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Analysis of Capsule 38° from the Arizona Public Service Company Palo Verde Unit 1 Reactor Vessel Radiation Surveillance Program

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Westinghouse

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PREFACE

This report has been technically reviewed and verified by:

Reviewer:

Sections 1 through 5, 7, 8, Appendices A, B and C	Ed Terek	Ed Terek
Section 6	G.N Wrights	S.L. Anderson for G.N. Wrights

RECORD OF REVISON

Revision 0: Original Issue

Revision 1: Corrected the surveillance plate material from M-6701-2 to M-4311-1. Changes are throughout the Table of Contents, Main Text, Tables, Figures and Appendices. No changes were required to Sections 2, 3, 6, 7 and 8. Appendix C was eliminated.

EXECUTIVE SUMMARY

The purpose of this report is to document the results of the testing of surveillance capsule 38° from Palo Verde Unit 1. Capsule 38° was removed at 9.81 EFPY and post irradiation mechanical tests of the Charpy V-notch and tensile specimens was performed, along with a fluence evaluation based methodology and nuclear data including recently released neutron transport and dosimetry cross-section libraries derived from the ENDF/B-VI database. The calculated peak clad base/metal vessel fluence after 9.81 EFPY of plant operation was 4.65×10^{18} n/cm^2 and the surveillance Capsule 38° calculated fluence was 7.85×10^{18} n/cm^2. 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.

1 SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance capsule 38° the second capsule to be removed from the Palo Verde Unit 1 reactor pressure vessel, led to the following conclusions: (General Note: Temperatures are reported to two significant digits only to match CVGraph output.)

- The capsule received an average fast neutron calculated fluence (E > 1.0 MeV) of 7.85 x 10^{18} n/cm^2 after 9.81 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel lower shell plate M-4311-1 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction of the plate (longitudinal orientation), to 7.85 x 10^{18} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 21.58°F and a 50 ft-lb transition temperature increase of 30.06°F. This results in an irradiated 30 ft-lb transition temperature of 8.72°F and an irradiated 50 ft-lb transition temperature of 42.52°F for the longitudinally oriented specimens

- Irradiation of the reactor vessel lower shell plate M-4311-1 Charpy specimens, oriented with the longitudinal axis of the specimen normal to the major working direction of the plate (transverse orientation), to 7.85 x 10^{18} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 1.11°F and a 50 ft-lb transition temperature increase of 12.14°F. This results in an irradiated 30 ft-lb transition temperature of 10.14°F and an irradiated 50 ft-lb transition temperature of 55.25°F for transversely oriented specimens.

- Irradiation of the weld metal Charpy specimens to 7.85 x 10^{18} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 6.27°F and a 50 ft-lb transition temperature increase of 8.12°F. This results in an irradiated 30 ft-lb transition temperature of –47.0°F and an irradiated 50 ft-lb transition temperature of -25.3°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 7.85 x 10^{18} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature decrease of -26.59°F and a 50 ft-lb transition temperature decrease of -13.43°F. This results in an irradiated 30 ft-lb transition temperature of -89.79°F and an irradiated 50 ft-lb transition temperature of -40.01°F.

- Irradiation of the standard reference material Charpy specimens to 7.85 x 10^{18} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 114.25°F and a 50 ft-lb transition temperature increase of 128.6°F. This results in an irradiated 30 ft-lb transition temperature of 136.16°F and an irradiated 50 ft-lb transition temperature of 176.21°F.

- The average upper shelf energy of the lower shell plate M-4311-1 (longitudinal orientation) resulted in an average energy decrease of 6 ft-lb after irradiation to 7.85 x 10^{18} n/cm^2 (E> 1.0 MeV). This results in an irradiated average upper shelf energy of 141 ft-lb for the longitudinally oriented specimens.

- The average upper shelf energy of the lower shell plate M-4311-1 (transverse orientation) resulted in an average energy decrease of 53 ft-lb after irradiation to 7.85 x 10^{18} n/cm^2 (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 115 ft-lb for the transversely oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted an average energy decrease of 6 ft-lb after irradiation to 7.85 x 10^{18} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 158 ft-lb for the weld metal specimens.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted an average energy decrease of 16 ft-lb after irradiation to 7.85 x 10^{18} n/cm^2 (E > 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 119 ft-lb for the weld HAZ metal.

- The average upper shelf energy of the standard reference material Charpy specimens resulted an average energy decrease of 24 ft-lb after irradiation to 7.85 x 10^{18} n/cm^2 (E > 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 105 ft-lb for the standard reference material.

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

  - The measured 30 ft-lb shift in transition temperature values for all the surveillance program materials (Weld and Plate) for capsule 38° are less than the Regulatory Guide 1.99, Revision 2, predictions.

  - The measured percent decrease in upper shelf energy of the Capsule 38° surveillance material is less than the Regulatory Guide 1.99, Revision 2, predictions, with exception to the lower shell plate M-4311-1 (Transverse Orientation).

- The peak calculated and best estimate end-of-license (32 EFPY) neutron fluence (E> 1.0 MeV) at the core midplane for the Palo Verde Unit 1 reactor vessel using the Regulatory Guide 1.99, Revision 2 attenuation formula (ie. Equation # 3 in the guide; $f_{(depth\ x)} = f_{surface} * e^{(-0.24x)}$) is as follows:

<u>Calculated:</u>	Vessel inner radius*	=	1.64 x 10^{19} n/cm^2
	Vessel 1/4 thickness	=	9.52 x 10^{18} n/cm^2
	Vessel 3/4 thickness	=	3.21 x 10^{18} n/cm^2
<u>Best Estimate:</u>	Vessel inner radius*	=	1.36 x 10^{19} n/cm^2
	Vessel 1/4 thickness	=	7.90 x 10^{18} n/cm^2
	Vessel 3/4 thickness	=	2.66 x 10^{18} n/cm^2

2 INTRODUCTION

This report presents the results of the examination of the Capsule located at 38°, the second capsule to be removed from the reactor in the continuing surveillance program which monitors the effects of neutron irradiation on the Palo Verde Unit 1 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the Arizona Public Service Company Palo Verde Unit 1 reactor pressure vessel materials was designed and recommended by Combustion Engineering. A description of the surveillance program and the preirradiation mechanical properties of the reactor vessel materials is presented in Reference 3. The surveillance program was planned to cover the 40-year design life of the reactor pressure vessel and was based on ASTM E185-82, "Standard Practice for conducting Surveillance Tests for light-water cooled Nuclear Power Reactor Vessels". Capsule 38° was removed from the reactor after 9.81 EFPY of exposure and shipped to the Westinghouse Science and Technology Center Hot Cell Facility, where the post irradiation 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 located at 38°, removed from the Palo Verde Unit 1 reactor vessel and discusses the analysis of the data.

3 BACKGROUND

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

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

RT_{NDT} is defined as the greater of either the drop weight nil-ductility transition temperature (NDTT per ASTM E-208[5]) or the temperature 60°F less than the 50 ft-lb (and 35-mil lateral expansion) temperature as determined from Charpy specimens oriented perpendicular (transverse) to the major working direction of the plate. The RT_{NDT} of a given material is used to index that material to a reference stress intensity factor curve (K_{Ia} curve) which appears in Appendix G to the ASME Code[4]. The K_{Ia} curve is a Intermediate bound of dynamic, crack arrest, and static fracture toughness results obtained from several heats of pressure vessel steel. When a given material is indexed to the K_{Ia} curve, allowable stress intensity factors can be obtained for this material as a function of temperature. Allowable operating limits can then be determined utilizing these allowable stress intensity factors. Note that Code Case N-640 now allows the use of the K_{Ic} curve as an alternative to the K_{Ia} curve.

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 Palo Verde Unit 1 reactor vessel radiation surveillance program[6], in which a surveillance capsule is periodically removed from the operating nuclear reactor and the encapsulated specimens tested. The increase in the average Charpy V-notch 30 ft-lb temperature (ΔRT_{NDT}) due to irradiation is added to the initial RT_{NDT}, along with a margin (M) to cover uncertainties, to adjust the RT_{NDT} (ART) for radiation embrittlement. This ART (RT_{NDT} initial + M + ΔRT_{NDT}) is used to index the material to the K_{Ia} curve and, in turn, to set operating limits for the nuclear power plant that take into account the effects of irradiation on the reactor vessel materials.

4 DESCRIPTION OF PROGRAM

Six surveillance capsules for monitoring the effects of neutron exposure on the Palo Verde Unit 1 reactor pressure vessel core region (beltline) materials were inserted in the reactor vessel prior to initial plant start-up. The capsules were positioned in the reactor vessel between the core support barrel and the vessel wall at locations shown in Figure 4-1. The vertical center of the capsules is opposite the vertical center of the core.

Capsule 38° was removed after 9.81 effective full power years (EFPY) of plant operation. This capsule contained Charpy V-notch impact and tensile specimens made from reactor vessel lower shell course plate M-4311-1, submerged arc weld metal representative of the beltline region welds, heat-affected-zone (HAZ) metal and standard reference material from HSST-01MY plate. All HAZ specimens are obtained within the heat-affected-zone of lower shell plate M-4311-1 and 4311-2.

Charpy V-notch impact specimens from Plate M-6701-2 were with the longitudinal axis of the specimen parallel to the major working direction of the plate (longitudinal orientation). Charpy V-notch impact specimens from Plate M-4311-1 were with the transverse axis of the specimen perpendicular to the major working direction of the plate (transverse orientation). The Charpy V-notch specimens from the weld metal were machined with the longitudinal axis of the specimen transverse to the weld direction with the notch oriented in the direction of the weld.

Tensile specimens from Plate M-4311-1 were machined in with the longitudinal axis of the specimen perpendicular to the major working direction of the plate (transverse orientation). Tensile specimens from the weld metal were oriented with the longitudinal axis of the specimen transverse to the weld direction.

Capsule 38° contained dosimeter wires of sulfur, iron, titanium, nickel (cadmium-shielded), cobalt (cadmium-shielded and unshielded), copper (cadmium shielded) and uranium (cadmium-shielded and unshielded).

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

80% Au, 20% Sn	Melting Point 536°F (280°C)
90% Pb, 5% Sn, 5% Ag	Melting Point 558°F (292°C)
2.5% Ag, 97.5% Pb	Melting Point 580°F (304°C)
1.75% Ag, 0.75% Sn, 97.5% Ag	Melting Point 590°F (310°C)

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 TR-V-MCM-012. The arrangement of the various mechanical test specimens, dosimeters and thermal monitors contained in capsule 38° is shown in Figure 4-2. A typical Palo Verde Unit 1 surveillance capsule Charpy impact compartment assembly is shown in Figure 4-3, while Figure 4-4 and 4-5 show the Tensile-Monitor Compartment and Charpy Flux & Compact Tension Compartment, respectively.

Table 4-1 Chemical Composition (wt %) of the Palo Verde Unit 1 Reactor Vessel Surveillance Materials

Element	Plate M-4311-1	Weld Metal M-4311-2/M-4311-3
C	0.24	0.16
Mn	1.48	1.08
P	0.003	0.005
S	0.006	0.005
Si	0.23	0.24
Ni	0.63	0.06
Cr	0.07	0.06
Mo	0.50	0.58
V	0.004	0.006
Cb	0.01	0.01
Ti	0.01	0.01
Co	0.014	0.018
Cu	0.04	0.04
Al	0.026	0.005
B	0.001	0.001
W	0.01	0.02
Sb	0.0022	0.0014
As	0.018	0.006
Sn	0.004	0.004
Zr	0.001	0.001
Pb	0.001	0.001
N	0.012	0.007

Table 4-2 Heat Treatment of the Palo Verde Unit 1 Reactor Vessel Surveillance Material

Material	Temperature (°F)	Time (hrs.)	Coolant
Surveillance Program	Austenitizing: 1600 ± 25	4	Water-quenched
Test Plate M-4311-1	Tempered: 1225 ± 25	4	Air Cooled
	Stress Relief: 1150 ± 25	40	Furnace Cooled to 600°F
Weld Metal	Stress Relief: 1125 ± 25	41 hr & 45 min.	Furnace Cooled

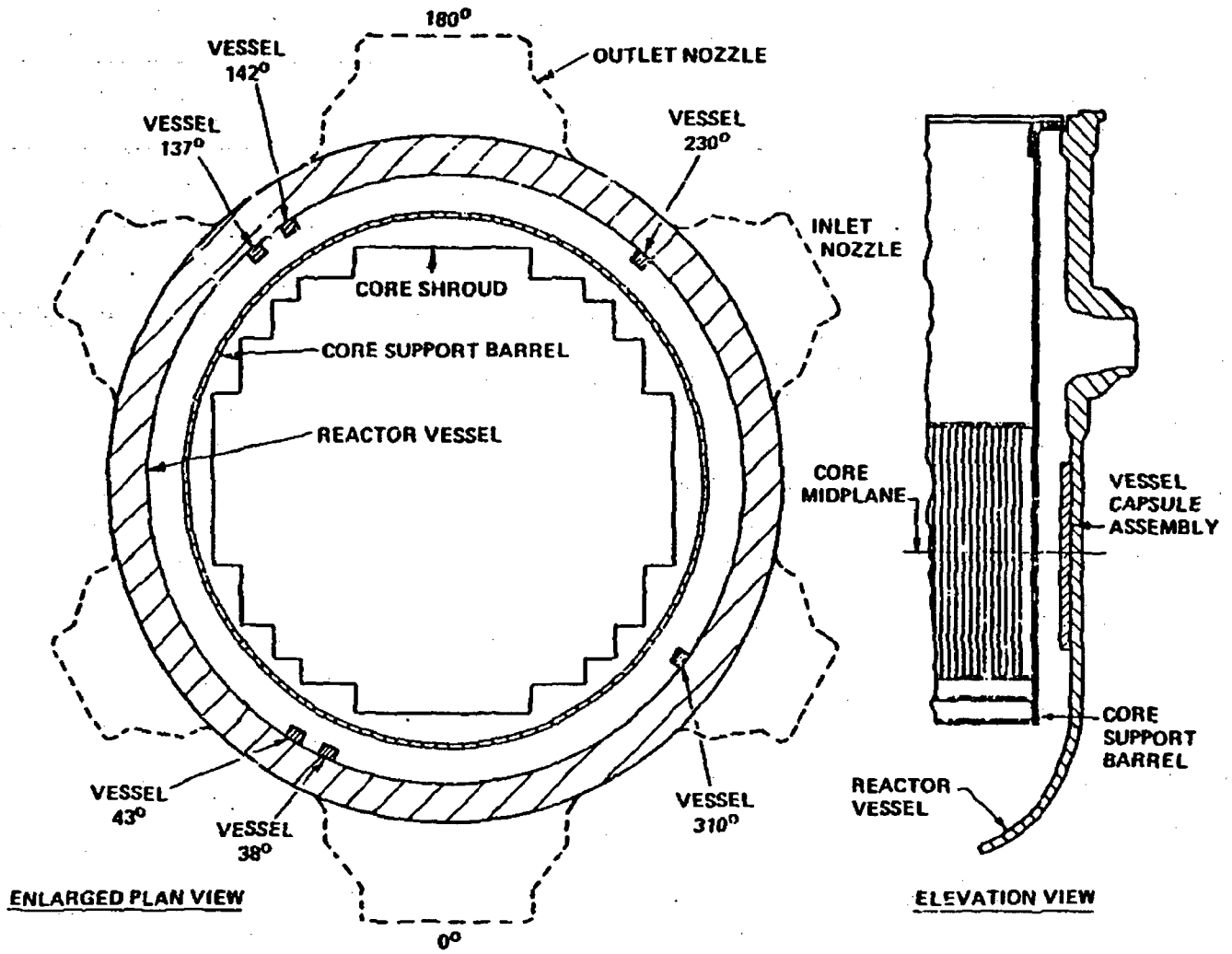


Figure 4-1. Arrangement of Surveillance Capsules in the Palo Verde Unit 1 Reactor Vessel

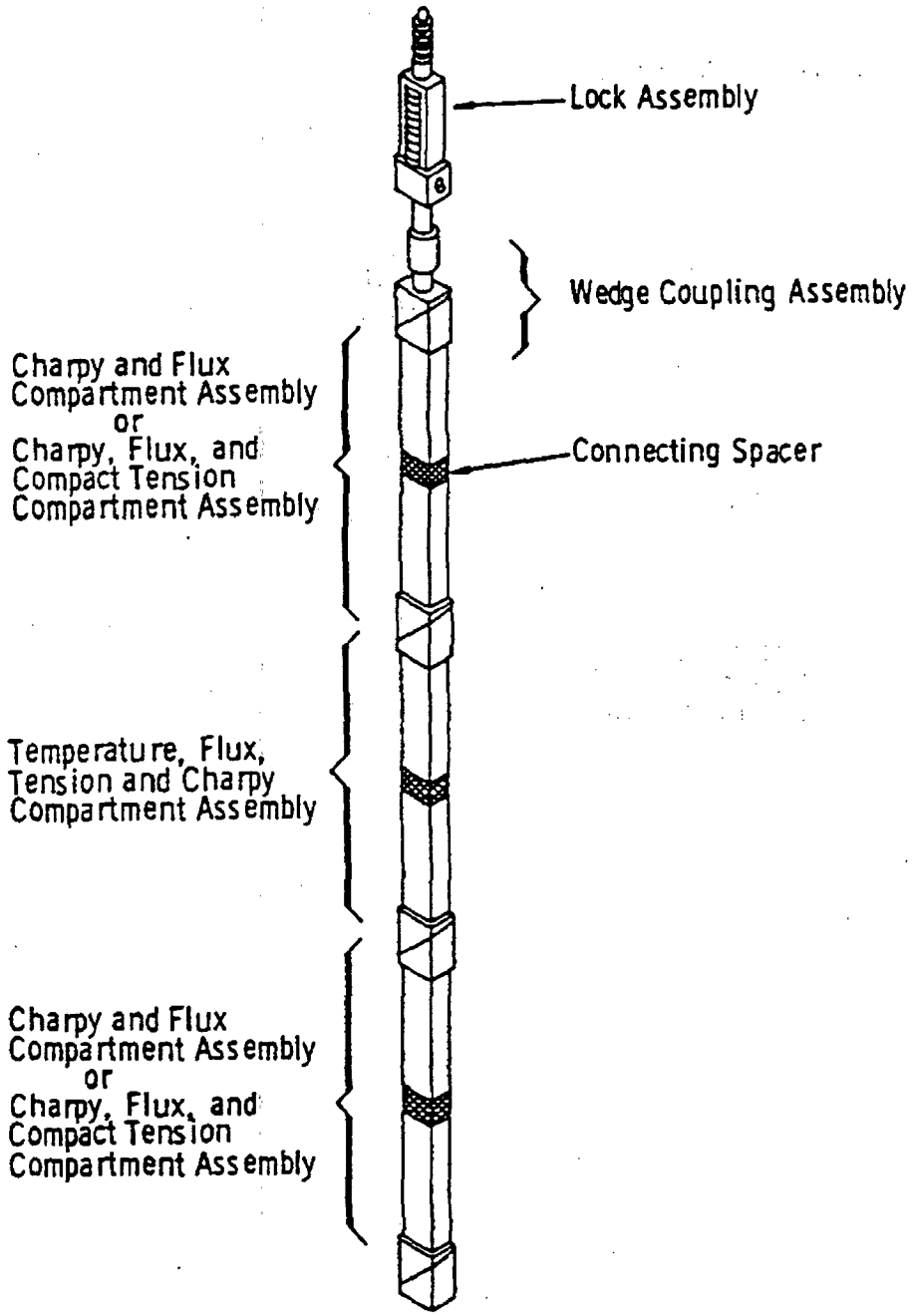


Figure 4-2 Typical Palo Verde Unit 1 Surveillance Capsule Assembly

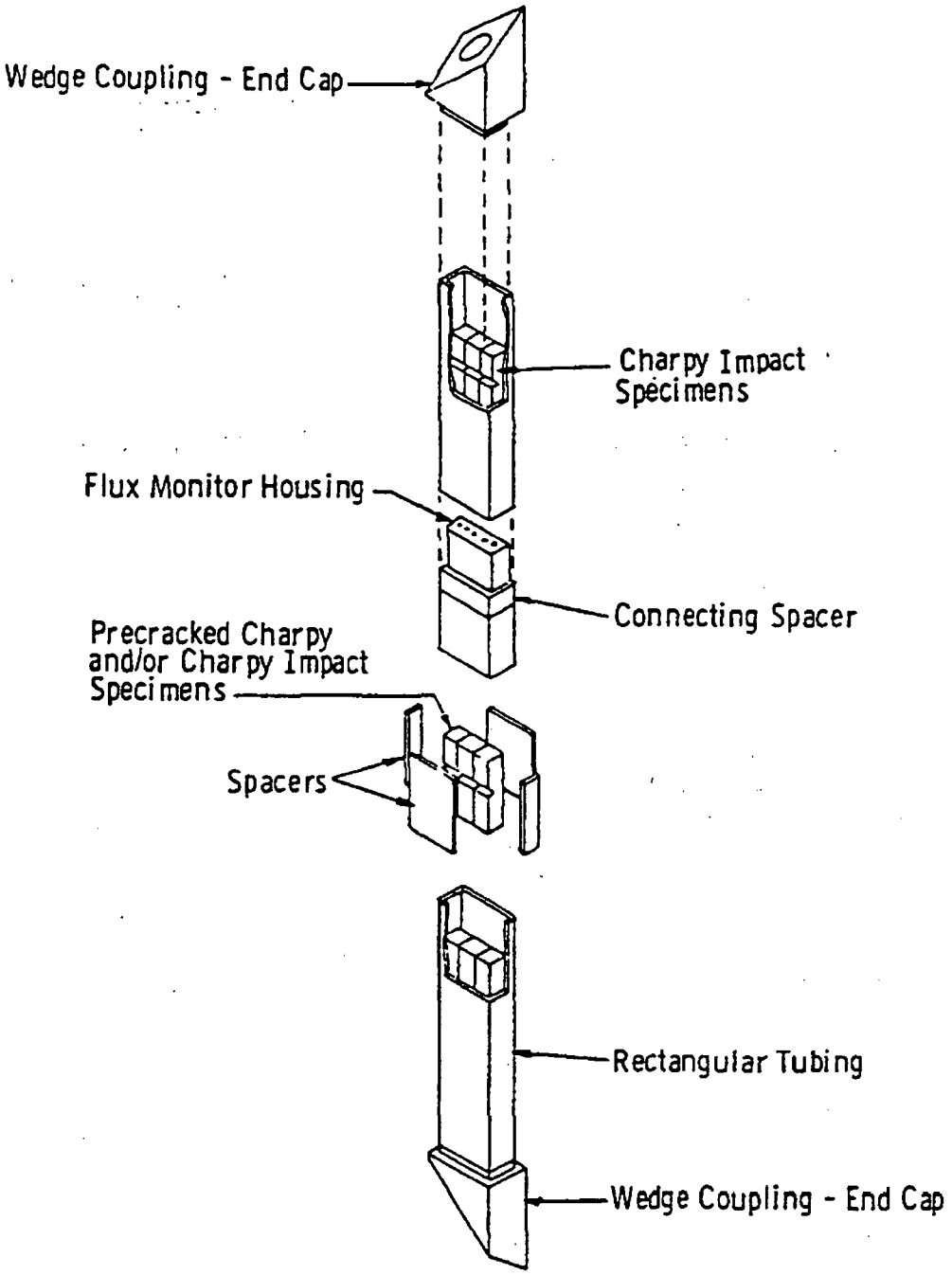


Figure 4-3 Typical Palo Verde Unit 1 Surveillance Capsule Charpy Impact Compartment Assembly

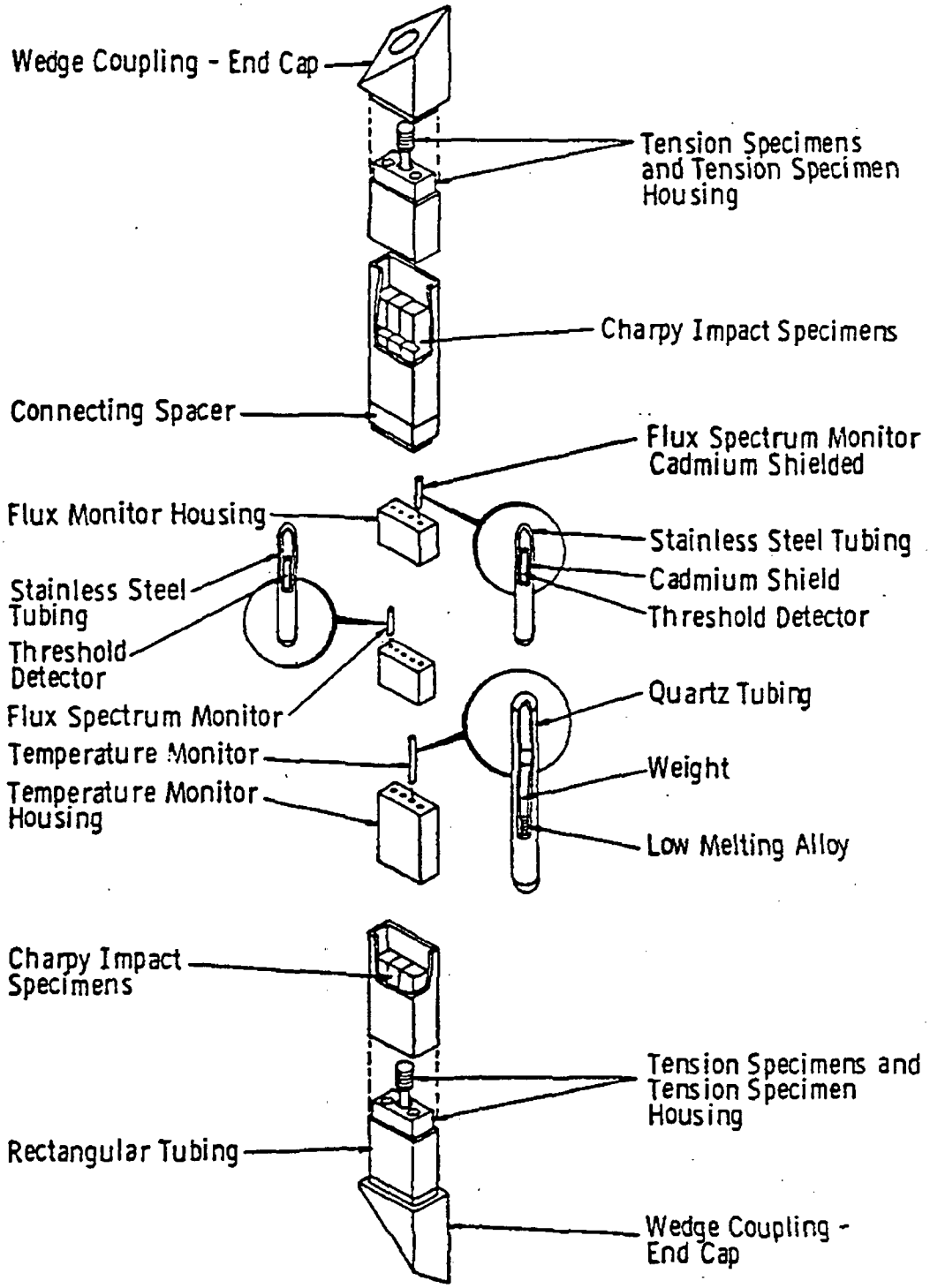


Figure 4-4 Typical Palo Verde Unit 1 Surveillance Capsule Tensile and Flux-Monitor Compartment Assembly

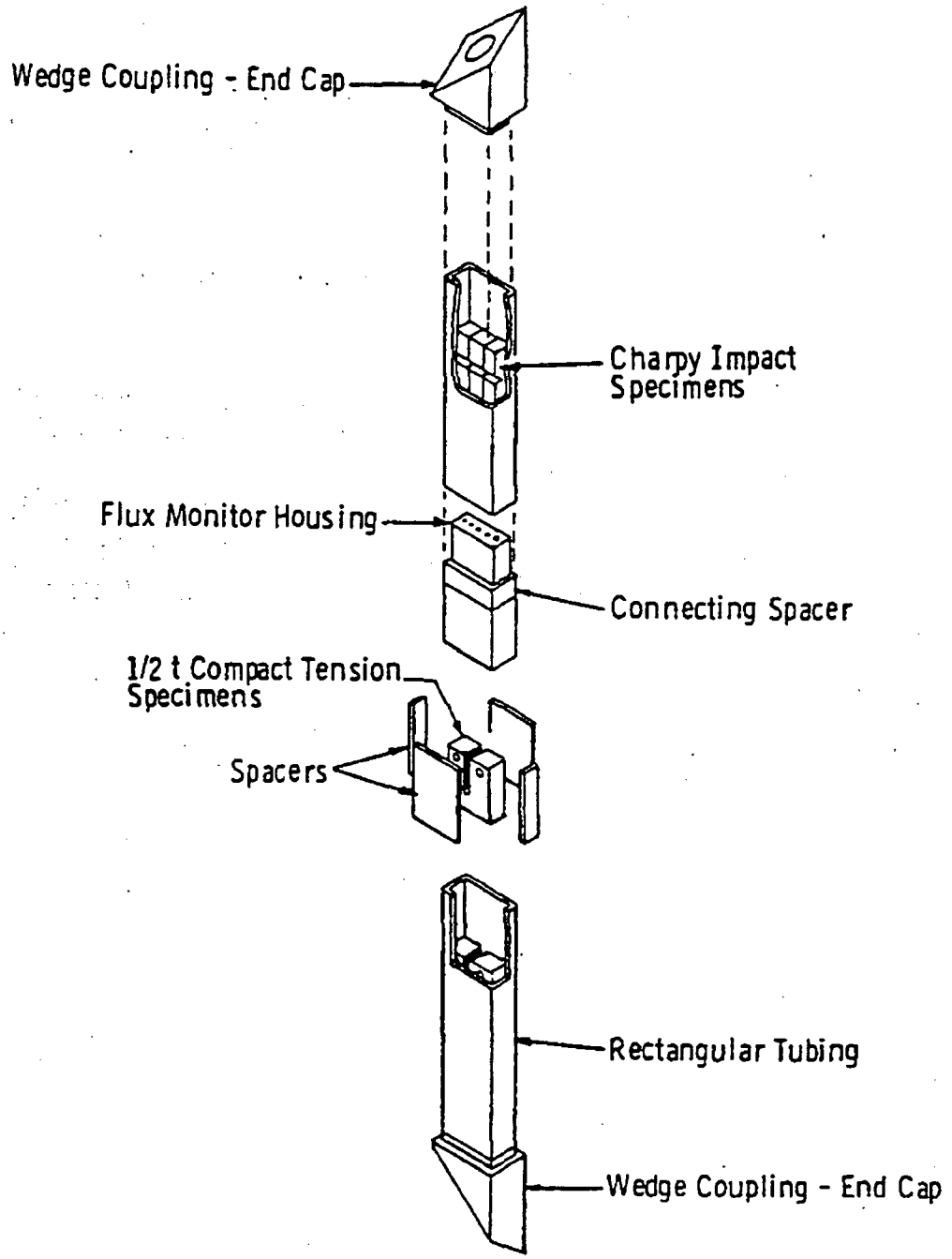


Figure 4-5 Typical Palo Verde Unit 1 Surveillance Capsule Charpy Flux and Compact Tension Compartment Assembly

5 TESTING OF SPECIMENS FROM CAPSULE 38°

5.1 OVERVIEW

The post-irradiation mechanical testing of the Charpy V-notch impact specimens and tensile specimens was performed in the Remote Metallographic Facility (RMF) at the Westinghouse Science and Technology Center. Testing was performed in accordance with 10CFR50, Appendices G and H[2], ASTM Specification E185-82[7], and Westinghouse Procedure RMF 8402, Revision 2 as modified by Westinghouse RMF Procedures 8102, Revision 1, and 8103, Revision 1.

Upon receipt of the capsule at the hot cell laboratory, the specimens and spacer blocks were carefully removed, inspected for identification number, and checked against the master lists in WCAP-14066[3]. No discrepancies were found.

Examination of the four low-melting, eutectic alloy thermal monitors indicated that the two lowest melting point monitors melted, and that the 580°F monitor had signs that some melting had occurred. Based on this examination, the maximum temperature to which the test specimens were exposed to was 580°F.

The Charpy impact tests were performed per ASTM Specification E23-98[8] and RMF Procedure 8103, Revision 1, on a Tinius-Olsen Model 74, 358J machine. The tup (striker) of the Charpy impact test machine is instrumented with a GRC 930-I instrumentation system, feeding information into an IBM compatible computer. With this system, load-time and energy-time signals can be recorded in addition to the standard measurement of Charpy energy (E_D). From the load-time curve (Appendix A), the load of general yielding (P_{GY}), the time to general yielding (t_{GY}), the maximum load (P_M), and the time to maximum load (t_M) can be determined. Under some test conditions, a sharp drop in load indicative of fast fracture was observed. The load at which fast fracture was initiated is identified as the fast fracture load (P_F), and the load at which fast fracture terminated is identified as the arrest load (P_A). The energy at maximum load (E_M) was determined by comparing the energy-time record and the load-time record. The energy at maximum load is approximately equivalent to the energy required to initiate a crack in the specimen. Therefore, the propagation energy for the crack (E_p) is the difference between the total energy to fracture (E_D) and the energy at maximum load (E_M).

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

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

where:
- L = distance between the specimen supports in the impact machine
- B = the width of the specimen measured parallel to the notch
- W = height of the specimen, measured perpendicularly to the notch
- a = notch depth

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

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

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

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

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:

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

Percent shear was determined from post-fracture photographs using the ratio-of-areas methods in compliance with ASTM Specification A370-97[9]. 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[10] and E21-92[11], and RMF Procedure 8102, Revision 1. All pull rods, grips, and pins were made of Inconel 718. The upper pull rod was connected through a universal joint to improve axiality of loading. The tests were conducted at a constant crosshead speed of 0.05 inches per minute throughout the test.

Extension measurements were made with a linear variable displacement transducer extensometer. The extensometer knife edges were spring-loaded to the specimen and operated through specimen failure. The extensometer gage length was 1.00 inch. The extensometer is rated as Class B-2 per ASTM E83-93[12].

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

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

5.2 CHARPY V-NOTCH IMPACT TEST RESULTS

The results of the Charpy V-notch impact tests performed on the various materials contained in capsule 38°, which received a fluence of 7.85 x 10^{18} n/cm^2 (E > 1.0 MeV) in 9.81 EFPY of operation, are presented in Tables 5-1 through 5-8 and are compared with unirradiated results as shown in Figures 5-1 through 5-12.

The transition temperature increases and upper shelf energy decreases for the capsule 38° materials are summarized in Table 5-9. These results led to the following conclusions:

Irradiation of the reactor vessel lower shell plate M-4311-1 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction of the plate (longitudinal orientation), to 7.85 x 10^{18} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 21.58°F and a 50 ft-lb transition temperature increase of 30.06°F. This results in an irradiated 30 ft-lb transition temperature of 8.72°F and an irradiated 50 ft-lb transition temperature of 42.52°F for the longitudinally oriented specimens

Irradiation of the reactor vessel lower shell plate M-4311-1 Charpy specimens, oriented with the longitudinal axis of the specimen normal to the major working direction of the plate (transverse orientation), to 7.85 x 10^{18} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 1.1°F and a 50 ft-lb transition temperature increase of 12.14°F. This results in an irradiated 30 ft-lb transition temperature of 10.14°F and an irradiated 50 ft-lb transition temperature of 55.25°F for transversely oriented specimens.

Irradiation of the weld metal Charpy specimens to 7.85 x 10^{18} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 6.27°F and a 50 ft-lb transition temperature increase of 8.12°F. This results in an irradiated 30 ft-lb transition temperature of –47.0°F and an irradiated 50 ft-lb transition temperature of -25.3°F.

Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 7.85 x 10^{18} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature decrease of -26.59°F and a 50 ft-lb transition temperature decrease of -13.43°F. This results in an irradiated 30 ft-lb transition temperature of -89.79°F and an irradiated 50 ft-lb transition temperature of -40.01°F.

Irradiation of the standard reference material Charpy specimens to 7.85 x 10^{18} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 114.25°F and a 50 ft-lb transition temperature increase of 128.6°F. This results in an irradiated 30 ft-lb transition temperature of 136.16°F and an irradiated 50 ft-lb transition temperature of 176.21°F.

The average upper shelf energy of the lower shell plate M-4311-2 (longitudinal orientation) resulted in an average energy decrease of 6 ft-lb after irradiation to 7.85 x 10^{18} n/cm^2 (E> 1.0 MeV). This results in an irradiated average upper shelf energy of 141 ft-lb for the longitudinally oriented specimens.

The average upper shelf energy of the Intermediate shell plate M-4311-1 (transverse orientation) resulted in an average energy decrease of 53 ft-lb after irradiation to 7.85 x 10^{18} n/cm^2 (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 115 ft-lb for the transversely oriented specimens.

The average upper shelf energy of the weld metal Charpy specimens resulted an average energy decrease of 6 ft-lb after irradiation to 7.85 x 10^{18} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 158 ft-lb for the weld metal specimens.

The average upper shelf energy of the weld HAZ metal Charpy specimens resulted an average energy decrease of 16 ft-lb after irradiation to 7.85 x 10^{18} n/cm^2 (E > 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 119 ft-lb for the weld HAZ metal.

The average upper shelf energy of the standard reference material Charpy specimens resulted an average energy decrease of 24 ft-lb after irradiation to 7.85 x 10^{18} n/cm^2 (E > 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 105 ft-lb for the standard reference material.

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

- The measured 30 ft-lb shift in transition temperature values for all the surveillance program materials (Weld and Plate) for capsule 38° are less than the Regulatory Guide 1.99, Revision 2, predictions.

- The measured percent decrease in upper shelf energy of the Capsule 38° surveillance material is less than the Regulatory Guide 1.99, Revision 2, predictions, with exception to the lower shell plate M-4311-1 (Transverse Orientation).

