	38	28	38	16	0.41	15
WL39	115	46	30	41	21	0.53	20
WL33	125	52	36	49	23	0.58	20
WL38	140	60	42	57	25	0.64	25
WL34	150	66	54	73	31	0.79	35
WL41	150	66	35	47	21	0.53	30
WL31	160	71	46	62	27	0.69	40
WL43	175	79	64	87	42	1.07	65
WL35	200	93	62	84	42	1.07	65
WL36	250	121	82	111	51	1.30	95
WL45	300	149	92	125	60	1.52	100
WL32	350	177	95	129	57	1.45	100

Table 5-2 Charpy V-notch Data for the Beaver Valley Unit 2 Intermediate Shell Plate B9004-2 Irradiated to a Fluence of 3.625×10^{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	%
WT33	-50	-46	11	15	7	0.18	2
WT44	0	-18	12	16	2	0.05	5
WT45	50	10	18	24	9	0.23	15
WT41	85	29	24	33	15	0.38	20
WT43	100	38	31	42	15	0.38	20
WT37	115	46	32	43	24	0.61	25
WT40	125	52	36	49	0	0.00	5
WT31	150	66	41	56	29	0.74	45
WT32	165	74	52	71	37	0.94	55
WT34	175	79	52	71	31	0.79	70
WT38	200	93	55	75	38	0.97	80
WT42	225	107	67	91	47	1.19	100
WT35	250	121	77	104	54	1.37	100
WT36	300	149	81	110	58	1.47	100
WT39	350	177	76	103	50	1.27	100

Table 5-3 Charpy V-notch Impact Data for Beaver Valley Unit 2 Surveillance Weld Metal Irradiated to a Fluence of 3.625 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	%
WW43	-75	-59	6	8	0	0.00	5
WW41	-50	-46	9	12	2	0.05	10
WW40	-25	-32	28	38	17	0.43	15
WW39	-20	-29	9	12	2	0.05	10
WW34	-15	-26	87	118	51	1.30	60
WW33	0	-18	47	64	30	0.76	25
WW35	15	-9	107	145	67	1.70	85
WW42	20	-7	78	106	46	1.17	65
WW45	25	-4	28	38	19	0.48	30
WW44	50	10	71	96	42	1.07	50
WW32	75	24	114	155	70	1.78	90
WW31	115	46	116	157	67	1.70	90
WW37	150	66	134	182	78	1.98	95
WW36	200	93	134	182	79	2.01	100
WW38	275	135	141	191	78	1.98	100

Table 5-4 Charpy V-notch Impact Data for Beaver Valley Unit 2 Representative Heat Affected Zone Material Irradiated to a Fluence of 3.625 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	%
WH44	-150	-101	13	18	1	0.03	5
WH37	-75	-59	14	19	3	0.08	10
WH45	-50	-46	26	35	10	0.25	25
WH36	-30	-34	58	79	34	0.86	60
WH39	-25	-32	32	43	18	0.46	40
WH38	-10	-23	11	15	11	0.28	15
WH43	-5	-21	44	60	21	0.53	25
WH42	0	-18	51	69	30	0.76	60
WH41	15	-9	64	87	42	1.07	70
WH34	50	10	76	103	40	1.02	85
WH33	100	38	78	106	45	1.14	100
WH35	125	52	82	111	52	1.32	100
WH32	150	66	129	175	74	1.88	100
WH31	200	93	133	180	79	2.01	100
WH40	275	135	97	132	56	1.42	100

Table 5-5 Instrumented Charpy Impact Test Results for the Beaver Valley Unit 2 Intermediate Shell Plate B9004-2 Irradiated to a Fluence of 3.625×10^{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)
WL40	-50	6	48	23	25	2743	0.13	2750	0.14	2743	0	91	91
WL42	0	9	73	44	29	4046	0.17	4046	0.17	4046	0	135	135
WL37	50	24	193	146	47	3983	0.17	4365	0.36	4363	0	133	139
WL44	100	28	226	147	79	3825	0.17	4253	0.37	4253	645	127	134
WL39	115	30	242	71	171	4386	0.17	4680	0.22	4425	1515	146	151
WL33	125	36	290	184	106	3811	0.17	4435	0.44	4428	1023	127	137
WL38	140	42	338	203	136	3727	0.17	4500	0.47	4462	1192	124	137
WL34	150	54	435	300	135	3706	0.17	4552	0.64	4488	1113	123	138
WL41	150	35	282	152	130	3675	0.17	4205	0.39	4201	1580	122	131
WL31	160	46	371	222	149	3662	0.17	4497	0.51	4463	1646	122	136
WL43	175	64	516	312	203	3699	0.17	4532	0.67	4383	1876	123	137
WL35	200	62	500	232	267	3693	0.17	4536	0.53	4336	2111	123	137
WL36	250	82	661	221	440	3594	0.17	4437	0.52	2711	1940	120	134
WL45	300	92	741	302	439	3516	0.17	4429	0.67	n/a	n/a	117	132
WL32	350	95	765	293	473	3270	0.17	4254	0.68	n/a	n/a	109	125

Table 5-6 Instrumented Charpy Impact Test Results for the Beaver Valley Unit 2 Intermediate Shell Plate B9004-2 Irradiated to a Fluence of 3.625 x 10^{19} n/cm^2 (E>1.0 MeV) (Transverse Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2) 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)
WT33	-50	11	89	50	39	4418	0.18	4422	0.18	4418	0	147	147
WT44	0	12	97	54	43	4168	0.17	4296	0.19	4283	0	139	141
WT45	50	18	145	69	76	3971	0.17	4252	0.22	4241	195	132	137
WT41	85	24	193	63	130	3824	0.17	4083	0.22	4040	487	127	132
WT43	100	31	250	159	91	3818	0.17	4294	0.39	4220	716	127	135
WT37	115	32	258	119	138	3746	0.17	4062	0.32	4010	1348	125	130
WT40	125	36	290	180	110	3748	0.17	4386	0.43	4326	1073	125	135
WT31	150	41	330	180	151	3550	0.17	4362	0.44	4278	1670	118	132
WT32	165	52	419	220	199	3609	0.17	4342	0.52	4196	2293	120	132
WT34	175	52	419	220	199	3604	0.17	4377	0.52	4271	2283	120	133
WT38	200	55	443	210	233	3512	0.17	4249	0.51	4045	2616	117	129
WT42	225	67	540	205	335	3418	0.17	4249	0.5	n/a	n/a	114	128
WT35	250	77	620	212	408	3297	0.17	4266	0.52	n/a	n/a	110	126
WT36	300	81	653	276	376	3369	0.17	4173	0.64	n/a	n/a	112	126
WT39	350	76	612	202	410	3282	0.17	4099	0.51	n/a	n/a	109	123

Table 5-7 Instrumented Charpy Impact Test Results for the Beaver Valley Unit 2 Surveillance Weld Metal Irradiated to a Fluence of 3.625 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)
WW43	-75	6	48	23	25	2634	0.15	2640	0.15	2634	0	88	88
WW41	-50	9	73	36	37	3655	0.16	3665	0.16	3655	0	122	122
WW40	-25	28	226	69	156	4233	0.17	4550	0.22	4356	256	141	146
WW39	-20	9	73	33	39	3404	0.17	3482	0.16	3404	0	113	115
WW34	-15	87	701	240	461	4177	0.17	4674	0.51	4179	1778	139	147
WW33	0	47	379	239	140	4066	0.17	4570	0.52	4322	440	135	144
WW35	15	107	862	328	534	4050	0.17	4539	0.68	3407	1355	135	143
WW42	20	78	628	329	299	4012	0.17	4517	0.68	4134	1264	134	142
WW45	25	28	226	67	159	3950	0.17	4229	0.22	4164	1029	132	136
WW44	50	71	572	317	255	3883	0.17	4413	0.68	4163	1350	129	138
WW32	75	114	919	314	604	3774	0.17	4415	0.68	3220	1760	126	136
WW31	115	116	935	308	626	3699	0.17	4320	0.68	3438	2733	123	134
WW37	150	134	1080	315	764	3761	0.17	4447	0.68	2604	1795	125	137
WW36	200	134	1080	303	776	3573	0.17	4282	0.68	n/a	n/a	119	131
WW38	275	141	1136	289	847	3349	0.17	4097	0.68	n/a	n/a	112	124

Table 5-8 Instrumented Charpy Impact Test Results for the Beaver Valley Unit 2 Representative Heat-Affected-Zone (HAZ) Metal Irradiated to a Fluence of 3.625 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)
WH44	-150	13	105	65	40	5057	0.17	5318	0.2	5318	0	168	173
WH37	-75	14	113	62	51	4673	0.17	4916	0.20	4916	0	156	160
WH45	-50	26	209	74	135	4450	0.17	4801	0.22	4603	603	148	154
WH36	-30	58	467	258	209	4417	0.17	4873	0.52	4666	1670	147	155
WH39	-25	32	258	72	186	4359	0.17	4651	0.22	4356	1233	145	150
WH38	-10	11	89	48	40	4084	0.17	4127	0.18	4125	0	136	137
WH43	-5	44	355	70	285	4264	0.17	4581	0.22	3861	1497	142	147
WH42	0	51	411	70	341	4301	0.17	4611	0.22	4549	1154	143	148
WH41	15	64	516	68	447	4404	0.17	4691	0.21	4434	1948	147	151
WH34	50	76	612	203	409	4148	0.17	4521	0.45	4176	2711	138	144
WH33	100	78	628	230	398	3986	0.17	4478	0.51	n/a	n/a	133	141
WH35	125	82	661	210	450	3802	0.17	4448	0.48	n/a	n/a	127	137
WH32	150	129	1039	329	710	3855	0.17	4601	0.69	n/a	n/a	128	141
WH31	200	133	1072	322	750	3823	0.17	4502	0.69	n/a	n/a	127	139
WH40	275	97	782	223	559	3662	0.17	4357	0.52	n/a	n/a	122	134

Table 5-9 Effect of Irradiation to 3.625 x 10^{19} n/cm^2 (E>1.0 MeV) on the Notch Toughness Properties of the Beaver Valley Unit 2 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*
Plate B9004-2 (Longitudinal)	35.54	106.58	71.04	82.95	173.36	90.41	80.31	158.82	78.5	95	94	-1
Plate B9004-2 (Transverse)	39.71	103.1	63.39	90.32	178.65	88.33	91.11	163.62	72.5	79	75	-4
Weld Metal	-39.75	-33.53	6.21	-19.94	9.13	29.08	-21.66	-1.3	20.35	139	136	-3
HAZ Metal	-87.37	-35.83	51.54	-21.71	28.32	50.03	-41.76	4.55	46.32	91	104	13

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 2 Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper Shelf Energy Decreases with Regulatory Guide 1.99, Revision 2, Predictions

Material	Capsule	Fluence (x 10^{19} n/cm^2)	30 ft-lb Transition Temperature Shift		Upper Shelf Energy Decrease	
			Predicted (°F) [(a)]	Measured (°F) [(b)]	Predicted (%) [(a)]	Measured (%)[(c)]
Intermediate Shell Plate B9004-2 (Longitudinal)	U	0.608	31.8	24.26	17	0
	V	2.63	46.6	55.93	23	10.5
	W	3.625	49.4	71.04	26	1.0
Intermediate Shell Plate B9004-2 (Transverse)	U	0.608	31.8	17.56	17	0
	V	2.63	46.6	46.27	23	4.0
	W	3.625	49.4	63.39	26	5.0
Weld Metal	U	0.608	32.7	3.64	18	4.0
	V	2.63	47.9	25.47	25	2.0
	W	3.625	50.7	6.21	28	2.0
HAZ Metal	U	0.608	--	0(d)	---	0
	V	2.63	--	41.47	---	4.0
	W	3.625	--	51.54	---	0

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 B)

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

(d) The actual measured Capsule W ΔRT_{NDT} value is –1.9°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 2 Reactor Vessel Surveillance Materials Irradiated to 3.625×10^{19} n/cm^2 (E > 1.0 MeV)

Material	Sample Number	Test Temp. (°F)	0.2% Yield Strength (ksi)	Ultimate Strength (ksi)	Fracture Load (kip)	Fracture Stress (ksi)	Fracture Strength (ksi)	Uniform Elongation (%)	Total Elongation (%)	Reduction in Area (%)
Intermediate Shell Plate B9004-2 (Longitudinal)	WL7 *	115	80.5	101.1	3.26	192.0	66.4	11.3	27.2	65
	WL8 *	240	75.4	96.0	3.24	171.5	65.9	10.5	22.9	62
	WL9	550	72.3	100.4	3.80	174.1	77.4	12.3	22.5	56
Intermediate Shell Plate B9004-2 (Transverse)	WT7	125	79.5	101.1	3.58	182.5	72.9	10.9	22.2	60
	WT8	245	76.4	96.8	3.66	169.1	74.5	9.8	19.3	56
	WT9	550	72.8	101.6	3.98	161.5	81.0	11.3	20.1	50
Surveillance Weld Metal	WW7	10	82.5	98.7	3.03	221.3	61.7	11.9	26.8	72
	WW8	125	78.9	92.9	2.82	216.0	57.5	11.7	23.8	73
	WW9	550	73.8	92.9	3.09	142.9	63.0	13.3	22.4	56

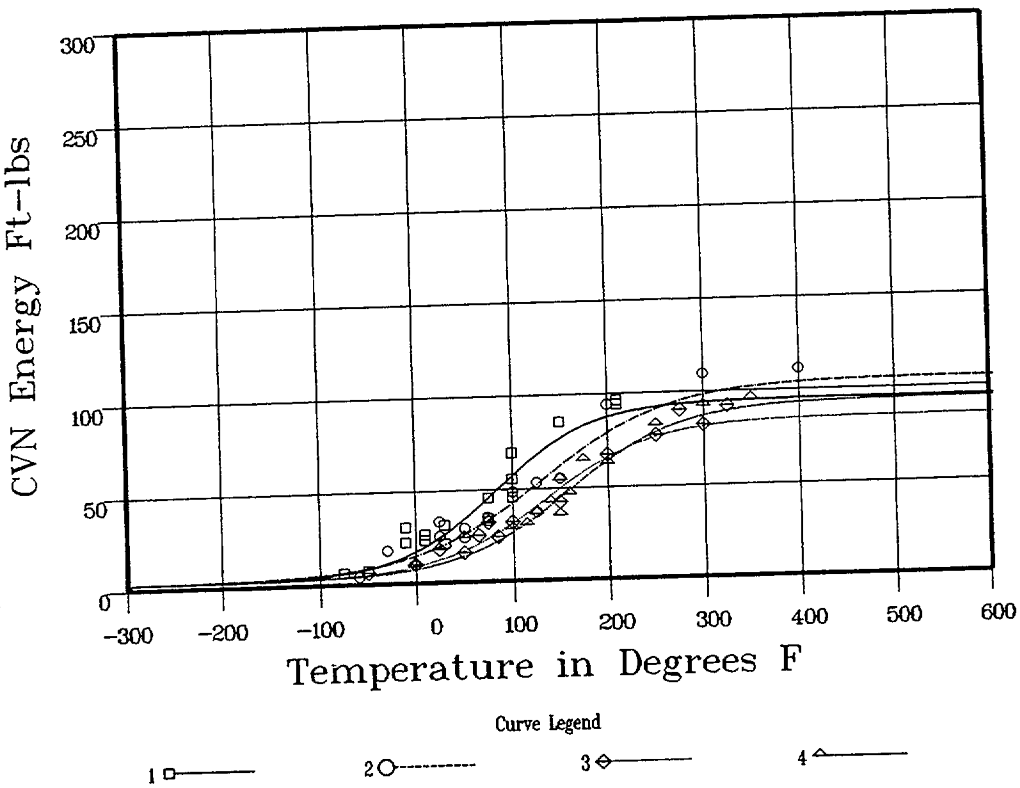
* May not be accurate due to clip gage slippage at end of test.

INTERMEDIATE SHELL PLATE B9004-2 (LONG.)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:17:08 on 02-05-2001

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	95	0	35.54	0	80.31	0
2	0	2.19	0	105	10	59.8	24.26	115.52	35.21
3	0	2.19	0	85	-10	91.48	55.93	146.48	66.17
4	0	2.19	0	94	-1	106.58	71.04	158.82	78.5



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV2	UNIRR	PLATE SA533B1	LT	C0544-2
2	BV2	U	PLATE SA533B1	LT	C0544-2
3	BV2	V	PLATE SA533B1	LT	C0544-2
4	BV2	W	PLATE SA533B1	LT	C0544-2

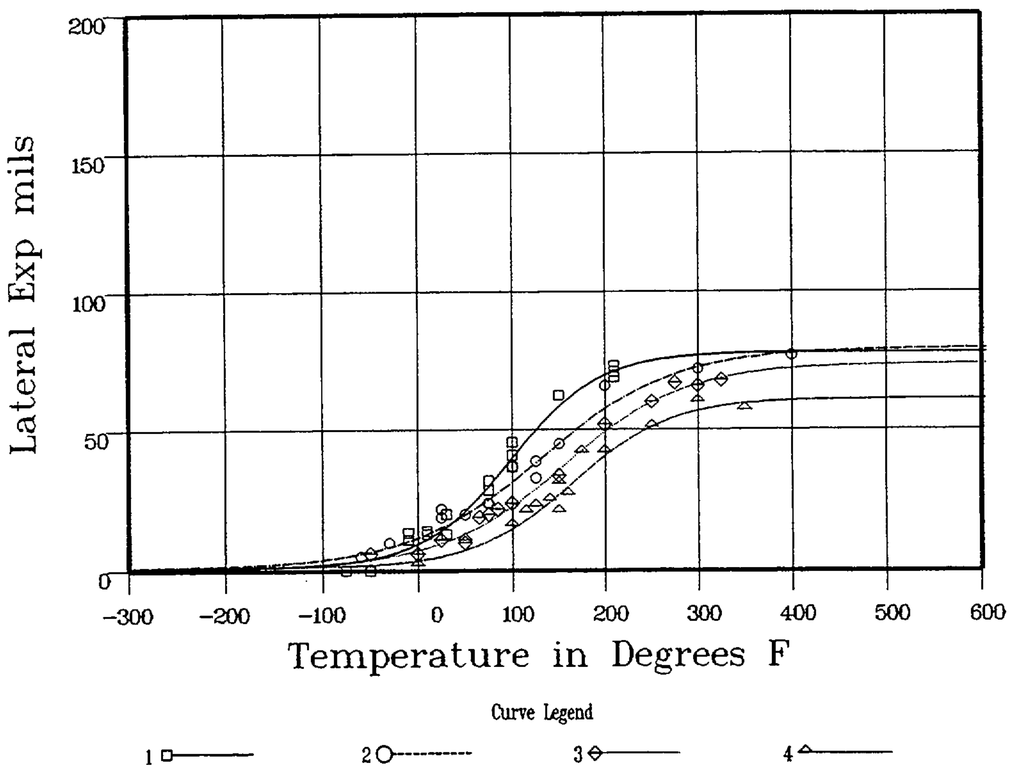
Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2(Longitudinal Orientation)

INTERMEDIATE SHELL PLATE B9004-2 (LONG.)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:33:10 on 02-05-2001

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	78.03	0	82.95	0
2	0	79.42	1.39	107.91	24.96
3	0	73.81	-4.22	141.91	58.95
4	0	61.16	-16.86	173.36	90.41



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV2	UNIRR	PLATE SA533B1	LT	C0544-2
2	BV2	U	PLATE SA533B1	LT	C0544-2
3	BV2	V	PLATE SA533B1	LT	C0544-2
4	BV2	W	PLATE SA533B1	LT	C0544-2

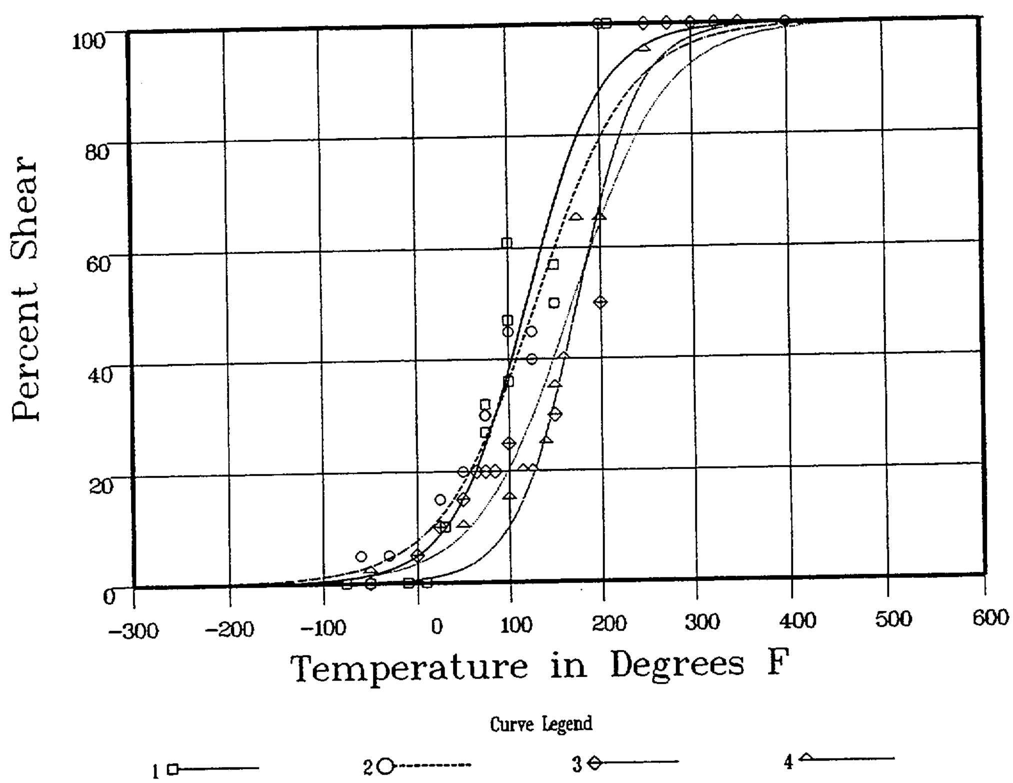
Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2(Longitudinal Orientation)

INTERMEDIATE SHELL PLATE B9004-2 (LONG.)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:50:32 on 02-05-2001

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	115.42	0
2	0	125.09	9.66
3	0	164.94	49.51
4	0	170.15	54.72



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV2	UNIRR	PLATE SA533B1	LT	C0544-2
2	BV2	U	PLATE SA533B1	LT	C0544-2
3	BV2	V	PLATE SA533B1	LT	C0544-2
4	BV2	W	PLATE SA533B1	LT	C0544-2

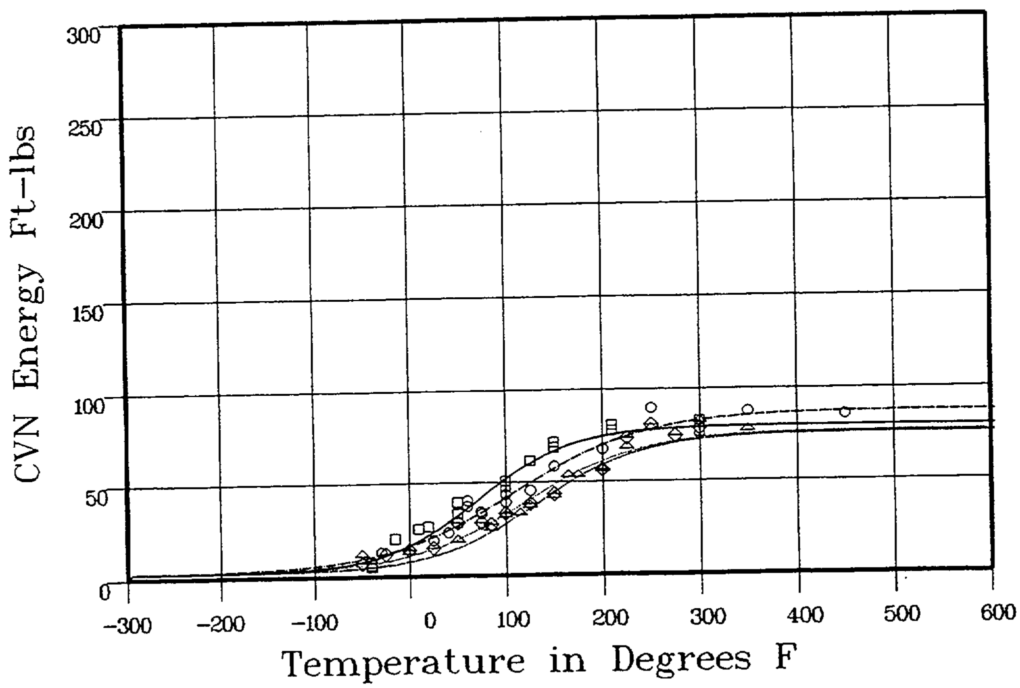
Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2(Longitudinal Orientation)

IINTERMEDIATE SHELL PLATE (TRANS.)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:42:39 on 02-05-2001

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	79	0	39.71	0	91.11	0
2	0	2.19	0	87	8	57.28	17.56	122.65	31.54
3	0	2.19	0	76	-3	85.99	46.27	151.95	60.83
4	0	2.19	0	75	-4	103.1	63.39	163.62	72.5



Curve Legend

1 □——— 2 ○--------- 3 ◇——— 4 △———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV2	UNIRR	PLATE SA533B1	TL	C0544-2
2	BV2	U	PLATE SA533B1	TL	C0544-2
3	BV2	V	PLATE SA533B1	TL	C0544-2
4	BV2	W	PLATE SA533B1	TL	C0544-2

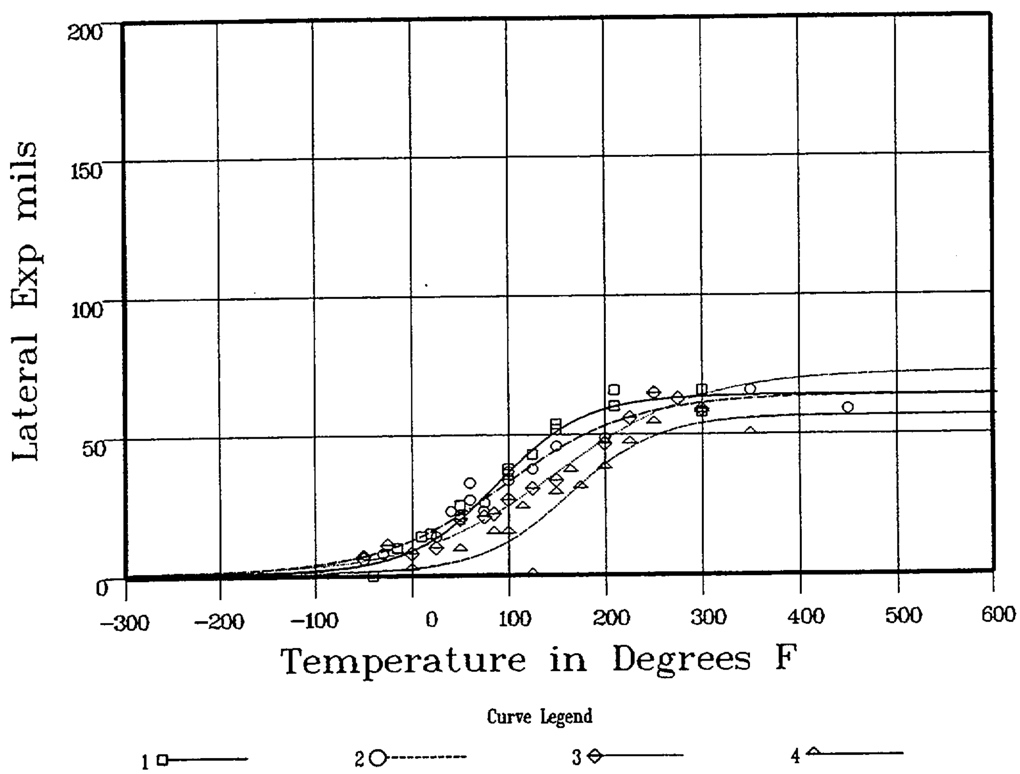
Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2(Transverse Orientation)

INTERMEDIATE SHELL PLATE B9004-2 (TRANS.)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:47:53 on 02-05-2001

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	64.21	0	90.32	0
2	0	64.12	-.09	102.02	11.69
3	0	72.35	8.13	138.38	48.06
4	0	56.69	-7.52	178.65	88.33



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV2	UNIRR	PLATE SA533B1	TL	C0544-2
2	BV2	U	PLATE SA533B1	TL	C0544-2
3	BV2	V	PLATE SA533B1	TL	C0544-2
4	BV2	W	PLATE SA533B1	TL	C0544-2

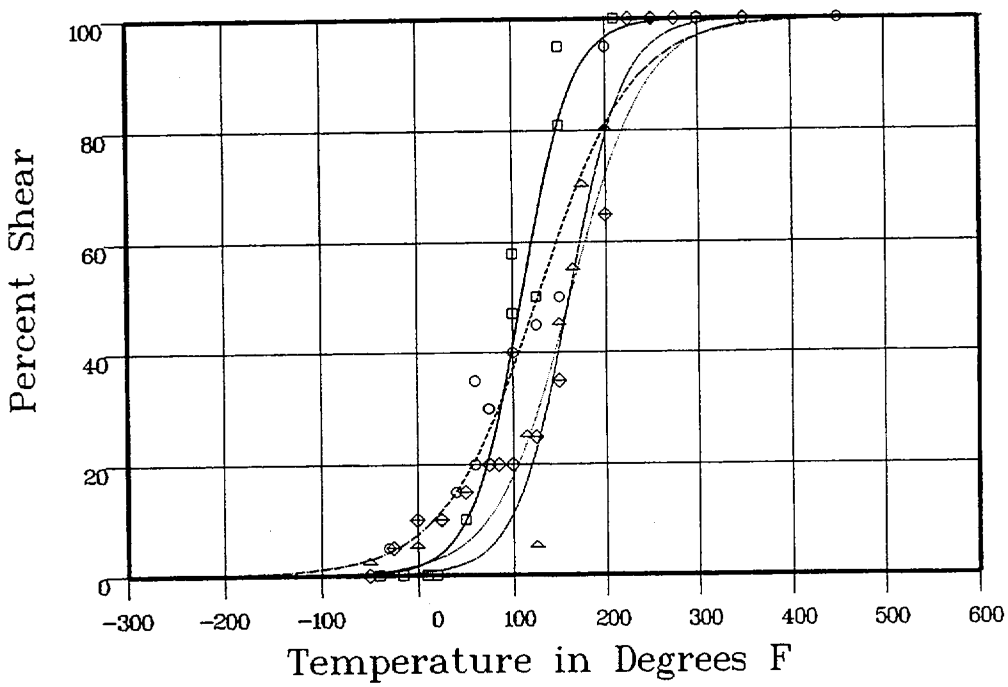
Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2(Transverse Orientation)

INTERMEDIATE SHELL PLATE B9004-2 (TRANS.)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:52:28 on 02-05-2001

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	104.88	0
2	0	122.16	17.28
3	0	157.03	52.14
4	0	156.13	51.25



Curve Legend

1 □——— 2 ○---------- 3 ◇——— 4 △———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV2	UNIRR	PLATE SA533B1	TL	C0544-2
2	BV2	U	PLATE SA533B1	TL	C0544-2
3	BV2	V	PLATE SA533B1	TL	C0544-2
4	BV2	W	PLATE SA533B1	TL	C0544-2

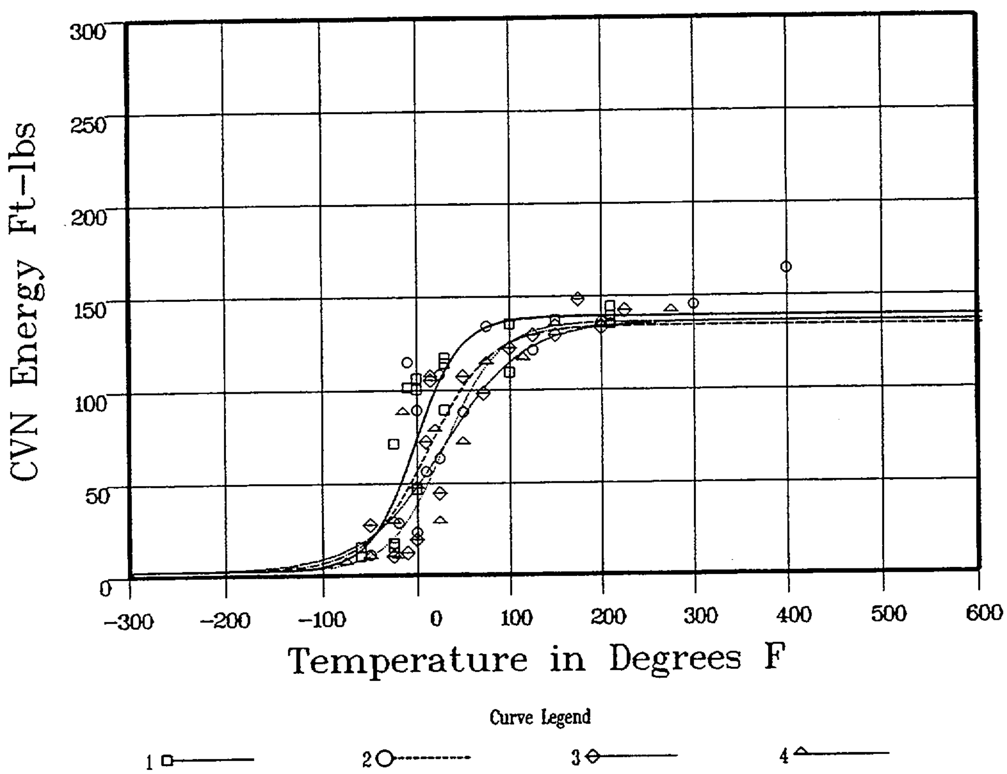
Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2(Transverse Orientation)

SURVEILLANCE PROGAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:19:09 on 02-06-2001

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	139	0	-39.75	0	-21.66	0
2	0	2.19	0	134	-5	-36.11	3.64	-10.86	10.79
3	0	2.19	0	136	-3	-14.28	25.47	7.67	29.33
4	0	2.19	0	136	-3	-33.53	6.21	-1.3	20.35



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV2	UNIRR	WELD LINDE 91		83642
2	BV2	U	WELD LINDE 91		83642
3	BV2	V	WELD LINDE 91		83642
4	BV2	W	WELD LINDE 91		83642

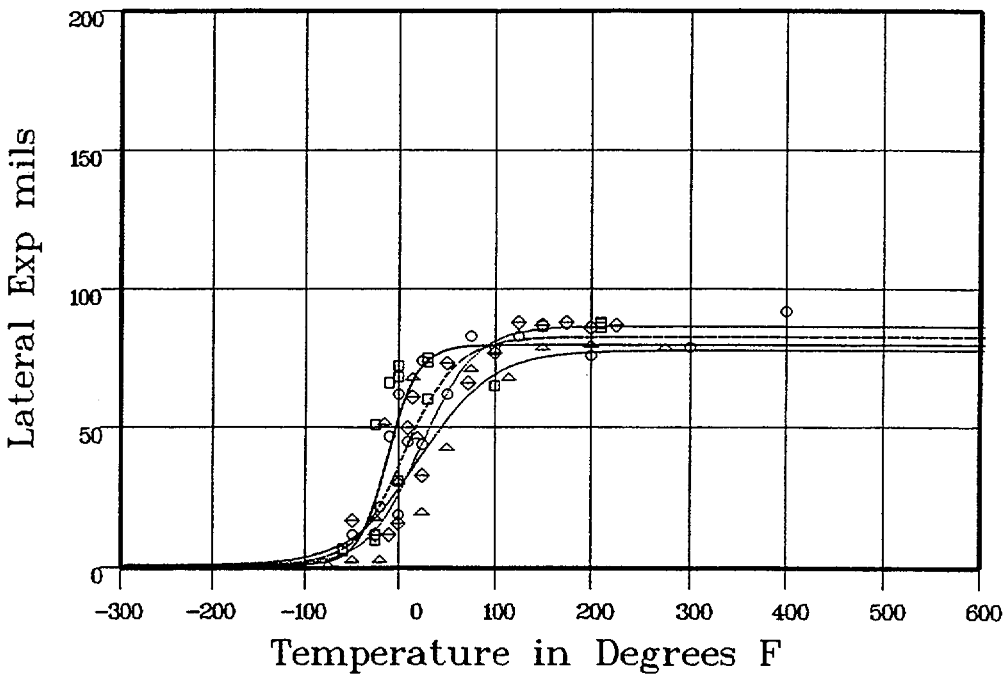
Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Weld Metal

SURVIELLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:32:46 on 04-30-2001

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	79.85	0	-19.94	0
2	0	82.66	2.8	-6.12	13.81
3	0	86.47	6.61	7.7	27.64
4	0	77.8	-2.05	9.13	29.08



Curve Legend

1 □——— 2 ○- - - - 3 ◇——— 4 △———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV2	UNIRR	WELD LINDE 91		83642
2	BV2	U	WELD LINDE 91		83642
3	BV2	V	WELD LINDE 91		83642
4	BV2	W	WELD LINDE 91		83642

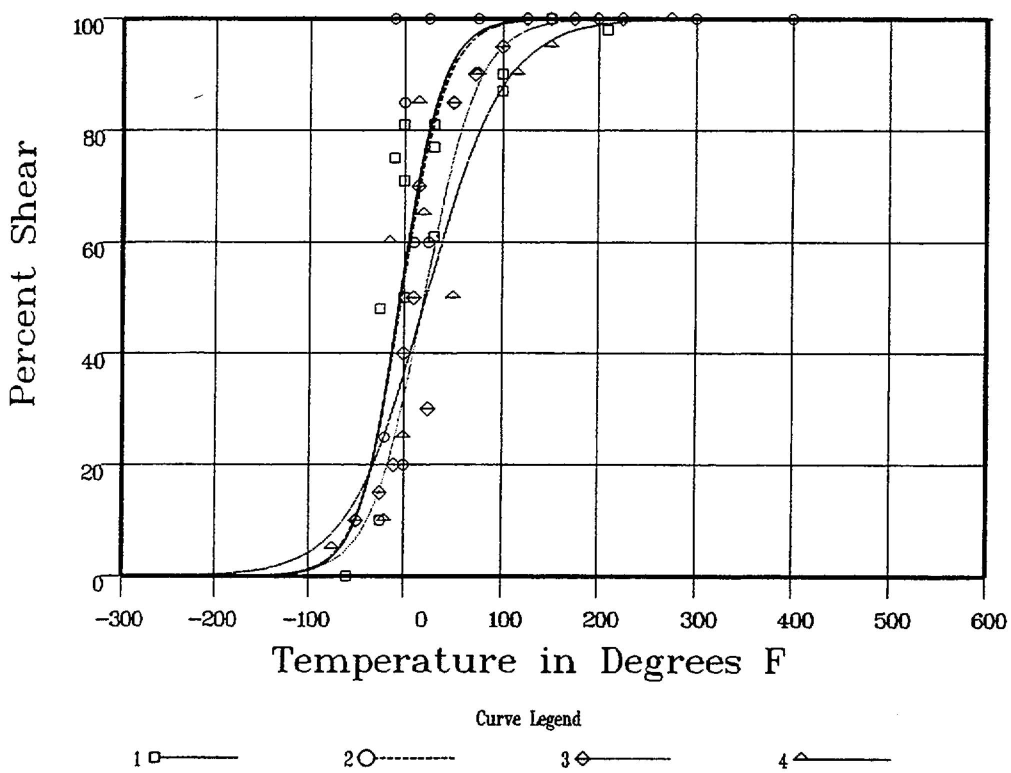
Figure 5-8 Charpy V-Notch Lateral Expansion vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Weld Metal

SURVIELLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:31:28 on 02-06-2001

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	-8.7	0
2	0	-7.5	1.2
3	0	15.93	24.63
4	0	17.81	26.51



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV2	UNIRR	WELD LINDE 91		83642
2	BV2	U	WELD LINDE 91		83642
3	BV2	V	WELD LINDE 91		83642
4	BV2	W	WELD LINDE 91		83642

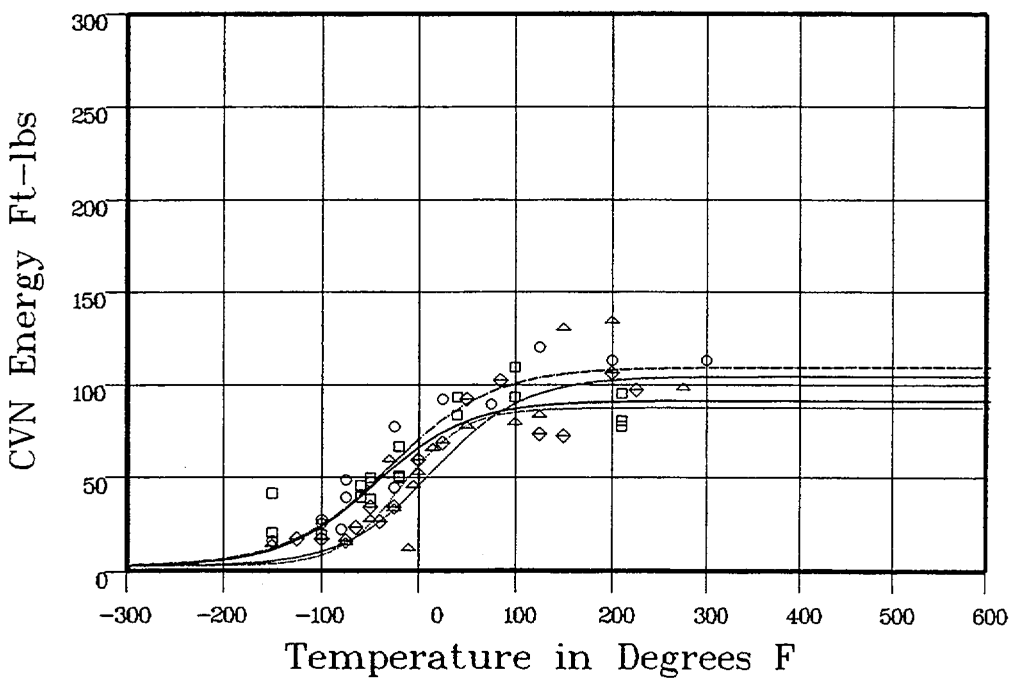
Figure 5-9 Charpy V-Notch Percent Shear vs Temperature for Beaver Valley Unit 2 Reactor Vessel Weld Metal

HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:42:58 on 02-06-2001

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	91	0	-87.37	0	-41.76	0
2	0	2.19	0	109	18	-89.28	-1.9	-45.1	-3.33
3	0	2.19	0	87	-4	-45.9	41.47	-14.15	27.61
4	0	2.19	0	104	13	-35.83	51.54	4.55	46.32



Curve Legend

1 □——— 2 ○--------- 3 ◇——— 4 △———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV2	UNIRR	HEAT AFFD ZONE		
2	BV2	U	HEAT AFFD ZONE		
3	BV2	V	HEAT AFFD ZONE		
4	BV2	W	HEAT AFFD ZONE		

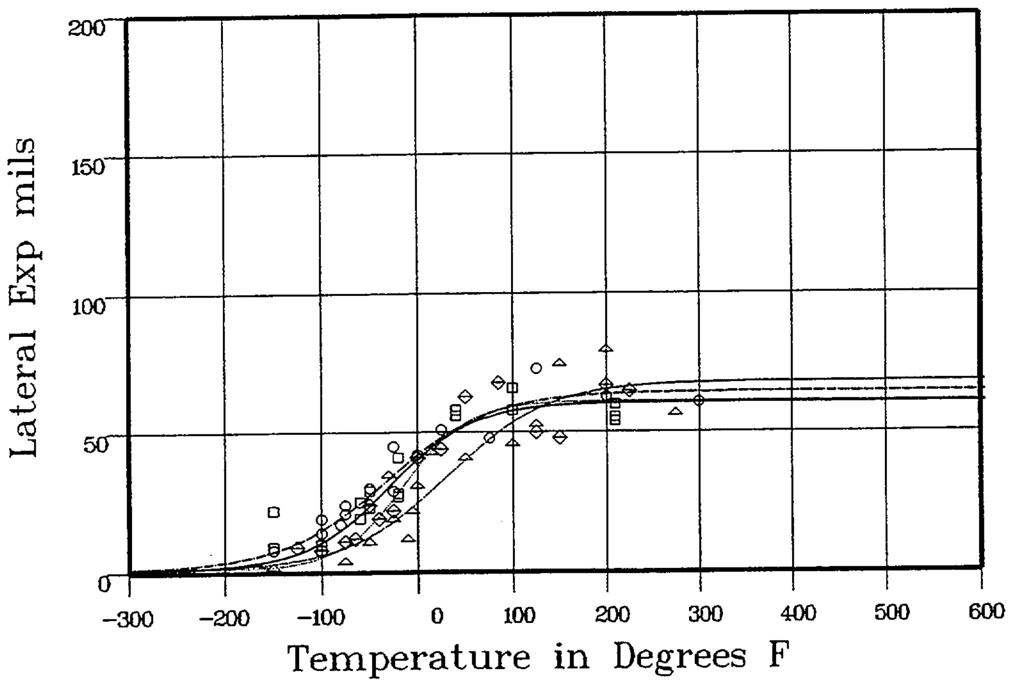
Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:47:12 on 02-06-2001

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	60.74	0	-21.71	0
2	0	64.63	3.89	-29.13	-7.42
3	0	61.26	.51	-10.04	11.67
4	0	68.27	7.53	28.32	50.03



Curve Legend

1 □——— 2 ○--------- 3 ◇——— 4 △———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV2	UNIRR	HEAT AFFD ZONE		
2	BV2	U	HEAT AFFD ZONE		
3	BV2	V	HEAT AFFD ZONE		
4	BV2	W	HEAT AFFD ZONE		

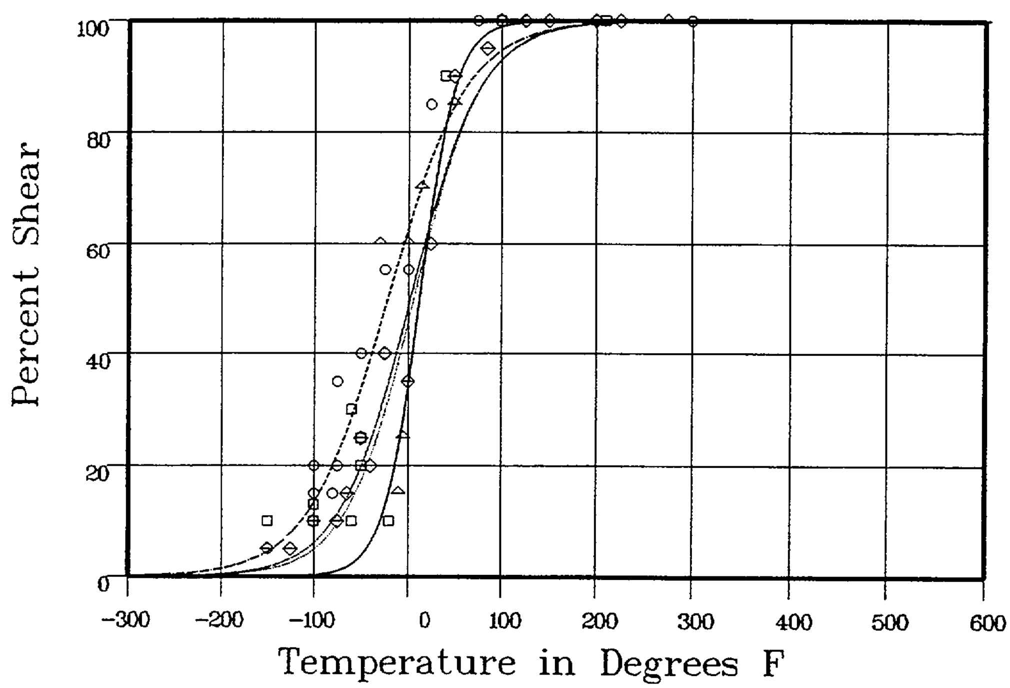
Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:50:44 on 02-06-2001

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	7.96	0
2	0	-26.25	-34.21
3	0	1.87	-6.09
4	0	-1.87	-9.84



Curve Legend

1 □———— 2 ○---------- 3 ◇———— 4 △————

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	BV2	UNIRR	HEAT AFFD ZONE		
2	BV2	U	HEAT AFFD ZONE		
3	BV2	V	HEAT AFFD ZONE		
4	BV2	W	HEAT AFFD ZONE		

Figure 5-12 Charpy V-Notch Percent Shear vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Heat-Affected-Zone Material

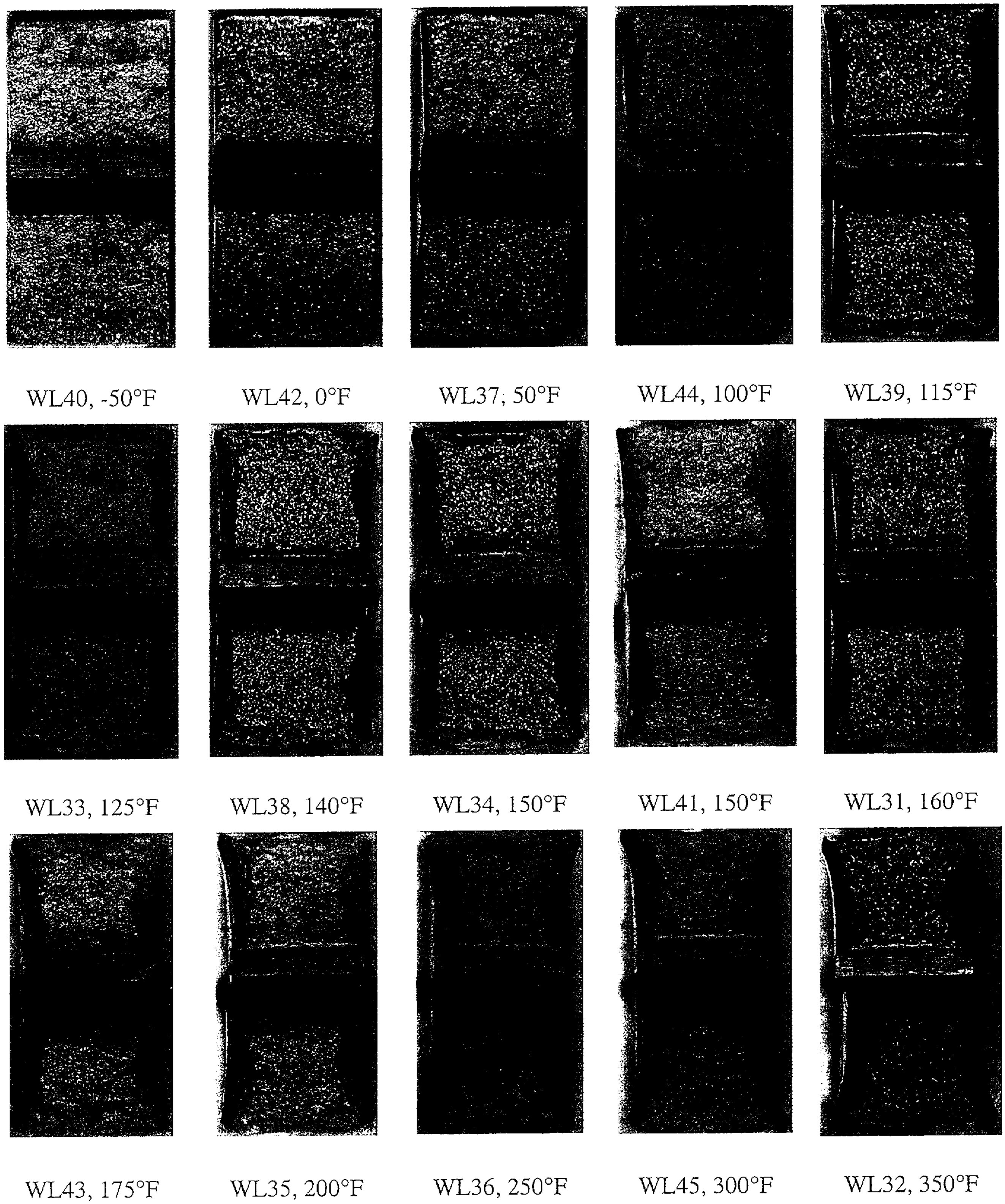
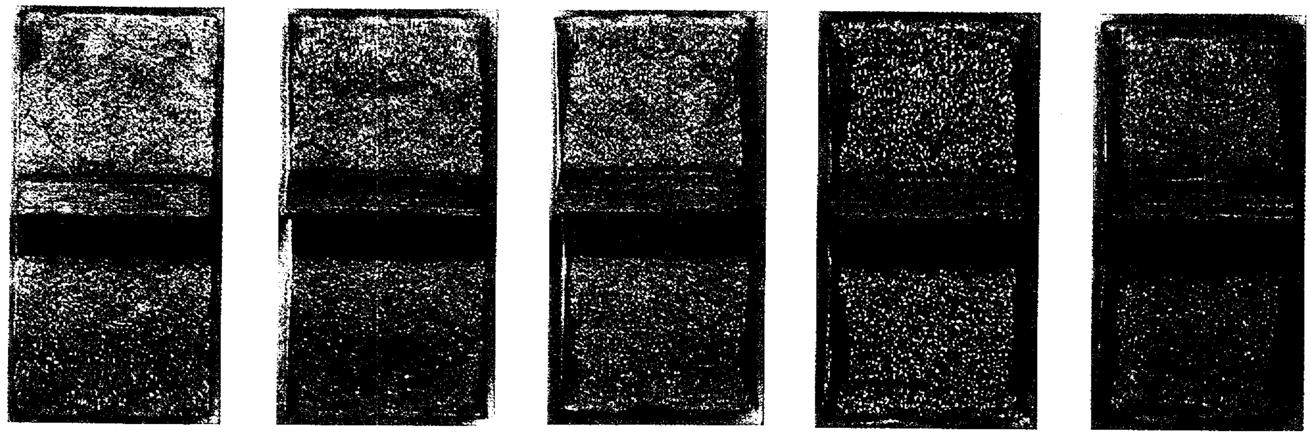
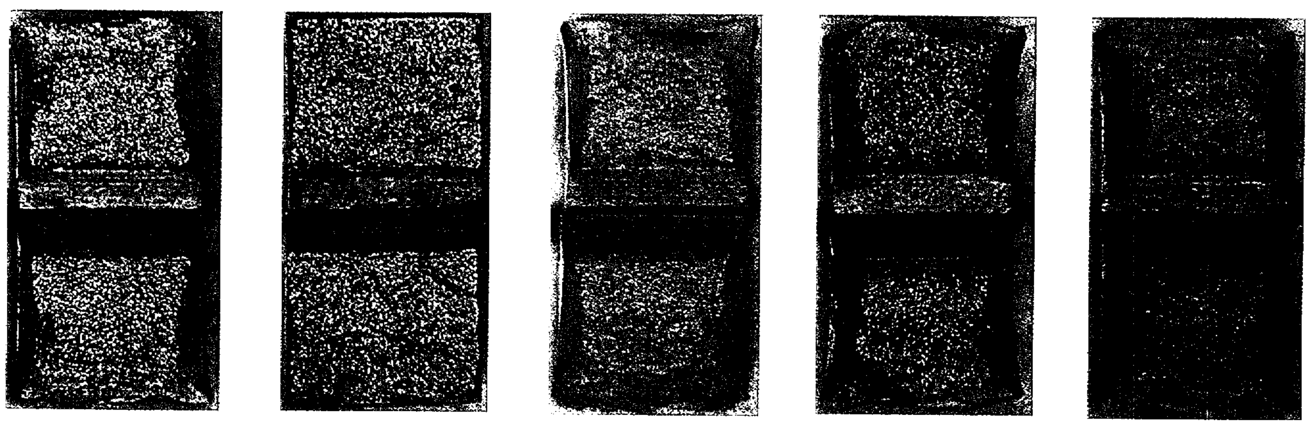


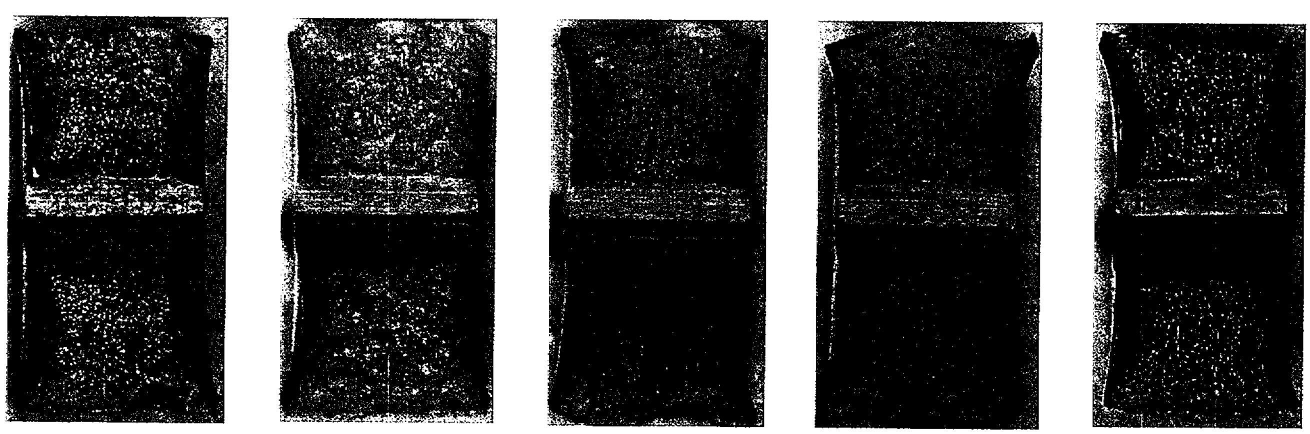
Figure 5-13 Charpy Impact Specimen Fracture Surfaces for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2(Longitudinal Orientation)



WT33, -50°F | WT44, 0°F | WT45, 50°F | WT41, 85°F | WT43, 100°F



WT37, 115°F | WT40, 125°F | WT31, 150°F | WT32, 165°F | WT34, 175°F



WT38, 200°F | WT42, 225°F | WT35, 250°F | WT36, 300°F | WT39, 350°F

Figure 5-14 Charpy Impact Specimen Fracture Surfaces for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Transverse Orientation)

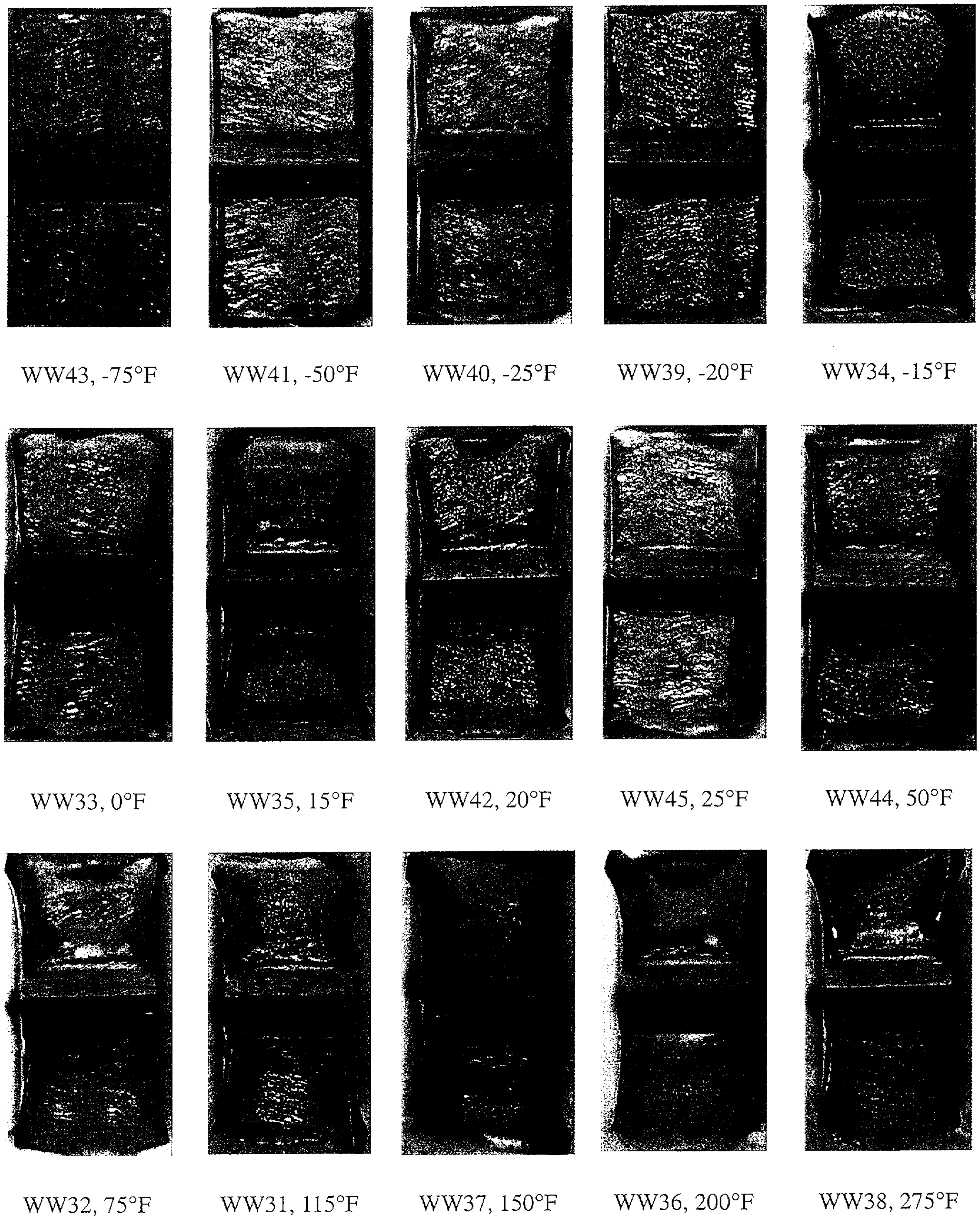


Figure 5-15 Charpy Impact Specimen Fracture Surfaces for Beaver Valley Unit 2 Reactor Vessel Weld Metal Specimen