The fracture appearance of each irradiated Charpy specimen from the various surveillance capsule 38° materials is shown in Figures 5-13 through 5-16 and show an increasingly ductile or tougher appearance with increasing test temperature.

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

The Charpy V-notch data presented in this report is based on a re-plot of all capsule data using CVGRAPH, Version 4.1, which is a hyperbolic tangent curve-fitting program. Hence, Appendix C contains a comparison of the Charpy V-notch shift results for each surveillance material (hand-fitting versus hyperbolic tangent curve-fitting). Additionally, Appendix B presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

5.3 TENSILE TEST RESULTS

The results of the tensile tests performed on the various materials contained in capsule 38° irradiated to 7.85×10^{18} n/cm^2 (E > 1.0 MeV) are presented in Table 5-13 and are compared with unirradiated results as shown in Figures 5-21 and 5-22.

The results of the tensile tests performed on the lower shell plate M-4311-1 (transverse orientation) indicated that irradiation to 7.85×10^{18} n/cm^2 (E> 1.0 MeV) caused an approximate increase of 8 to 10 ksi in the 0.2 percent offset yield strength and approximately a 0 to 5 ksi increase in the ultimate tensile strength when compared to unirradiated data[1] (Figure 5-21).

The results of the tensile tests performed on the surveillance weld metal indicated that irradiation to 7.85×10^{18} n/cm^2 (E > 1.0 MeV) caused a 5 ksi increase in the 0.2 percent offset yield strength and a 4 to 10 ksi increase in the ultimate tensile strength when compared to unirradiated data (Figure 5-22).

The fractured tensile specimens for the lower shell plate M-4311-1 material are shown in Figure 5-23, while the fractured tensile specimens for the surveillance weld metal and heat-affected-zone material are shown in Figure 5-24.

The engineering stress-strain curves for the tensile tests are shown in Figures 5-25 and 5-26.

Table 5-1 Charpy V-notch Data for the Palo Verde Unit 1 Lower Shell Plate M-4311-1 Irradiated to a Fluence of 7.85 x 10^{18} n/cm^2 (E> 1.0 MeV) (Longitudinal Orientation)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	ft-lbs	Joules	mils	mm	%
1A11T	-75	-59	5	7	1	0.03	5
1A127	0	-18	19	26	12	0.30	15
1A112	20	-7	38	52	31	0.79	25
1A125	30	-1	43	58	39	0.99	25
1A13U	50	10	60	81	44	1.12	35
1A111	100	38	91	123	66	1.68	65
1A122	150	66	116	157	74	1.88	85
1A144	225	107	138	187	60	1.52	100
1A13K	275	135	144	195	106	2.69	100

Table 5-2 Charpy V-notch Data for the Palo Verde Unit 1 Lower Shell Plate M-4311-1 Irradiated to a Fluence of 7.85 x 10^{18} n/cm^2 (E> 1.0 MeV) (Transverse Orientation)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	ft-lbs	Joules	mils	mm	%
1A255	-75	-59	4	5	5	0.13	2
1A21E	-40	-40	8	11	4	0.10	5
1A25P	0	-18	24	33	21	0.53	10
1A232	5	-15	39	53	38	0.97	15
1A21J	10	-12	39	53	30	0.76	15
1A23A	25	-4	37	50	30	0.76	20
1A25E	50	10	38	52	28	0.71	25
1A25U	50	10	47	64	38	0.97	30
1A261	70	21	55	75	42	1.07	45
1A222	80	27	65	88	51	1.30	50
1A247	125	52	89	121	71	1.80	60
1A21M	150	66	110	149	79	2.01	90
1A256	150	66	62	84	51	1.30	60
1A235	200	93	112	152	84	2.13	100
1A263	250	121	118	160	78	1.98	100

Table 5-3 Charpy V-notch Data for the Palo Verde Unit 1 Surveillance Weld Metal Irradiated to a Fluence of 7.85 x 10^{18} n/cm^2 (E> 1.0 MeV)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	ft-lbs	Joules	mils	mm	%
1A31Y	-96	-71	7	9	7	0.18	10
1A354	-70	-57	19	26	17	0.43	20
1A324	-55	-48	11	15	14	0.36	20
1A3A2	-50	-46	34	46	26	0.66	25
1A3B3	-45	-43	25	34	22	0.56	25
1A372	-25	-32	48	65	37	0.94	40
1A33K	-10	-23	95	129	69	1.75	70
1A32U	0	-18	65	88	52	1.32	60
1A342	15	-9	96	130	69	1.75	70
1A35E	25	-4	114	155	71	1.80	85
1A32M	50	10	129	175	85	2.16	90
1A323	100	38	149	202	90	2.29	100
1A35U	150	66	163	221	92	2.34	100
1A331	200	93	151	205	90	2.29	100
1A33B	250	121	170	231	97	2.46	100

Table 5-4 Charpy V-notch Data for the Palo Verde Unit 1 Heat Affected Zone Metal Irradiated to a Fluence of 7.85 x 10^{18} n/cm^2 (E> 1.0 MeV)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	ft-lbs	Joules	mils	mm	%
1A441	-175	-115	12	16	4	0.10	5
1A442	-120	-84	23	31	12	0.30	10
1A43D	-90	-68	54	73	39	0.99	45
1A41U	-75	-59	53	72	33	0.84	40
1A44Y	-50	-46	18	24	16	0.41	30
1A453	-30	-34	30	41	24	0.61	40
1A416	-25	-32	47	64	46	1.17	50
1A443	0	-18	103	140	64	1.63	85
1A44D	25	-4	62	84	48	1.22	50
1A41M	70	21	108	146	75	1.91	100
1A42B	130	54	100	136	70	1.78	100
1A43T	200	93	148	201	90	2.29	100

Table 5-5 Charpy V-notch Data for the Palo Verde Unit 1 Standard Reference Material Irradiated to a Fluence of 7.85 x 10^{18} n/cm^2 (E> 1.0 MeV)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	ft-lbs	Joules	mils	mm	%
1AB6M	0	-18	4	5	1	0.03	5
1AB56	100	38	28	38	14	0.36	10
1AB4A	125	52	30	41	28	0.71	15
1AB53	175	79	42	57	42	1.07	25
1AB6P	200	93	45	61	40	1.02	45
1AB5K	225	107	91	123	90	2.29	95
1AB4B	250	121	88	119	72	1.83	90
1AB44	325	163	110	149	71	1.80	100
1AB45	375	191	100	136	82	2.08	100

Table 5-6 Instrumented Charpy Impact Test Results for the Palo Verde Unit 1 Lower Shell Plate M-4311-1 Irradiated to a Fluence of 7.85 x 10^{18} n/cm^2 (E>1.0 MeV) (Longitudinal Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2)			Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. T_m (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_p/A								
1A11T	-75	5	40	19	21	2216	0.15	2228	0.14	2216	0	74	74
1A127	0	19	153	65	88	3565	0.17	4077	0.23	4077	0	119	127
1A112	20	38	306	212	94	3925	0.18	4503	0.49	4497	447	131	140
1A125	30	43	346	273	74	3857	0.18	4454	0.60	4452	0	128	138
1A13U	50	60	483	293	191	3202	0.17	4040	0.71	3996	518	107	121
1A111	100	91	733	320	414	3750	0.18	4566	0.69	3913	1091	125	138
1A122	150	116	935	308	626	3582	0.18	4401	0.69	3578	2280	119	133
1A144	225	138	1112	314	798	2686	0.17	3625	0.84	n/a	n/a	89	105
1A13K	275	144	1160	353	808	3166	0.18	4109	0.83	n/a	n/a	105	121

Table 5-7 Instrumented Charpy Impact Test Results for the Palo Verde Unit 1 Lower Shell Plate M-4311-1 Irradiated to a Fluence of 7.85 x 10^{18} n/cm^2 (E>1.0 MeV) (Transverse Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2)			Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. T_m (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_p/A								
1A255	-75	4	32	16	16	2076	0.12	2088	0.13	2076	0	69	69
1A21E	-40	8	64	36	29	3390	0.17	3390	0.17	3390	0	113	113
1A25P	0	24	193	138	55	3412	0.18	3683	0.4	3681	0	114	118
1A232	5	39	314	224	90	3739	0.18	4221	0.53	4215	0	125	133
1A21J	10	39	314	240	75	3748	0.17	4475	0.54	4416	0	125	137
1A23A	25	37	298	198	100	3206	0.17	3742	0.53	3658	0	107	116
1A25E	50	38	306	200	106	3369	0.17	3997	0.51	3963	580	112	123
1A25U	50	47	379	266	113	3101	0.17	3754	0.68	3574	450	103	114
1A261	70	55	443	290	153	3379	0.18	4089	0.7	4072	1096	113	124
1A222	80	65	524	273	250	3219	0.17	3905	0.68	3821	1304	107	119
1A247	125	89	717	297	420	3452	0.18	4237	0.69	3848	1597	115	128
1A21M	150	110	886	306	580	3448	0.17	4326	0.69	3043	2071	115	129
1A256	150	62	500	259	240	2944	0.17	3684	0.69	3582	1313	98	110
1A235	200	112	902	252	651	2797	0.17	3585	0.69	n/a	n/a	93	106
1A263	250	118	951	302	648	2534	0.17	3483	0.84	n/a	n/a	84	100

Table 5-8 Instrumented Charpy Impact Test Results for the Palo Verde Unit 1 Surveillance Weld Metal Irradiated to a Fluence of 7.85 x 10^{18} n/cm^2 (E>1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2)			Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. T_m (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_p/A								
1A31Y	-96	7	56	32	25	3362	0.16	3362	0.16	3362	0	112	112
1A354	-70	19	153	71	82	4128	0.18	4478	0.23	4362	0	137	143
1A324	-55	11	89	40	48	3838	0.17	3845	0.17	3838	0	128	128
1A3A2	-50	34	274	192	82	3870	0.18	4168	0.47	4164	0	129	134
1A3B3	-45	25	201	66	135	4119	0.17	4427	0.22	4231	0	137	142
1A372	-25	48	387	210	176	3686	0.17	4058	0.51	3979	924	123	129
1A33K	-10	95	765	308	457	3790	0.17	4217	0.69	3585	1218	126	133
1A32U	0	65	524	216	308	3555	0.17	4087	0.53	4071	1422	118	127
1A342	15	96	774	320	453	3926	0.18	4323	0.70	3566	1239	131	137
1A35E	25	114	919	329	589	3925	0.17	4482	0.70	3480	1822	131	140
1A32M	50	129	1039	332	707	3147	0.17	3682	0.83	2798	1728	105	114
1A323	100	149	1201	274	927	3407	0.2	3833	0.68	n/a	n/a	113	121
1A35U	150	163	1313	275	1039	3170	0.17	3799	0.69	n/a	n/a	106	116
1A331	200	151	1217	269	948	3132	0.17	3807	0.68	n/a	n/a	104	116
1A33B	250	170	1370	343	1026	3173	0.18	3816	0.84	n/a	n/a	106	116

Table 5-9 Instrumented Charpy Impact Test Results for the Palo Verde Unit 1 Heat Affected Zone Material Irradiated to a Fluence of 7.85 x 10^{18} n/cm^2 (E>1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2)			Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. T_m (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_p/A								
1A441	-175	12	97	55	42	4205	0.18	4372	0.2	4366	0	140	143
1A442	-120	23	185	70	115	4217	0.17	4751	0.22	4474	0	140	149
1A43D	-90	54	435	251	184	4413	0.17	4914	0.51	4862	753	147	155
1A41U	-75	53	427	228	199	3862	0.17	4336	0.52	4167	0	129	136
1A44Y	-50	18	145	62	83	4015	0.17	4220	0.21	3976	0	134	137
1A453	-30	30	242	58	184	3478	0.17	3814	0.22	3677	458	116	121
1A416	-25	47	379	223	156	3938	0.17	4347	0.51	4230	1046	131	138
1A443	0	103	830	375	455	4244	0.18	5340	0.70	4541	1555	141	160
1A44D	25	62	500	197	302	3479	0.18	3705	0.52	3570	1888	116	120
1A41M	70	108	870	266	604	3364	0.17	3746	0.67	n/a	n/a	112	118
1A42B	130	100	806	259	547	3228	0.17	3659	0.67	n/a	n/a	107	115
1A43T	200	148	1192	320	872	3704	0.17	4442	0.7	n/a	n/a	123	136

Table 5-10 Instrumented Charpy Impact Test Results for the Palo Verde Unit 1 Standard Reference Material Irradiated to a Fluence of 7.85 x 10^{18} n/cm^2 (E>1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2)			Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. T_m (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_P/A								
1AB6M	0	4	32	8	24	1207	0.11	1207	0.11	1207	0	40	40
1AB56	100	28	226	166	59	3648	0.18	4317	0.43	4315	0	121	133
1AB4A	125	30	242	170	72	3807	0.18	4257	0.42	4228	503	127	134
1AB53	175	42	338	207	132	3582	0.17	4319	0.50	4183	1327	119	132
1AB6P	200	45	363	222	141	3736	0.17	4515	0.51	4513	792	124	137
1AB5K	225	91	733	291	443	3466	0.18	4297	0.67	3190	2469	115	129
1AB4B	250	88	709	267	442	3056	0.17	3862	0.67	1261	575	102	115
1AB44	325	110	886	292	595	3470	0.17	4317	0.66	n/a	n/a	116	130
1AB45	375	100	806	283	523	3328	0.18	4113	0.67	n/a	n/a	111	124

Table 5-11 Effect of Irradiation to 7.85 x 10^{19} n/cm^2 (E>1.0 MeV) on the Notch Toughness Properties of the Palo Verde Unit 1 Reactor Vessel Surveillance Materials

Material	Average 30 (ft-lb)[a] Transition Temperature (°F)			Average 35 mil Lateral[b] Expansion Temperature (°F)			Average 50 ft-lb[a] Transition Temperature (°F)			Average Energy Absorption[a] at Full Shear (ft-lb)		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔE
Lower Shell Plate M-4311-1 (Longitudinal)	-12.85	8.72	21.58	14.24	33.19	18.95	12.46	42.52	30.06	147	141	-6
Lower Shell Plate M-4311-1 (Transverse)	9.04	10.14	1.1	36.51	40.65	4.14	43.11	55.25	12.14	168	115	-53
Weld Metal	-53.28	-47	6.27	-30.94	-31.79	-0.84	-33.43	-25.3	8.12	164	158	-6
HAZ Metal	-63.2	-89.79	-26.59	-29.74	-42.71	-12.97	-26.57	-40.01	-13.43	135	119	-16
SRM	21.9	136.16	114.25	47.48	153.84	106.35	47.61	176.21	128.6	129	105	-24

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, 5-10 and 5-13).

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, 5-11 and 5-14)

Table 5-12 Comparison of the Palo Verde Unit 1 Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper Shelf Energy Decrease with Regulatory Guide 1.99, Revision 2, Predictions

Material	Capsule	Fluence ($\times 10^{19}$ n/cm^2)[a]	30 ft-lb Transition Temperature Shift		Upper Shelf Energy Decrease	
			Predicted (°F)	Measured (°F)	Predicted (%)[b]	Measured (%)
Lower Shell Plate M-4311-1 (Longitudinal)	38°	0.785	24.23	21.58	18	5
Lower Shell Plate M-4311-1 (Transverse)	38°	0.785	24.23	1.1	18	31.5
Surveillance Program Weld Metal	137°	0.433	22.8	-2.94	16	1
	38°	0.785	23.3	6.27	18	4
Heat Affected Zone Material	137°	0.433	--	-10.98	---	8
	38°	0.785	--	-26.59	---	12

Notes:

(a) Calculated Fluences from capsule 38° dosimetry analysis results (E > 1.0 MeV)

(b) From Figure 2 of Regulatory Guide 1.99, Revision 2, using the Cu wt. Percent and capsule fluence values.

Table 5-13 Tensile Specimens From Lower Shell Course Plate M-4311-1 and Weld

Sample Number	Material	Test Temperature (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 (%)
1A2JC	PLATE	50	61.1	85.7	3.01	165.8	61.3	15.1	29.6	63
1A2K2	PLATE	175	60.1	79.8	2.87	162.4	58.4	13.4	25.5	64
*1A2J5**	PLATE	*550*	*	*77.7*	*2.71*	*155.6*	*55.3*	*	*20.2*	*64*
1A3JC	WELD	-15	75.4	85.9	2.70	194.4	55.0	13.6	27.3	72
1A3J4	WELD	75	72.8	86.7	2.63	201.2	53.6	11.5	26.1	73
1A3J7	WELD	550	62.1	82.5	2.47	169.8	50.2	10.6	23.8	70

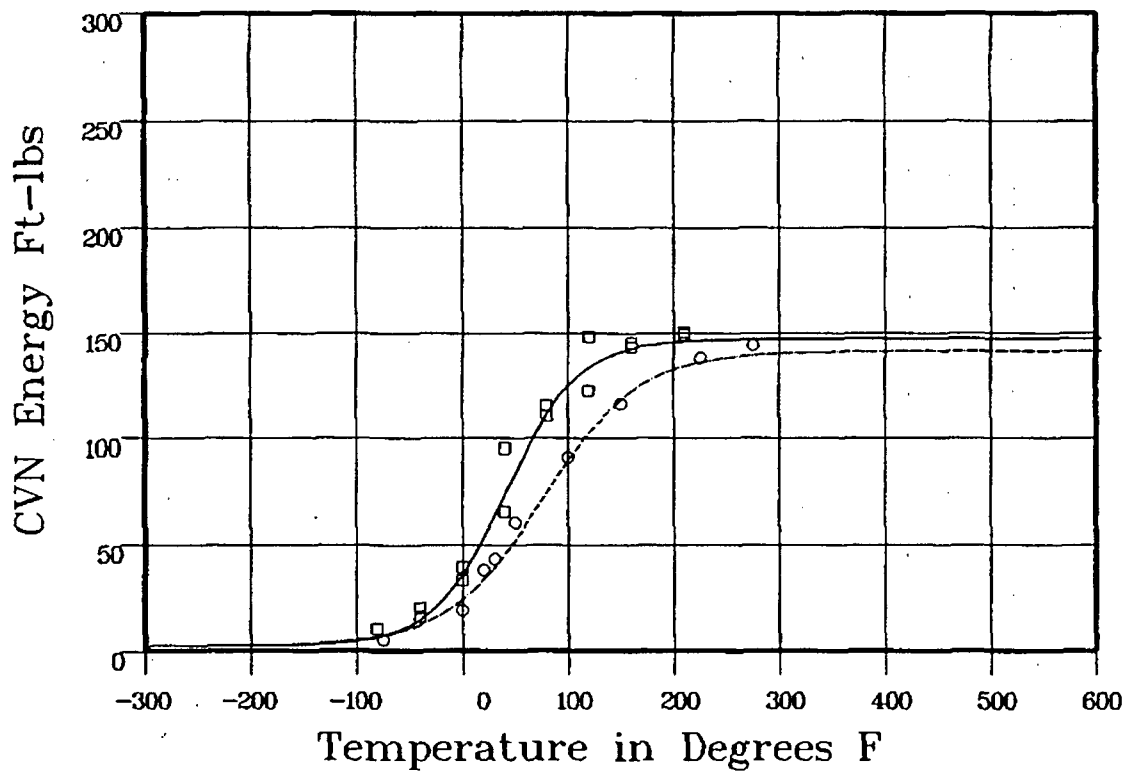
* NOTE: Testing difficulties make the yield strength and uniform elongation of specimen 1A2J5 invalid.

LOWER SHELL M-4311-1 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:35:25 on 01-29-2001

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	147	0	-12.85	0	12.46	0
2	0	2.19	0	141	-6	8.72	21.58	42.52	30.06



Curve Legend

1 □——— 2 ○---------

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	PV1	UNIRR	PLATE SA533B1	LT	M-4311-1
2	PV1	38	PLATE SA533B1	LT	M-4311-1

Figure 5-1 **Charpy V-Notch Impact Energy vs. Temperature for Palo Verde Unit 1 Reactor Vessel Lower Shell Plate M-4311-1 (Longitudinal Orientation)**

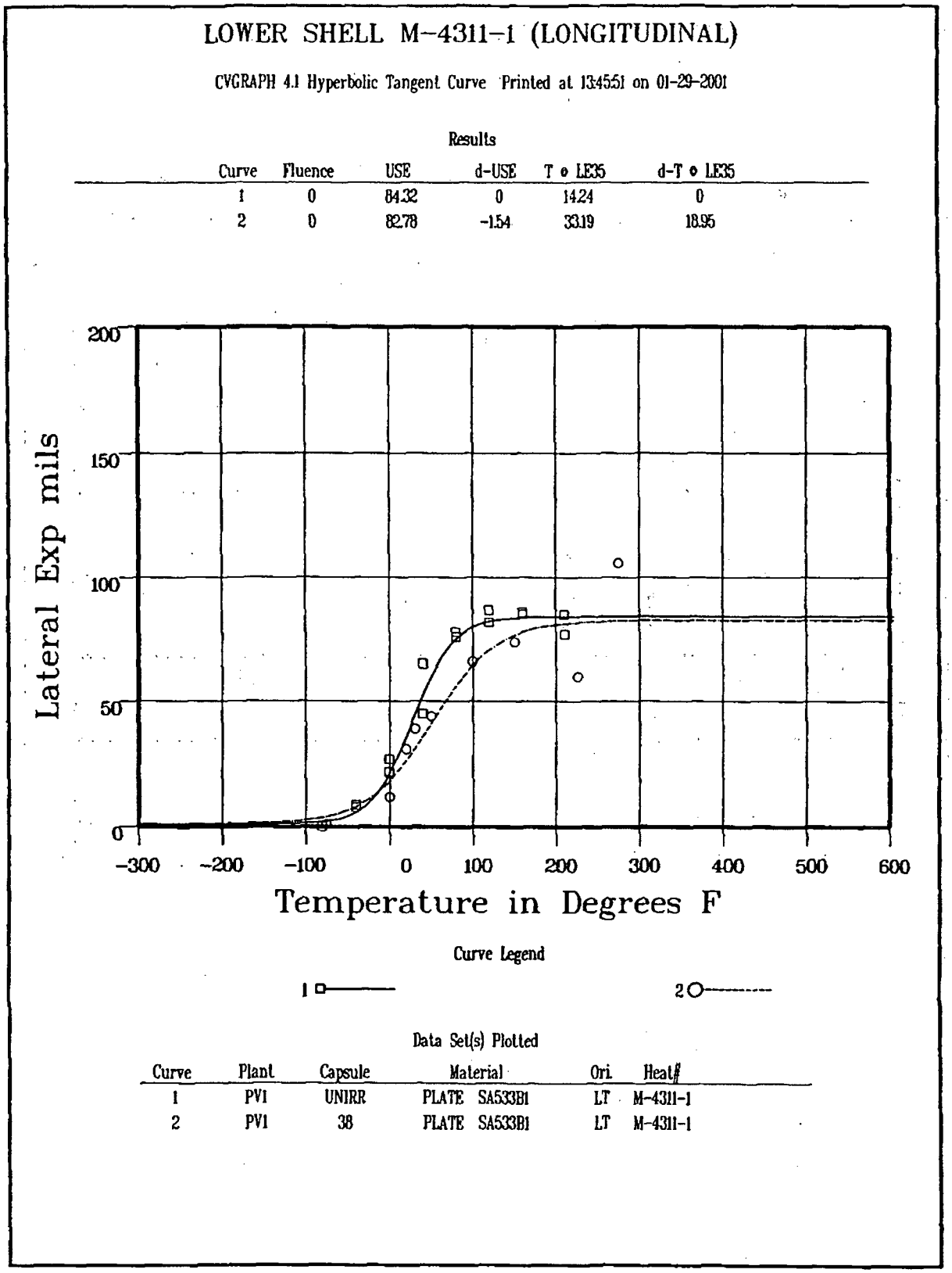


Figure 5-2 **Charpy V-Notch Lateral Expansion vs. Temperature for Palo Verde Unit 1 Reactor Vessel Lower Shell Plate M-4311-1 (Longitudinal Orientation)**

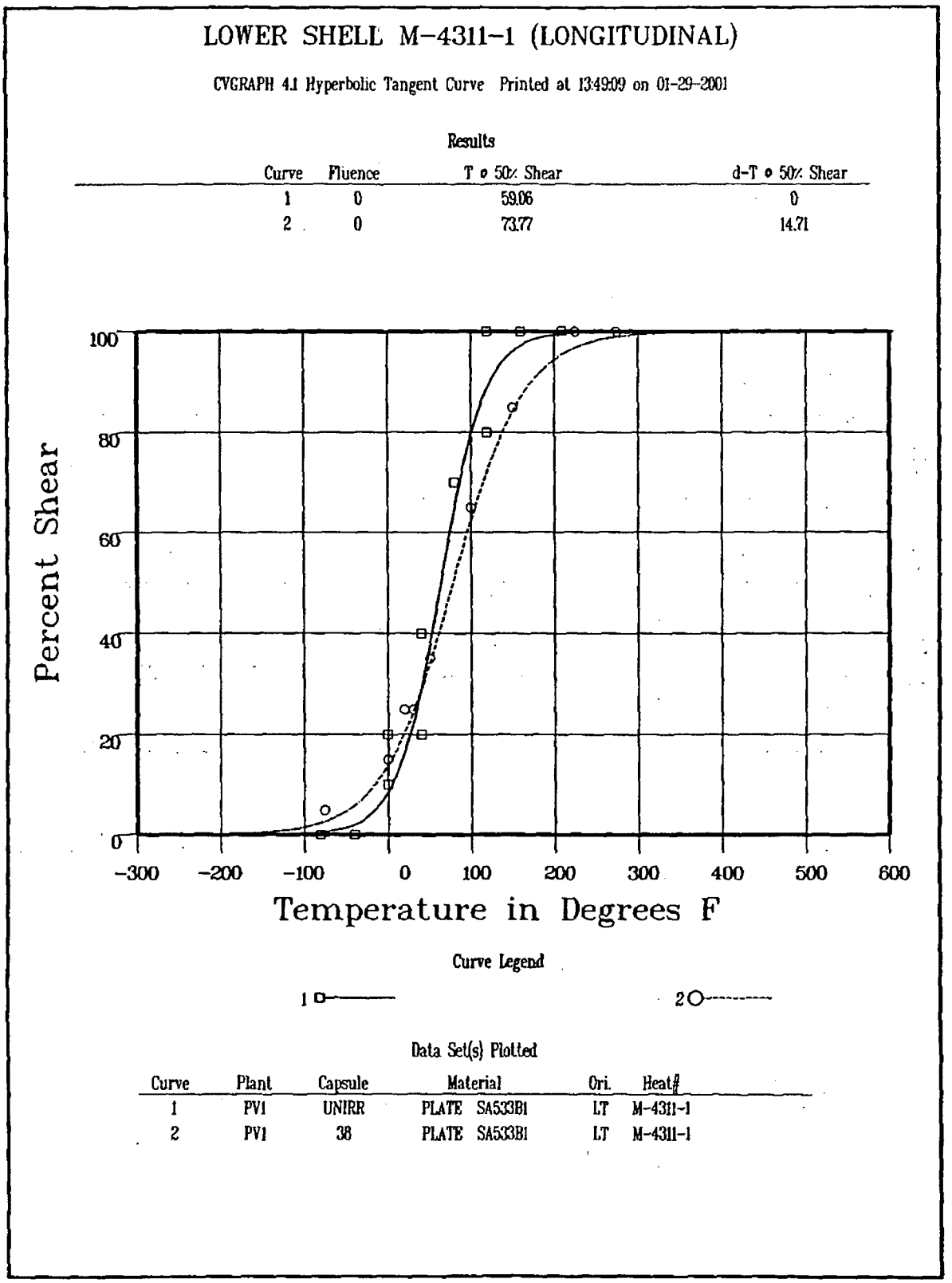


Figure 5-3 **Charpy V-Notch Percent Shear vs. Temperature for Palo Verde Unit 1 Reactor Vessel Lower Shell Plate M-4311-1 (Longitudinal Orientation)**

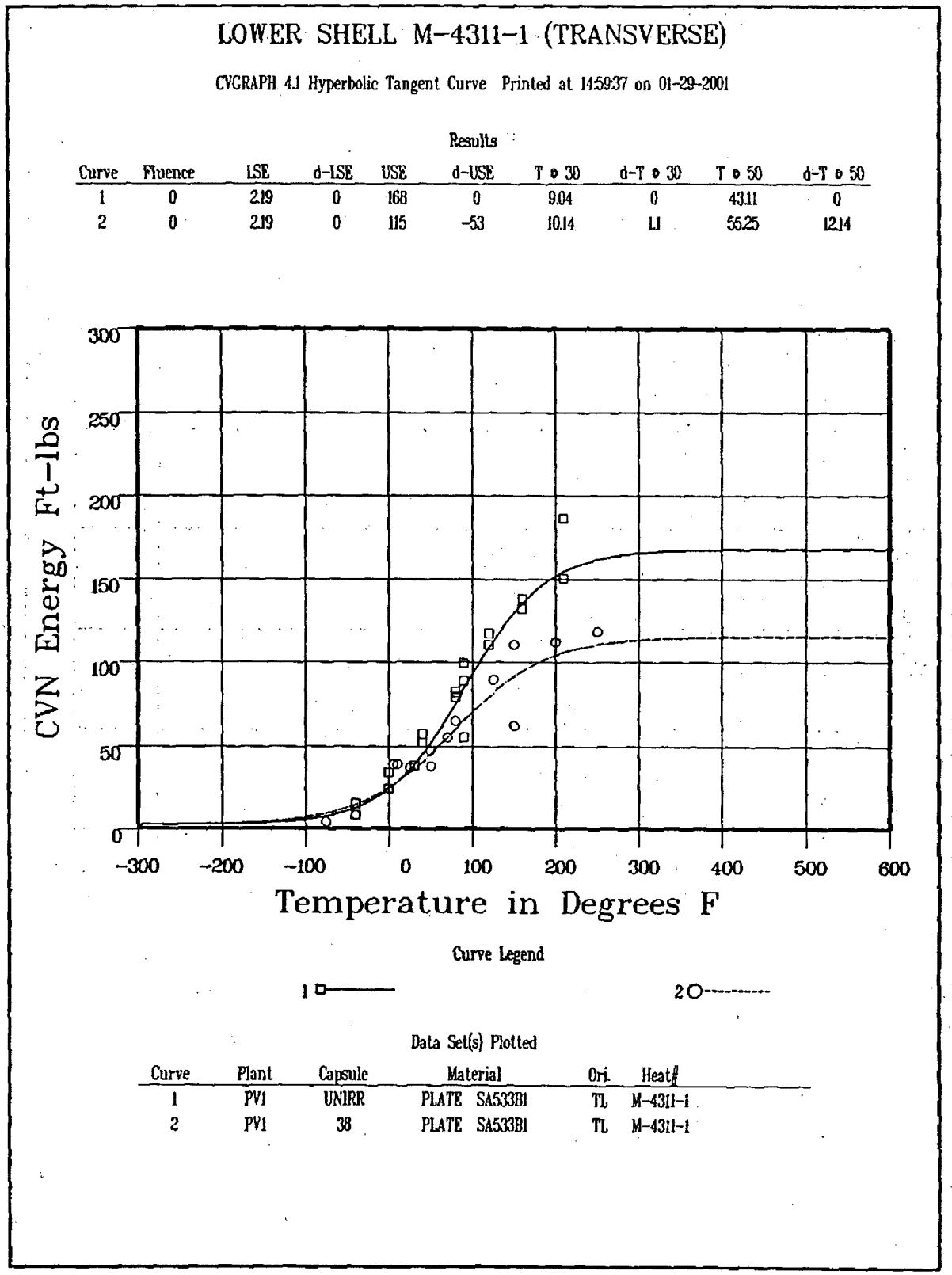


Figure 5-4 **Charpy V-Notch Impact Energy vs. Temperature for Palo Verde Unit 1 Reactor Vessel Lower Shell Plate M-4311-1 (Transverse Orientation)**

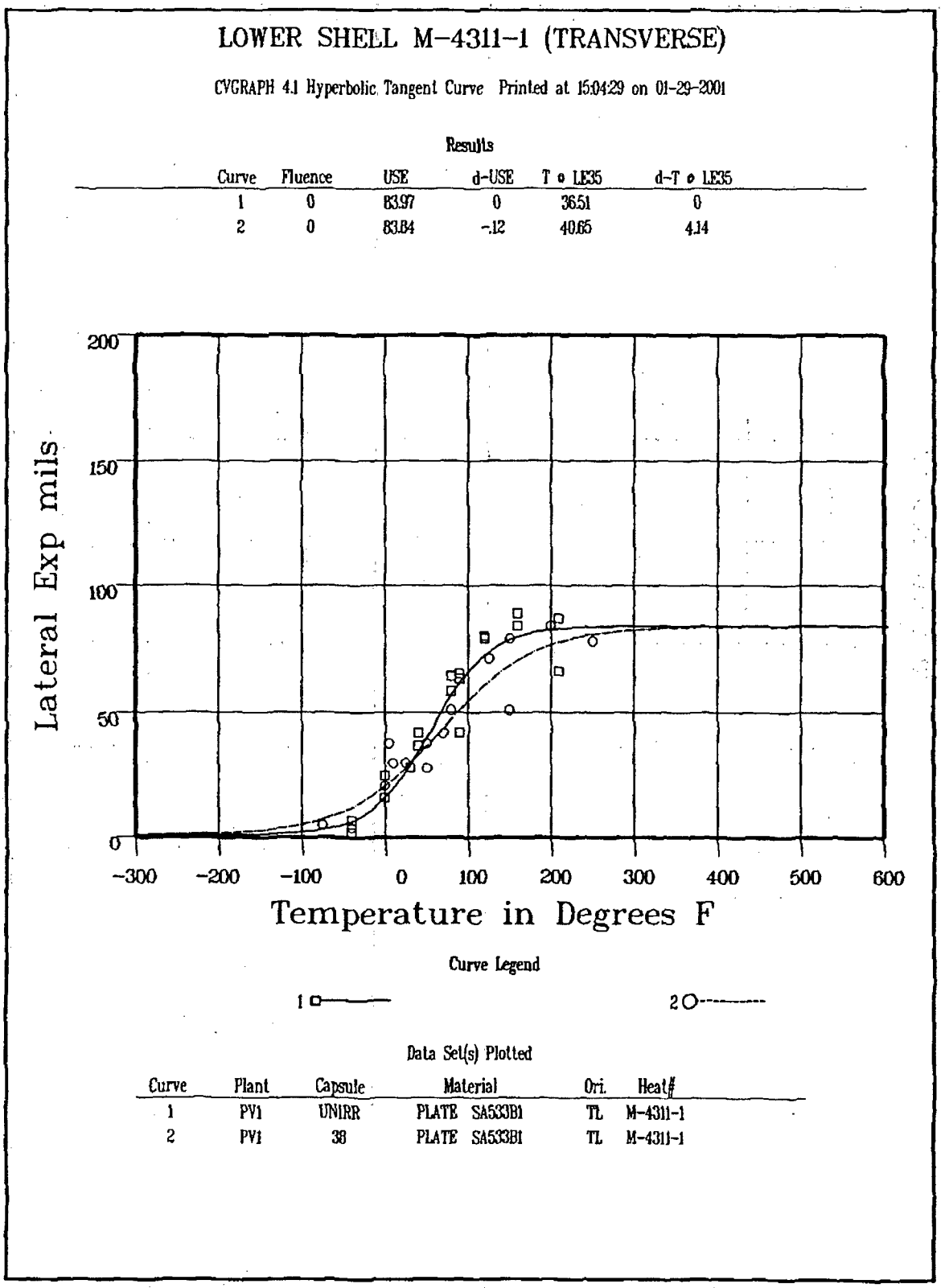


Figure 5-5 **Charpy V-Notch Lateral Expansion vs. Temperature for Palo Verde Unit 1 Reactor Vessel Lower Shell Plate M-4311-1 (Transverse Orientation)**

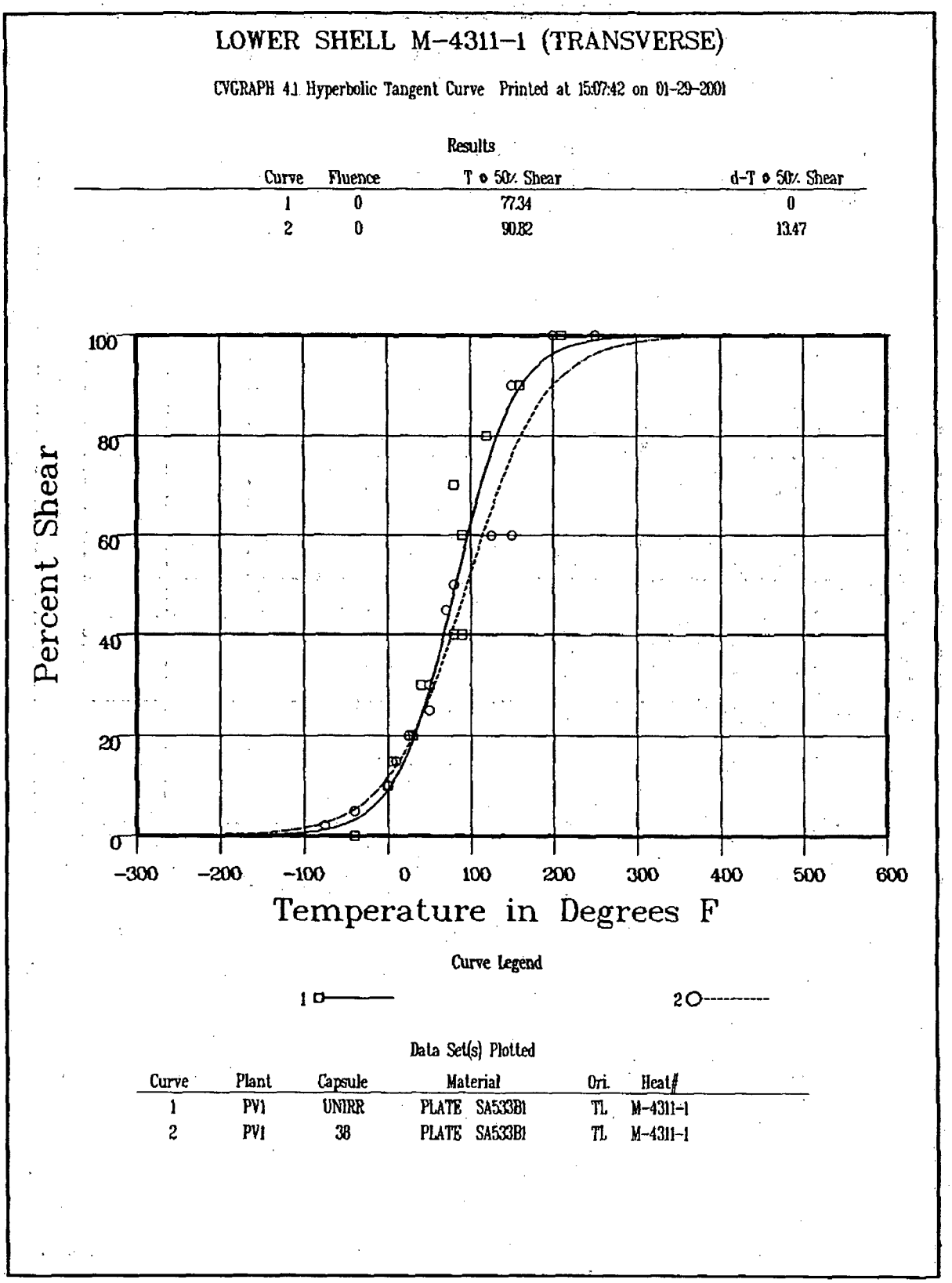


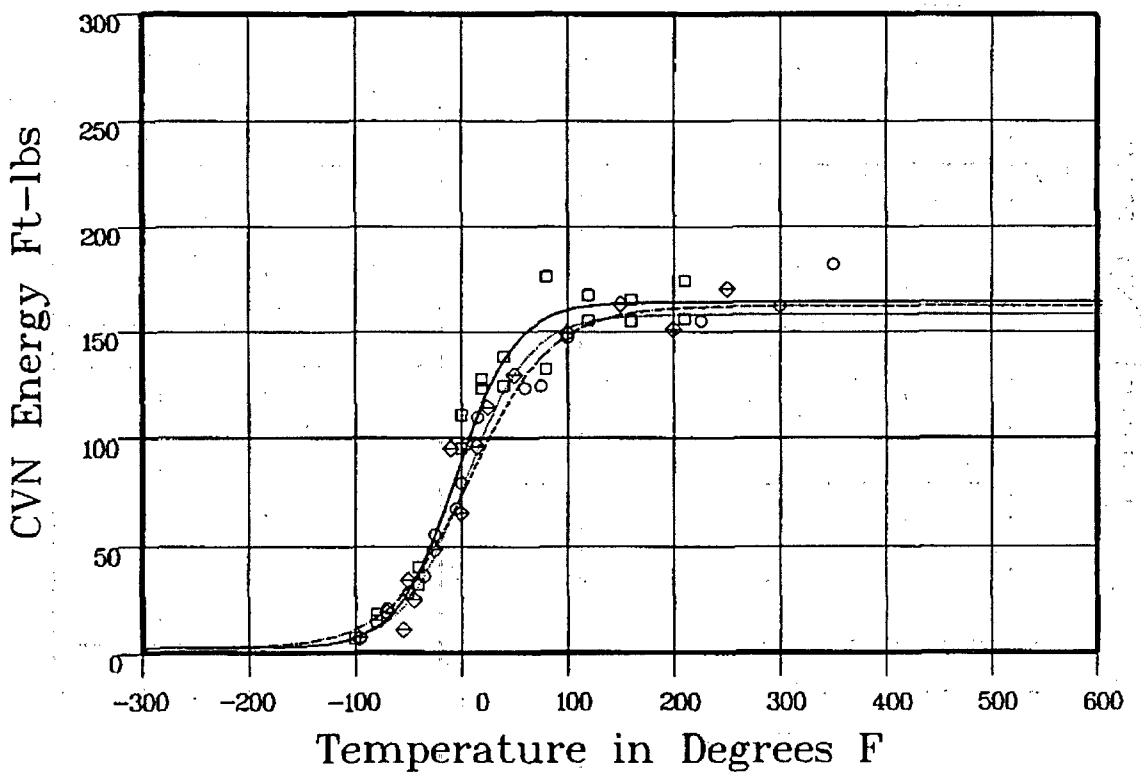
Figure 5-6 **Charpy V-Notch Percent Shear vs. Temperature for Palo Verde Unit 1 Reactor Vessel Lower Shell Plate M-4311-1 (Transverse Orientation)**

SURVEILLANCE WELD

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:10:14 on 08-04-2000

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T o 30	d-T o 30	T o 50	d-T o 50
1	0	2.19	0	164	0	-53.28	0	-33.43	0
2	0	2.19	0	162	-2	-56.22	-2.94	-28.82	4.6
3	0	2.19	0	158	-6	-47	6.27	-25.3	8.12



Curve Legend

1 □——— 2 ○- - - - - 3 ◇———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori. Heat#
1	PV1	UNIRR	WELD	M-4311-1/M-4311-2
2	PV1	137	WELD	M-4311-1/M-4311-2
3	PV1	38	WELD	M-4311-1/M-4311-2

Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for Palo Verde Unit 1 Reactor Vessel Surveillance Weld Material

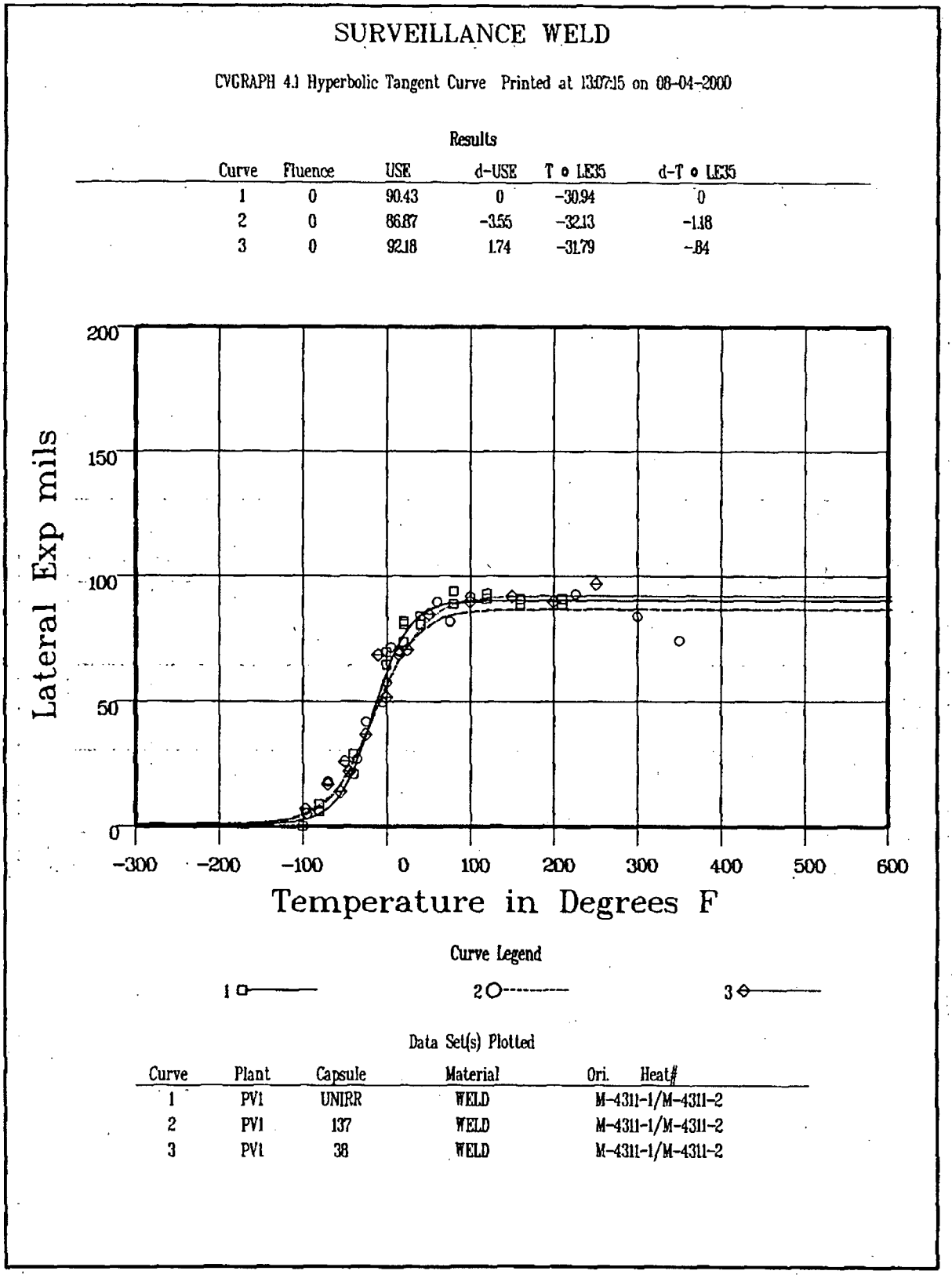


Figure 5-8 **Charpy V-Notch Lateral Expansion vs. Temperature for Palo Verde Unit 1 Reactor Vessel Surveillance Weld Metal**

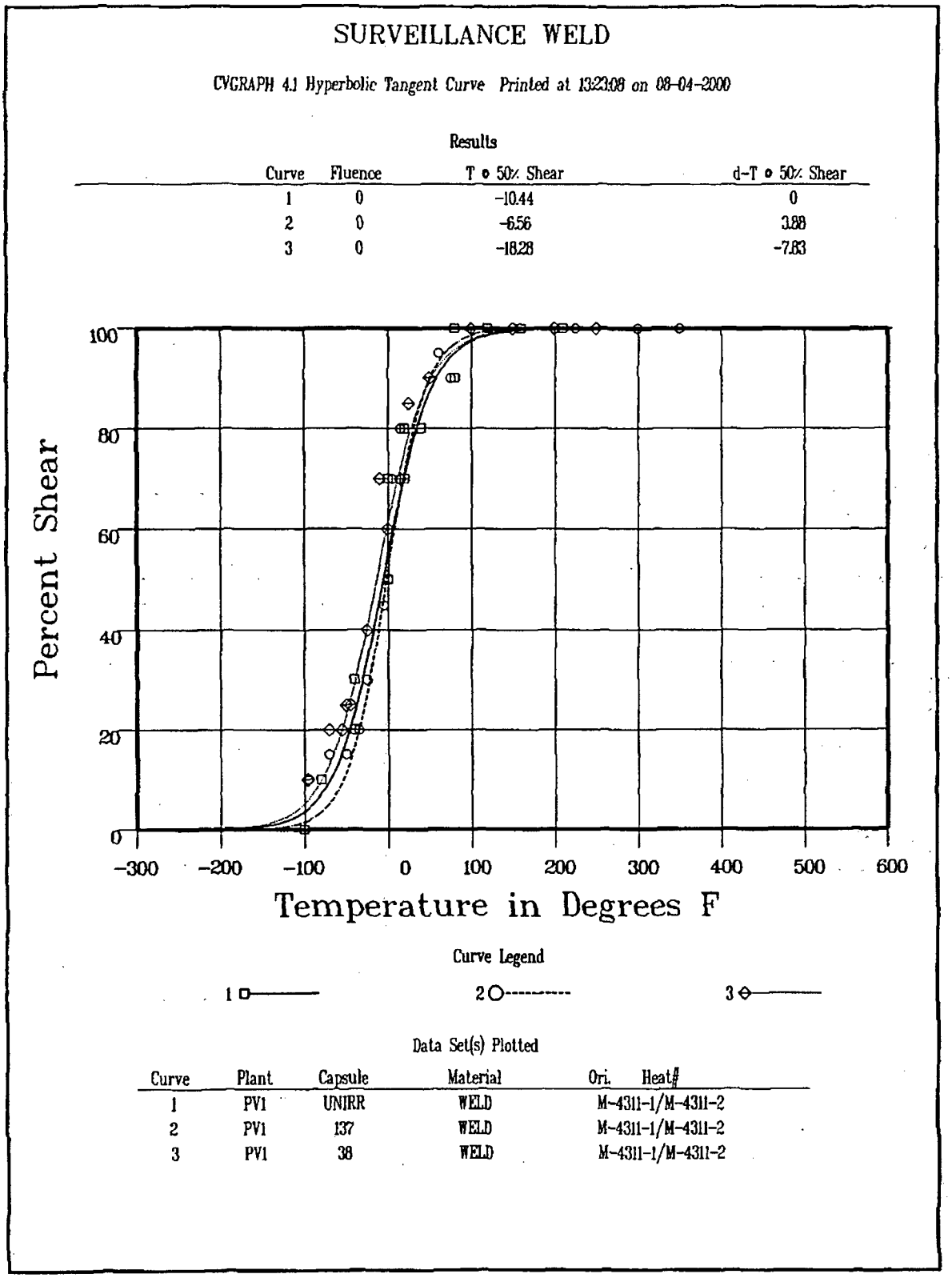


Figure 5-9 **Charpy V-Notch Percent Shear vs. Temperature for Palo Verde Unit 1 Reactor Vessel Surveillance Weld Metal**

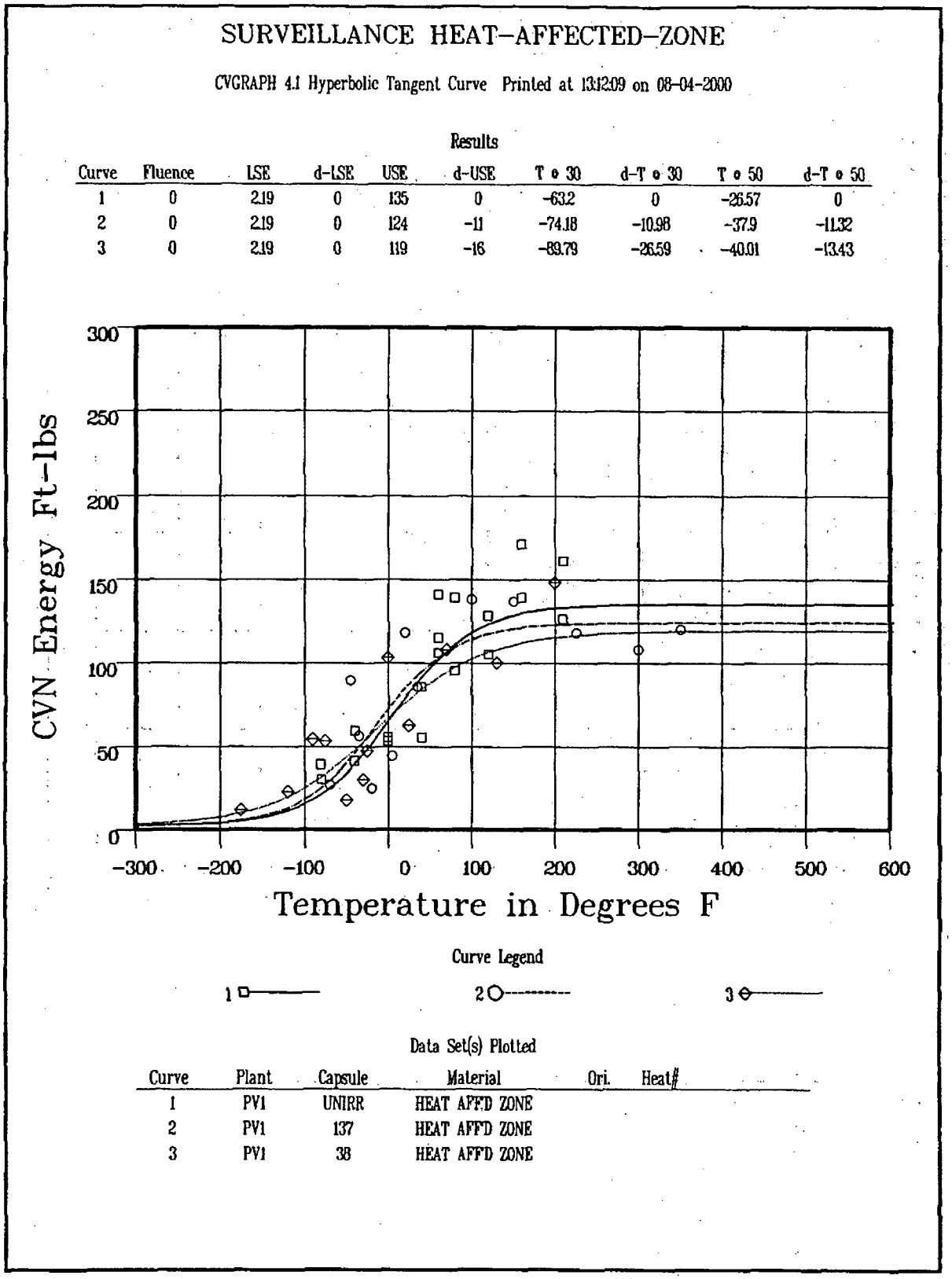


Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for Palo Verde Unit 1 Reactor Vessel Heat Affected Zone Material

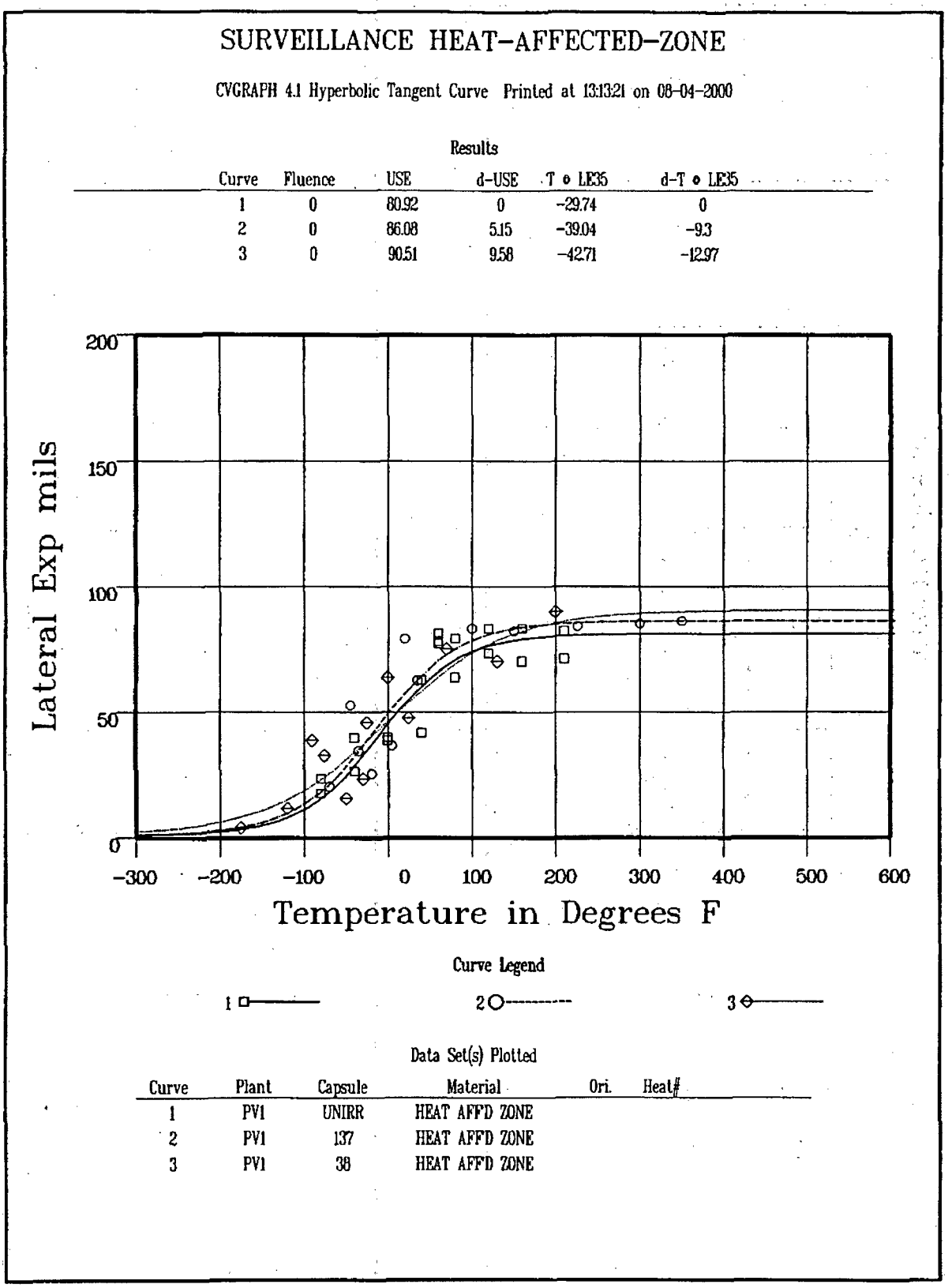


Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for Palo Verde Unit 1 Reactor Vessel Heat Affected Zone Material

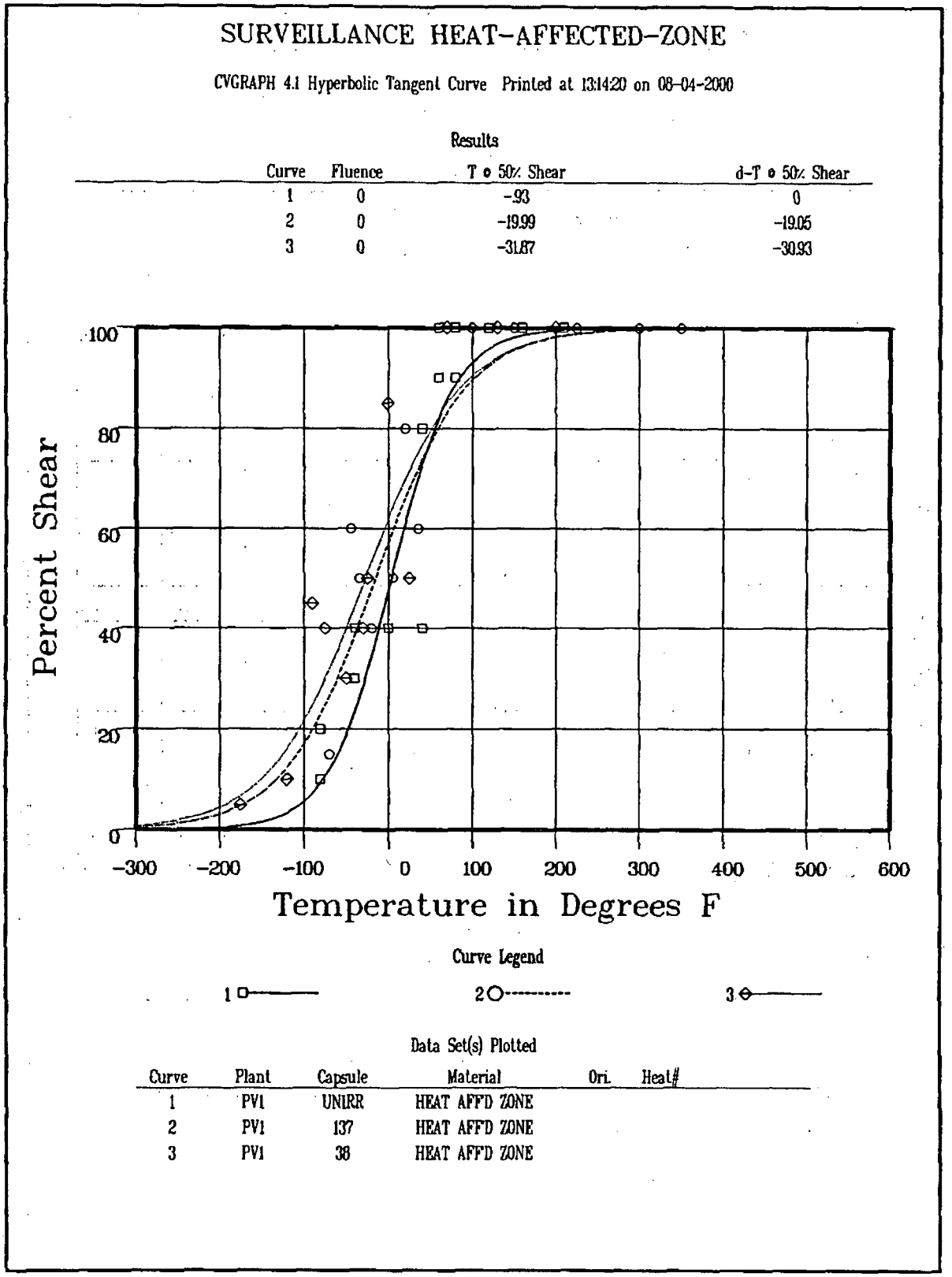


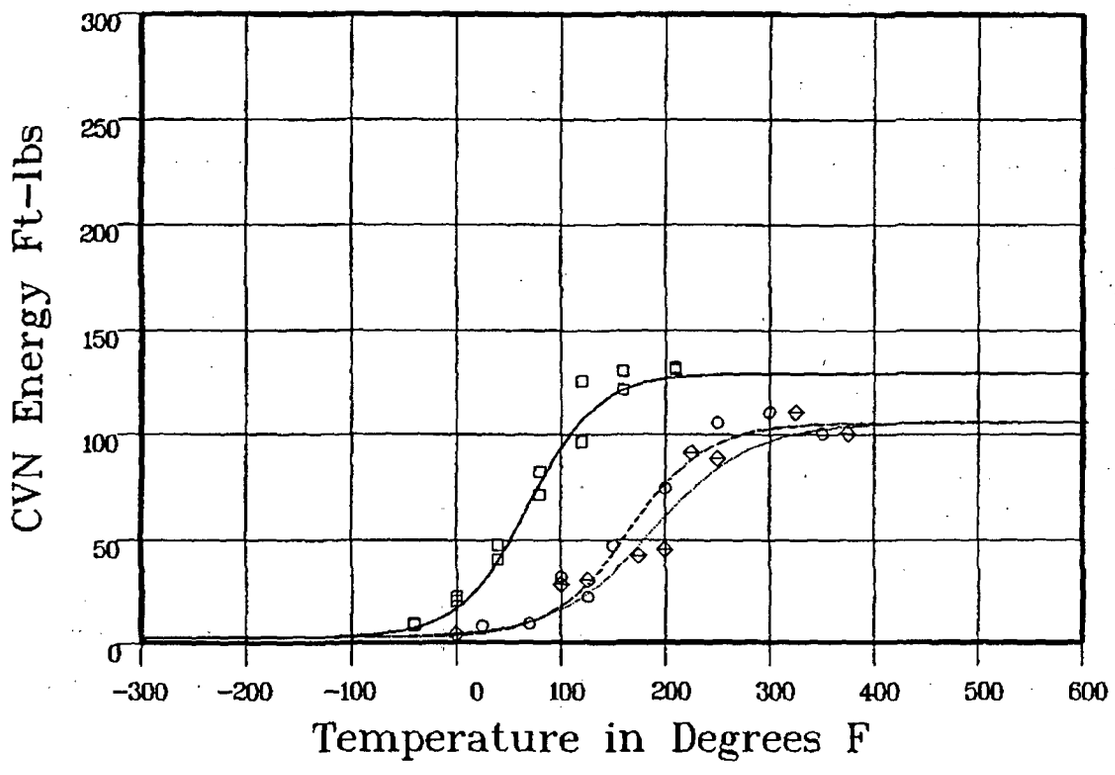
Figure 5-12 Charpy V-Notch Percent Shear vs. Temperature for Palo Verde Unit 1 Reactor Vessel Heat Affected Zone Material

STANDARD REFERENCE MATERIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:16:57 on 08-04-2000

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T o 30	d-T o 30	T o 50	d-T o 50
1	0	2.19	0	129	0	21.9	0	47.61	0
2	0	2.19	0	105	-24	123.29	101.39	155.28	107.66
3	0	2.19	0	105	-24	136.16	114.25	176.21	128.6



Curve Legend

1 ——— 2 - - - - - - 3 ———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	PV1	UNIRR	SRM SA533B1	LT	
2	PV1	137	SRM SA533B1	LT	
3	PV1	38	SRM SA533B1		

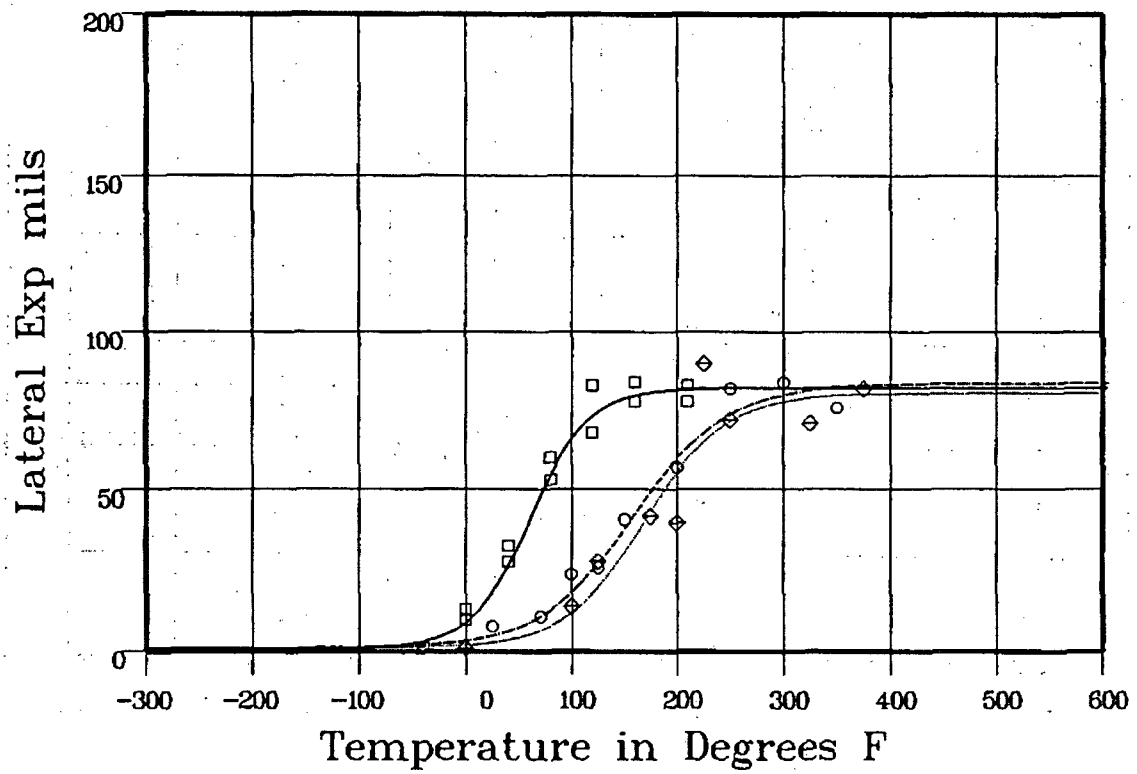
Figure 5-13 Charpy V-Notch Impact Energy vs. Temperature for Palo Verde Unit 1 Reactor Vessel Standard Reference Material

STANDARD REFERENCE MATERIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:18:12 on 08-04-2000

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	82.27	0	47.48	0
2	0	83.64	1.37	138.54	91.05
3	0	80.62	-1.64	153.84	106.35



Curve Legend

1 □———— 2 ○--------- 3 ◇————

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	PV1	UNIRR	SRM SA533B1	LT	
2	PV1	137	SRM SA533B1	LT	
3	PV1	38	SRM SA533B1		

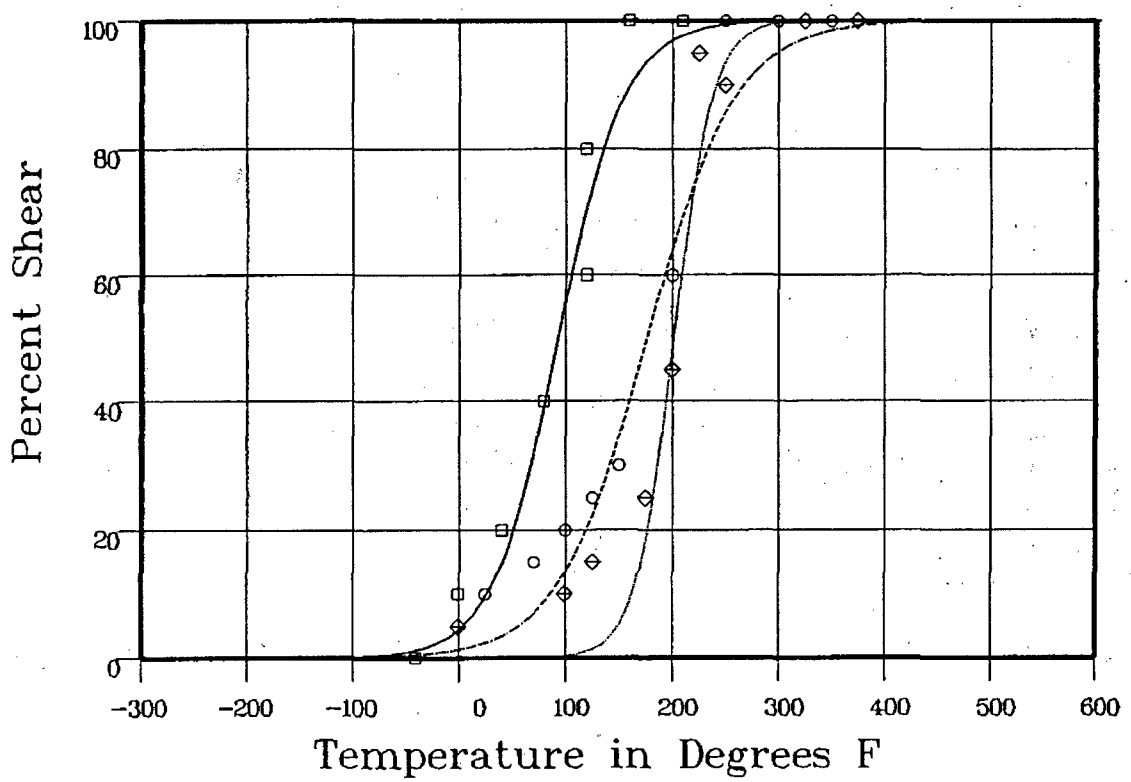
Figure 5-14 Charpy V-Notch Lateral Expansion vs. Temperature for Palo Verde Unit 1 Reactor Vessel Standard Reference Material

STANDARD REFERENCE MATERIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:19:05 on 08-04-2000

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	88.76	0
2	0	171.67	82.91
3	0	196.95	108.18



Curve Legend

1 □——— 2 ○---------- 3 ◇———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	PV1	UNIRR	SRM SA533B1	LT	
2	PV1	137	SRM SA533B1	LT	
3	PV1	38	SRM SA533B1		

Figure 5-15 Charpy V-Notch Percent Shear vs. Temperature for Palo Verde Unit 1 Reactor Vessel Standard Reference Material

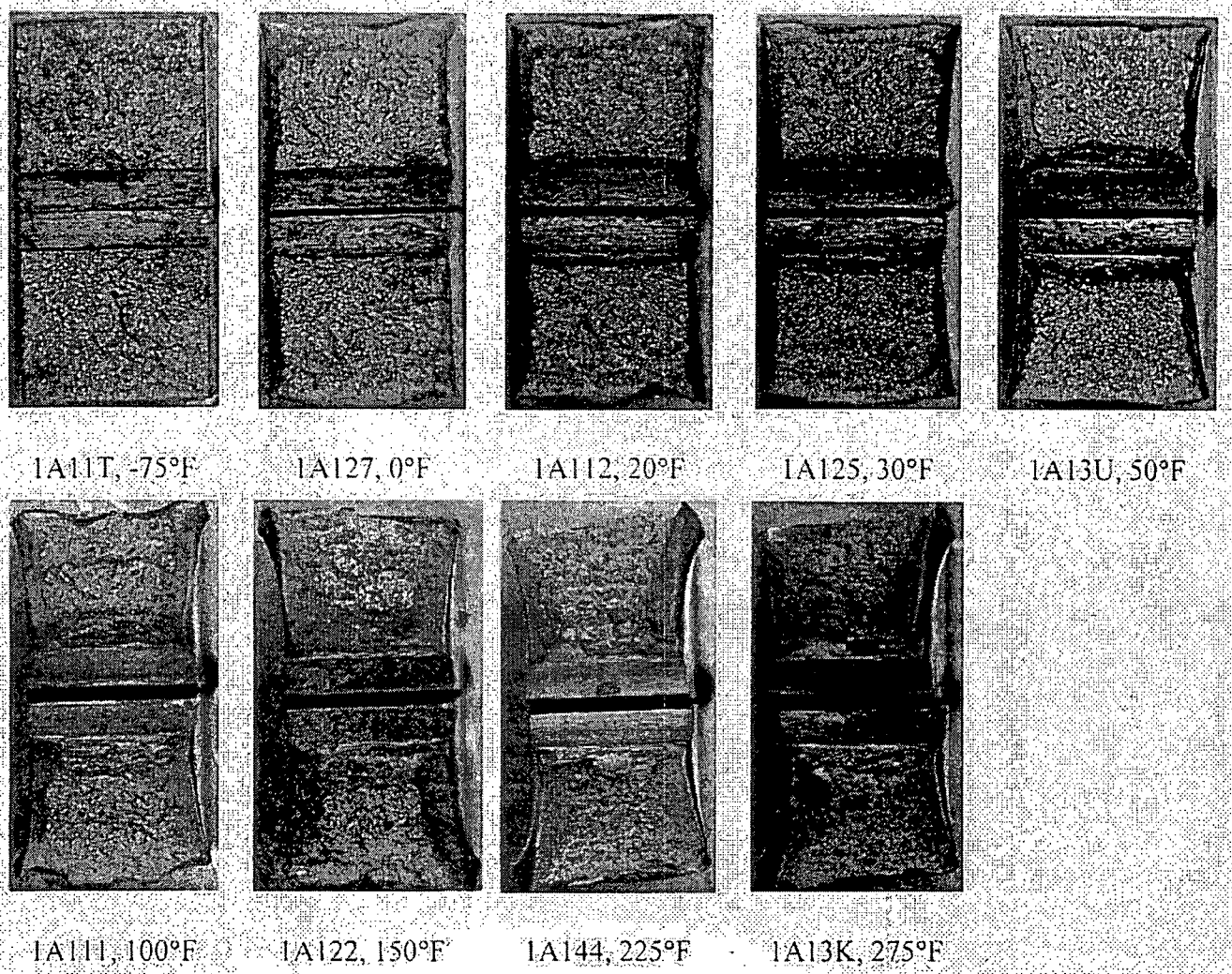


Figure 5-16 Charpy Impact Specimen Fracture Surfaces for Palo Verde Unit 1 Reactor Vessel Lower Shell Plate M-4311-1 (Transverse Orientation)