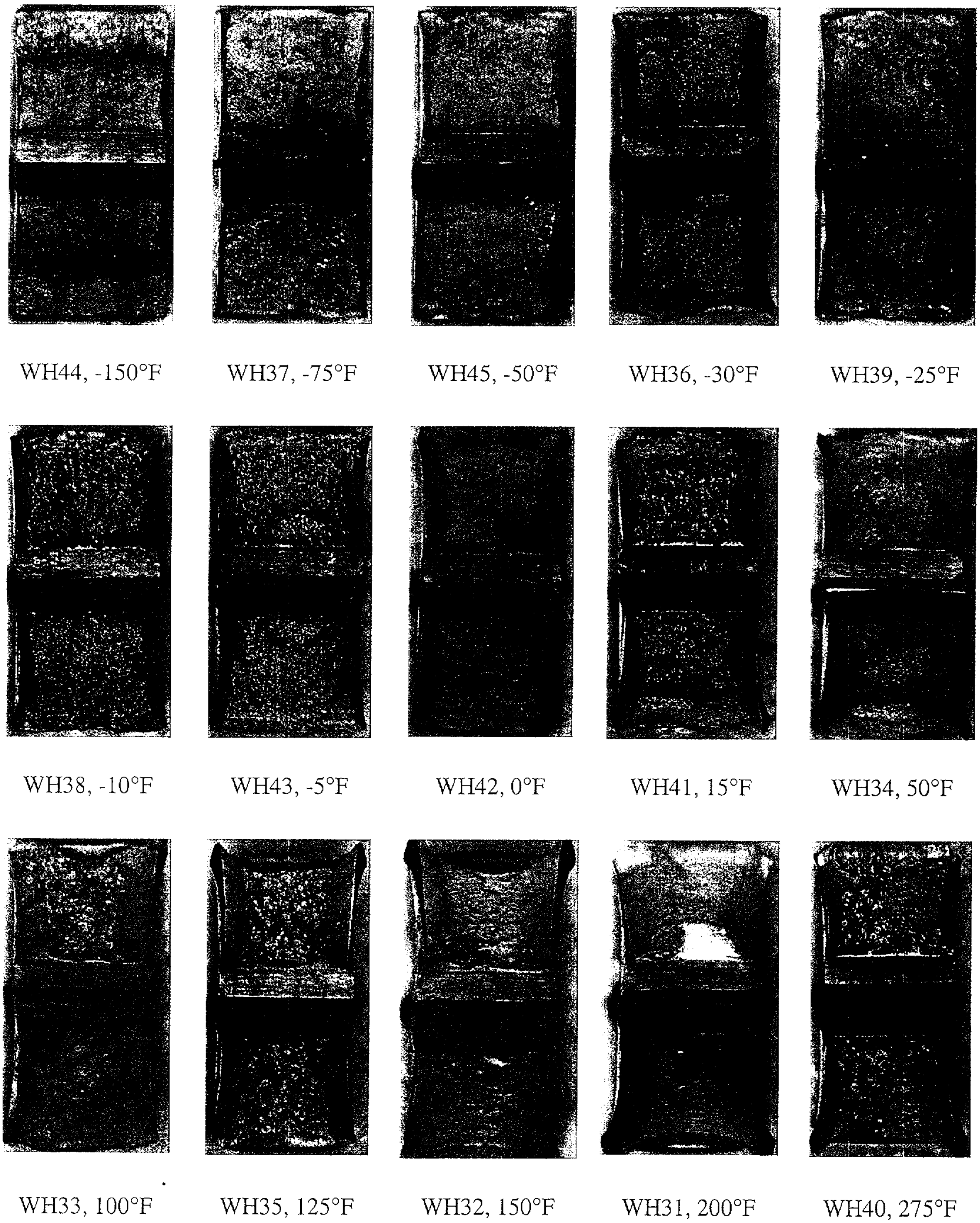


Figure 5-16 Charpy Impact Specimen Fracture Surfaces for Beaver Valley Unit 2 Reactor Vessel Heat-Affected-Zone Metal

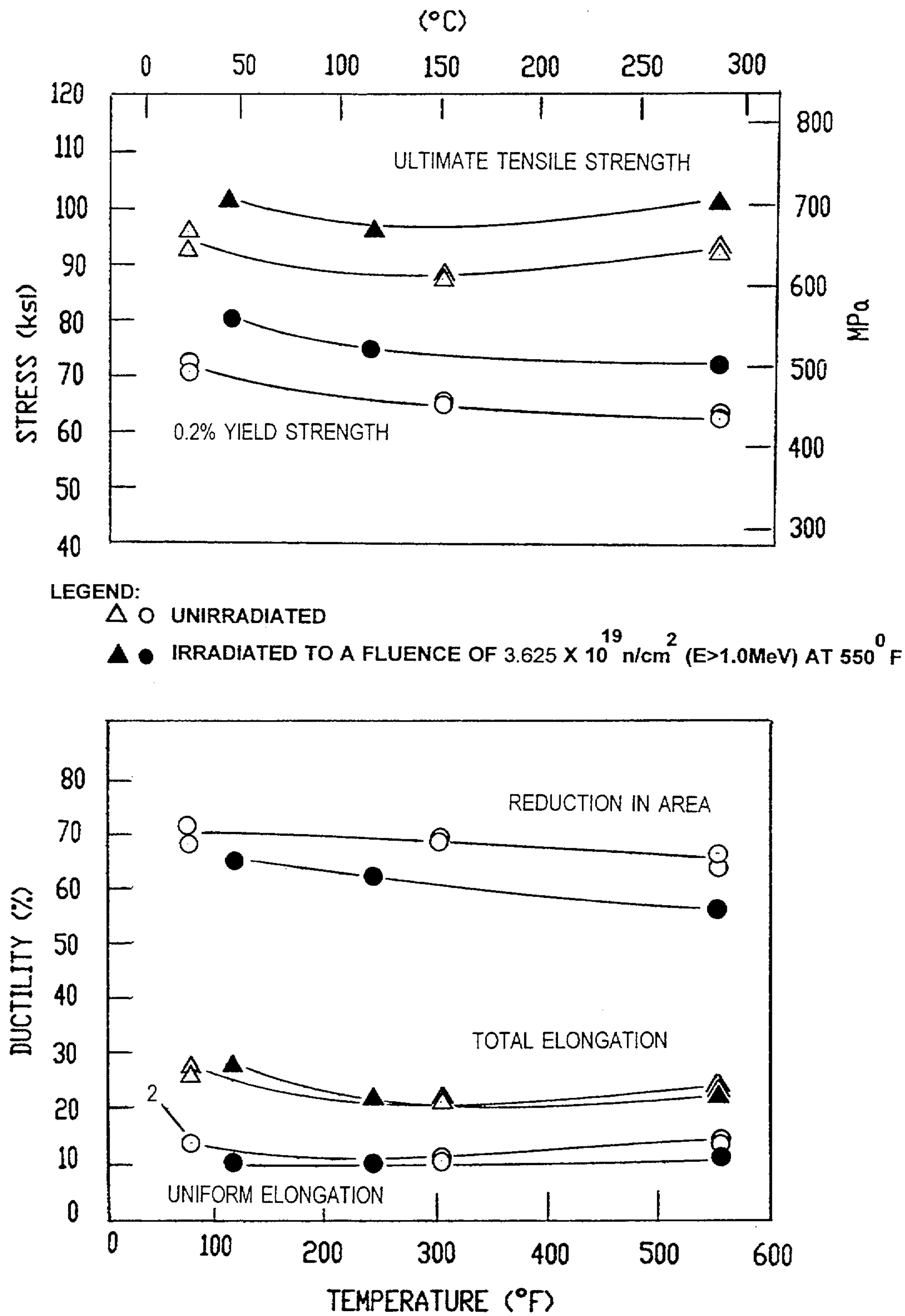


Figure 5-17 Tensile Properties for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Longitudinal Orientation)

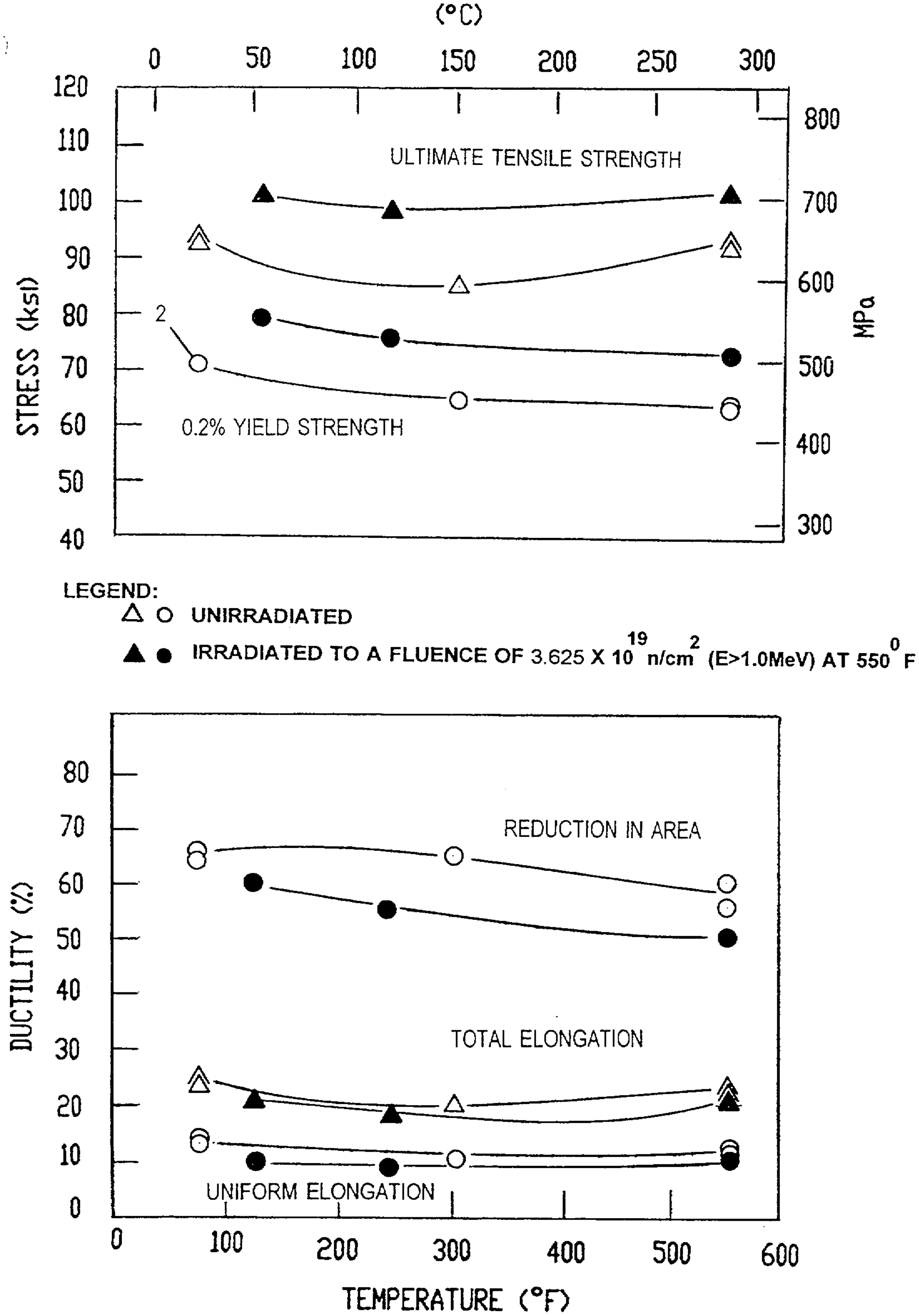


Figure 5-18 Tensile Properties for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Transverse Orientation)

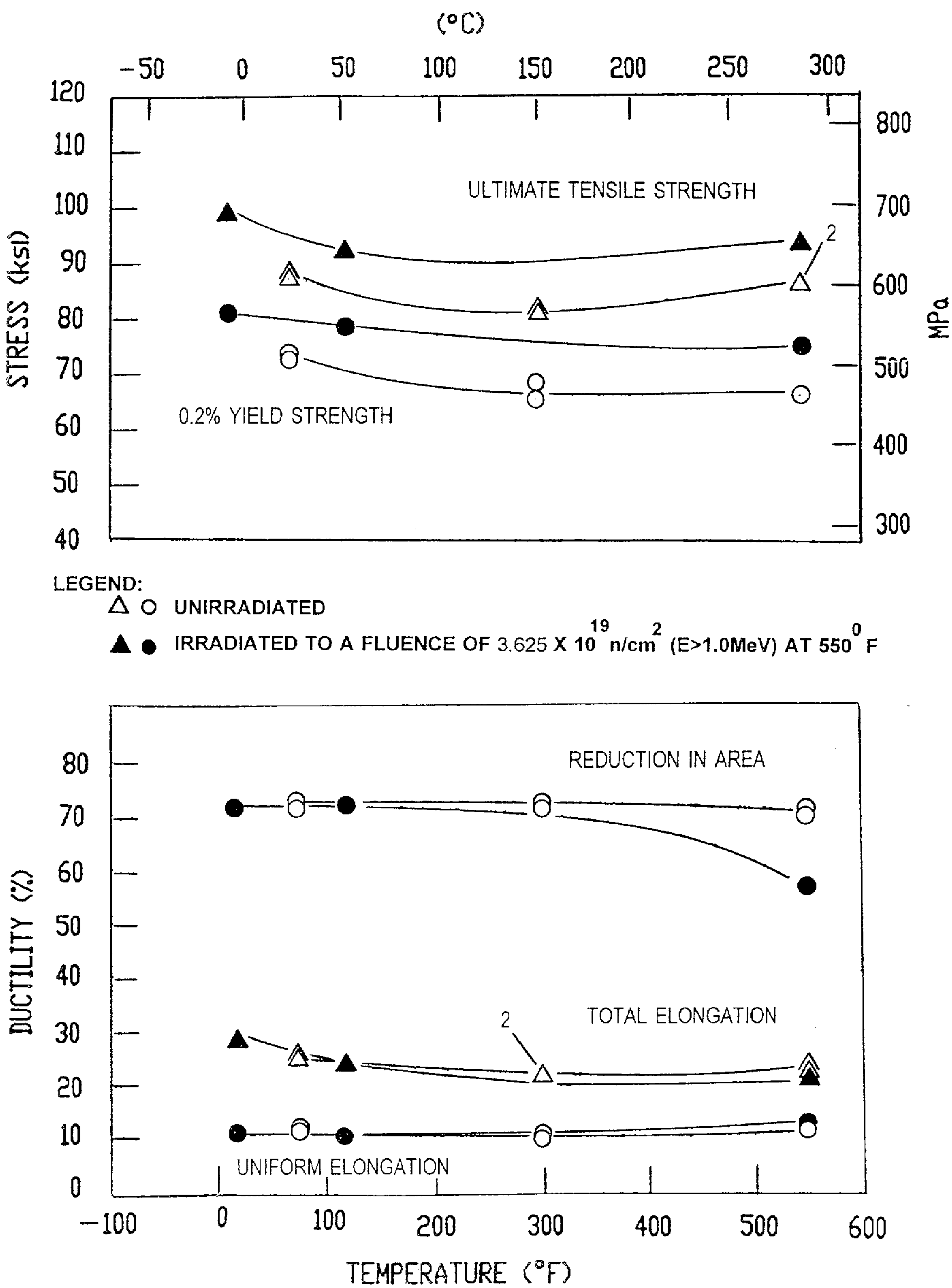
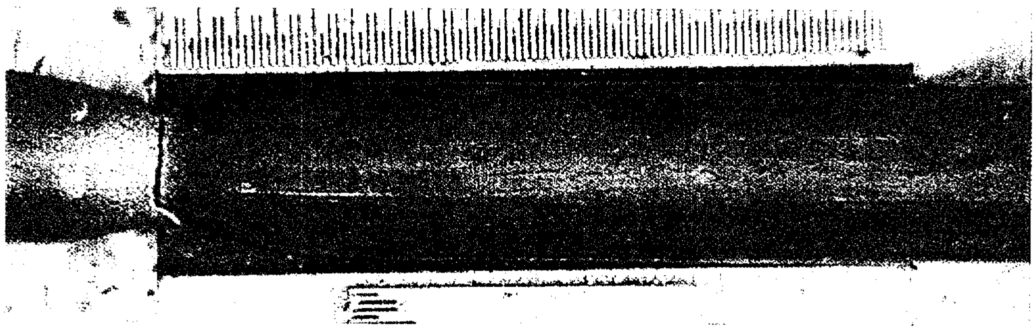
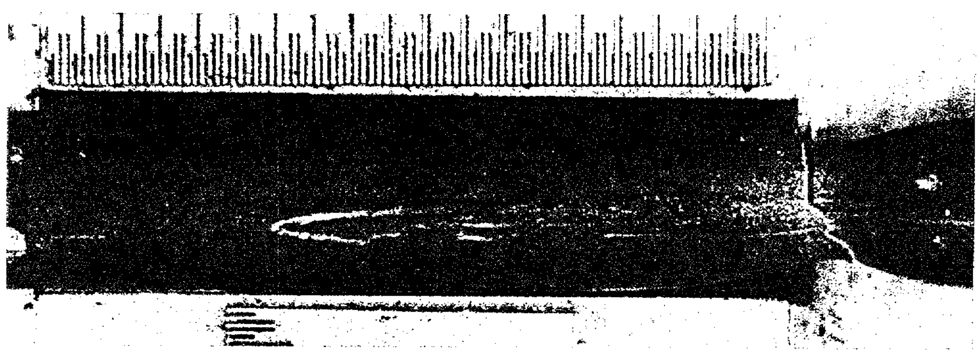


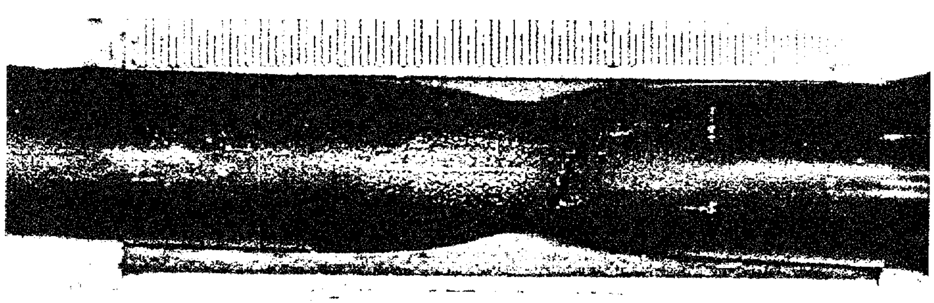
Figure 5-19 Tensile Properties for the Beaver Valley Unit 2 Reactor Vessel Weld Metal



Specimen WL7 Tested at 115°F

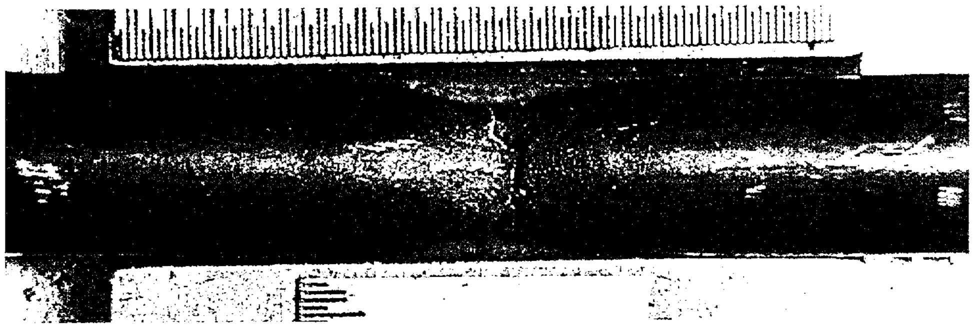


Specimen WL8 Tested at 240°F

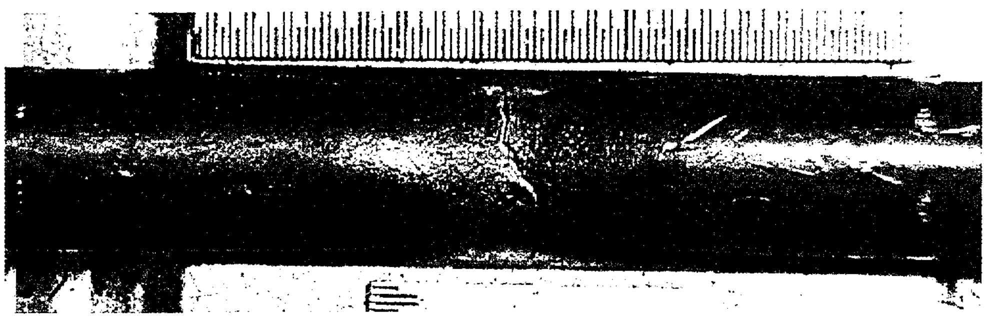


Specimen WL9 Tested at 550°F

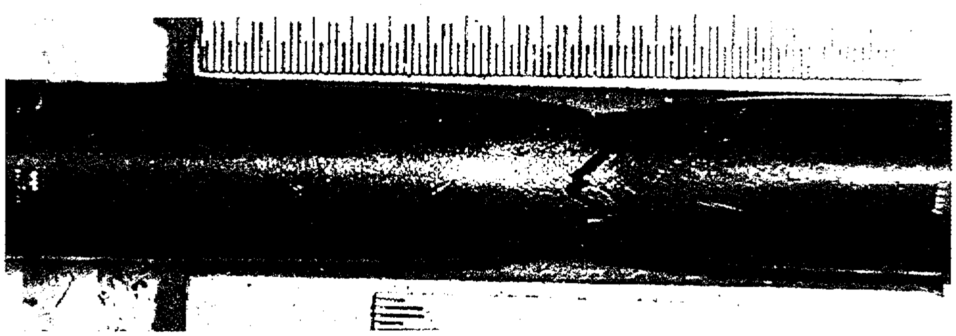
Figure 5-20 Fractured Tensile Specimens from Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2(Longitudinal Orientation)



Specimen WT7 Tested at 125°F

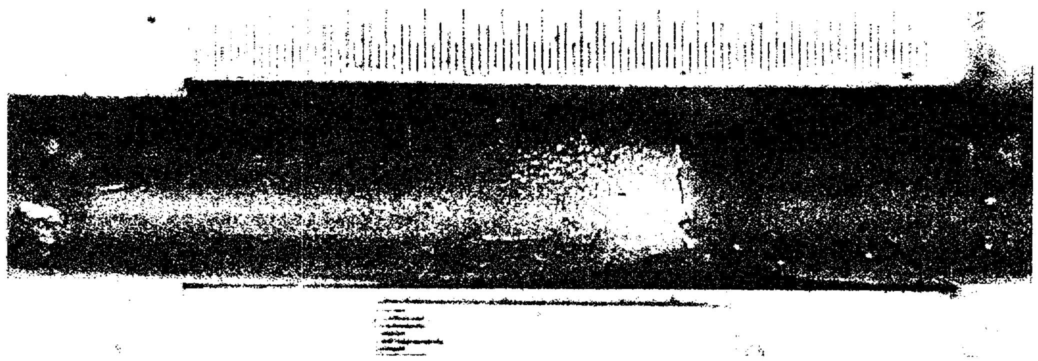


Specimen WT8 Tested at 245°F

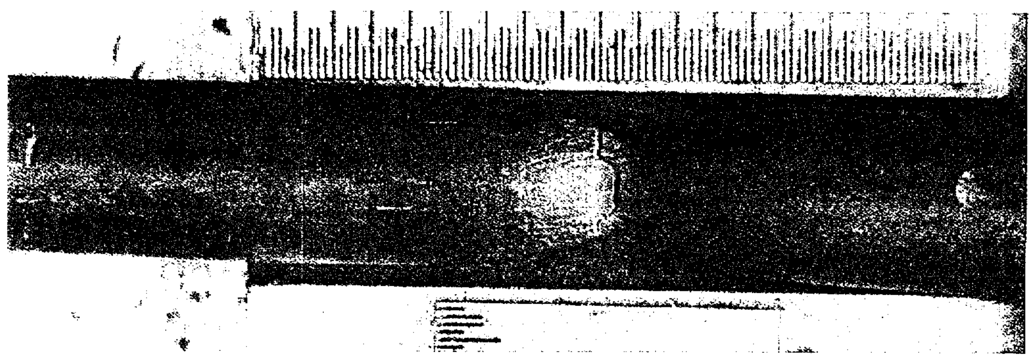


Specimen WT9 Tested at 550°F

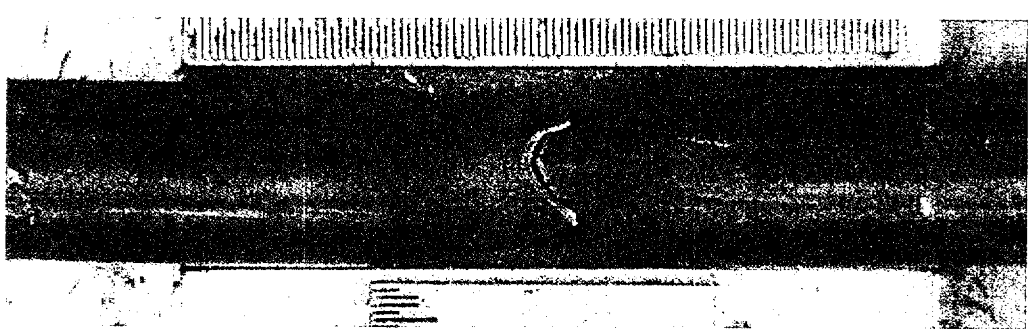
Figure 5-21 Fractured Tensile Specimens from Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2(Transverse Orientation)



Specimen WW7 Tested at 10°F

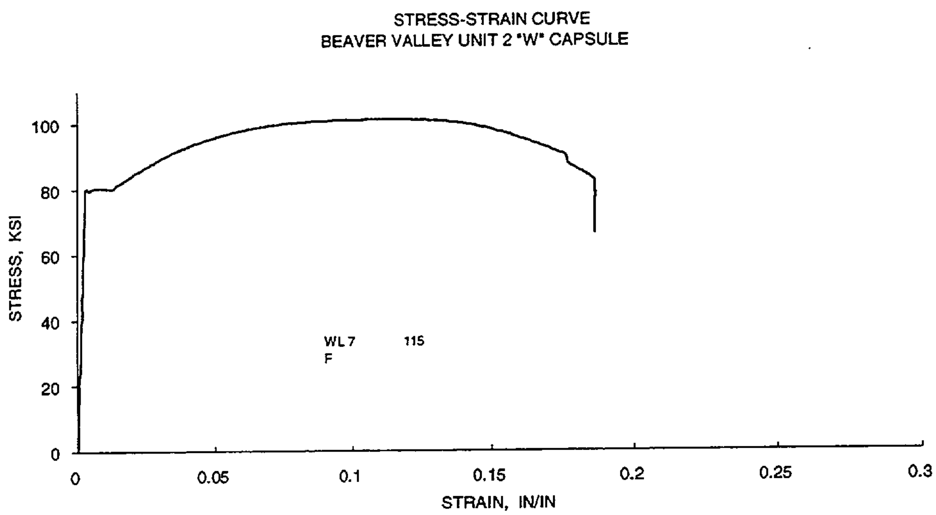


Specimen WW8 Tested at 125°F



Specimen WW9 Tested at 550°F

Figure 5-22 Fractured Tensile Specimens from Beaver Valley Unit 2 Reactor Vessel Weld Metal



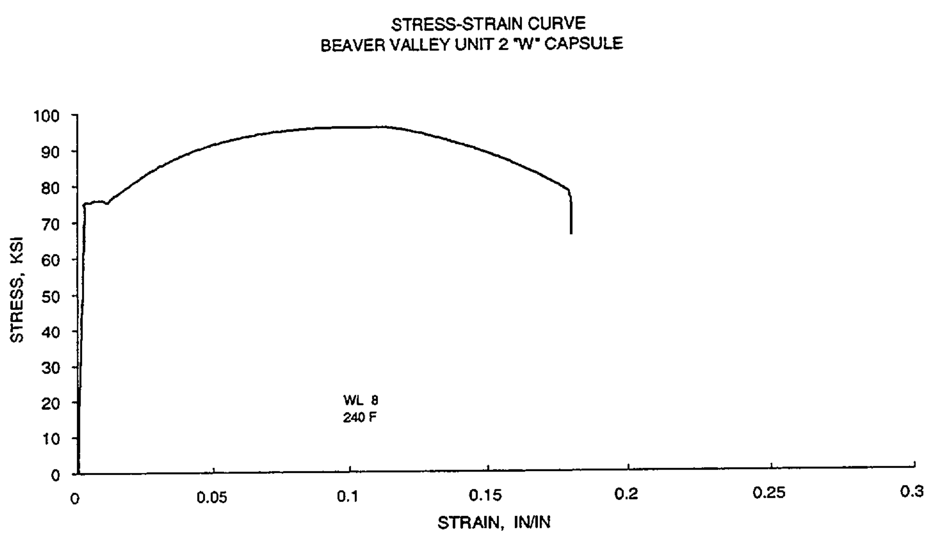


Figure 5-23 Engineering Stress-Strain Curves for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2, Tensile Specimens WL7 and WL8. [Note: Clip gage slipped toward end of tests]

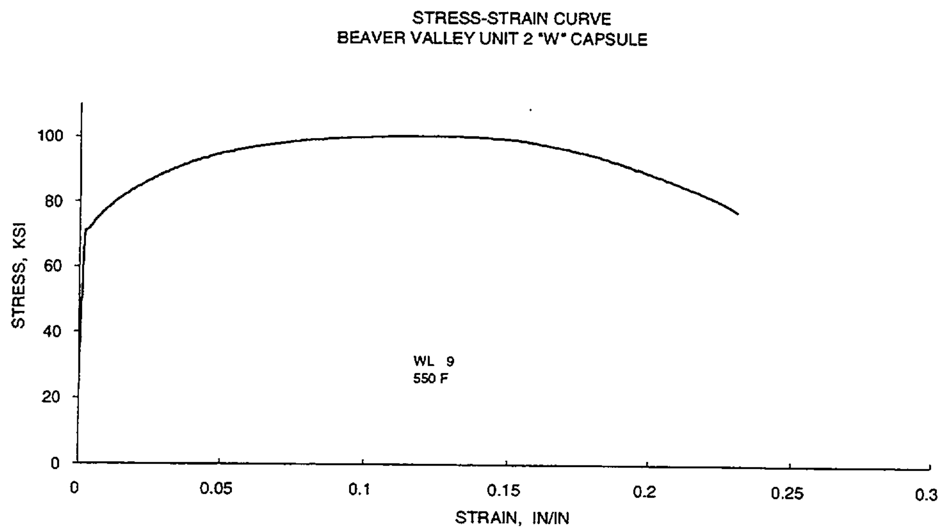
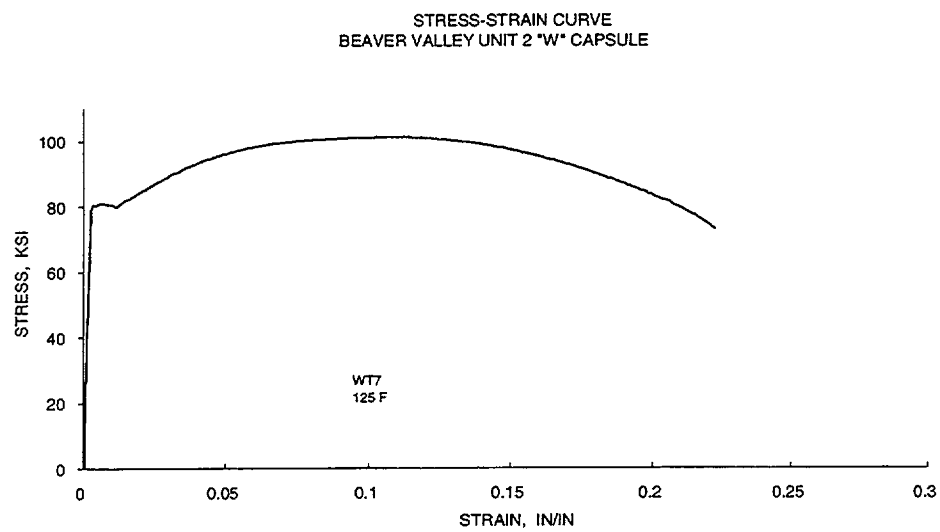


Figure 5-24 Engineering Stress-Strain Curves for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 Tensile Specimen WL9 (longitudinal Orientation)



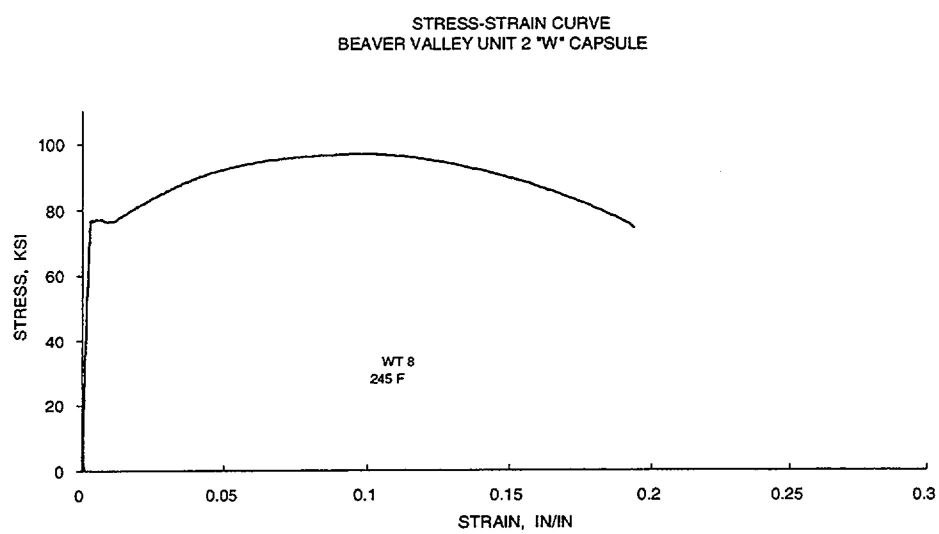


Figure 5-25 Engineering Stress-Strain Curves for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 Tensile Specimen WT7 and WT8 (Transverse Orientation)

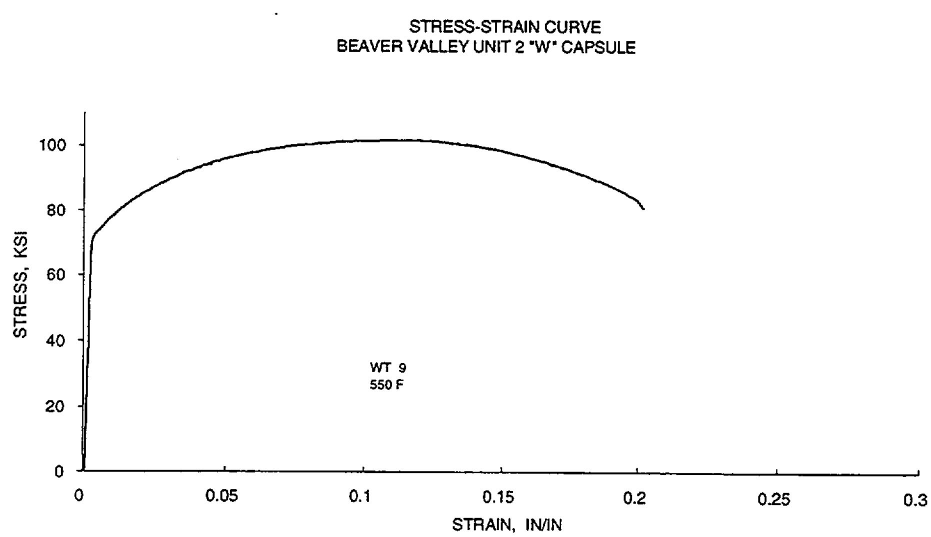
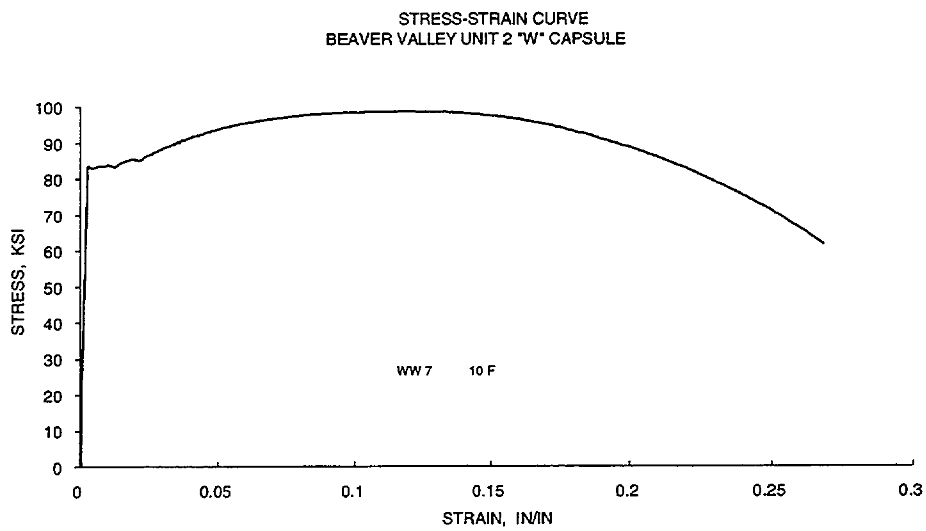


Figure 5-26 Engineering Stress-Strain Curves for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 Tensile Specimen WT9 (Transverse Orientation)



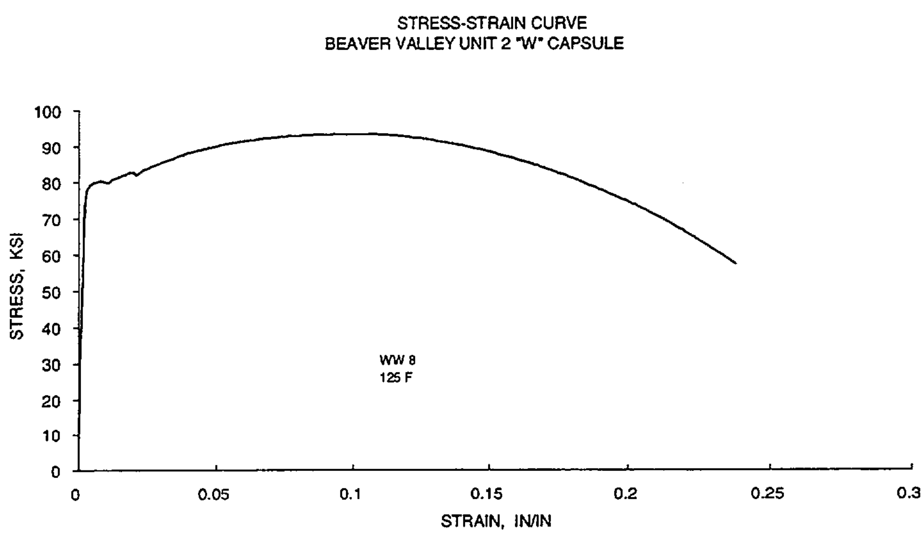


Figure 5-27 Engineering Stress-Strain Curves for Beaver Valley Unit 2 Reactor Vessel Weld Metal, Tensile Specimens WW7 and WW8.

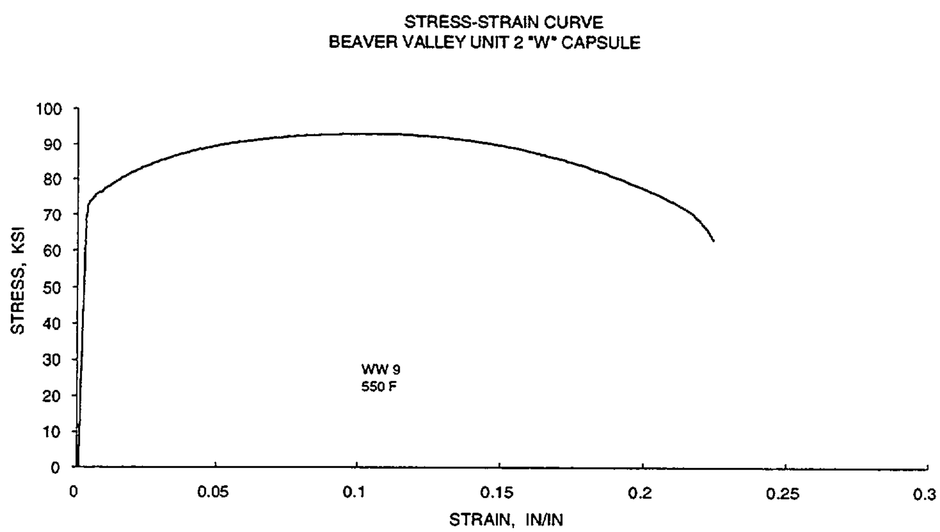


Figure 5-28 Engineering Stress-Strain Curves for Beaver Valley Unit 2 Reactor Vessel Weld Metal, Tensile Specimens WW9.

6.0 RADIATION ANALYSIS AND NEUTRON DOSIMETRY

6.1 INTRODUCTION

This section describes a discrete ordinates S_n transport analysis performed for the Beaver Valley Unit 2 reactor to determine the neutron radiation environment within the reactor pressure vessel and surveillance capsules. In this evaluation, fast neutron exposure parameters in terms of fast neutron fluence (E > 1.0 MeV) and iron atom displacements (dpa) were established on a plant and fuel cycle specific basis for the first eight reactor operating cycles. In addition, neutron dosimetry sensor sets from surveillance capsules U, V, and W withdrawn from the Beaver Valley Unit 2 reactor at the conclusion of fuel cycles 1, 5, and 8 were analyzed using current dosimetry evaluation methodology. Comparisons of the results of these dosimetry evaluations with the analytical predictions provided a validation of the plant specific neutron transport calculations. These validated calculations were then used to provide projections of the neutron exposure of the reactor pressure vessel for operating periods extending to 54 effective full power years (efpy). These projections accounted for assumed plant uprating from 2652 MWt to 2689 MWt in June 2001, followed by a second power uprate to 2910 MWt in June 2003.

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."

All of the calculations and dosimetry evaluations described in this section were based on the latest available nuclear cross-section data derived from ENDF/B-VI and made use of the latest available calculational tools. Furthermore, the neutron transport and dosimetry evaluation methodologies follow the guidance and meet the requirements of Regulatory Guide 1.190, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence."[16] Additionally, the methods used to develop the calculated 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.[17] The specific calculational methods applied are also consistent with those described in WCAP-15557, "Qualification of the Westinghouse Pressure Vessel Neutron Fluence Evaluation Methodology".[18]

6.2 DISCRETE ORDINATES ANALYSIS

A plan view of the Beaver Valley Unit 2 reactor geometry at the core midplane is shown in Figure 4-1. Six irradiation capsules attached to the neutron pad are included in the reactor design to constitute the reactor vessel surveillance program. The capsules are located at azimuthal angles of 107°, 287°, 343° (17° from the core cardinal axes) and 110°, 290°, 340° (20° from the core cardinal axes). The stainless steel specimen containers are 1.182 by 1-inch in cross-section and approximately 56 inches in height. The containers are positioned axially such that the test specimens are centered on the core midplane, thus spanning the central 5 feet of the 12-foot high reactor core.

From a neutronic standpoint, the surveillance capsules and associated support structures are significant. The presence of these materials has a marked effect on both the spatial distribution of neutron flux and the neutron energy spectrum in the water annulus between the neutron pads 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.

The fast neutron exposure evaluations for the Beaver Valley Unit 2 surveillance capsules and reactor vessel were based on a series of fuel cycle specific forward transport calculations that were combined using the following three-dimensional flux synthesis technique:

$$\phi(r,\theta,z) = [\phi(r,\theta)] * [\phi(r,z)]/[\phi(r)]$$

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. This synthesis procedure was carried out for each operating cycle at Beaver Valley Unit 2.

For the Beaver Valley Unit 2 calculations, two octant symmetric r,θ models were developed. The first model contained the extended neutron pad (26° span) including the surveillance capsules, while the second contained the shortened neutron pad (15° span) with no surveillance capsules. The former model was used to perform surveillance capsule dosimetry evaluations and subsequent comparisons with calculated results, while the latter model was used to generate the maximum fluence at the pressure vessel wall. In developing these analytical models, nominal design dimensions were employed for the various structural components. Likewise, water temperatures, and hence, coolant densities in the reactor core and downcomer regions of the reactor were taken to be representative of full power operating conditions. The coolant densities were treated on a fuel cycle specific basis. The reactor core itself was treated as a homogeneous mixture of fuel, cladding, water, and miscellaneous core structures such as fuel assembly grids, guide tubes, etc. The r,θ geometric mesh description of the reactor models consisted of 185 radial by 92 azimuthal intervals. Mesh sizes were chosen to assure that proper convergence of the inner iterations was achieved on a pointwise basis. The pointwise inner iteration flux convergence criterion utilized in the r,θ calculations was set at a value of 0.001.

The r,z model used for the Beaver Valley Unit 2 calculations extended radially from the centerline of the reactor core out to a location interior to the primary biological shield and over an axial span from an elevation 1 foot below the active fuel to 1 foot above the active fuel. As in the case of the r,θ models, nominal design dimensions and full power coolant densities were employed in the calculations. In this case, the homogenous core region was treated as an equivalent cylinder with a volume equal to that of the active core zone. The stainless steel former plates located between the core baffle and core barrel regions were also explicitly included in the model. The r,z geometric mesh description of the reactor model consisted of 149 radial by 89 axial intervals. As in the case of the r,θ calculations, mesh sizes were chosen to assure that proper convergence of the inner iterations was achieved on a pointwise basis. The pointwise inner iteration flux convergence criterion utilized in the r,z calculations was also set at a value of 0.001.

The one-dimensional radial model used in the synthesis procedure consisted of the same 149 radial mesh intervals included in the r,z model. Thus, radial synthesis factors could be determined on a meshwise basis throughout the entire geometry.

The core power distributions used in the plant specific transport calculations were taken from the appropriate Beaver Valley Unit 2 fuel cycle design reports[19 through 27]. The data extracted from the design reports represented cycle dependent fuel assembly enrichments, burnups, and axial power distributions. These data were used to develop spatial and energy dependent core source distributions averaged over each individual fuel cycle. Therefore, the results from the neutron transport calculations provided data in terms of fuel cycle averaged neutron flux, which when multiplied by the appropriate fuel cycle length, yielded the incremental fast neutron exposure for each fuel cycle. In constructing these core source distributions, the energy distribution of the source accounted for an appropriate fission split for uranium and plutonium isotopes based on the initial enrichment and burnup history of individual fuel assemblies. From these assembly dependent fission splits, composite values of energy release per fission, neutron yield per fission, and fission spectrum were determined.

For this analysis, all of the transport calculations were carried out using the DORT discrete ordinates code Version 3.1[28] and the BUGLE-96 cross-section library[29]. 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. Energy and space dependent core power distributions as well as system operating temperatures were treated on a fuel cycle specific basis.

Selected results from the neutron transport analyses are provided in Tables 6-1 through 6-4. The data listed in these tables establish the means for absolute comparisons of analysis and measurement for the Capsules U, V, and W irradiation and provide the calculated neutron exposure of the pressure vessel wall for the first eight fuel cycles. In Table 6-1, the calculated exposure rates and integrated exposures, expressed in terms of both neutron fluence (E > 1.0 MeV) and dpa, are given at the radial and azimuthal center of the two azimuthally symmetric surveillance capsule positions (17° and 20°). These data, representative of the axial midplane of the active core, are meant to establish the exposure of the surveillance capsules withdrawn to date and to provide an absolute comparison of measurement with calculation. Similar data are given in Table 6-2 for the reactor vessel inner radius. The vessel data given in Table 6-2 are representative of the axial elevation of the maximum neutron exposure at each of four azimuthal locations. Again, both fluence (E > 1.0 MeV) and dpa data are provided. It is important to note that the data for the vessel inner radius were taken at the clad/base metal interface, and thus, represent the maximum calculated exposure levels of the vessel plates and welds.

Radial gradient information applicable to $\phi(E > 1.0\ MeV)$ and dpa/sec are given in Tables 6-3 and 6-4, respectively. The data, based on the Cycles 1 through 8 cumulative fluence, are presented on a relative basis for each exposure parameter at several azimuthal locations. Exposure distributions through the vessel wall may be obtained by multiplying the calculated exposure at the vessel inner radius by the relative gradient data listed in Tables 6-3 and 6-4.

6.3 NEUTRON DOSIMETRY

6.3.1 Sensor Reaction Rate Determinations

In this section, the results of the evaluations of the three neutron sensor sets withdrawn to date as a part of the Beaver Valley Unit 2 Reactor Vessel Materials Surveillance Program are presented. The capsule designation, location within the reactor, and time of withdrawal of each of these dosimetry sets were as follows:

Capsule ID	Azimuthal Location	Withdrawal Time	Irradiation Time [efpy]
U	17°	End of Cycle 1	1.24
V	17°	End of Cycle 5	5.98
W	20°	End of Cycle 8	9.77

The azimuthal locations included in the above tabulation represent the first octant equivalent azimuthal angle of the geometric center of the respective surveillance capsules.

The passive neutron sensors included in the evaluations of surveillance capsules U, V, and W are summarized as follows:

Sensor Material	Reaction of Interest	Capsule U	Capsule V	Capsule W
Copper	$^{63}Cu(n,\alpha)^{60}Co$	X	X	X
Iron	$^{54}Fe(n,p)^{54}Mn$	X	X	X
Nickel	$^{58}Ni(n,p)^{58}Co$	X	X	X
Uranium-238	$^{238}U(n,f)^{137}Cs$	X	X	Damaged
Neptunium-237	$^{237}Np(n,f)^{137}Cs$	X	X	X
Cobalt-Aluminum	$^{59}Co(n,\gamma)^{60}Co$	X	X	X

The copper, iron, nickel, and cobalt aluminum monitors, in wire form, were placed in holes drilled in spacers at several axial levels within the capsules. All of these wire sensors were positioned at the radial center of the respective capsules. The cobalt-aluminum sensors were irradiated both with and without cadmium covers, while the copper, iron, and nickel wires were irradiated only without cadmium covers. The cadmium shielded uranium and neptunium fission monitors were accommodated within the dosimeter block centered at the radial, azimuthal, and axial center of the material test specimen array. Pertinent physical and nuclear characteristics of these sensors are listed in Table 6-5.

The use of passive monitors such as those listed above 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 radiometric counting of the neutron sensors from Capsules U and V was carried out at the Westinghouse Analytical Services Laboratory at the Waltz Mill Site. The radiometric counting of the sensors from Capsule W was completed at the Antech Analytical Laboratory, also located at the Waltz Mill Site. In all cases, the radiometric counting followed established ASTM procedures. Following sample preparation and weighing, the specific activity of each sensor was determined by means of a high resolution gamma spectrometer. For the copper, iron, nickel, and cobalt-aluminum sensors, these analyses were performed by direct counting of each of the individual samples. In the case of the uranium and neptunium fission sensors, the analyses were carried out by direct counting preceded by dissolution and chemical separation of cesium from the sensor material.

The irradiation history of the reactor over the irradiation periods experienced by Capsules U, V, and W was based on the reported monthly power generation of Beaver Valley Unit 2 from initial reactor startup through the end of the dosimetry evaluation period. For the sensor sets utilized in the surveillance capsules, the half-lives of the product isotopes are long enough that a monthly histogram describing reactor operation has proven to be an adequate representation for use in radioactive decay corrections for the reactions of interest in the exposure evaluations. The irradiation history applicable to Capsules U, V, and W is given in Table 6-6.

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

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

where:

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

λ = Decay constant of the product isotope (1/sec).

t_j = Length of irradiation period j (sec).

t_d = Decay time following irradiation period j (sec).

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

In the equation describing the reaction rate calculation, the ratio $[P_j]/[P_{ref}]$ accounts for month-by-month variation of reactor core power level within any given fuel cycle as well as over multiple fuel cycles. The ratio C_j, which was 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 should be employed. The impact of changing flux levels for constant power operation can be quite significant for sensor sets that have been irradiated for many cycles in a reactor that has transitioned from non-low leakage to low leakage fuel management or for sensor sets contained in surveillance capsules that have been moved from one capsule location to another. The fuel cycle specific neutron flux values along with the computed values for C_j are listed in Table 6-7. These flux values represent the cycle dependent results at the radial and azimuthal center of the respective capsules at the axial elevation of the active fuel midplane.

Prior to using the measured reaction rates in the least squares evaluations of the dosimetry sensor sets, additional corrections were made to the ^{238}U measurements to account for the presence of ^{235}U impurities in the sensors as well as to adjust for the build-in of plutonium isotopes over the course of the irradiation. Corrections were also made to the ^{238}U and ^{237}Np sensor reaction rates to account for gamma ray induced fission reactions that occurred over the course of the capsule irradiations. The correction factors applied to the Beaver Valley Unit 2 fission sensor reaction rates are summarized as follows:

Correction	Capsule U	Capsule V	Capsule W
^{235}U Impurity/Pu Build-in	0.861	0.789	
$^{238}U(\gamma,f)$	0.976	0.976	
Net ^{238}U Correction	0.840	0.770	Not Applicable
$^{237}Np(\gamma,f)$	0.994	0.994	0.994

These factors were applied in a multiplicative fashion to the decay corrected fission sensor reaction rates.

Results of the sensor reaction rate determinations for Capsules U, V, and W are given in Table 6-8. In Table 6-8, the measured specific activities, decay corrected saturated specific activities, and computed sensor reaction rates are listed for each capsule. The fission sensor reaction rates are listed both with and without the applied corrections for ^{238}U impurities, plutonium build-in, and gamma ray induced fission effects.

6.3.2 Least Squares Evaluation of Sensor Sets

Least squares adjustment methods provide the capability of combining the measurement data with the corresponding neutron transport calculations resulting in a Best Estimate neutron energy spectrum with associated uncertainties. Best Estimates for key exposure parameters such as $\phi(E > 1.0\ MeV)$ or dpa/s along with their uncertainties are then easily obtained from the adjusted spectrum. In general, the least squares methods, as applied to surveillance capsule dosimetry evaluations, act to reconcile the measured sensor reaction rate data, dosimetry reaction cross-sections, and the calculated neutron energy spectrum within their respective uncertainties. For example,

$$R_i \pm \delta_{R_i} = \sum_g (\sigma_{ig} \pm \delta_{\sigma_{ig}})(\phi_g \pm \delta_{\phi_g})$$

relates a set of measured reaction rates, R_i, to a single neutron spectrum, ϕ_g, through the multigroup dosimeter reaction cross-section, σ_{ig}, each with an uncertainty δ. The primary objective of the least squares evaluation is to produce unbiased estimates of the neutron exposure parameters at the location of the measurement.

For the least squares evaluation of the Beaver Valley Unit 2 surveillance capsule dosimetry, The FERRET code[30] was employed to combine the results of the plant specific neutron transport calculations and sensor set reaction rate measurements to determine best estimate values of exposure parameters (ϕ(E > 1.0 MeV) and dpa/s) along with associated uncertainties for the three in-vessel capsules withdrawn to date.

The application of the least squares methodology requires the following input:

1 - The calculated neutron energy spectrum and associated uncertainties at the measurement location.

2 - The measured reaction rates and associated uncertainty for each sensor contained in the multiple foil set.

3 - The energy dependent dosimetry reaction cross-sections and associated uncertainties for each sensor contained in the multiple foil sensor set.

For the Beaver Valley Unit 2 application, the calculated neutron spectrum was obtained from the results of plant specific neutron transport calculations described in Section 6.2 of this report. The sensor reaction rates were derived from the measured specific activities using the procedures described in Section 6.3.1. The dosimetry reaction cross-sections and uncertainties were obtained from the SNLRML dosimetry cross-section library[31]. The SNLRML library is an evaluated dosimetry reaction cross-section compilation recommended for use in LWR evaluations by ASTM Standard E1018, "Application of ASTM Evaluated Cross-Section Data File, Matrix E 706 (IIB)".

The uncertainties associated with the measured reaction rates, dosimetry cross-sections, and calculated neutron spectrum were input to the least squares procedure in the form of variances and covariances. The assignment of the input uncertainties followed the guidance provided in ASTM Standard E 944, "Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance."

The following provides a summary of the uncertainties associated with the least squares evaluation of the Beaver Valley Unit 2 surveillance capsule sensor sets:

<u>Reaction Rate Uncertainties</u>

The overall uncertainty associated with the measured reaction rates includes components due to the basic measurement process, irradiation history corrections, and corrections for competing reactions. A high level of accuracy in the reaction rate determinations is assured by utilizing laboratory procedures that conform to the ASTM National Consensus Standards for reaction rate determinations for each sensor type.

After combining all of these uncertainty components, the sensor reaction rates derived from the counting and data evaluation procedures were assigned the following net uncertainties for input to the least squares evaluation:

Reaction	Uncertainty
$^{63}Cu(n,\alpha)^{60}Co$	5%
$^{54}Fe(n,p)^{54}Mn$	5%
$^{58}Ni(n,p)^{58}Co$	5%
$^{238}U(n,f)^{137}Cs$	10%
$^{237}Np(n,f)^{137}Cs$	10%
$^{59}Co(n,\gamma)^{60}Co$	5%

These uncertainties are given at the 1σ level.

Dosimetry Cross-Section Uncertainties

The reaction rate cross-sections used in the least squares evaluations were taken from the SNLRML library. This data library provides reaction cross-sections and associated uncertainties, including covariances, for 66 dosimetry sensors in common use. Both cross-sections and uncertainties are provided in a fine multigroup structure for use in least squares adjustment applications. These cross-sections were compiled from the most recent cross-section evaluations and they have been tested with respect to their accuracy and consistency for least squares evaluations. Further, the library has been empirically tested for use in fission spectra determination as well as in the fluence and energy characterization of 14 MeV neutron sources

For sensors included in the Beaver Valley Unit 2 surveillance program, the following uncertainties in the fission spectrum averaged cross-sections are provided in the SNLRML documentation package.

Reaction	Uncertainty
$^{63}Cu(n,\alpha)^{60}Co$	4.08-4.16%
$^{54}Fe(n,p)^{54}Mn$	3.05-3.11%
$^{58}Ni(n,p)^{58}Co$	4.49-4.56%
$^{238}U(n,f)^{137}Cs$	0.54-0.64%
$^{237}Np(n,f)^{137}Cs$	10.32-10.97%
$^{59}Co(n,\gamma)^{60}Co$	0.79-3.59%

These tabulated ranges provide an indication of the dosimetry cross-section uncertainties associated with the sensor sets used in LWR irradiations.

Calculated Neutron Spectrum

The neutron spectra input to the least squares adjustment procedure were obtained directly from the results of plant specific transport calculations for each surveillance capsule irradiation period and location. The spectrum for each capsule was input in an absolute sense (rather than as simply a relative spectral shape). Therefore, within the constraints of the assigned uncertainties, the calculated data were treated equally with the measurements.

While the uncertainties associated with the reaction rates were obtained from the measurement procedures and counting benchmarks and the dosimetry cross-section uncertainties were supplied directly with the SNLRML library, the uncertainty matrix for the calculated spectrum was constructed from the following relationship:

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

where R_n specifies an overall fractional normalization uncertainty and the fractional uncertainties R_g and $R_{g'}$ specify additional random groupwise uncertainties 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 the short range correlations over a group range γ (θ specifies the strength of the latter term). The value of δ is 1.0 when g = g', and is 0.0 otherwise.

The set of parameters defining the input covariance matrix for the Beaver Valley Unit 2 calculated spectra was as follows:

Flux Normalization Uncertainty (R_n)	15%
Flux Group Uncertainties (R_g, $R_{g'}$)	
(E > 0.0055 MeV)	15%
(0.68 eV < E < 0.0055 MeV)	29%
(E < 0.68 eV)	52%
Short Range Correlation (θ)	
(E > 0.0055 MeV)	0.9
(0.68 eV < E < 0.0055 MeV)	0.5
(E < 0.68 eV)	0.5
Flux Group Correlation Range (γ)	
(E > 0.0055 MeV)	6
(0.68 eV < E < 0.0055 MeV)	3
(E < 0.68 eV)	2

6.3.3 Comparisons of Measurements and Calculations

Results of the least squares evaluations of the dosimetry from the three Beaver Valley Unit 2 surveillance capsules withdrawn to date are provided in Tables 6-9 and 6-10. In Table 6-9, measured, calculated, and best estimate values for sensor reaction rates are given for each capsule. Also provided in this tabulation are ratios of the measured reaction rates to both the calculated and least squares adjusted reaction rates. These ratios of M/C and M/BE illustrate the consistency of the fit of the calculated neutron energy spectra to the measured reaction rates both before and after adjustment. In Table 6-10, comparison of the calculated and best estimate values of neutron flux (E > 1.0 MeV) and iron atom displacement rate are tabulated along with the BE/C ratio observed for each of the capsules.

The data comparisons provided in Tables 6-9 and 6-10 show that the adjustments to the calculated spectra are relatively small and well within the assigned uncertainties for the calculated spectra, measured sensor reaction rates, and dosimetry reaction cross-sections. Further, these results indicate that the use of the least squares evaluation results in a reduction in the uncertainties associated with the exposure of the surveillance capsules. From Section 6.4 of this report, it may be noted that the uncertainty associated with the unadjusted calculation of neutron flux(E > 1.0 MeV) and iron atom displacement rate at the surveillance capsule locations is specified as 12% at the 1σ level. From Table 6-10, it is noted that the corresponding uncertainties associated with the least squares adjusted exposure parameters have been reduced to 6%-7% for neutron flux(E > 1.0 MeV) and to 8% for iron atom displacement rate. Again, the uncertainties from the least squares evaluation are at the 1σ level.

Further comparisons of the measurement results with calculations are given in Tables 6-11 and 6-12. These comparisons are given on two levels. In Table 6-11, calculations of individual threshold sensor reaction rates are compared directly with the corresponding measurements. These threshold reaction rate comparisons provide a good evaluation of the accuracy of the fast neutron portion of the calculated energy spectra. In Table 6-12, calculations of fast neutron exposure rates in terms of ϕ(E > 1.0 MeV) and dpa/s are compared with the best estimate results obtained from the least squares evaluation of the three capsule dosimetry results. These two levels of comparison yield consistent and similar results with all measurement to calculation comparisons falling well within the 20% limits specified as the acceptance criteria in Regulatory Guide 1.190.

In the case of the direct comparison of measured and calculated sensor reaction rates, the M/C comparisons for fast neutron reactions range from 0.89–1.11 for the 14 samples included in the data set. The overall average M/C ratio for the entire set of Beaver Valley Unit 2 data is 0.99 with an associated standard deviation of 7.4%.

In the comparisons of best estimate and calculated fast neutron exposure parameters, the corresponding BE/C comparisons for the three capsule data set range from 0.95–0.98 for neutron flux (E > 1.0 MeV) and from 0.96 to 0.99 for iron atom displacement rate. The overall average BE/C ratios for neutron flux (E > 1.0 MeV) and iron atom displacement rate are 0.97 with a standard deviation of 1.4% and 0.97 with a standard deviation of 1.7%, respectively.

Based on these comparisons, it is concluded that the data comparisons validate the use of the calculated fast neutron exposures provided in Section 6.4 of this report for use in the assessment of the condition of the materials comprising the beltline region of the Beaver Valley Unit 2 reactor pressure vessel.

6.4 PROJECTIONS OF REACTOR VESSEL EXPOSURE

The final results of the fluence evaluations performed for the three surveillance capsules withdrawn from the Beaver Valley Unit 2 reactor are provided in Table 6-13. These assigned neutron exposure levels are based on the plant and fuel cycle specific neutron transport calculations performed for the Beaver Valley Unit 2 reactor. As shown by the comparisons provided in Tables 6-11 and 6-12, the validity of these calculated fluence levels is demonstrated both by a direct comparison with measured sensor reaction rates as well by comparison with the least squares evaluation performed for each of the capsule dosimetry sets.

The corresponding calculated fast neutron fluence (E > 1.0 MeV) and dpa exposure values for the Beaver Valley Unit 2 pressure vessel are provided in Table 6-14. As presented, these data represent the maximum exposure of the clad/base metal interface at azimuthal angles of 0, 15, 30, and 45 degrees relative to the core cardinal axes. The data tabulation includes the plant and fuel cycle specific calculated fluence at the end of the eighth operating fuel cycle as well as projections for future operation to 25, 32, 48, and 54 effective full power years. The projections were based on the assumption that the spatial power distributions averaged over fuel cycles 1 through 8 were representative of future plant operation. These projections also include allowance for an initial power uprate from 2652 MWt to 2689 MWt in June 2001, followed by an additional power uprate to 2900 MWt in June 2003.

Updated lead factors for the Beaver Valley Unit 2 surveillance capsules are provided in Table 6-15. The capsule lead factor is defined as the ratio of the calculated fluence (E > 1.0 MeV) at the geometric center of the surveillance capsule to the corresponding maximum calculated fluence at the pressure vessel clad/base metal interface. In Table 6-15, the lead factors for capsules that have been withdrawn from the reactor (U, V, and W) were based on the calculated fluence values for the irradiation period corresponding to the time of withdrawal for the individual capsules. For the capsules remaining in the reactor (X, Y, and Z), the lead factors correspond to the calculated fluence values at the end of cycle 8, the last fuel cycle for which fuel cycle specific transport calculations have been completed.

The uncertainty associated with the calculated neutron exposure of the Beaver Valley Unit 2 surveillance capsule and reactor pressure vessel is based on the recommended approach provided in Regulatory Guide 1.190. In particular, the qualification of the methodology was carried out in the following four stages:

1 - Comparison of calculations with benchmark measurements from the Pool Critical Assembly (PCA) simulator at the Oak Ridge National Laboratory (ORNL).

2 - Comparisons of calculations with surveillance capsule and reactor cavity measurements from the H. B. Robinson power reactor benchmark experiment.

3 - An analytical sensitivity study addressing the uncertainty components resulting important input parameters applicable to the plant specific transport calculations used in the neutron exposure assessments.

4 - Comparisons of the plant specific calculations with all available dosimetry results from the Beaver Valley Unit 2 surveillance program.

The first phase of the methods qualification (PCA comparisons) addressed the adequacy of basic transport calculation and dosimetry evaluation techniques and associated cross-sections. This phase, however, did not test the accuracy of commercial core neutron source calculations nor did it address uncertainties in operational or geometric variables that impact power reactor calculations. The second phase of the qualification (H. B. Robinson comparisons) addressed uncertainties in these additional areas that are primarily methods related and would tend to apply generically to all fast neutron exposure evaluations. The third phase of the qualification (analytical sensitivity study) identified the potential uncertainties introduced into the overall evaluation due to calculational methods approximations as well as to a lack of knowledge relative to various plant specific input parameters. The overall calculational uncertainty applicable to the Beaver Valley Unit 2 analysis was established from results of these three phases of the methods qualification.

The fourth phase of the uncertainty assessment (comparisons with Beaver Valley Unit 2 measurements) was used solely to demonstrate the validity of the transport calculations and to confirm the uncertainty estimates associated with the analytical results. The comparison was used only as a check and was not used in any way to modify the calculated surveillance capsule and pressure vessel neutron exposures.
The following summarizes the uncertainties developed from the first three phases of the methodology qualification. Additional information pertinent to these evaluations is provided in Reference 18.

	Capsule	Vessel IR
PCA Comparisons	3%	3%
H. B. Robinson Comparisons	3%	3%
Analytical Sensitivity Studies	10%	11%
Additional Uncertainty for Factors not Explicitly Evaluated	5%	5%
Net Calculational Uncertainty	12%	13%

The net calculational uncertainty was determined by combining the individual components in quadrature. Therefore, the resultant uncertainty was random and no systematic bias was applied to the analytical results.

The plant specific measurement comparisons provided in Tables 6-11 and 6-12 support these uncertainty assessments for Beaver Valley Unit 2.

Table 6-1

Calculated Neutron Exposure Rates and Integrated Exposures
At The Surveillance Capsule Center

Neutrons (E > 1.0 MeV)

Cycle	Cycle Length [EFPY]	Total Irradiation Time [EFPY]	Neutron Flux (E > 1.0 MeV) [n/cm^2-s]		Neutron Fluence (E > 1.0 MeV) [n/cm^2]	
			17 Degrees	20 Degrees	17 Degrees	20 Degrees
1	1.24	1.24	1.55E+11	1.34E+11	6.08E+18	5.26E+18
2	1.01	2.26	1.26E+11	1.11E+11	1.01E+19	8.81E+18
3	1.24	3.49	1.41E+11	1.27E+11	1.56E+19	1.38E+19
4	1.26	4.76	1.38E+11	1.23E+11	2.11E+19	1.87E+19
5	1.22	5.98	1.34E+11	1.16E+11	2.63E+19	2.31E+19
6	1.23	7.21	1.25E+11	1.14E+11	3.11E+19	2.76E+19
7	1.25	8.46	1.23E+11	1.09E+11	3.60E+19	3.19E+19
8	1.32	9.77	1.19E+11	1.06E+11	4.09E+19	3.63E+19

Iron Atom Displacements

Cycle	Cycle Length [EFPY]	Total Irradiation Time [EFPY]	Displacement Rate [dpa/s]		Displacements [dpa]	
			17 Degrees	20 Degrees	17 Degrees	20 Degrees
1	1.24	1.24	3.19E-10	2.70E-11	1.25E-02	1.06E-02
2	1.01	2.26	2.54E-10	2.20E-11	2.06E-02	1.76E-02
3	1.24	3.49	2.85E-10	2.52E-11	3.18E-02	2.74E-02
4	1.26	4.76	2.79E-10	2.43E-11	4.29E-02	3.71E-02
5	1.22	5.98	2.73E-10	2.30E-11	5.34E-02	4.60E-02
6	1.23	7.21	2.53E-10	2.26E-11	6.32E-02	5.48E-02
7	1.25	8.46	2.49E-10	2.17E-11	7.30E-02	6.33E-02
8	1.32	9.77	2.40E-10	2.10E-11	8.30E-02	7.20E-02

Table 6-2

Calculated Azimuthal Variation of Maximum Exposure Rates
And Integrated Exposures at The Reactor Vessel
Clad/Base Metal Interface

Cycle	Cycle Length [EFPY]	Total Irradiation Time [EFPY]	Neutron Flux (E > 1.0 MeV) [n/cm^2-s]			
			0 Degrees	15 Degrees	30 Degrees	45 Degrees
1	1.24	1.24	4.86E+10	2.71E+10	2.00E+10	1.37E+10
2	1.01	2.26	3.38E+10	2.11E+10	1.58E+10	1.08E+10
3	1.24	3.49	3.39E+10	2.29E+10	1.80E+10	1.29E+10
4	1.26	4.76	3.68E+10	2.30E+10	1.67E+10	1.07E+10
5	1.22	5.98	3.75E+10	2.27E+10	1.56E+10	1.06E+10
6	1.23	7.21	3.18E+10	2.11E+10	1.79E+10	1.29E+10
7	1.25	8.46	3.32E+10	2.08E+10	1.71E+10	1.30E+10
8	1.32	9.77	3.07E+10	1.97E+10	1.54E+10	1.06E+10

Cycle	Cycle Length [EFPY]	Total Irradiation Time [EFPY]	Neutron Fluence (E > 1.0 MeV) [n/cm^2]			
			0 Degrees	15 Degrees	30 Degrees	45 Degrees
1	1.24	1.24	1.92E+18	1.07E+18	7.91E+17	5.41E+17
2	1.01	2.26	2.98E+18	1.74E+18	1.29E+18	8.82E+17
3	1.24	3.49	4.31E+18	2.63E+18	1.99E+18	1.38E+18
4	1.26	4.76	5.77E+18	3.55E+18	2.66E+18	1.81E+18
5	1.22	5.98	7.22E+18	4.42E+18	3.26E+18	2.22E+18
6	1.23	7.21	8.46E+18	5.24E+18	3.96E+18	2.72E+18
7	1.25	8.46	9.76E+18	6.06E+18	4.63E+18	3.23E+18
8	1.32	9.77	1.10E+19	6.88E+18	5.27E+18	3.67E+18

Note: At the end of Cycle 8, the maximum neutron exposure at the pressure vessel wall occurs at an axial elevation 62.3 cm below the midplane of the active fuel. The neutron flux values tabulated above are also characteristic of that axial elevation.

Table 6-2 Cont'd

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

Cycle	Cycle Length [EFPY]	Total Irradiation Time [EFPY]	Iron Atom Displacement Rate [dpa/s]			
			0 Degrees	15 Degrees	30 Degrees	45 Degrees
1	1.24	1.24	7.73E-11	4.27E-11	3.08E-11	2.12E-11
2	1.01	2.26	5.37E-11	3.32E-11	2.43E-11	1.67E-11
3	1.24	3.49	5.39E-11	3.60E-11	2.77E-11	1.99E-11
4	1.26	4.76	5.85E-11	3.61E-11	2.57E-11	1.66E-11
5	1.22	5.98	5.95E-11	3.56E-11	2.40E-11	1.64E-11
6	1.23	7.21	5.06E-11	3.31E-11	2.75E-11	1.99E-11
7	1.25	8.46	5.27E-11	3.27E-11	2.63E-11	2.00E-11
8	1.32	9.77	4.87E-11	3.10E-11	2.36E-11	1.65E-11

Cycle	Cycle Length [EFPY]	Total Irradiation Time [EFPY]	Iron Atom Displacements [dpa]			
			0 Degrees	15 Degrees	30 Degrees	45 Degrees
1	1.24	1.24	3.04E-03	1.68E-03	1.21E-03	8.35E-04
2	1.01	2.26	4.75E-03	2.73E-03	1.98E-03	1.37E-03
3	1.24	3.49	6.85E-03	4.14E-03	3.06E-03	2.14E-03
4	1.26	4.76	9.18E-03	5.57E-03	4.09E-03	2.80E-03
5	1.22	5.98	1.15E-02	6.95E-03	5.02E-03	3.44E-03
6	1.23	7.21	1.34E-02	8.24E-03	6.09E-03	4.21E-03
7	1.25	8.46	1.55E-02	9.52E-03	7.12E-03	5.00E-03
8	1.32	9.77	1.75E-02	1.08E-02	8.10E-03	5.68E-03

Note: At the end of Cycle 8, the maximum neutron exposure at the pressure vessel wall occurs at an axial elevation 62.3 cm below the midplane of the active fuel. The neutron flux values tabulated above are also characteristic of that axial elevation.

Table 6-3

Relative Radial Distribution Of Neutron Fluence (E > 1.0 MeV)
Within The Reactor Vessel Wall

RADIUS (cm)	AZIMUTHAL ANGLE			
	0°	15°	30°	45°
199.95	1.000	1.000	1.000	1.000
204.95	0.583	0.596	0.595	0.599
209.95	0.297	0.312	0.310	0.314
214.95	0.146	0.157	0.156	0.160
219.95	0.067	0.077	0.076	0.081

Note:
Base Metal Inner Radius = 199.95 cm
Base Metal 1/4T = 204.95 cm
Base Metal 1/2T = 209.95 cm
Base Metal 3/4T = 214.95 cm
Base Metal Outer Radius = 219.95 cm

Table 6-4

Relative Radial Distribution Of Iron Atom Displacements (dpa)
Within The Reactor Vessel Wall

RADIUS (cm)	AZIMUTHAL ANGLE			
	0°	15°	30°	45°
199.95	1.000	1.000	1.000	1.000
204.95	0.665	0.677	0.663	0.666
209.95	0.416	0.432	0.413	0.418
214.95	0.254	0.271	0.254	0.262
219.95	0.140	0.161	0.150	0.162

Note:
Base Metal Inner Radius = 199.95 cm
Base Metal 1/4T = 204.95 cm
Base Metal 1/2T = 209.95 cm
Base Metal 3/4T = 214.95 cm
Base Metal Outer Radius = 219.95 cm

Table 6-5

Nuclear Parameters Used In The Evaluation Of Neutron Sensors

Monitor Material	Reaction of Interest	Target Atom Fraction	90% Response Range (MeV)	Product Half-life	Fission Yield (%)
Copper	$^{63}Cu\ (n,\alpha)$	0.6917	4.9 – 11.8	5.271 y	
Iron	$^{54}Fe\ (n,p)$	0.0585	2.1 – 8.3	312.3 d	
Nickel	$^{58}Ni\ (n,p)$	0.6808	1.5 – 8.1	70.82 d	
Uranium-238	$^{238}U\ (n,f)$	0.9996	1.2 – 6.7	30.07 y	6.02
Neptunium-237	$^{237}Np\ (n,f)$	1.0000	0.4 – 3.5	30.07 y	6.17
Cobalt-Al	$^{59}Co\ (n,\gamma)$	0.0015	non-threshold	5.271 y	

Note: The 90% response range is defined such that, in the neutron spectrum characteristic of the Beaver Valley Unit 2 surveillance capsules, approximately 90% of the sensor response is due to neutrons in the energy range specified with approximately 5% of the total response due to neutrons with energies below the lower limit and 5% of the total response due to neutrons with energies above the upper limit.

Table 6-6

Monthly Thermal Generation During The First Eight Fuel Cycles
Of The Beaver Valley Unit 2 Reactor
(Reactor Power of 2652 MWt)

Year	Month	Thermal Generation (MWt-hr)	Year	Month	Thermal Generation (MWt-hr)	Year	Month	Thermal Generation (MWt-hr)
87	8	188655	90	5	1489609	93	2	1702839
87	9	309627	90	6	1431870	93	3	1947152
87	10	1138592	90	7	1577454	93	4	1786447
87	11	517531	90	8	1664072	93	5	1839535
87	12	1868106	90	9	74406	93	6	1888001
88	1	1647518	90	10	0	93	7	1834053
88	2	948305	90	11	375293	93	8	1951094
88	3	1961547	90	12	1962999	93	9	782113
88	4	1816453	91	1	1966105	93	10	0
88	5	1963013	91	2	1772383	93	11	0
88	6	1795032	91	3	1920061	93	12	1318343
88	7	1881079	91	4	1899670	94	1	1957437
88	8	1783059	91	5	1959596	94	2	1767624
88	9	1802754	91	6	1764771	94	3	1957207
88	10	1882405	91	7	1941503	94	4	1895053
88	11	1900844	91	8	1954146	94	5	1960148
88	12	1963294	91	9	1881952	94	6	1121998
89	1	1863158	91	10	1861135	94	7	1954090
89	2	1018798	91	11	1674762	94	8	1958831
89	3	612808	91	12	1636047	94	9	1897976
89	4	0	92	1	1870700	94	10	1962873
89	5	12973	92	2	1796307	94	11	1894630
89	6	1009593	92	3	509755	94	12	1950889
89	7	1033532	92	4	0	95	1	1917701
89	8	1948907	92	5	1023309	95	2	1754716
89	9	1900600	92	6	1809717	95	3	1200818
89	10	1966839	92	7	1934799	95	4	0
89	11	1899581	92	8	1959446	95	5	1147307
89	12	1814015	92	9	1859358	95	6	1864365
90	1	1686721	92	10	1960015	95	7	1916207
90	2	1194673	92	11	1752279	95	8	1773194
90	3	1476919	92	12	1708578	95	9	1880865
90	4	1380856	93	1	1635667	95	10	1957436

Table 6-6 Cont'd

Monthly Thermal Generation During The First Eight Fuel Cycles
Of The Beaver Valley Unit 2 Reactor
(Reactor Power of 2652 MWt)

Year	Month	Thermal Generation (MWt-hr)	Year	Month	Thermal Generation (MWt-hr)	Year	Month	Thermal Generation (MWt-hr)
95	11	1754746	97	7	1082321	99	3	0
95	12	1891016	97	8	1914272	99	4	964605
96	1	1810014	97	9	1572152	99	5	1943731
96	2	1742890	97	10	1944012	99	6	1859034
96	3	1915329	97	11	1895487	99	7	1226305
96	4	1777999	97	12	990665	99	8	1928918
96	5	1934637	98	1	0	99	9	1874313
96	6	1857380	98	2	0	99	10	1323291
96	7	1918340	98	3	0	99	11	1682987
96	8	1469931	98	4	0	99	12	1775505
96	9	0	98	5	0	00	1	1903763
96	10	0	98	6	0	00	2	1677554
96	11	0	98	7	0	00	3	1681774
96	12	694343	98	8	0	00	4	1873178
97	1	1210605	98	9	25385	00	5	1944510
97	2	1776258	98	10	1935467	00	6	1857436
97	3	1178064	98	11	1624078	00	7	1931752
97	4	1768747	98	12	1955838	00	8	1925633
97	5	1942927	99	1	1954784	00	9	1207003
97	6	1853679	99	2	1626617			

Table 6-7

Calculated $\phi(E > 1.0\ MeV)$ and C_j Factors at the Surveillance Capsule Center Core Midplane Elevation

Fuel Cycle	$\phi(E > 1.0\ MeV)$ [n/cm^2-s]			C_j		
	Capsule U	Capsule V	Capsule W	U	V	W
1	1.55E+11	1.55E+11	1.34E+11	1.000	1.114	1.142
2		1.26E+11	1.11E+11		0.902	0.942
3		1.41E+11	1.27E+11		1.014	1.081
4		1.38E+11	1.23E+11		0.989	1.043
5		1.34E+11	1.16E+11		0.963	0.983
6			1.14E+11			0.971
7			1.09E+11			0.929
8			1.06E+11			0.902
Average	1.55E+11	1.39E+11	1.18E+11	1.000	1.000	1.000

Table 6-8

Measured Sensor Activities and Reaction Rates

Surveillance Capsule U

Reaction	Location	Measured Activity (dps/g)	Saturated Activity (dps/g)	Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	Top	7.54E+04	5.18E+05	7.90E-17
	Middle	7.17E+04	4.92E+05	7.51E-17
	Bottom	6.70E+04	4.60E+05	7.02E-17
	Average			**7.48E-17**
^{54}Fe (n,p) ^{54}Mn	Top	2.77E+06	5.33E+06	8.44E-15
	Middle	2.53E+06	4.87E+06	7.71E-15
	Bottom	2.44E+06	4.69E+06	7.44E-15
	Average			**7.86E-15**
^{58}Ni (n,p) ^{58}Co	Top		Not Recovered	
	Middle	3.49E+07	7.80E+07	1.12E-14
	Bottom	3.37E+07	7.54E+07	1.08E-14
	Average			**1.10E-14**
^{59}Co (n,γ) ^{60}Co	Top	1.50E+07	1.03E+08	6.72E-12
	Top	1.28E+07	8.79E+07	5.73E-12
	Middle	1.36E+07	9.34E+07	6.09E-12
	Middle	1.58E+07	1.09E+08	7.08E-12
	Bottom		Not Recovered	
	Bottom	1.43E+07	9.82E+07	6.41E-12
	Average			**6.41E-12**
^{59}Co (n,γ) ^{60}Co (Cd)	Top	8.57E+06	5.88E+07	3.84E-12
	Middle	8.69E+06	5.97E+07	3.89E-12
	Bottom	9.17E+06	6.30E+07	4.11E-12
	Average			**3.95E-12**
^{238}U (n,f) ^{137}Cs	Middle	2.66E+05	9.48E+06	6.23E-14
^{238}U (n,f) ^{137}Cs	Including ^{235}U, ^{239}Pu, and γ,fission corrections			**5.23E-14**
^{237}Np (n,f) ^{137}Cs	Middle	1.99E+06	7.10E+07	4.53E-13
^{237}Np (n,f) ^{137}Cs	Including γ,fission correction			**4.50E-13**

Note: Measured specific activities are indexed to a counting date of May 17, 1989.

Table 6-8 Cont'd

Measured Sensor Activities and Reaction Rates

Surveillance Capsule V

Reaction	Location	Measured Activity (dps/g)	Saturated Activity (dps/g)	Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	Top	2.41E+05	4.96E+05	7.56E-17
	Middle	2.27E+05	4.67E+05	7.13E-17
	Bottom	2.16E+05	4.44E+05	6.78E-17
	Average			**7.16E-17**
$^{54}Fe\ (n,p)\ ^{54}Mn$	Top	3.25E+06	4.80E+06	7.61E-15
	Middle	3.08E+06	4.55E+06	7.21E-15
	Bottom	2.94E+06	4.34E+06	6.88E-15
	Average			**7.23E-15**
$^{58}Ni\ (n,p)\ ^{58}Co$	Top	2.56E+07	7.45E+07	1.07E-14
	Middle	2.41E+07	7.01E+07	1.00E-14
	Bottom	2.34E+07	6.81E+07	9.75E-15
	Average			**1.02E-14**
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Top	4.07E+07	8.37E+07	5.46E-12
	Top	3.63E+07	7.47E+07	4.87E-12
	Middle	3.67E+07	7.55E+07	4.93E-12
	Middle	4.36E+07	8.97E+07	5.85E-12
	Bottom	3.71E+07	7.63E+07	4.98E-12
	Bottom	4.40E+07	9.05E+07	5.91E-12
	Average			**5.33E-12**
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)	Top	2.41E+07	4.96E+07	3.24E-12
	Middle	2.48E+07	5.10E+07	3.33E-12
	Bottom	2.51E+07	5.16E+07	3.37E-12
	Average			**3.31E-12**
$^{238}U\ (n,f)\ ^{137}Cs$	Middle	1.13E+06	8.97E+06	5.89E-14
$^{238}U\ (n,f)\ ^{137}Cs$	Including ^{235}U, ^{239}Pu, and γ,fission corrections			**4.53E-14**
$^{237}Np\ (n,f)\ ^{137}Cs$	Middle	8.97E+06	7.01E+07	4.47E-13
$^{237}Np\ (n,f)\ ^{137}Cs$	Including γ,fission correction			**4.45E-13**

Note: Measured specific activities are indexed to a counting date of June 30, 1995.

Table 6-8 Cont'd

Measured Sensor Activities and Reaction Rates

Surveillance Capsule W

Reaction	Location	Measured Activity (dps/g)	Saturated Activity (dps/g)	Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	Top	2.39E+05	4.11E+05	6.27E-17
	Middle	2.17E+05	3.73E+05	5.69E-17
	Bottom	2.11E+05	3.63E+05	5.54E-17
	Average			**5.83E-17**
$^{54}Fe\ (n,p)\ ^{54}Mn$	Top	2.91E+06	4.29E+06	6.80E-15
	Middle	2.65E+06	3.90E+06	6.19E-15
	Bottom	2.44E+06	3.60E+06	5.70E-15
	Average			**6.23E-15**
$^{58}Ni\ (n,p)\ ^{58}Co$	Top	4.39E+07	6.88E+07	9.85E-15
	Middle	3.94E+07	6.17E+07	8.84E-15
	Bottom	3.85E+07	6.03E+07	8.63E-15
	Average			**9.11E-15**
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Top	3.24E+07	5.57E+07	3.64E-12
	Top	3.73E+07	6.42E+07	4.19E-12
	Middle	3.33E+07	5.73E+07	3.74E-12
	Middle	3.98E+07	6.85E+07	4.47E-12
	Bottom	3.40E+07	5.85E+07	3.82E-12
	Bottom	3.89E+07	6.69E+07	4.37E-12
	Average			**4.03E-12**
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)	Top	2.22E+07	3.82E+07	2.49E-12
	Middle	2.27E+07	3.90E+07	2.55E-12
	Bottom	2.31E+07	3.97E+07	2.59E-12
	Average			**2.54E-12**
$^{238}U\ (n,f)\ ^{137}Cs$	Middle		Damaged	
$^{237}Np\ (n,f)\ ^{137}Cs$	Middle	1.06E+07	5.50E+07	3.51E-13
$^{237}Np\ (n,f)\ ^{137}Cs$	Including γ,fission correction			**3.49E-13**

Note: Measured specific activities are indexed to a counting date of October 20, 2000.

Table 6-9

Comparison of Measured, Calculated, and Best Estimate
Reaction Rates At The Surveillance Capsule Center

Capsule U

	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	7.48E-17	6.82E-17	7.22E-17	1.10	1.03
$^{54}Fe(n,p)^{54}Mn$	7.86E-15	8.22E-15	8.09E-15	0.96	0.97
$^{58}Ni(n,p)^{58}Co$	1.10E-14	1.17E-14	1.14E-14	0.94	0.96
$^{238}U(n,f)^{137}Cs$ (Cd)	5.23E-14	4.71E-14	4.59E-14	1.11	1.14
$^{237}Np(n,f)^{137}Cs$ (Cd)	4.50E-13	5.05E-13	4.71E-13	0.89	0.96
$^{59}Co(n,\gamma)^{60}Co$	6.41E-12	4.92E-12	6.24E-12	1.30	1.03
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	3.95E-12	3.77E-12	4.02E-12	1.05	0.98

Capsule V

	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	7.16E-17	6.47E-17	6.88E-17	1.11	1.04
$^{54}Fe(n,p)^{54}Mn$	7.23E-15	7.59E-15	7.47E-15	0.95	0.97
$^{58}Ni(n,p)^{58}Co$	1.02E-14	1.07E-14	1.05E-14	0.94	0.96
$^{238}U(n,f)^{137}Cs$ (Cd)	4.53E-14	4.27E-14	4.18E-14	1.06	1.08
$^{237}Np(n,f)^{137}Cs$ (Cd)	4.45E-13	4.49E-13	4.43E-13	0.99	1.00
$^{59}Co(n,\gamma)^{60}Co$	5.33E-12	4.26E-12	5.20E-12	1.25	1.03
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	3.31E-12	3.27E-12	3.37E-12	1.01	0.98

Capsule W

	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	5.83E-17	5.90E-17	5.78E-17	0.99	1.01
$^{54}Fe(n,p)^{54}Mn$	6.23E-15	6.70E-15	6.37E-15	0.93	0.98
$^{58}Ni(n,p)^{58}Co$	9.11E-15	9.44E-15	9.04E-15	0.96	1.01
$^{237}Np(n,f)^{137}Cs$ (Cd)	3.49E-13	3.70E-13	3.52E-13	0.94	0.99
$^{59}Co(n,\gamma)^{60}Co$	4.03E-12	3.28E-12	3.93E-12	1.23	1.03
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	2.54E-12	2.53E-12	2.59E-12	1.00	0.98

Table 6-10

Comparison of Calculated and Best Estimate Exposure Rates
At The Surveillance Capsule Center

Capsule ID	$\phi(E > 1.0\ MeV)$ [n/cm^2-s]			
	Calculated	Best Estimate	Uncertainty (1σ)	BE/C
U	1.55E+11	1.51E+11	6%	0.97
V	1.39E+11	1.37E+11	6%	0.98
W	1.18E+11	1.12E+11	7%	0.95

Capsule ID	Iron Atom Displacement Rate [dpa/s]			
	Calculated	Best Estimate	Uncertainty (1σ)	BE/C
U	3.19E-10	3.10E-10	8%	0.97
V	2.83E-10	2.80E-10	8%	0.99
W	2.34E-10	2.23E-10	8%	0.96

Table 6-11

Comparison of [Measured]/[Calculated] (M/C) Sensor Reaction Rate Ratios Including all Fast Neutron Threshold Reactions

Reaction	M/C Ratio		
	Capsule U	Capsule V	Capsule W
$^{63}Cu(n,\alpha)^{60}Co$	1.10	1.11	0.99
$^{54}Fe(n,p)^{54}Mn$	0.96	0.95	0.93
$^{58}Ni(n,p)^{58}Co$	0.94	0.94	0.96
$^{238}U(n,p)^{137}Cs$ (Cd)	1.11	1.06	n/a
$^{237}Np(n,f)^{137}Cs$ (Cd)	0.89	0.99	0.94
Average	1.00	1.01	0.96
% Standard Deviation	9.9	7.2	2.8

Note: The overall average M/C ratio for the set of 14 sensor measurements is 0.99 with an associated standard deviation of 7.4%.

Table 6-12

Comparison of [Best Estimate]/[Calculated] (BE/C) Exposure Rate Ratios

Capsule ID	BE/C Ratio	
	$\phi(E > 1.0\ MeV)$	dpa/s
U	0.97	0.97
V	0.98	0.99
W	0.95	0.96
Average	0.97	0.97
% Standard Deviation	1.4	1.7

Table 6-13

Calculated Fast Neutron Exposure of Surveillance Capsules
Withdrawn from Beaver Valley Unit 2

Capsule	Irradiation Time [efpy]	Fluence (E > 1.0 MeV) [n/cm^2]	Iron Displacements [dpa]
U	1.24	6.08E+18	1.25E-02
V	5.98	2.63E+19	5.34E-02
W	9.77	3.63E+19	7.20E-02

Table 6-14

Calculated Maximum Fast Neutron Exposure of the Beaver Valley Unit 2
Reactor Pressure Vessel at the Clad/Base Metal Interface

Neutron Fluence [E > 1.0 MeV]

Cumulative Operating Time [efpy]	Neutron Fluence [n/cm^2]			
	0.0 Degrees	15.0 Degrees	30.0 Degrees	45.0 Degrees
9.77 (EOC 8)	1.10E+19	6.88E+18	5.27E+18	3.67E+18
25.00	2.98E+19	1.85E+19	1.42E+19	9.88E+18
32.00	3.85E+19	2.40E+19	1.84E+19	1.28E+19
48.00	5.84E+19	3.64E+19	2.78E+19	1.94E+19
54.00	6.58E+19	4.10E+19	3.14E+19	2.19E+19

Iron Atom Displacements

Cumulative Operating Time [efpy]	Iron Atom Displacements [dpa]			
	0.0 Degrees	15.0 Degrees	30.0 Degrees	45.0 Degrees
9.77 (EOC 8)	1.75E-02	1.08E-02	8.10E-03	5.68E-03
25.00	4.73E-02	2.91E-02	2.18E-02	1.53E-02
32.00	6.12E-02	3.77E-02	2.82E-02	1.98E-02
48.00	9.28E-02	5.72E-02	4.28E-02	3.00E-02
54.00	1.05E-01	6.45E-02	4.83E-02	3.39E-02

Note: Calculated maximum exposure values occur at an axial elevation 62.3 cm below the midplane of the active fuel region.

Table 6-15

Calculated Surveillance Capsule Lead Factors

Capsule ID And Location	Status	Lead Factor
U (17°)	Withdrawn EOC 1	3.17
V (17°)	Withdrawn EOC 5	3.64
W (20°)	Withdrawn EOC 8	3.29
X (17°)	In Reactor	3.71
Y (20°)	In Reactor	3.29
Z (20°)	In Reactor	3.29

Note: Lead factors for capsules remaining in the reactor are based on cycle specific exposure calculations through fuel cycle 8.

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 2 reactor vessel.

Table 7-1 Beaver Valley Unit 2 Reactor Vessel Surveillance Capsule Withdrawal Schedule

Capsule	Location	Lead Factor[(a)]	Removal Time (EFPY)[(b)]	Fluence (n/cm^2, E>1.0 MeV)[(a)]
U	343°	3.17	1.24	6.08×10^{18} (c)
V	107°	3.64	5.98	2.63×10^{19} (c)
W	110°	3.29	9.77	3.625×10^{19} (c)
X	287°	3.71	14	5.77×10^{19} (d)
Y	290°	3.29	Standby [(e)]	--
Z	340°	3.29	Standby [(e)]	--

Notes:

(a) Updated in Capsule W dosimetry analysis.

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

(c) Actual plant evaluation calculated fluence.

(d) Approximately equal to the projected peak vessel fluence at 48 EFPY, not less than once or greater than twice the maximum EOL (32 EFPY) inner vessel wall fluence.

(e) These capsules will reach a fluence of approximately 6.584×10^{19} (54EFPY Peak Fluence) @ 17 EFPY. It is recommended that these standby capsules are withdrawn at this time and placed in storage.

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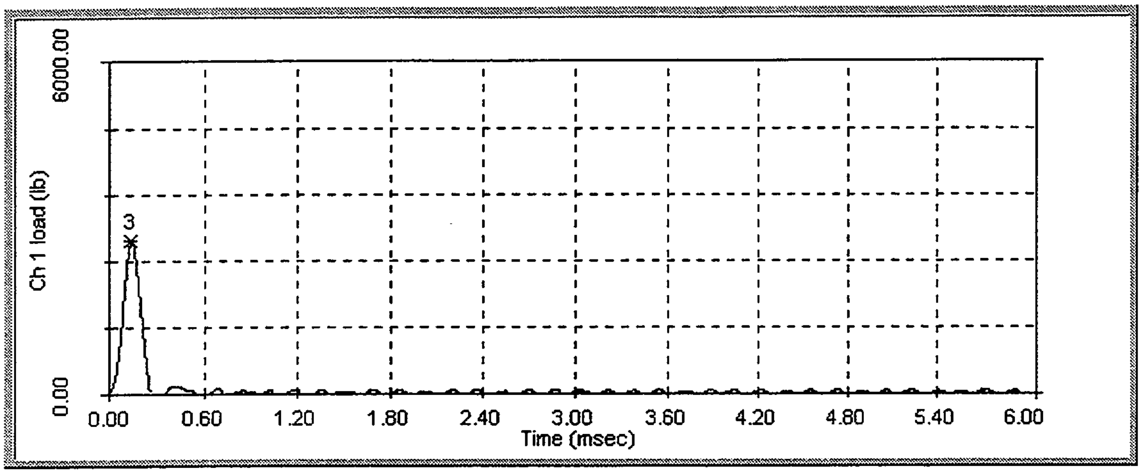
APPENDIX A

LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS



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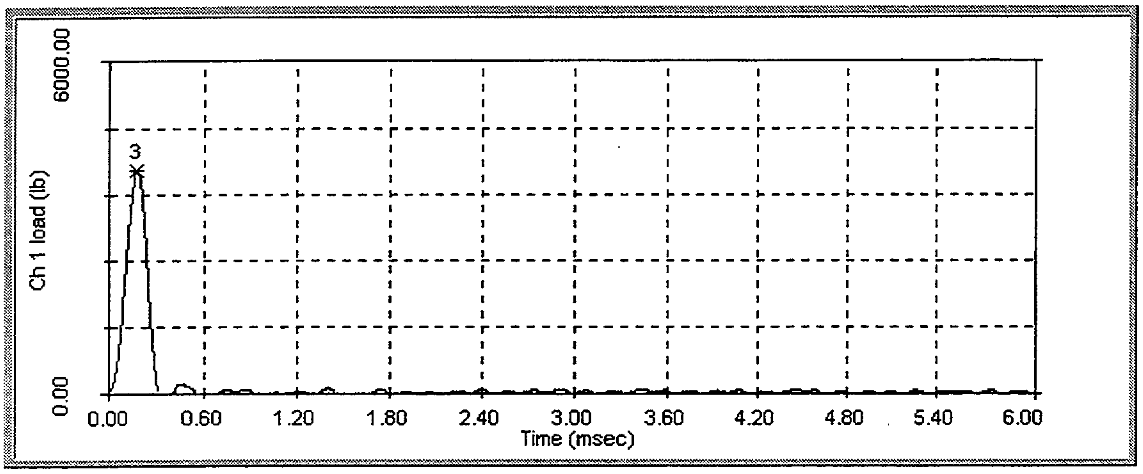

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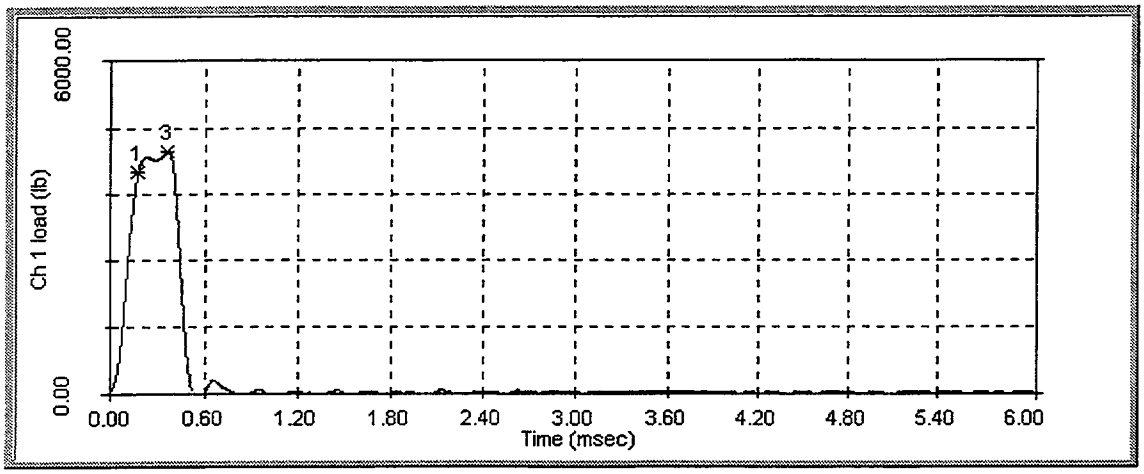
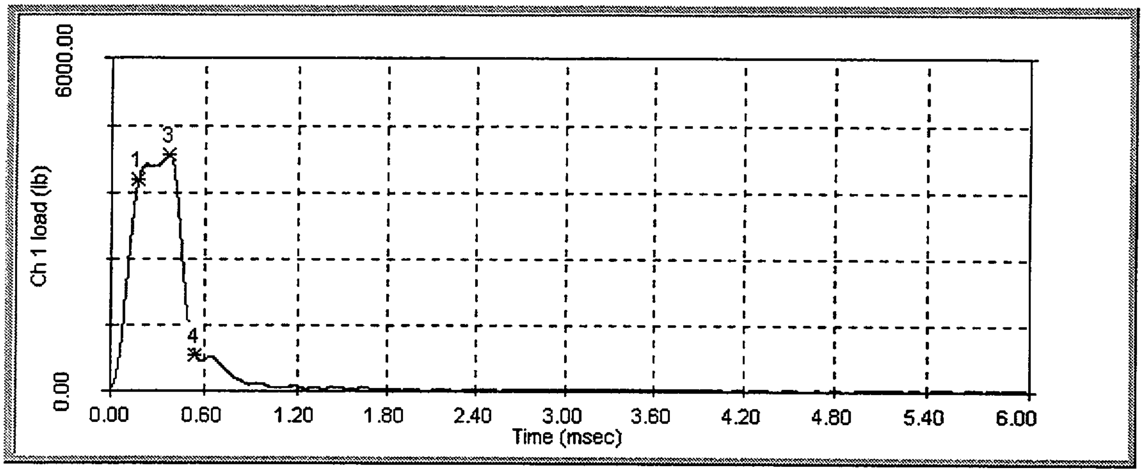
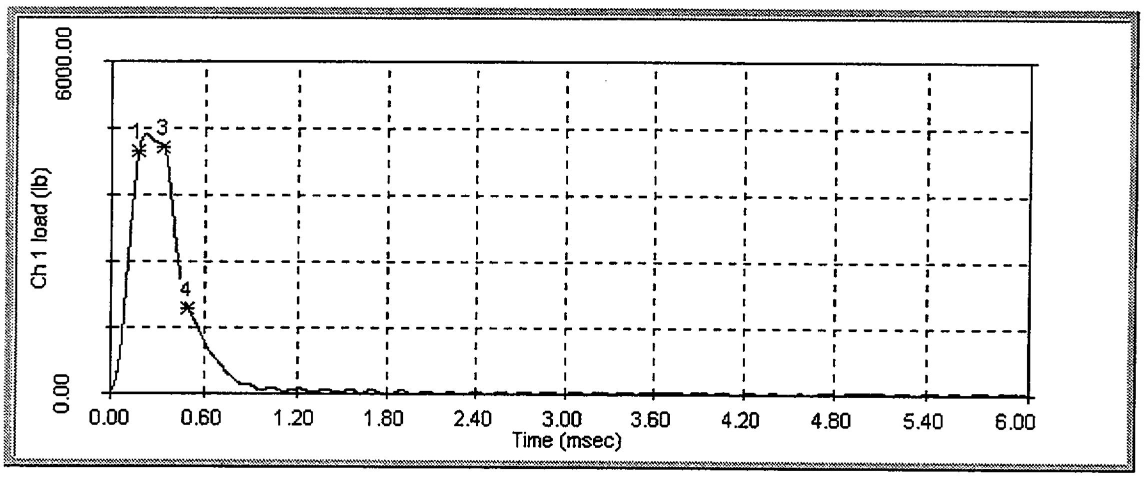


WL37, 50°F



WL44, 100°F



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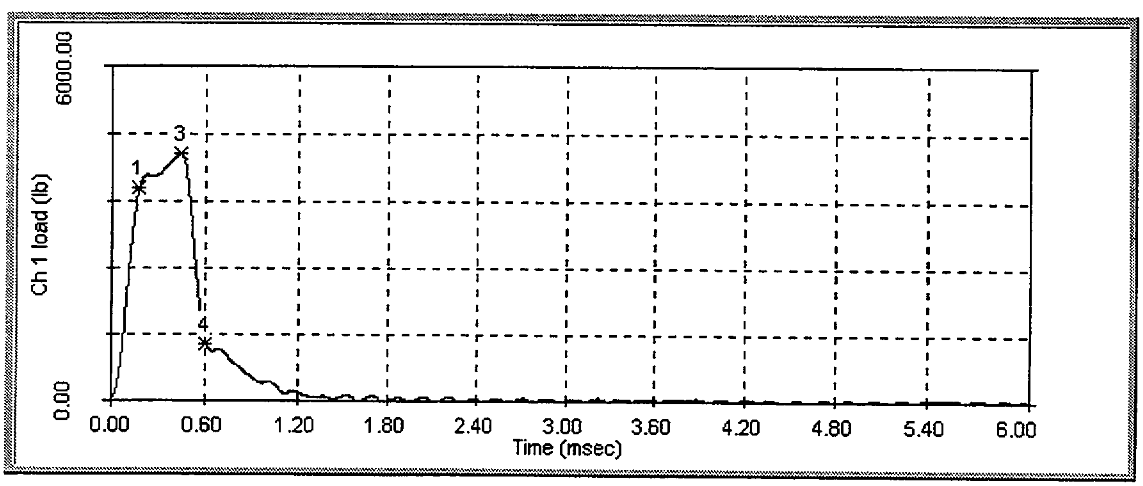
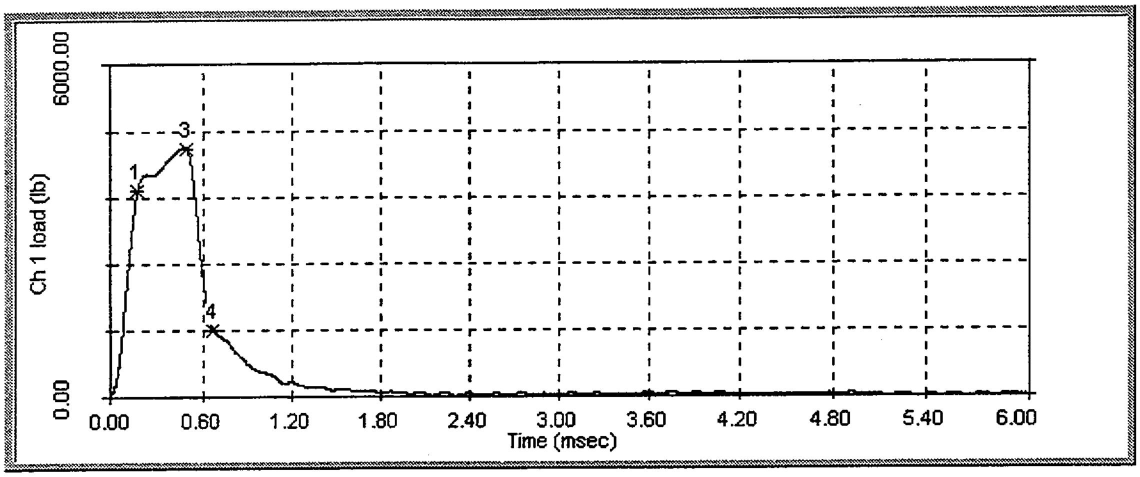


WL33, 125°F



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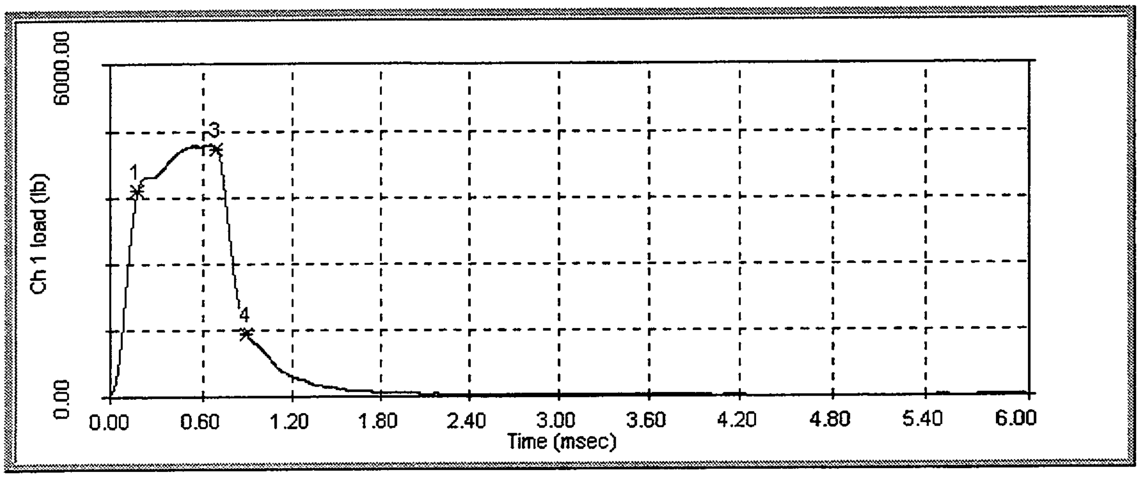

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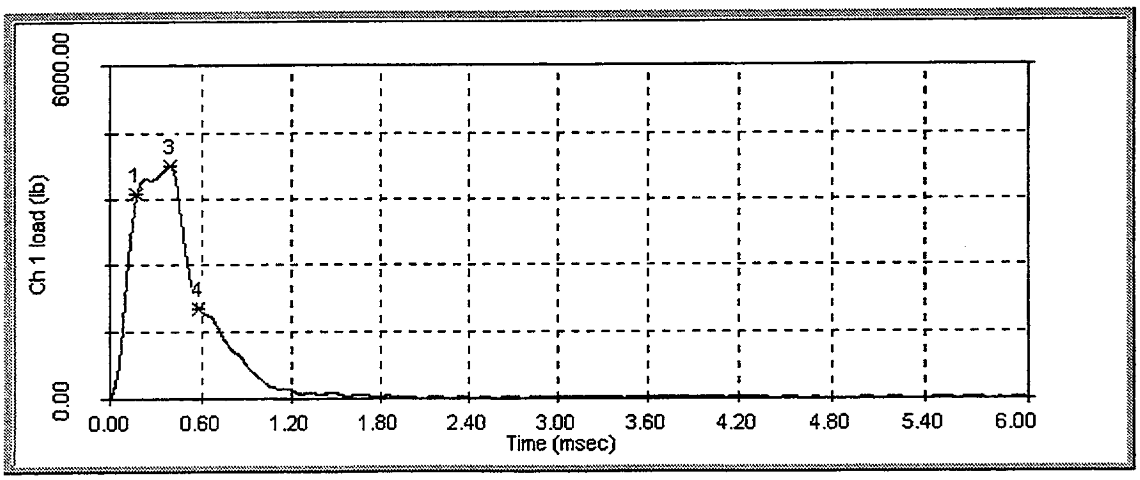
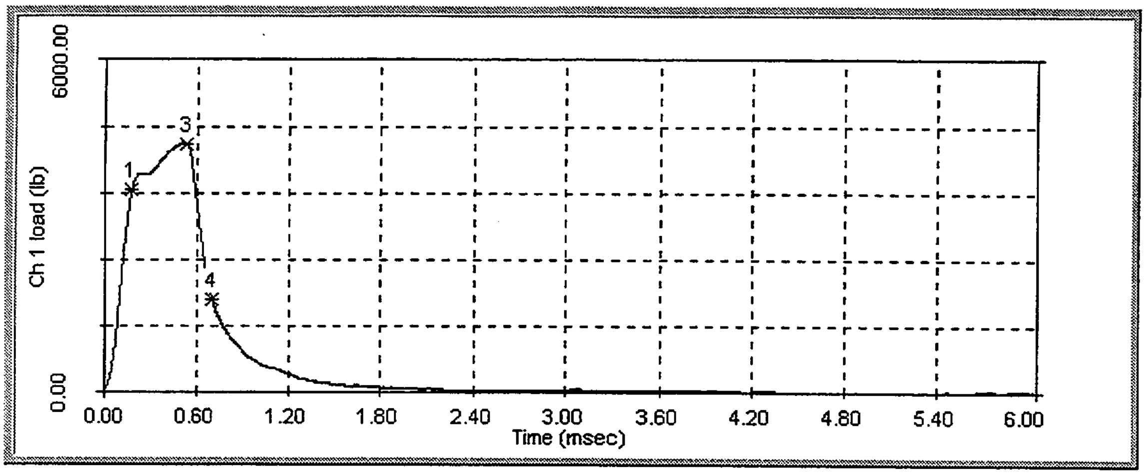


WL41, 150°F



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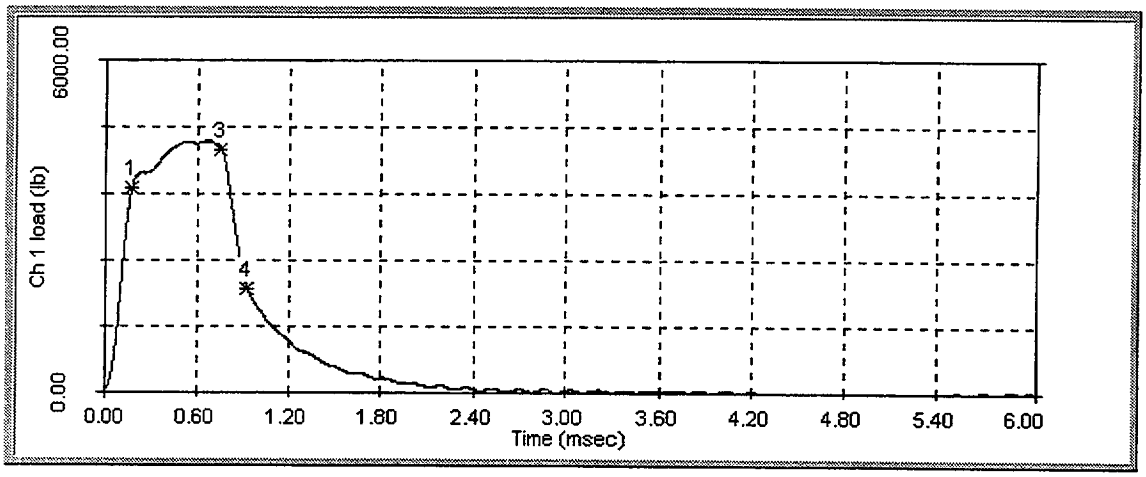

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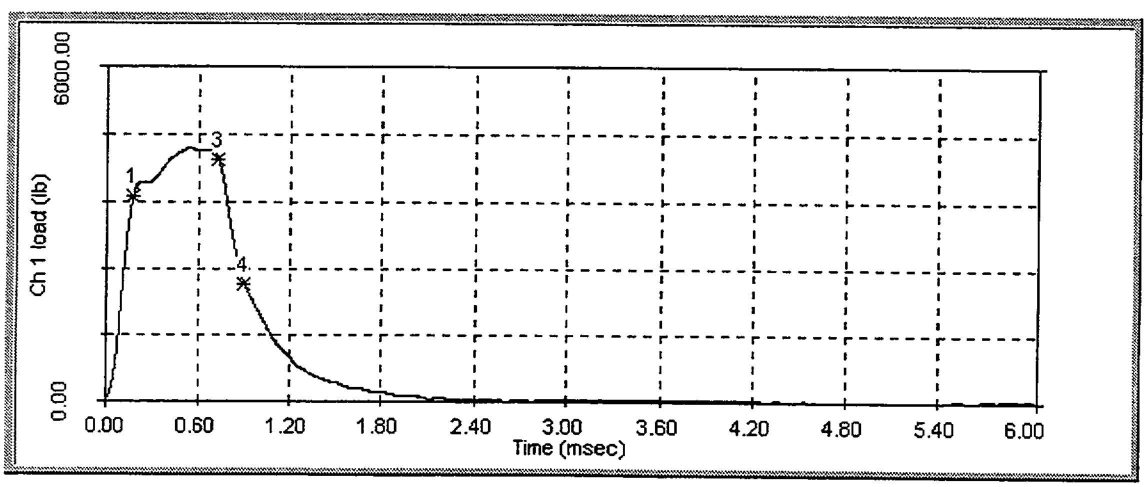

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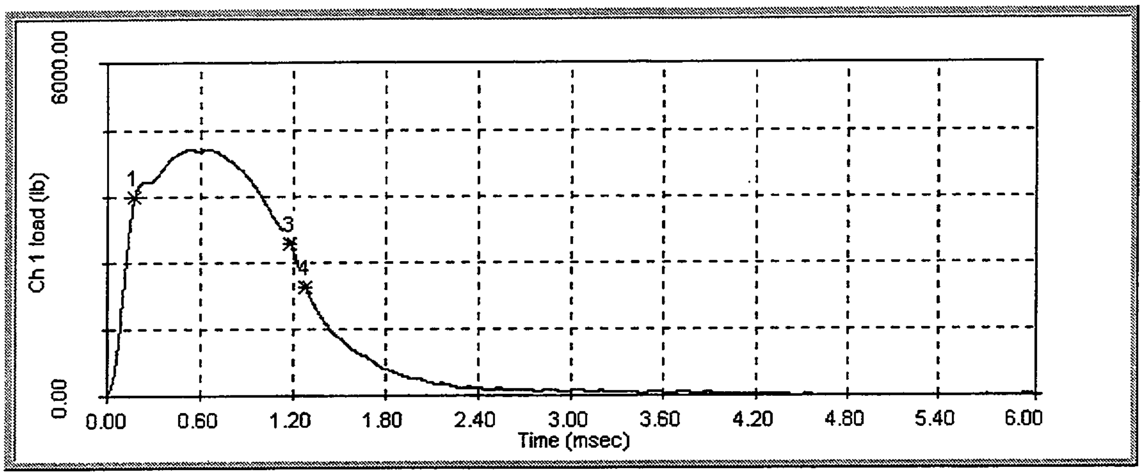

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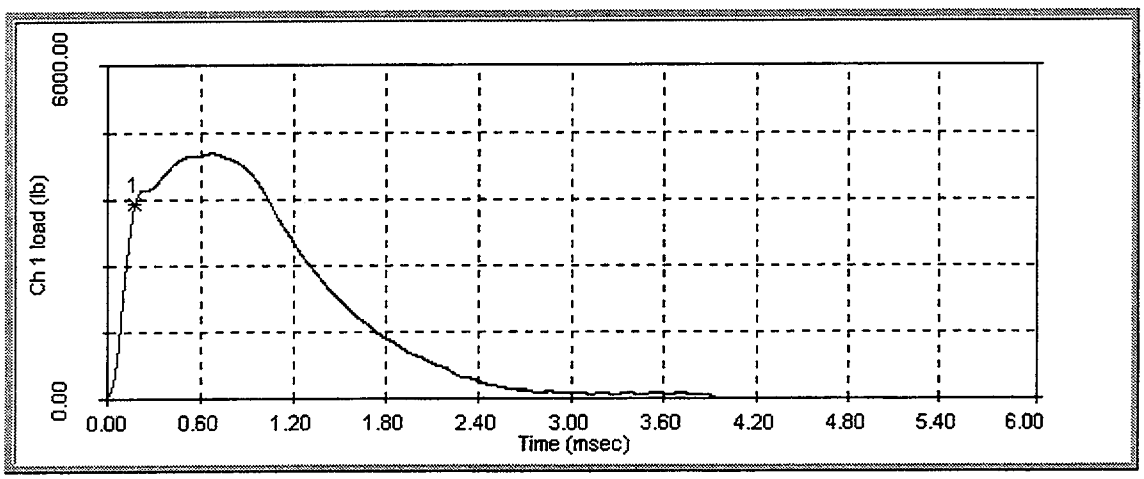

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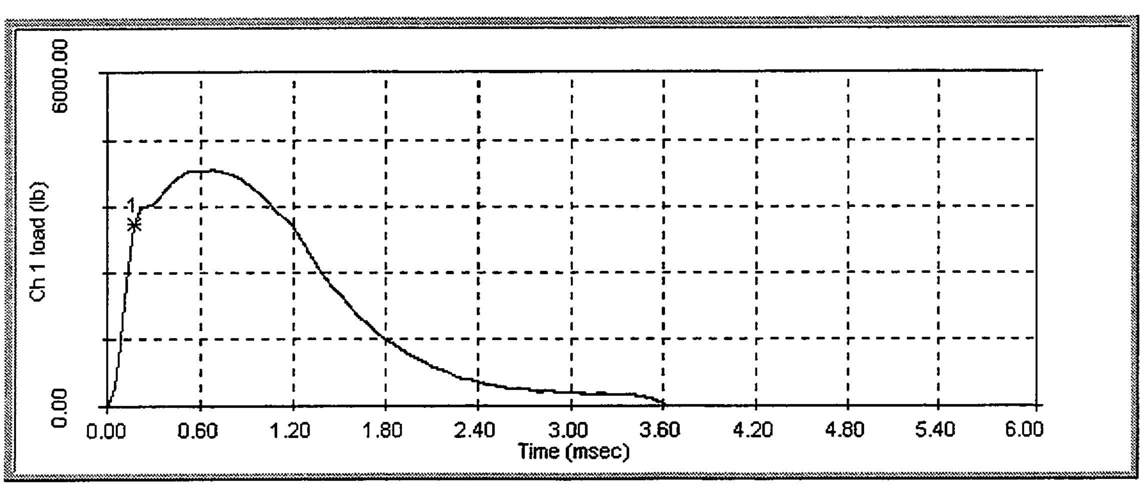