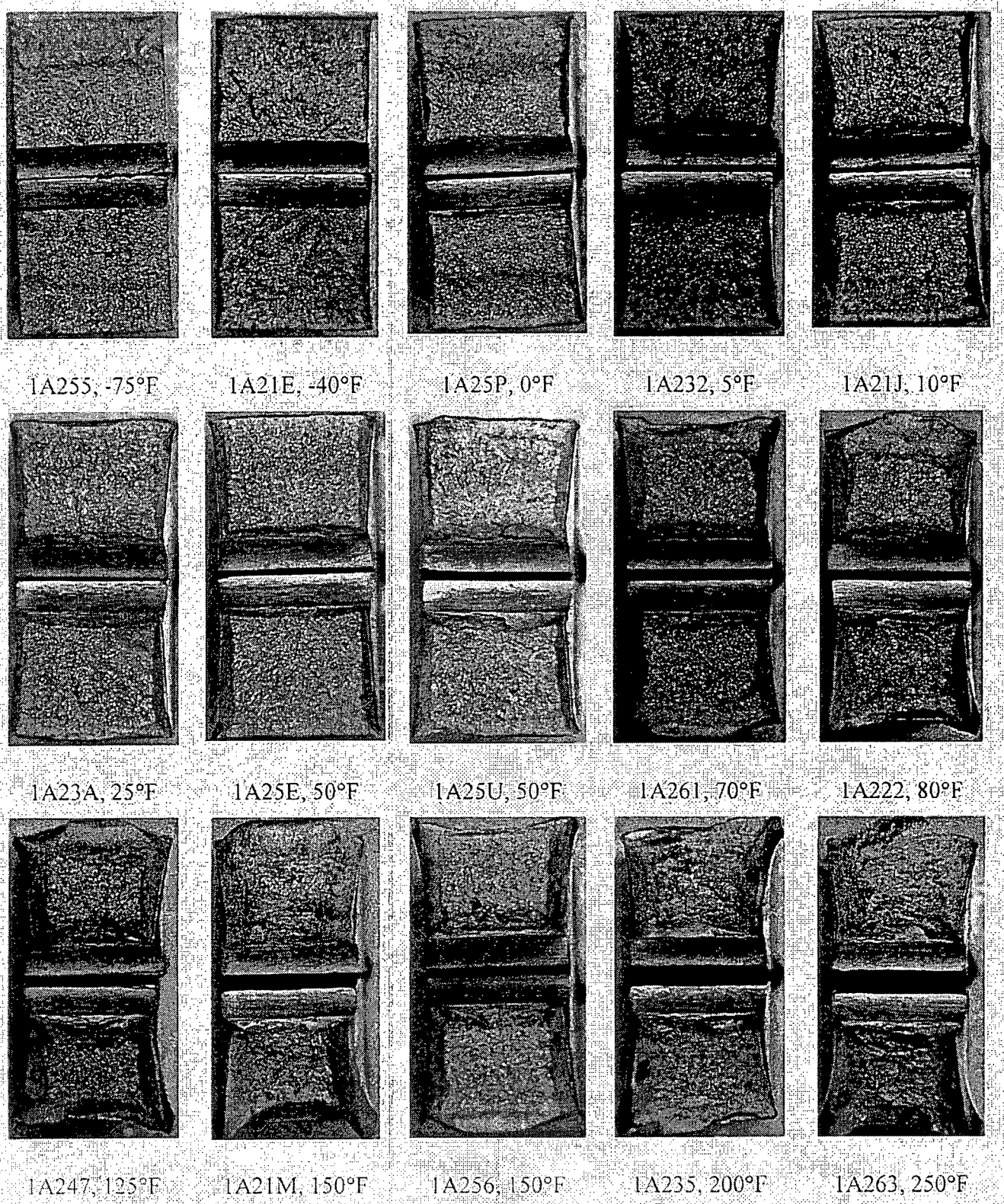


Figure 5-17 Charpy Impact Specimen Fracture Surfaces for Palo Verde Unit 1 Reactor Vessel Lower Shell Plate M-4311-1 (Longitudinal Orientation)

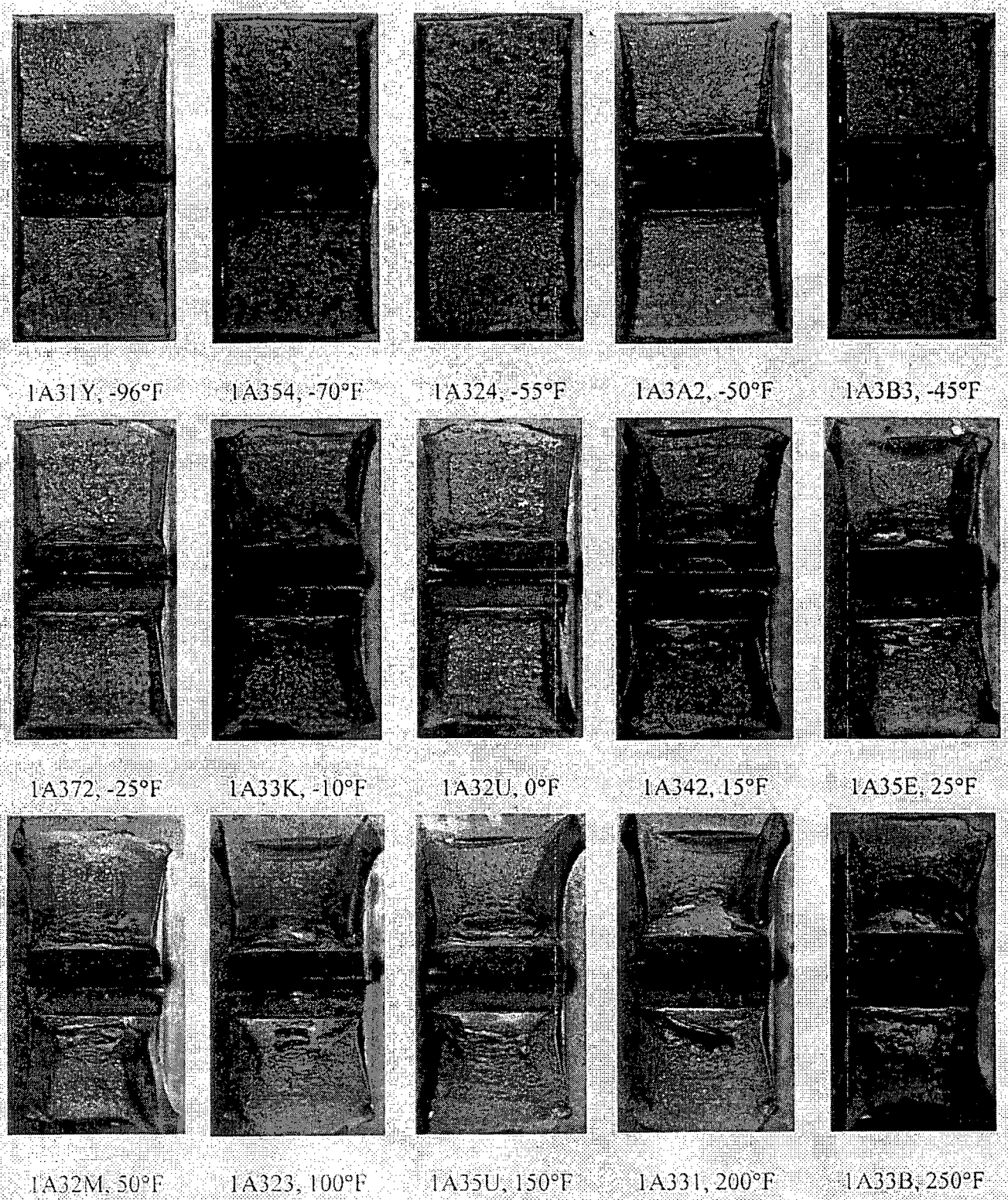


Figure 5-18 Charpy Impact Specimen Fracture Surfaces for Palo Verde Unit 2 Reactor Vessel Weld Metal Specimens

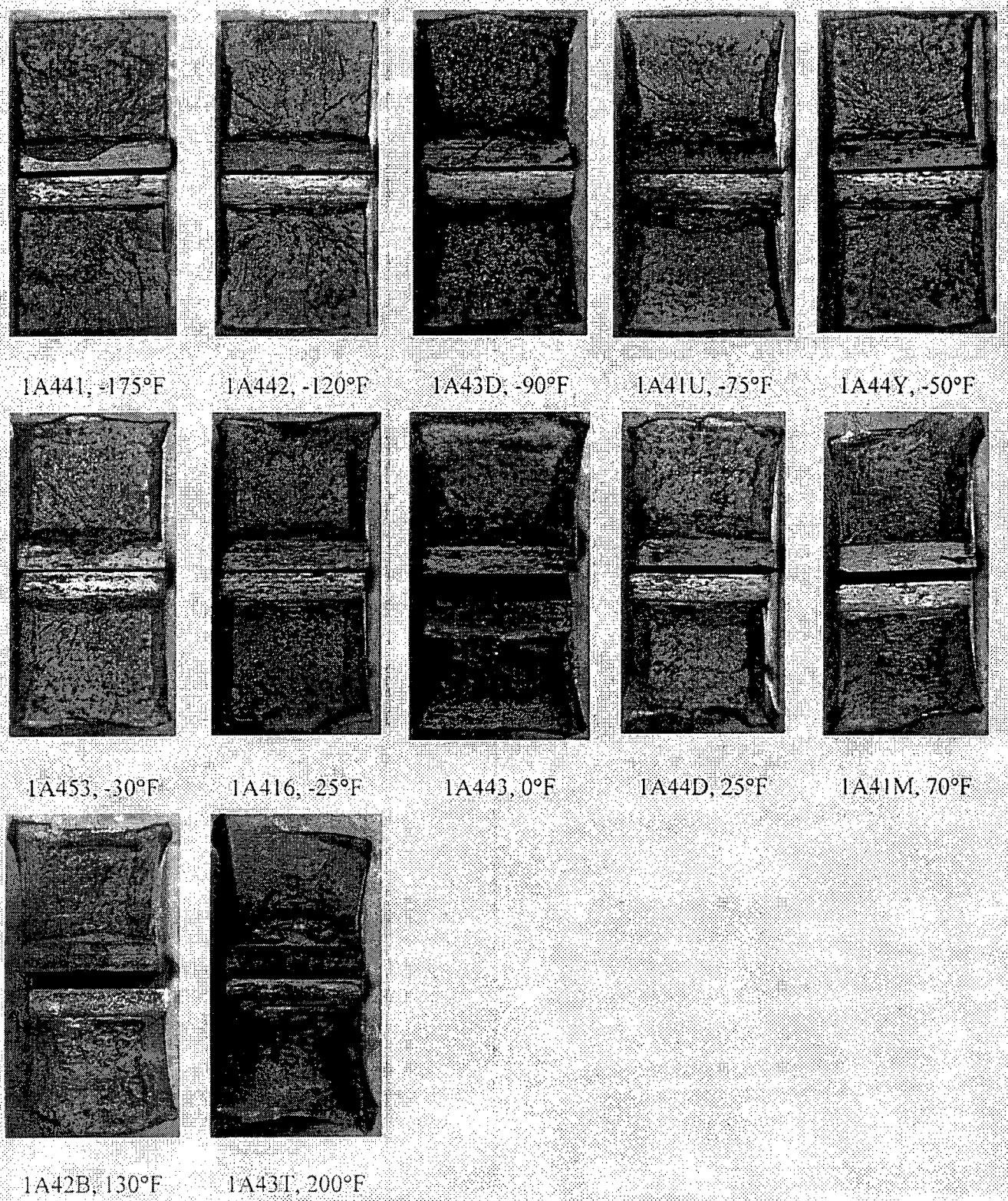


Figure 5-19 Charpy Impact Specimen Fracture Surfaces for Palo Verde Unit 1 Reactor Vessel Heat Affected Zone (HAZ)

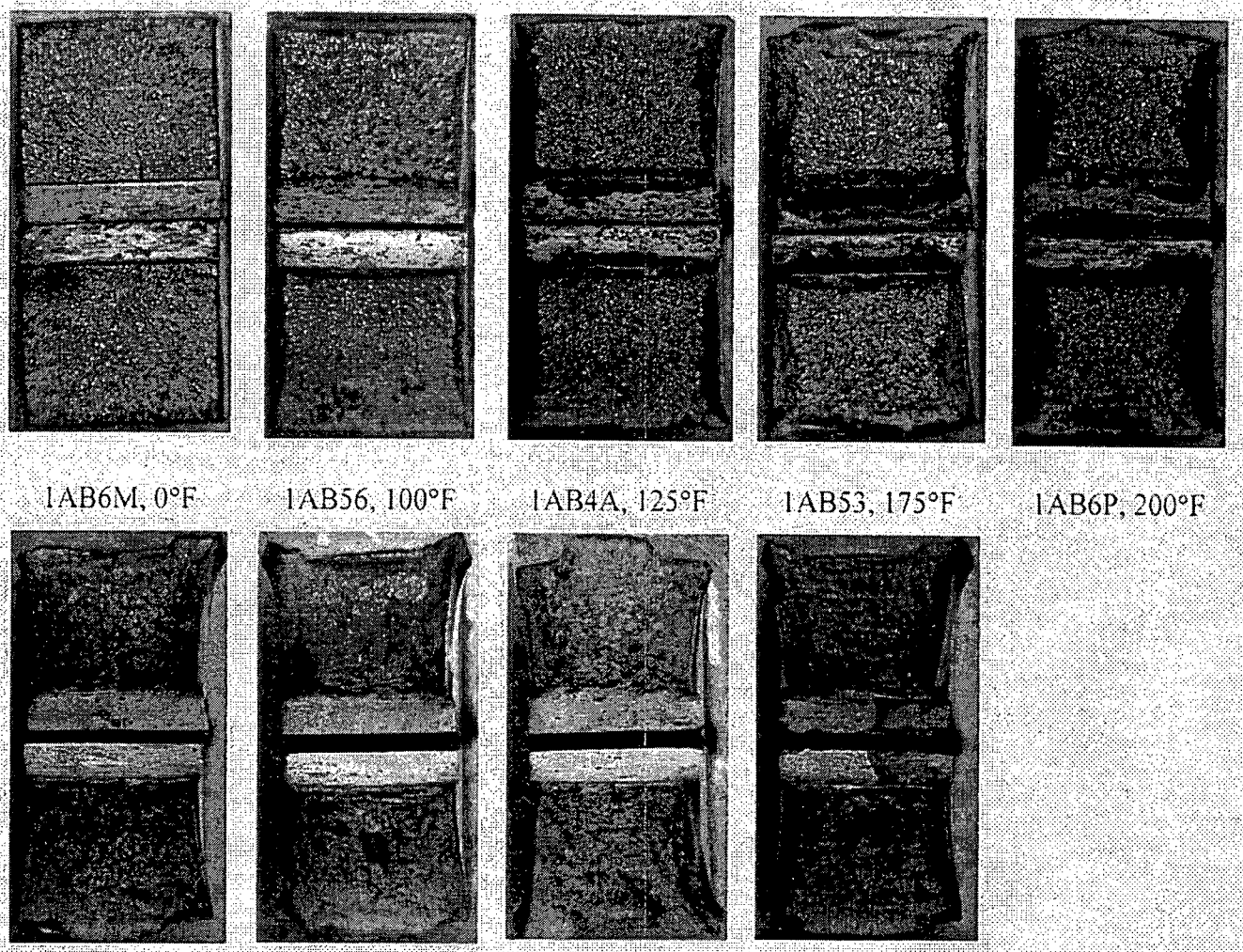
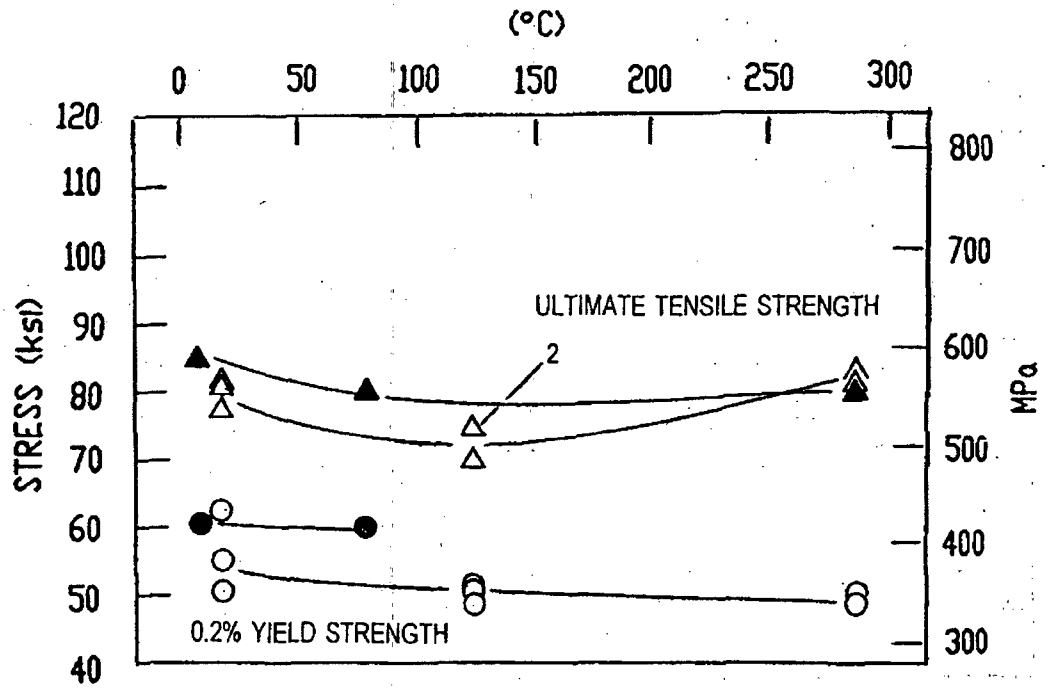


Figure 5-20 Charpy Impact Specimen Fracture Surfaces for Palo Verde Unit 1 Reactor Vessel Standard Reference Material



LEGEND:

○ △ **UNIRRADIATED**

● ▲ **IRRADIATED TO A FLUENCE OF 7.85 X 10^{18} n/cm^2 (E>1.0MeV) AT 550°F**

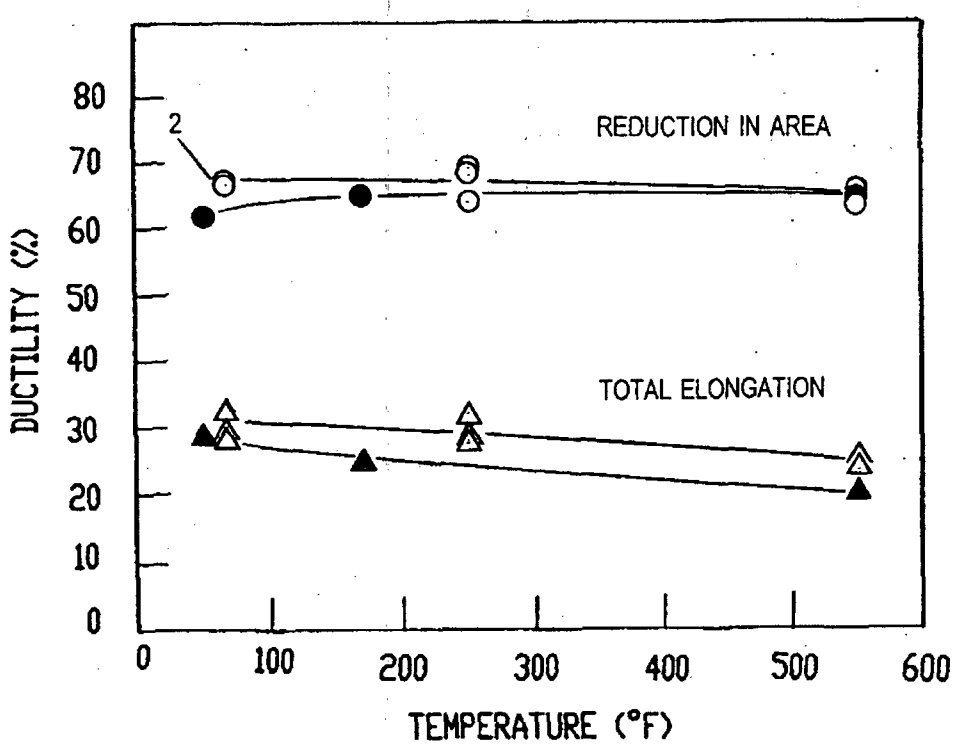
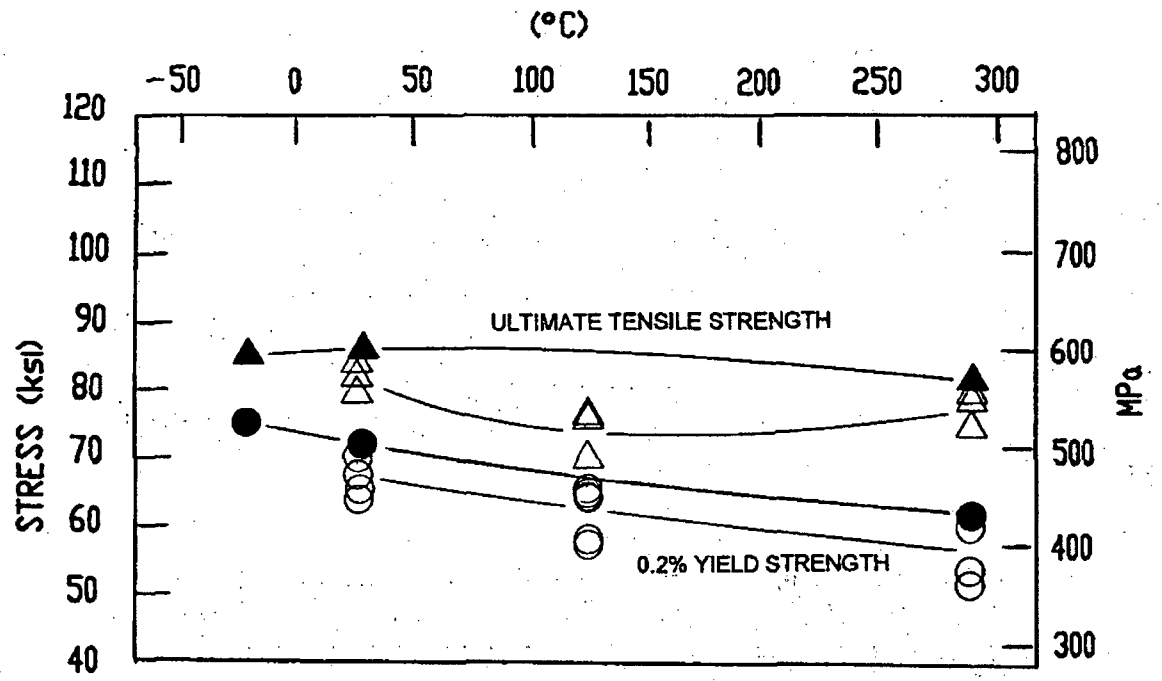


Figure 5-21 **Tensile Properties for Palo Verde Unit 1 Reactor Vessel Lower Shell Plate M-4311-1 (Transverse Orientation)**



LEGEND:

○ △ **UNIRRADIATED**

● ▲ **IRRADIATED TO A FLUENCE OF 7.85 X 10^{18} n/cm^2 (E>1.0MeV) AT 550°F**

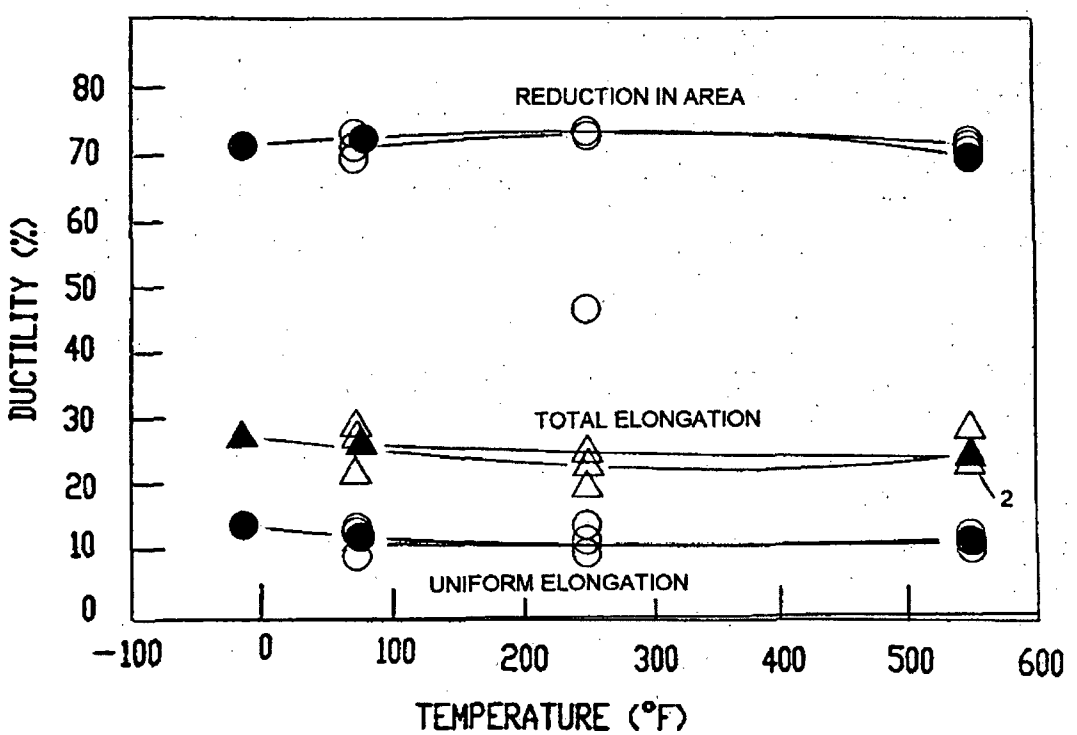
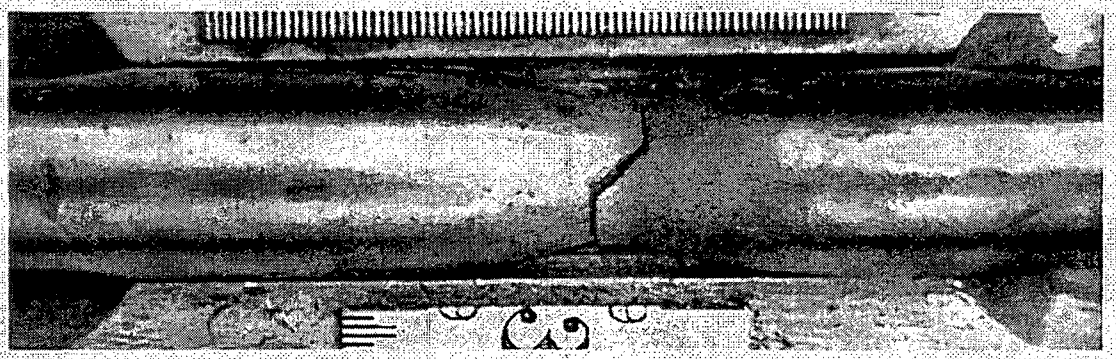
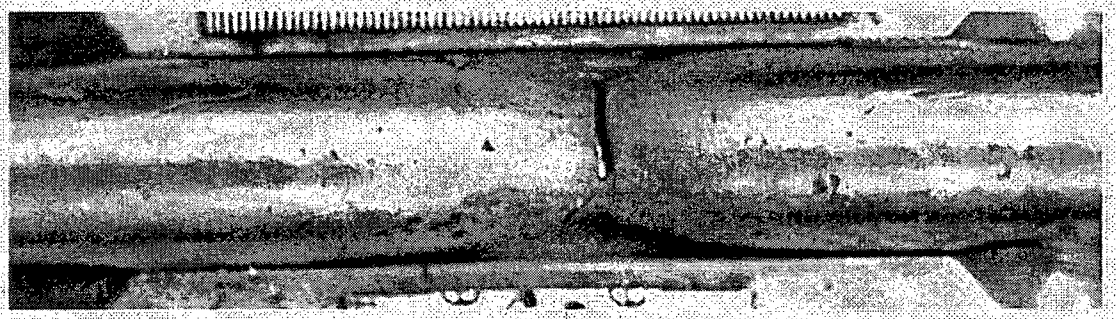


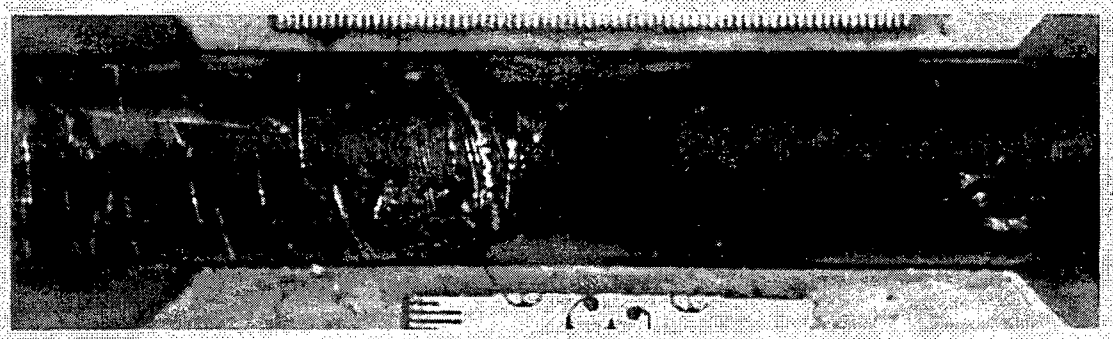
Figure 5-22 Tensile Properties for Palo Verde Unit 1 Reactor Vessel Weld Metal



Specimen 1A2JC Tested at 50°F

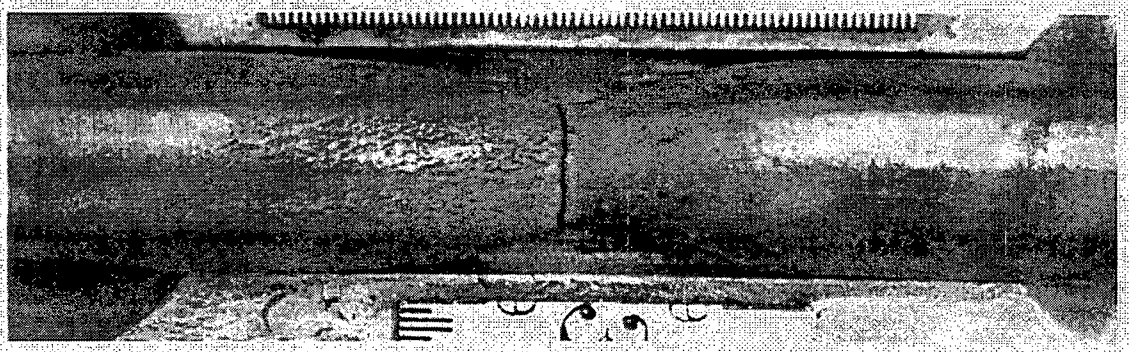


Specimen 1A2K2 Tested at 175°F

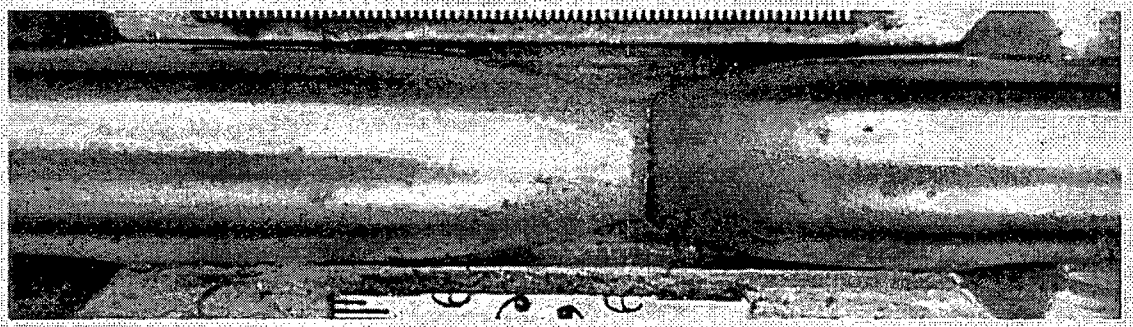


Specimen 1A2J5 Tested at 550°F

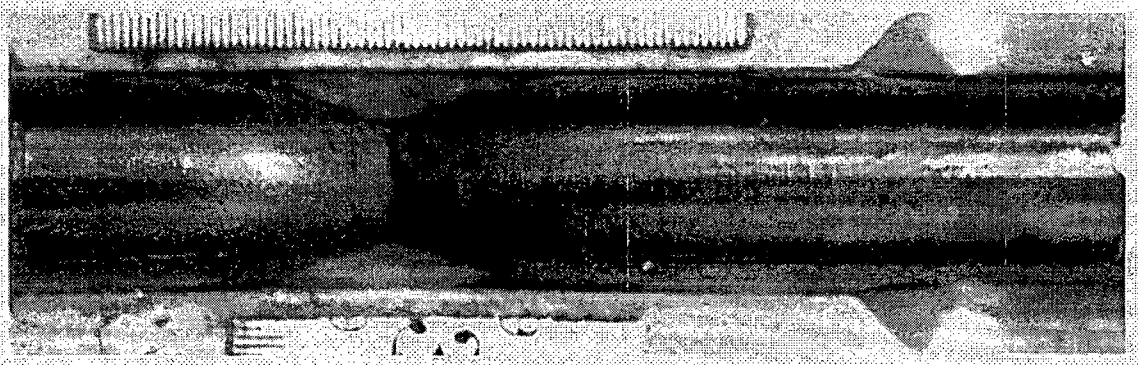
Figure 5-23 Fractured Tensile Specimens from Palo Verde Unit 1 Reactor Vessel Lower Shell Plate M-4311-1 (Transverse Orientation)



Specimen 1A3JC Tested at -15°F



Specimen 1A3J4 Tested at 75°F



Specimen 1A3J7 Tested at 550°F

Figure 5-24 Fractured Tensile Specimens from Palo Verde Unit 1 Reactor Vessel Weld Metal

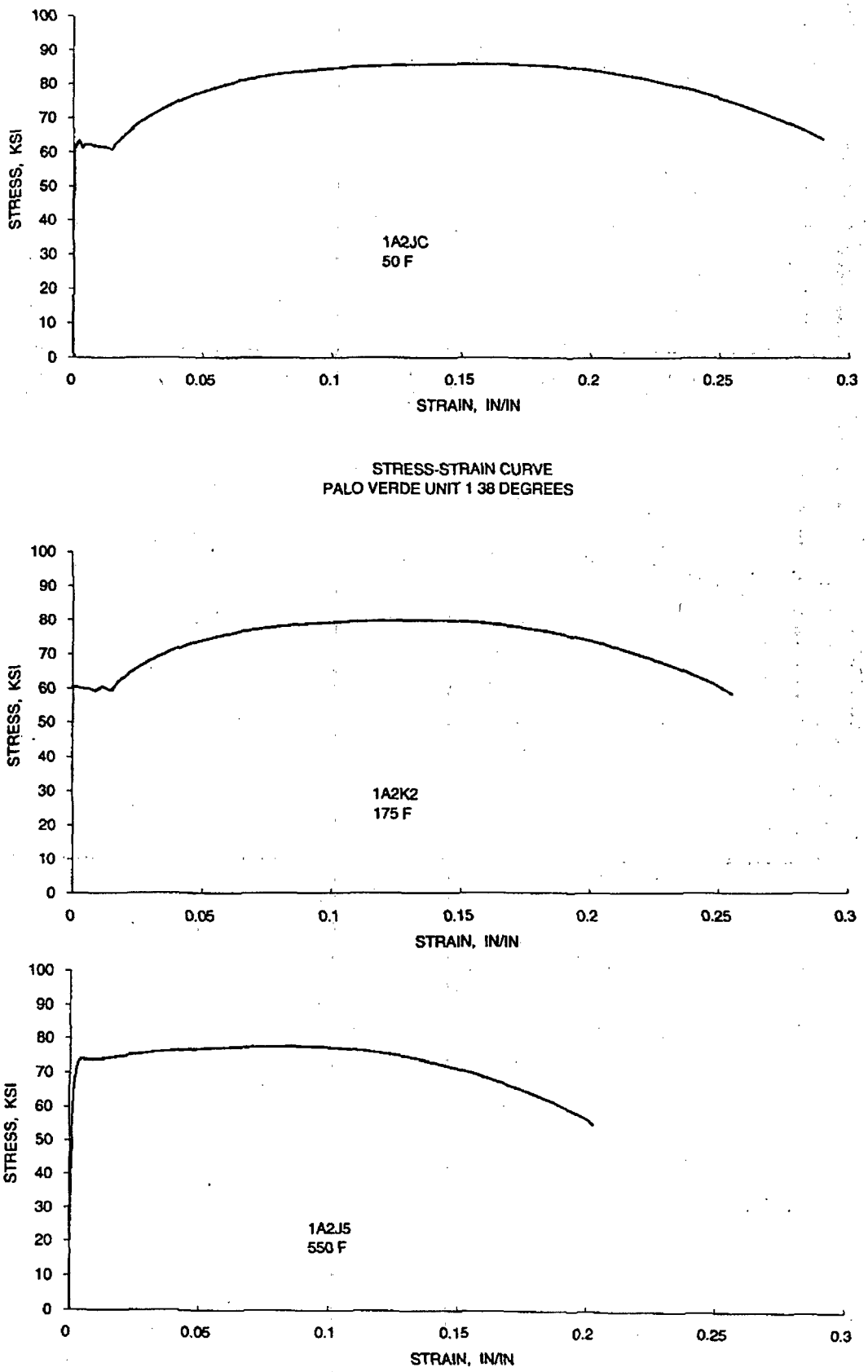


Figure 5-25 Engineering Stress-Strain Curves for Lower Shell Plate M-4311-1 Tensile Specimens 1A2JC, 1A2K2 and 1A2J5 (Transverse Orientation)