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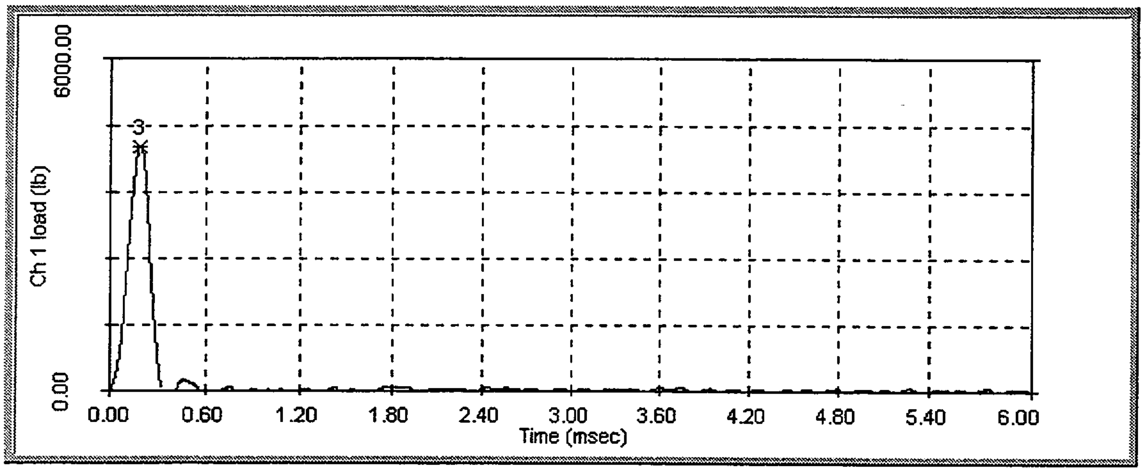

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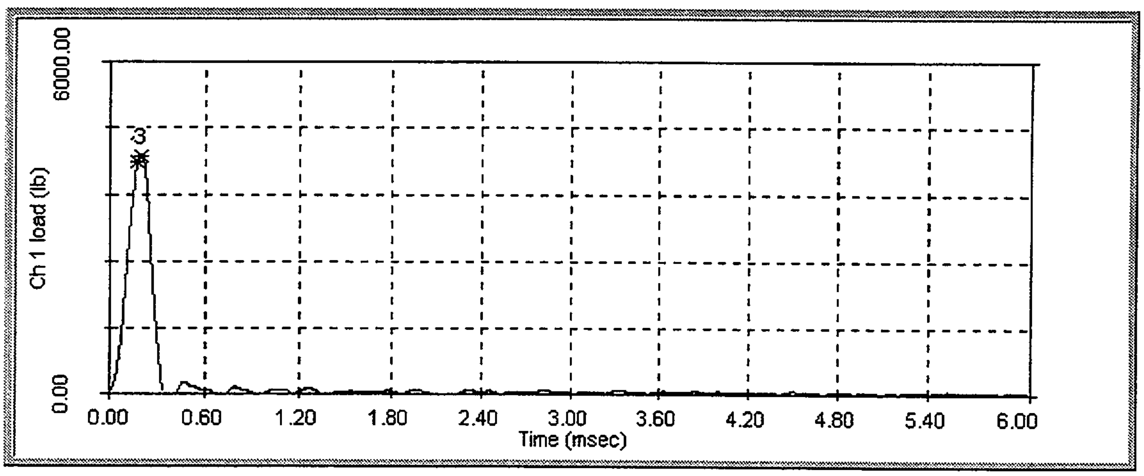

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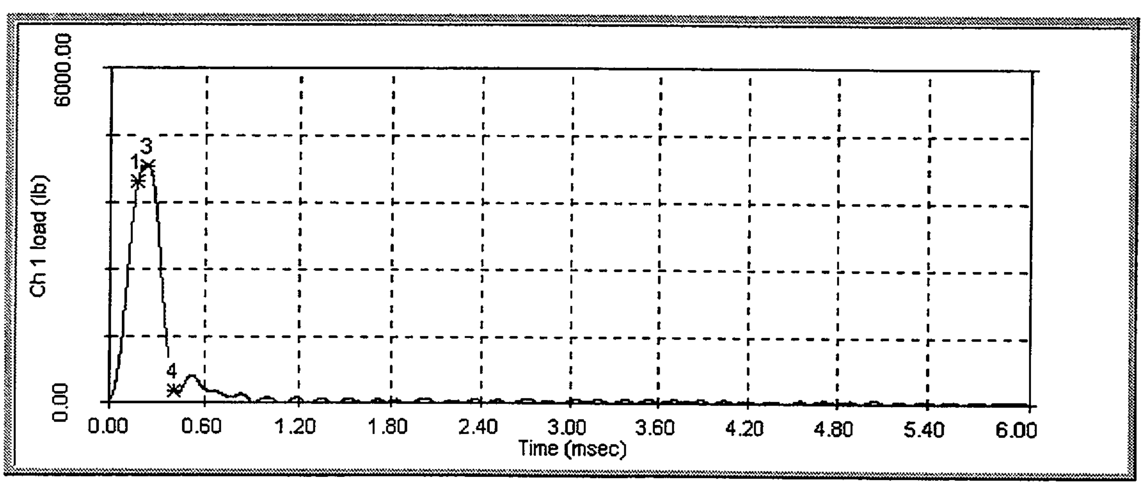

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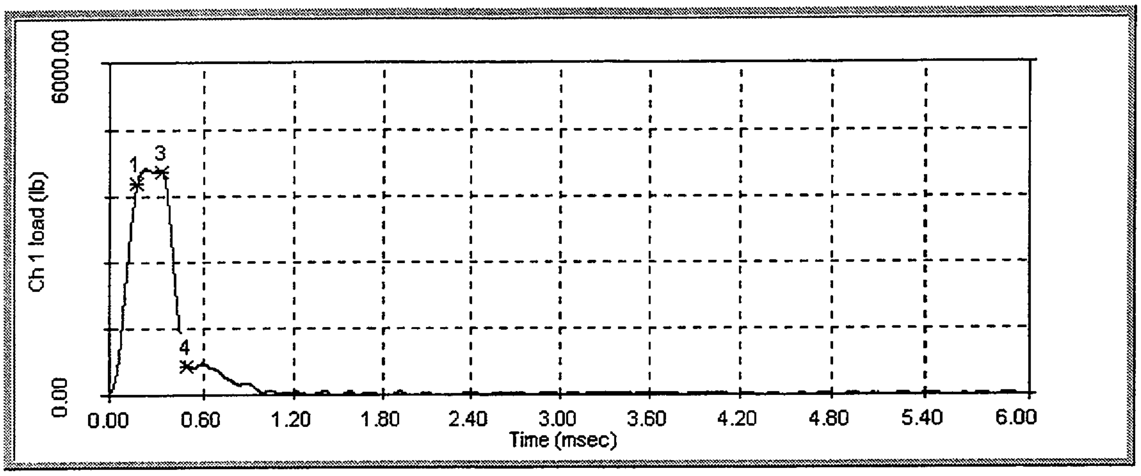
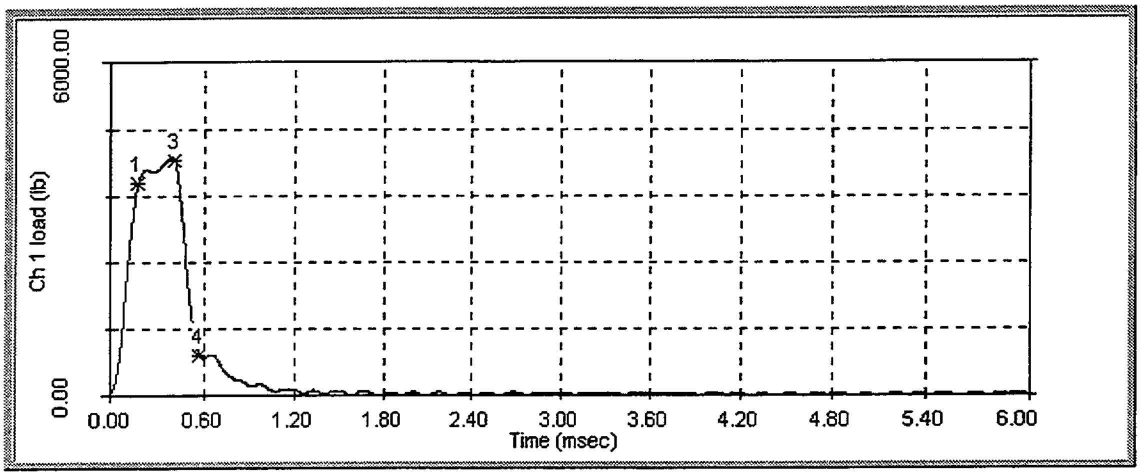
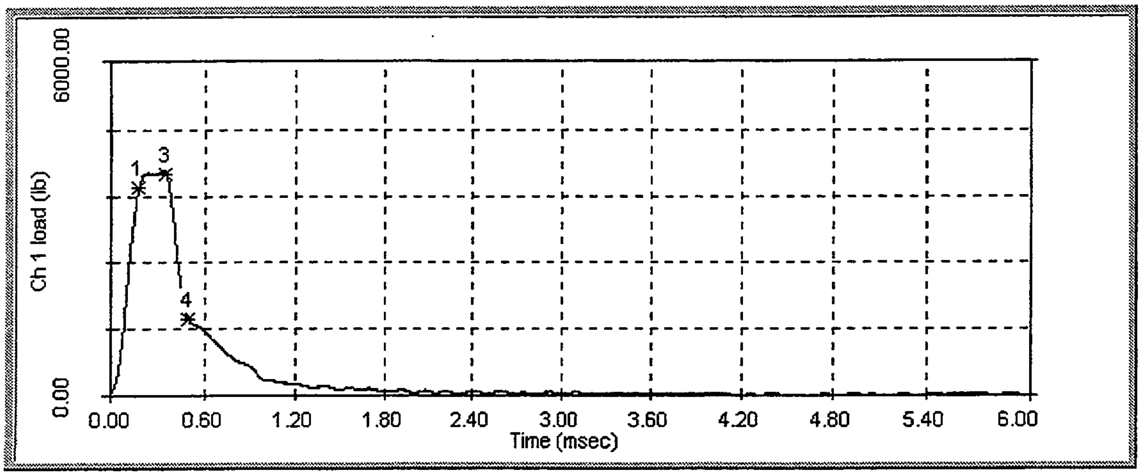


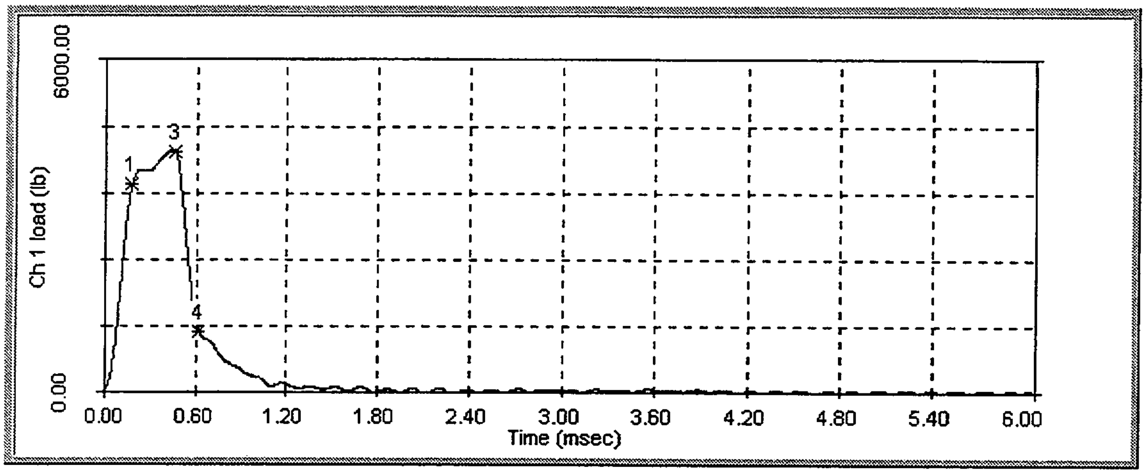
WT41, 85°F



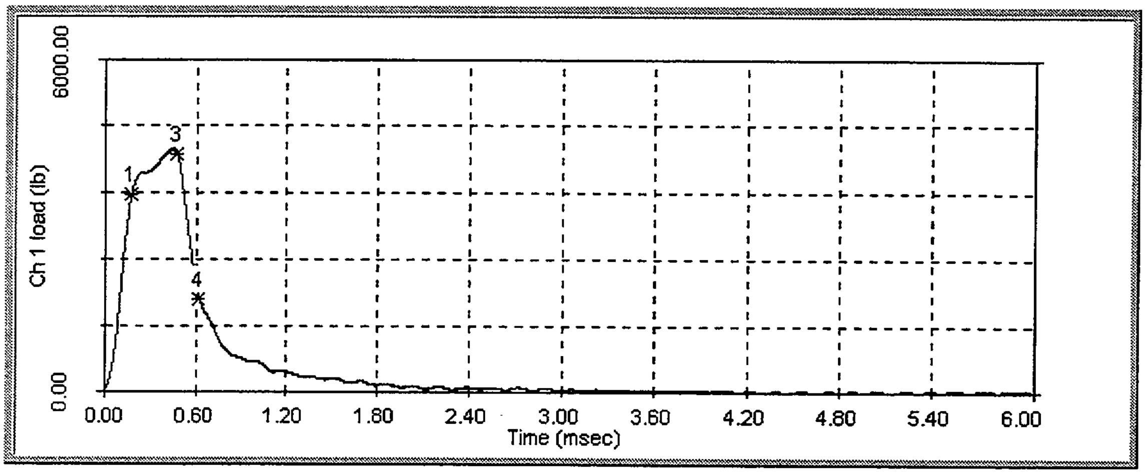
WT43, 100°F



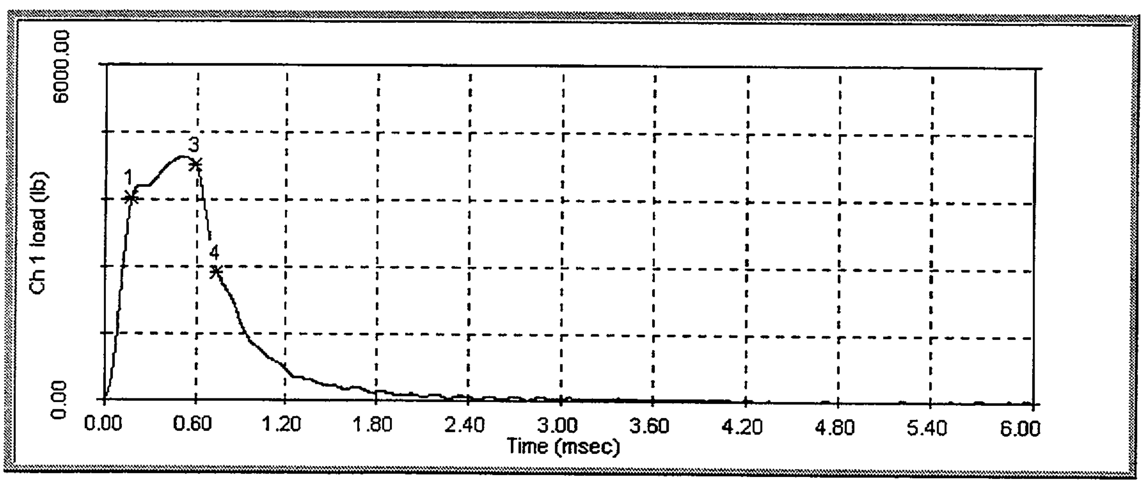
WT37, 115°F



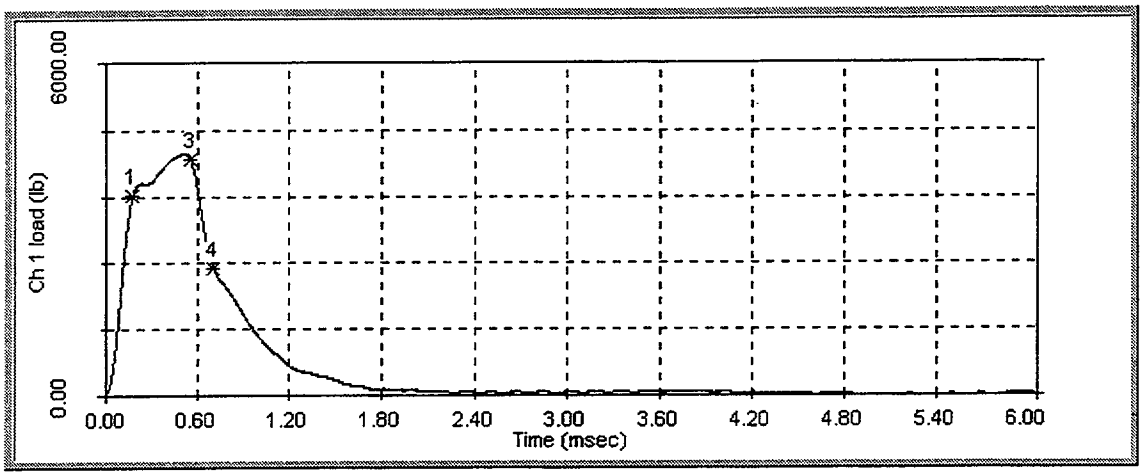
WT40, 125°F



WT31, 150°F



WT32, 165°F



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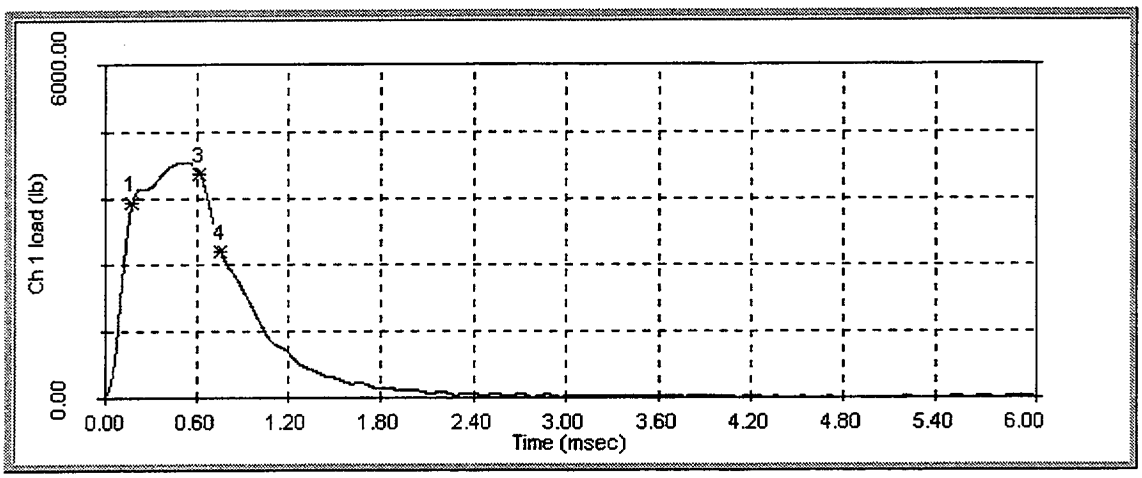

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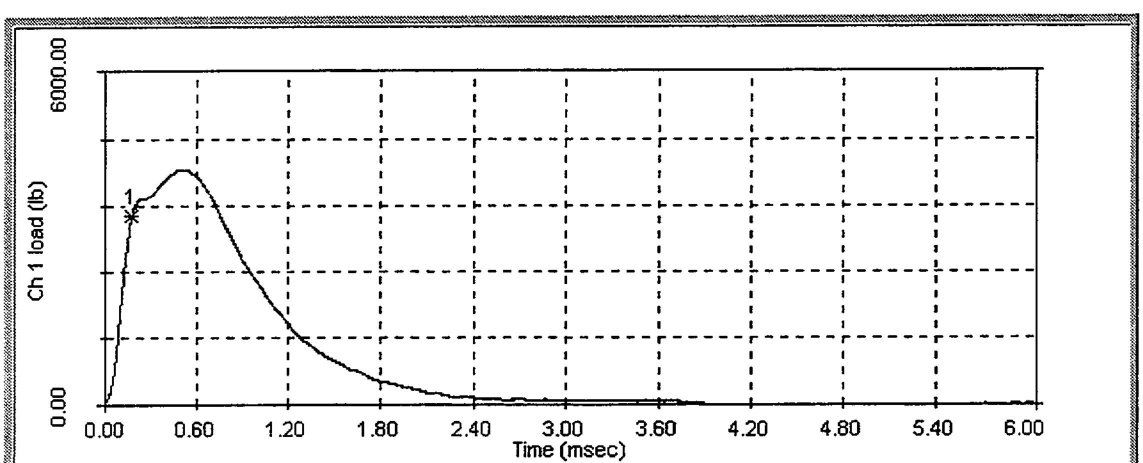
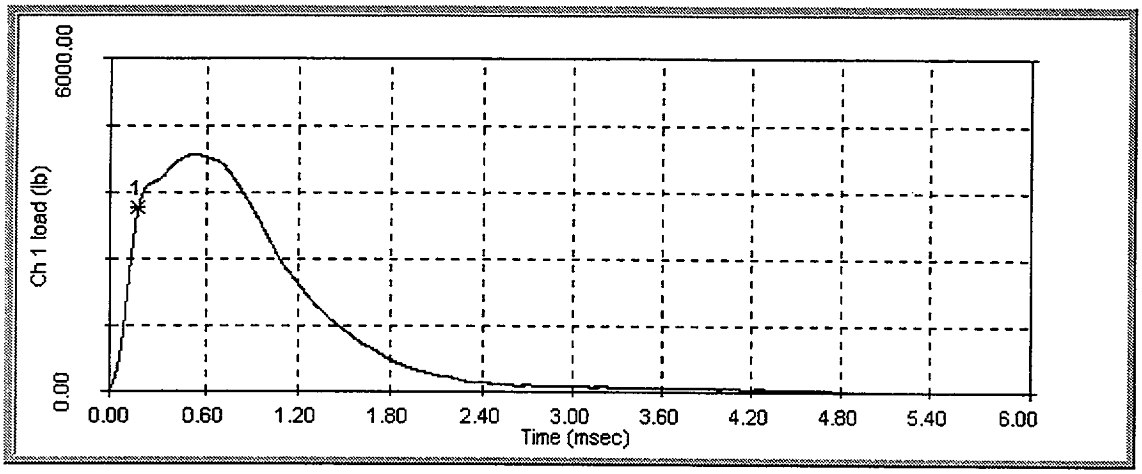


WT42, 225°F



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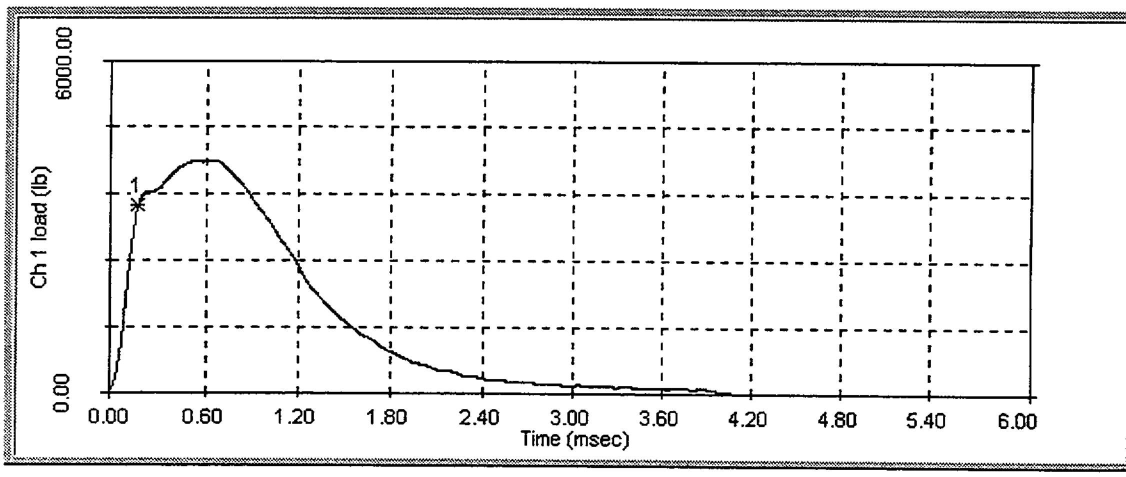

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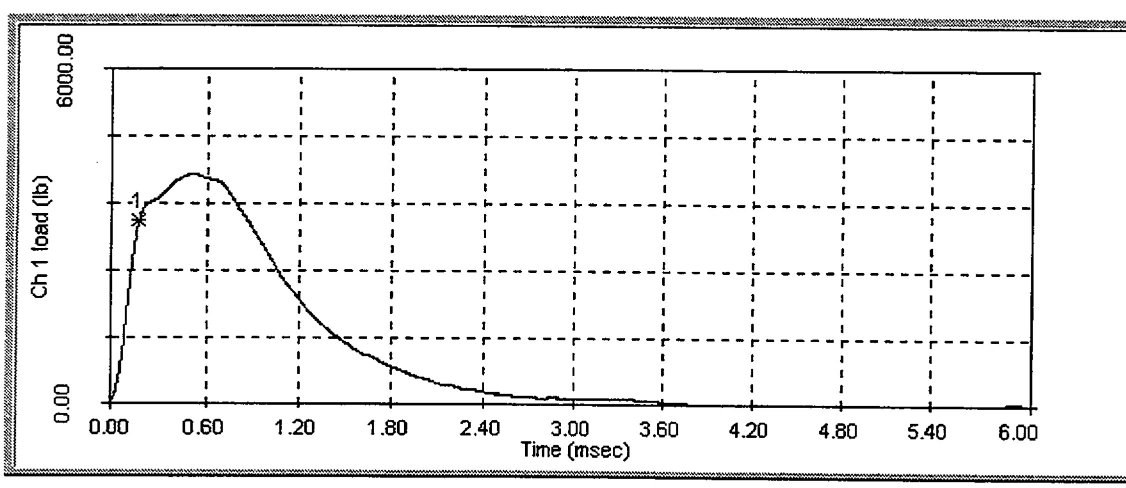

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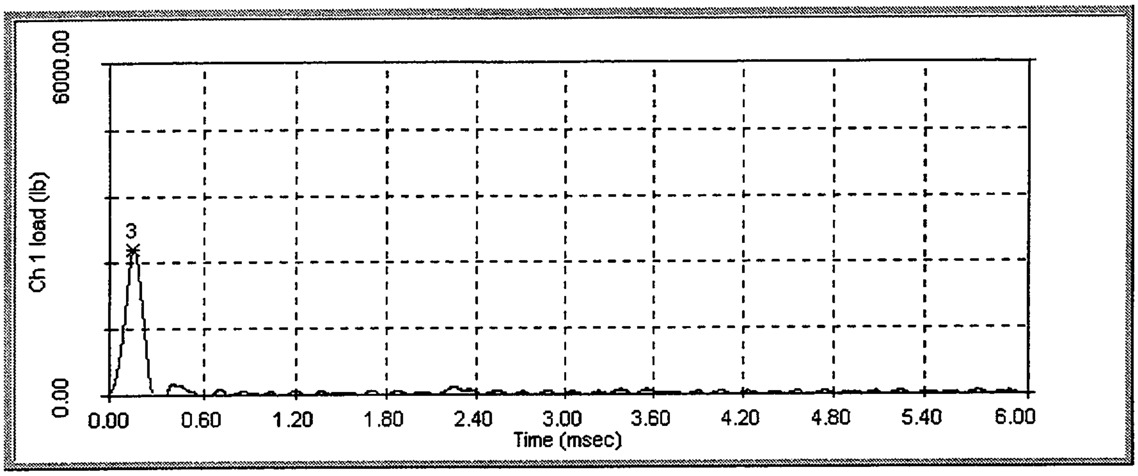

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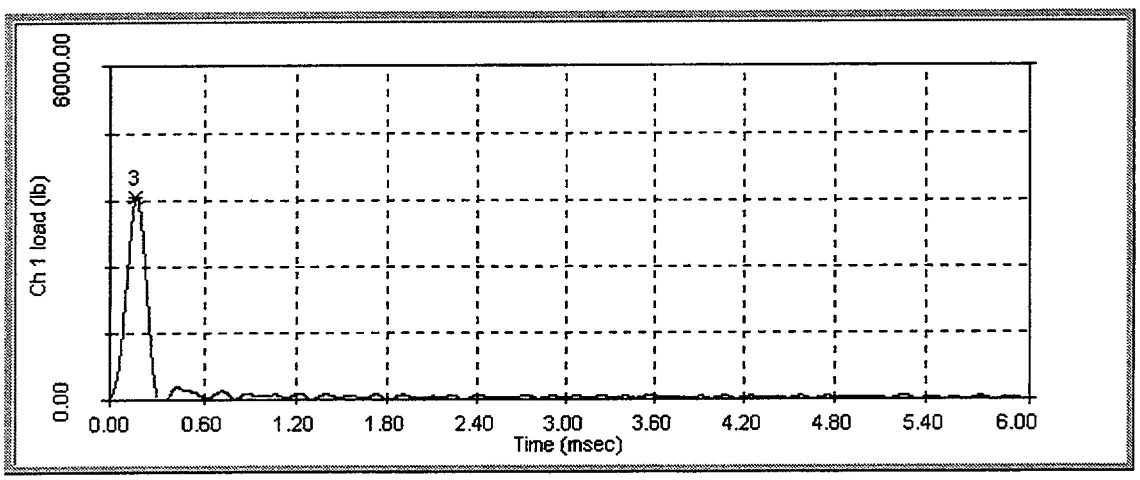

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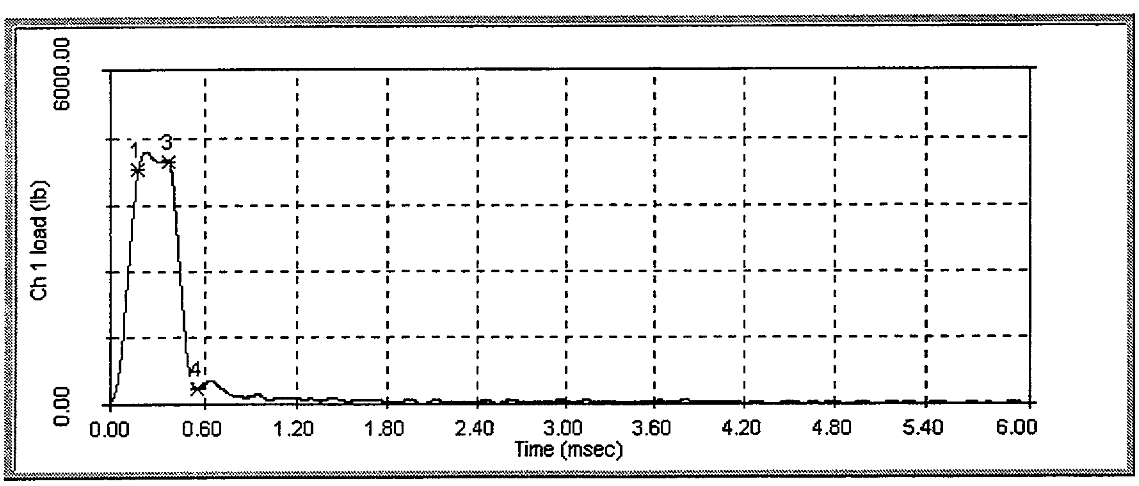

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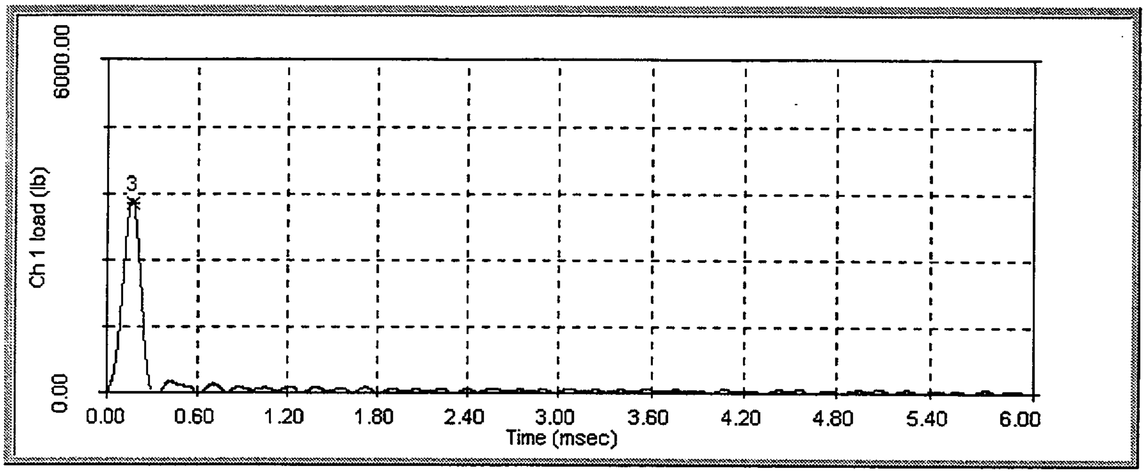

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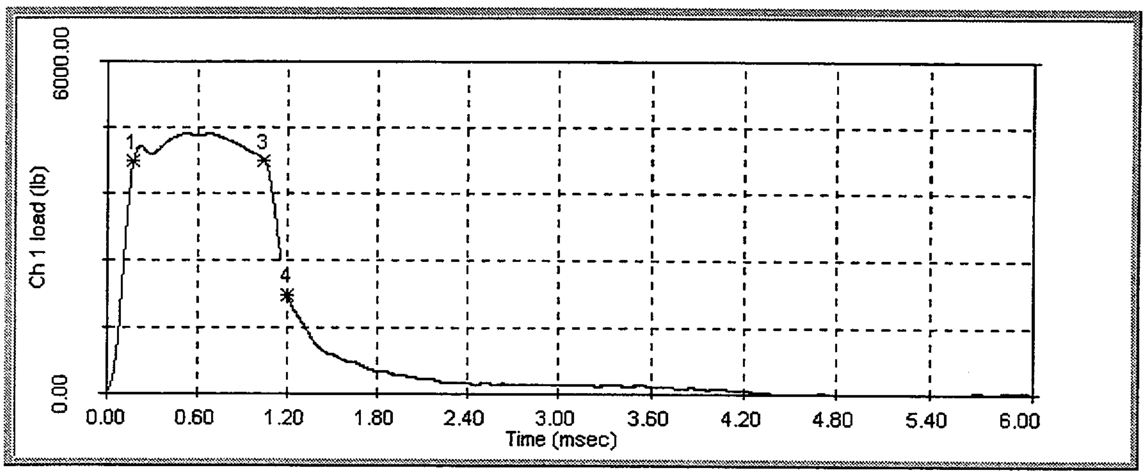

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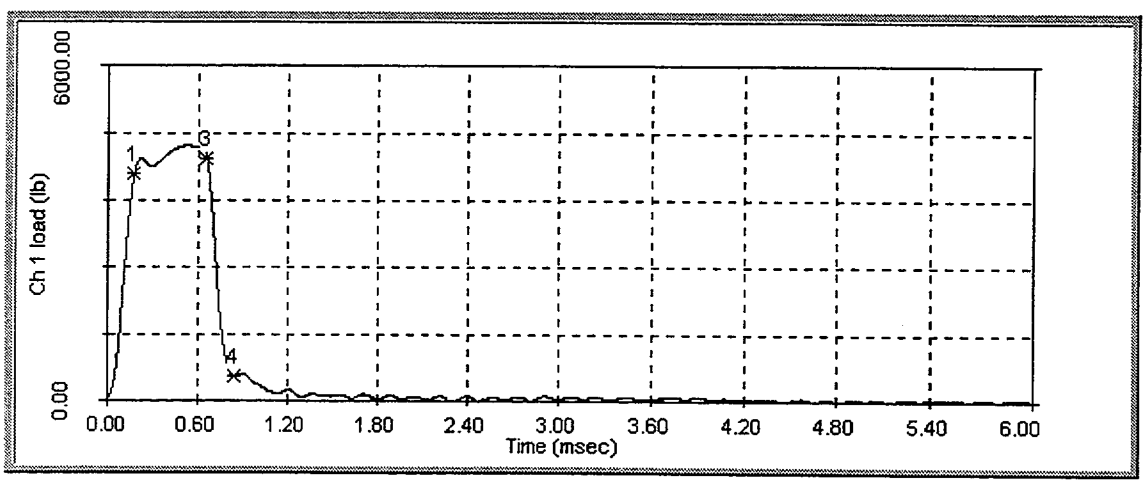

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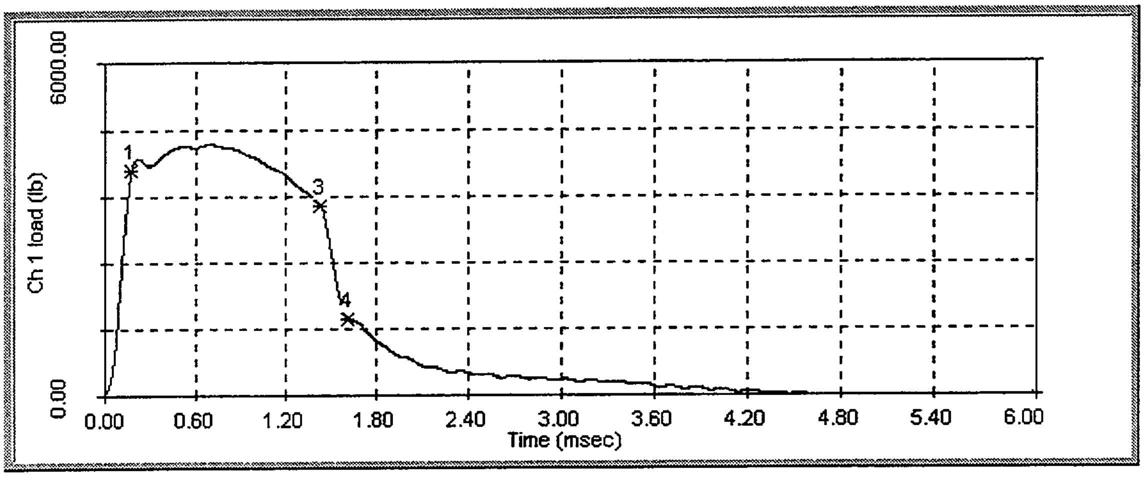

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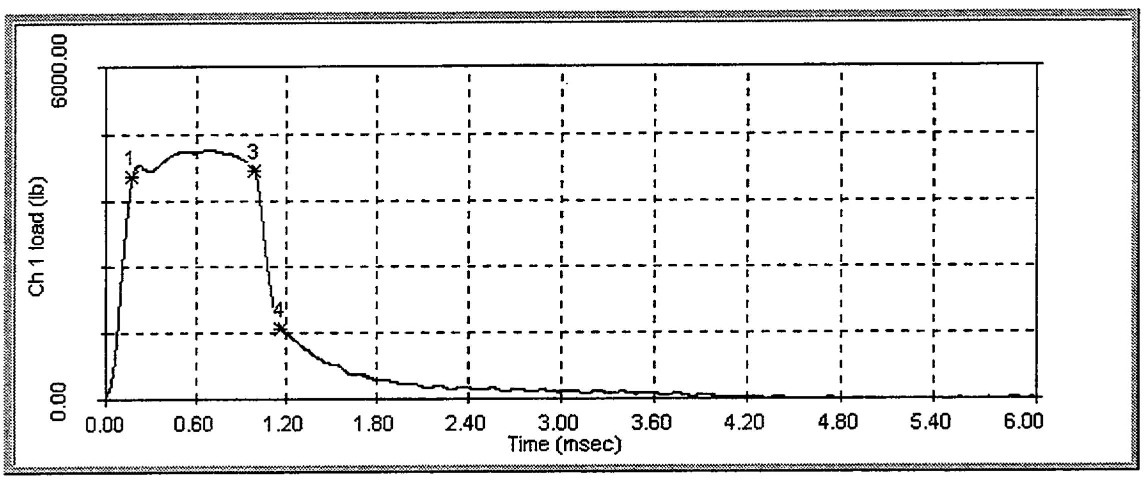
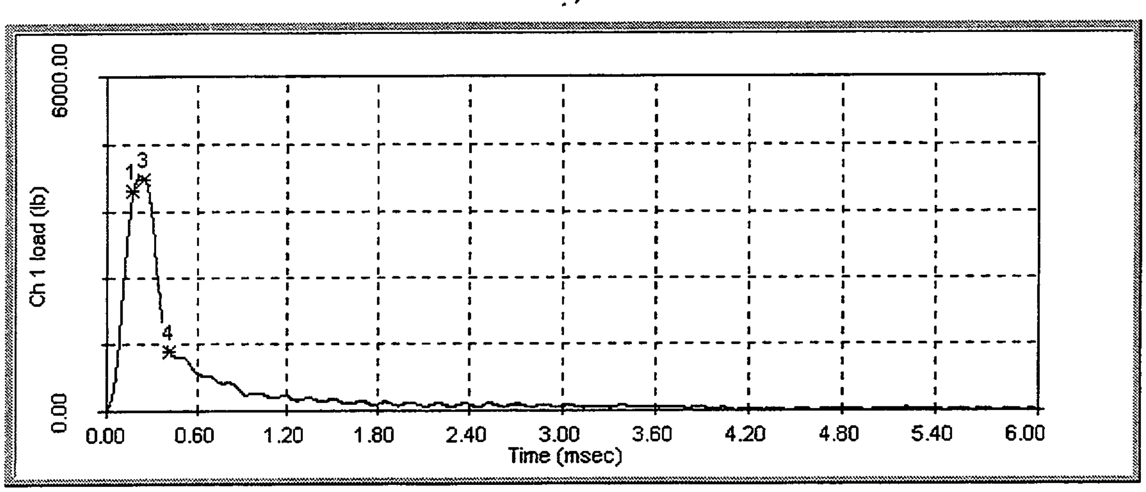


WW42, 20°F



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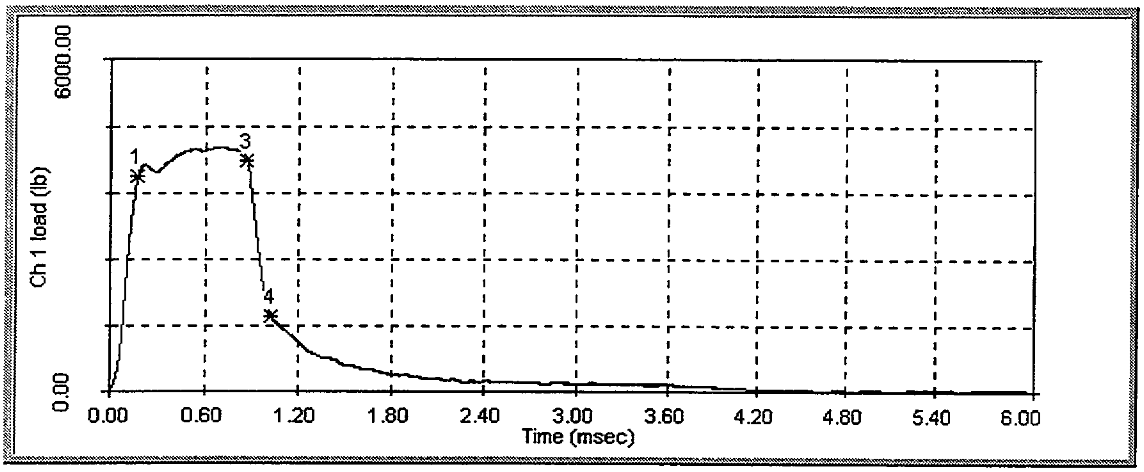
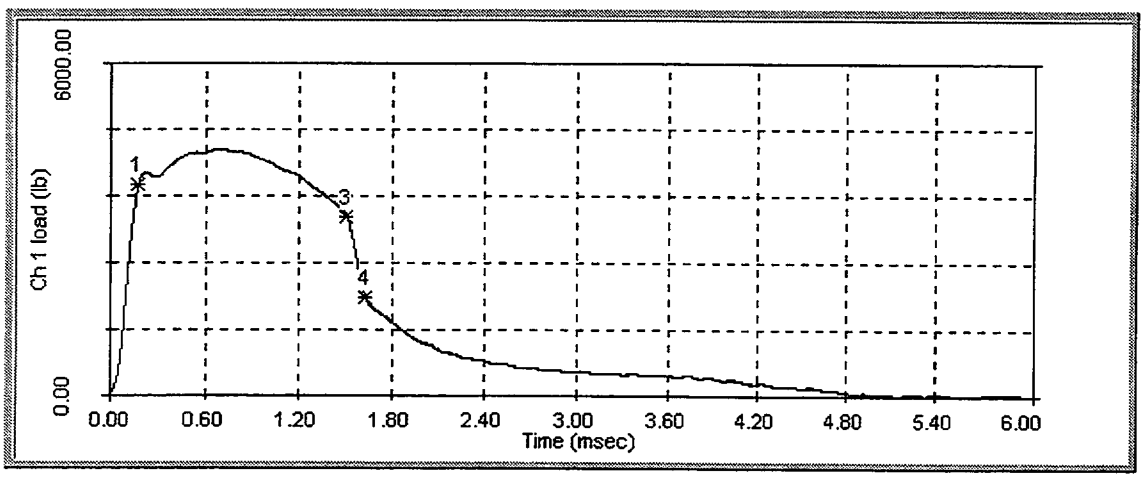


WW44, 50°F



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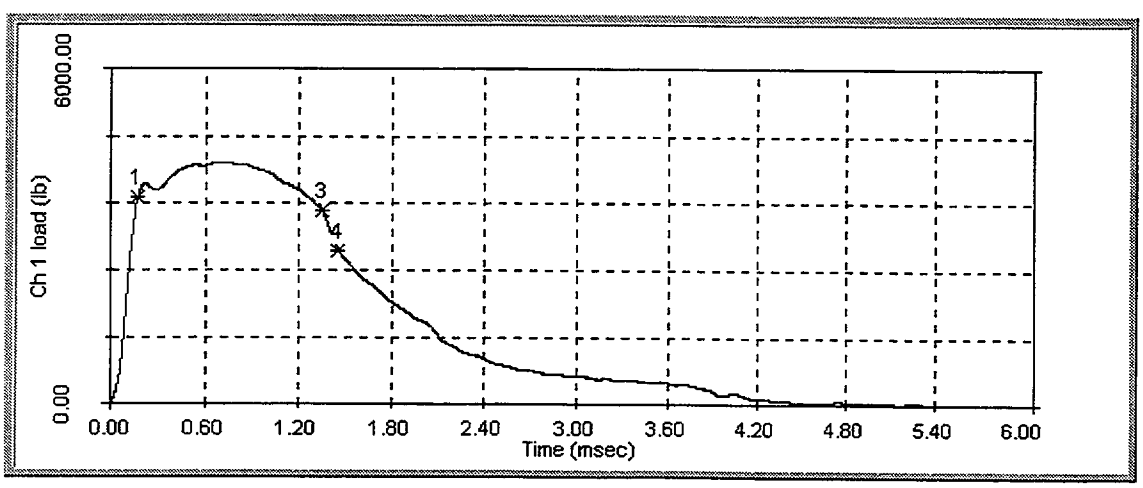
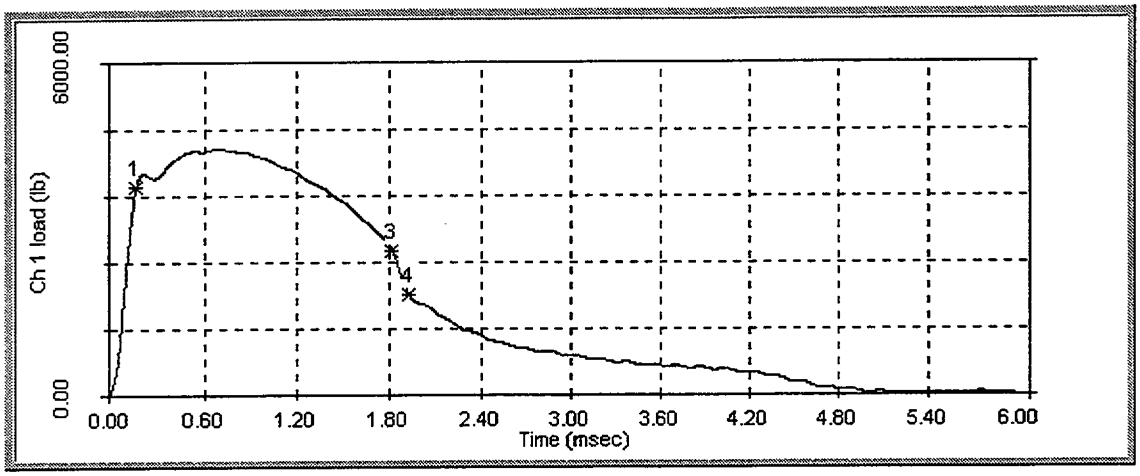


WW31, 115°F



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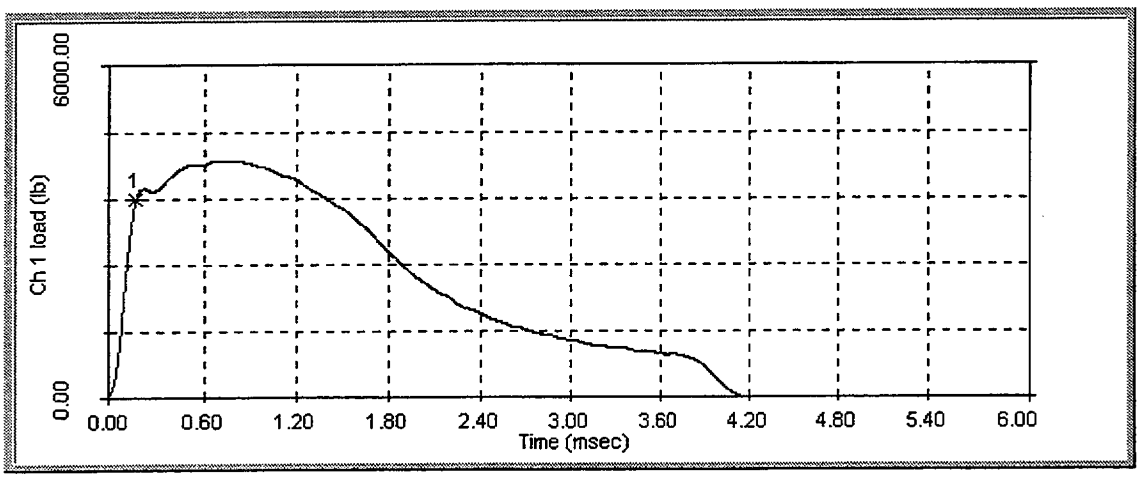
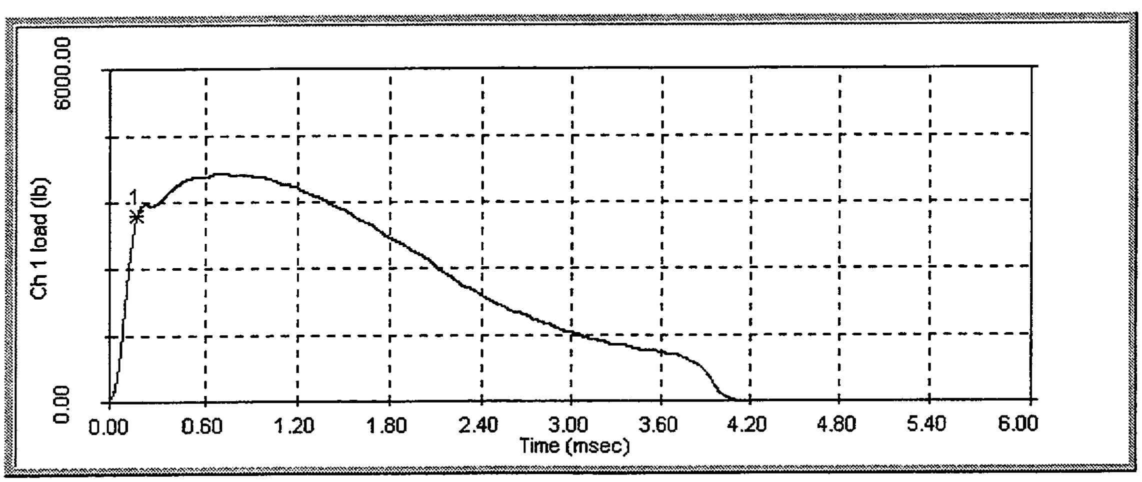


WW36, 200°F



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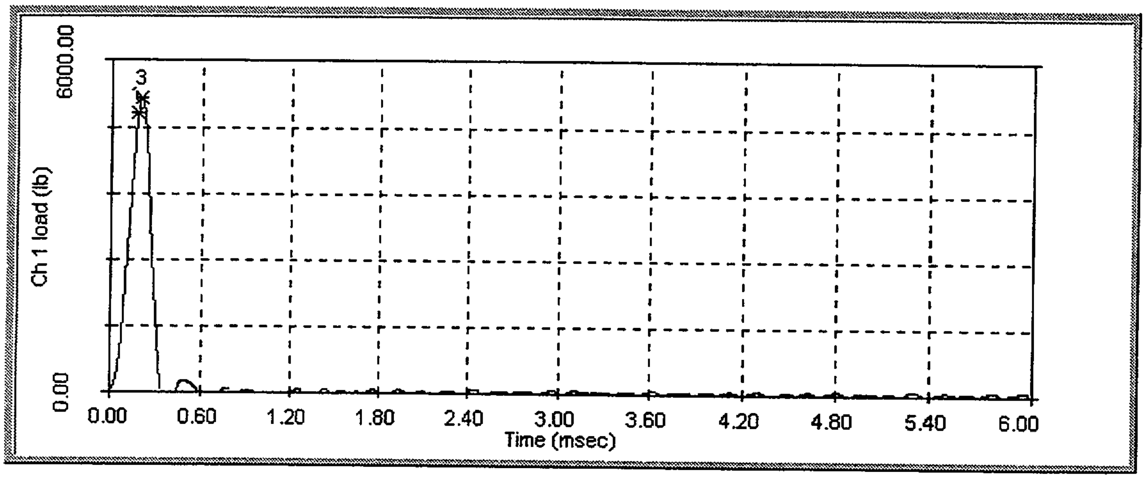

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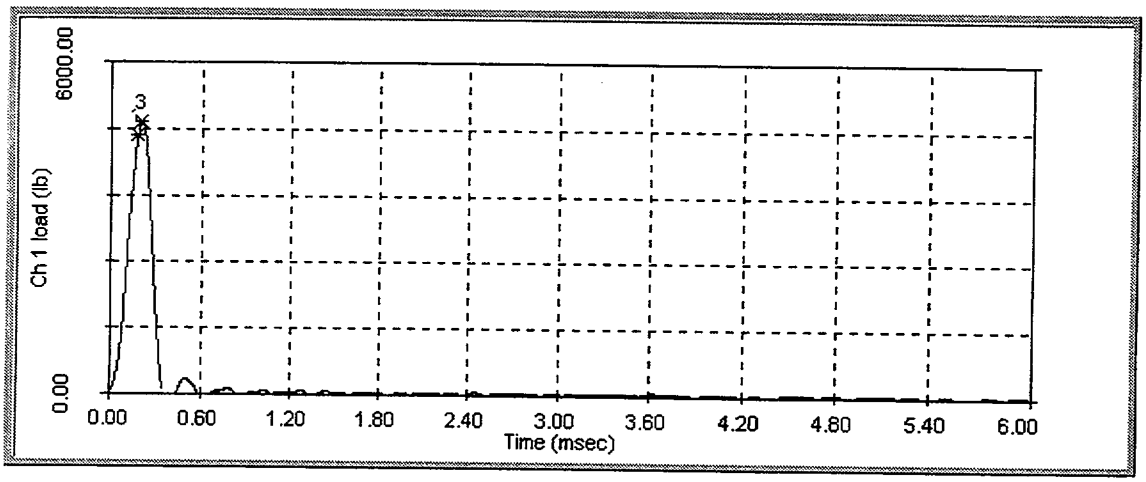

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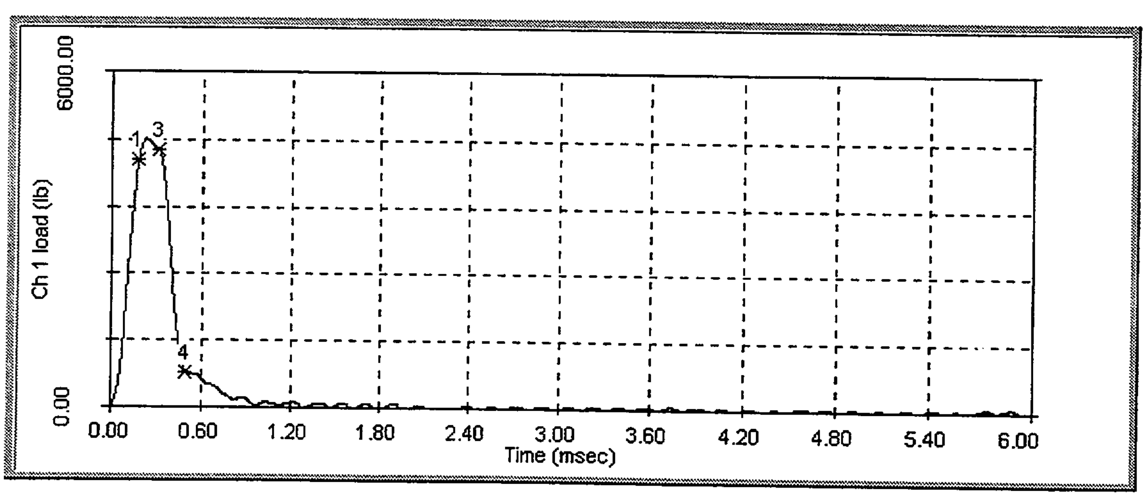

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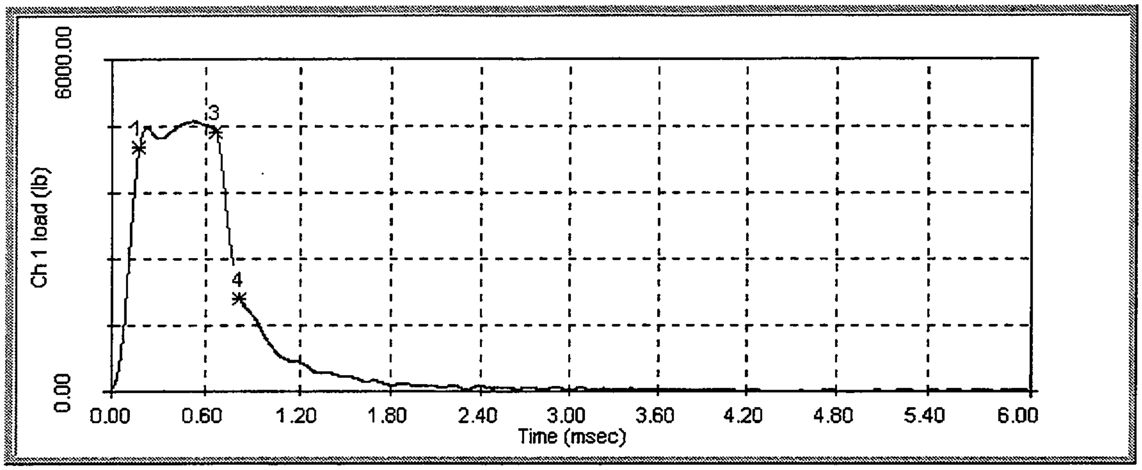
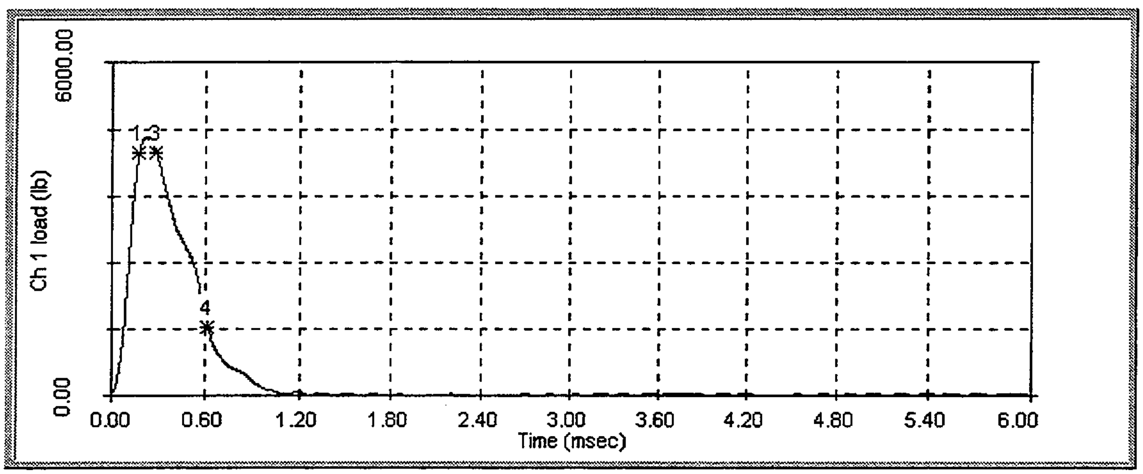
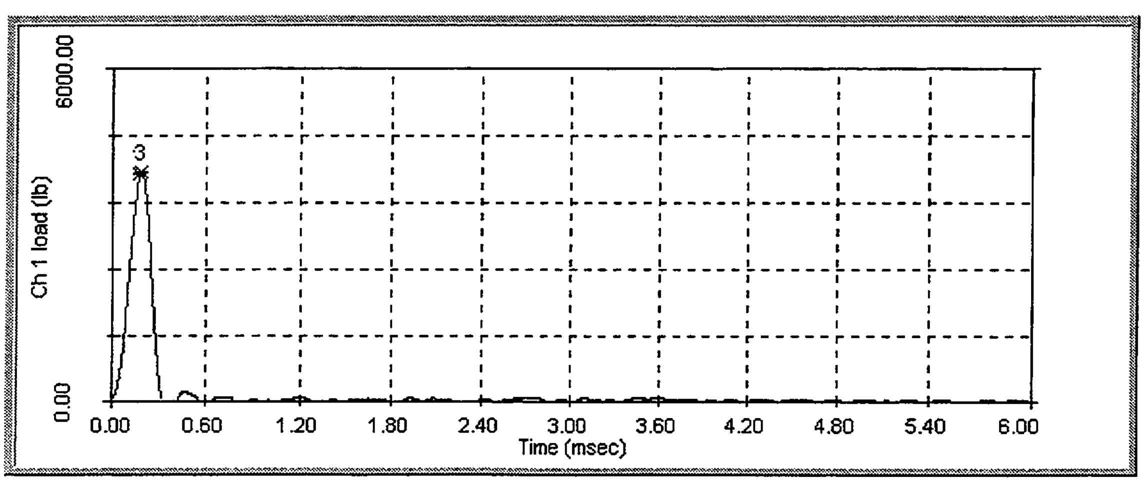