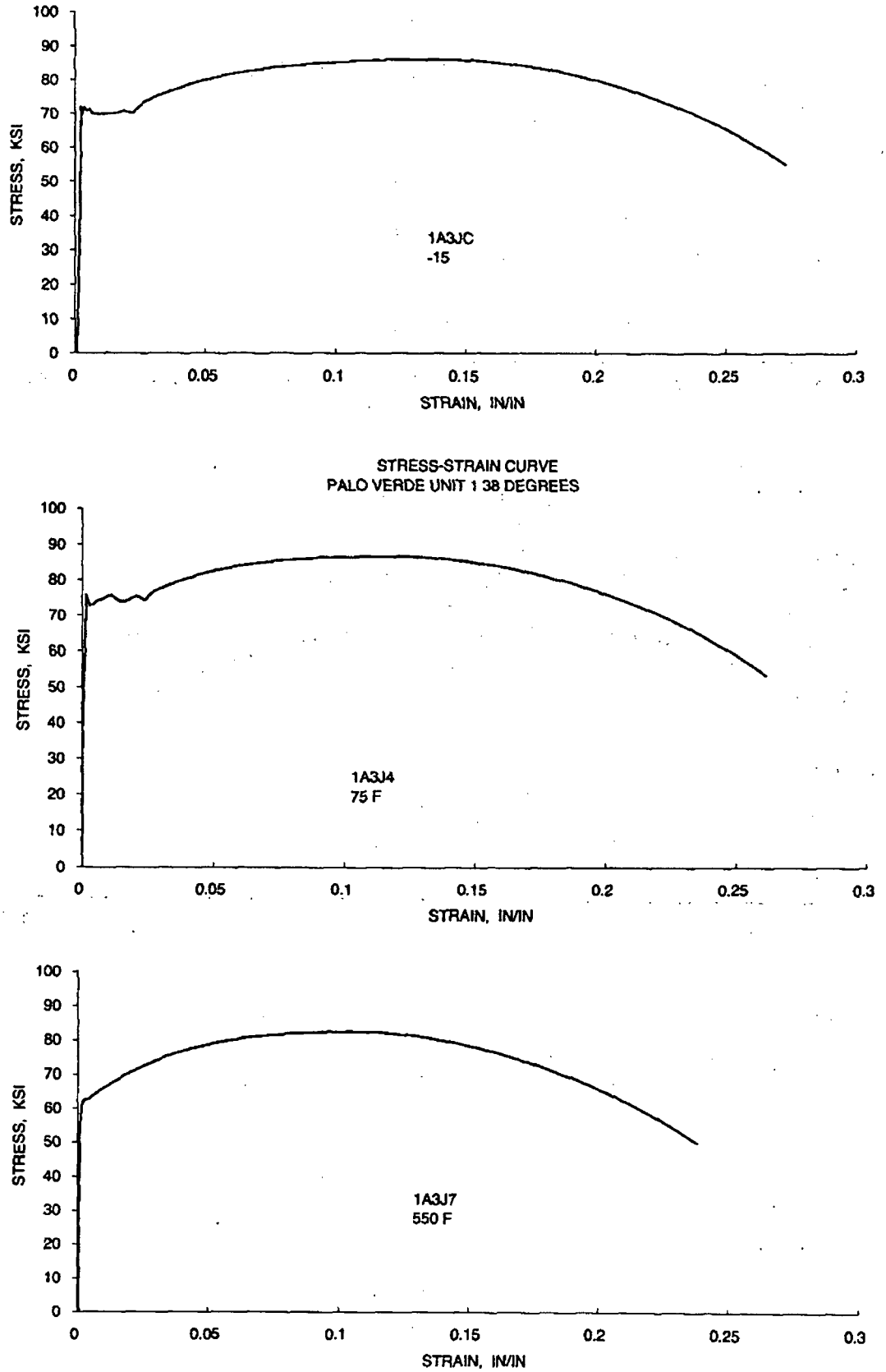


Figure 5-26 Engineering Stress-Strain Curves Weld Metal Tensile Specimens 1A3JC, 1A3J4, and 1A3J7

6 RADIATION ANALYSIS AND NEUTRON DOSIMETRY

6.1 INTRODUCTION

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

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

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

This section provides the results of the neutron dosimetry evaluations performed in conjunction with the analysis of test specimens contained in surveillance Capsules W137 and W38 which were withdrawn after the fourth and eighth fuel cycles, respectively. This evaluation is based on current state-of-the-art methodology and nuclear data including neutron transport and dosimetry cross-section libraries derived from the
ENDF/B-VI data base. This report provides a consistent up-to-date neutron exposure database for use in evaluating the material properties of the Palo Verde Unit 1 reactor vessel. Included in the neutron exposure database is information related to the standby surveillance capsules W43, W142, W230, and W310.

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

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

6.2 DISCRETE ORDINATES ANALYSIS

A plan view of the reactor geometry at the core midplane is shown in Figure 4-1. Six irradiation capsules attached to the reactor vessel are included in the reactor design to constitute the reactor vessel surveillance program. The capsules are located at azimuthal angles of 38°, 43°, 137°, 142°, 230°, and 330° relative to the core cardinal axis as shown in Figure 4-1.

A plan view of the 45 degree R-θ sector model of the reactor including the surveillance capsule holder modeling attached to the reactor vessel is shown in Figure 6-1. The 45-degree model assumes azimuthal symmetry conditions in the reactor and the three capsules modeled at 38°, 40°, and 43° represent the locations of all six surveillance capsules. The stainless steel surveillance capsule holder containers are a 1.968-inch by 1.293-inch inner dimension with a 0.138-inch wall thickness. The stainless steel specimen containers are 1.5 inch by 0.75-inch and approximately 96 inches in height. The containers are positioned axially such that the test specimens are centered on the core midplane, thus spanning the central 8 feet of the 12.5-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 distributions of neutron flux and the neutron energy spectrum in the water annulus between the core barrel 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 effect of the surveillance capsules on the neutron environment at the vessel clad base metal interface is shown in Figure 6-2.

In performing the fast neutron exposure evaluations for the surveillance capsules and reactor vessel, two sets of transport calculations were carried out. The first set of two-dimensional R-θ model calculations for each of the eight cycles use a model containing no surveillance capsules. The second set of R-θ computations were for each of the eight cycles with the surveillance capsule modeling shown in Figure 6-1 included at the 38°, 40°, and 43° locations in the 45 degree model. The two sets of calculations were used to obtain relative neutron energy distributions throughout the reactor geometry as well as to establish relative radial distributions of exposure parameters {$\phi(E > 1.0$ MeV), $\phi(E > 0.1$ MeV), and dpa/sec} through the vessel wall. The neutron spectral information was required for the interpretation of neutron dosimetry withdrawn from the surveillance capsule as well as for the determination of exposure parameter ratios, i.e., [dpa/sec]/[$\phi(E > 1.0$ MeV)], within the reactor vessel geometry. The relative radial gradient information was required to permit the projection of measured exposure parameters to locations interior to the reactor vessel wall, i.e., the ¼T and ¾T locations.

The absolute cycle-specific results from the forward transport calculations included the neutron energy spectra and radial distribution information in the two-dimensional r,θ model and provided the information required to:

1. Evaluate neutron dosimetry obtained from surveillance capsules,

2. Relate dosimetry results to key locations at the inner radius and through the thickness of the reactor vessel wall,

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

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

The two-dimensional r,θ transport calculation model for the reactor configuration shown in Figure 4-1 is plotted in Figure 6-1. The transport calculations were carried out using the DORT two-dimensional discrete ordinates code Version 3.1[13] and the BUGLE-96 cross-section library [14]. The BUGLE-96 library is a 47 energy group ENDF/B-VI based data set produced specifically for light water reactor applications. In the transport analyses, a forward solution mode is used with anisotropic scattering treated with a P_5 Legendre polynomial expansion of the scattering cross-sections and angular discretization modeled as an S_{16} order of angular quadrature.

The core power distribution utilized in the forward transport calculation for each cycle were derived from assembly power and pin-by-pin power data provided by APS. The cycle averaged axial power distribution derived from APS data is shown in Figure 6-3. The axial power distribution data was used to define the maximum exposure parameter value.

Selected results from the neutron transport analyses are provided in Tables 6-1 through 6-5. The data listed in these tables establish the means for absolute comparisons of analysis and measurement for the Capsules W137 and W38 irradiation periods and provide the means to correlate dosimetry results with the corresponding exposure of the reactor vessel wall. The tabulations also provide the data for the 40° surveillance capsule location.

In Table 6-1, the calculated exposure parameters [$\phi(E > 1.0$ MeV), $\phi(E > 0.1$ MeV), and dpa/sec] are given at the geometric center of the three azimuthally symmetric surveillance capsule positions (38°, 40°, and 43°). All results are based on the Palo Verde Unit 1 core power distributions for the eight cycles of operation. The DORT forward solution transport analyses for each cycle are used to establish the absolute comparison of measurement values with analysis results. Similar neutron exposure rate data are given in Table 6-2 for the reactor vessel inner radius. Again, the three pertinent exposure parameters are listed for the Cycles 1 through 8 based on the cycle-by-cycle core power distributions. Also listed in Table 6-2 are the average exposure values for the both the first 4 cycles of operation, for the 8 cycles of operation, and for cycles 5 through 8. The average values for cycles 5 through 8 are used for exposure projections.

It is important to note that the data for the vessel inner radius were taken at the clad/base metal interface, and, thus, represent the maximum predicted exposure levels of the vessel plates and welds.

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

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

$$\phi_{1/4T}(0°) = \phi(233.756, 0°)\, F(239.409, 0°)$$

where:

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

$\phi(233.756, 0°)$ = Projected or calculated neutron flux at the vessel inner radius on the 0° azimuth.

$F(239.409, 0°)$ = Ratio of the neutron flux at the ¼T position to the flux at the vessel inner radius for the 0° azimuth. This data is obtained from Table 6-3.

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

6.3 NEUTRON DOSIMETRY

The passive neutron sensors included in the Palo Verde Unit 1 surveillance program are listed in Table 6-6. Also given in Table 6-6 are the primary nuclear reactions and associated nuclear constants that were used in the evaluation of the neutron energy spectrum within the surveillance capsules and in the subsequent determination of the various exposure parameters of interest [ϕ(E > 1.0 MeV), ϕ(E > 0.1 MeV), dpa/sec]. The relative locations of the neutron sensors within the capsules are shown in Figure 4-2. The iron, nickel, copper, titanium, and cobalt-aluminum monitors, in wire form, were placed in holes drilled in spacers at several axial levels within the capsules. The cadmium shielded uranium fission monitors were accommodated within the dosimeter block located near the center of the capsule.

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

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

Specific activities for each of the monitors contained in Capsule W137 were determined using established ASTM procedures as documented in prior analysis [15]. The specific activities for each of the monitors contained in Capsule W38 were determined using established ASTM procedures [16 through 29]. Following sample preparation and weighing, the activity of each monitor was determined by means of a high-resolution gamma spectrometer. The irradiation history for the first four operating cycles of the Palo Verde Unit 1 reactor were from NUREG-0020, "Licensed Operating Reactors Status Summary Report". The irradiation history for the Cycles 5 to 8 operating periods of the Palo Verde Unit 1 reactor was obtained from plant personnel [30]. The irradiation history applicable to the exposure of Capsules W137 and W38 is given in Table 6-7.

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

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

where:

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

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

In the equation describing the reaction rate calculation, the ratio $[P_j]/[P_{ref}]$ accounts for month-by-month variation of reactor core power level within any given fuel cycle as well as over multiple fuel cycles. The ratio C_j, which can be calculated for each fuel cycle using the transport technology discussed in Section 6.2, accounts for the change in sensor reaction rates caused by variations in flux level induced by changes in core spatial power distributions from fuel cycle to fuel cycle. For a single cycle irradiation, C_j is normally taken to be 1.0. However, for multiple-cycle irradiations, particularly those employing low leakage fuel management, the additional C_j term 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.

Measured and saturated reaction product specific activities as well as the derived full power reaction rates are listed in Table 6-8. All the measurements of fission monitors were updated with the following corrections. The reaction rates of the ^{238}U sensors provided in Table 6-8 includes corrections for ^{235}U impurities, plutonium build-in, and gamma ray induced fission.

Values of key fast neutron exposure parameters were derived from the measured reaction rates using the FERRET least squares adjustment code [31]. The FERRET approach used the measured reaction rate data, sensor reaction cross-sections, and a calculated trial spectrum as input and proceeded to adjust the group fluxes from the trial spectrum to produce a best fit (in a least squares sense) within the constraints of the parameter uncertainties. The best estimate exposure parameters, along with the associated uncertainties, were then obtained from the best-estimate spectrum.

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

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

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

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

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

In the least squares adjustment, the continuous quantities (i.e., neutron spectra and cross-sections) were approximated in a multi-group format consisting of 53 energy groups. The trial input spectrum was converted to the FERRET 53-group structure using the SAND-II code [32]. This procedure was carried out by first expanding the 47 group calculated spectrum into the SAND-II 620 group structure using a SPLINE interpolation procedure in regions where group boundaries do not coincide. The 620 point spectrum was then re-collapsed into the group structure used in FERRET.

The sensor set reaction cross-sections, obtained from the ENDF/B-VI dosimetry file [33], were also collapsed into the 53-energy group structure using the SAND-II code. In this instance, the trial spectrum, as expanded to 620 groups, was employed as a weighting function in the cross-section collapsing procedure. Reaction cross-section uncertainties in the form of a 53 × 53 covariance matrix for each sensor reaction were also constructed from the information contained on the ENDF/B-VI data files. These matrices included energy group to energy group uncertainty correlations for each of the individual reactions. However, correlations between cross-sections for different sensor reactions were not included. The omission of this additional uncertainty information does not significantly impact the results of the adjustment.

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

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

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

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

where:

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

The first term in the correlation matrix equation specifies purely random uncertainties, while the second term describes short range correlations over a group range γ (θ specifies the strength of the latter term). The value of δ is 1 when g = g' and 0 otherwise. For the trial spectrum used in the current evaluations, a short range correlation of $\gamma = 6$ groups was used. This choice implies that neighboring groups are strongly correlated when θ is close to 1. Strong long-range correlations (or anti-correlations) were justified based on information presented by R. E. Maerker[34]. The uncertainties associated with the measured reaction rates included both statistical (counting) and systematic components. The systematic component of the overall uncertainty accounts for counter efficiency, counter calibrations, irradiation history corrections, and corrections for competing reactions in the individual sensors.

Results of the FERRET evaluation of the Capsule W137 and W38 dosimetry are given in Table 6-9. The data summarized in this table include fast neutron exposure evaluations in terms of $\Phi(E > 1.0$ MeV), $\Phi(E > 0.1$ MeV), and dpa. In general, excellent results were achieved in the fits of the best estimate spectra to the individual measured reaction rates. The measured, calculated and best estimate reaction rates for each reaction are given in Table 6-10. An examination of Table 6-10 shows that, in all cases, reaction rates calculated with the best estimate spectra match the measured reaction rates to better than 6%. The best estimate and measured reaction rates compared to calculated reaction rates for the Co monitors show unusually high values. Although the reason has not been identified, a higher Co content in the monitor than that documented and used in the analysis would result in high values. In any event, Co reaction is monitored for an energy range much lower than the fast flux of primary interest; thus the Co data has insignificant effect on the best estimate fast flux from the analysis. The best estimate spectra from the least squares evaluation is given in Table 6-11 in the FERRET 53 energy group structure.

In Table 6-12, absolute comparisons of the best estimate and calculated fluence at the center of Capsules W137 and W38 are presented. The results for the Capsules W137 and W38 dosimetry evaluation (BE/C ratio of 0.832 for $\Phi(E > 1.0$ MeV)) are within expected tolerances compared with results obtained from similar evaluations of dosimetry from other reactors using methodologies based on ENDF/B-VI cross-sections.

6.4 PROJECTIONS OF REACTOR VESSEL EXPOSURE

The best estimate exposure of the Palo Verde Unit 1 reactor vessel was developed using a combination of absolute plant specific transport calculations and all available plant specific measurement data. In the case of Palo Verde Unit 1, the measurement database contains measurements from the five surveillance capsules discussed in this report.

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

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

where:

$\Phi_{Best\ Est.}$	=	The best estimate fast neutron exposure at the location of interest.
K	=	The plant specific best estimate/calculation (BE/C) bias factor derived from the surveillance capsule dosimetry data.
$\Phi_{Calc.}$	=	The absolute calculated fast neutron exposure at the location of interest.

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

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

For Palo Verde Unit 1, the derived plant specific bias factors were 0.832, 0.894, 0.902 for $\Phi(E > 1.0\ MeV)$, $\Phi(E > 0.1\ MeV)$, and dpa, respectively. Bias factors of this magnitude developed with BUGLE-96 are within expected tolerances for fluence calculated using the ENDF/B-VI based cross-section library.

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

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

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

The net uncertainty in the bias factor, K, is combined with the uncertainty from the analytical sensitivity study to define the overall fluence uncertainty at the reactor vessel wall. In the case of Palo Verde Unit 1, the derived uncertainties in the bias factor, K, and the additional uncertainty from the analytical sensitivity studies combine to yield a net uncertainty of $\pm$ 7.6%.

Based on this best estimate approach, neutron exposure projections at key locations on the reactor vessel inner radius are given in Table 6-13; furthermore, calculated neutron exposure projections are also provided for comparison purposes. Along with the current (9.81 EFPY) exposure, projections are also provided for exposure periods of 15, 32, 40, 45, and 54 EFPY. Projections for future operation were based on the assumption that the Cycles 5 through 8 exposure rates would continue to be applicable throughout plant life.

In the derivation of best estimate and calculated exposure gradients within the reactor vessel wall for the Palo Verde Unit 1 reactor vessel, exposure projections to 15, 32, 40, 45, and 54 EFPY were also employed. Data based on both a $\Phi(E > 1.0\ \text{MeV})$ slope and a plant-specific dpa slope through the vessel wall are provided in Table 6-14.

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

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

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

In Table 6-15, updated lead factors are listed for all of the Palo Verde Unit 1 surveillance capsules.

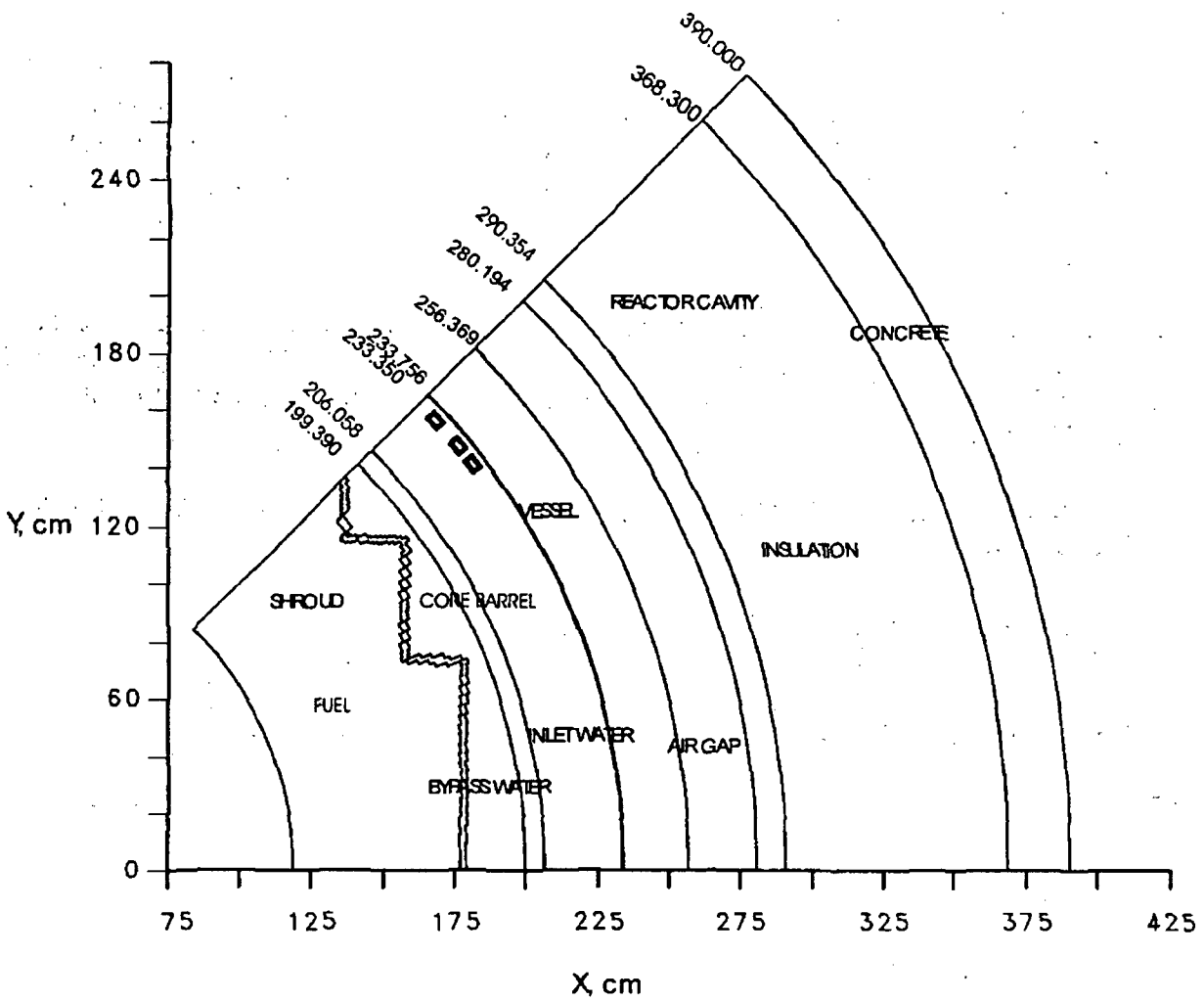


Figure 6-1. Palo Verde Reactor Model (45 Degree R-Θ Sector) Including Vessel Surveillance Capsules

Figure 6-2

Azimuthal Variation of Neutron Flux (E > 1.0 Mev)
At The Reactor Vessel Inner Radius

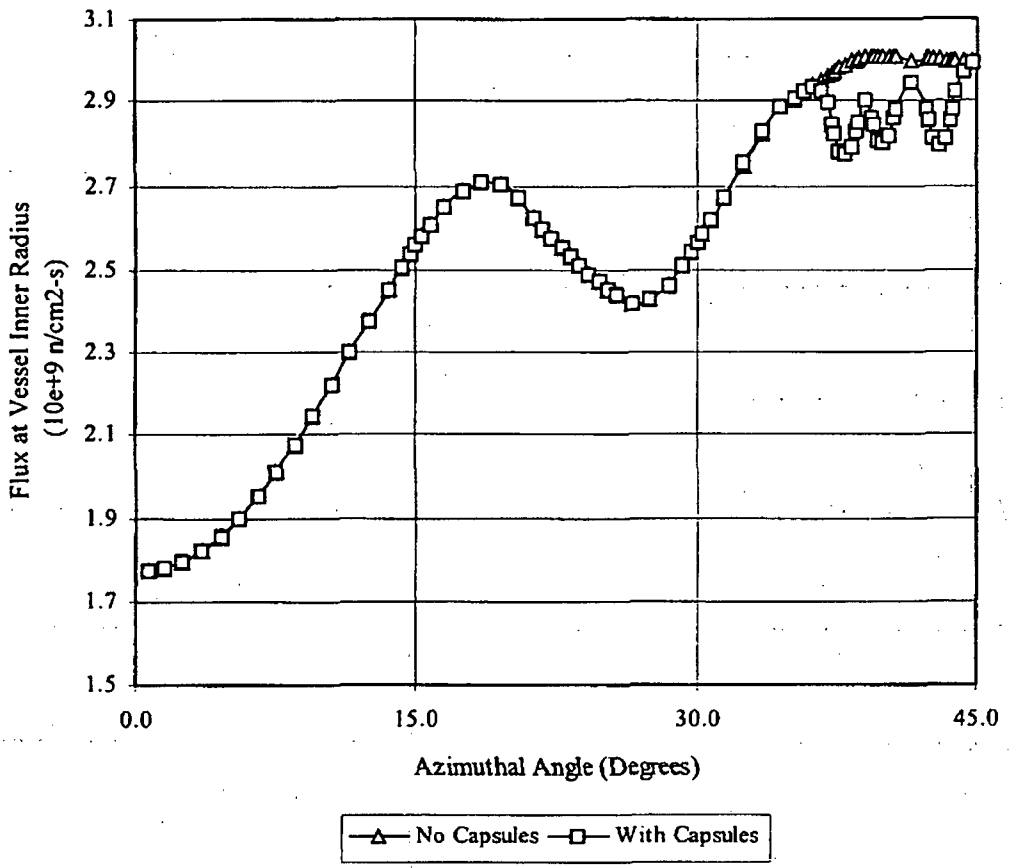


Figure 6-3

Axial Distribution of Reactor Power

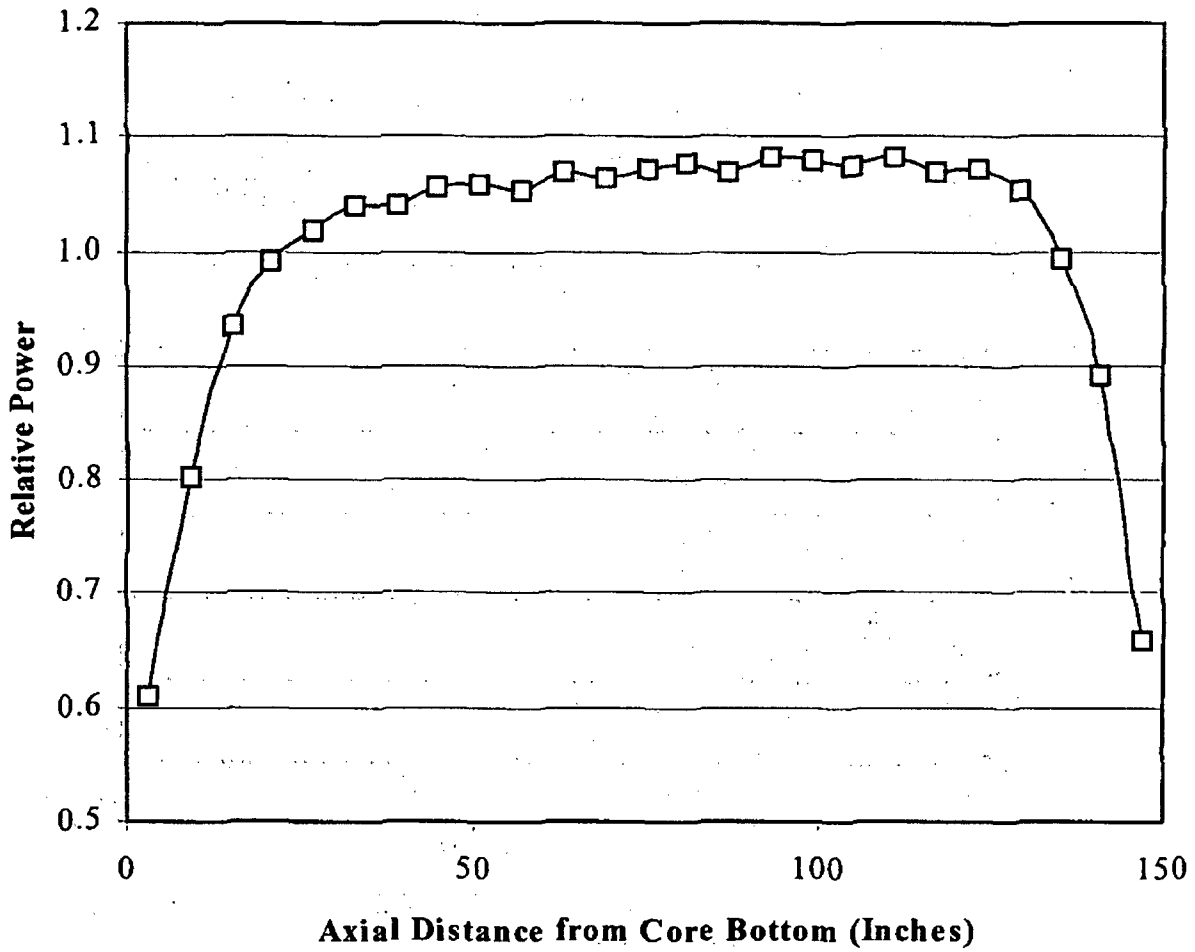


Table 6-1

Calculated Fast Neutron Exposure Rates
at the Center of the Surveillance Capsules
Core Midplane Elevation

Operating Cycle	Capsule Location 38°	40°	43°
	Flux(E>1.0 Mev) [n/cm^2-sec]		
Cycle 1	4.201E+10	4.224E+10	4.167E+10
Cycle 2	2.804E+10	2.803E+10	2.751E+10
Cycle 3	2.493E+10	2.511E+10	2.487E+10
Cycle 4	2.655E+10	2.657E+10	2.606E+10
Cycle 5	2.518E+10	2.621E+10	2.658E+10
Cycle 6	2.647E+10	2.748E+10	2.779E+10
Cycle 7	1.718E+10	1.751E+10	1.745E+10
Cycle 8	1.669E+10	1.708E+10	1.709E+10
Average(1-4)	3.046E+10	3.058E+10	3.013E+10
Average(1-8)	2.542E+10	2.583E+10	2.570E+10
Average(5-8)	2.104E+10	2.170E+10	2.184E+10
	Flux(E>0.1 Mev) [n/cm^2-sec]		
Cycle 1	7.783E+10	7.808E+10	7.655E+10
Cycle 2	5.156E+10	5.143E+10	5.017E+10
Cycle 3	4.581E+10	4.605E+10	4.535E+10
Cycle 4	4.890E+10	4.882E+10	4.761E+10
Cycle 5	4.623E+10	4.803E+10	4.845E+10
Cycle 6	4.865E+10	5.038E+10	5.068E+10
Cycle 7	3.145E+10	3.199E+10	3.171E+10
Cycle 8	3.057E+10	3.122E+10	3.108E+10
Average(1-4)	5.617E+10	5.626E+10	5.512E+10
Average(1-8)	4.677E+10	4.742E+10	4.692E+10
Average(5-8)	3.859E+10	3.972E+10	3.978E+10
	Iron Atom Displacement Rate [dpa]		
Cycle 1	6.094E-11	6.130E-11	6.047E-11
Cycle 2	4.079E-11	4.079E-11	4.004E-11
Cycle 3	3.629E-11	3.654E-11	3.619E-11
Cycle 4	3.860E-11	3.864E-11	3.791E-11
Cycle 5	3.663E-11	3.813E-11	3.866E-11
Cycle 6	3.849E-11	3.996E-11	4.041E-11
Cycle 7	2.503E-11	2.552E-11	2.543E-11
Cycle 8	2.432E-11	2.488E-11	2.489E-11
Average(1-4)	4.426E-11	4.444E-11	4.379E-11
Average(1-8)	3.697E-11	3.757E-11	3.738E-11
Average(5-8)	3.062E-11	3.158E-11	3.179E-11

Table 6-2

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

			Flux (E > 1.0 Mev) [n/cm2-sec]		
Operating Cycle	0 Deg	15 Deg	30 Deg	42.3 Deg	45 Deg
Cycle 1	1.77E+10	2.56E+10	2.57E+10	3.01E+10	3.00E+10
Cycle 2	1.53E+10	1.57E+10	1.75E+10	1.86E+10	1.85E+10
Cycle 3	1.71E+10	1.89E+10	1.62E+10	1.70E+10	1.70E+10
Cycle 4	1.36E+10	1.89E+10	1.75E+10	1.85E+10	1.83E+10
Cycle 5	9.48E+09	1.16E+10	1.34E+10	1.85E+10	1.86E+10
Cycle 6	8.26E+09	1.09E+10	1.39E+10	1.94E+10	1.95E+10
Cycle 7	7.66E+09	1.01E+10	1.07E+10	1.24E+10	1.24E+10
Cycle 8	8.39E+09	9.71E+09	1.02E+10	1.21E+10	1.21E+10
Average (1-4)	1.60E+10	2.01E+10	1.93E+10	2.12E+10	2.11E+10
Average (1-8)	1.20E+10	1.50E+10	1.54E+10	1.80E+10	1.80E+10
Average (5-8)	8.42E+09	1.05E+10	1.19E+10	1.53E+10	1.54E+10

			Flux (E > 0.1 Mev) [n/cm2-sec]		
Operating Cycle	0 Deg	15 Deg	30 Deg	42.3 Deg	45 Deg
Cycle 1	3.74E+10	5.41E+10	5.49E+10	6.43E+10	6.42E+10
Cycle 2	3.20E+10	3.32E+10	3.72E+10	3.97E+10	3.95E+10
Cycle 3	3.57E+10	3.98E+10	3.45E+10	3.63E+10	3.62E+10
Cycle 4	2.85E+10	3.99E+10	3.72E+10	3.94E+10	3.92E+10
Cycle 5	1.98E+10	2.45E+10	2.85E+10	3.91E+10	3.94E+10
Cycle 6	1.73E+10	2.29E+10	2.95E+10	4.11E+10	4.14E+10
Cycle 7	1.60E+10	2.11E+10	2.25E+10	2.62E+10	2.62E+10
Cycle 8	1.75E+10	2.04E+10	2.16E+10	2.56E+10	2.56E+10
Average (1-4)	3.36E+10	4.25E+10	4.11E+10	4.52E+10	4.50E+10
Average (1-8)	2.51E+10	3.16E+10	3.26E+10	3.84E+10	3.84E+10
Average (5-8)	1.76E+10	2.21E+10	2.52E+10	3.25E+10	3.26E+10

			dpa/sec		
Operating Cycle	0 Deg	15 Deg	30 Deg	42.3 Deg	45 Deg
Cycle 1	2.74E-11	3.91E-11	3.94E-11	4.60E-11	4.58E-11
Cycle 2	2.37E-11	2.41E-11	2.69E-11	2.86E-11	2.84E-11
Cycle 3	2.63E-11	2.90E-11	2.50E-11	2.61E-11	2.60E-11
Cycle 4	2.10E-11	2.90E-11	2.69E-11	2.83E-11	2.81E-11
Cycle 5	1.47E-11	1.79E-11	2.07E-11	2.82E-11	2.84E-11
Cycle 6	1.28E-11	1.67E-11	2.13E-11	2.97E-11	2.99E-11
Cycle 7	1.19E-11	1.55E-11	1.64E-11	1.90E-11	1.90E-11
Cycle 8	1.30E-11	1.49E-11	1.57E-11	1.85E-11	1.85E-11
Average (1-4)	2.48E-11	3.09E-11	2.97E-11	3.24E-11	3.23E-11
Average (1-8)	1.85E-11	2.30E-11	2.36E-11	2.76E-11	2.76E-11
Average (5-8)	1.30E-11	1.62E-11	1.83E-11	2.35E-11	2.35E-11

Table 6-3

Relative Radial Distribution Of $\phi(E > 1.0\ MeV)$
Within The Reactor Vessel Wall

RADIUS (cm)	AZIMUTHAL ANGLE				
	0°	15°	30°	40°	45°
233.756	1.000	1.000	1.000	1.000	1.000
234.006	0.989	0.989	0.989	0.990	0.989
234.631	0.946	0.945	0.945	0.944	0.945
235.506	0.872	0.870	0.871	0.869	0.871
236.631	0.774	0.772	0.773	0.770	0.771
237.924	0.668	0.665	0.666	0.662	0.664
239.410	0.558	0.554	0.555	0.551	0.553
241.197	0.446	0.442	0.444	0.440	0.441
243.205	0.344	0.341	0.343	0.339	0.340
245.063	0.269	0.267	0.269	0.265	0.265
246.478	0.222	0.220	0.221	0.219	0.218
247.780	0.185	0.183	0.184	0.183	0.182
249.192	0.152	0.150	0.151	0.150	0.150
250.716	0.123	0.121	0.121	0.121	0.120
252.056	0.101	0.099	0.100	0.099	0.099
253.098	0.086	0.085	0.085	0.084	0.084
254.182	0.073	0.071	0.072	0.071	0.071
255.182	0.062	0.060	0.060	0.059	0.059
255.994	0.053	0.051	0.051	0.050	0.050
256.369	0.051	0.049	0.049	0.048	0.047

Note:
Base Metal Inner Radius = 233.756 cm
Base Metal 1/4T = 239.409 cm
Base Metal 1/2T = 245.063 cm
Base Metal 3/4T = 250.716 cm
Base Metal Outer Radius = 256.369 cm

Table 6-4

Relative Radial Distribution Of $\phi(E > 0.1\ MeV)$
Within The Reactor Vessel Wall

RADIUS (cm)	AZIMUTHAL ANGLE 0°	15°	30°	40°	45°
233.756	1.000	1.000	1.000	1.000	1.000
234.006	1.010	1.010	1.010	1.010	1.009
234.631	1.014	1.011	1.013	1.010	1.011
235.506	1.001	0.996	0.998	0.994	0.996
236.631	0.969	0.963	0.966	0.959	0.961
237.924	0.924	0.915	0.920	0.911	0.913
239.410	0.866	0.855	0.861	0.850	0.852
241.197	0.794	0.781	0.788	0.775	0.777
243.205	0.713	0.700	0.707	0.693	0.694
245.063	0.641	0.627	0.634	0.619	0.619
246.478	0.586	0.572	0.578	0.564	0.564
247.780	0.536	0.521	0.527	0.514	0.514
249.192	0.485	0.469	0.475	0.461	0.461
250.716	0.431	0.415	0.420	0.406	0.406
252.056	0.385	0.370	0.374	0.360	0.359
253.098	0.349	0.333	0.337	0.323	0.322
254.182	0.312	0.296	0.299	0.285	0.284
255.182	0.278	0.262	0.263	0.249	0.248
255.994	0.247	0.231	0.231	0.217	0.216
256.369	0.239	0.222	0.222	0.207	0.206

Note:
Base Metal Inner Radius = 233.756 cm
Base Metal 1/4T = 239.409 cm
Base Metal 1/2T = 245.063 cm
Base Metal 3/4T = 250.716 cm
Base Metal Outer Radius = 256.369 cm

Table 6-5

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

RADIUS (cm)	AZIMUTHAL ANGLE 0°	15°	30°	40°	45°
233.756	1.000	1.000	1.000	1.000	1.000
234.006	0.990	0.990	0.991	0.991	0.990
234.631	0.953	0.952	0.953	0.952	0.953
235.506	0.891	0.890	0.891	0.889	0.890
236.631	0.810	0.808	0.810	0.807	0.808
237.924	0.721	0.719	0.722	0.717	0.719
239.410	0.629	0.626	0.629	0.624	0.626
241.197	0.534	0.530	0.534	0.528	0.530
243.205	0.444	0.440	0.444	0.438	0.439
245.063	0.374	0.371	0.375	0.369	0.369
246.478	0.327	0.324	0.328	0.322	0.322
247.780	0.289	0.285	0.288	0.284	0.284
249.192	0.253	0.248	0.251	0.247	0.247
250.716	0.218	0.213	0.216	0.211	0.211
252.056	0.190	0.185	0.188	0.183	0.182
253.098	0.169	0.164	0.167	0.162	0.161
254.182	0.150	0.144	0.146	0.141	0.141
255.182	0.132	0.126	0.128	0.122	0.122
255.994	0.117	0.111	0.112	0.106	0.106
256.369	0.113	0.107	0.107	0.102	0.101

Note:
Base Metal Inner Radius = 233.756 cm
Base Metal 1/4T = 239.409 cm
Base Metal 1/2T = 245.063 cm
Base Metal 3/4T = 250.716 cm
Base Metal Outer Radius = 256.369 cm

Table 6-6

Nuclear Parameters Used In The Evaluation Of Neutron Sensors

Monitor Material	Atomic Weight	Reaction of Interest	Target Atom Fraction	Response Range	Product Half-life	Fission Yield (%)
Copper	63.546	$Cu^{63}(n,\alpha)Co^{60}$	0.6917	E > 5 Mev	1925.5d	
Iron	55.845	$Fe^{54}(n,p)Mn^{54}$	0.0585	E > 2 Mev	312.3d	
Nickel	58.693	$Ni^{58}(n,p)Co^{58}$	0.6808	E > 2 Mev	70.82d	
Titanium	45.953	$Ti^{46}(n,p)Sc^{46}$	0.0825	E > 2 Mev	83.79d	
Uranium-238	238.051	$U^{238}(n,f)Cs^{137}$	0.9996	E > 1 Mev	10983.3d	6.02
Uranium-238	238.051	$U^{238}(n,f)Zr^{95}$	0.9996	E > 1 Mev	64.02d	5.15
Uranium-238	238.051	$U^{238}(n,f)Ru^{103}$	0.9996	E > 1 Mev	39.27d	6.26
Cobalt-Al	58.933	$Co^{59}(n,\gamma)Co^{60}$	0.0017	Non-threshold	1925.5d	

Notes:

1. Atomic weight data taken from the Chart of the Nuclides, 15th Edition, Dated 1996.
2. Half-life data and target fraction data for the $Cu^{63}(n,\alpha)$, $Fe^{54}(n,p)$, $Ni^{58}(n,p)$, $Ti^{46}(n,p)$, and $Co^{59}(n,\gamma)$ reactions were taken from ASTM Standard E 1005-97.
3. Half-life and fission yield data for the $U^{238}(n,f)$ reaction taken from ASTM Standard E 1005-97.
4. Target atom fraction for the U^{238} assumed as 350 ppm of U^{235}.

Table 6-7

Monthly Thermal Generation During The First Eight Fuel Cycles
Of The Palo Verde Unit 1 Reactor
(Reactor Power of 3800 MWt)

Cycle 1		Cycle 2		Cycle 3		Cycle 4	
Mo-Year	Thermal Generation (MWt-hr)	Mo-Year	Thermal Generation (MWt-hr)	Mo-Year	Thermal Generation (MWt-hr)	Mo-Year	Thermal Generation (MWt-hr)
Jun-85	488193	Mar-88	1667501	Jun-90	10825	May-92	389734
Jul-85	488786	Apr-88	2300328	Jul-90	2146547	Jun-92	2726926
Aug-85	83645	May-88	2371300	Aug-90	2337547	Jul-92	2825923
Sep-85	1069383	Jun-88	2698106	Sep-90	1652836	Aug-92	2825394
Oct-85	962630	Jul-88	503771	Oct-90	2797086	Sep-92	2545283
Nov-85	194	Aug-88	69686	Nov-90	2704935	Oct-92	2610331
Dec-85	1460729	Sep-88	2565055	Dec-90	2813104	Nov-92	2734833
Jan-86	1265571	Oct-88	2659128	Jan-91	996506	Dec-92	2576546
Feb-86	2011169	Nov-88	2708768	Feb-91	1084003	Jan-93	2645967
Mar-86	566400	Dec-88	2789443	Mar-91	2822719	Feb-93	2461534
Apr-86	0	Jan-89	2775471	Apr-91	2731759	Mar-93	2806238
May-86	597004	Feb-89	2385008	May-91	2824227	Apr-93	2735243
Jun-86	2473534	Mar-89	404819	Jun-91	2725393	May-93	2606624
Jul-86	1814285			Jul-91	2825868	Jun-93	2730282
Aug-86	1746682			Aug-91	2824884	Jul-93	2487672
Sep-86	1929290			Sep-91	1725887	Aug-93	2019059
Oct-86	2413152			Oct-91	2386029	Sep-93	174976
Nov-86	2440676			Nov-91	2700441		
Dec-86	2768558			Dec-91	2822439		
Jan-87	1462574			Jan-92	1430983		
Feb-87	0			Feb-92	1248802		
Mar-87	1861757						
Apr-87	2705174						
May-87	2615160						
Jun-87	2387981						
Jul-87	29941						
Aug-87	2431392						
Sep-87	2502710						
Oct-87	144005						

Table 6-7 (Continued)

Monthly Thermal Generation During The First Eight Fuel Cycles
Of The Palo Verde Unit 1 Reactor
(Reactor Power of 3800 MWt)

Cycle 5		Cycle 6		Cycle 7		Cycle 8	
Mo-Year	Thermal Generation (MWt-hr)	Mo-Year	Thermal Generation (MWt-hr)	Mo-Year	Thermal Generation (MWt-hr)	Mo-Year	Thermal Generation (MWt-hr)
Nov-93	175241	May-95	124734	Oct-96	19736	Apr-98	856293
Dec-93	2408701	Jun-95	2522346	Nov-96	2575629	May-98	2882404
Jan-94	2402290	Jul-95	2818244	Dec-96	2882996	Jun-98	2790255
Feb-94	2170013	Aug-95	2672598	Jan-97	2882444	Jul-98	2879986
Mar-94	2397621	Sep-95	2732753	Feb-97	2602247	Aug-98	2874823
Apr-94	2342627	Oct-95	2826498	Mar-97	2852026	Sep-98	2790115
May-94	2430079	Nov-95	2422865	Apr-97	2790215	Oct-98	2883307
Jun-94	2361925	Dec-95	2334446	May-97	2441952	Nov-98	2790301
Jul-94	2768631	Jan-96	2826311	Jun-97	2774045	Dec-98	2883381
Aug-94	2763506	Feb-96	2267706	Jul-97	2882408	Jan-99	2883251
Sep-94	2669901	Mar-96	2519048	Aug-97	2876879	Feb-99	2603835
Oct-94	2769680	Apr-96	1373041	Sep-97	2789493	Mar-99	2581165
Nov-94	2256552	May-96	2742983	Oct-97	2842908	Apr-99	2790255
Dec-94	2718645	Jun-96	2735425	Nov-97	2782268	May-99	2883223
Jan-95	2808750	Jul-96	2821260	Dec-97	2883231	Jun-99	2786766
Feb-95	2552287	Aug-96	2630990	Jan-98	2883225	Jul-99	2882991
Mar-95	2638589	Sep-96	1682394	Feb-98	2272117	Aug-99	2882823
Apr-95	76			Mar-98	1202072	Sep-99	2778552
						Oct-99	85396

Table 6-8

Measured Sensor Activities And Reaction Rates

Surveillance Capsule W137

Reaction	Location	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	Top	1.04E+05	2.985E+05	4.553E-17
	Middle	9.81E+04	2.815E+05	4.295E-17
	Bottom	9.89E+04	2.838E+05	4.330E-17
$^{54}Fe\ (n,p)\ ^{54}Mn$	Top	9.79E+05	2.218E+06	3.516E-15
	Middle	9.09E+05	2.059E+06	3.265E-15
	Bottom	9.21E+05	2.087E+06	3.308E-15
$^{58}Ni\ (n,p)\ ^{58}Co$	Middle	3.36E+06	2.979E+07	4.265E-15
$^{46}Ti\ (n,p)\ ^{46}Sc$	Top	1.09E+05	7.165E+05	6.627E-16
	Middle	1.03E+05	6.770E+05	6.262E-16
	Bottom	1.03E+05	6.770E+05	6.262E-16
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Middle	5.24E+07	1.504E+08	8.657E-12
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)	Middle	6.35E+06	1.822E+07	1.049E-12
$^{238}U\ (n,f)\ ^{137}Cs$ (Cd)	Top	4.12E+04	4.341E+05	2.852E-15
	Middle	1.00E+05	1.054E+06	6.922E-15
	Bottom	7.56E+04	7.966E+05	5.233E-15
$^{238}U\ (n,f)\ ^{95}Zr$ (Cd)	Top	4.08E+04	4.449E+05	3.416E-15
	Middle	8.72E+04	9.509E+05	7.300E-15
	Bottom	6.54E+04	7.132E+05	5.475E-15
$^{238}U\ (n,f)\ ^{103}Ru$ (Cd)	Top	1.37E+04	5.853E+05	3.697E-15
	Middle	2.70E+05	1.154E+07	7.286E-14
	Bottom	1.94E+04	8.288E+05	5.235E-15
$^{238}U\ (n,f)\ ^{137}Cs$	Top	2.06E+05	2.171E+06	1.426E-14
	Middle	3.68E+05	3.878E+06	2.547E-14
	Bottom	2.87E+05	3.024E+06	1.987E-14
$^{238}U\ (n,f)\ ^{95}Zr$	Top	2.34E+05	2.552E+06	1.959E-14
	Middle	4.18E+05	4.558E+06	3.499E-14
	Bottom	3.03E+05	3.304E+06	2.537E-14
$^{238}U\ (n,f)\ ^{103}Ru$	Top	6.27E+04	2.679E+06	1.692E-14
	Middle	1.08E+05	4.614E+06	2.914E-14
	Bottom	7.09E+04	3.029E+06	1.913E-14

Table 6-8 cont'd

Measured Sensor Activities And Reaction Rates

Surveillance Capsule W38

Reaction	Location	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	Top	1.320E+05	2.494E+05	3.805E-17
	Middle	1.510E+05	2.853E+05	4.352E-17
	Bottom	1.140E+05	2.154E+05	3.286E-17
$^{54}Fe\ (n,p)\ ^{54}Mn$	Top	5.940E+05	1.735E+06	2.751E-15
	Middle	5.560E+05	1.624E+06	2.575E-15
	Bottom	5.470E+05	1.598E+06	2.533E-15
$^{58}Ni\ (n,p)\ ^{58}Co$	Middle	9.210E+05	2.538E+07	3.634E-15
$^{46}Ti\ (n,p)\ ^{46}Sc$	Top	2.550E+04	4.491E+05	4.154E-16
	Middle	3.150E+04	5.548E+05	5.131E-16
	Bottom	3.170E+04	5.583E+05	5.164E-16
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Middle	6.880E+07	1.300E+08	7.483E-12
$^{238}U\ (n,f)\ ^{137}Cs$	Top	6.790E+05	3.581E+06	2.352E-14
	Middle	4.110E+05	2.167E+06	1.424E-14
	Bottom	1.080E+06	5.695E+06	3.741E-14
$^{238}U\ (n,f)\ ^{95}Zr$	Top	1.000E+05	3.750E+06	2.879E-14
	Middle	6.840E+05	2.565E+07	1.969E-13
	Bottom	1.740E+05	6.524E+07	5.009E-14
$^{238}U\ (n,f)\ ^{103}Ru$	Top	1.360E+04	3.860E+06	2.438E-14
	Middle	8.700E+03	2.470E+06	1.560E-14
	Bottom	2.410E+04	6.481E+06	4.321E-14

Table 6-9

Summary Of Neutron Dosimetry Results
Surveillance Capsule W137

Best Estimate Flux and Fluence for Capsule W137

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	Uncertainty
ϕ (E > 1.0 MeV)	2.584E+10	Φ (E > 1.0 MeV)	3.724E+18	7%
ϕ (E > 0.1 MeV)	5.165E+10	Φ (E > 0.1 MeV)	7.444E+18	10%
ϕ (E < 0.414 eV)	2.790E+11	Φ (E < 0.414 eV)	4.021E+19	7%
dpa/sec	4.018E-11	dpa	5.791E-03	6%

Best Estimate Flux and Fluence for Capsule W38

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	Uncertainty
ϕ (E > 1.0 MeV)	2.041E+10	Φ (E > 1.0 MeV)	6.320E+18	7%
ϕ (E > 0.1 MeV)	3.974E+10	Φ (E > 0.1 MeV)	1.231E+19	10%
ϕ (E < 0.414 eV)	2.583E+11	Φ (E < 0.414 eV)	7.998E+19	6%
dpa/sec	3.187E-11	dpa	9.868E-03	6%

Table 6-10

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

Surveillance Capsule W137

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
$^{63}Cu\ (n,\alpha)^{60}Co$	4.39E-17	4.79E-17	4.30E-17	0.98	0.90	0.92
$^{54}Fe\ (n,p)^{54}Mn$	3.36E-15	4.10E-15	3.44E-15	1.02	0.84	0.82
$^{58}Ni\ (n,p)^{58}Co$	4.26E-15	5.33E-15	4.45E-15	1.04	0.83	0.80
$^{46}Ti\ (n,p)^{46}Sc$	6.38E-16	7.39E-16	6.38E-16	1.00	0.86	0.86
$^{59}Co\ (n,\gamma)^{60}Co$	8.66E-12	1.38E-12	8.47E-12	0.98	6.14	6.28
$^{59}Co\ (n,\gamma)^{60}Co$ (Cd)	1.05E-12	2.89E-13	1.01E-12	0.96	3.49	3.63

Surveillance Capsule W38

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
$^{63}Cu\ (n,\alpha)^{60}Co$	3.81E-17	4.02E-17	3.57E-17	0.94	0.89	0.95
$^{54}Fe\ (n,p)^{54}Mn$	2.62E-15	3.44E-15	2.75E-15	1.05	0.80	0.76
$^{58}Ni\ (n,p)^{58}Co$	3.63E-15	4.48E-15	3.63E-15	1.00	0.81	0.81
$^{46}Ti\ (n,p)^{46}Sc$	4.82E-16	6.20E-16	5.05E-16	1.05	0.81	0.78
$^{59}Co\ (n,\gamma)^{60}Co$	7.48E-12	1.12E-12	7.31E-12	0.98	6.53	6.68

Table 6-11

Best Estimate Neutron Energy Spectrum At The
Center Of Surveillance Capsules

Capsule W137

Group Number	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	7.464E+06	28	9.12E-03	2.551E+09
2	1.49E+01	1.539E+07	29	5.53E-03	2.529E+09
3	1.35E+01	5.215E+07	30	3.36E-03	8.815E+08
4	1.16E+01	1.314E+08	31	2.84E-03	9.226E+08
5	1.00E+01	2.861E+08	32	2.40E-03	9.861E+08
6	8.61E+00	4.696E+08	33	2.04E-03	3.216E+09
7	7.41E+00	1.162E+09	34	1.23E-03	3.520E+09
8	6.07E+00	1.626E+09	35	7.49E-04	3.813E+09
9	4.97E+00	2.799E+09	36	4.54E-04	4.112E+09
10	3.68E+00	2.580E+09	37	2.75E-04	4.759E+09
11	2.87E+00	4.124E+09	38	1.67E-04	8.040E+09
12	2.23E+00	3.933E+09	39	1.01E-04	4.976E+09
13	1.74E+00	4.046E+09	40	6.14E-05	4.629E+09
14	1.35E+00	3.114E+09	41	3.73E-05	4.221E+09
15	1.11E+00	4.378E+09	42	2.26E-05	3.821E+09
16	8.21E-01	4.012E+09	43	1.37E-05	3.462E+09
17	6.39E-01	3.740E+09	44	8.32E-06	3.226E+09
18	4.98E-01	2.635E+09	45	5.04E-06	3.144E+09
19	3.88E-01	3.108E+09	46	3.06E-06	3.078E+09
20	3.02E-01	4.676E+09	47	1.86E-06	2.996E+09
21	1.83E-01	4.083E+09	48	1.13E-06	2.817E+09
22	1.11E-01	3.177E+09	49	6.83E-07	3.058E+09
23	6.74E-02	2.971E+09	50	4.14E-07	4.465E+09
24	4.09E-02	2.094E+09	51	2.51E-07	1.949E+10
25	2.55E-02	1.528E+09	52	1.52E-07	4.378E+10
26	1.99E-02	1.203E+09	53	9.24E-08	2.112E+11
27	1.50E-02	2.504E+09			

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

Table 6-11 cont'd

Best Estimate Neutron Energy Spectrum At The
Center Of Surveillance Capsules

Capsule W38

Group Number	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	5.948E+06	28	1.73E+09	1.728E+09
2	1.49E+01	1.237E+07	29	1.67E+09	1.671E+09
3	1.35E+01	4.210E+07	30	5.63E+08	5.633E+08
4	1.16E+01	1.065E+08	31	5.63E+08	5.639E+08
5	1.00E+01	2.329E+08	32	5.66E+08	5.673E+08
6	8.61E+00	3.820E+08	33	1.70E+09	1.708E+09
7	7.41E+00	9.447E+08	34	1.68E+09	1.692E+09
8	6.07E+00	1.309E+09	35	1.62E+09	1.639E+09
9	4.97E+00	2.239E+09	36	1.57E+09	1.589E+09
10	3.68E+00	2.060E+09	37	1.66E+09	1.692E+09
11	2.87E+00	3.270E+09	38	1.70E+09	1.752E+09
12	2.23E+00	3.094E+09	39	1.69E+09	1.738E+09
13	1.74E+00	3.158E+09	40	1.69E+09	1.742E+09
14	1.35E+00	2.410E+09	41	1.69E+09	1.753E+09
15	1.11E+00	3.361E+09	42	1.68E+09	1.762E+09
16	8.21E-01	3.055E+09	43	1.66E+09	1.755E+09
17	6.39E-01	2.826E+09	44	1.65E+09	1.767E+09
18	4.98E-01	1.976E+09	45	1.68E+09	1.827E+09
19	3.88E-01	2.315E+09	46	1.69E+09	1.872E+09
20	3.02E-01	3.456E+09	47	1.68E+09	1.890E+09
21	1.83E-01	3.001E+09	48	1.60E+09	1.830E+09
22	1.11E-01	2.318E+09	49	1.43E+09	2.029E+09
23	6.74E-02	2.154E+09	50	1.70E+09	3.084E+09
24	4.09E-02	1.504E+09	51	5.49E+09	1.411E+10
25	2.55E-02	1.088E+09	52	9.28E+09	3.409E+10
26	1.99E-02	8.444E+08	53	2.01E+10	2.070E+11
27	1.50E-02	1.732E+09			

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

Table 6-12

Comparison Of Calculated And Best Estimate Integrated Neutron Exposure Of Palo Verde Unit 1 Surveillance Capsules W137 and W38

CAPSULE W137

	Calculated	Best Estimate	BE/C
$\Phi(E > 1.0\ MeV)$ [n/cm^2]	4.33E+18	3.72E+18	0.86
$\Phi(E > 0.1\ MeV)$ [n/cm^2]	7.94E+18	7.44E+18	0.94
dpa	6.23E-03	5.79E-03	0.93

CAPSULE W38

	Calculated	Best Estimate	BE/C
$\Phi(E > 1.0\ MeV)$ [n/cm^2]	7.85E+18	6.32E+18	0.80
$\Phi(E > 0.1\ MeV)$ [n/cm^2]	1.45E+19	1.23E+19	0.85
dpa	1.13E-02	9.87E-03	0.87

AVERAGE BE/C RATIOS

	BE/C
$\Phi(E > 1.0\ MeV)$ [n/cm^2]	0.832
$\Phi(E > 0.1\ MeV)$ [n/cm^2]	0.894
dpa	0.902

Table 6-13

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

Best Estimate

	0°	15°	30°	42.3°	45°
9.81 EFPY					
E>1.0 MeV	3.08E+18	3.87E+18	3.96E+18	4.65E+18	4.65E+18
E>0.1 MeV	6.93E+18	8.75E+18	9.03E+18	1.06E+19	1.06E+19
dpa	5.17E-03	6.43E-03	6.59E-03	7.72E-03	7.71E-03
15 EFPY					
E>1.0 MeV	4.23E+18	5.30E+18	5.58E+18	6.74E+18	6.74E+18
E>0.1 MeV	9.51E+18	1.20E+19	1.27E+19	1.54E+19	1.54E+19
dpa	7.09E-03	8.81E-03	9.30E-03	1.12E-02	1.12E-02
32 EFPY					
E>1.0 MeV	7.99E+18	1.00E+19	1.09E+19	1.36E+19	1.36E+19
E>0.1 MeV	1.79E+19	2.26E+19	2.48E+19	3.09E+19	3.10E+19
dpa	1.34E-02	1.66E-02	1.82E-02	2.25E-02	2.26E-02
40 EFPY					
E>1.0 MeV	9.76E+18	1.22E+19	1.34E+19	1.68E+19	1.68E+19
E>0.1 MeV	2.19E+19	2.76E+19	3.05E+19	3.83E+19	3.84E+19
dpa	1.64E-02	2.03E-02	2.23E-02	2.79E-02	2.79E-02
45 EFPY					
E>1.0 MeV	1.09E+19	1.36E+19	1.50E+19	1.88E+19	1.89E+19
E>0.1 MeV	2.44E+19	3.07E+19	3.41E+19	4.28E+19	4.30E+19
dpa	1.82E-02	2.26E-02	2.49E-02	3.12E-02	3.13E-02
54 EFPY					
E>1.0 MeV	1.29E+19	1.61E+19	1.78E+19	2.24E+19	2.25E+19
E>0.1 MeV	2.88E+19	3.63E+19	4.05E+19	5.11E+19	5.12E+19
dpa	2.16E-02	2.68E-02	2.96E-02	3.72E-02	3.73E-02

Note: Maximum neutron exposure projection is at either 42.3° or 45°

Table 6-13, cont'd

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

Calculated

	0°	15°	30°	42.3°	45°
9.81 EFPY					
E>1.0 MeV	3.71E+18	4.64E+18	4.75E+18	5.59E+18	5.58E+18
E>0.1 MeV	7.76E+18	9.79E+18	1.01E+19	1.19E+19	1.19E+19
dpa	5.73E-03	7.12E-03	7.31E-03	8.55E-03	8.55E-03
15 EFPY					
E>1.0 MeV	5.09E+18	6.37E+18	6.70E+18	8.10E+18	8.10E+18
E>0.1 MeV	1.06E+19	1.34E+19	1.42E+19	1.72E+19	1.72E+19
dpa	7.87E-03	9.77E-03	1.03E-02	1.24E-02	1.24E-02
32 EFPY					
E>1.0 MeV	9.60E+18	1.20E+19	1.31E+19	1.63E+19	1.64E+19
E>0.1 MeV	2.01E+19	2.53E+19	2.78E+19	3.46E+19	3.47E+19
dpa	1.49E-02	1.84E-02	2.01E-02	2.50E-02	2.50E-02
40 EFPY					
E>1.0 MeV	1.17E+19	1.47E+19	1.61E+19	2.02E+19	2.02E+19
E>0.1 MeV	2.45E+19	3.09E+19	3.42E+19	4.28E+19	4.29E+19
dpa	1.82E-02	2.25E-02	2.48E-02	3.09E-02	3.10E-02
45 EFPY					
E>1.0 MeV	1.31E+19	1.63E+19	1.80E+19	2.26E+19	2.27E+19
E>0.1 MeV	2.73E+19	3.44E+19	3.81E+19	4.79E+19	4.81E+19
dpa	2.02E-02	2.51E-02	2.77E-02	3.46E-02	3.47E-02
54 EFPY					
E>1.0 MeV	1.55E+19	1.93E+19	2.14E+19	2.70E+19	2.70E+19
E>0.1 MeV	3.23E+19	4.06E+19	4.53E+19	5.72E+19	5.74E+19
dpa	2.39E-02	2.97E-02	3.29E-02	4.13E-02	4.14E-02

Note: Maximum neutron exposure projection is at either 42.3° or 45°

Table 6-14

Neutron Exposure Values Within The
Palo Verde Unit 1 Reactor Vessel

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

	0°	15°	30°	42.3°	45°
9.81 EFPY					
Surface	3.08E+18	3.87E+18	3.96E+18	4.65E+18	4.65E+18
¼ T	1.72E+18	2.14E+18	2.20E+18	2.58E+18	2.57E+18
¾ T	3.83E+17	4.68E+17	4.82E+17	5.65E+17	5.63E+17
15 EFPY					
Surface	4.23E+18	5.30E+18	5.58E+18	6.74E+18	6.74E+18
¼ T	2.36E+18	2.94E+18	3.10E+18	3.74E+18	3.74E+18
¾ T	5.25E+17	6.42E+17	6.79E+17	8.18E+17	8.17E+17
32 EFPY					
Surface	7.99E+18	1.00E+19	1.09E+19	1.36E+19	1.36E+19
¼ T	4.47E+18	5.55E+18	6.05E+18	7.54E+18	7.54E+18
¾ T	9.92E+17	1.21E+18	1.33E+18	1.65E+18	1.65E+18
40 EFPY					
Surface	9.76E+18	1.22E+19	1.34E+19	1.68E+19	1.68E+19
¼ T	5.46E+18	6.77E+18	7.44E+18	9.33E+18	9.33E+18
¾ T	1.21E+18	1.48E+18	1.63E+18	2.04E+18	2.04E+18
45 EFPY					
Surface	1.09E+19	1.36E+19	1.50E+19	1.88E+19	1.89E+19
¼ T	6.07E+18	7.54E+18	8.31E+18	1.04E+19	1.05E+19
¾ T	1.35E+18	1.65E+18	1.82E+18	2.28E+18	2.28E+18
54 EFPY					
Surface	1.29E+19	1.61E+19	1.78E+19	2.24E+19	2.25E+19
¼ T	7.19E+18	8.92E+18	9.88E+18	1.25E+19	1.25E+19
¾ T	1.60E+18	1.95E+18	2.16E+18	2.72E+18	2.73E+18

Notes:

- Maximum neutron exposure projection is at either 42.3° or 45°
- The ¼T and ¾T values were determined using the calculational methods described in Section 6.2 and not by the empirical relation described in Regulatory Guide 1.99, Rev. 2.

Table 6-14, cont'd

Neutron Exposure Values Within The
Palo Verde Unit 1 Reactor Vessel

Best Estimate Fluence (n/cm^2) Based on dpa Slope

	0°	15°	30°	42.3°	45°
9.81 EFPY					
Surface	3.08E+18	3.87E+18	3.96E+18	4.65E+18	4.65E+18
¼ T	1.96E+18	2.43E+18	2.50E+18	2.93E+18	2.92E+18
¾ T	6.96E+17	8.34E+17	8.64E+17	1.01E+18	1.00E+18
15 EFPY					
Surface	4.23E+18	5.30E+18	5.58E+18	6.74E+18	6.74E+18
¼ T	2.68E+18	3.33E+18	3.53E+18	4.25E+18	4.24E+18
¾ T	9.55E+17	1.14E+18	1.22E+18	1.47E+18	1.45E+18
32 EFPY					
Surface	7.99E+18	1.00E+19	1.09E+19	1.36E+19	1.36E+19
¼ T	5.07E+18	6.28E+18	6.89E+18	8.57E+18	8.56E+18
¾ T	1.80E+18	2.16E+18	2.38E+18	2.95E+18	2.94E+18
40 EFPY					
Surface	9.76E+18	1.22E+19	1.34E+19	1.68E+19	1.68E+19
¼ T	6.19E+18	7.67E+18	8.47E+18	1.06E+19	1.06E+19
¾ T	2.20E+18	2.63E+18	2.93E+18	3.65E+18	3.63E+18
45 EFPY					
Surface	1.09E+19	1.36E+19	1.50E+19	1.88E+19	1.89E+19
¼ T	6.89E+18	8.54E+18	9.46E+18	1.19E+19	1.19E+19
¾ T	2.45E+18	2.93E+18	3.27E+18	4.09E+18	4.07E+18
54 EFPY					
Surface	1.29E+19	1.61E+19	1.78E+19	2.24E+19	2.25E+19
¼ T	8.16E+18	1.01E+19	1.12E+19	1.42E+19	1.41E+19
¾ T	2.90E+18	3.47E+18	3.88E+18	4.88E+18	4.85E+18

Notes:

- Maximum neutron exposure projection is at either 42.3° or 45°
- The ¼T and ¾T values were determined using the calculational methods described in Section 6.2 and not by the empirical relation described in Regulatory Guide 1.99, Rev. 2.

Table 6-14, cont'd

Neutron Exposure Values Within The
Palo Verde Unit 1 Reactor Vessel

Calculated Fluence (n/cm^2) Based on E > 1.0 MeV Slope

	0°	15°	30°	42.3°	45°
9.81 EFPY					
Surface	3.71E+18	4.64E+18	4.75E+18	5.59E+18	5.58E+18
¼ T	2.07E+18	2.58E+18	2.64E+18	3.10E+18	3.09E+18
¾ T	4.60E+17	5.62E+17	5.79E+17	6.78E+17	6.76E+17
15 EFPY					
Surface	5.09E+18	6.37E+18	6.70E+18	8.10E+18	8.10E+18
¼ T	2.84E+18	3.53E+18	3.72E+18	4.50E+18	4.49E+18
¾ T	6.31E+17	7.71E+17	8.16E+17	9.83E+17	9.81E+17
32 EFPY					
Surface	9.60E+18	1.20E+19	1.31E+19	1.63E+19	1.64E+19
¼ T	5.37E+18	6.66E+18	7.27E+18	9.06E+18	9.06E+18
¾ T	1.19E+18	1.45E+18	1.59E+18	1.98E+18	1.98E+18
40 EFPY					
Surface	1.17E+19	1.47E+19	1.61E+19	2.02E+19	2.02E+19
¼ T	6.55E+18	8.14E+18	8.94E+18	1.12E+19	1.12E+19
¾ T	1.46E+18	1.78E+18	1.96E+18	2.45E+18	2.45E+18
45 EFPY					
Surface	1.31E+19	1.63E+19	1.80E+19	2.26E+19	2.27E+19
¼ T	7.30E+18	9.06E+18	9.99E+18	1.26E+19	1.26E+19
¾ T	1.62E+18	1.98E+18	2.19E+18	2.74E+18	2.75E+18
54 EFPY					
Surface	1.55E+19	1.93E+19	2.14E+19	2.70E+19	2.70E+19
¼ T	8.63E+18	1.07E+19	1.19E+19	1.50E+19	1.50E+19
¾ T	1.92E+18	2.34E+18	2.60E+18	3.27E+18	3.27E+18

Notes:

- Maximum neutron exposure projection is at either 42.3° or 45°
- The ¼T and ¾T values were determined using the calculational methods described in Section 6.2 and not by the empirical relation described in Regulatory Guide 1.99, Rev. 2.

Table 6-14, cont'd

Neutron Exposure Values Within The
Palo Verde Unit 1 Reactor Vessel

Calculated Fluence (n/cm^2) Based on dpa Slope

	0°	15°	30°	42.3°	45°
9.81 EFPY					
Surface	3.71E+18	4.64E+18	4.75E+18	5.59E+18	5.58E+18
¼ T	2.35E+18	2.92E+18	3.00E+18	3.53E+18	3.51E+18
¾ T	8.36E+17	1.00E+18	1.04E+18	1.21E+18	1.20E+18
15 EFPY					
Surface	5.09E+18	6.37E+18	6.70E+18	8.10E+18	8.10E+18
¼ T	3.23E+18	4.00E+18	4.24E+18	5.11E+18	5.09E+18
¾ T	1.15E+18	1.37E+18	1.46E+18	1.76E+18	1.75E+18
32 EFPY					
Surface	9.60E+18	1.20E+19	1.31E+19	1.63E+19	1.64E+19
¼ T	6.09E+18	7.55E+18	8.27E+18	1.03E+19	1.03E+19
¾ T	2.17E+18	2.59E+18	2.86E+18	3.55E+18	3.53E+18
40 EFPY					
Surface	1.17E+19	1.47E+19	1.61E+19	2.02E+19	2.02E+19
¼ T	7.44E+18	9.22E+18	1.02E+19	1.27E+19	1.27E+19
¾ T	2.65E+18	3.16E+18	3.51E+18	4.39E+18	4.36E+18
45 EFPY					
Surface	1.31E+19	1.63E+19	1.80E+19	2.26E+19	2.27E+19
¼ T	8.28E+18	1.03E+19	1.14E+19	1.43E+19	1.42E+19
¾ T	2.95E+18	3.52E+18	3.93E+18	4.92E+18	4.89E+18
54 EFPY					
Surface	1.55E+19	1.93E+19	2.14E+19	2.70E+19	2.70E+19
¼ T	9.80E+18	1.21E+19	1.35E+19	1.70E+19	1.70E+19
¾ T	3.48E+18	4.17E+18	4.66E+18	5.86E+18	5.83E+18

Notes:

- Maximum neutron exposure projection is at either 42.3° or 45°
- The ¼T and ¾T values were determined using the calculational methods described in Section 6.2 and not by the empirical relation described in Regulatory Guide 1.99, Rev. 2.

Table 6-15

Updated Lead Factors For Palo Verde Unit 1
Surveillance Capsules

Capsule	Location	Capsule Fluence	Midplane Max. Wall Fluence	Lead Factor
W137[a]	43°	4.33E+18	3.05E+18	1.42
W38[b]	38°	7.85E+18	5.59E+18	1.41
W43	43°	7.95E+18	5.59E+18	1.42
W142	38°	7.86E+18	5.59E+18	1.41
W230	40°	7.99E+18	5.59E+18	1.43
W310	40°	7.99E+18	5.59E+18	1.43

Notes:
[a] - Withdrawn at the end of Cycle 4.
[b] - Withdrawn at the end of Cycle 8.

The surveillance capsule lead factor is defined by:

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

where Φ is the neutron fluence (E > 1.0 MeV) at the time of the capsule withdrawal. In the case of the standby capsules, the neutron fluence is at the time of the latest withdrawn capsule.

7 SURVEILLANCE CAPSULE REMOVAL SCHEDULE

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

TABLE 7-1

Palo Verde Unit 1 Reactor Vessel Surveillance Capsule Withdrawal Schedule

Capsule	Location	Lead Factor[a]	Removal Time (EFPY)[b]	Fluence (n/cm^2, $E > 1.0$ MeV)[a]
137°	137°	1.42	4.533	4.33×10^{18} [c]
38°	38°	1.41	9.81	7.85×10^{18} [c]
230°	230°	1.43	15	1.16×10^{19}
310°	310°	1.43	EOL	2.35×10^{19} [d]
43°	43°	1.42	Standby	(e)
142°	142°	1.41	Standby	(e)

Notes:

(a) Updated in Capsule 38° dosimetry analysis.

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

(c) Plant specific evaluation.

(d) The 310° Capsule should be removed at 32 EFPY or at 37.1 EFPY if a License Renewal is obtained from the NRC.

(e) Capsules 43° and 142° will reach an EOL license renewal (54 EFPY) fluence of 2.70×10^{19} n/cm^2 ($E > 1.0$ MeV) at 38 EFPY. Thus, it is recommended that these Capsules be removed at this time and placed in storage.

8 REFERENCES

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

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

3. TR-F-MCM-012, "Arizona Public Service Company Palo Verde Unit 1 – Evaluation of Baseline Specimens Reactor Vessel Materials Irradiation Surveillance Program", B.C. Chang, January 31, 1987.