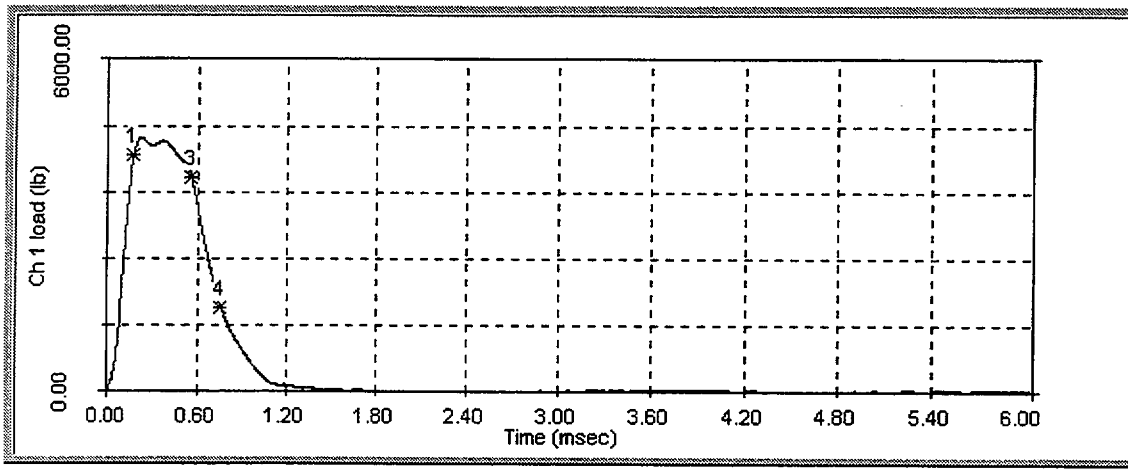
WH36, -30°F



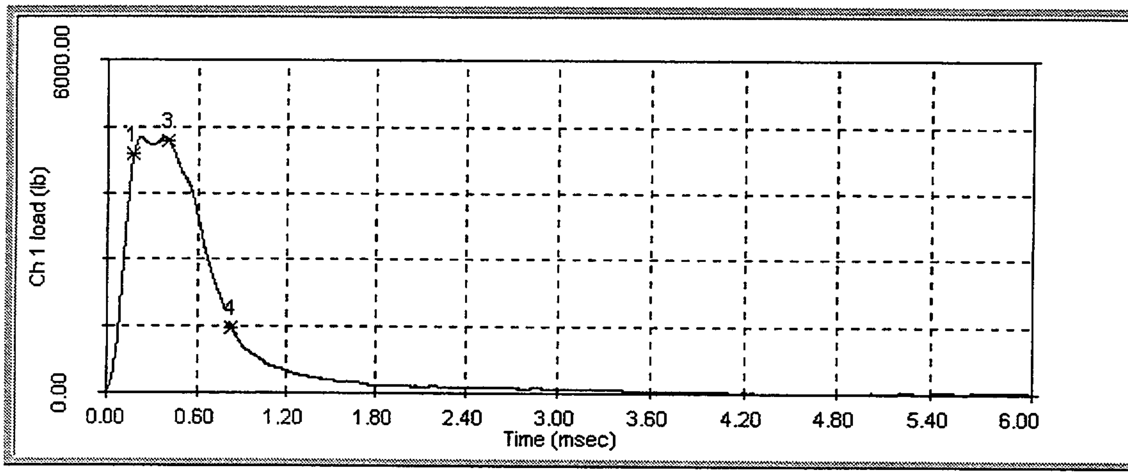
WH39, -25°F



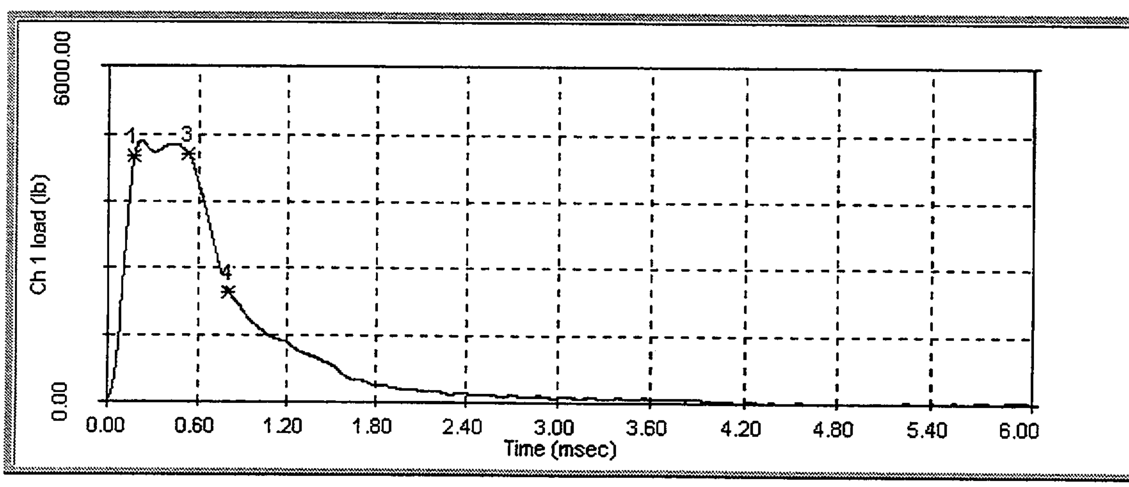
WH38, -10°F



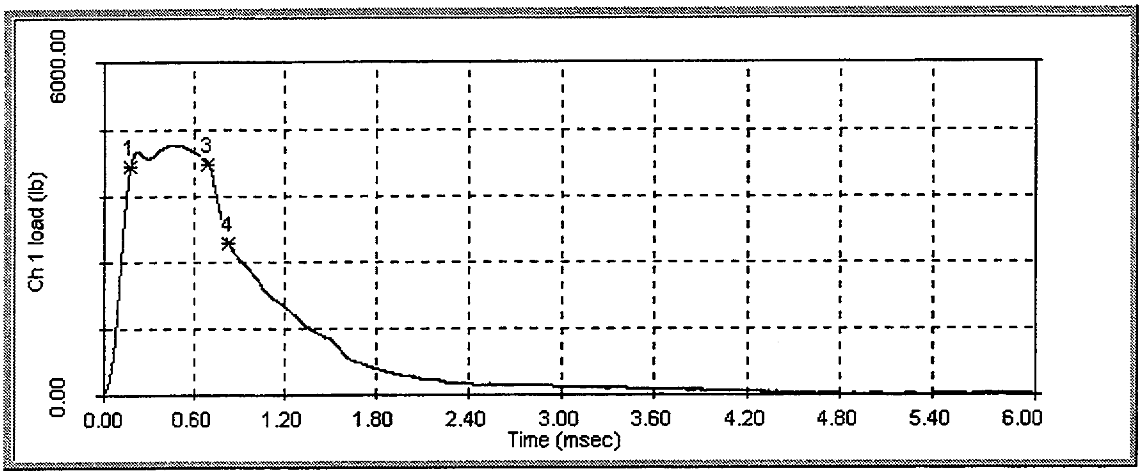
WH43, -5°F



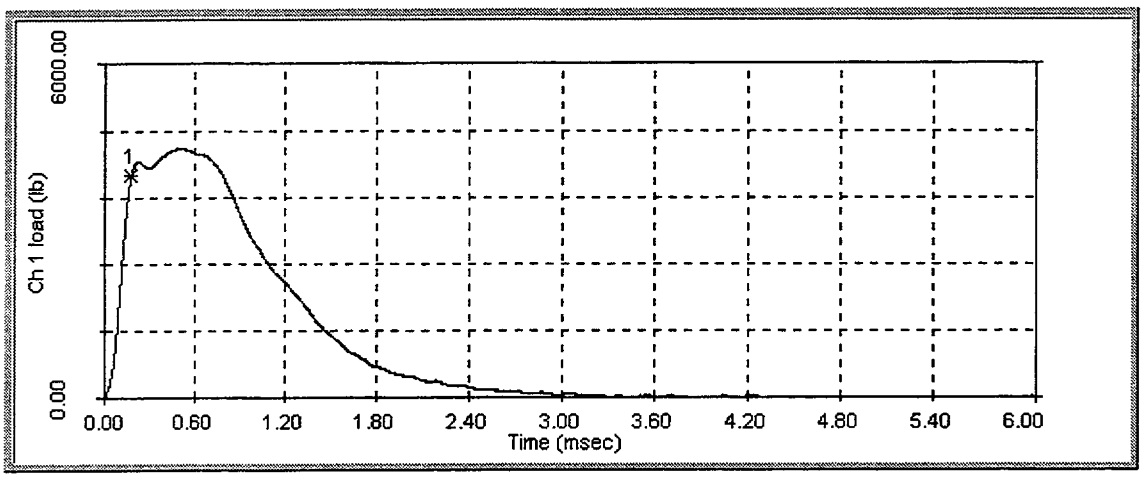
WH42, 0°F



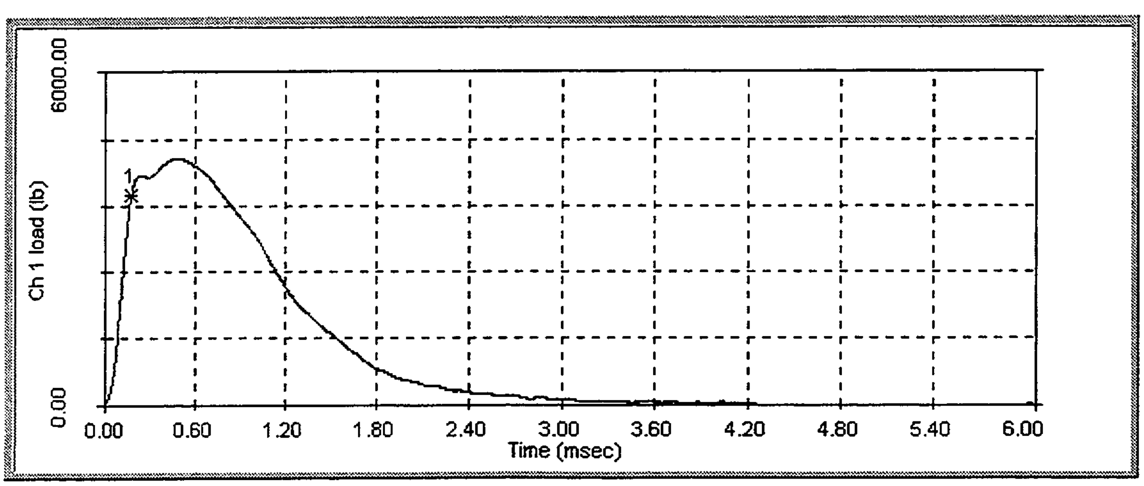
WH41, 15°F



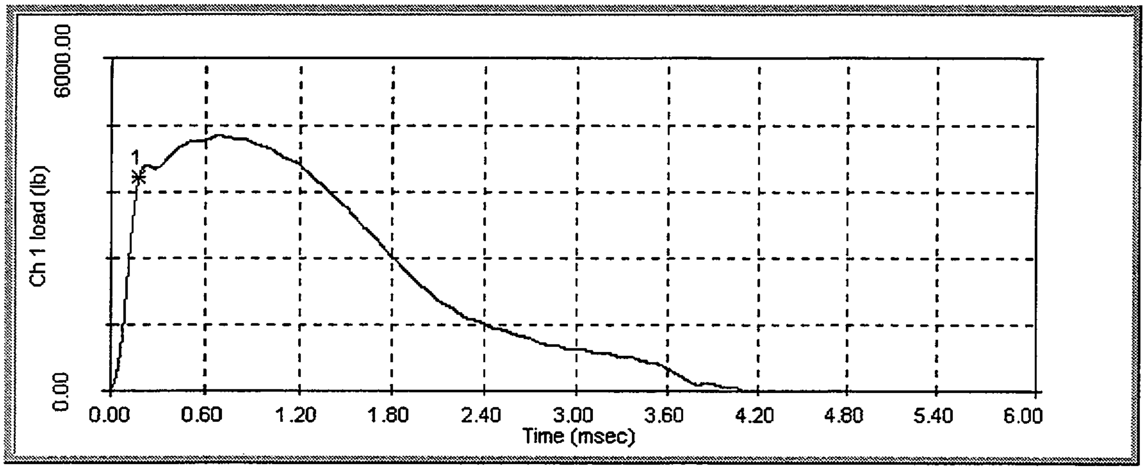
WH34, 50°F



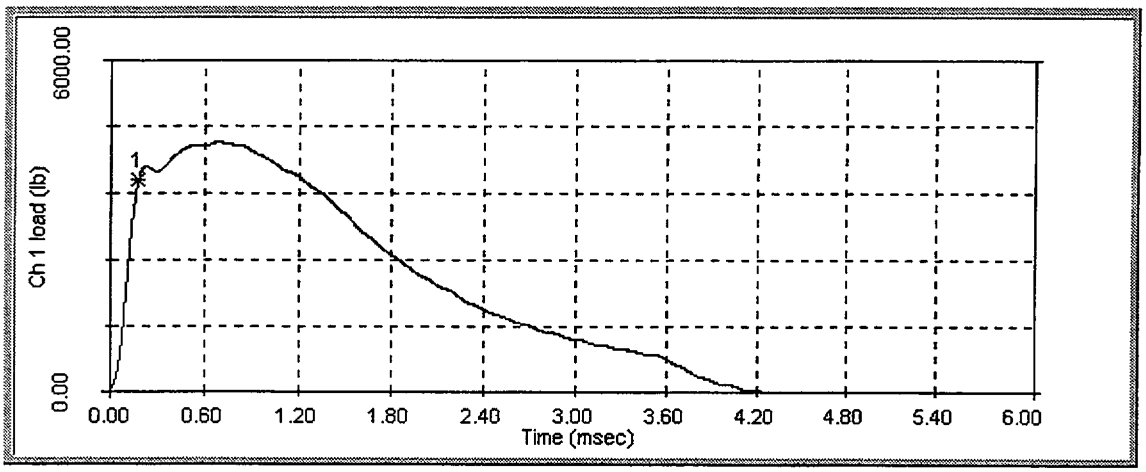
WH33, 100°F



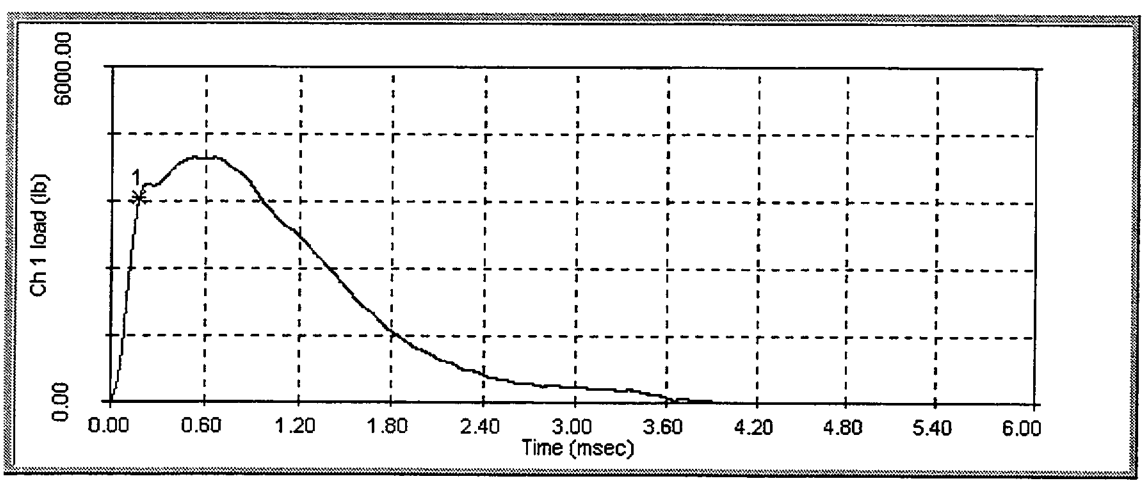
WH35, 125°F



WH32, 150°F



WH31, 200°F



WH40, 275°F

APPENDIX B

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

Contained in Table B-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 B-1
Upper Shelf Energy Values Fixed in CVGRAPH

Material	Unirradiated	Capsule U	Capsule V	Capsule W
Intermediate Shell Plate B9004-2 (Longitudinal Orientation)	95	105	85	94
Intermediate Shell Plate B9004-2 (Transverse Orientation)	79	87	76	75
Weld Metal (Heat # 83642)	139	134	136	136
HAZ Material	91	109	87	104

UNIRRADIATED (LONGITUDINAL ORIENTION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:17:08 on 02-05-2001

Page 1

Coefficients of Curve 1

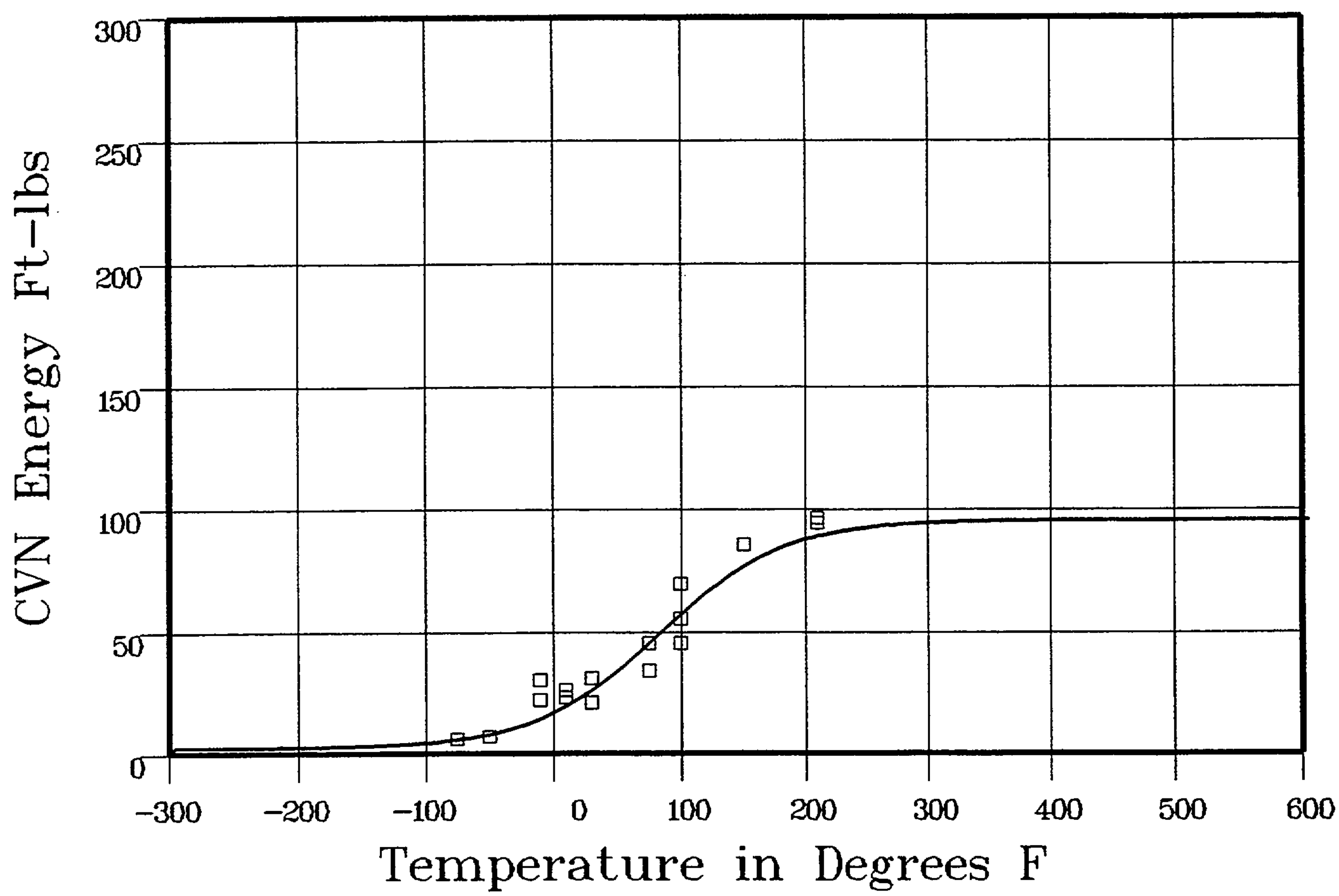
A = 48.59	B = 46.4	C = 98.42	T0 = 77.34

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

Upper Shelf Energy: 95 Fixed   Temp. at 30 ft-lbs: 35.5   Temp. at 50 ft-lbs: 80.3   Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1   Heat Number: C0544-2   Orientation: LT

Capsule: UNIRR   Total Fluence:



Data Set(s) Plotted

Plant: BV2   Cap.: UNIRR   Material: PLATE SA533B1   Ori.: LT   Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-75	6	6.21	-.21
-50	7	8.69	-1.69
-10	22	15.65	6.34
-10	30	15.65	14.34
10	26	21.02	4.97
10	23	21.02	1.97
30	31	27.85	3.14
30	21	27.85	-6.85
75	45	47.49	-2.49

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

UNIRRADIATED (LONGITUDINAL ORIENTION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
75	34	47.49	-13.49
100	69	59.09	9.9
100	55	59.09	-4.09
100	45	59.09	-14.09
150	85	77.74	7.25
150	85	77.74	7.25
210	94	89.13	4.86
210	96	89.13	6.86
210	94	89.13	4.86

SUM of RESIDUALS = 28.86

CAPSULE U (LONGITUDINAL ORIENTION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:17:08 on 02-05-2001

Page 1

Coefficients of Curve 2

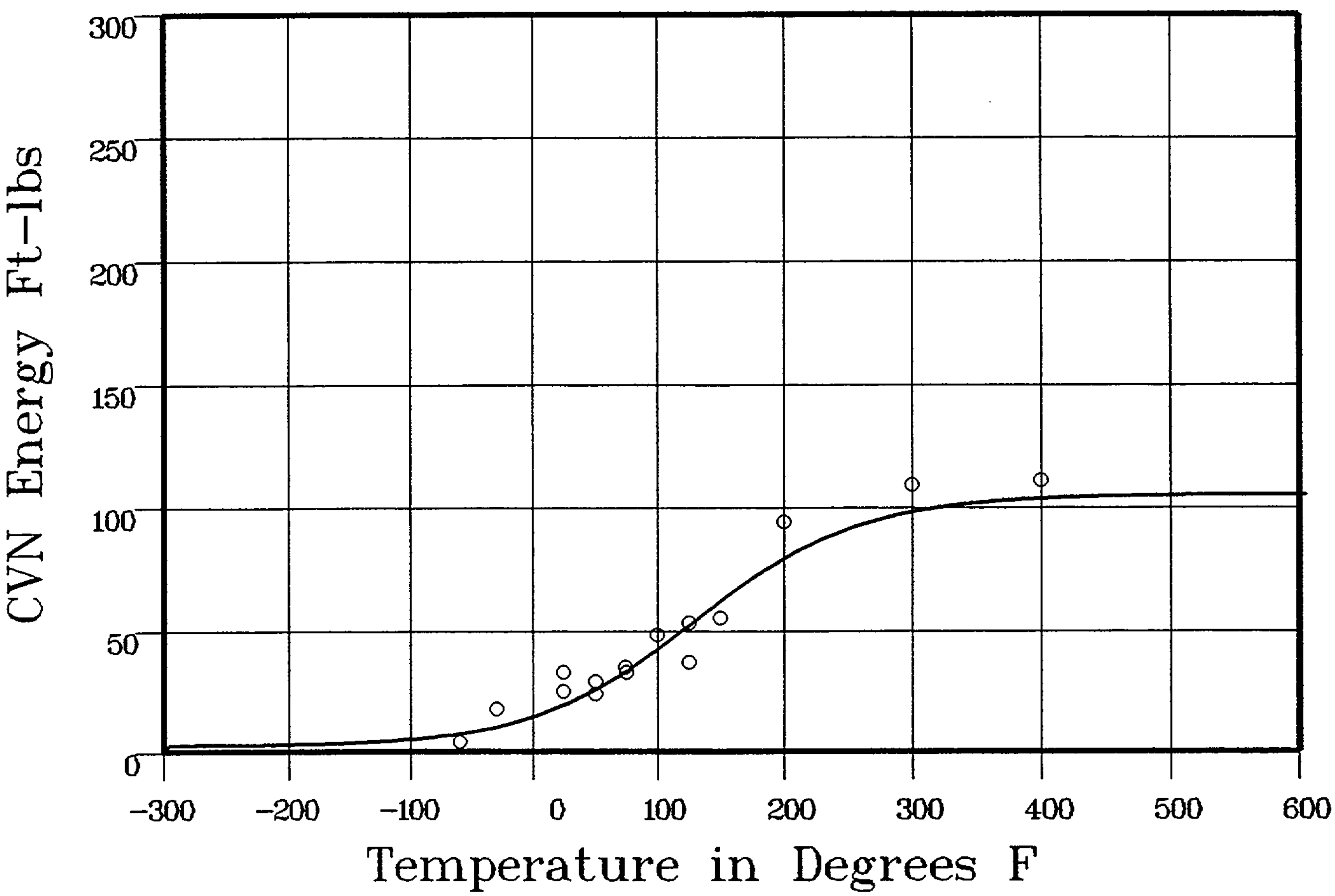
A = 53.59	B = 51.4	C = 130.78	T0 = 124.7

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

Upper Shelf Energy: 105 Fixed Temp. at 30 ft-lbs: 59.8 Temp. at 50 ft-lbs: 115.5 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: U Material: PLATE SA533B1 Ori.: LT Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-60	4	7.95	-3.95
-30	18	11.02	6.97
25	25	20.57	4.42
25	33	20.57	12.42
50	24	27.06	-3.06
50	29	27.06	1.93
74	35	34.61	.38
75	33	34.95	-1.95

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

CAPSULE U (LONGITUDINAL ORIENTION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
100	48	44	3.99
125	37	53.71	-16.71
125	53	53.71	-.71
150	55	63.41	-8.41
200	94	80.3	13.69
300	109	98.4	10.59
400	111	103.49	7.5

SUM of RESIDUALS = 27.09

CAPSULE V (LONGITUDINAL ORIENTION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:17:08 on 02-05-2001

Page 1

Coefficients of Curve 3

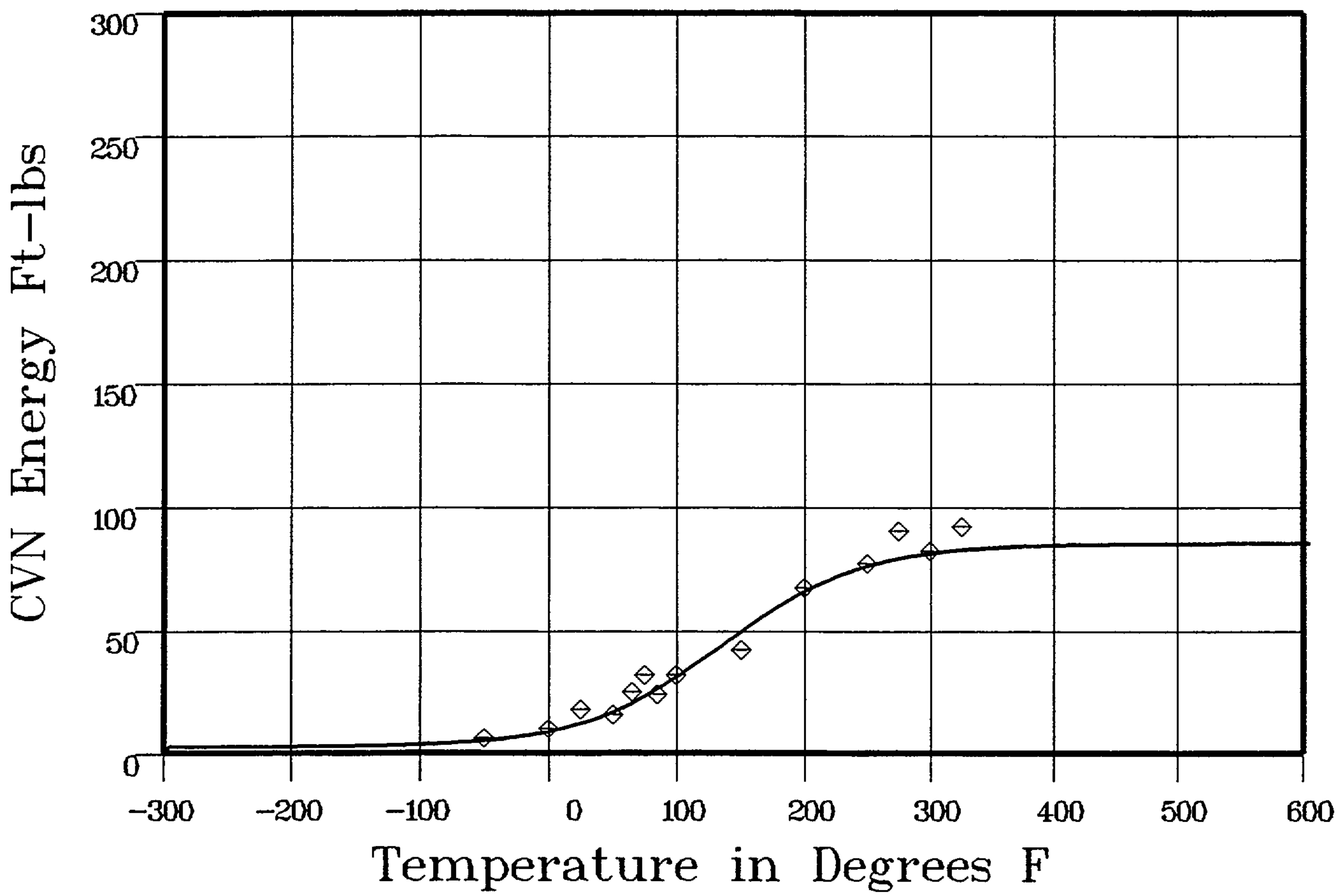
A = 43.59	B = 41.4	C = 110.67	T0 = 129.23

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

Upper Shelf Energy: 85 Fixed   Temp. at 30 ft-lbs: 91.4   Temp. at 50 ft-lbs: 146.4   Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1   Heat Number: C0544-2   Orientation: LT

Capsule: V   Total Fluence:



Data Set(s) Plotted

Plant: BV2   Cap.: V   Material: PLATE SA533B1   Ori.: LT   Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	6	5.32	.67
0	10	9.5	.49
25	18	13.12	4.87
50	16	18.16	-2.16
65	25	21.94	3.05
75	32	24.79	7.2
85	24	27.87	-3.87
100	32	32.9	-.9

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

CAPSULE V (LONGITUDINAL ORIENTION)

Page 2

Material: PLATE SA533B1   Heat Number: C0544-2   Orientation: LT

Capsule: V   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
150	42	51.27	-9.27
200	67	66.96	.03
250	77	76.6	.39
275	90	79.45	10.54
300	82	81.38	.61
325	92	82.66	9.33

SUM of RESIDUALS = 21

CAPSULE W (LONGITUDINAL ORIENTION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:17:08 on 02-05-2001

Page 1

Coefficients of Curve 4

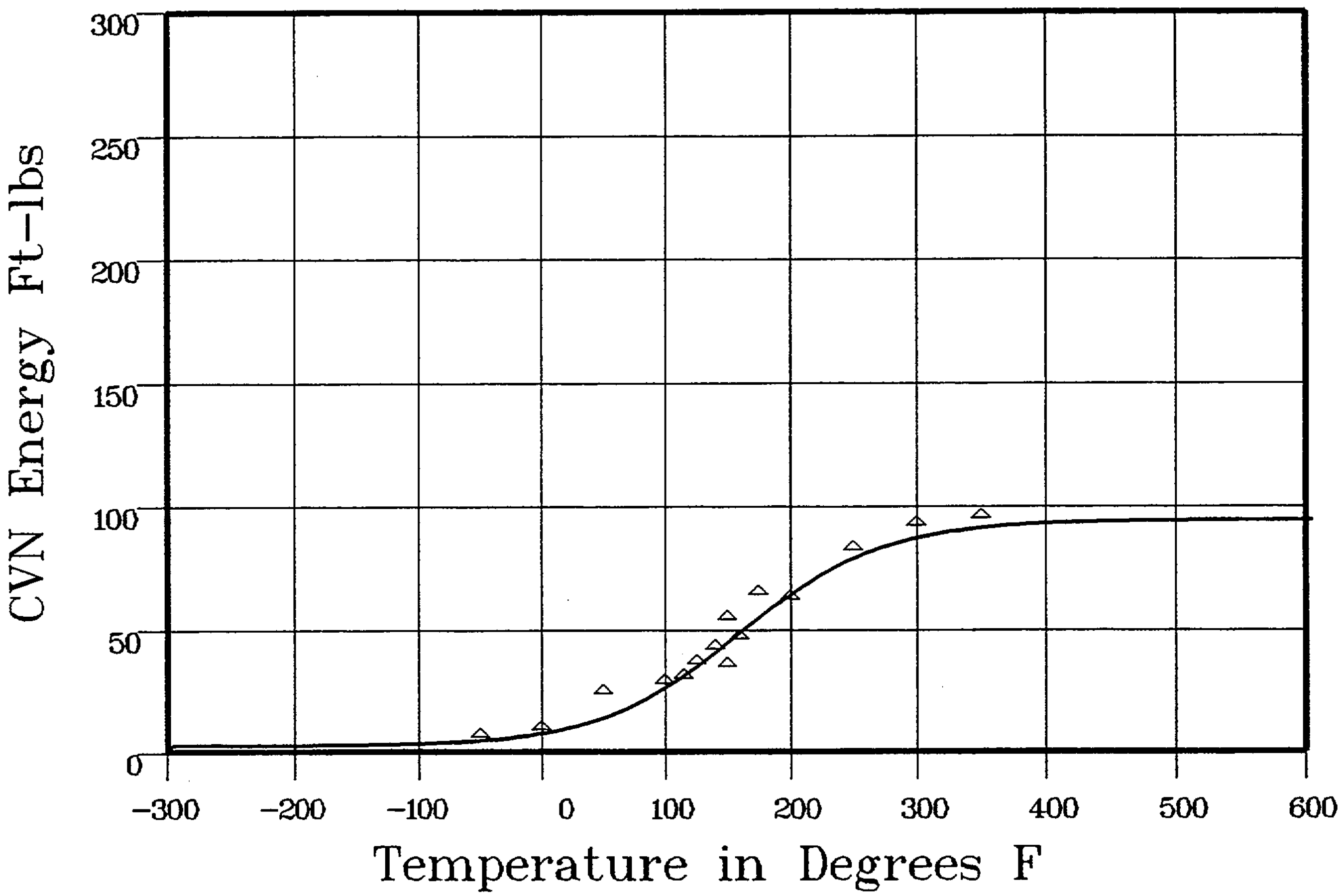
A = 48.09	B = 45.9	C = 113.96	T0 = 154.1

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

Upper Shelf Energy: 94 Fixed Temp. at 30 ft-lbs: 106.5 Temp. at 50 ft-lbs: 158.8 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: W Material: PLATE SA533B1 Ori.: LT Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	6	4.68	1.31
0	9	7.95	1.04
50	24	14.92	9.07
100	28	27.81	.18
115	30	32.94	-2.94
125	36	36.62	-.62
140	42	42.44	-.44

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

CAPSULE W (LONGITUDINAL ORIENTION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
150	35	46.44	-11.44
150	54	46.44	7.55
160	46	50.47	-4.47
175	64	56.42	7.57
200	62	65.64	-3.64
250	82	79.61	2.38
300	92	87.41	4.58
350	95	91.14	3.85

SUM of RESIDUALS = 13.98

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:33:10 on 02-05-2001

Page 1

Coefficients of Curve 1

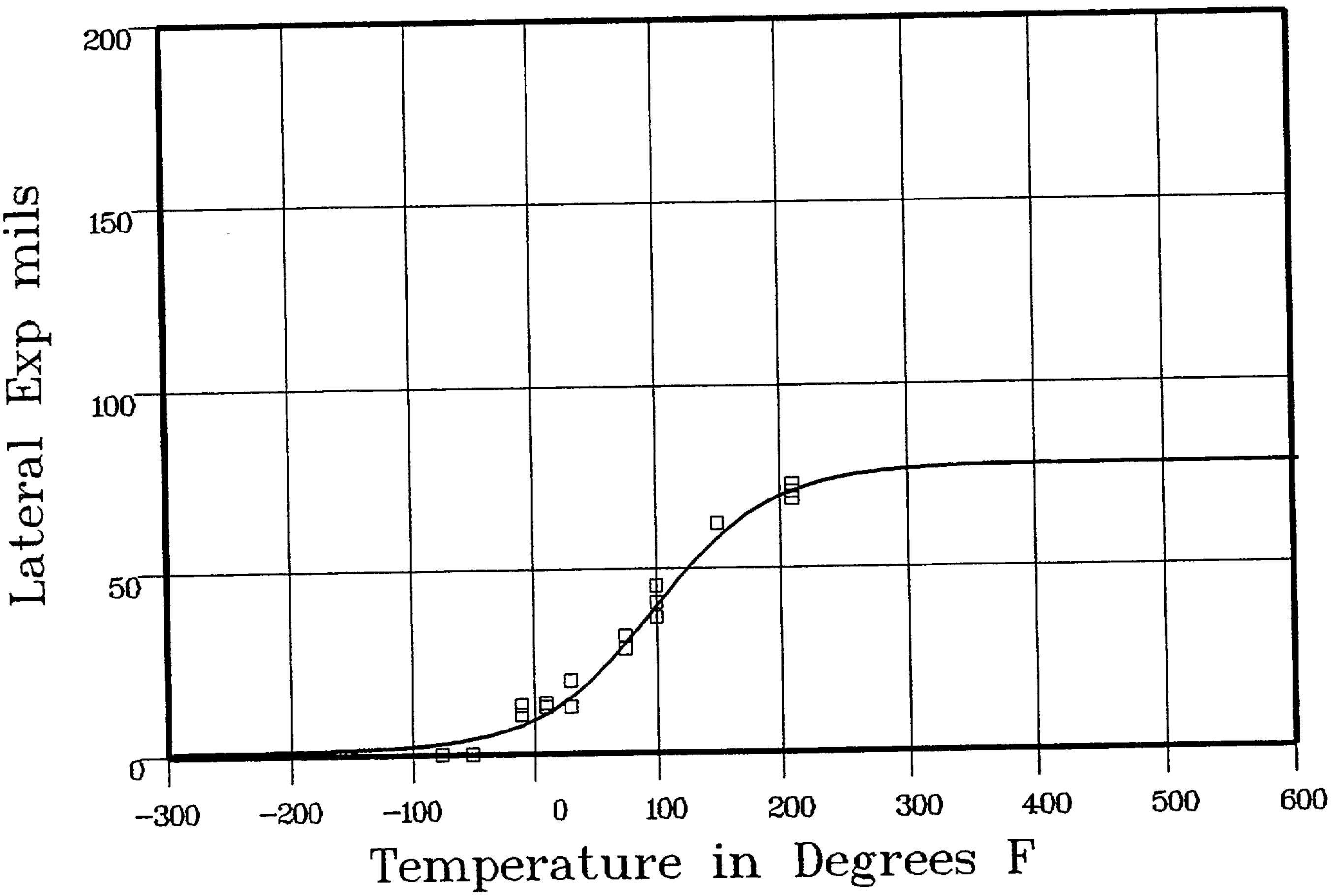
A = 39.51	B = 38.51	C = 94.85	T0 = 94.13

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

Upper Shelf L.E.: 78.03 Temperature at L.E. 35: 82.9 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: UNIRR Material: PLATE SA533B1 Ori.: LT Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-75	0	3.11	-3.11
-50	0	4.52	-4.52
-10	11	8.71	2.28
-10	13.5	8.71	4.78
10	14	12.17	1.82
10	13	12.17	.82
30	20	16.83	3.16
30	13	16.83	-3.83
75	32	31.85	.14

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

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed LE.	Differential
75	28.5	31.85	-3.35
100	45.5	41.89	3.6
100	37	41.89	-4.89
100	41	41.89	-.89
150	62.5	59.9	2.59
150	62.5	59.9	2.59
210	69	71.87	-2.87
210	73	71.87	1.12
210	71	71.87	-.87

SUM of RESIDUALS = -1.41

CAPSULE U (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:33:10 on 02-05-2001

Page 1

Coefficients of Curve 2

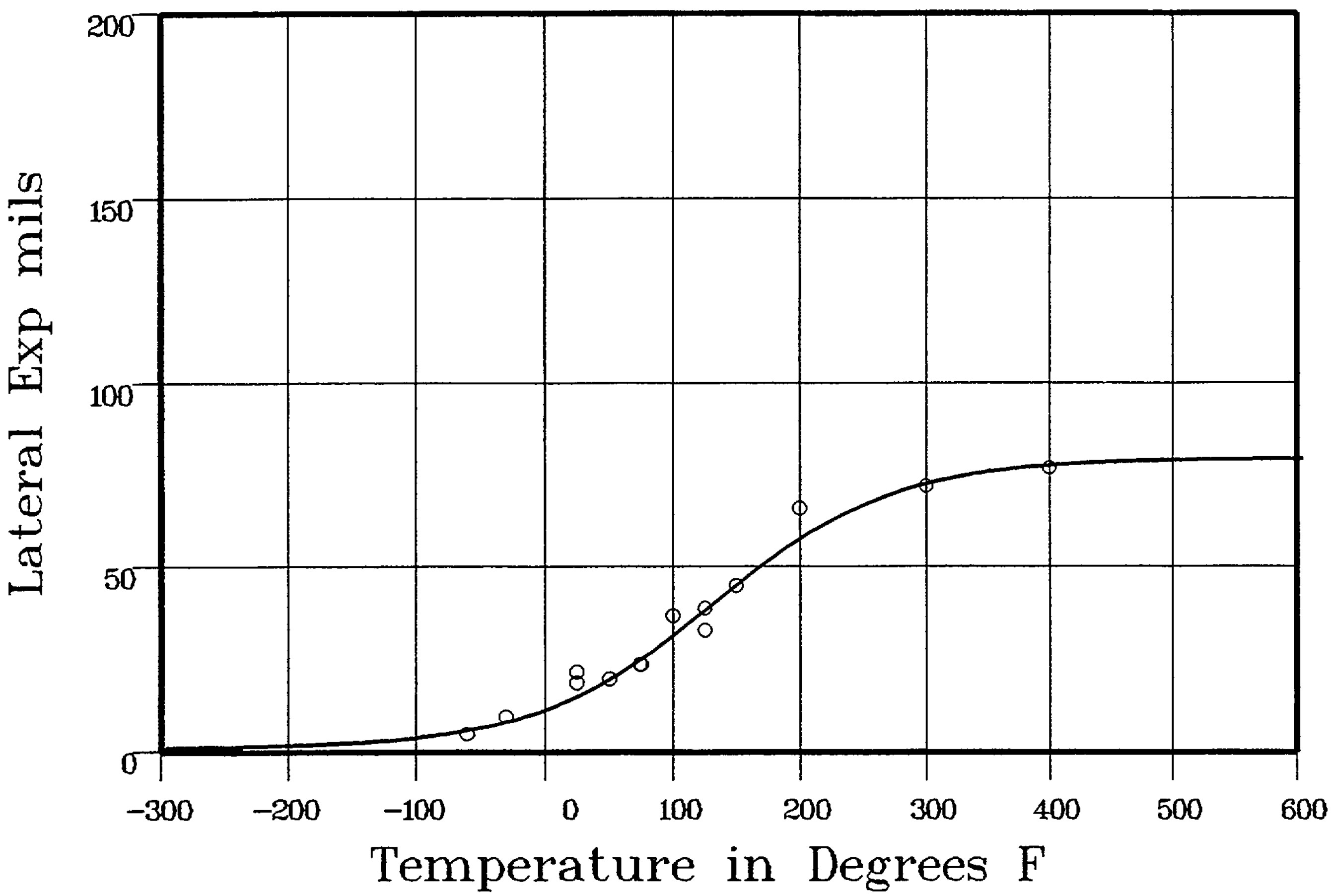
A = 40.21	B = 39.21	C = 142.91	T0 = 127.03

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

Upper Shelf L.E.: 79.42 Temperature at L.E. 35: 107.9 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: U Material: PLATE SA533B1 Ori.: LT Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-60	5	6.33	-1.33
-30	10	8.84	1.15
25	19	16.16	2.83
25	22	16.16	5.83
50	20	20.91	-.91
50	20	20.91	-.91
74	24	26.29	-2.29
75	24	26.53	-2.53

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

CAPSULE U (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
100	37	32.88	4.11
125	33	39.65	-6.65
125	39	39.65	-.65
150	45	46.46	-1.46
200	66	58.65	7.34
300	72	73.02	-1.02
400	77	77.74	-.74

SUM of RESIDUALS = 2.74

CAPSULE V (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:33:10 on 02-05-2001
Page 1
Coefficients of Curve 3

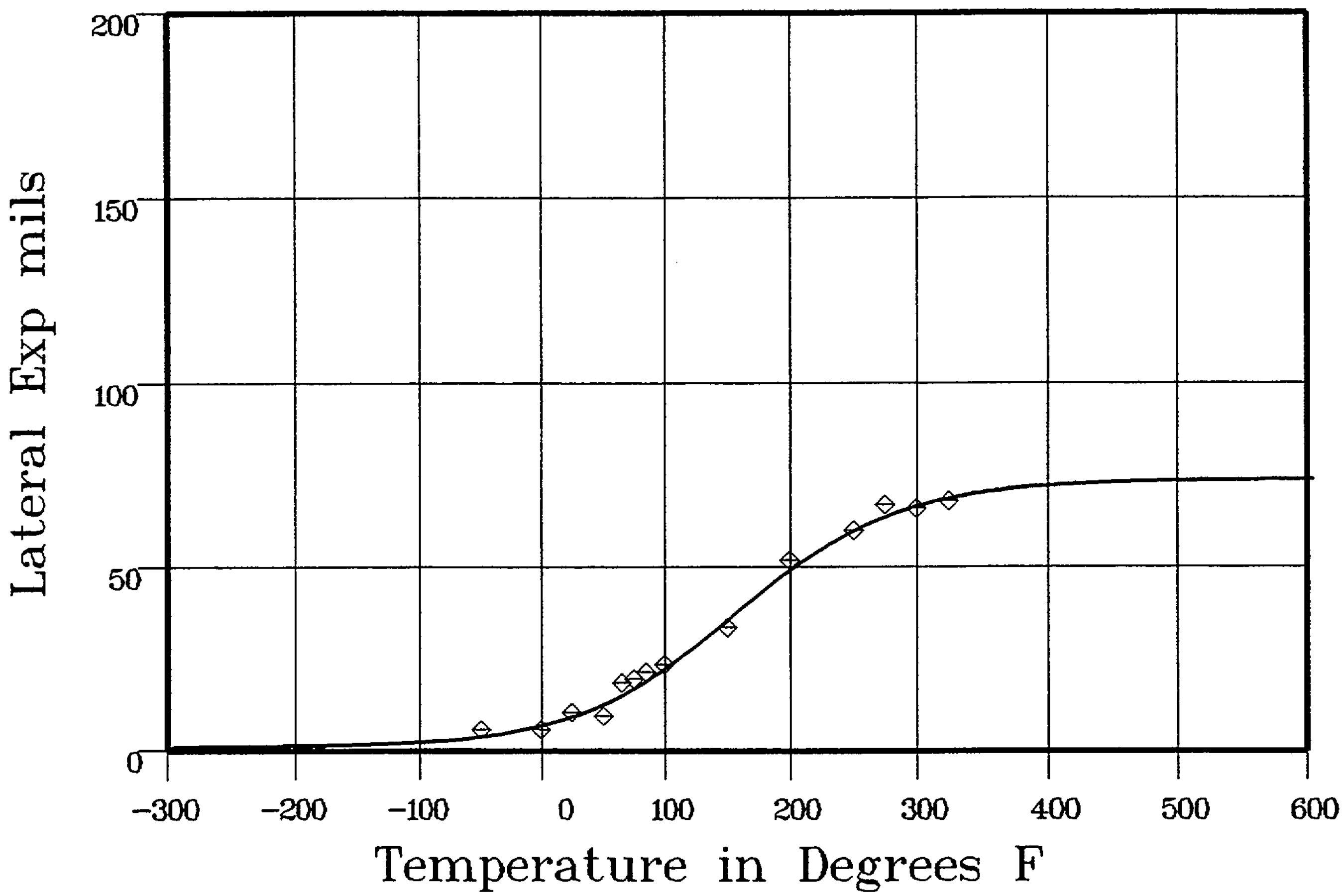
A = 37.4	B = 36.4	C = 130.99	T0 = 150.58

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

Upper Shelf L.E.: 73.81   Temperature at L.E. 35: 141.9   Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1   Heat Number: C0544-2   Orientation: LT

Capsule: V   Total Fluence:



Data Set(s) Plotted
Plant: BV2   Cap.: V   Material: PLATE SA533B1   Ori.: LT   Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	6	4.25	1.74
0	6	7.64	-1.64
25	11	10.33	.66
50	10	13.89	-3.89
65	19	16.51	2.48
75	20	18.45	1.54
85	22	20.56	1.43
100	24	24	0

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

CAPSULE V (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
150	34	37.24	-3.24
200	52	50.52	1.47
250	60	60.72	-.72
275	67	64.33	2.66
300	66	67.06	-1.06
325	68	69.06	-1.06

SUM of RESIDUALS = .37

CAPSULE W (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:33:10 on 02-05-2001

Page 1

Coefficients of Curve 4

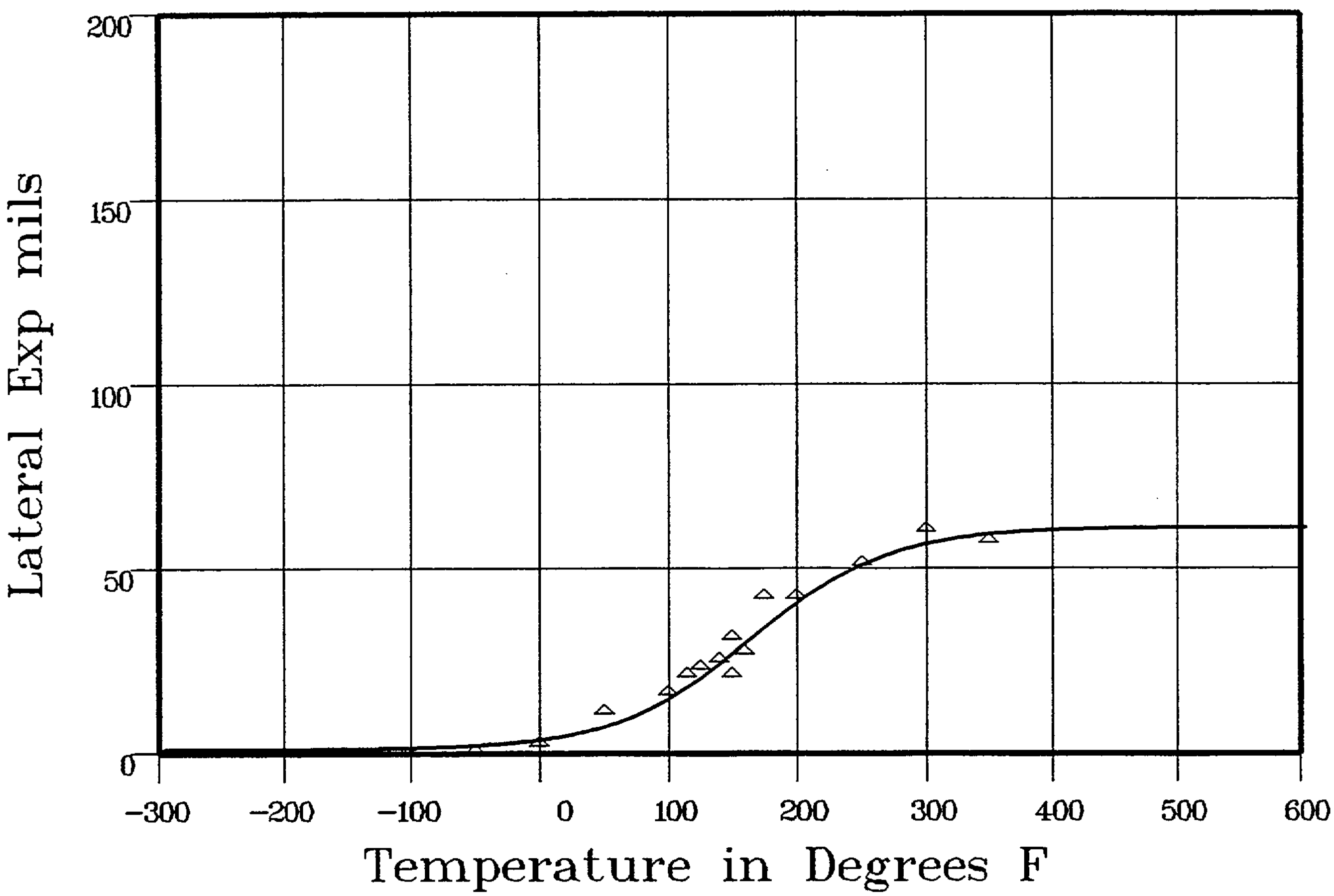
A = 31.08	B = 30.08	C = 106.87	T0 = 159.37

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

Upper Shelf L.E.: 61.16 Temperature at L.E. 35: 173.3 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: W Material: PLATE SA533B1 Ori.: LT Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	0	2.17	-2.17
0	2	3.9	-1.9
50	11	7.88	3.11
100	16	15.9	.09
115	21	19.26	1.73
125	23	21.72	1.27
140	25	25.68	-.68

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

CAPSULE W (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
150	21	28.45	-7.45
150	31	28.45	2.54
160	27	31.25	-4.25
175	42	35.45	6.54
200	42	41.99	0
250	51	51.84	-.84
300	60	57.12	2.87
350	57	59.51	-2.51

SUM of RESIDUALS = -1.63

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:50:32 on 02-05-2001

Page 1

Coefficients of Curve 1

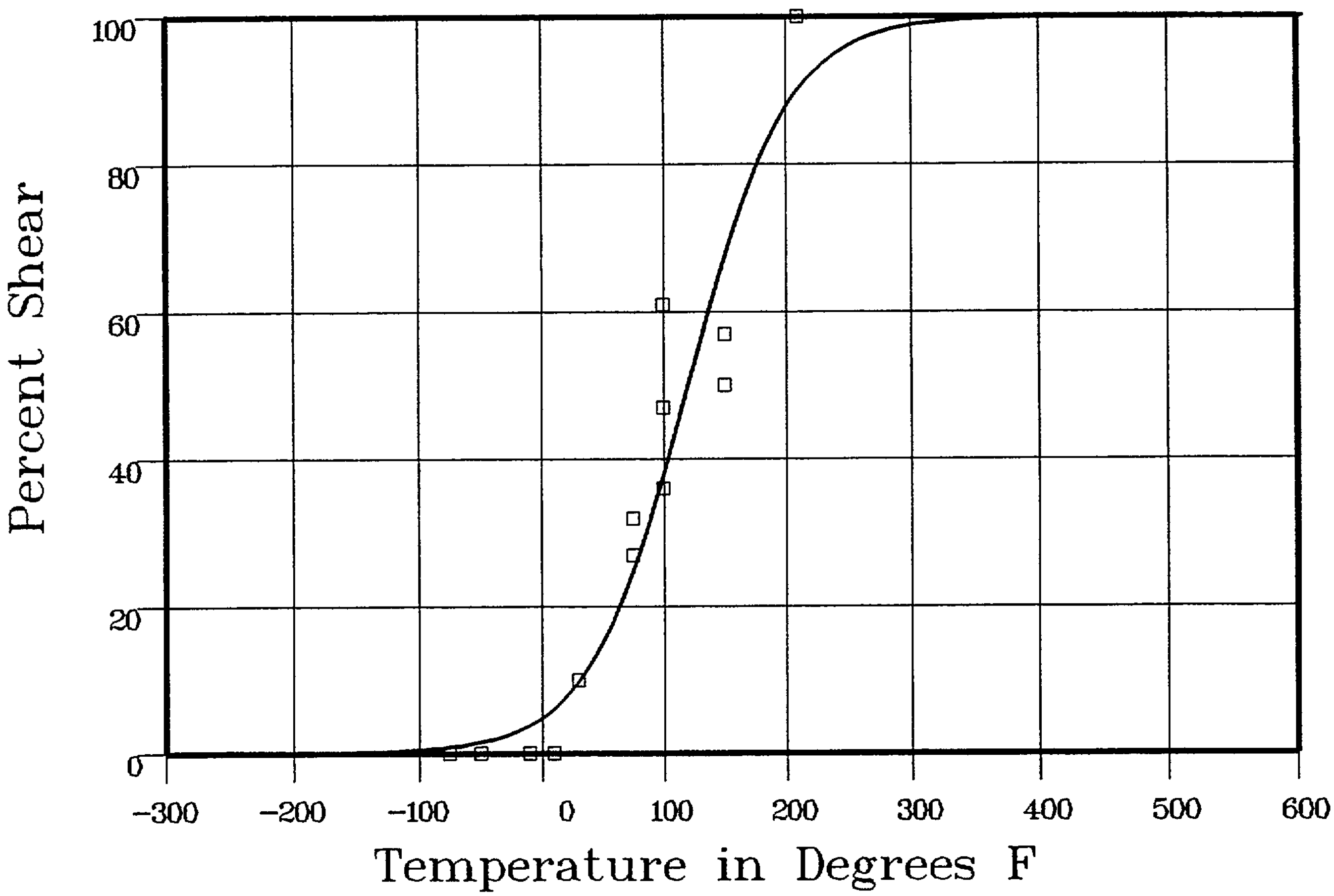
A = 50	B = 50	C = 81.2	T0 = 115.42

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

Temperature at 50% Shear: 115.4

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: UNIRR Material: PLATE SA533B1 Ori.: LT Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75	0	.91	-.91
-50	0	1.67	-1.67
-10	0	4.35	-4.35
-10	0	4.35	-4.35
10	0	6.93	-6.93
10	0	6.93	-6.93
30	10	10.86	-.86
30	10	10.86	-.86
75	27	26.97	.02

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

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
75	32	26.97	5.02
100	61	40.61	20.38
100	47	40.61	6.38
100	36	40.61	-4.61
150	50	70.08	-20.08
150	57	70.08	-13.08
210	100	91.12	8.87
210	100	91.12	8.87
210	100	91.12	8.87

SUM of RESIDUALS = -6.24

CAPSULE U (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:50:32 on 02-05-2001