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

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

6. TR-V-MCM-002, "Summary Report on Manufacture of Test Specimens and Assembly of Capsules For Irradiation Surveillance of Palo Verde Unit 1 Reactor Vessel Materials", A.D. Emery, July 14, 1982.

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

8. ASTM E23-98, *Standard Test Methods for Notched Bar Impact Testing of Metallic Materials*, in ASTM Standards, Section 3, American Society for Testing and Materials, Philadelphia, PA, 1998.

9. ASTM A370-97, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*, in ASTM Standards, Section 3, American Society for Testing and Materials, Philadelphia, PA, 1997.

10. ASTM E8-99, *Standard Test Methods for Tension Testing of Metallic Materials*, in ASTM Standards, Section 3, American Society for Testing and Materials, Philadelphia, PA, 1999.

11. ASTM E21-92 (1998), *Standard Test Methods for Elevated Temperature Tension Tests of Metallic Materials*, in ASTM Standards, Section 3, American Society for Testing and Materials, Philadelphia, PA, 1998.

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

13. RSIC Computer Code Collection CCC-650, "DOORS 3.1 One, Two- and Three-Dimensional Discrete Ordinates Neutron/Photon Transport Code System, ", August 1996.

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

15. WCAP-14066, "Analysis of the 137° Capsule from the Arizona Public Service Company Palo Verde Unit 1 Reactor Vessel Surveillance Program", J.M. Chicots, et. al., May 1994.

16. ASTM Designation E482-89 (Re-approved 1996), *Standard Guide for Application of Neutron Transport Methods for Reactor Vessel Surveillance*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 2000.

17. ASTM Designation E560-84 (Re-approved 1996), *Standard Recommended Practice for Extrapolating Reactor Vessel Surveillance Dosimetry Results*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 2000.

18. ASTM Designation E693-94, *Standard Practice for Characterizing Neutron Exposures in Iron and Low Alloy Steels in Terms of Displacements per Atom (dpa)*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 2000.

19. ASTM Designation E706-87 (Re-approved 1994), *Standard Master Matrix for Light-Water Reactor Pressure Vessel Surveillance Standard*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 2000.

20. ASTM Designation E853-87 (Re-approved 1995), *Standard Practice for Analysis and Interpretation of Light-Water Reactor Surveillance Results*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 2000.

21. ASTM Designation E261-98, *Standard Practice for Determining Neutron Fluence Rate, Fluence, and Spectra by Radioactivation Techniques*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 2000.

22. ASTM Designation E262-97, *Standard Method for Determining Thermal Neutron Reaction and Fluence Rates by Radioactivation Techniques*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 2000.

23. ASTM Designation E263-00, *Standard Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Iron*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 2000.

24. ASTM Designation E264-92 (Re-approved 1996), *Standard Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Nickel*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 2000.

25. ASTM Designation E481-97, *Standard Method for Measuring Neutron-Fluence Rate by Radioactivation of Cobalt and Silver*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 2000.

26. ASTM Designation E523-92 (Re-approved 1996), *Standard Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Copper*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 2000.

27. ASTM Designation E704-96, *Standard Test Method for Measuring Reaction Rates by Radioactivation of Uranium-238*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 2000.

28. ASTM Designation E705-96, *Standard Test Method for Measuring Reaction Rates by Radioactivation of Neptunium-237*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 2000.

29. ASTM Designation E1005-97, *Standard Test Method for Application and Analysis of Radiometric Monitors for Reactor Vessel Surveillance*, in ASTM Standards, Section 12, American Society for Testing and Materials, Philadelphia, PA, 2000.

30. Electronic Mail Correspondence, "Monthly Thermal Power Histoty and Reactor Physics Data", from Messrs. Fernandez/Neville (APS) to Mr. Bencini (Westinghouse), July – August 2000.

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

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

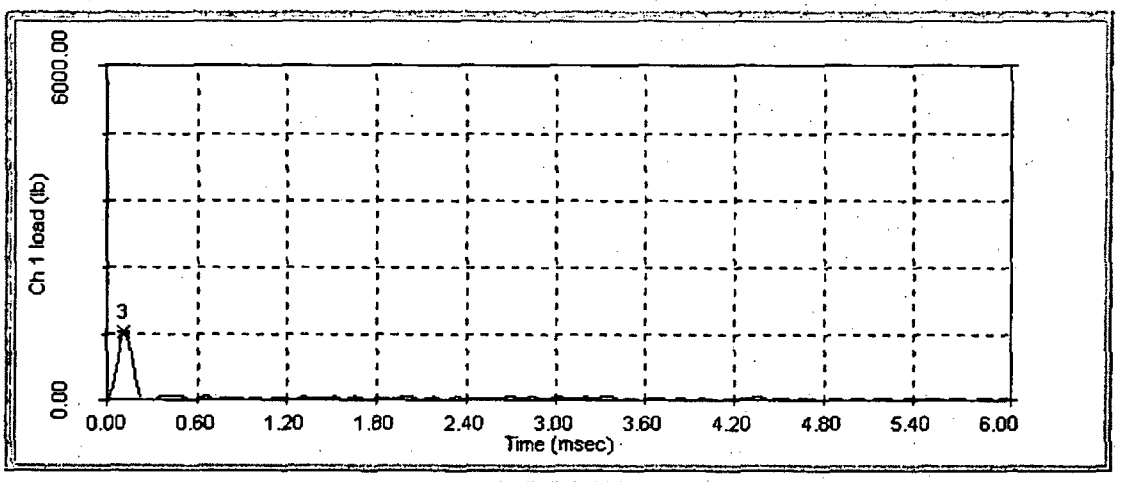
33. RSIC Data Library Collection DLC-178, "SNLRML Recommended Dosimetry Cross-Section Compendium", July 1994.

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

APPENDIX A

INSTRUMENTED CHARPY IMPACT TEST CURVES

- Specimen prefix "1A1" denotes Intermediate Plate, Longitudinal Orientation
- Specimen prefix "1A2" denotes Intermediate Plate, Transverse Orientation
- Specimen prefix "1A3" denotes weld material
- Specimen prefix "1A4" denotes Heat-Affected Zone material
- Specimen prefix "1AB" denotes Standard Reference Material Plate, Longitudinal Orientation



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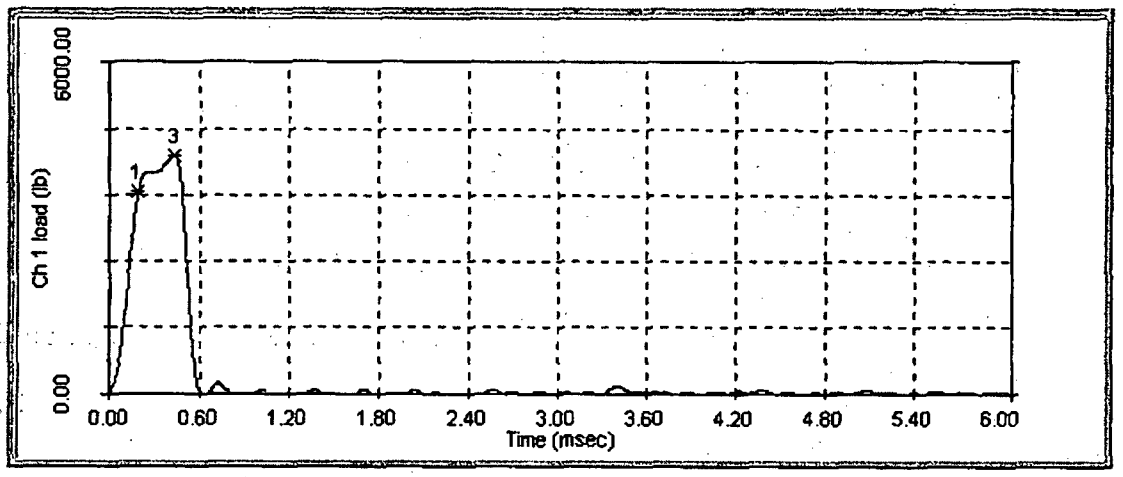

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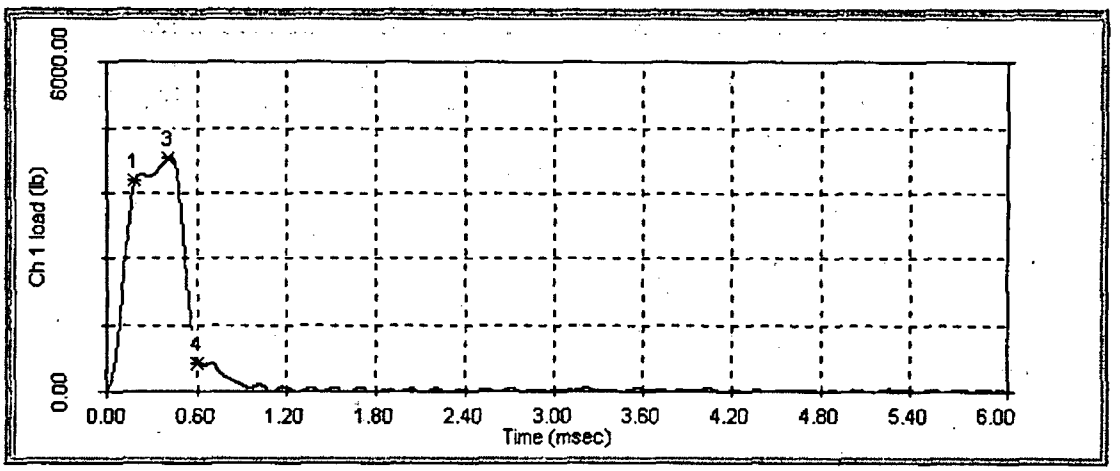

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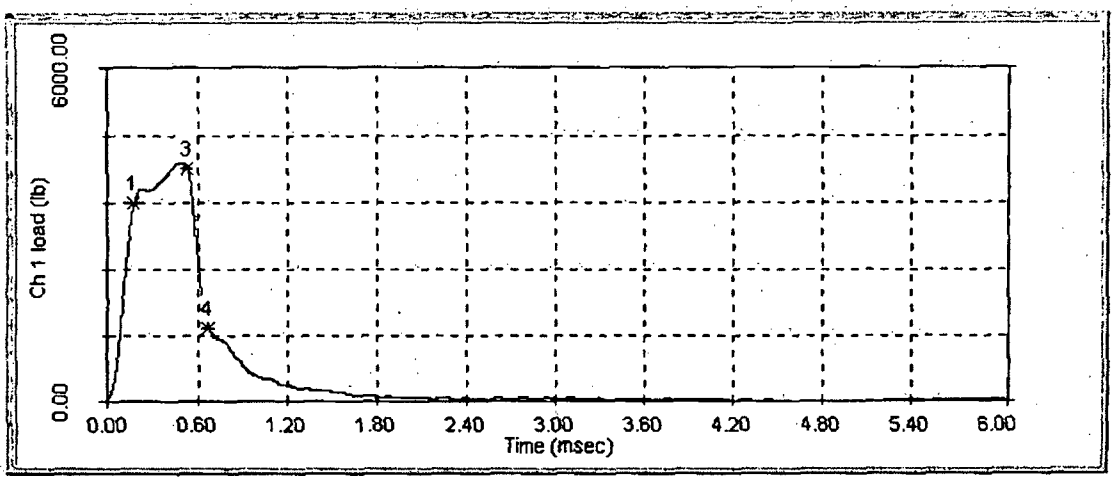

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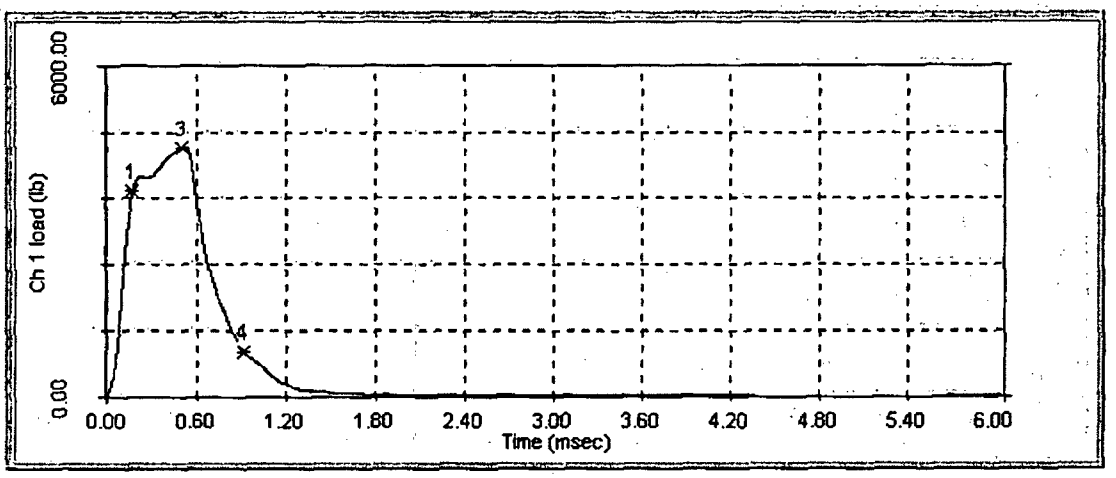
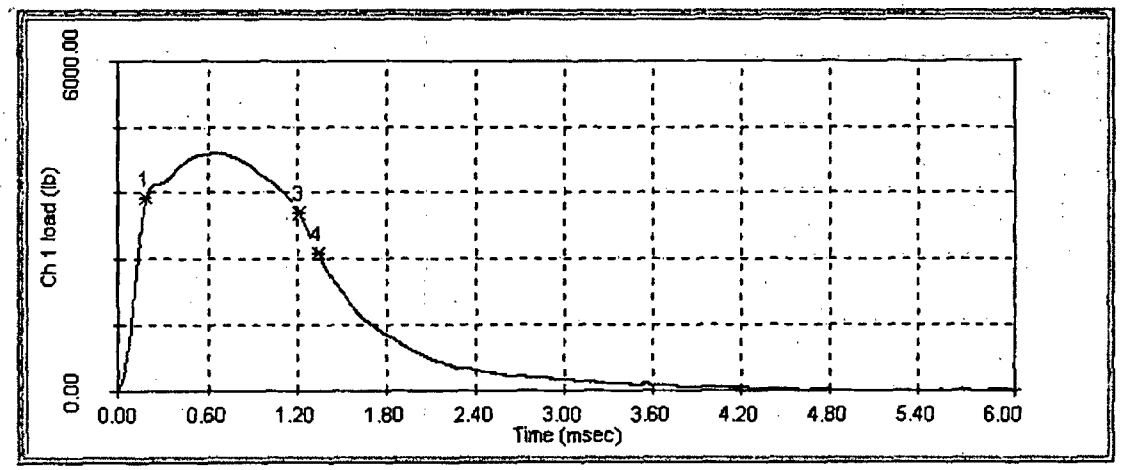
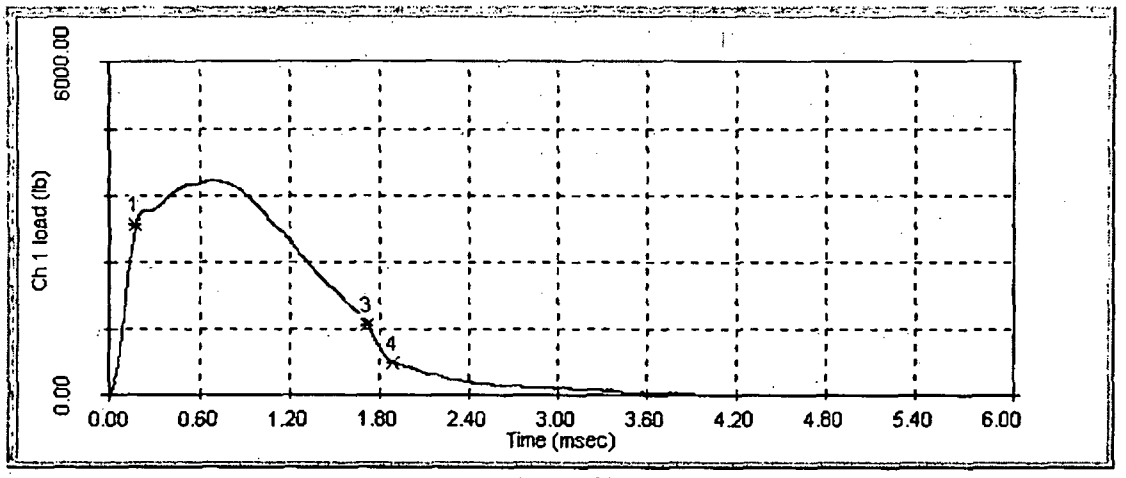