Page 1

Coefficients of Curve 2

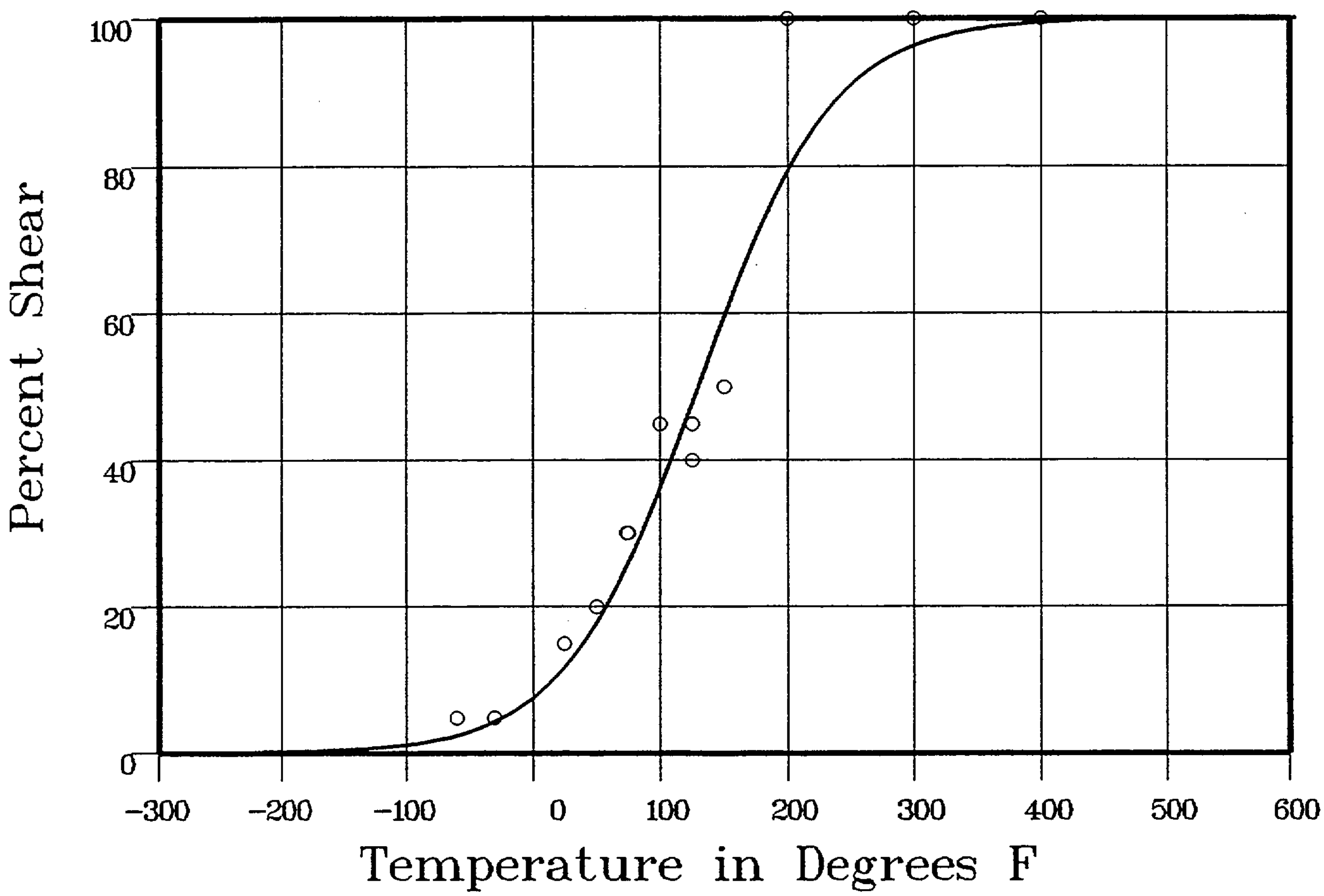
A = 50	B = 50	C = 104.3	T0 = 125.09

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

Temperature at 50% Shear: 125

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap: U Material: PLATE SA533B1 Ori: LT Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-60	5	2.79	2.2
-30	5	4.86	.13
25	15	12.79	2.2
25	15	12.79	2.2
50	20	19.15	.84
50	20	19.15	.84
74	30	27.29	2.7
75	30	27.67	2.32

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

CAPSULE U (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100	45	38.19	6.8
125	40	49.95	-9.95
125	45	49.95	-4.95
150	50	61.71	-11.71
200	100	80.78	19.21
300	100	96.62	3.37
400	100	99.48	.51

SUM of RESIDUALS = 16.76

CAPSULE V (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:50:32 on 02-05-2001

Page 1

Coefficients of Curve 3

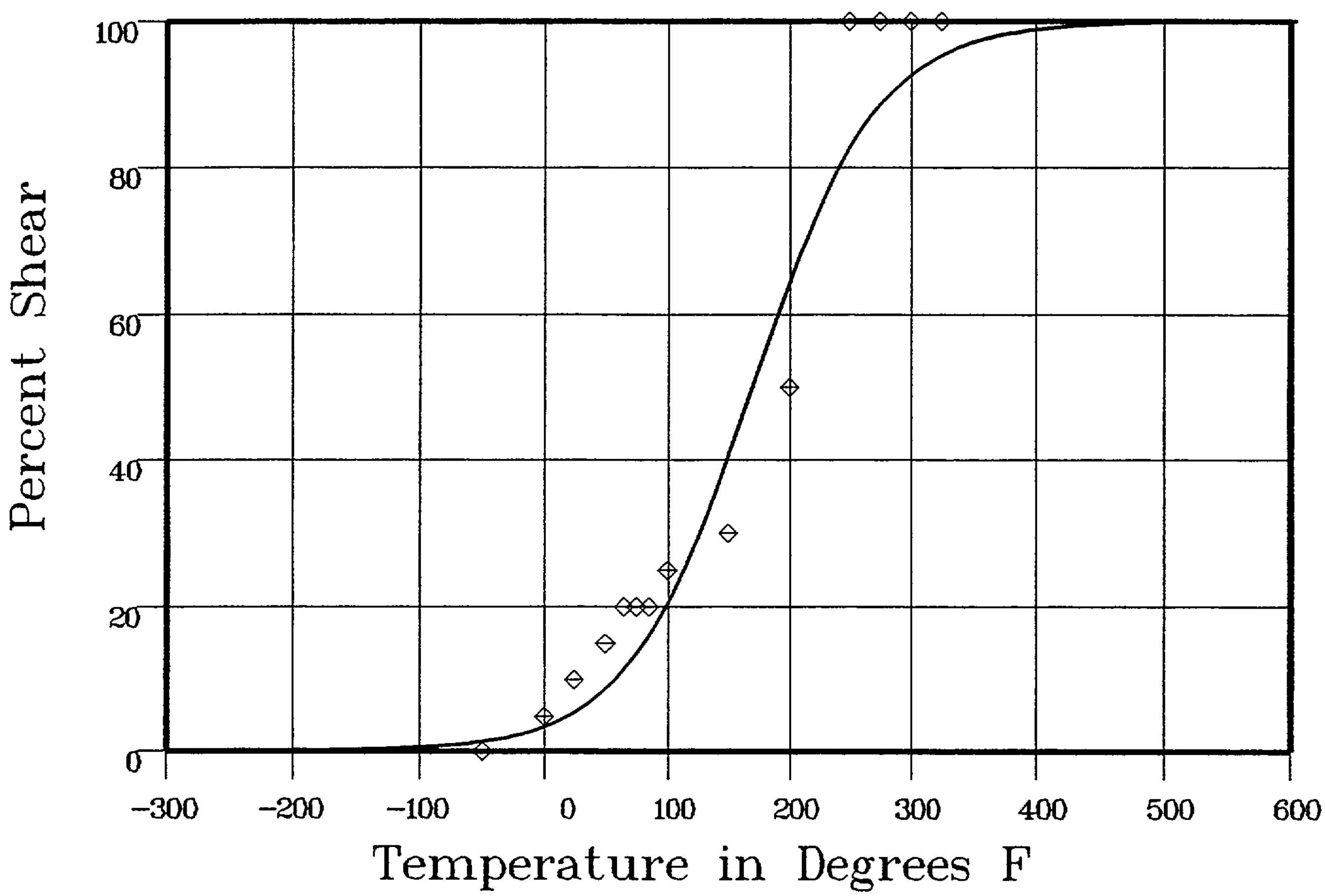
A = 50	B = 50	C = 102.5	T0 = 164.94

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

Temperature at 50% Shear: 164.9

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: V Material: PLATE SA533B1 Ori.: LT Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	0	1.48	-1.48
0	5	3.84	1.15
25	10	6.12	3.87
50	15	9.59	5.4
65	20	12.45	7.54
75	20	14.74	5.25
85	20	17.36	2.63
100	25	21.97	3.02

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

CAPSULE V (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
150	30	42.76	-12.76
200	50	66.46	-16.46
250	100	84.01	15.98
275	100	89.54	10.45
300	100	93.3	6.69
325	100	95.78	4.21

SUM of RESIDUALS = 35.52

CAPSULE W (LONGITUDINAL ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:50:32 on 02-05-2001

Page 1

Coefficients of Curve 4

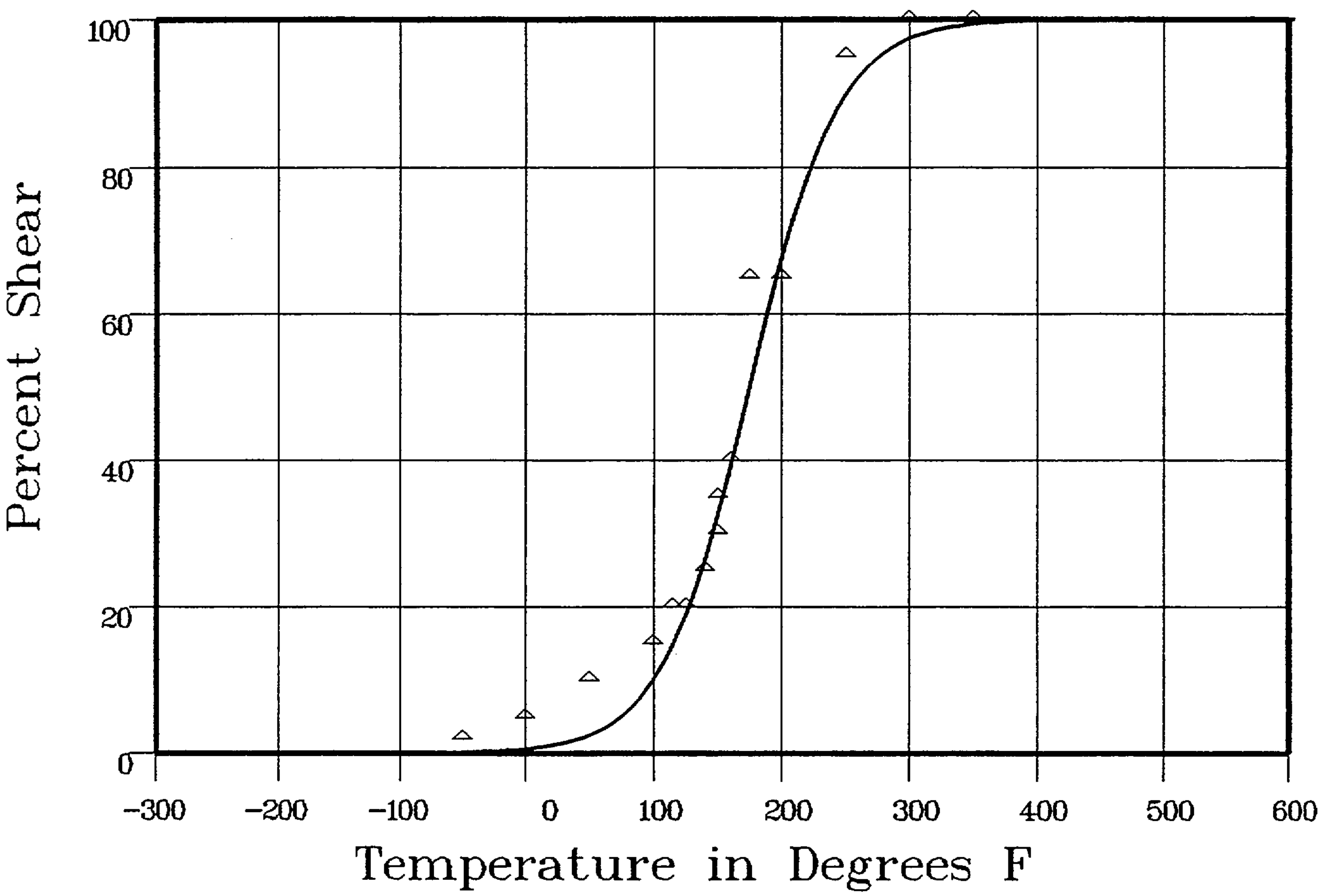
A = 50	B = 50	C = 68.64	T0 = 170.15

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

Temperature at 50% Shear: 170.1

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: W Material: PLATE SA533B1 Ori.: LT Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	2	.16	1.83
0	5	.69	4.3
50	10	2.92	7.07
100	15	11.46	3.53
115	20	16.69	3.3
125	20	21.15	-1.15
140	25	29.34	-4.34

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

CAPSULE W (LONGITUDINAL ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: LT

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
150	30	35.72	-5.72
150	35	35.72	-.72
160	40	42.65	-2.65
175	65	53.52	11.47
200	65	70.46	-5.46
250	95	91.1	3.89
300	100	97.77	2.22
350	100	99.47	.52

SUM of RESIDUALS = 18.09

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:42:39 on 02-05-2001

Page 1

Coefficients of Curve 1

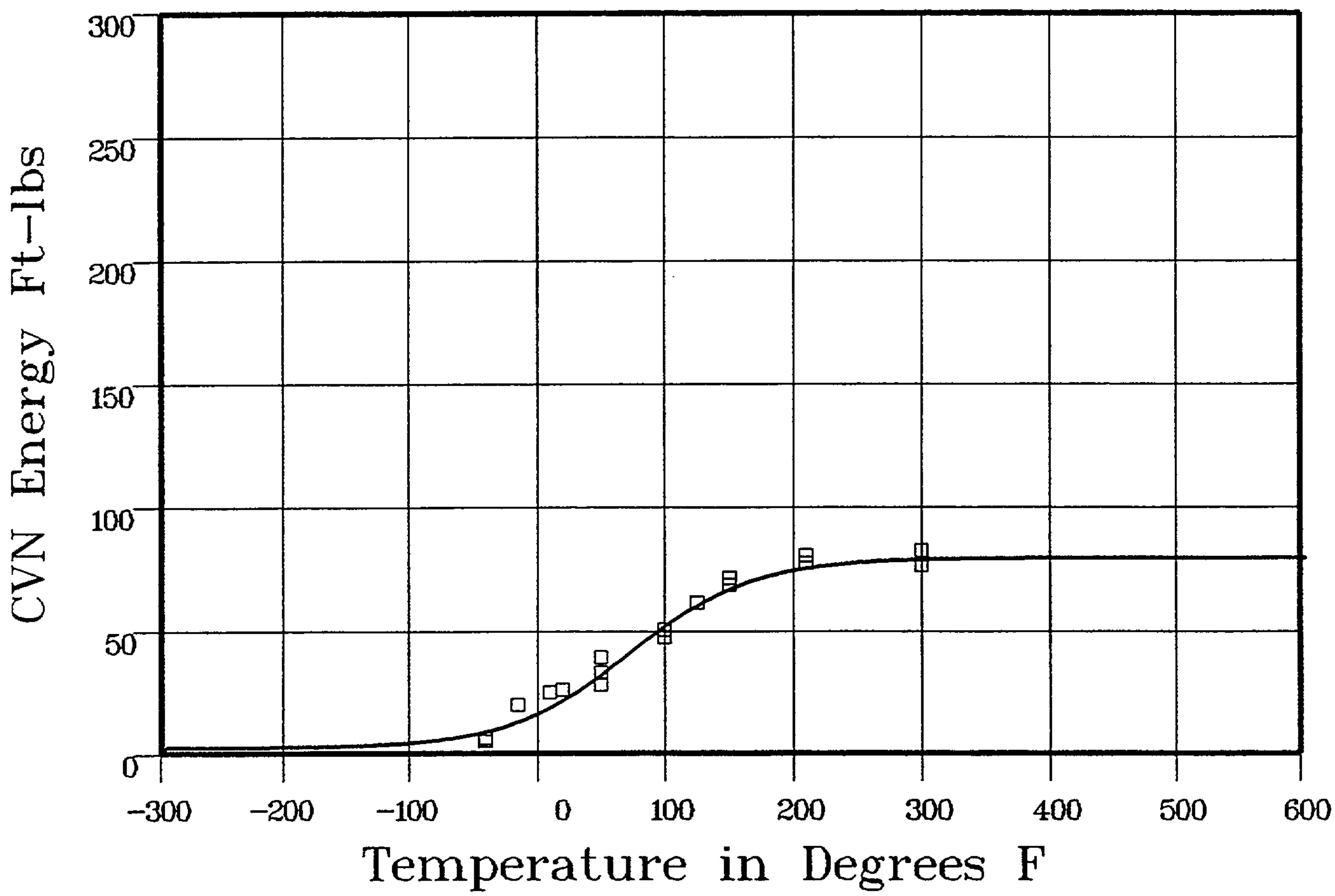
A = 40.59	B = 38.4	C = 96.39	T0 = 67.03

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

Upper Shelf Energy: 79 Fixed Temp. at 30 ft-lbs: 39.7 Temp. at 50 ft-lbs: 91.1 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: UNIRR Material: PLATE SA533B1 Ori.: TL Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-40	6	9.71	-3.71
-40	5	9.71	-4.71
-15	20	14.04	5.95
10	25	20.2	4.79
20	26	23.22	2.77
50	39	33.88	5.11
50	28	33.88	-5.88
50	33	33.88	-.88
100	50	53.24	-3.24

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

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
100	47	53.24	-6.24
125	61	61.26	-.26
150	68	67.35	.64
150	71	67.35	3.64
210	77	75.23	1.76
210	80	75.23	4.76
210	80	75.23	4.76
300	82	78.39	3.6
300	76	78.39	-2.39

SUM of RESIDUALS = 10.48

CAPSULE U (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:42:39 on 02-05-2001

Page 1

Coefficients of Curve 2

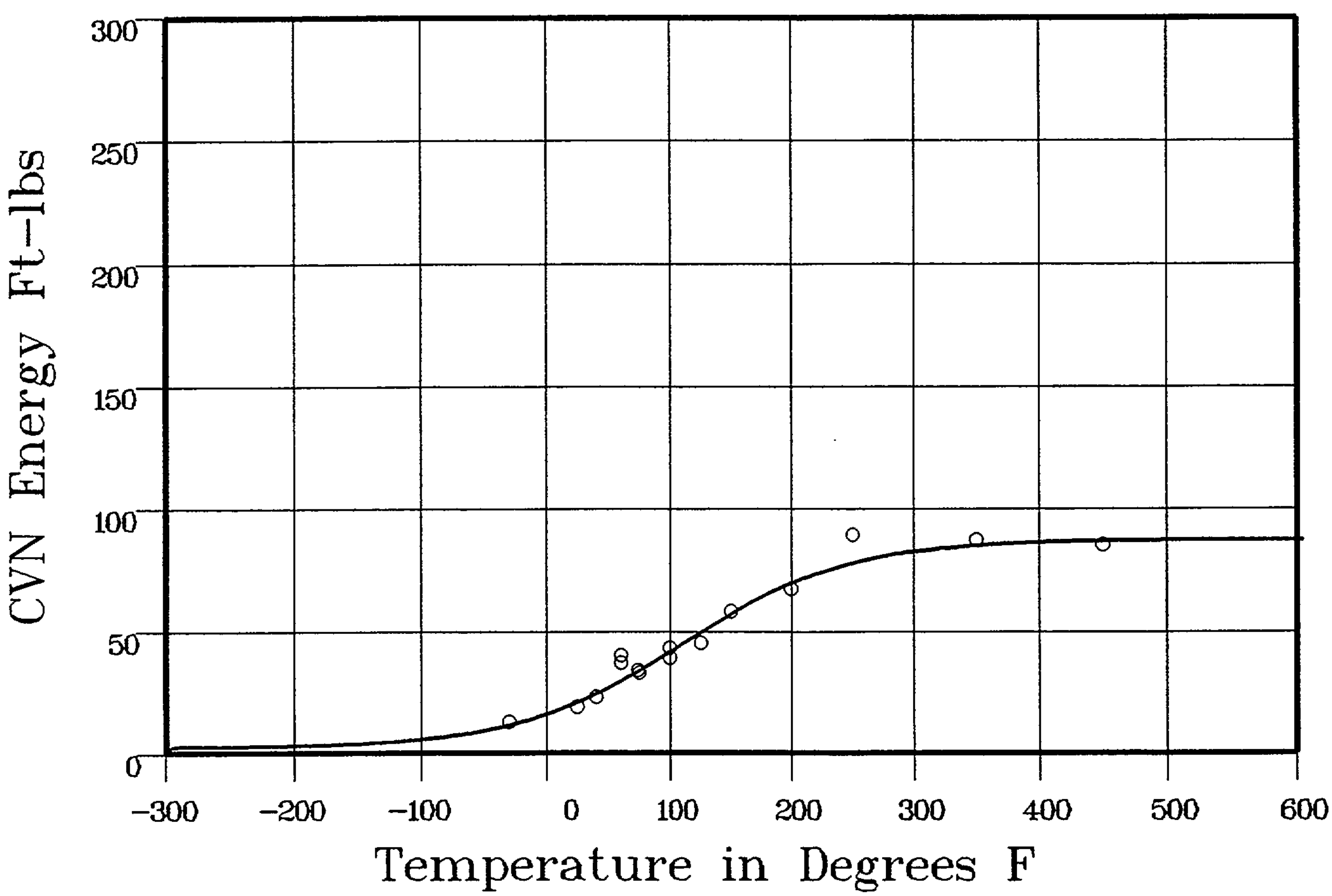
A = 44.59	B = 42.4	C = 134.22	T0 = 105.46

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

Upper Shelf Energy: 87 Fixed Temp. at 30 ft-lbs: 57.2 Temp. at 50 ft-lbs: 122.6 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-30	13	12.14	.85
25	19	21.84	-2.84
40	23	25.41	-2.41
60	37	30.76	6.23
60	40	30.76	9.23
74	34	34.83	-.83
75	33	35.13	-2.13
100	43	42.87	.12

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

CAPSULE U (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
100	39	42.87	-3.87
125	45	50.72	-5.72
150	58	58.17	-.17
200	67	70.33	-3.33
250	89	78.18	10.81
350	87	84.83	2.16
450	85	86.5	-1.5

SUM of RESIDUALS = 6.58

CAPSULE V (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:42:39 on 02-05-2001

Page 1

Coefficients of Curve 3

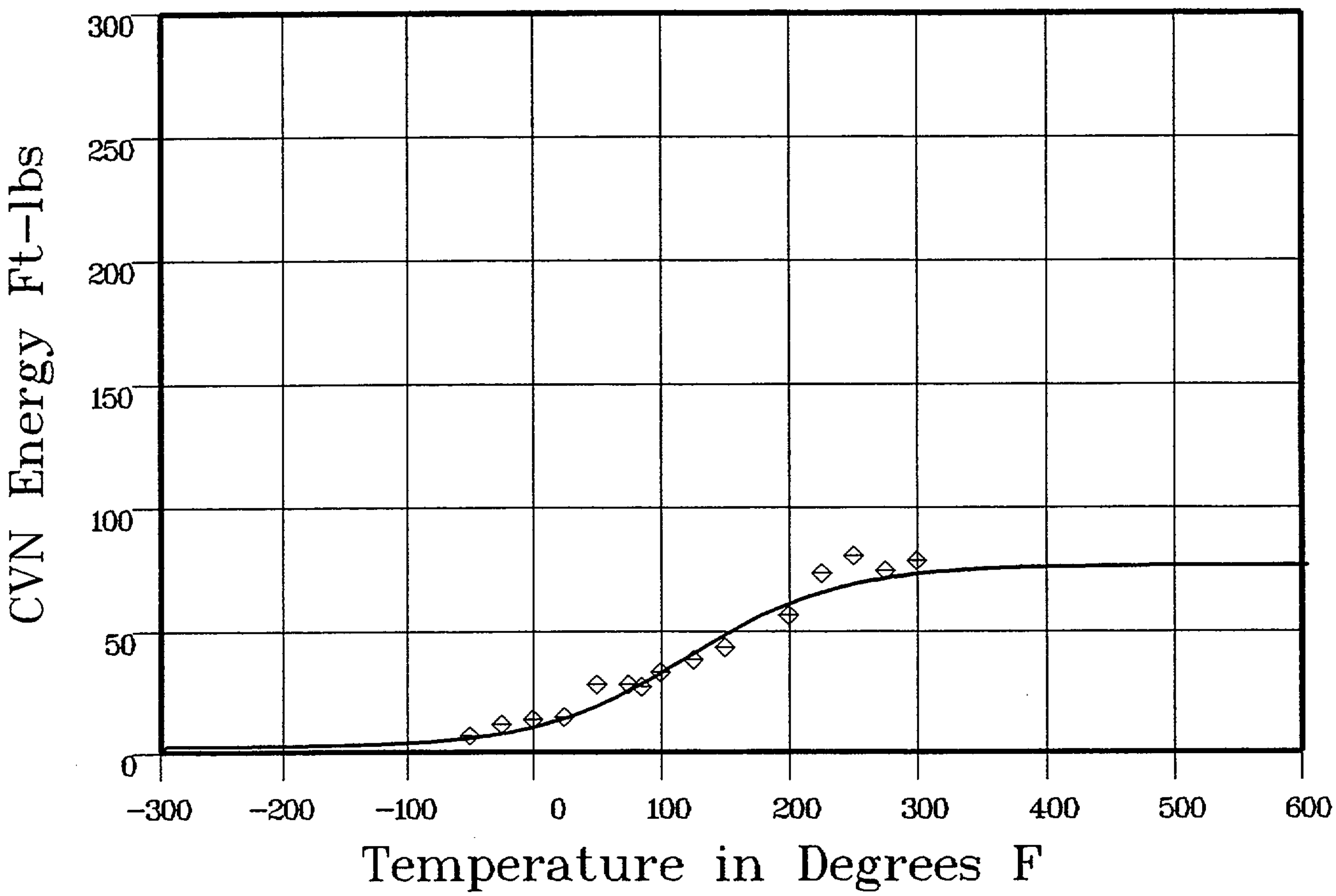
A = 39.09	B = 36.9	C = 118.57	T0 = 115.85

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

Upper Shelf Energy: 76 Fixed Temp. at 30 ft-lbs: 85.9 Temp. at 50 ft-lbs: 151.9 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: V Material: PLATE SA533B1 Ori.: TL Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	7	6.44	.55
-25	12	8.47	3.52
0	14	11.35	2.64
25	15	15.31	-.31
50	28	20.48	7.51
75	28	26.86	1.13
85	27	29.71	-2.71
100	33	34.19	-1.19

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

CAPSULE V (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
125	38	41.94	-3.94
150	43	49.44	-6.44
200	56	61.62	-5.62
225	73	65.89	7.1
250	80	69.04	10.95
275	74	71.28	2.71
300	78	72.83	5.16

SUM of RESIDUALS = 21.08

CAPSULE W (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:42:39 on 02-05-2001

Page 1

Coefficients of Curve 4

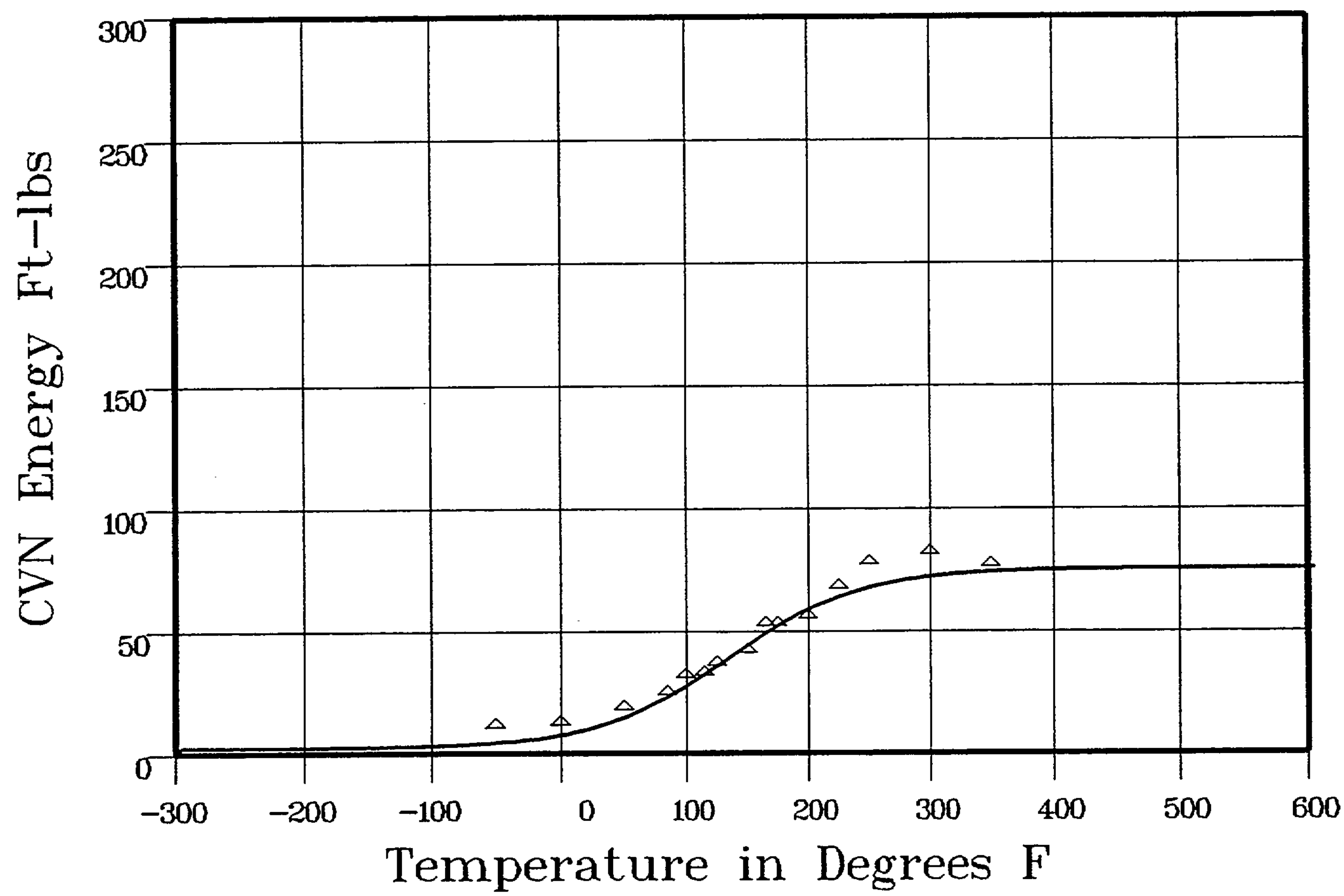
A = 38.59	B = 36.4	C = 107.13	T0 = 128.9

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

Upper Shelf Energy: 75 Fixed Temp. at 30 ft-lbs: 103.1 Temp. at 50 ft-lbs: 163.6 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: W Material: PLATE SA533B1 Ori.: TL Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	11	4.69	6.3
0	12	8.21	3.78
50	18	15.77	2.22
85	24	24.46	-.46
100	31	29.01	1.98
115	32	33.9	-1.9
125	36	37.27	-1.27

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

CAPSULE W (TRANSVERSE ORIENTATION)

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
150	41	45.67	-4.67
165	52	50.41	1.58
175	52	53.36	-1.36
200	55	59.73	-4.73
225	67	64.61	2.38
250	77	68.12	8.87
300	81	72.13	8.86
350	76	73.84	2.15

SUM of RESIDUALS = 23.74

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:47:53 on 02-05-2001

Page 1

Coefficients of Curve 1

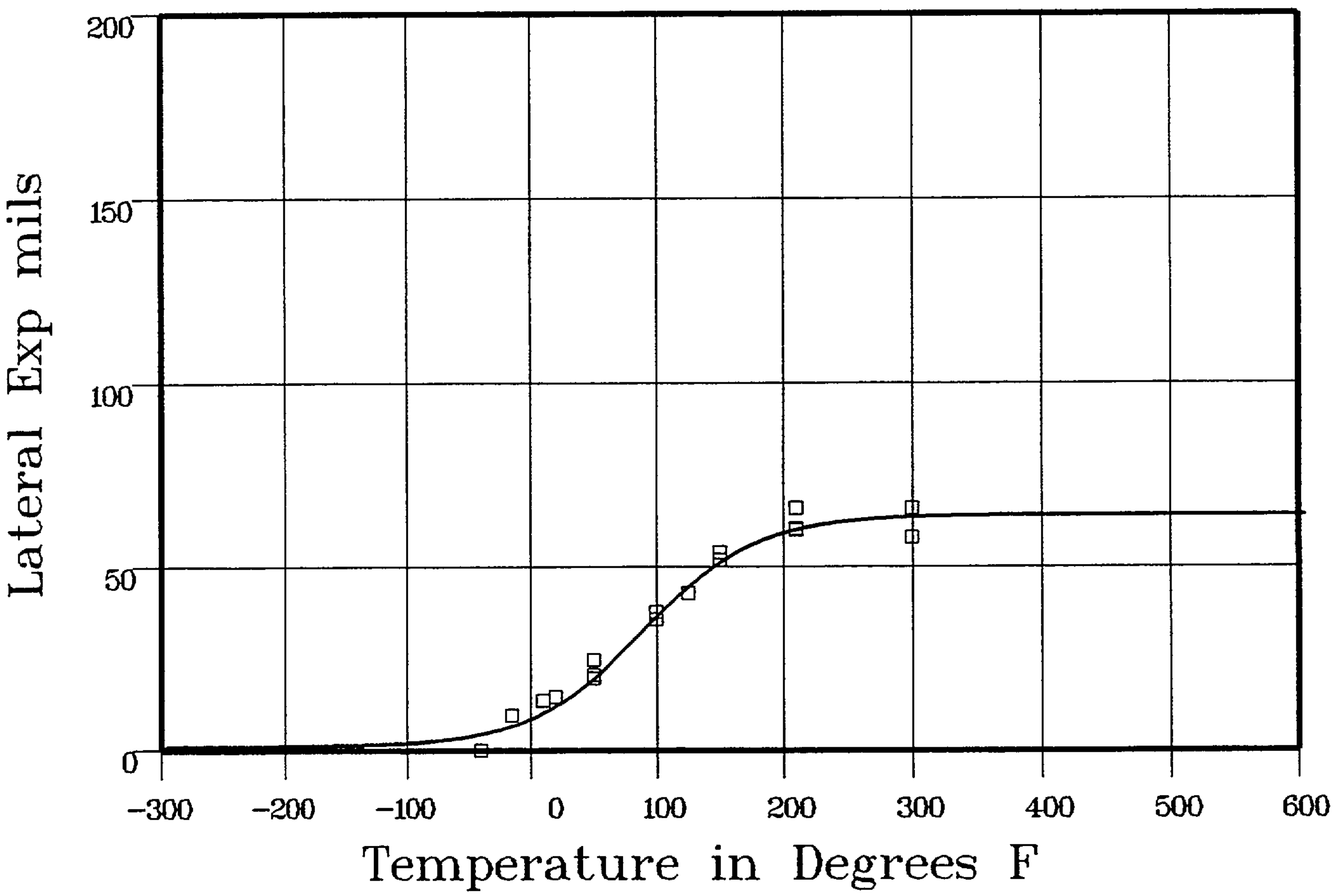
A = 32.6	B = 31.6	C = 90.92	T0 = 83.43

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

Upper Shelf L.E.: 64.21 Temperature at L.E. 35: 90.3 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: UNIRR Material: PLATE SA533B1 Ori.: TL Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-40	0	4.92	-4.92
-40	0	4.92	-4.92
-15	10	7.5	2.49
10	14	11.48	2.51
20	15	13.55	1.44
50	25	21.48	3.51
50	20	21.48	-1.48
50	21	21.48	-.48
100	38	38.3	-.3

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

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
100	36	38.3	-2.3
125	43	46.12	-3.12
150	54	52.34	1.65
150	52	52.34	-.34
210	60.5	60.53	-.03
210	66	60.53	5.46
210	60	60.53	-.53
300	66	63.68	2.31
300	58	63.68	-5.68

SUM of RESIDUALS = -4.75

CAPSULE U (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:47:53 on 02-05-2001

Page 1

Coefficients of Curve 2

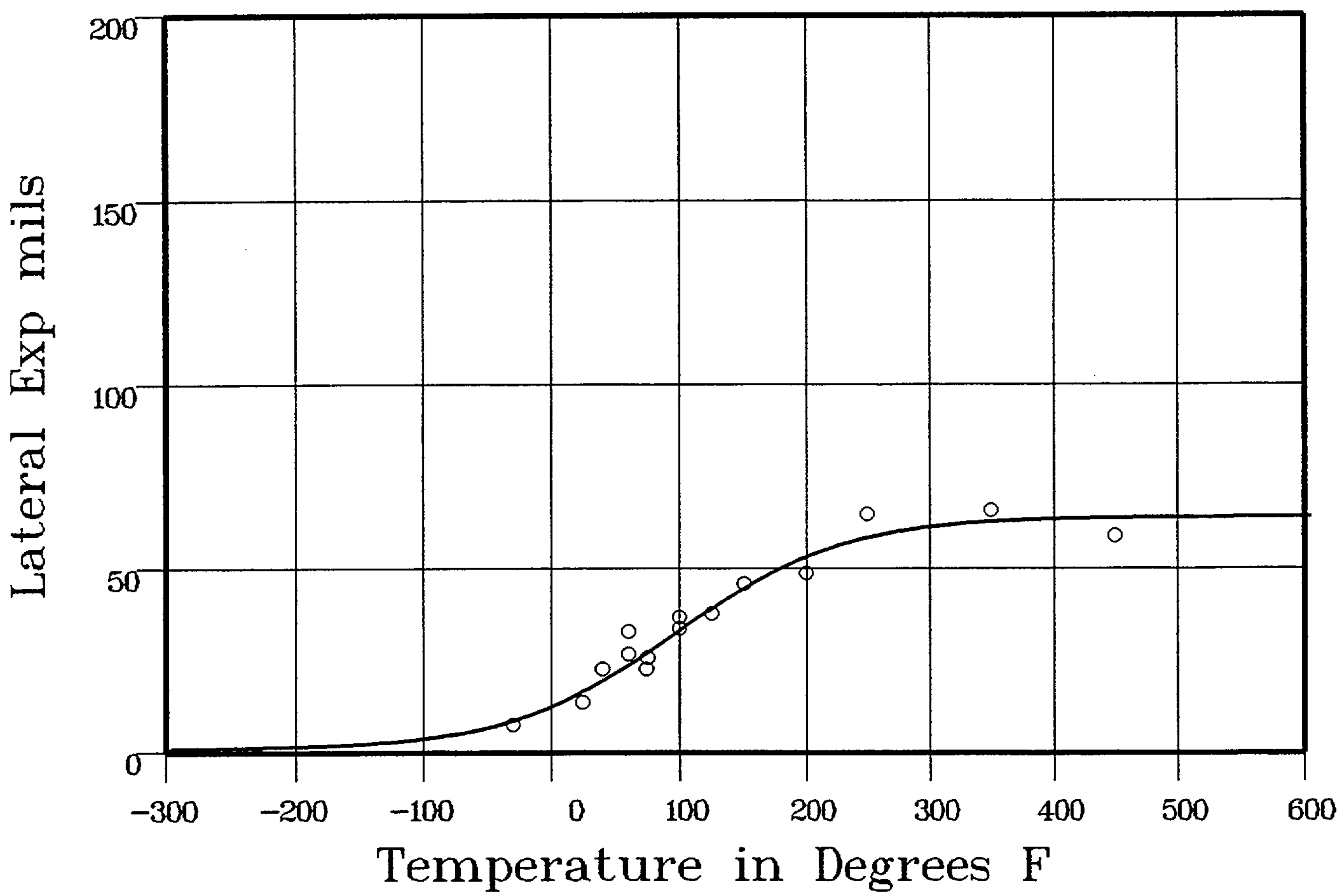
A = 32.56	B = 31.56	C = 131.12	T0 = 91.87

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

Upper Shelf L.E.: 64.12 Temperature at L.E. 35: 102 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-30	8	9.51	-1.51
25	14	17.72	-3.72
40	23	20.68	2.31
60	27	25.03	1.96
60	33	25.03	7.96
74	23	28.28	-5.28
75	26	28.52	-2.52
100	37	34.51	2.48

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

CAPSULE U (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
100	34	34.51	-.51
125	38	40.36	-2.36
150	46	45.7	.29
200	49	53.94	-4.94
250	65	58.92	6.07
350	66	62.91	3.08
450	59	63.85	-4.85

SUM of RESIDUALS = -1.55

CAPSULE V (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:47:53 on 02-05-2001

Page 1

Coefficients of Curve 3

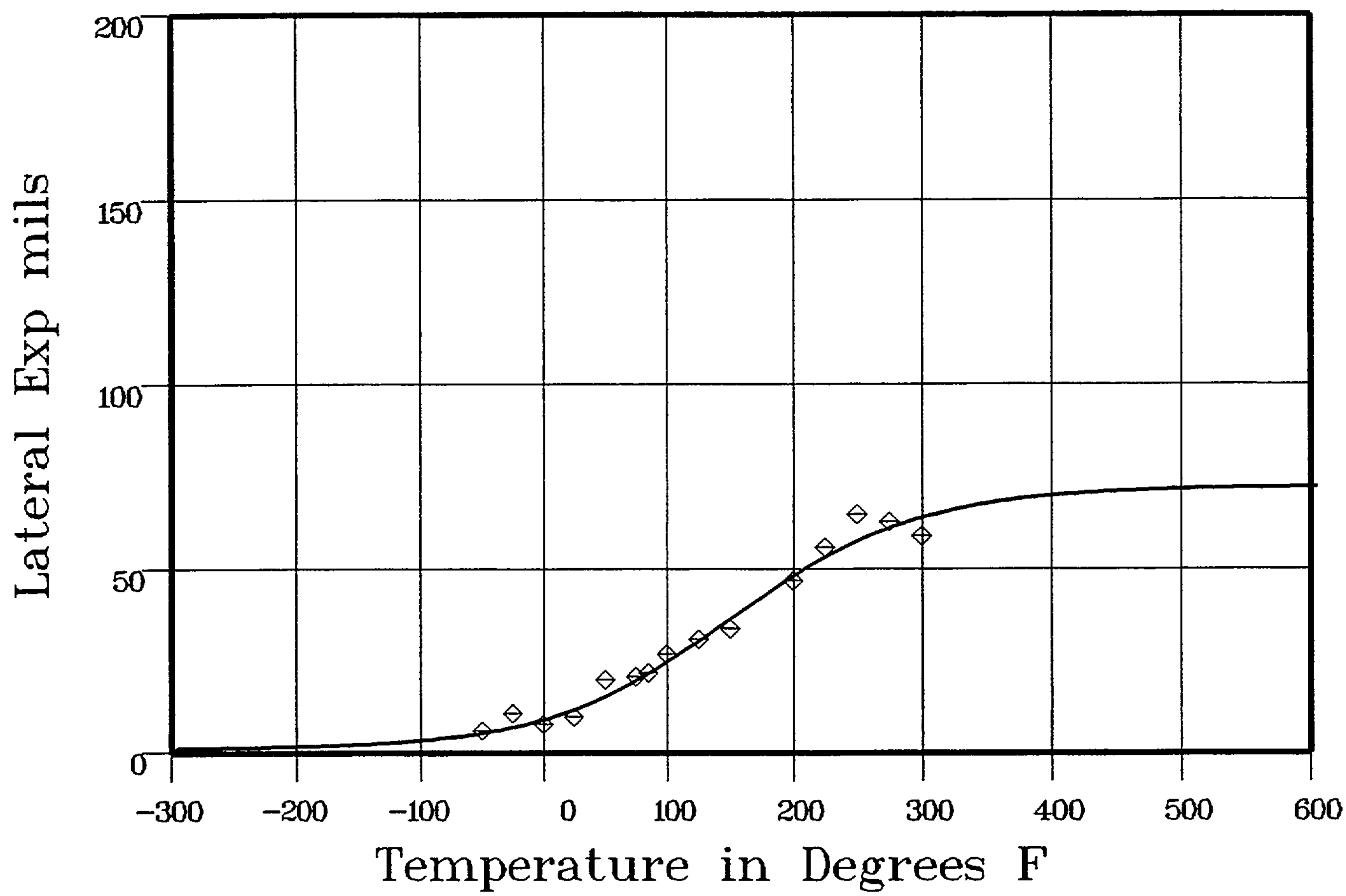
A = 36.67	B = 35.67	C = 147.22	T0 = 145.31

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

Upper Shelf L.E.: 72.35 Temperature at L.E. 35: 138.3 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: V Material: PLATE SA533B1 Ori.: TL Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	6	5.69	.3
-25	11	7.42	3.57
0	8	9.7	-1.7
25	10	12.64	-2.64
50	20	16.34	3.65
75	21	20.82	.17
85	22	22.82	-.82
100	27	26.03	.96

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

CAPSULE V (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1   Heat Number: C0544-2   Orientation: TL

Capsule: V   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
125	31	31.78	-.78
150	34	37.81	-3.81
200	47	49.35	-2.35
225	56	54.29	1.7
250	65	58.48	6.51
275	63	61.89	1.1
300	59	64.57	-5.57
		SUM of RESIDUALS =	.3

CAPSULE W (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:47:53 on 02-05-2001
Page 1
Coefficients of Curve 4

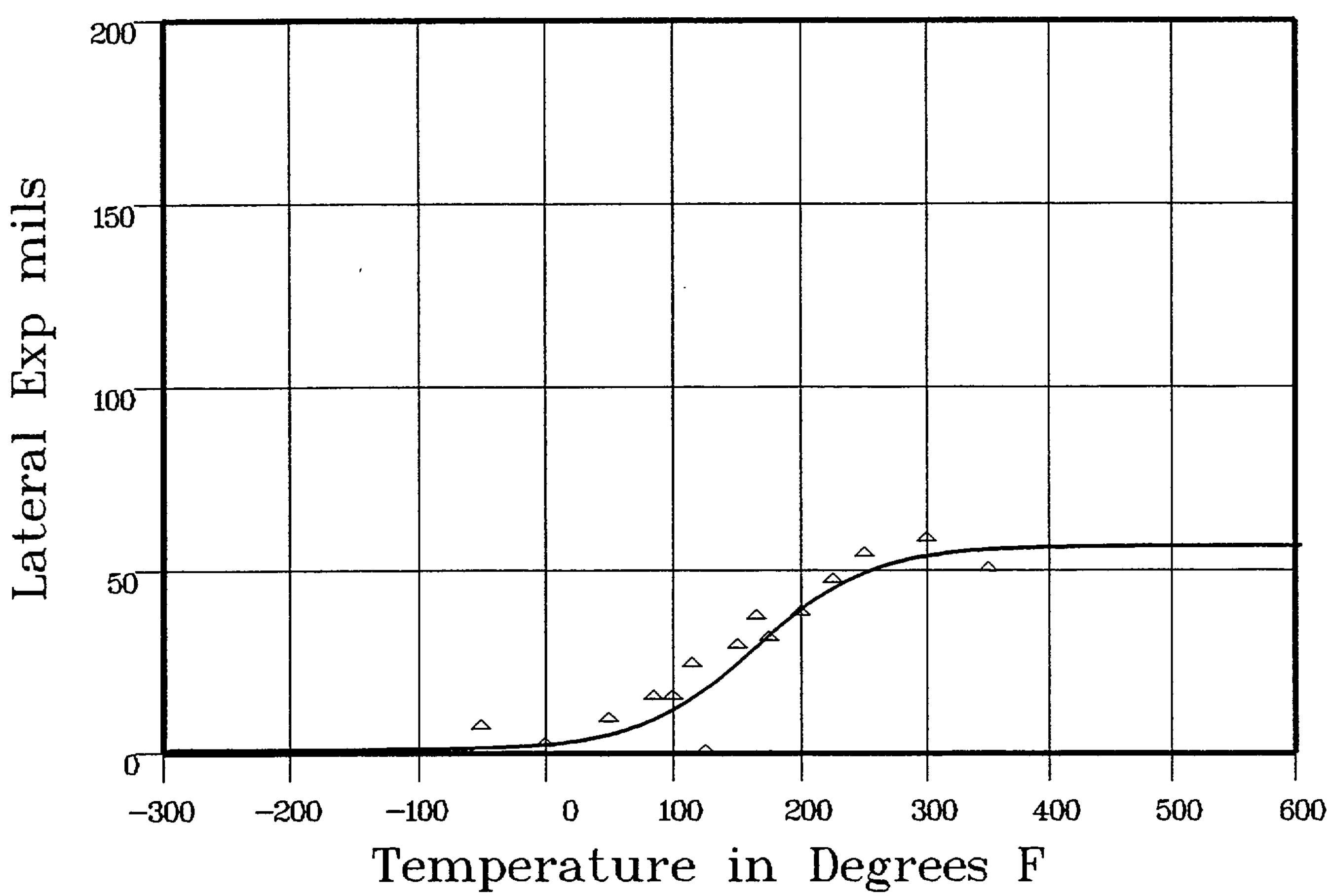
A = 28.84	B = 27.84	C = 91.06	T0 = 158.2

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

Upper Shelf L.E.: 56.69 Temperature at L.E. 35: 178.6 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: W Total Fluence:



Data Set(s) Plotted
Plant: BV2 Cap.: W Material: PLATE SA533B1 Ori.: TL Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	7	1.56	5.43
0	2	2.67	-.67
50	9	5.73	3.26
85	15	10.29	4.7
100	15	13.13	1.86
115	24	16.54	7.45
125	0	19.12	-19.12

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

CAPSULE W (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
150	29	26.34	2.65
165	37	30.92	6.07
175	31	33.92	-2.92
200	38	40.8	-2.8
225	47	46.25	.74
250	54	50.15	3.84
300	58	54.32	3.67
350	50	55.88	-5.88

SUM of RESIDUALS = 8.3

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:52:28 on 02-05-2001

Page 1

Coefficients of Curve 1

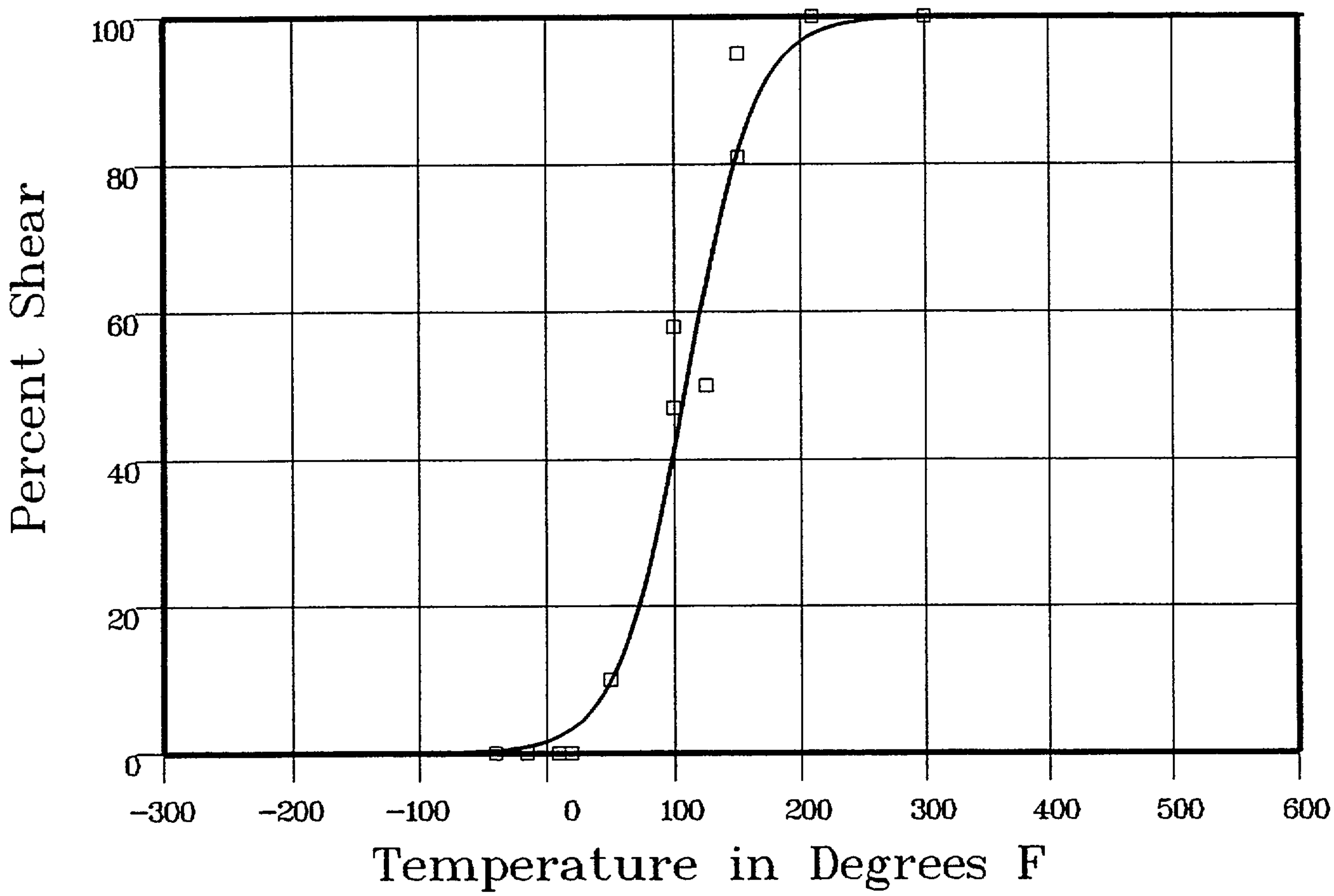
A = 50	B = 50	C = 53.67	T0 = 104.88

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

Temperature at 50% Shear: 104.8

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: UNIRR Material: PLATE SA533B1 Ori.: TL Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40	0	.45	-.45
-40	0	.45	-.45
-15	0	1.13	-1.13
10	0	2.83	-2.83
20	0	4.05	-4.05
50	10	11.45	-1.45
50	10	11.45	-1.45
50	10	11.45	-1.45
100	58	45.46	12.53

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

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100	47	45.46	1.53
125	50	67.9	-17.9
150	95	84.3	10.69
150	81	84.3	-3.3
210	100	98.04	1.95
210	100	98.04	1.95
210	100	98.04	1.95
300	100	99.93	.06
300	100	99.93	.06

SUM of RESIDUALS = -3.74

CAPSULE U (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:52:28 on 02-05-2001

Page 1

Coefficients of Curve 2

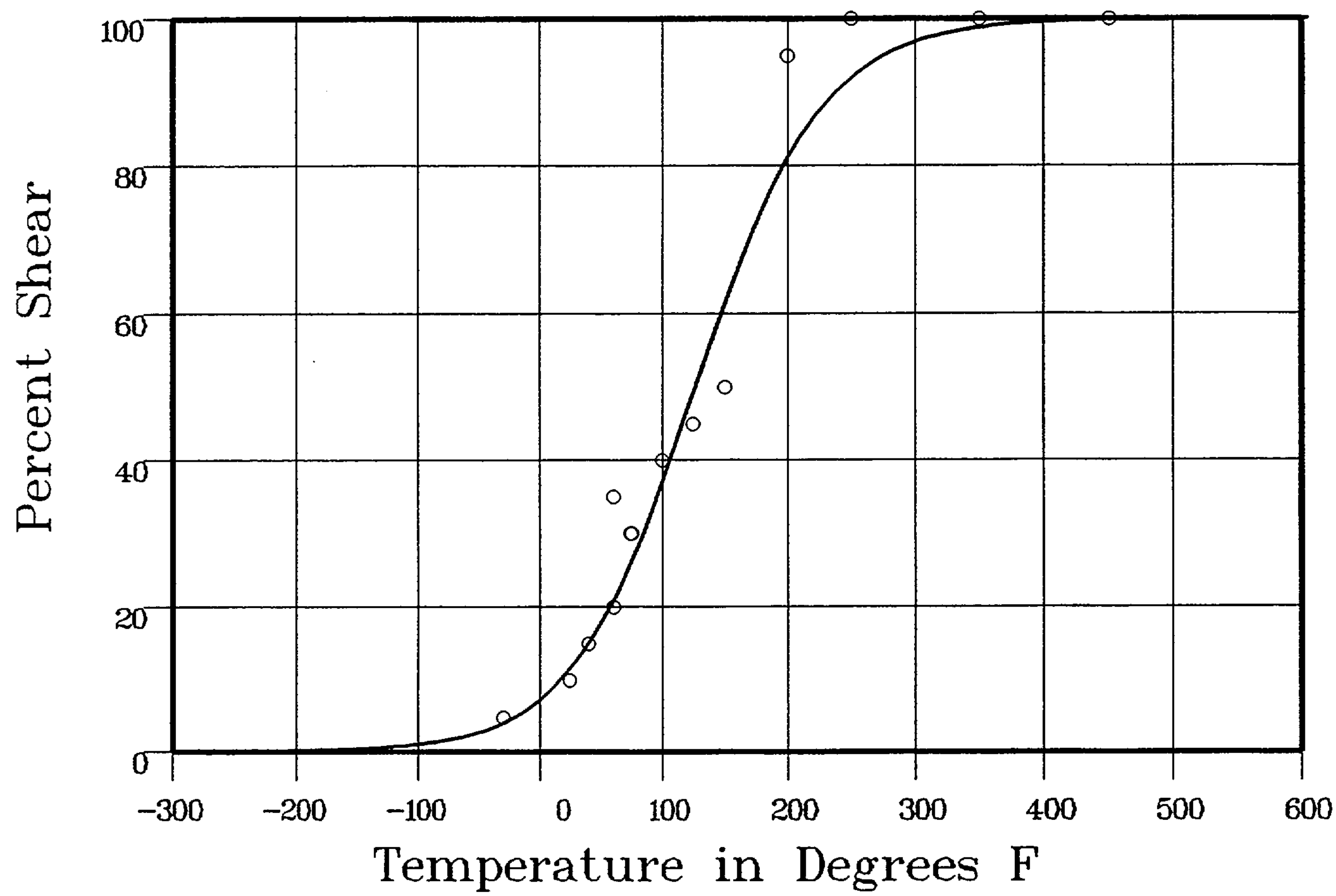
A = 50	B = 50	C = 100.48	T0 = 122.16

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

Temperature at 50% Shear: 122.1

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-30	5	4.61	.38
25	10	12.63	-2.63
40	15	16.3	-1.3
60	20	22.48	-2.48
60	35	22.48	12.51
74	30	27.71	2.28
75	30	28.11	1.88
100	40	39.14	.85

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

CAPSULE U (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100	40	39.14	.85
125	45	51.4	-6.4
150	50	63.5	-13.5
200	95	82.47	12.52
250	100	92.71	7.28
350	100	98.93	1.06
450	100	99.85	.14

SUM of RESIDUALS = 13.44

CAPSULE V (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:52:28 on 02-05-2001
Page 1
Coefficients of Curve 3

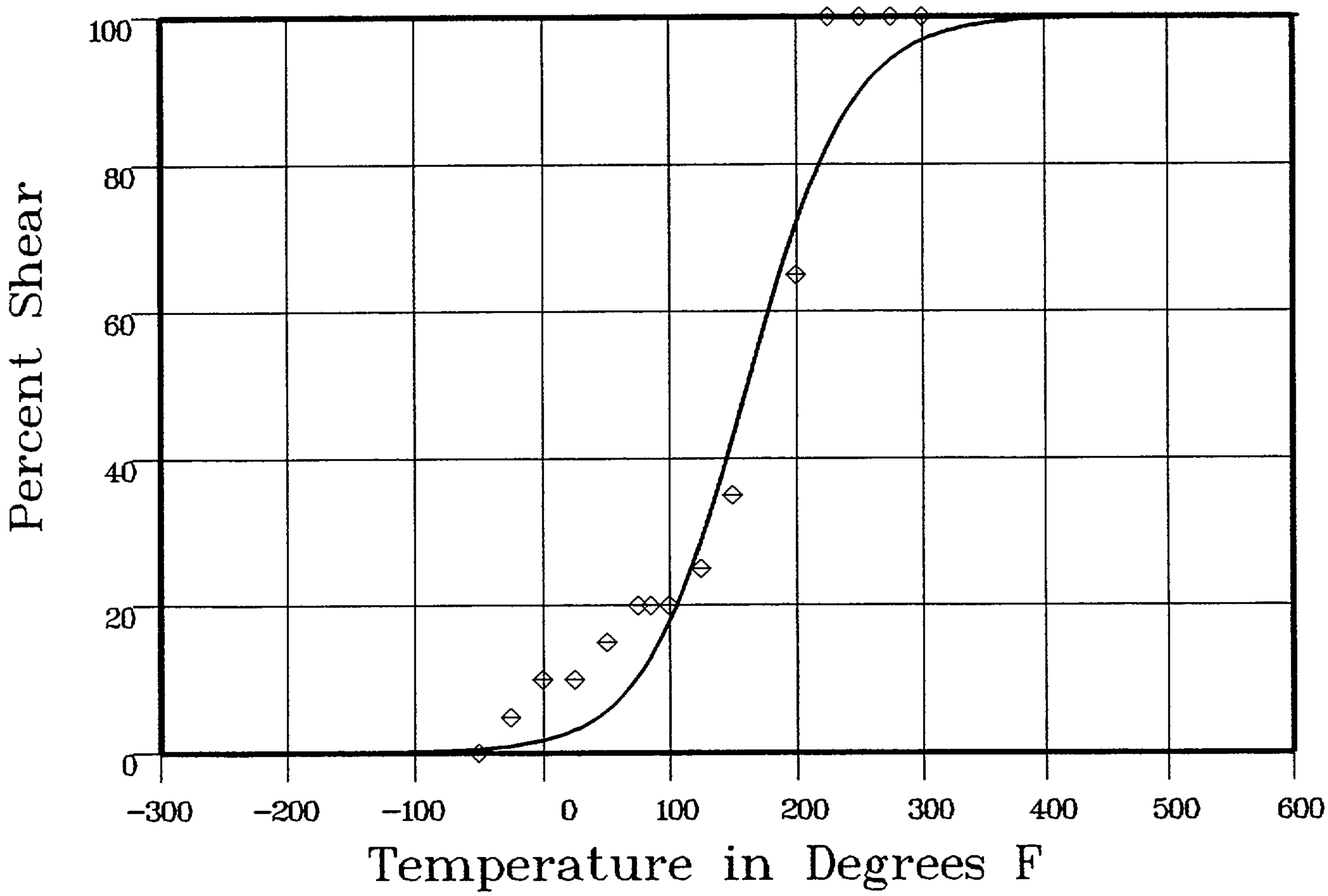
A = 50	B = 50	C = 80.79	T0 = 157.03

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

Temperature at 50% Shear: 157

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: V Total Fluence:



Data Set(s) Plotted
Plant: BV2 Cap.: V Material: PLATE SA533B1 Ori.: TL Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	0	.59	-.59
-25	5	1.09	3.9
0	10	2	7.99
25	10	3.66	6.33
50	15	6.6	8.39
75	20	11.6	8.39
85	20	14.39	5.6
100	20	19.59	.4

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

CAPSULE V (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
125	25	31.15	-6.15
150	35	45.65	-10.65
200	65	74.33	-9.33
225	100	84.32	15.67
250	100	90.89	9.1
275	100	94.88	5.11
300	100	97.17	2.82

SUM of RESIDUALS = 47.01

CAPSULE W (TRANSVERSE ORIENTATION)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:52:28 on 02-05-2001

Page 1

Coefficients of Curve 4

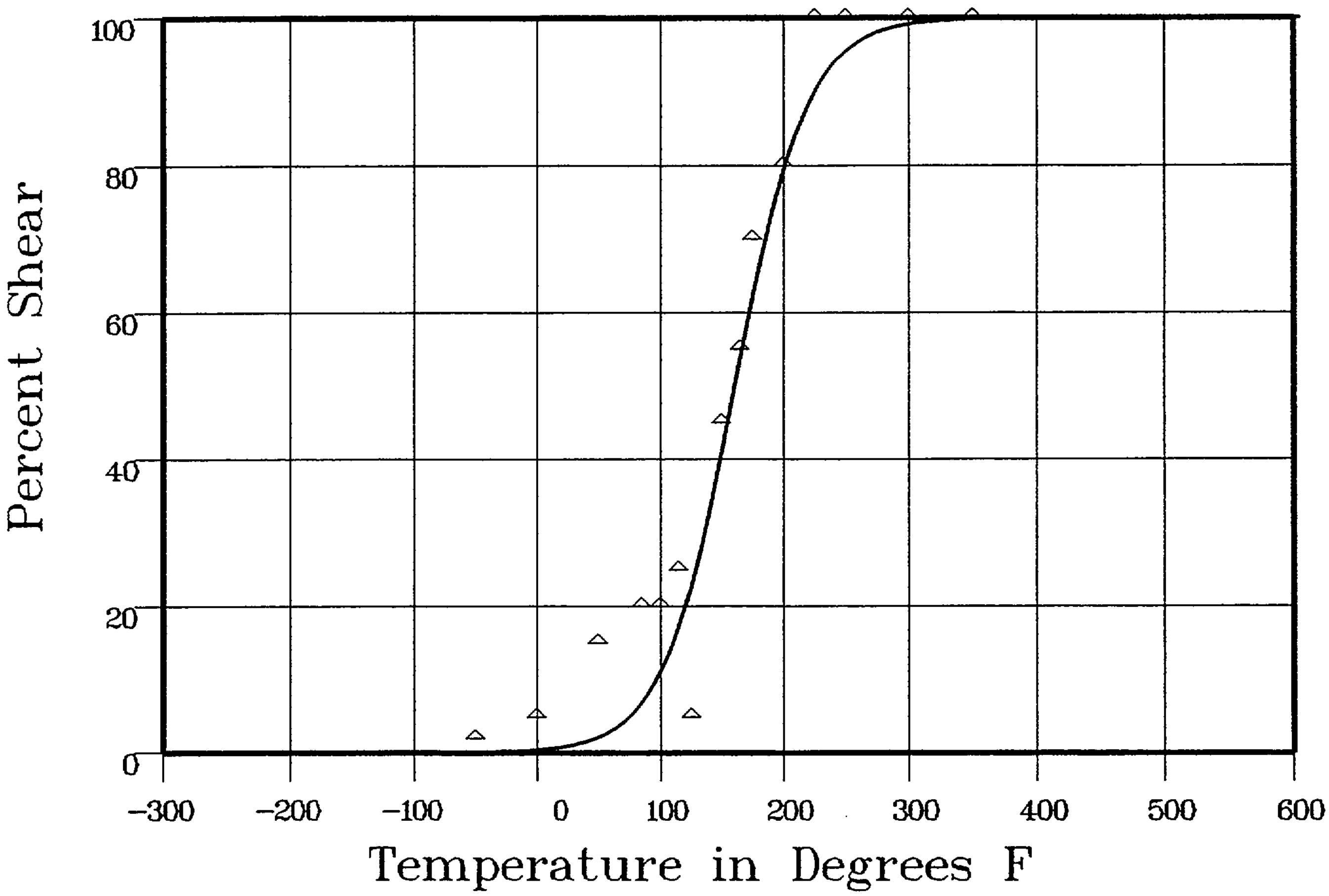
A = 50	B = 50	C = 58.35	T0 = 156.13

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

Temperature at 50% Shear: 156.1

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: W Material: PLATE SA533B1 Ori.: TL Heat #: C0544-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	2	.08	1.91
0	5	.47	4.52
50	15	2.56	12.43
85	20	8.03	11.96
100	20	12.74	7.25
115	25	19.62	5.37
125	5	25.59	-20.59

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

CAPSULE W (TRANSVERSE ORIENTATION)

Page 2

Material: PLATE SA533B1 Heat Number: C0544-2 Orientation: TL

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
150	45	44.75	.24
165	55	57.53	-2.53
175	70	65.61	4.38
200	80	81.8	-1.8
225	100	91.37	8.62
250	100	96.14	3.85
300	100	99.28	.71
350	100	99.86	.13

SUM of RESIDUALS = 36.49

UNIRRADIATED (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:19:09 on 02-06-2001

Page 1

Coefficients of Curve 1

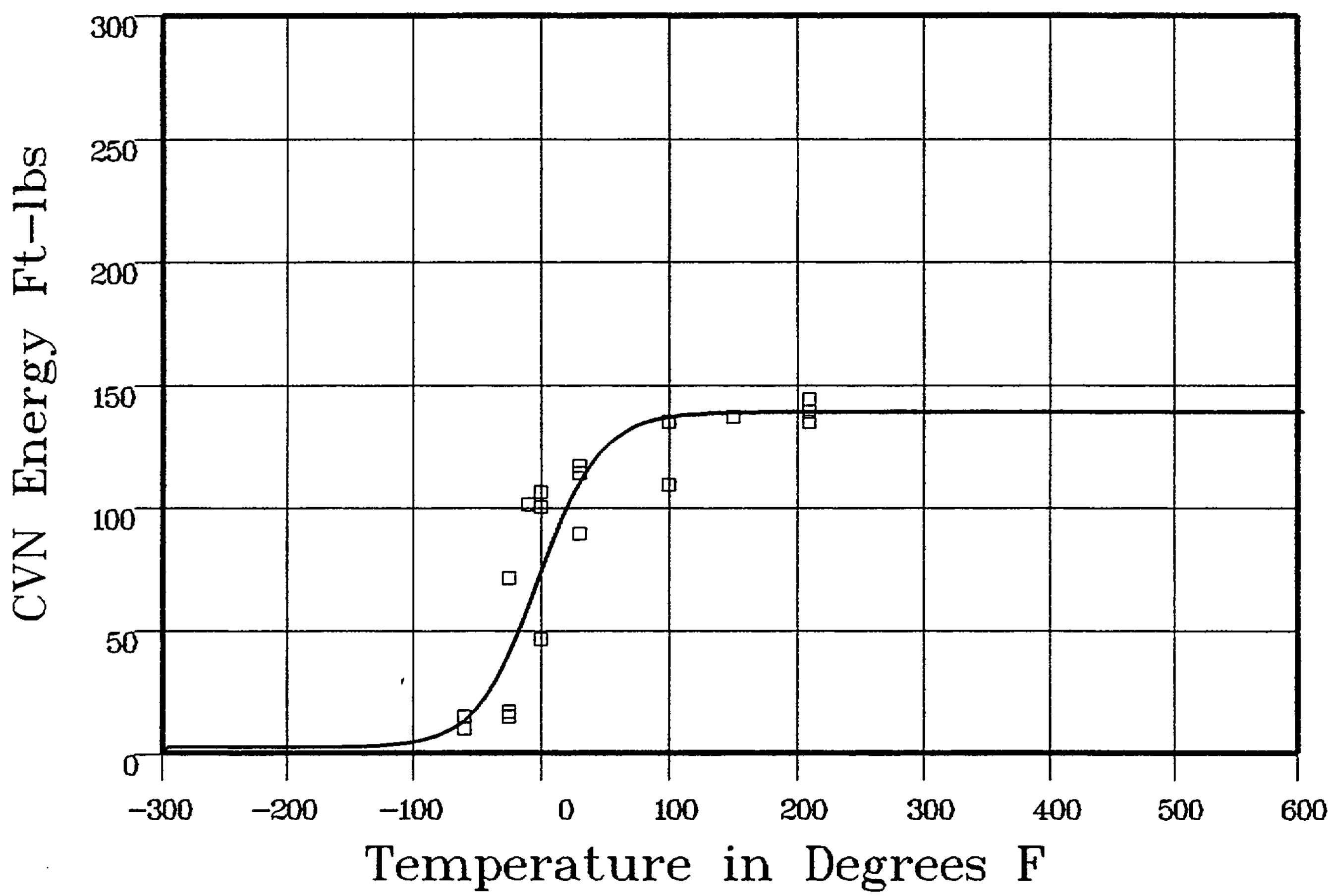
A = 70.59	B = 68.4	C = 48.59	T0 = -6.56

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

Upper Shelf Energy: 139 Fixed   Temp. at 30 ft-lbs: -39.7   Temp. at 50 ft-lbs: -21.6   Lower Shelf Energy: 2.19 Fixed

Material: WELD LINDE 91   Heat Number: 83642   Orientation:

Capsule: UNIRR   Total Fluence:



Data Set(s) Plotted

Plant: BV2   Cap.: UNIRR   Material: WELD LINDE 91   Ori.:   Heat #: 83642

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-60	10	15.85	-5.85
-60	15	15.85	-.85
-25	17	45.82	-28.82
-25	15	45.82	-30.82
-25	71	45.82	25.17
-10	101	65.76	35.23
0	46	79.78	-33.78
0	106	79.78	26.21
0	100	79.78	20.21

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

UNIRRADIATED (WELD)

Page 2

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
30	114	114.14	-.14
30	117	114.14	2.85
30	89	114.14	-25.14
100	135	137.31	-2.31
100	109	137.31	-28.31
150	137	138.78	-1.78
210	135	138.98	-3.98
210	139	138.98	.01
210	144	138.98	5.01

SUM of RESIDUALS =-47.08

CAPSULE U (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:19:09 on 02-06-2001

Page 1

Coefficients of Curve 2

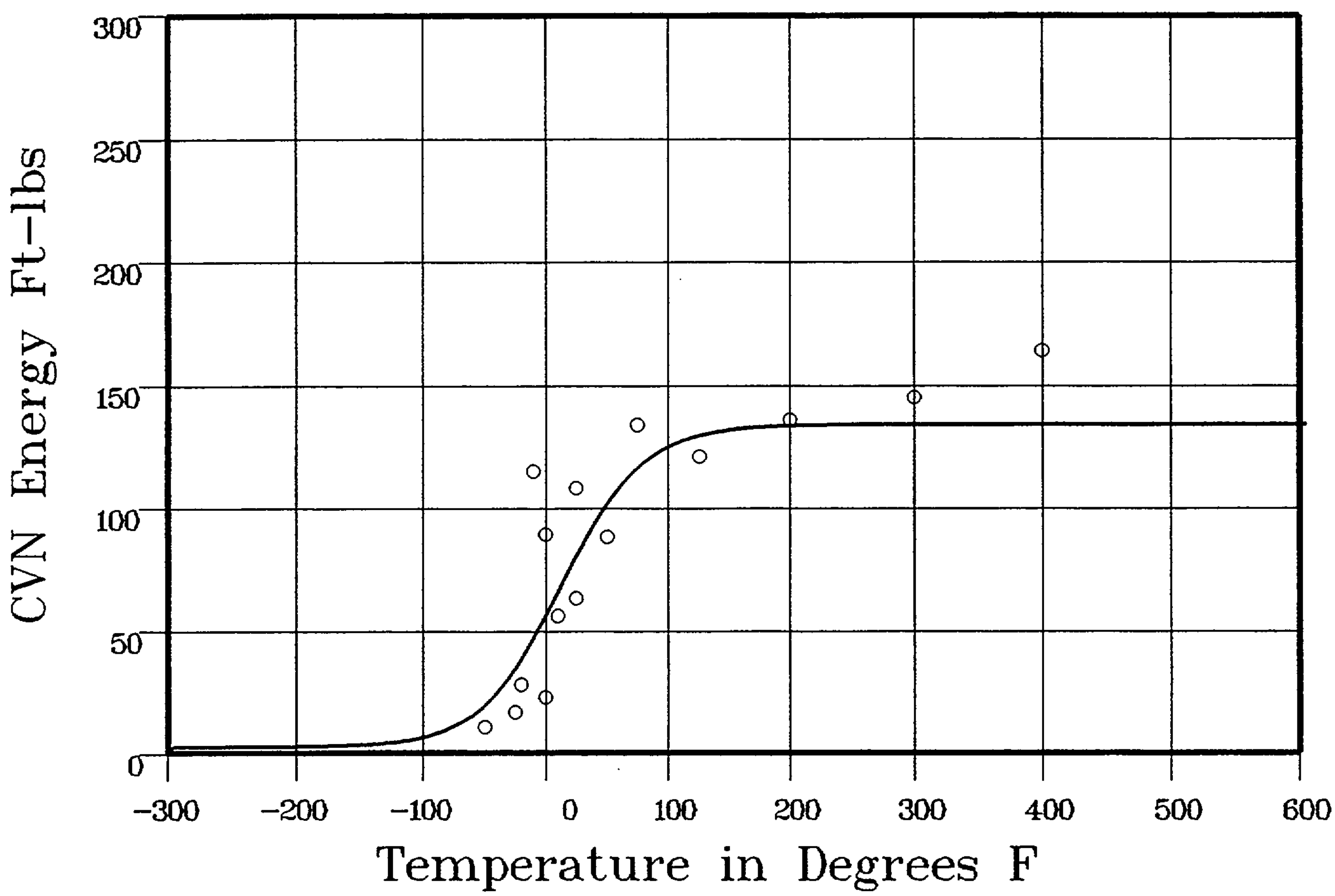
A = 68.09	B = 65.9	C = 66.82	T0 = 7.96

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

Upper Shelf Energy: 134 Fixed Temp. at 30 ft-lbs: -36.1 Temp. at 50 ft-lbs: -10.8 Lower Shelf Energy: 2.19 Fixed

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: U Material: WELD LINDE 91 Ori.: Heat #: 83642

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	11	21.96	-10.96
-25	17	37.99	-20.99
-20	28	42.02	-14.02
-10	115	50.79	64.2
0	23	60.27	-37.27
0	89	60.27	28.72
10	56	70.1	-14.1
25	108	84.54	23.45

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

CAPSULE U (WELD)

Page 2

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
25	63	84.54	-21.54
50	88	104.83	-16.83
75	134	118.37	15.62
125	121	130.14	-9.14
200	136	133.58	2.41
300	145	133.97	11.02
400	164	133.99	30

SUM of RESIDUALS = 30.57

CAPSULE V (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:19:09 on 02-06-2001

Page 1

Coefficients of Curve 3

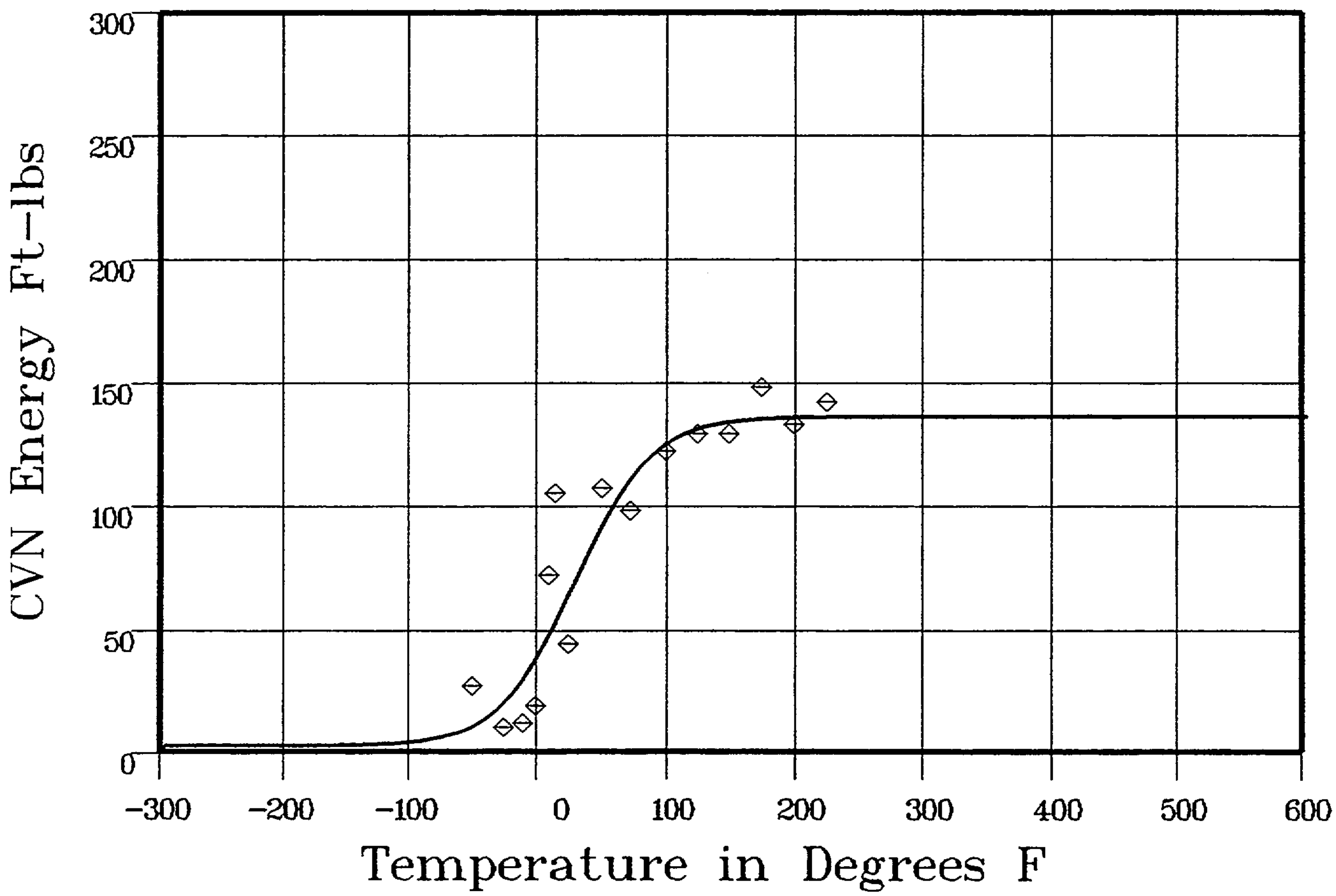
A = 69.09	B = 66.9	C = 58.47	T0 = 24.84

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

Upper Shelf Energy: 136 Fixed Temp. at 30 ft-lbs: -14.2 Temp. at 50 ft-lbs: 7.6 Lower Shelf Energy: 2.19 Fixed

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: V Material: WELD LINDE 91 Ori.: Heat #: 83642

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	27	11.8	15.19
-25	10	22.78	-12.78
-10	12	33.36	-21.36
0	19	42.27	-23.27
10	72	52.47	19.52
15	105	57.94	47.05
25	44	69.27	-25.27
50	107	96.22	10.77

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

CAPSULE V (WELD)

Page 2

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
72	98	113.76	-15.76
100	122	126.49	-4.49
125	129	131.78	-2.78
150	129	134.17	-5.17
175	148	135.21	12.78
200	133	135.66	-2.66
225	142	135.85	6.14

SUM of RESIDUALS = -2.1

CAPSULE W (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:22:50 on 02-06-2001

Page 1

Coefficients of Curve 1

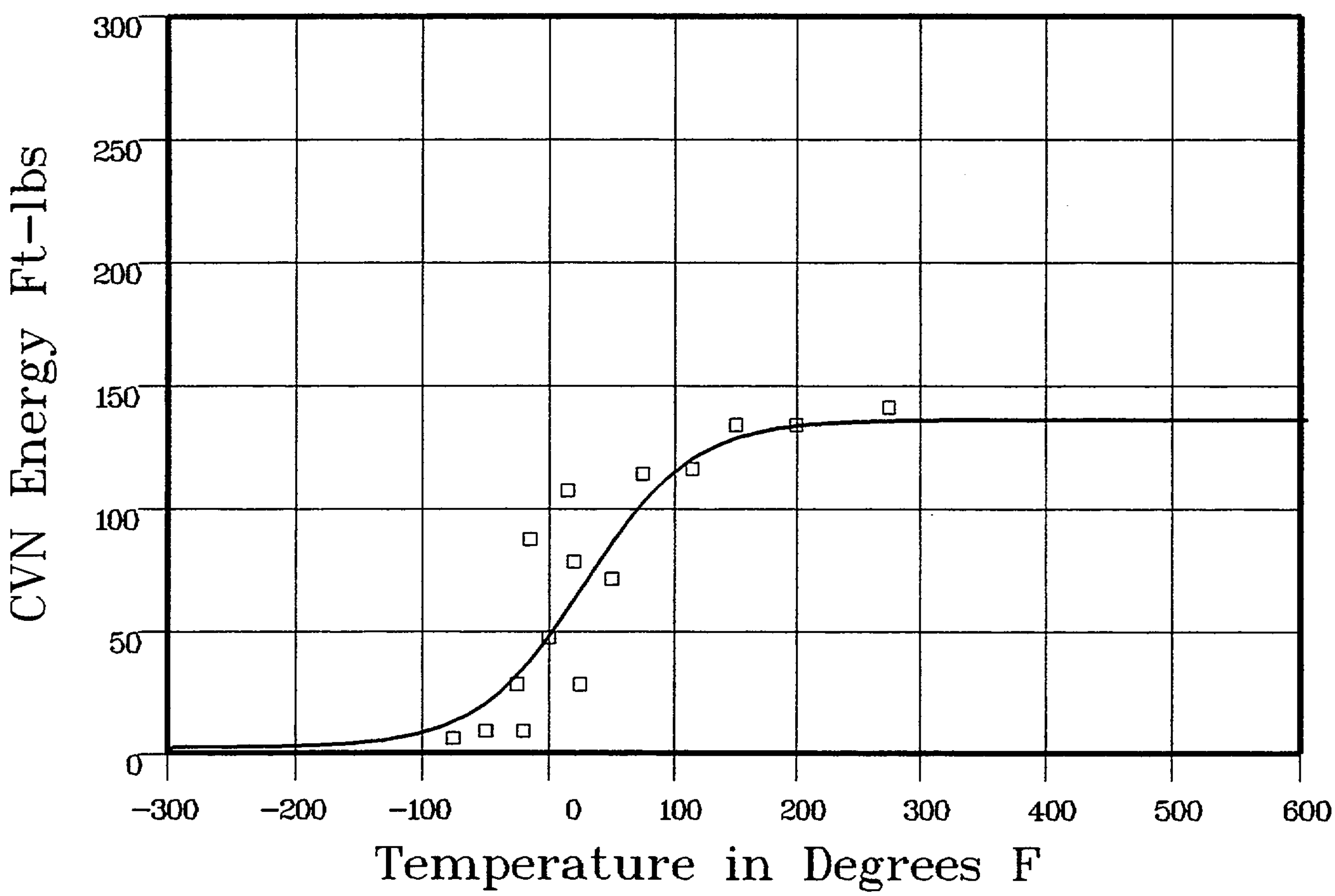
A = 69.09	B = 66.9	C = 85.83	T0 = 23.9

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

Upper Shelf Energy: 136 Fixed Temp. at 30 ft-lbs: -33.5 Temp. at 50 ft-lbs: -1.3 Lower Shelf Energy: 2.19 Fixed

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: W Material: WELD LINDE 91 Ori.: Heat #: 83642

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-75	6	14.34	-8.34
-50	9	22.48	-13.48
-25	28	34.63	-6.63
-20	9	37.58	-28.58
-15	87	40.69	46.3
0	47	50.93	-3.93
15	107	62.18	44.81
20	78	66.06	11.93
25	28	69.95	-41.95

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

CAPSULE W (WELD)

Page 2

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	71	88.83	-17.83
75	114	104.8	9.19
115	116	121.69	-5.69
150	134	129.27	4.72
200	134	133.82	.17
275	141	135.61	5.38

SUM of RESIDUALS = -3.94

UNIRRADIATED (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve   Printed at 09:27:29 on 02-06-2001
Page 1
Coefficients of Curve 1

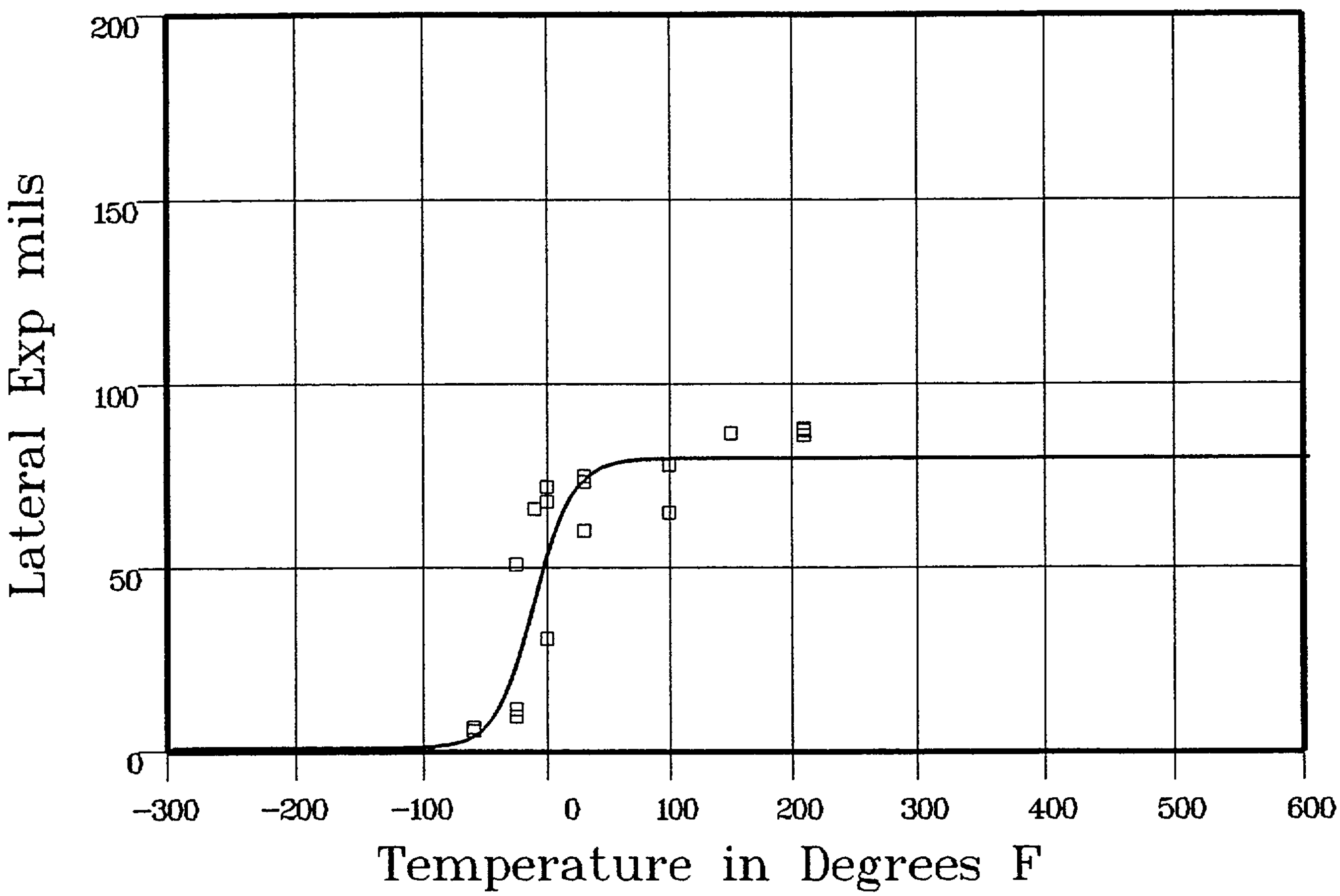
A = 40.42	B = 39.42	C = 32.31	T0 = -15.46

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

Upper Shelf L.E.: 79.85   Temperature at L.E. 35: -19.9   Lower Shelf L.E.: 1 Fixed

Material: WELD LINDE 91   Heat Number: 83642   Orientation:

Capsule: UNIRR   Total Fluence:



Data Set(s) Plotted
Plant: BV2   Cap.: UNIRR   Material: WELD LINDE 91   Ori.:   Heat #: 83642

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-60	6	5.7	.29
-60	7	5.7	1.29
-25	12	29.12	-17.12
-25	10	29.12	-19.12
-25	51	29.12	21.87
-10	66	47.03	18.96
0	31	57.98	-26.98
0	72	57.98	14.01
0	68	57.98	10.01

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

UNIRRADIATED (WELD)

Page 2

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
30	73.5	75.39	-1.89
30	75	75.39	-.39
30	60	75.39	-15.39
100	78	79.79	-1.79
100	65	79.79	-14.79
150	86.5	79.85	6.64
210	87.5	79.85	7.64
210	86	79.85	6.14
210	88	79.85	8.14

SUM of RESIDUALS = -2.49

CAPSULE U (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:27:29 on 02-06-2001

Page 1

Coefficients of Curve 2

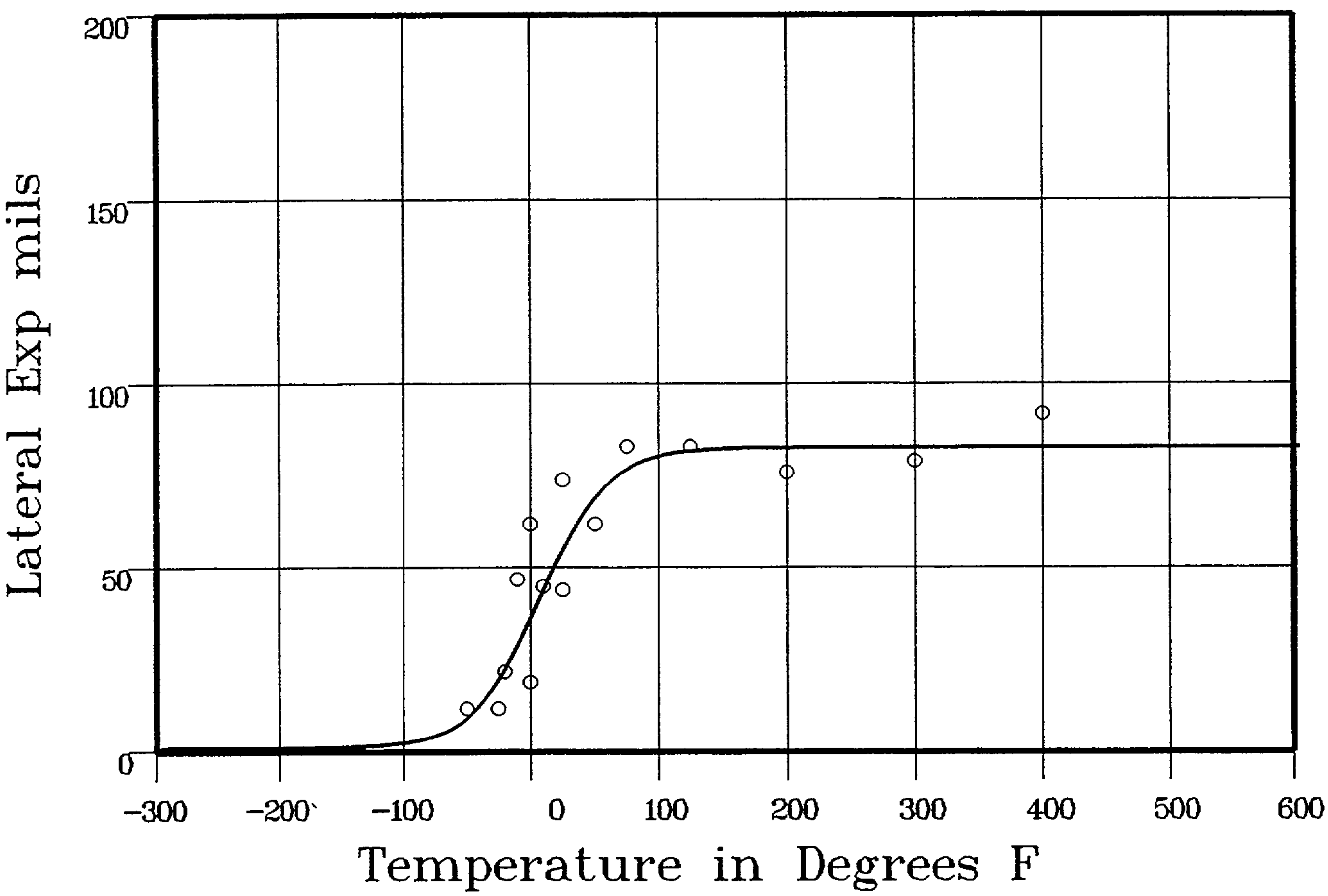
A = 41.83	B = 40.83	C = 52.93	T0 = 2.81

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

Upper Shelf L.E.: 82.66 Temperature at L.E. 35: -6.1 Lower Shelf L.E.: 1 Fixed

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: U Material: WELD LINDE 91 Ori.: Heat #: 83642

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	12	10.77	1.22
-25	12	22.15	-10.15
-20	22	25.24	-3.24
-10	47	32.13	14.86
0	19	39.66	-20.66
0	62	39.66	22.33
10	45	47.34	-2.34
25	74	58.01	15.98

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

CAPSULE U (WELD)

Page 2

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
25	44	58.01	-14.01
50	62	70.9	-8.9
75	83	77.65	5.34
125	83	81.86	1.13
200	76	82.61	-6.61
300	79	82.66	-3.66
400	92	82.66	9.33
		SUM of RESIDUALS =	.62

CAPSULE V (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:27:29 on 02-06-2001
Page 1
Coefficients of Curve 3

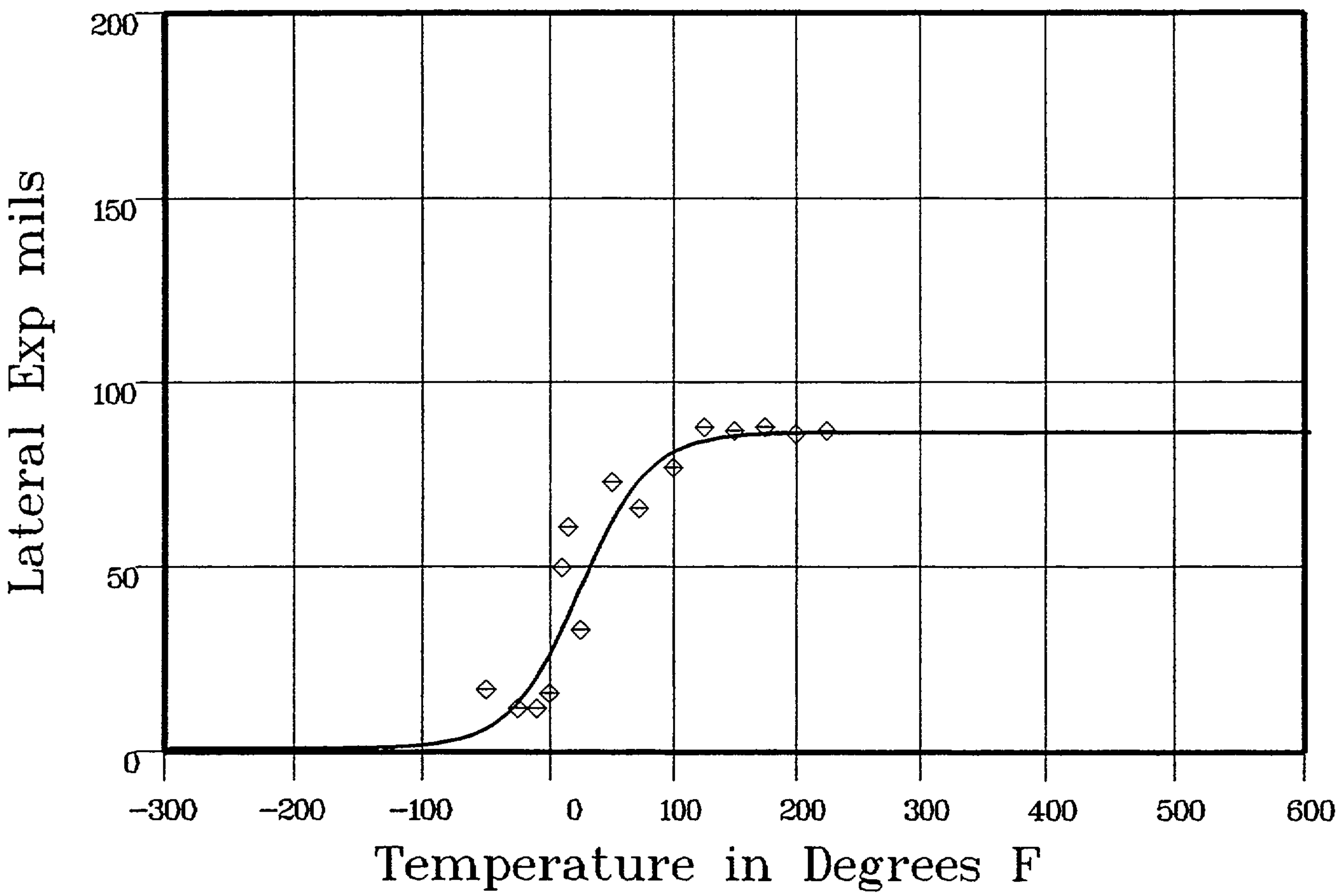
A = 43.73	B = 42.73	C = 55.53	T0 = 19.21

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

Upper Shelf L.E.: 86.47 Temperature at L.E. 35: 7.7 Lower Shelf L.E.: 1 Fixed

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted
Plant: BV2 Cap.: V Material: WELD LINDE 91 Ori.: Heat #: 83642

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	17	7.52	9.47
-25	12	15.44	-3.44
-10	12	23.12	-11.12
0	16	29.51	-13.51
10	50	36.7	13.29
15	61	40.49	20.5
25	33	48.17	-15.17
50	73	65.26	7.73

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

CAPSULE V (WELD)

Page 2

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed LE.	Differential
72	66	75.36	-9.36
100	77	82.05	-5.05
125	88	84.62	3.37
150	87	85.71	1.28
175	88	86.16	1.83
200	86	86.34	-.34
225	87	86.42	.57
		SUM of RESIDUALS =	.05

CAPSULE W (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:27:29 on 02-06-2001

Page 1

Coefficients of Curve 4

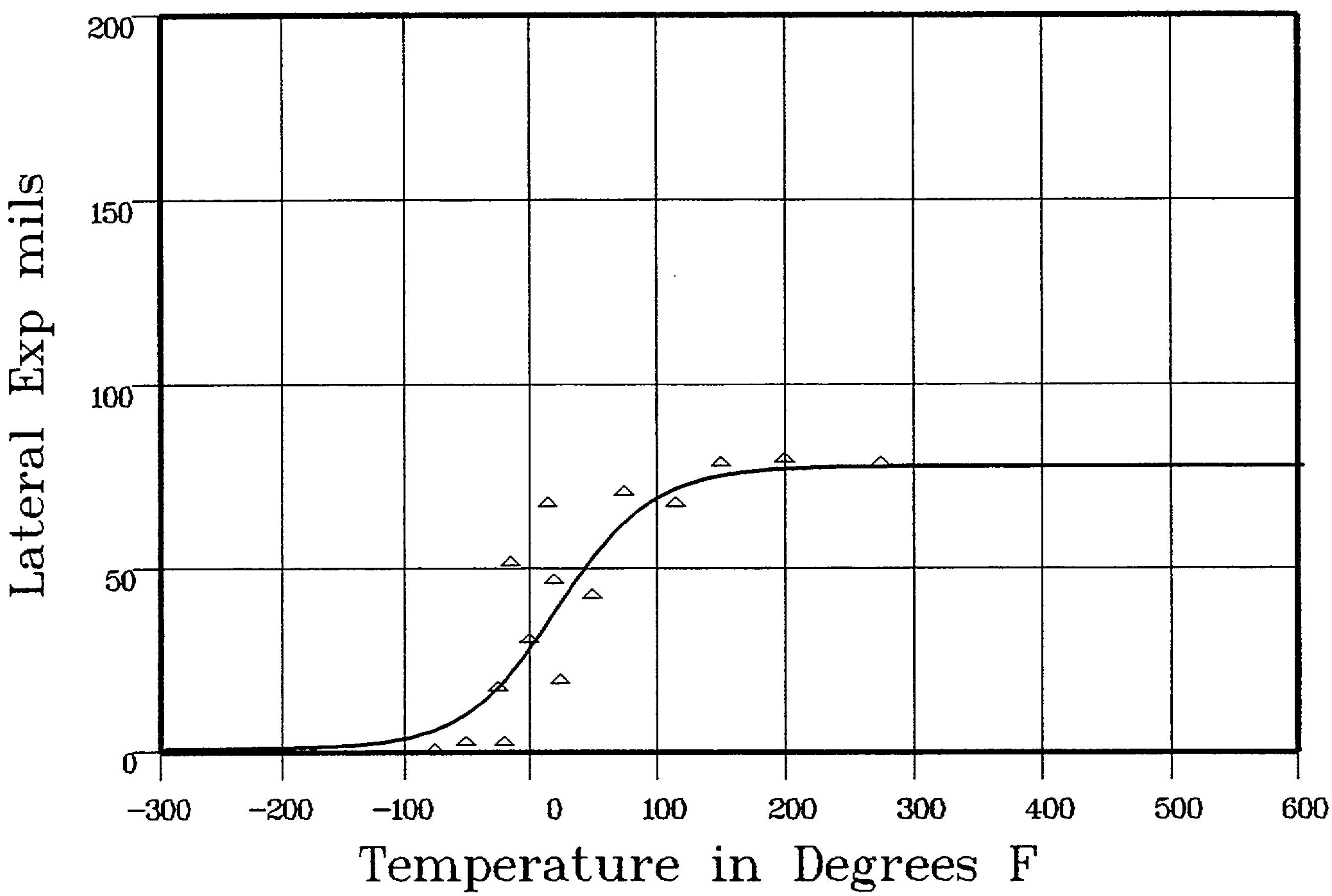
A = 39.4	B = 38.4	C = 75.33	T0 = 17.81

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

Upper Shelf L.E.: 77.8 Temperature at L.E. 35: 9.1 Lower Shelf L.E.: 1 Fixed

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: W Material: WELD LINDE 91 Ori.: Heat #: 83642

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-75	0	7.02	-7.02
-50	2	11.89	-9.89
-25	17	19.66	-2.66
-20	2	21.59	-19.59
-15	51	23.66	27.33
0	30	30.48	-.48
15	67	37.97	29.02

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

CAPSULE W (WELD)

Page 2

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
20	46	40.51	5.48
25	19	43.05	-24.05
50	42	54.87	-12.87
75	70	64	5.99
115	67	72.39	-5.39
150	78	75.57	2.42
200	79	77.2	1.79
275	78	77.72	.27

SUM of RESIDUALS = -9.64

UNIRRADIATED (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:31:28 on 02-06-2001
Page 1
Coefficients of Curve 1

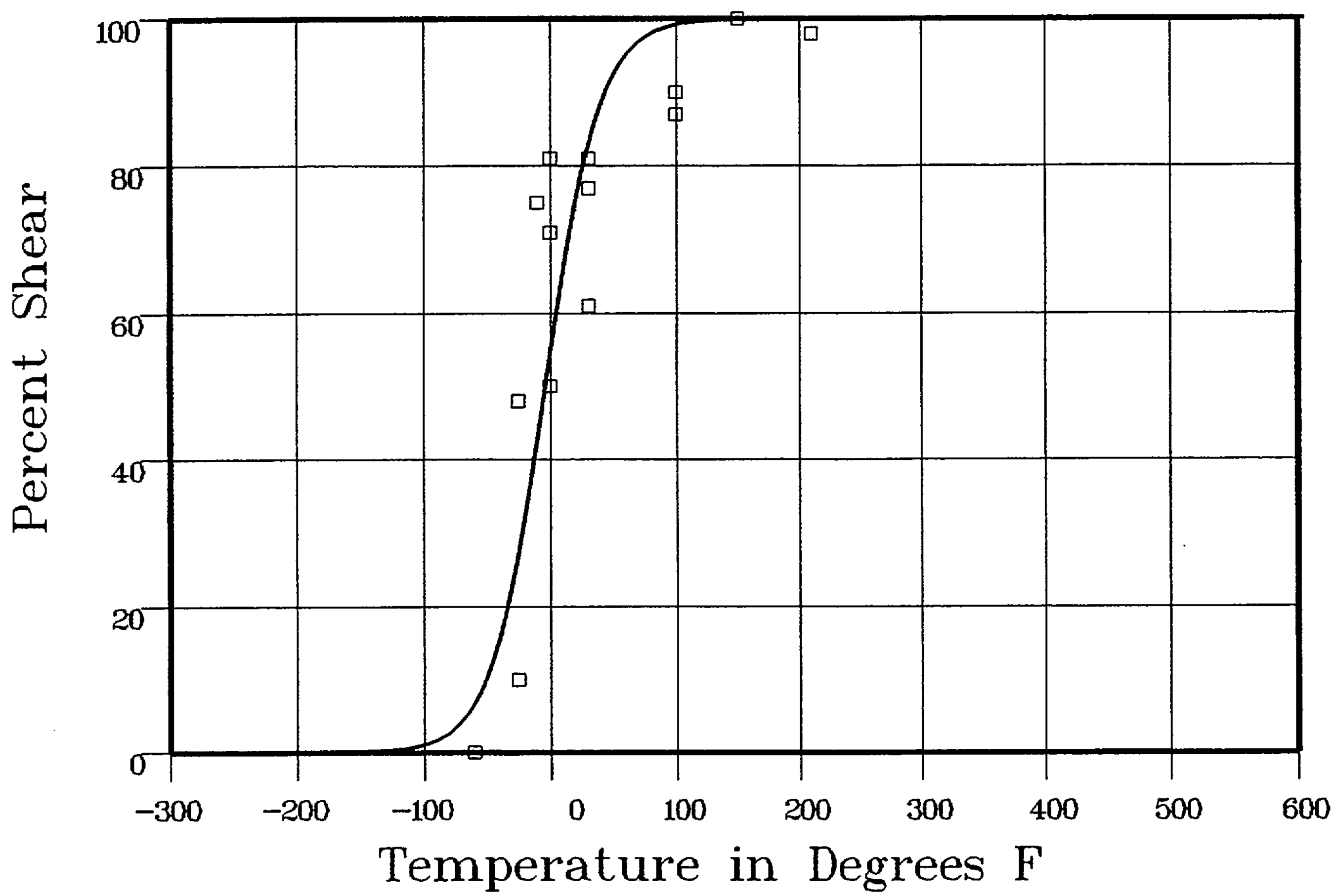
A = 50	B = 50	C = 42.71	T0 = -8.7

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

Temperature at 50% Shear: -8.7

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: UNIRR Material: WELD LINDE 91 Ori.: Heat #: 83642

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-60	0	8.3	-8.3
-60	0	8.3	-8.3
-25	10	31.79	-21.79
-25	10	31.79	-21.79
-25	48	31.79	16.2
-10	75	48.47	26.52
0	50	60.04	-10.04
0	81	60.04	20.95
0	71	60.04	10.95

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

UNIRRADIATED (WELD)

Page 2

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
30	77	85.96	-8.96
30	81	85.96	-4.96
30	61	85.96	-24.96
100	90	99.38	-9.38
100	87	99.38	-12.38
150	100	99.94	.05
210	98	99.99	-1.99
210	98	99.99	-1.99
210	98	99.99	-1.99

SUM of RESIDUALS = -62.2

CAPSULE U (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:31:28 on 02-06-2001

Page 1

Coefficients of Curve 2

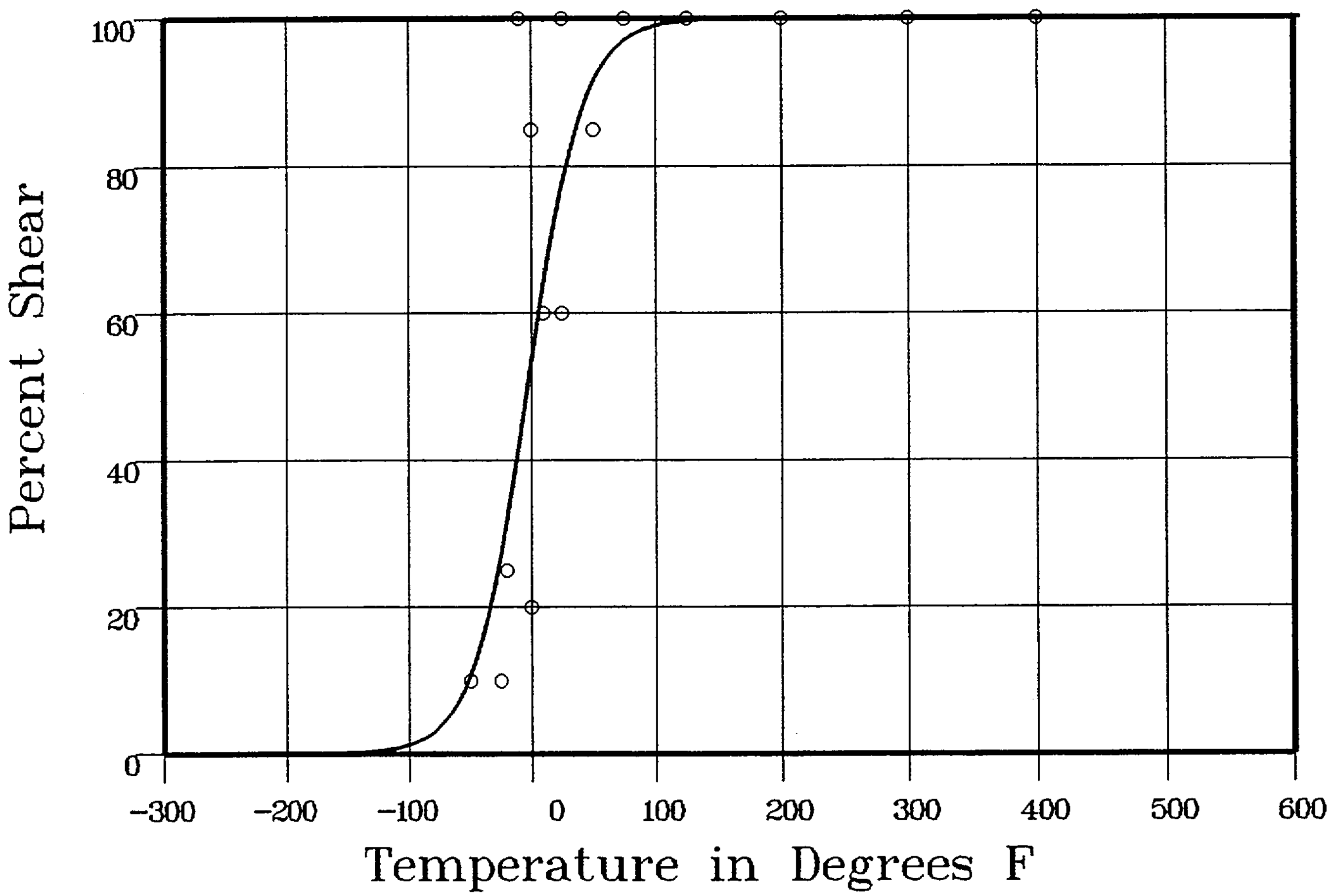
A = 50	B = 50	C = 44.54	T0 = -7.5

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

Temperature at 50% Shear: -7.5

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: U Material: WELD LINDE 91 Ori.: Heat #: 83642

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	10	12.91	-2.91
-25	10	31.3	-21.3
-20	25	36.32	-11.32
-10	100	47.19	52.8
0	20	58.33	-38.33
0	85	58.33	26.66
10	60	68.69	-8.69
25	100	81.14	18.85

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

CAPSULE U (WELD)

Page 2

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25	60	81.14	-21.14
50	85	92.96	-7.96
75	100	97.59	2.4
125	100	99.73	.26
200	100	99.99	0
300	100	99.99	0
400	100	100	0

SUM of RESIDUALS = -10.69

CAPSULE V (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:31:28 on 02-06-2001
Page 1
Coefficients of Curve 3

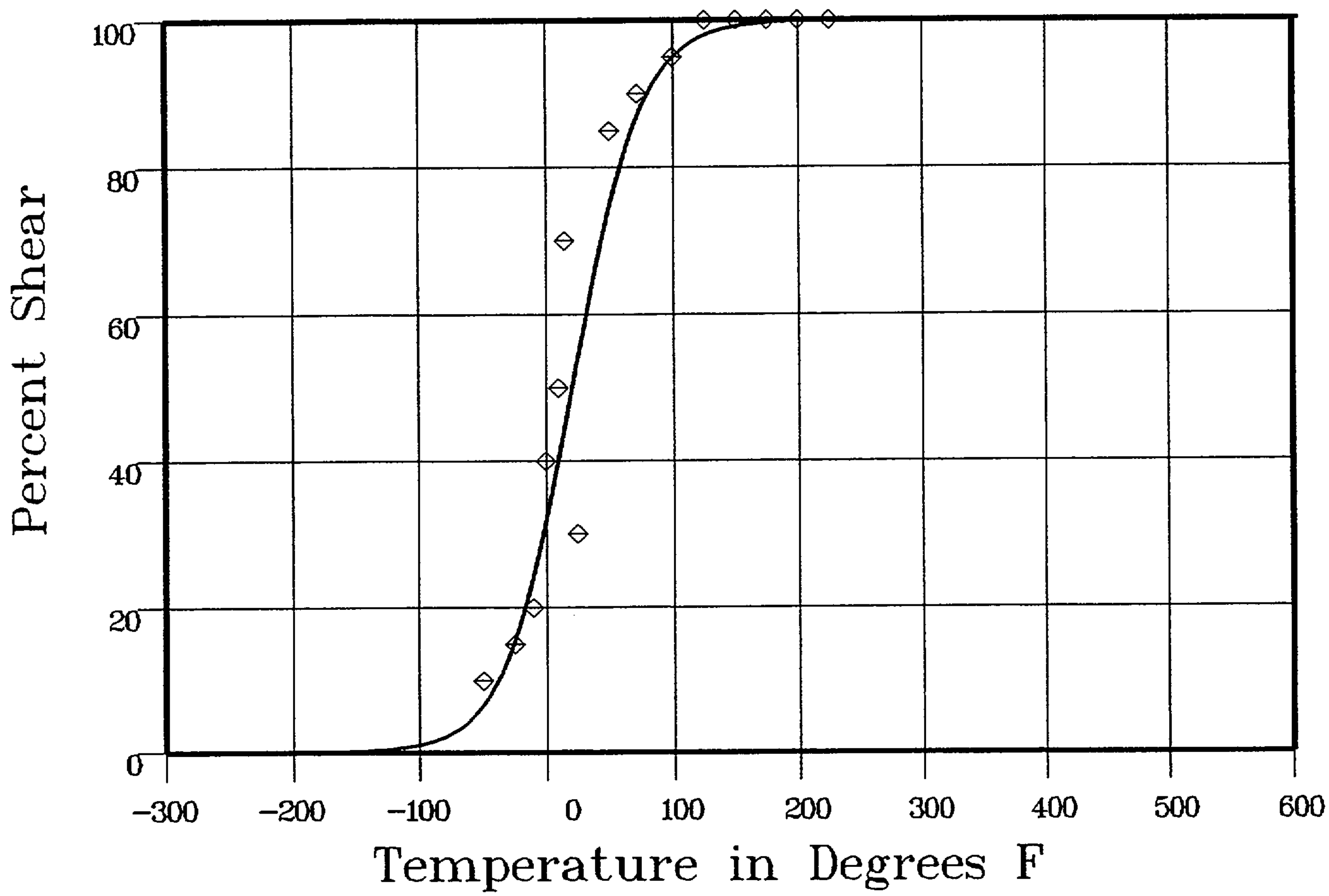
A = 50	B = 50	C = 53.83	T0 = 15.93

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

Temperature at 50% Shear: 15.9

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted
Plant: BV2 Cap.: V Material: WELD LINDE 91 Ori.: Heat #: 83642

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	10	7.94	2.05
-25	15	17.93	-2.93
-10	20	27.61	-7.61
0	40	35.61	4.38
10	50	44.5	5.49
15	70	49.12	20.87
25	30	58.33	-28.33
50	85	77.99	7

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

CAPSULE V (WELD)

Page 2

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
72	90	88.92	1.07
100	95	95.78	-.78
125	100	98.29	1.7
150	100	99.31	.68
175	100	99.72	.27
200	100	99.89	.1
225	100	99.95	.04

SUM of RESIDUALS = 4.02

CAPSULE W (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:31:28 on 02-06-2001
Page 1
Coefficients of Curve 4

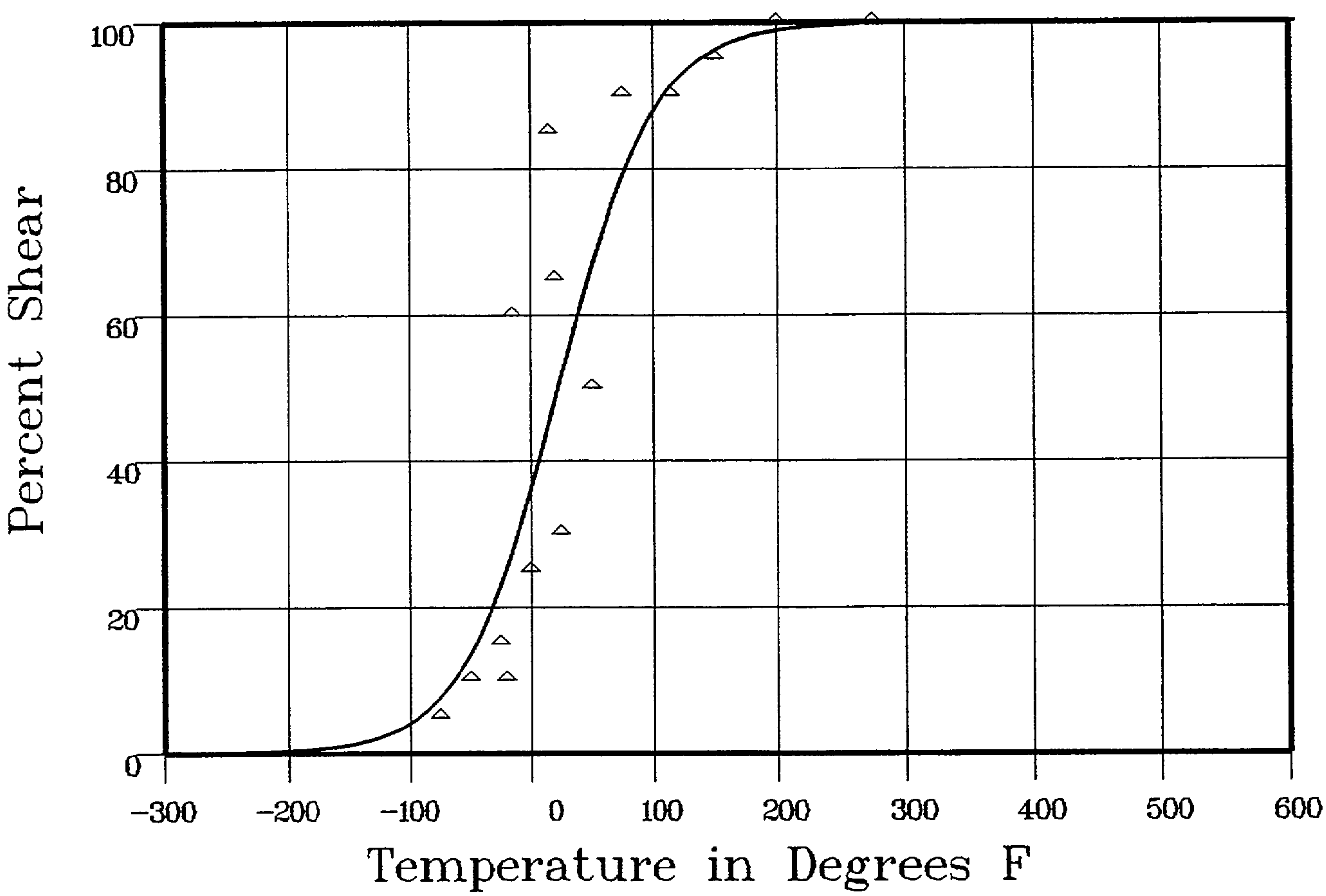
A = 50	B = 50	C = 78.64	T0 = 17.81

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

Temperature at 50% Shear: 17.8

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted
Plant: BV2 Cap.: W Material: WELD LINDE 91 Ori.: Heat #: 83642

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75	5	8.62	-3.62
-50	10	15.12	-5.12
-25	15	25.18	-10.18
-20	10	27.65	-17.65
-15	60	30.27	29.72
0	25	38.86	-13.86
15	85	48.21	36.78

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

CAPSULE W (WELD)

Page 2

Material: WELD LINDE 91 Heat Number: 83642 Orientation:

Capsule: W Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
20	65	51.39	13.6
25	30	54.55	-24.55
50	50	69.39	-19.39
75	90	81.06	8.93
115	90	92.21	-2.21
150	95	96.64	-1.64
200	100	99.03	.96
275	100	99.85	.14

SUM of RESIDUALS = -8.1

UNIRRADIATED (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:42:58 on 02-06-2001

Page 1

Coefficients of Curve 1

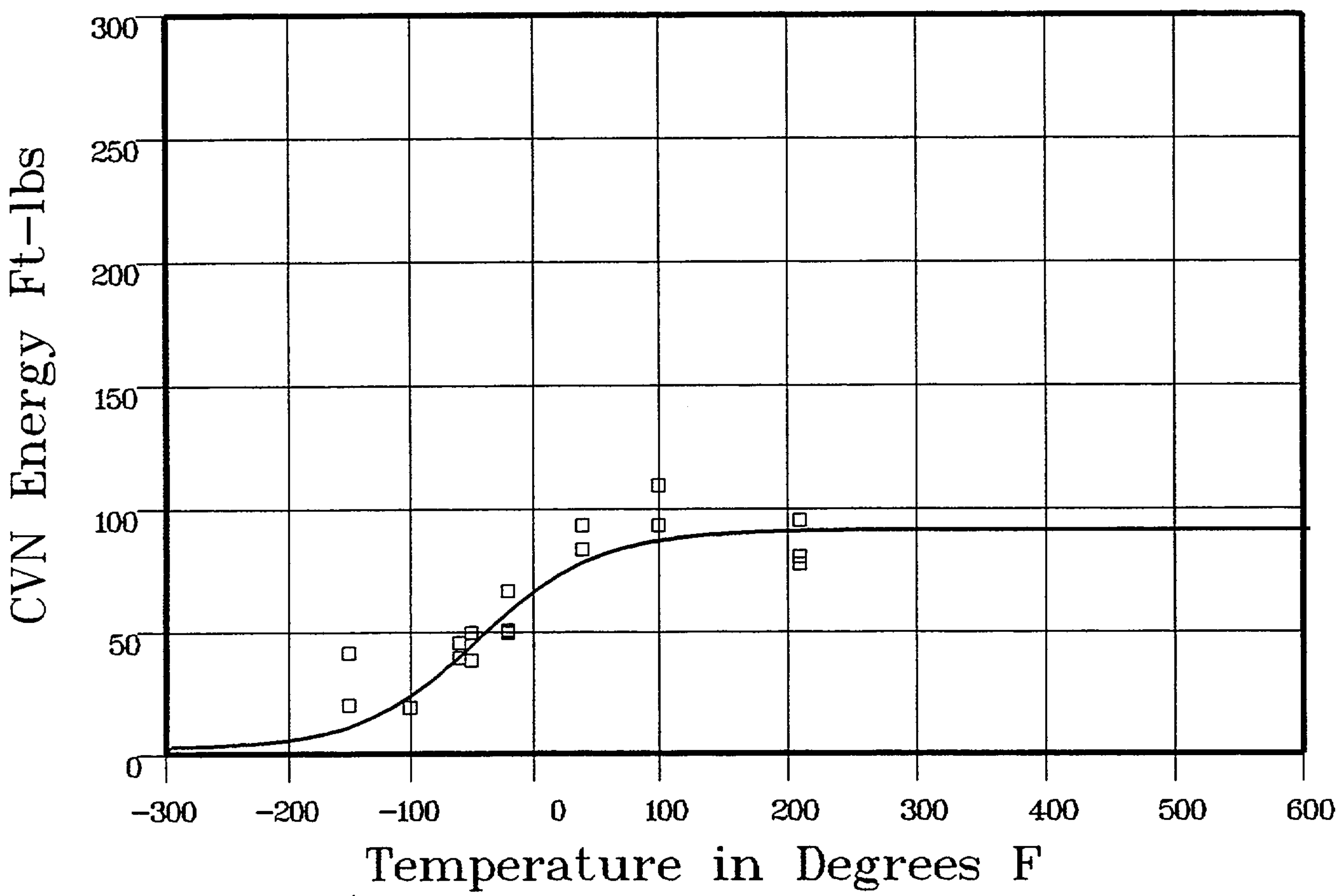
A = 46.59	B = 44.4	C = 97.1	T0 = -49.21

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

Upper Shelf Energy: 91 Fixed Temp. at 30 ft-lbs: -87.3 Temp. at 50 ft-lbs: -41.7 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: UNIRR Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-150	41	12.09	28.9
-150	20	12.09	7.9
-100	19	25.28	-6.28
-100	19	25.28	-6.28
-60	45	41.69	3.3
-60	39	41.69	-2.69
-50	38	46.24	-8.24
-50	49	46.24	2.75
-20	49	59.57	-10.57

**** 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	50	59.57	-9.57
-20	66	59.57	6.42
40	93	78.8	14.19
40	83	78.8	4.19
100	109	87.07	21.92
100	93	87.07	5.92
210	77	90.57	-13.57
210	80	90.57	-10.57
210	95	90.57	4.42

SUM of RESIDUALS = 32.16

CAPSULE U (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:42:58 on 02-06-2001

Page 1

Coefficients of Curve 2

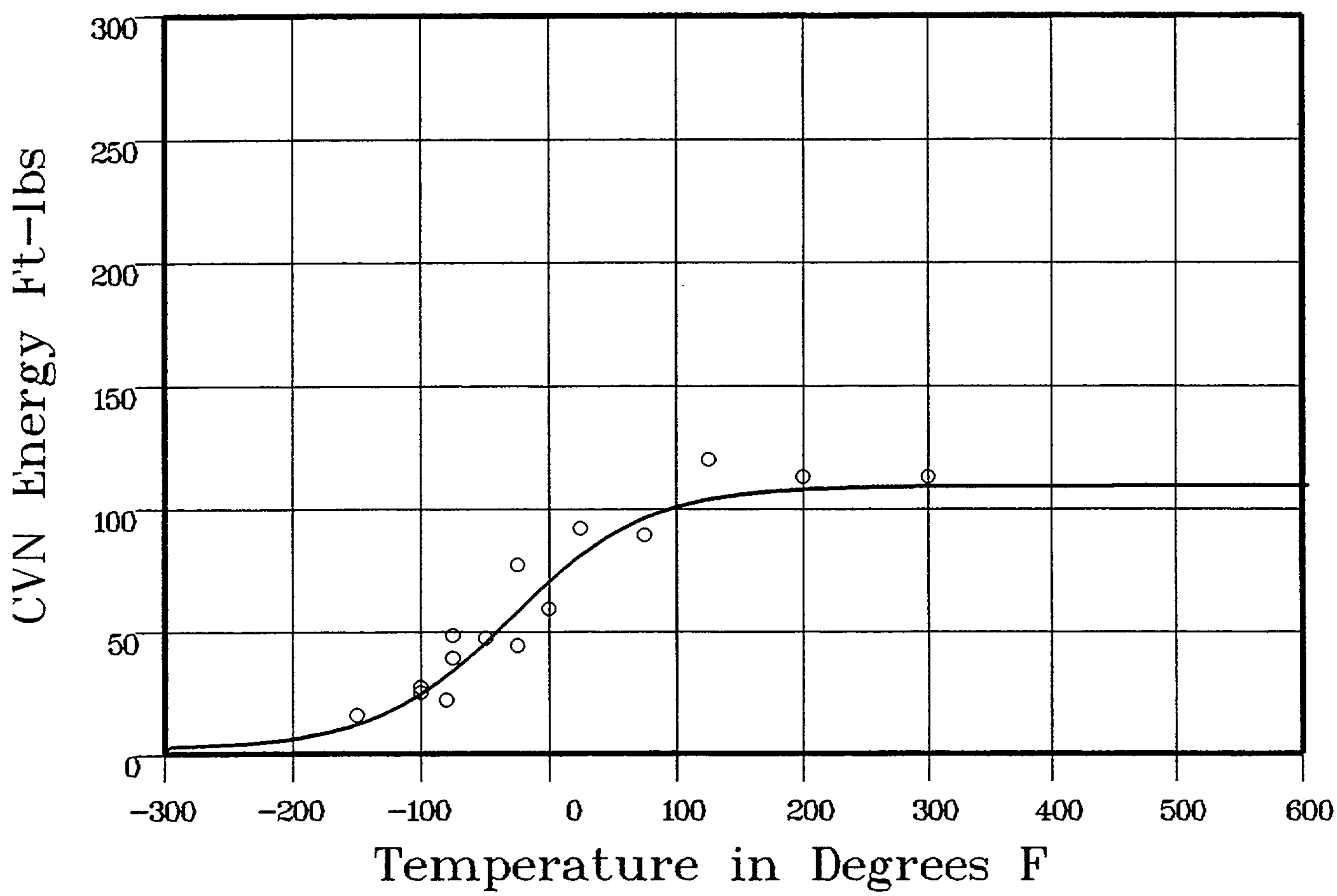
A = 55.59	B = 53.4	C = 105.95	T0 = -33.95

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

pper Shelf Energy: 109 Fixed Temp. at 30 ft-lbs: -89.2 Temp. at 50 ft-lbs: -45.1 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: U Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-150	16	12.94	3.05
-100	25	26.04	-1.04
-100	27	26.04	.95
-80	22	33.75	-11.75
-75	39	35.88	3.11
-75	48	35.88	12.11
-50	47	47.57	-.57
-25	77	60.1	16.89

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

CAPSULE U (HAZ)

Page 2

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	44	60.1	-16.1
0	59	72.14	-13.14
25	92	82.58	9.41
75	89	96.89	-7.89
125	120	103.93	16.06
200	113	107.72	5.27
300	113	108.8	4.19

SUM of RESIDUALS = 20.57

CAPSULE V (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:42:58 on 02-06-2001

Page 1

Coefficients of Curve 3

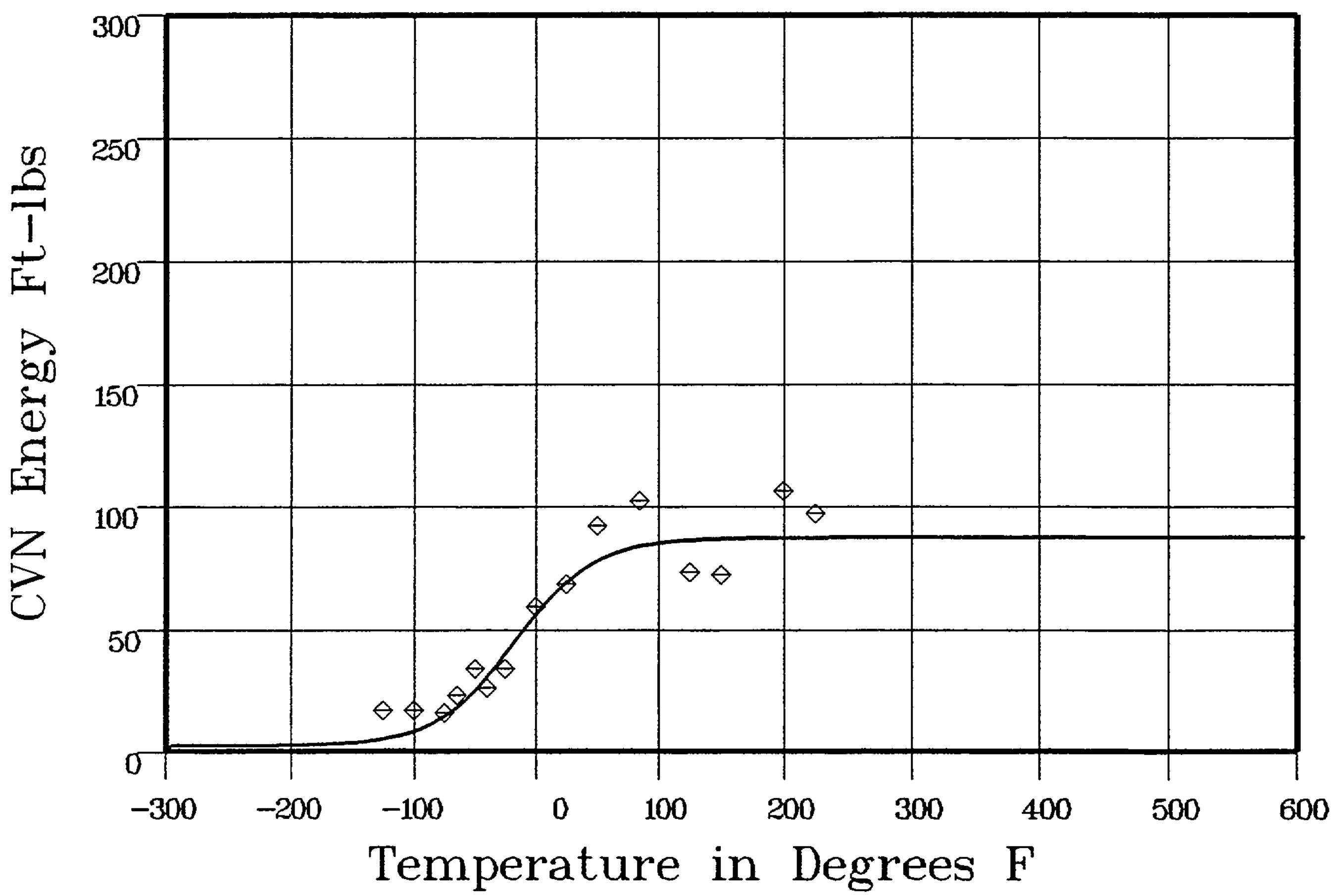
A = 44.59	B = 42.4	C = 65.18	T0 = -22.5

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

Upper Shelf Energy: 87 Fixed Temp. at 30 ft-lbs: -45.9 Temp. at 50 ft-lbs: -14.1 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: V Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-125	17	5.7	11.29
-100	17	9.39	7.6
-75	16	16.31	-.31
-65	23	20.3	2.69
-50	34	27.7	6.29
-40	26	33.48	-7.48
-25	34	42.97	-8.97
0	59	58.68	.31

**** 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
25	68	70.98	-2.98
50	92	78.72	13.27
85	102	83.97	18.02
125	73	86.09	-13.09
150	72	86.57	-14.57
200	106	86.9	19.09
225	97	86.95	10.04

SUM of RESIDUALS = 41.21

CAPSULE W (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:42:58 on 02-06-2001

Page 1

Coefficients of Curve 4

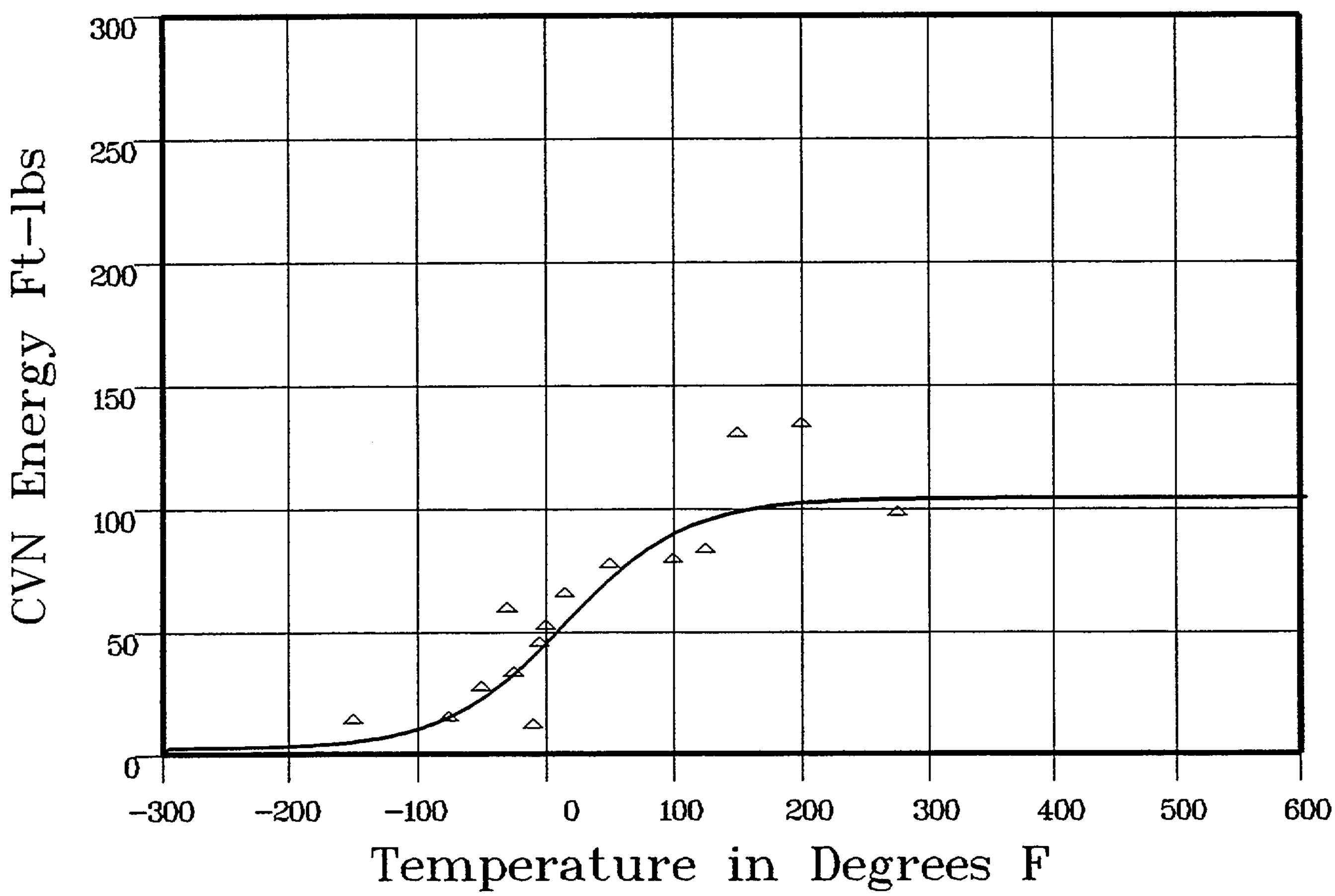
A = 53.09	B = 50.9	C = 94.24	T0 = 10.3

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

pper Shelf Energy: 104 Fixed   Temp. at 30 ft-lbs: -35.8   Temp. at 50 ft-lbs: 4.5   Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: W   Total Fluence:



Data Set(s) Plotted

Plant: BV2   Cap.: W   Material: HEAT AFFD ZONE   Ori.:   Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-150	13	5.48	7.51
-75	14	16.51	-2.51
-50	26	24.35	1.64
-30	58	32.57	25.42
-25	32	34.87	-2.87
-10	11	42.3	-31.3
-5	44	44.9	-.9

**** 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 CVN Energy	Computed CVN Energy	Differential
0	51	47.55	3.44
15	64	55.63	8.36
50	76	73.35	2.64
100	78	90.79	-12.79
125	82	95.79	-13.79
150	129	99	29.99
200	133	102.21	30.78
275	97	103.63	-6.63

SUM of RESIDUALS = 39

UNIRRADIATED (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve   Printed at 09:47:12 on 02-06-2001

Page 1

Coefficients of Curve 1

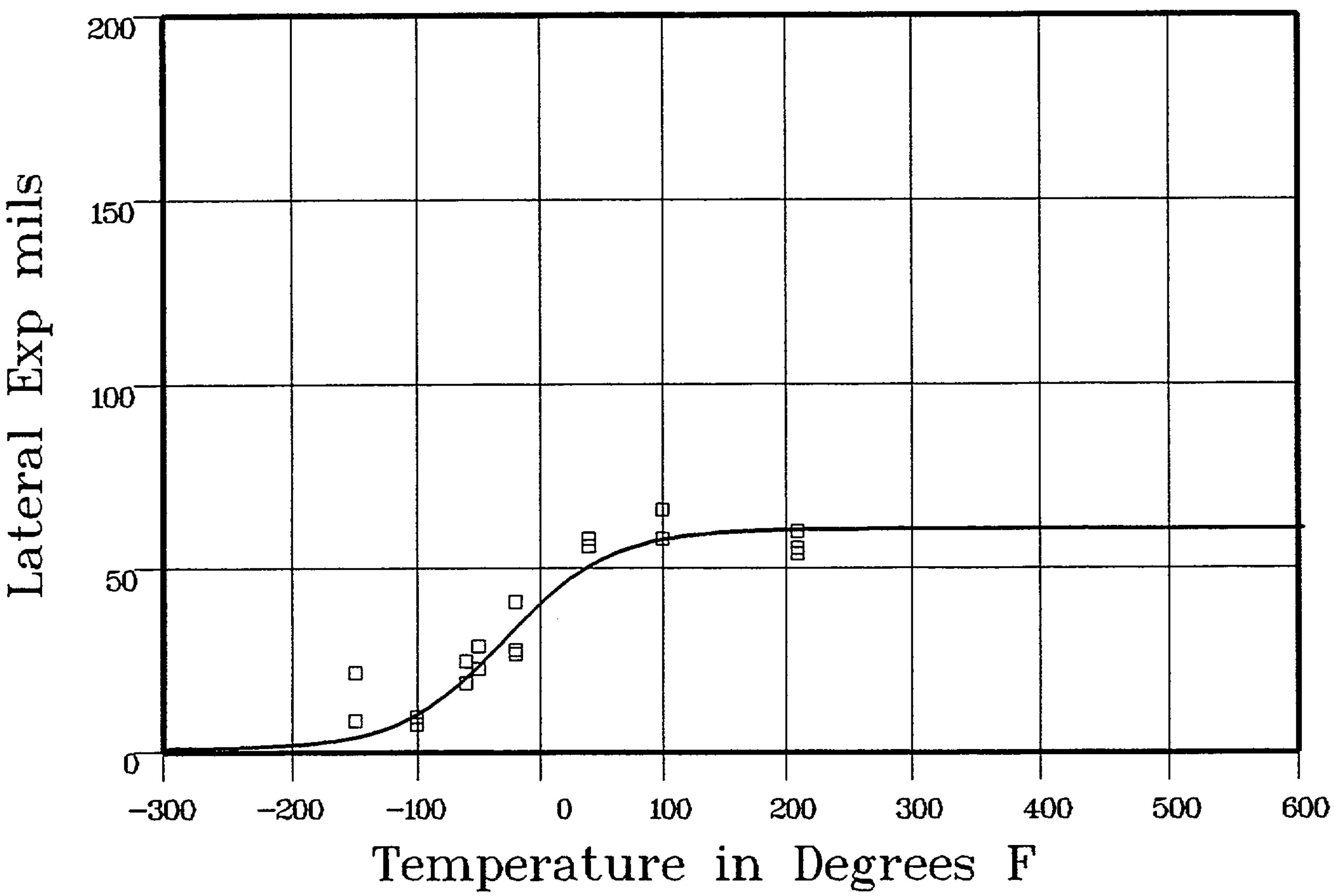
A = 30.87	B = 29.87	C = 86.51	T0 = -33.75

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

Upper Shelf L.E.: 60.74   Temperature at L.E. 35: -21.7   Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: UNIRR   Total Fluence:



Data Set(s) Plotted

Plant: BV2   Cap.: UNIRR   Material: HEAT AFFD ZONE   Ori.:   Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-150	9	4.8	4.19
-150	22	4.8	17.19
-100	8	11.62	-3.62
-100	10	11.62	-1.62
-60	25	22.07	2.92
-60	19	22.07	-3.07
-50	23	25.32	-2.32
-50	29	25.32	3.67
-20	27	35.57	-8.57

**** 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
-20	28	35.57	-7.57
-20	41	35.57	5.42
40	56	51.55	4.44
40	58	51.55	6.44
100	66	58.14	7.85
100	58	58.14	-.14
210	54	60.52	-6.52
210	55.5	60.52	-5.02
210	60	60.52	-.52

SUM of RESIDUALS = 13.12

CAPSULE U (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:47:12 on 02-06-2001

Page 1

Coefficients of Curve 2

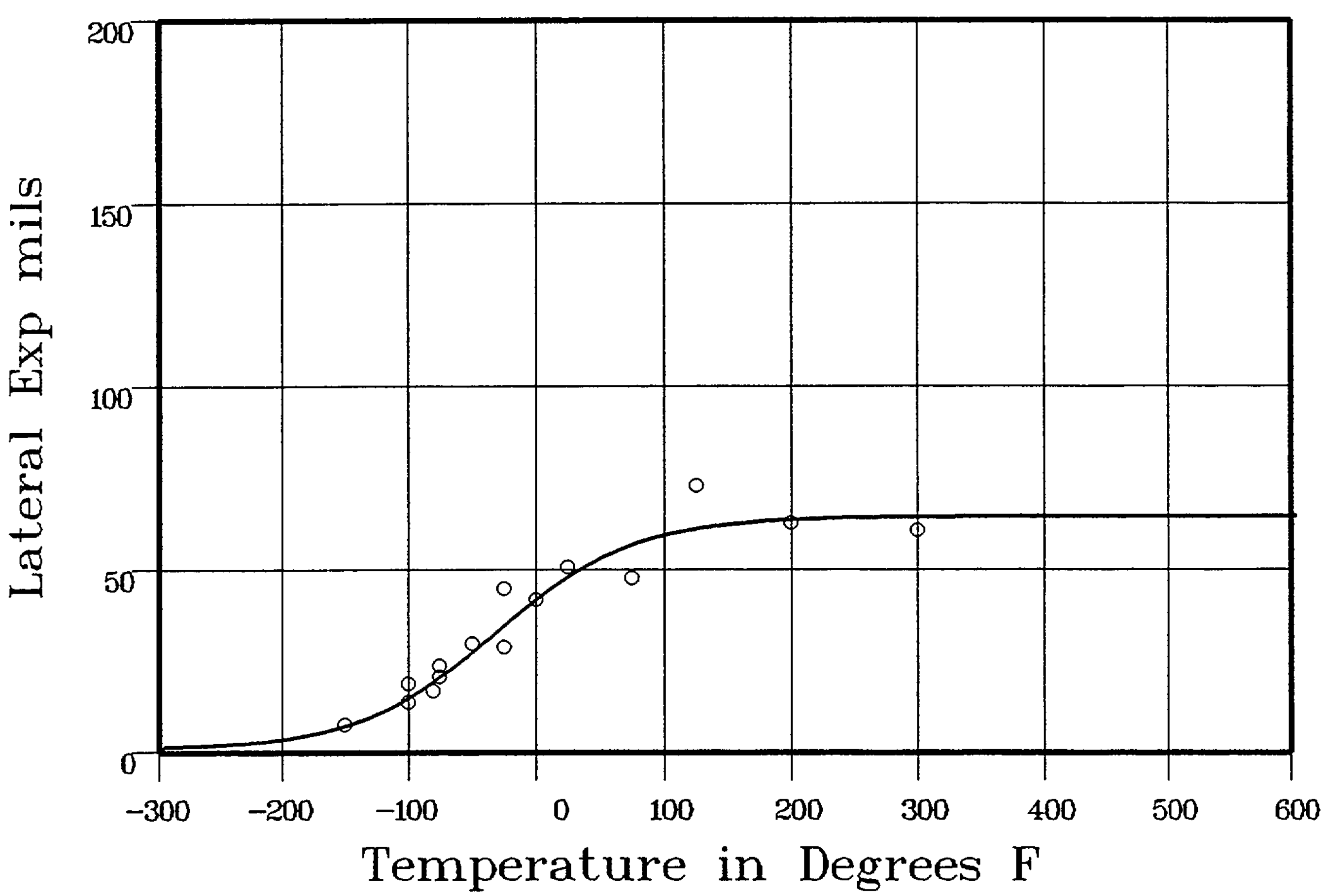
A = 32.81	B = 31.81	C = 108.08	T0 = -36.56

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

Upper Shelf L.E.: 64.63 Temperature at L.E. 35: -29.1 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: U Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-150	8	7.94	.05
-100	19	16.02	2.97
-100	14	16.02	-2.02
-80	17	20.67	-3.67
-75	21	21.95	-.95
-75	24	21.95	2.04
-50	30	28.88	1.11
-25	45	36.2	8.79

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

CAPSULE U (HAZ)

Page 2

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

Capsule: U   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	29	36.2	-7.2
0	42	43.18	-1.18
25	51	49.2	1.79
75	48	57.46	-9.46
125	73	61.58	11.41
200	63	63.84	-.84
300	61	64.51	-3.51

SUM of RESIDUALS = -.7

CAPSULE V (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:47:12 on 02-06-2001
Page 1
Coefficients of Curve 3

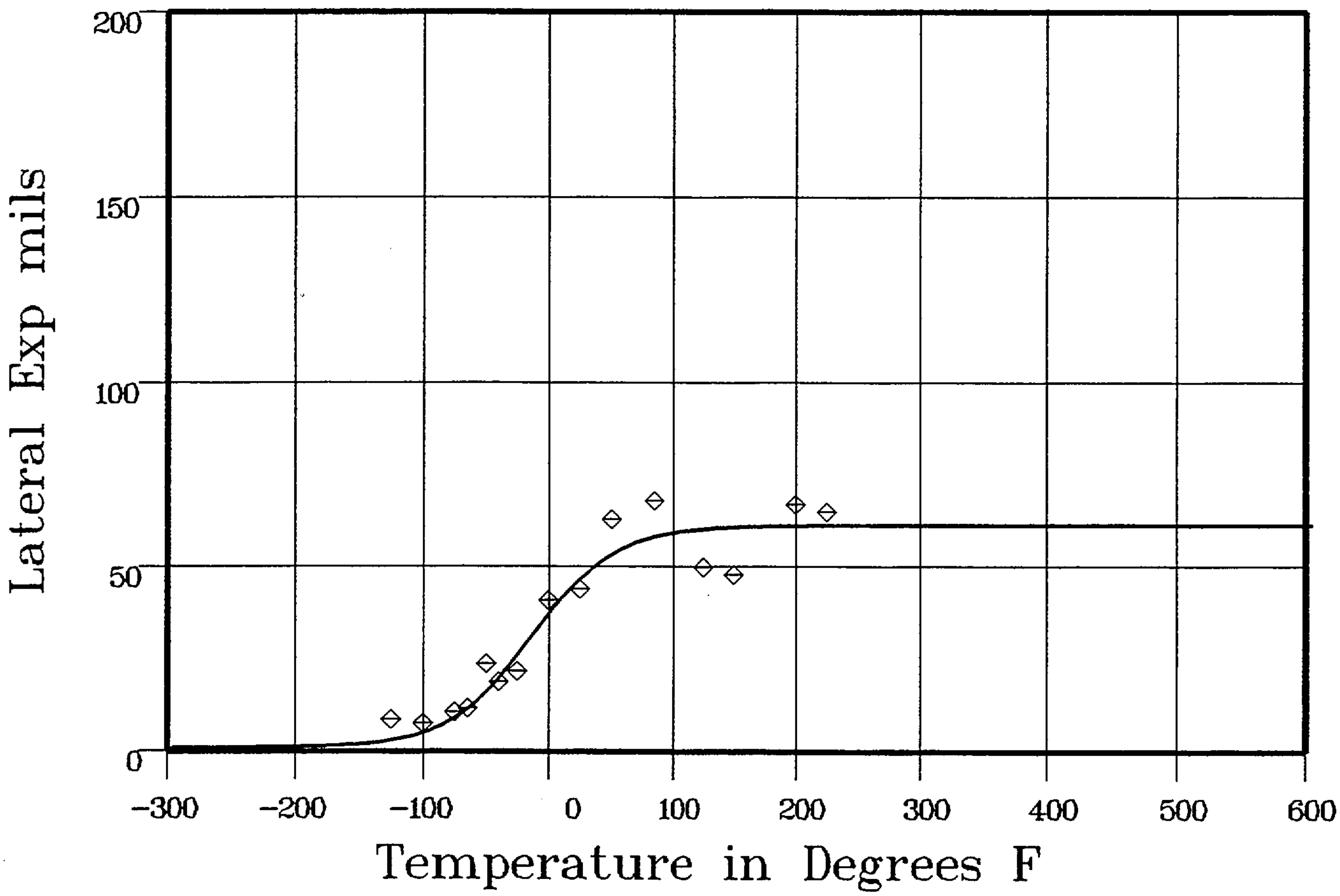
A = 31.13	B = 30.13	C = 67.41	T0 = -18.75

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

Upper Shelf L.E.: 61.26   Temperature at L.E. 35: -10   Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: V   Total Fluence:



Data Set(s) Plotted
Plant: BV2   Cap.: V   Material: HEAT AFFD ZONE   Ori.:   Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-125	9	3.47	5.52
-100	8	5.96	2.03
-75	11	10.55	.44
-65	12	13.19	-1.19
-50	24	18.08	5.91
-40	19	21.93	-2.93
-25	22	28.34	-6.34
0	41	39.3	1.69

**** 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
25	44	48.33	-4.33
50	63	54.32	8.67
85	68	58.6	9.39
125	50	60.42	-10.42
150	48	60.86	-12.86
200	67	61.16	5.83
225	65	61.21	3.78

SUM of RESIDUALS = 5.2

CAPSULE W (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:47:12 on 02-06-2001

Page 1

Coefficients of Curve 4

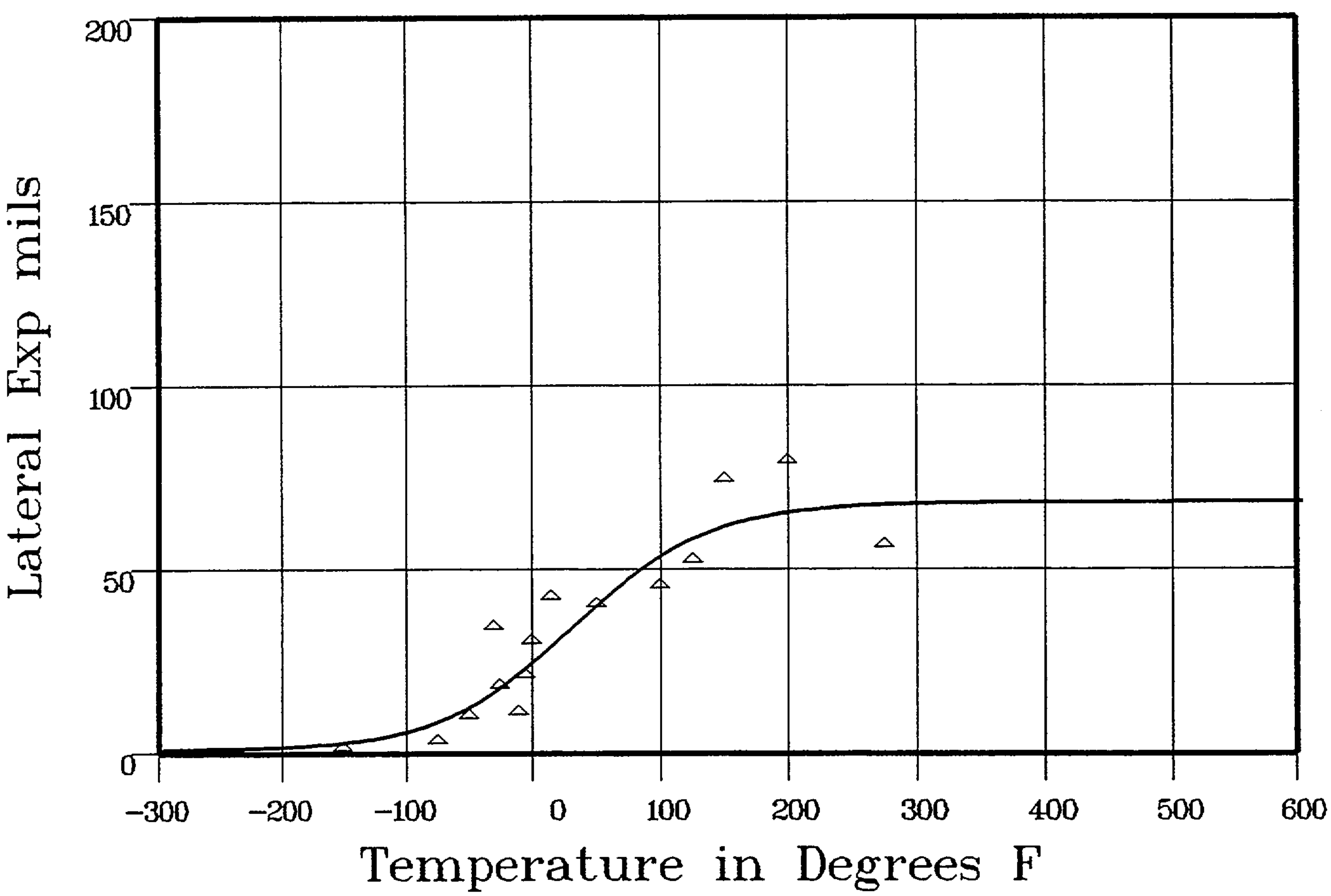
A = 34.63	B = 33.63	C = 106.04	T0 = 27.18

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

Upper Shelf L.E.: 68.27 Temperature at L.E. 35: 28.3 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: W Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-150	1	3.29	-2.29
-75	3	9.54	-6.54
-50	10	13.72	-3.72
-30	34	18.07	15.92
-25	18	19.3	-1.3
-10	11	23.3	-12.3
-5	21	24.73	-3.73

**** 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 Lateral Expansion	Computed LE.	Differential
0	30	26.19	3.8
15	42	30.79	11.2
50	40	41.76	-1.76
100	45	54.68	-9.68
125	52	59.09	-7.09
150	74	62.23	11.76
200	79	65.78	13.21
275	56	67.65	-11.65

SUM of RESIDUALS = -4.2

UNIRRADIATED (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:50:44 on 02-06-2001

Page 1

Coefficients of Curve 1

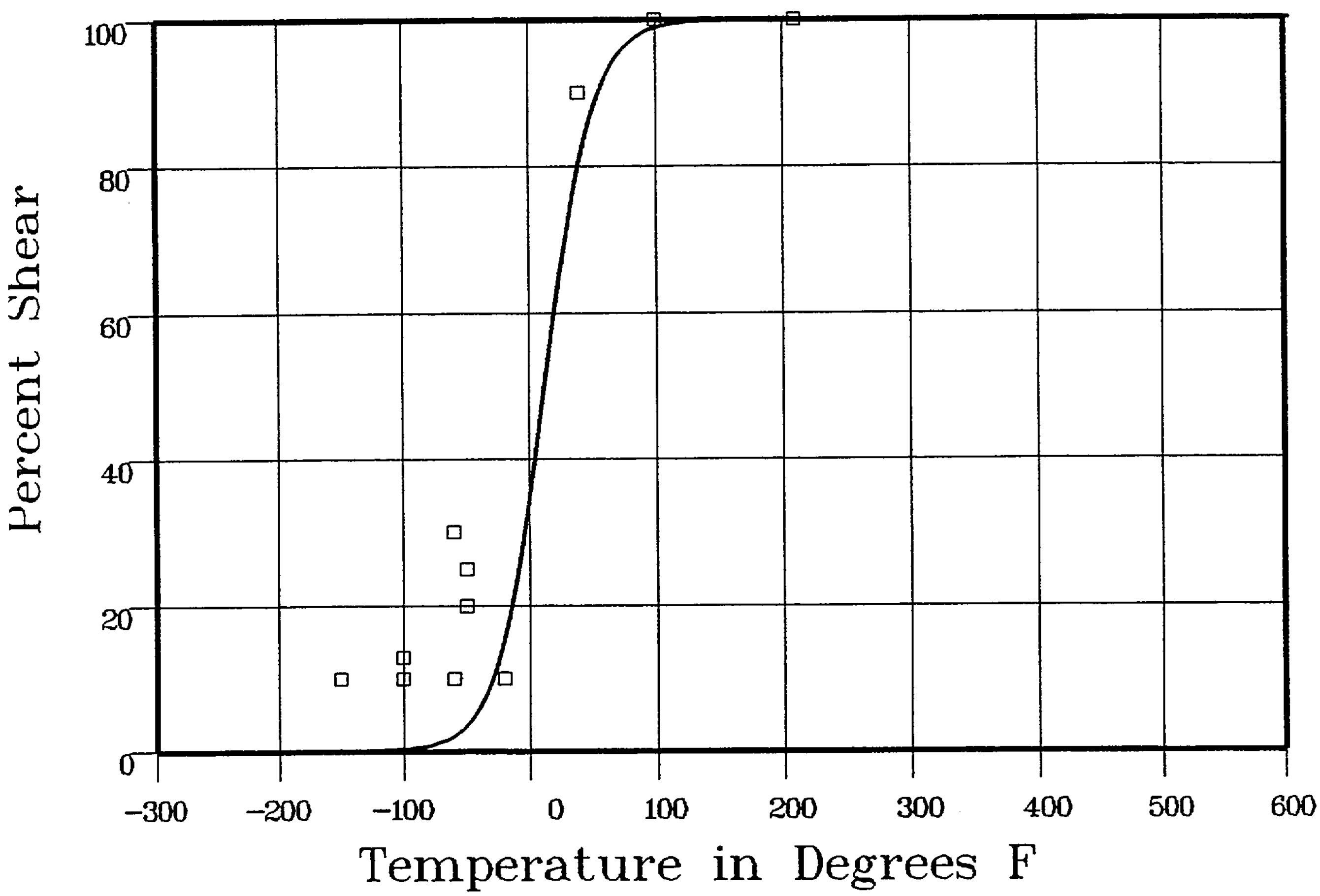
A = 50	B = 50	C = 38.44	T0 = 7.96

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

Temperature at 50% Shear: 7.9

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: UNIRR   Total Fluence:



Data Set(s) Plotted

Plant: BV2   Cap.: UNIRR   Material: HEAT AFFD ZONE   Ori.:   Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-150	10	.02	9.97
-150	10	.02	9.97
-100	10	.36	9.63
-100	13	.36	12.63
-60	30	2.82	27.17
-60	10	2.82	7.17
-50	20	4.67	15.32
-50	25	4.67	20.32
-20	10	18.92	-8.92

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

UNIRRADIATED (HAZ)

Page 2

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

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-20	10	18.92	-8.92
-20	10	18.92	-8.92
40	90	84.11	5.88
40	90	84.11	5.88
100	100	99.17	.82
100	100	99.17	.82
210	100	99.99	0
210	100	99.99	0
210	100	99.99	0

SUM of RESIDUALS = 98.89

CAPSULE U (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:50:44 on 02-06-2001

Page 1

Coefficients of Curve 2

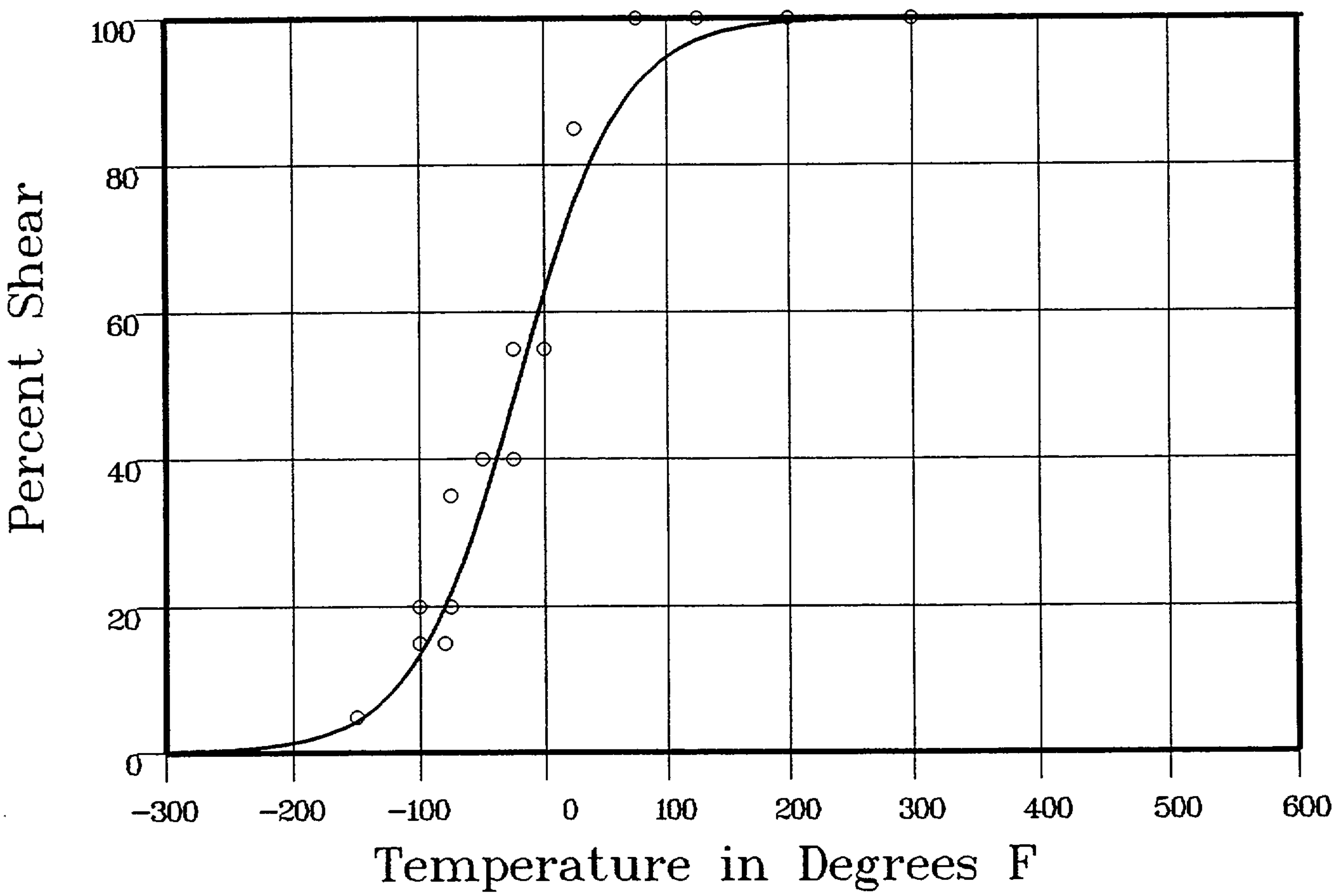
A = 50	B = 50	C = 84.1	T0 = -26.25

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

Temperature at 50% Shear: -26.2

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: U Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-150	5	5	0
-100	15	14.75	.24
-100	20	14.75	5.24
-80	15	21.78	-6.78
-75	20	23.88	-3.88
-75	35	23.88	11.11
-50	40	36.24	3.75
-25	55	50.74	4.25

**** 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 Percent Shear	Computed Percent Shear	Differential
-25	40	50.74	-10.74
0	55	65.11	-10.11
25	85	77.18	7.81
75	100	91.74	8.25
125	100	97.33	2.66
200	100	99.54	.45
300	100	99.95	.04

SUM of RESIDUALS = 12.32

CAPSULE V (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:50:44 on 02-06-2001

Page 1

Coefficients of Curve 3

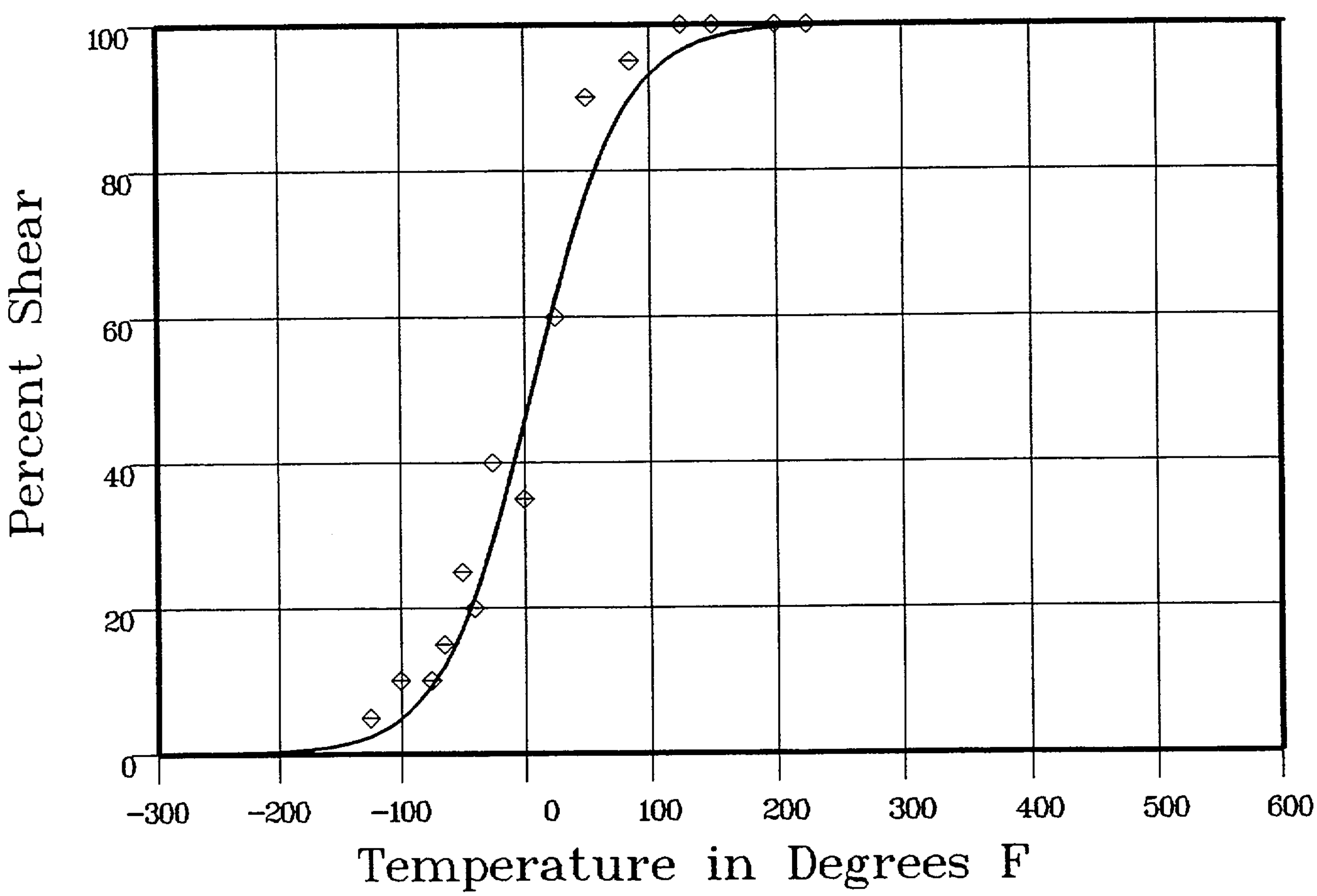
A = 50	B = 50	C = 71.89	T0 = 1.87

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

Temperature at 50% Shear: 1.8

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap: V Material: HEAT AFFD ZONE Ori: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-125	5	2.84	2.15
-100	10	5.55	4.44
-75	10	10.54	-.54
-65	15	13.46	1.53
-50	25	19.1	5.89
-40	20	23.77	-3.77
-25	40	32.13	7.86
0	35	48.69	-13.69

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

CAPSULE V (HAZ)

Page 2

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: V   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25	60	65.55	-5.55
50	90	79.22	10.77
85	95	90.99	4
125	100	96.84	3.15
150	100	98.4	1.59
200	100	99.59	.4
225	100	99.79	.2

SUM of RESIDUALS = 18.46

CAPSULE W (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:50:44 on 02-06-2001

Page 1

Coefficients of Curve 4

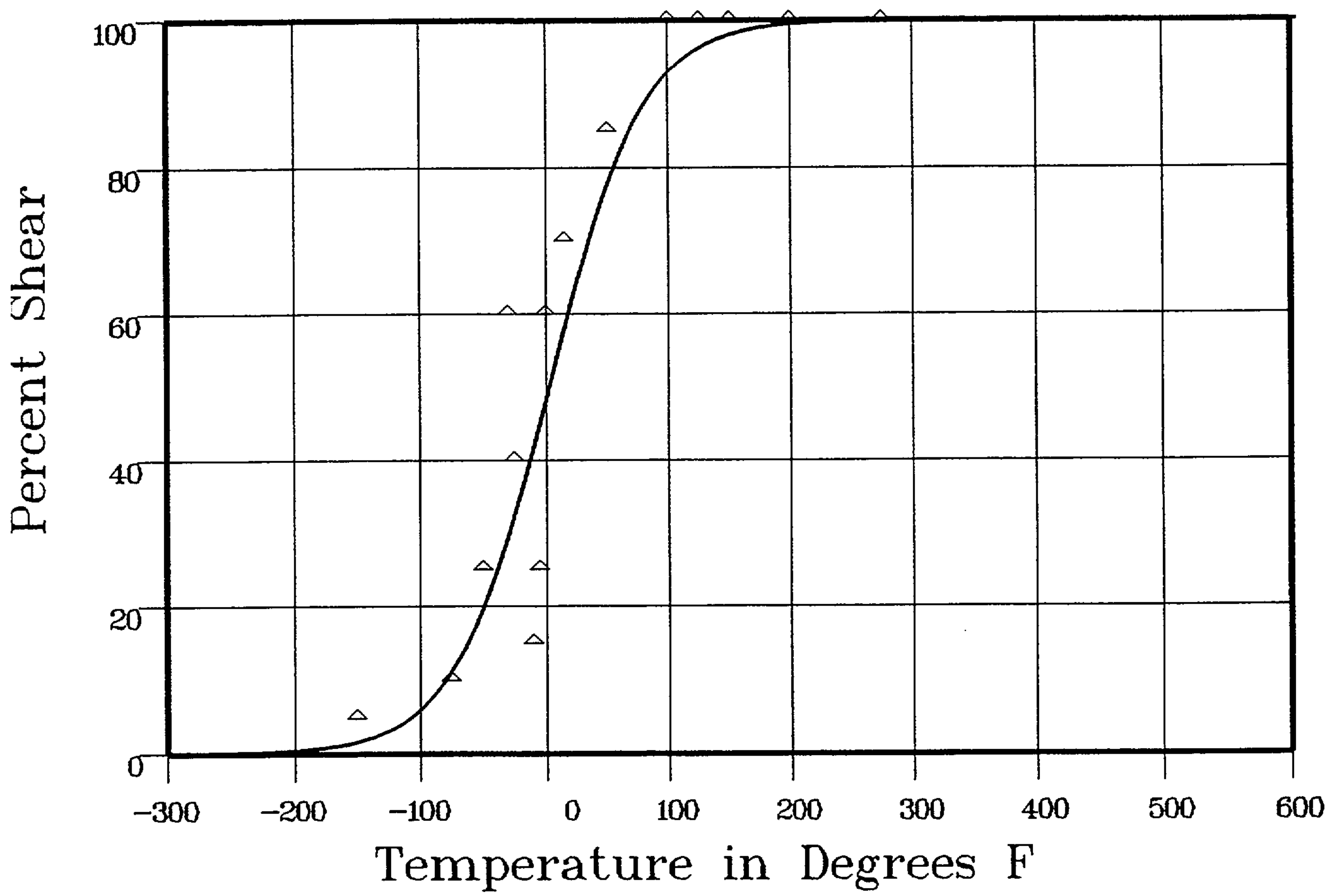
A = 50	B = 50	C = 75.28	T0 = -1.87

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

Temperature at 50% Shear: -1.8

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: W Total Fluence:



Data Set(s) Plotted

Plant: BV2 Cap.: W Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-150	5	1.91	3.08
-75	10	12.53	-2.53
-50	25	21.78	3.21
-30	60	32.14	27.85
-25	40	35.1	4.89
-10	15	44.62	-29.62
-5	25	47.92	-22.92

**** 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
0	60	51.24	8.75
15	70	61.02	8.97
50	85	79.86	5.13
100	100	93.74	6.25
125	100	96.67	3.32
150	100	98.26	1.73
200	100	99.53	.46
275	100	99.93	.06

SUM of RESIDUALS = 18.67

APPENDIX C

BEAVER VALLEY UNIT 2 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 three surveillance capsules removed from the Beaver Valley Unit 2 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 of Regulatory Guide 1.99, Revision 2, to the Beaver Valley Unit 2 reactor vessel surveillance data and determine if the Beaver Valley Unit 2 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 2 reactor vessel consists of the following beltline region materials:

1. Intermediate Shell Plate B9004-1 (Heat # C0544-1)
2. Intermediate Shell Plate B9004-2 (Heat # C0544-2)
3. Lower Shell Plate B9005-1 (Heat # C1408-2)
4. Lower Shell Plate B9005-2 (Heat # C1408-1)
5. Intermediate Shell Longitudinal Weld Seams 101-124 A & B
   (Wire Heat 83642, Linde 0091, Flux Lot NO. 3536)
6. Intermediate to Lower Shell Circumferential Weld Seam 101-171
   (Wire Heat 83642, Linde 0091, Flux Lot NO. 3536)

7. Lower Shell Longitudinal Weld Seams 101-142 A & B (Wire Heat 83642, Linde 0091, Flux Lot NO. 3536)

Per WCAP-9615 Rev. 1[1], the Beaver Valley Unit 2 surveillance program was based on ASTM E185-73, "Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels". Per Section 4.1 of ASTM E185-73, "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. The test material should be selected on the basis of initial transition temperature, upper shelf energy level, and estimated increase in transition temperature considering chemical composition (copper (CU) and phosphorus (P)) and neutron fluence."

Therefore, at the time the Beaver Valley Unit 2 surveillance capsule program was developed, intermediate shell plate B9004-2 was judged to be most limiting based on it having the lowest initial USE and was utilized in the surveillance program.

The surveillance program weld for Beaver Valley Unit 2 was fabricated using the same heat of weld wire used to fabricate the intermediate and lower shell vertical seams and girth welds. The results of mechanical property tests performed on the surveillance weld are considered to be representative of the property changes expected in the reactor vessel beltline seams.

Therefore, the materials selected for use in the Beaver Valley Unit 2 surveillance program were those judged to be most likely controlling with regard to radiation embrittlement according to the accepted methodology at the time the surveillance program was developed. The Beaver Valley Unit 2 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 B 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 2 surveillance materials unambiguously. Hence, the Beaver Valley Unit 2 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.
Following is the calculation of the best fit line as described in Regulatory Position 2.1 of Regulatory Guide 1.99, Revision 2.

TABLE C-1
Calculation of Chemistry Factors using Beaver Valley Units 2 Surveillance Capsule Data

Material	Capsule	Capsule f(a)	FF(b)	ΔRT_{NDT}(c)	FF*ΔRT_{NDT}	FF^2
Intermediate Shell Plate B9004-2 (Longitudinal)	U	.608	.86	24.26	20.86	.74
	V	2.63	1.26	55.93	70.47	1.59
	W	3.625	1.335	71.04	94.83	1.78
Intermediate Shell Plate B9004-2 (Transverse)	U	.608	.86	17.56	15.10	.74
	V	2.64	1.26	46.27	58.30	1.59
	W	3.625	1.335	63.39	84.63	1.78
				SUM:	344.19	8.22
	$CF = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (344.19) \div (8.22) =$ **41.9 °F**					
Surveillance Weld Metal (Heat 83642)	U	.608	.86	3.64	3.13	.74
	V	2.64	1.26	25.47	32.09	1.59
	W	3.625	1.335	6.21	8.29	1.78
				SUM:	43.51	4.11
	$CF = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (43.51) \div (4.11) =$ **10.6°F**					

Notes:
(a) f = Measured fluence from capsule W dosimetry analysis results (x 10^{19} n/cm^2, E > 1.0 MeV)..
(b) FF = fluence factor = $f^{(0.28 - 0.1*\log f)}$.
(c) ΔRT_{NDT} values are the measured 30 ft-lb shift values (Appendix B) 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 C-2

Best Fit Evaluation for Beaver Valley Unit 2 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)
Intermediate Shell Plate B9004-2 (Longitudinal)	U	41.9	0.86	24.26	36.03	-11.77	YES
	V	41.9	1.26	55.93	52.79	3.14	YES
	W	41.9	1.335	71.04	55.94	15.1	YES
Intermediate Shell Plate B9004-2 (Transverse)	U	41.9	0.86	17.56	36.03	-18.47	NO
	V	41.9	1.26	46.27	52.79	-6.52	YES
	W	41.9	1.335	63.39	55.94	7.45	YES
Surveillance Weld Metal (Heat 83642)	U	10.6	0.86	3.64	9.12	-5.48	YES
	V	10.6	1.26	25.47	13.36	12.11	YES
	W	10.6	1.335	6.21	14.15	-7.94	YES

Notes:

(a) f = Measured fluence from capsule W dosimetry analysis results (x 10^{19} n/cm^2, E > 1.0 MeV). Ref. 25

(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) 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.

$$\text{Best Fit } \Delta RT_{NDT} = (\text{Slope}_{best\ fit}) * (\text{Fluence Factor})$$

From Table D-2 above, the Beaver Valley Unit 2 Plate Data has only one out of six data points outside the 17°F scatter band. The surveillance weld has all three data points within the 28°F scatter band.

Therefore based on engineering judgment, this criterion is met for the Beaver Valley Unit 2 surveillance material.

Criterion 4: The irradiation temperature of the Charpy specimens in the capsule should match the vessel wall temperature at the cladding/base metal interface within +/- 25°F.

The Beaver Valley Unit 2 capsule specimens are located in the reactor between the thermal shield and the vessel wall and are positioned opposite the center of the core. The test capsules are in baskets attached to the thermal shield. The location of the specimens with respect to the reactor vessel beltline provides assurance that the reactor vessel wall and the specimens experience equivalent operating conditions and will not differ by more than 25°F.

Criterion 5: The surveillance data for the correlation monitor material in the capsule should fall within the scatter band of the database for that material.

The Beaver Valley Unit 2 surveillance program does not contain correlation monitor material. Therefore, this criterion is not applicable to the Beaver Valley Unit 2 surveillance program.

CONCLUSION:

Based on the preceding responses to all five criteria of Regulatory Guide 1.99, Revision 2, Section B, and the application of engineering judgment, the Beaver Valley Unit 2 surveillance data is credible.