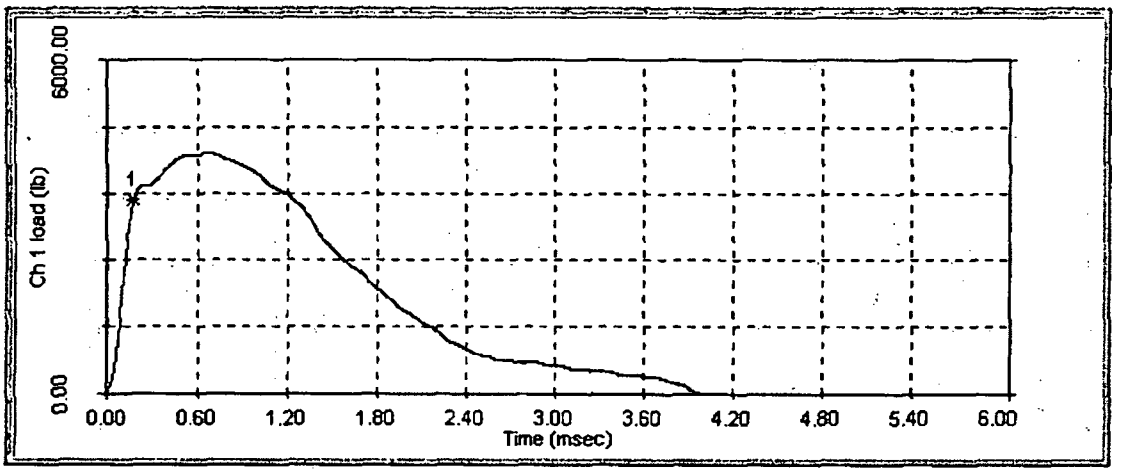
1AB6P, 200°F



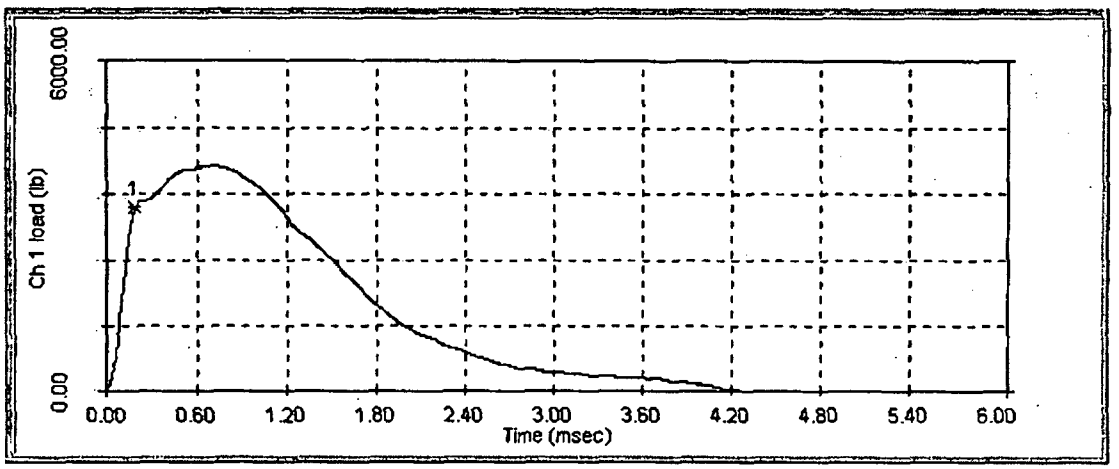
1AB5K, 225°F



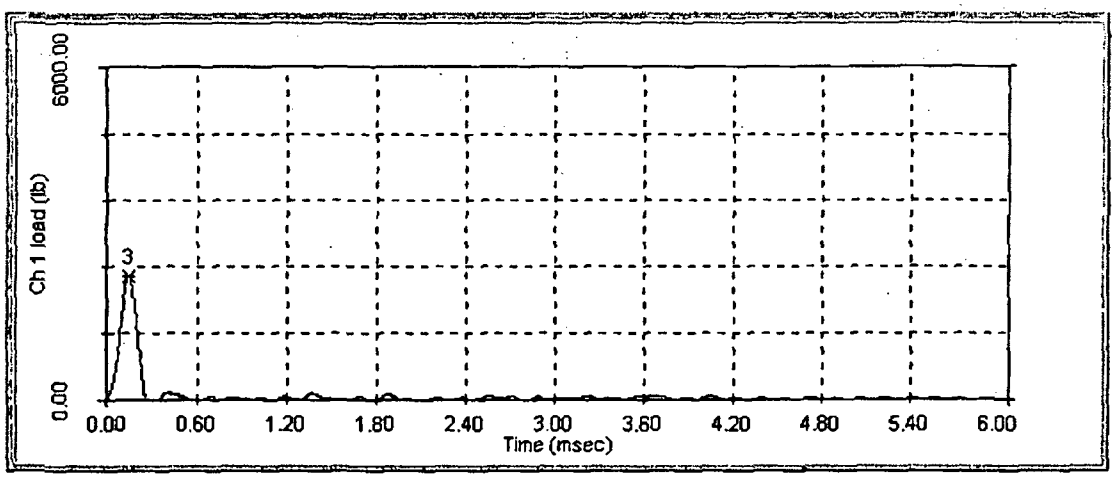
1AB4B, 250°F



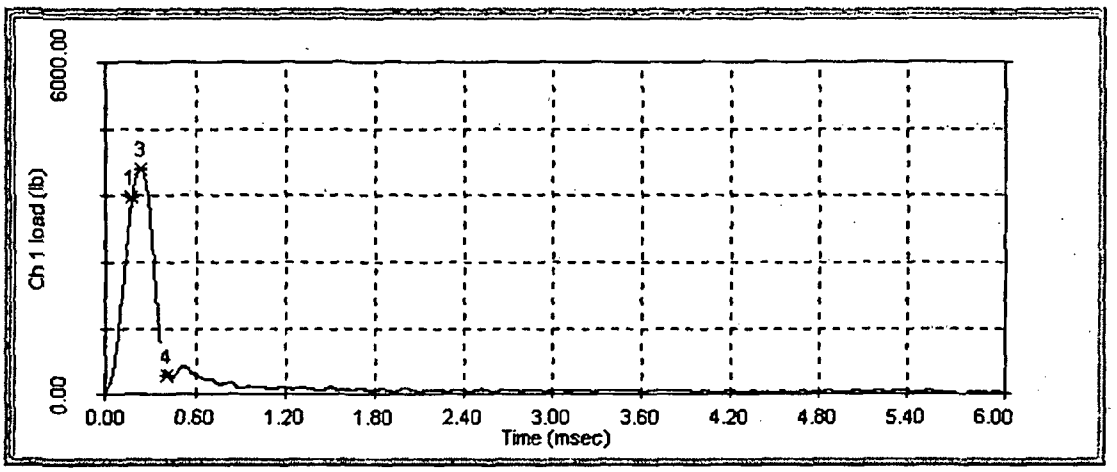
1AB44, 325°F



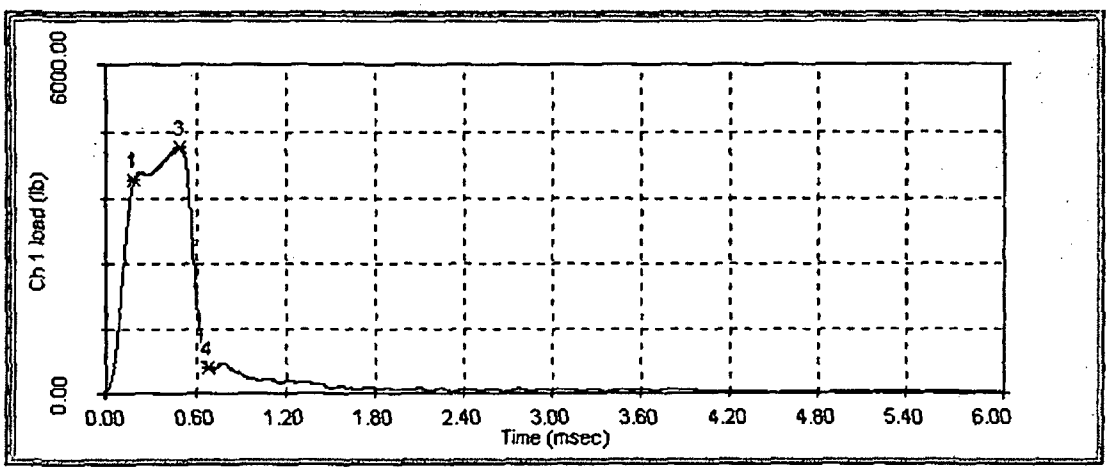
1AB45, 375°F



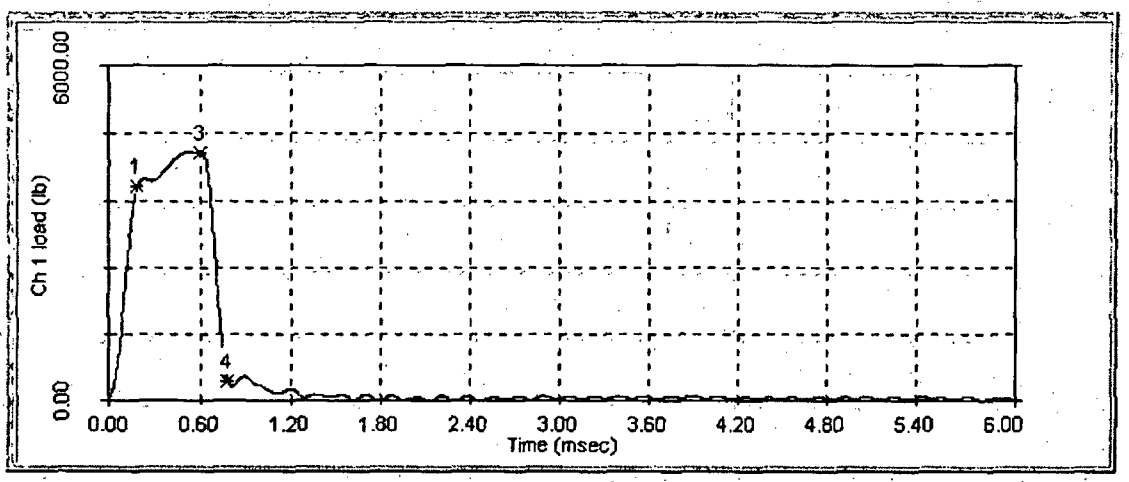
1A11T, -75°F



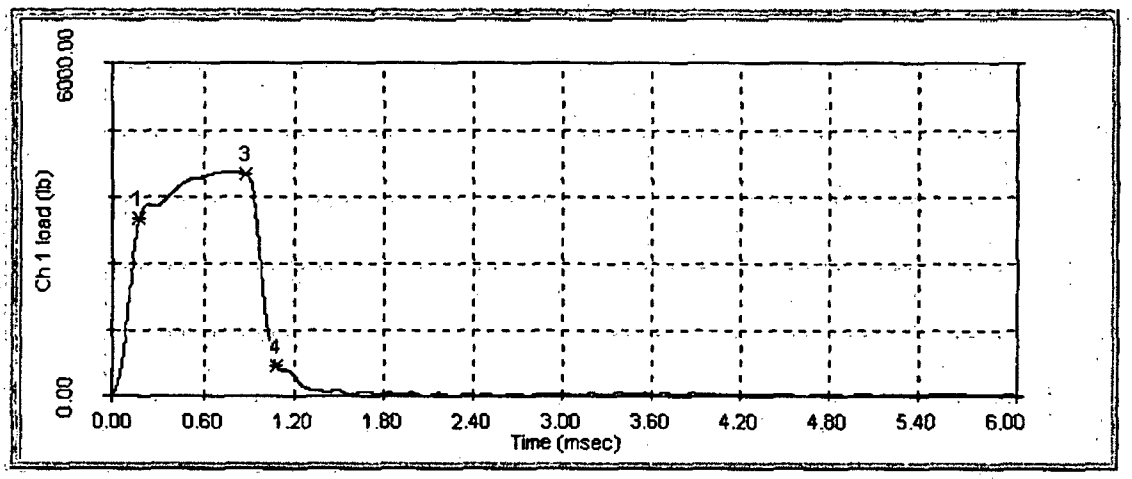
1A127, 0°F



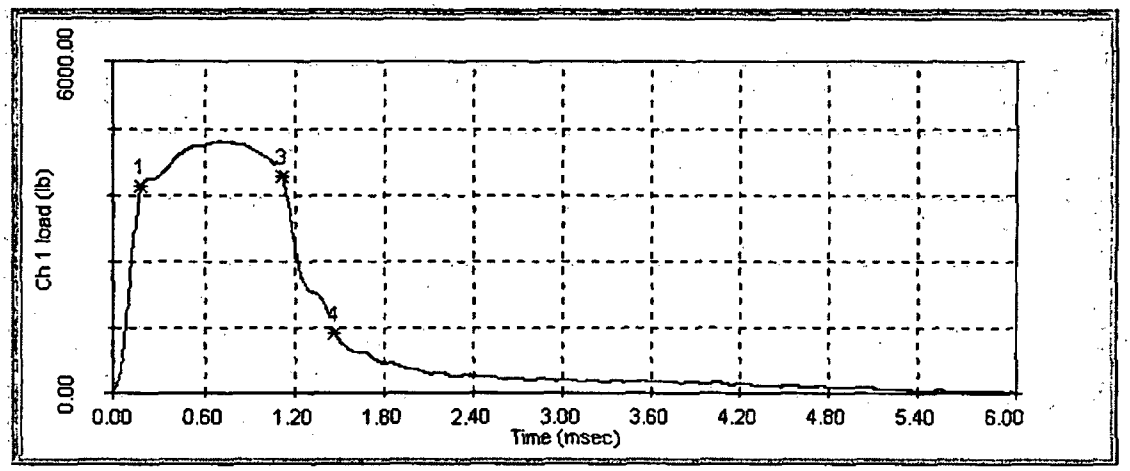
1A112, 20°F



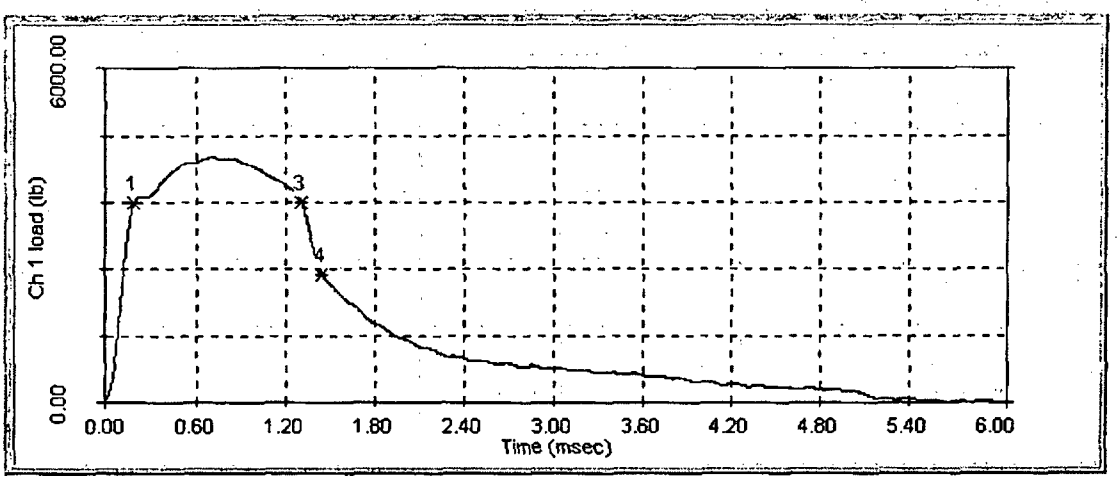
1A125, 30°F



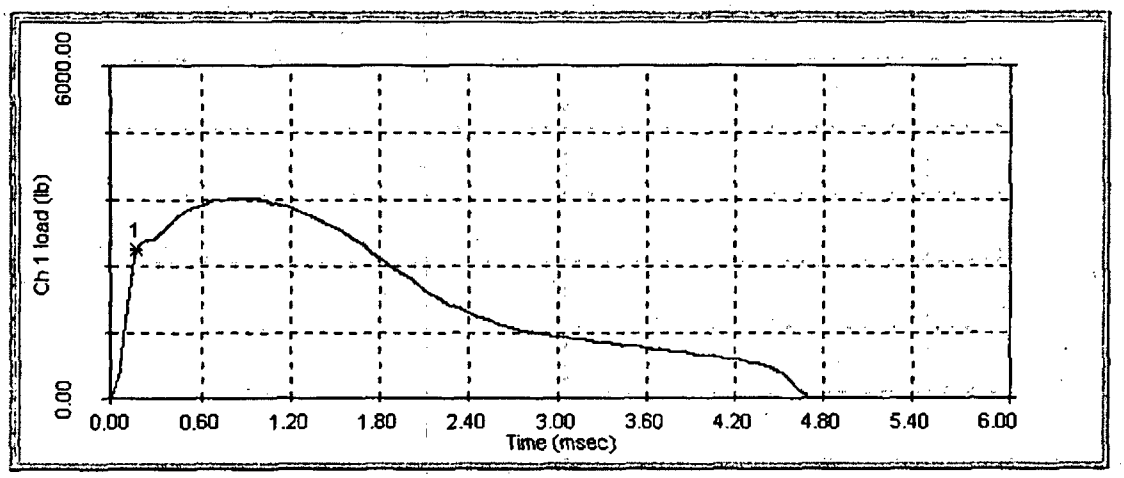
1A13U, 50°F



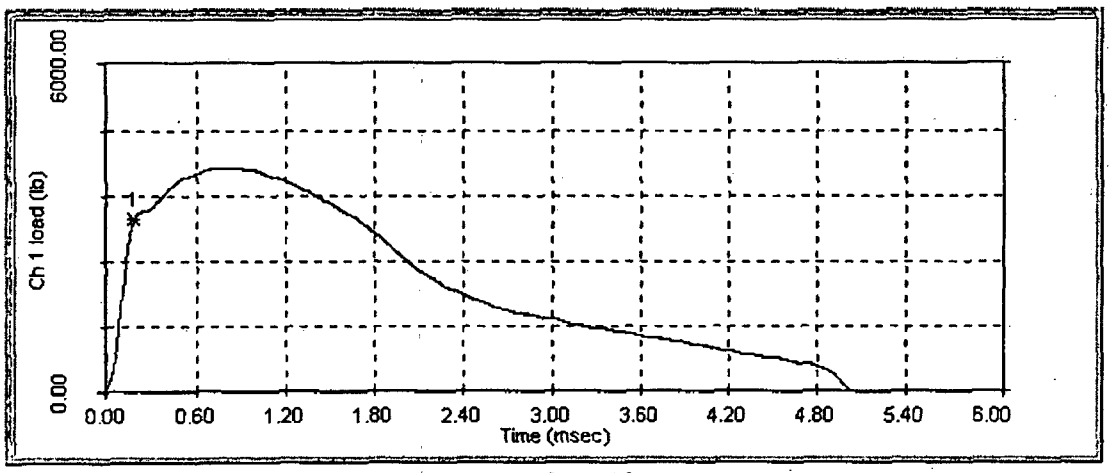
1A111, 100°F



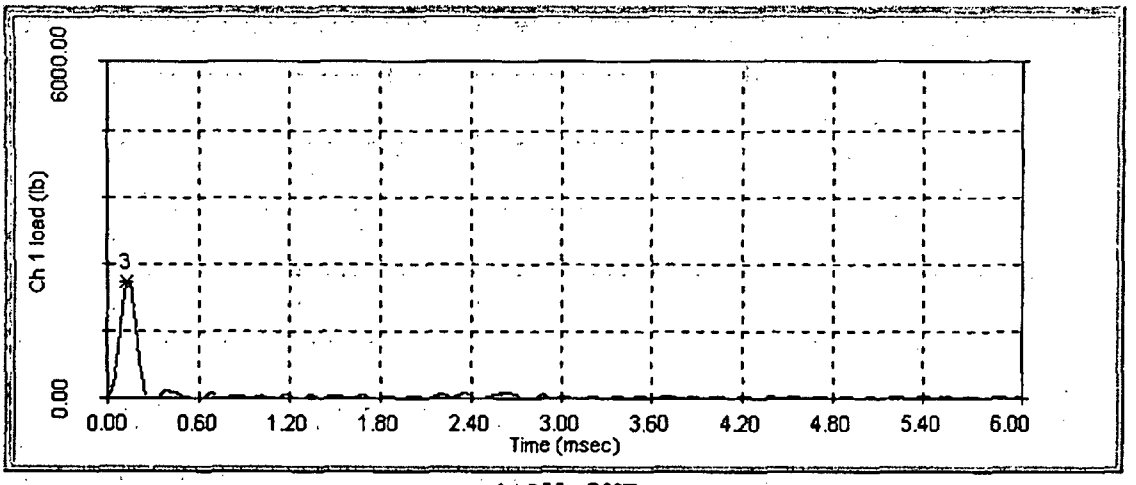
1A122, 150°F



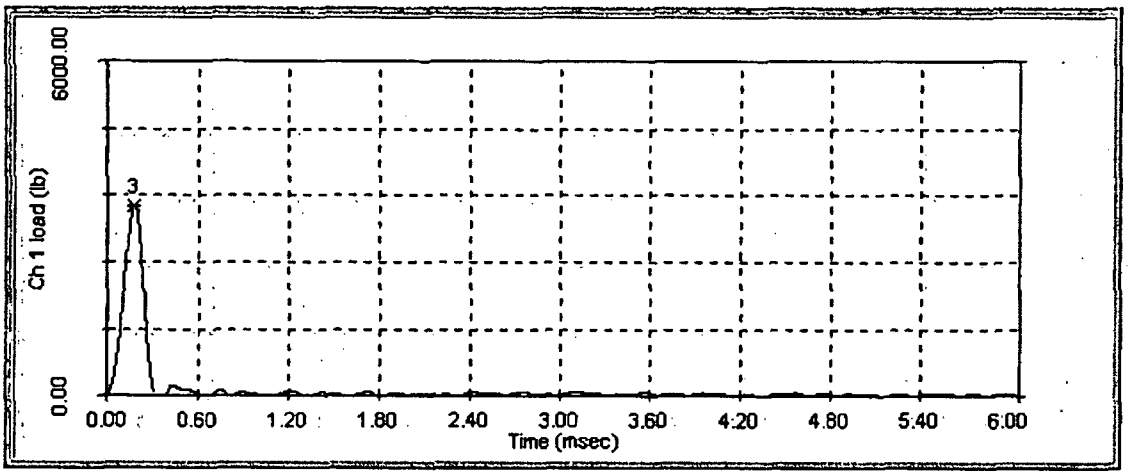
1A144, 225°F



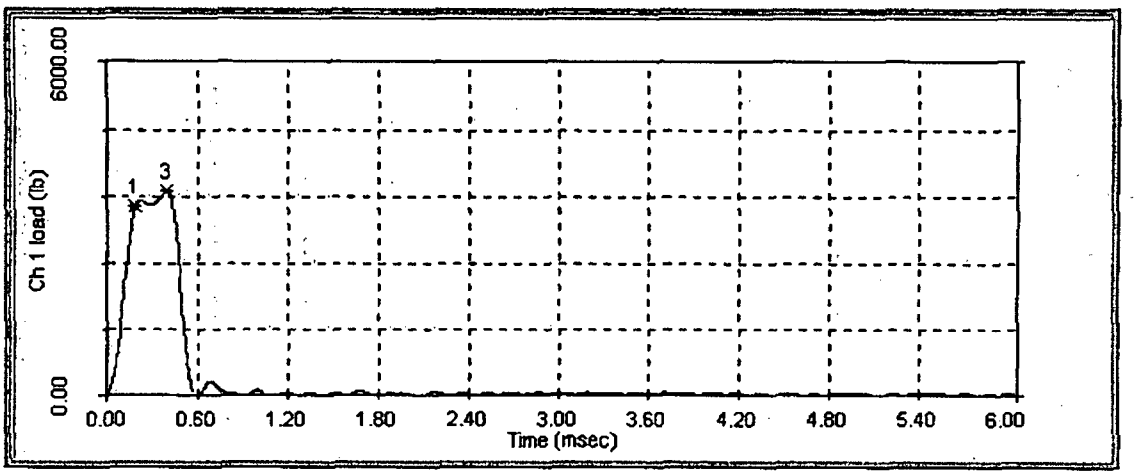
1A13K; 275°F



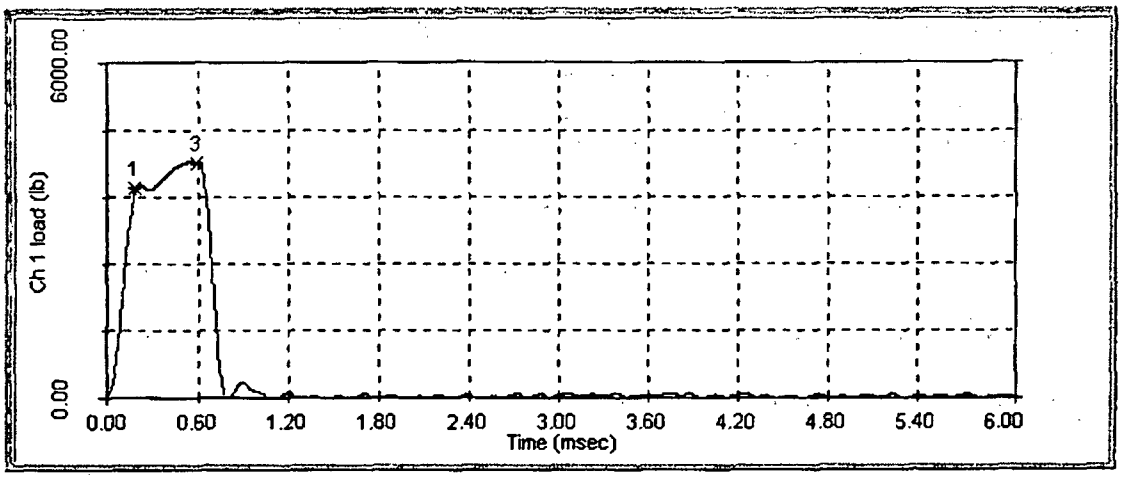
1A255, -75°F



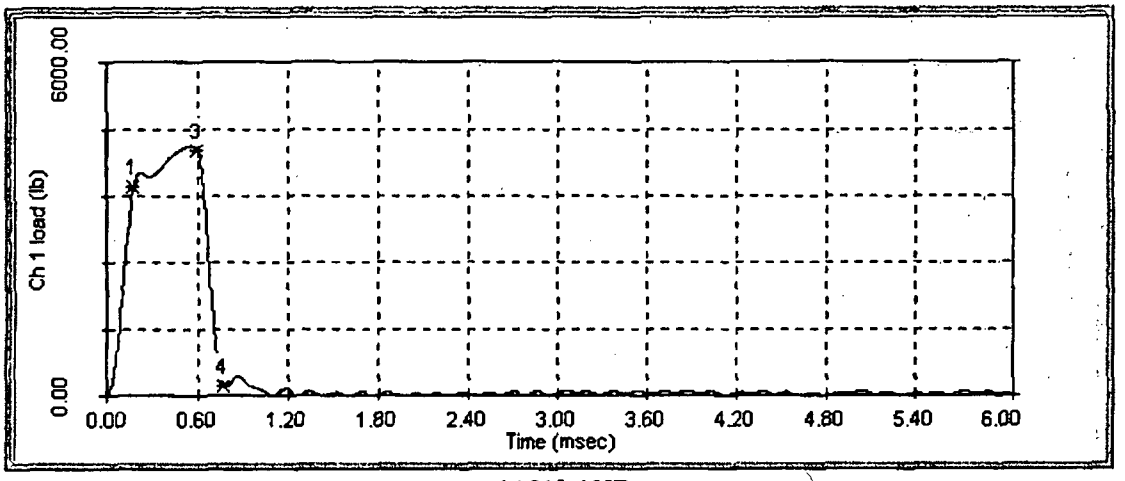
1A21E, -40°F



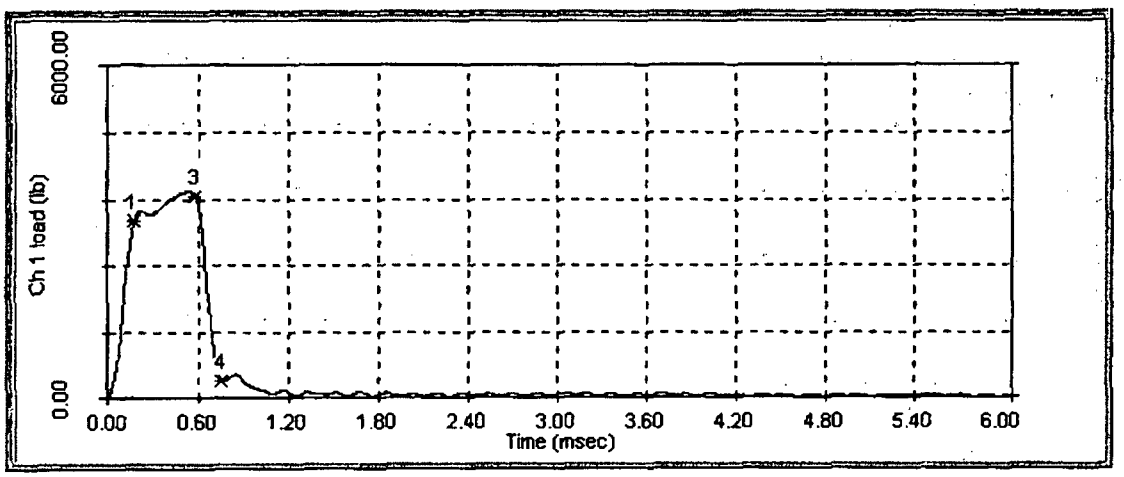
1A25P, 0°F



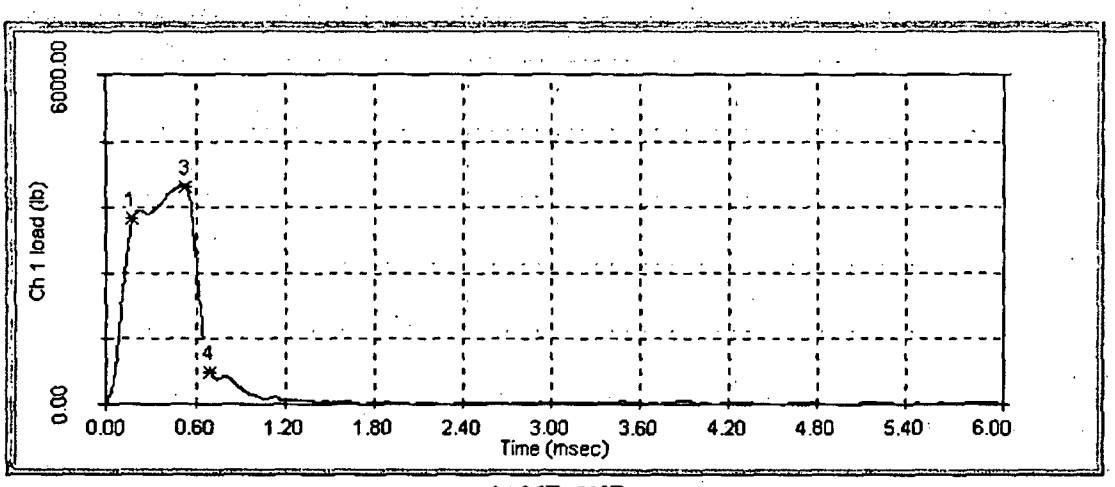
1A232, 5°F



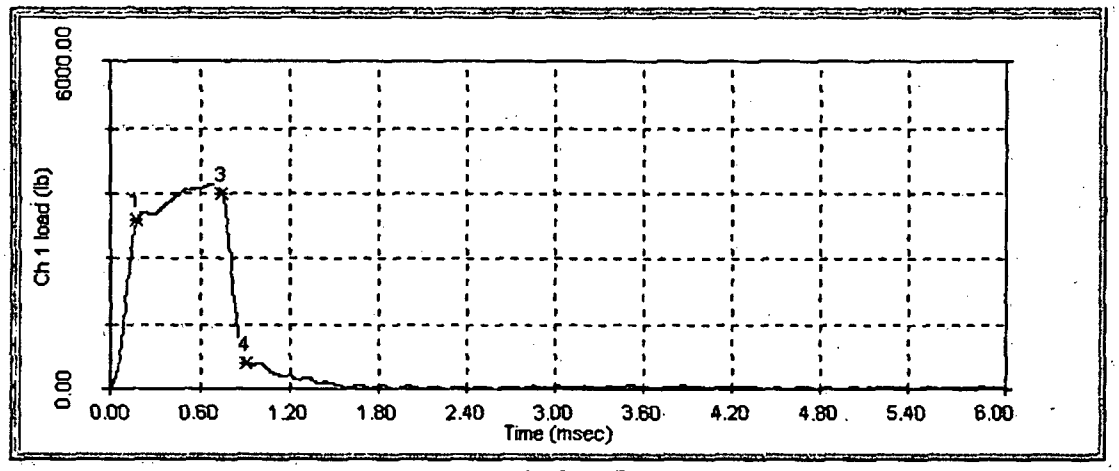
1A21J, 10°F



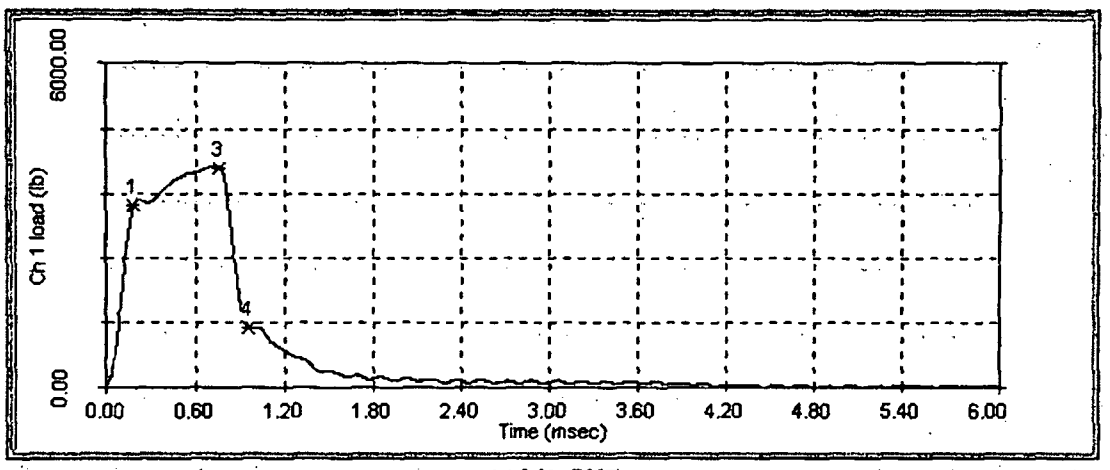
1A23A, 25°F



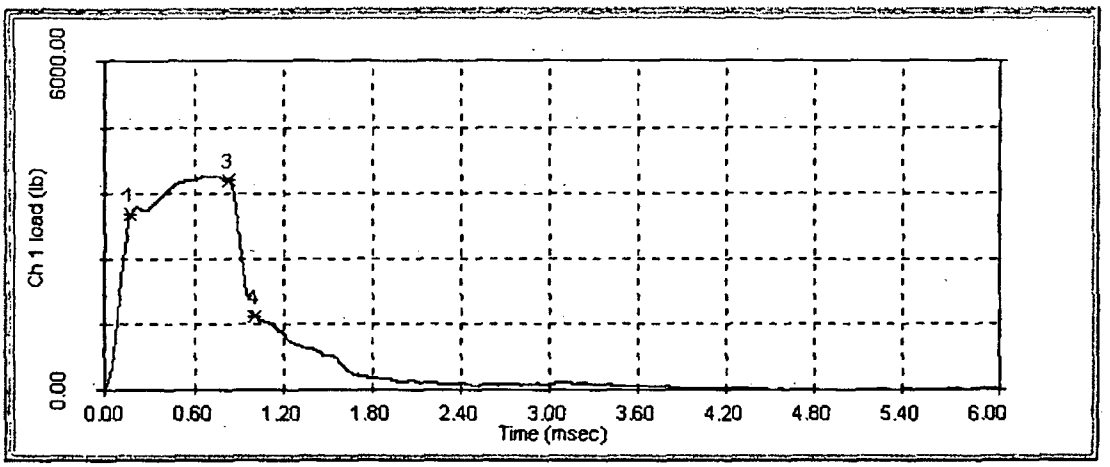
1A25E, 50°F



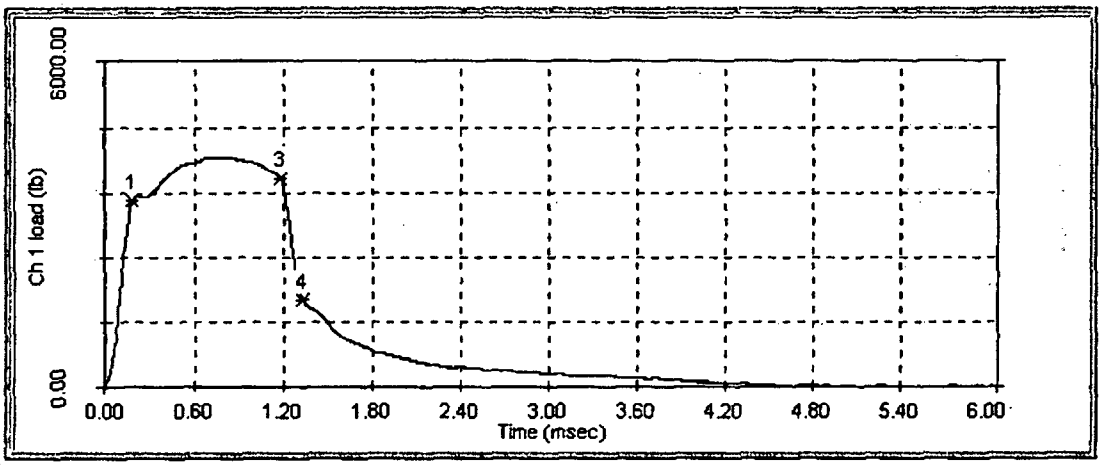
1A25U, 50°F



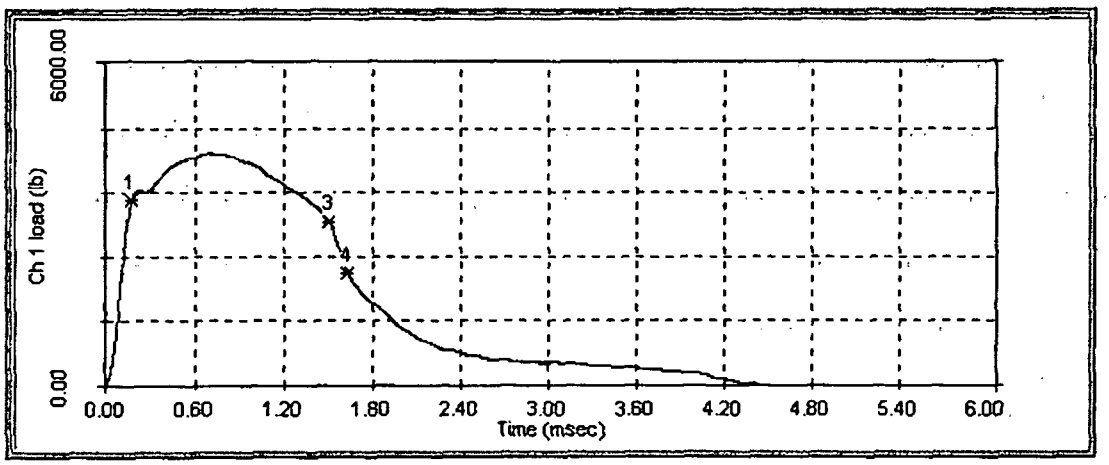
1A261, 70°F



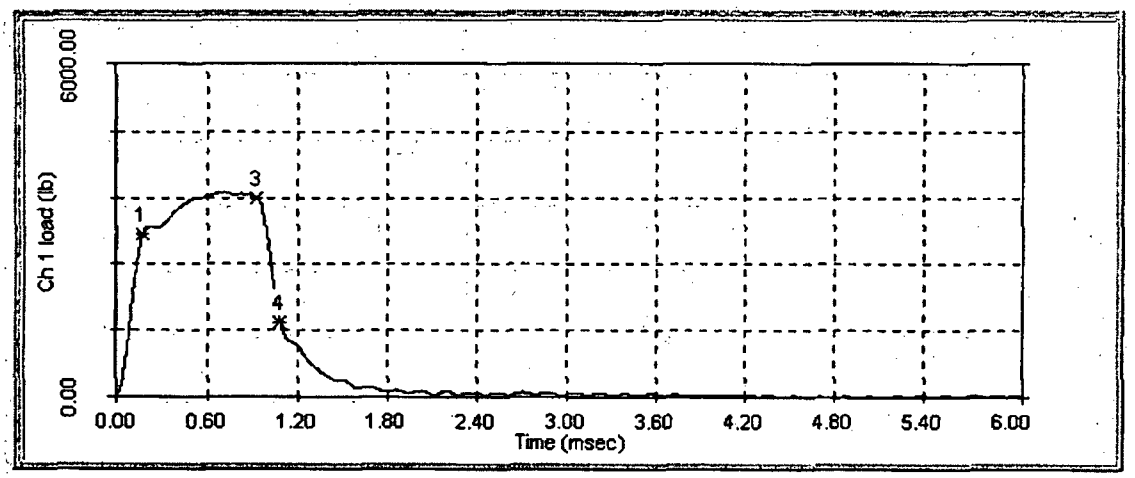
1A222, 80°F



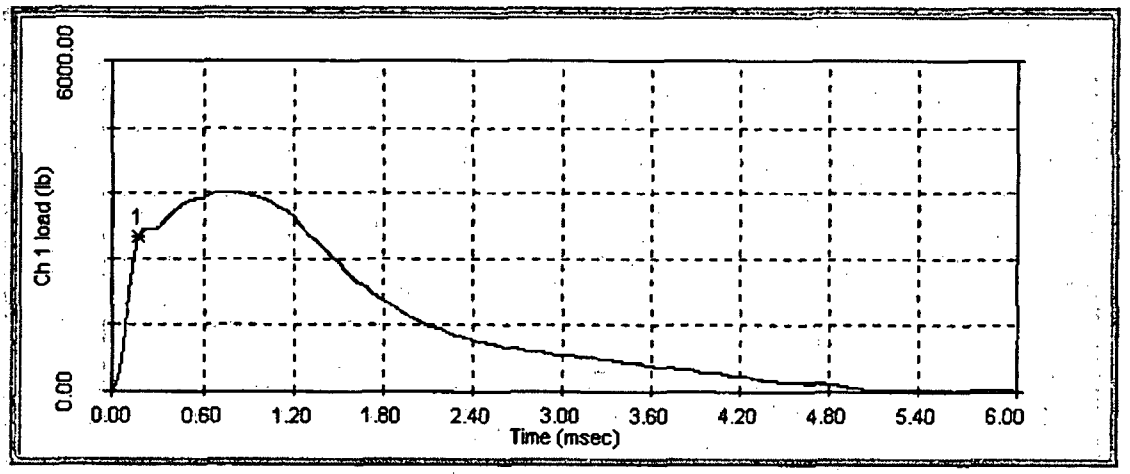
1A247, 125°F



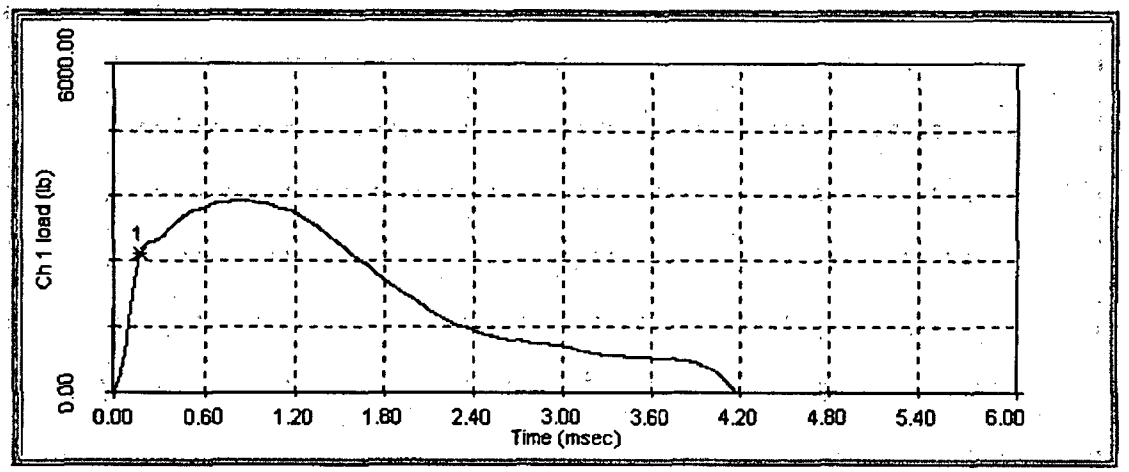
1A21M, 150°F



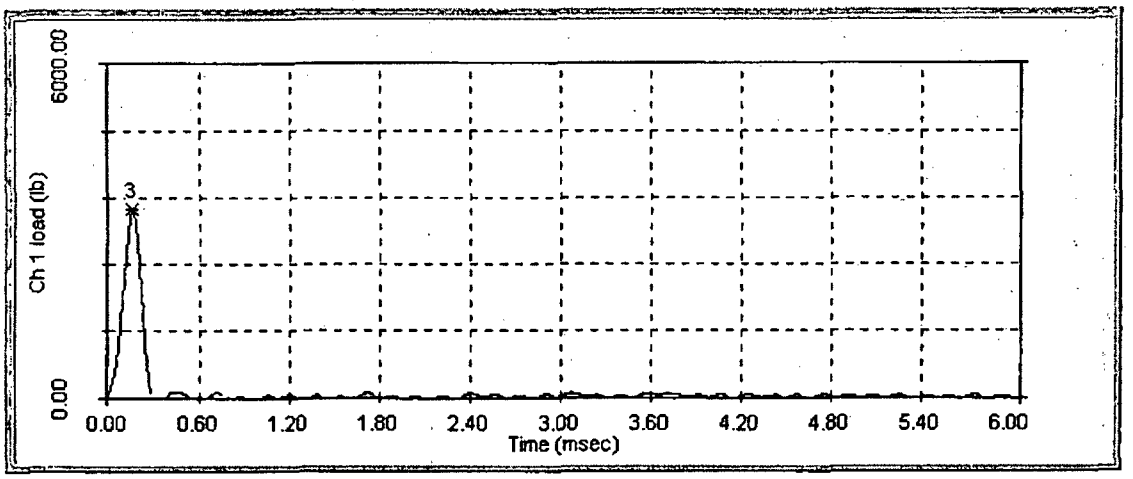
1A256, 150°F



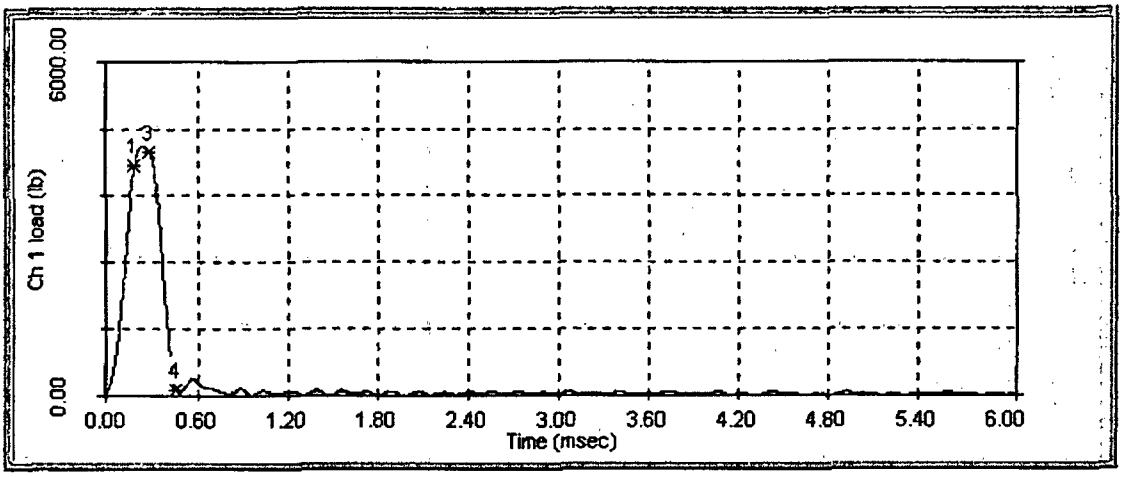
1A235, 200°F



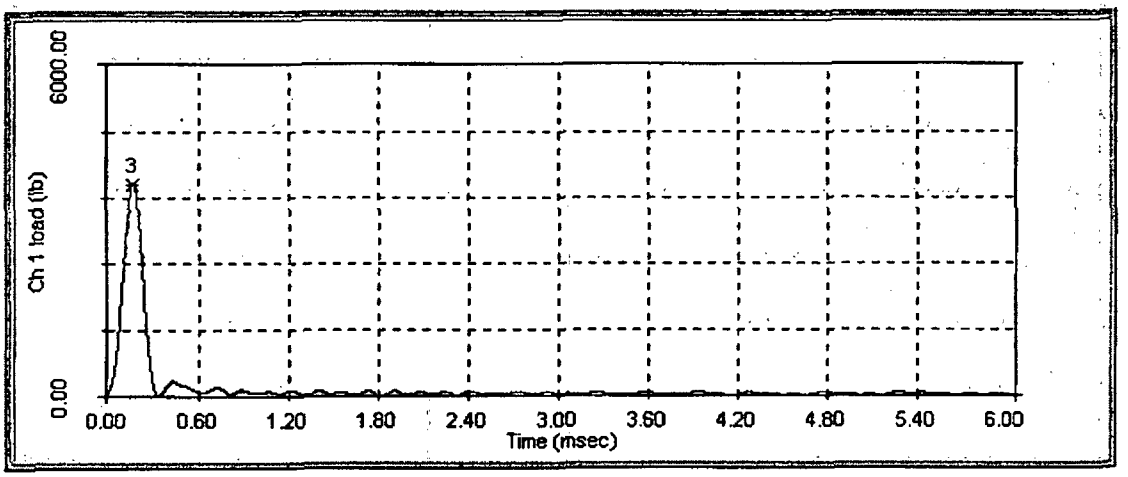
1A263, 250°F



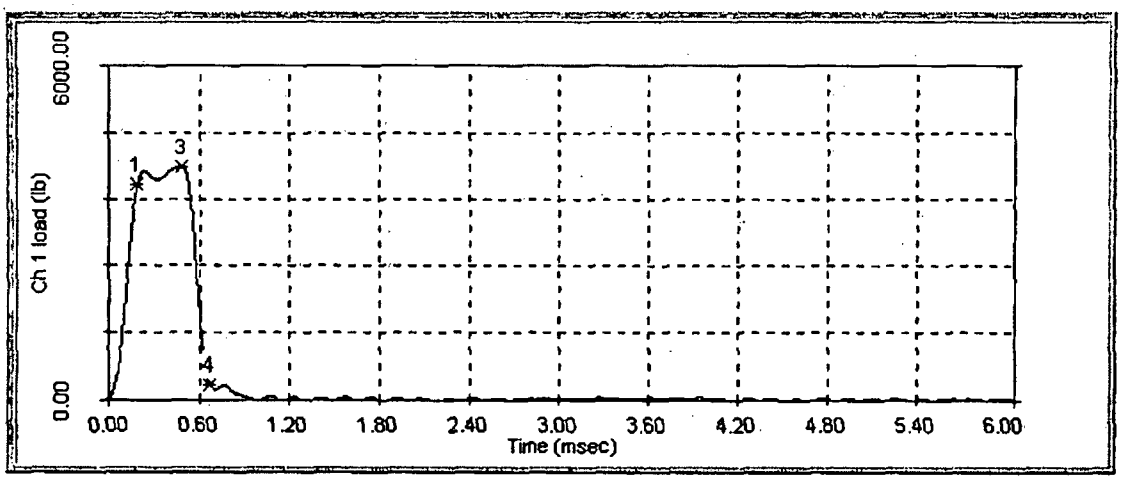
1A31Y, -96°F



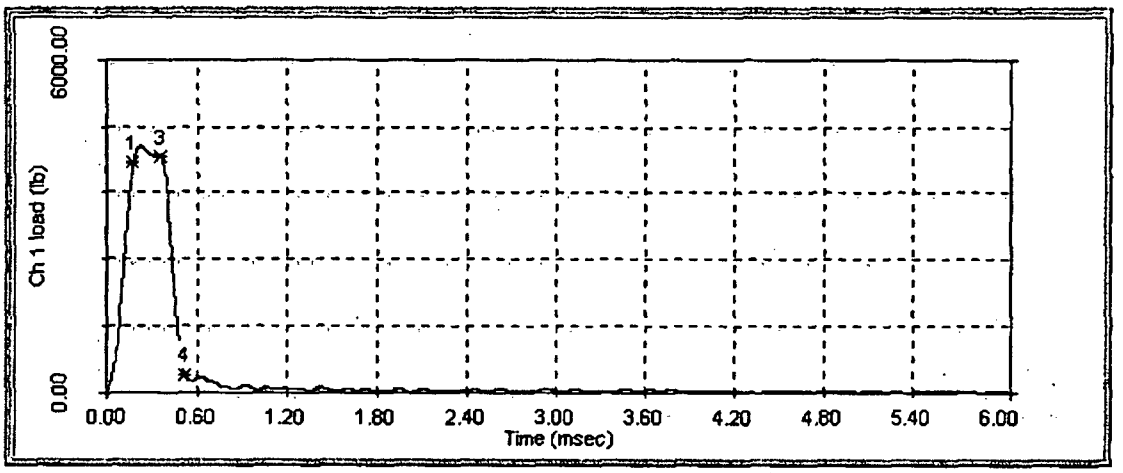
1A354, -70°F



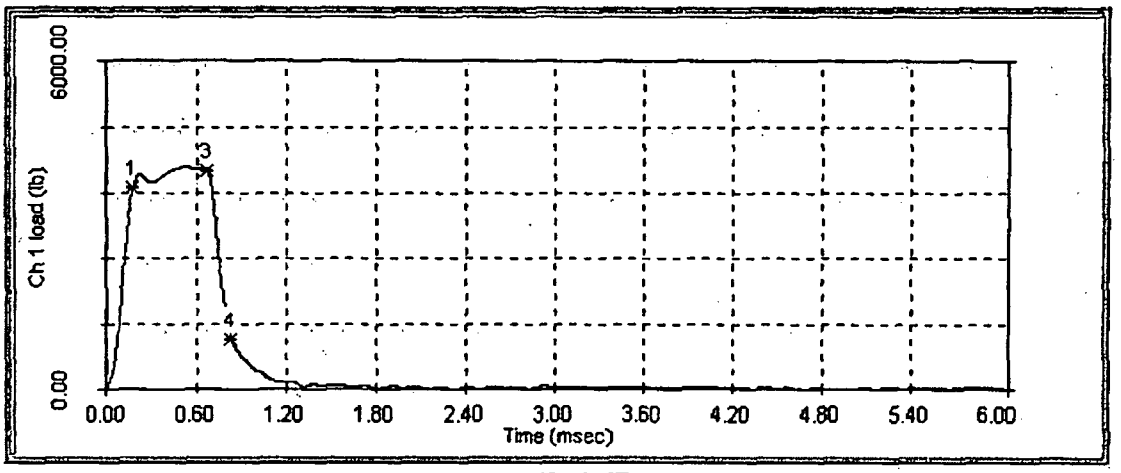
1A324, -55°F



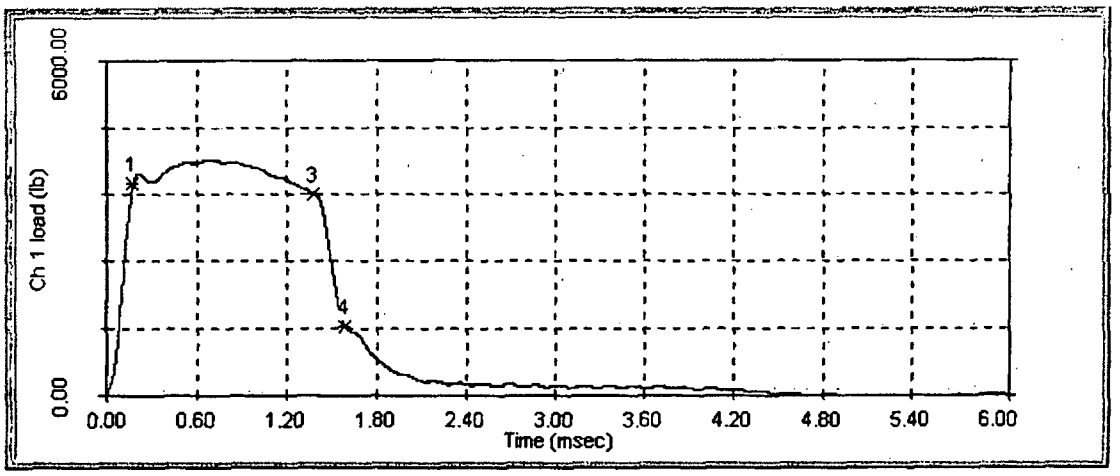
1A3A2, -50°F



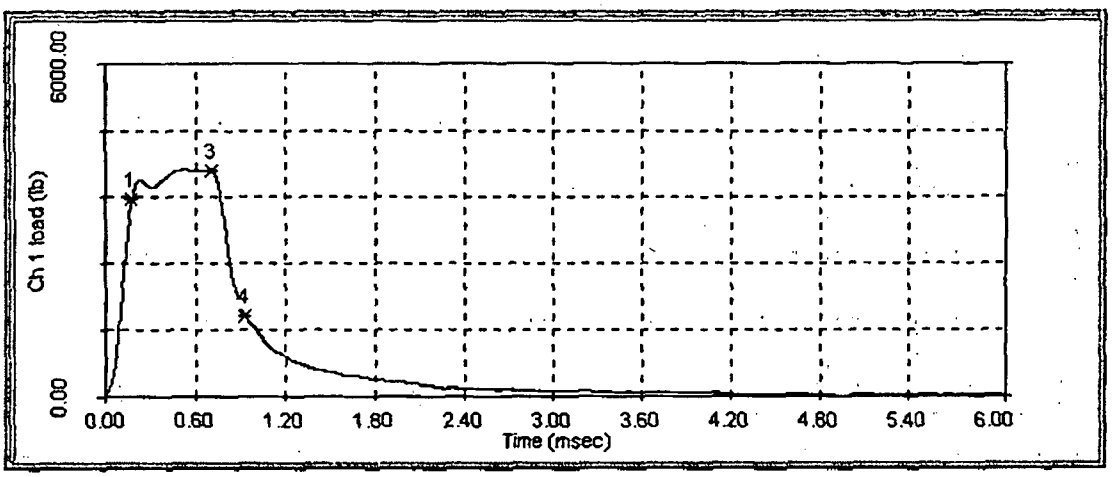
1A3B3, -45°F



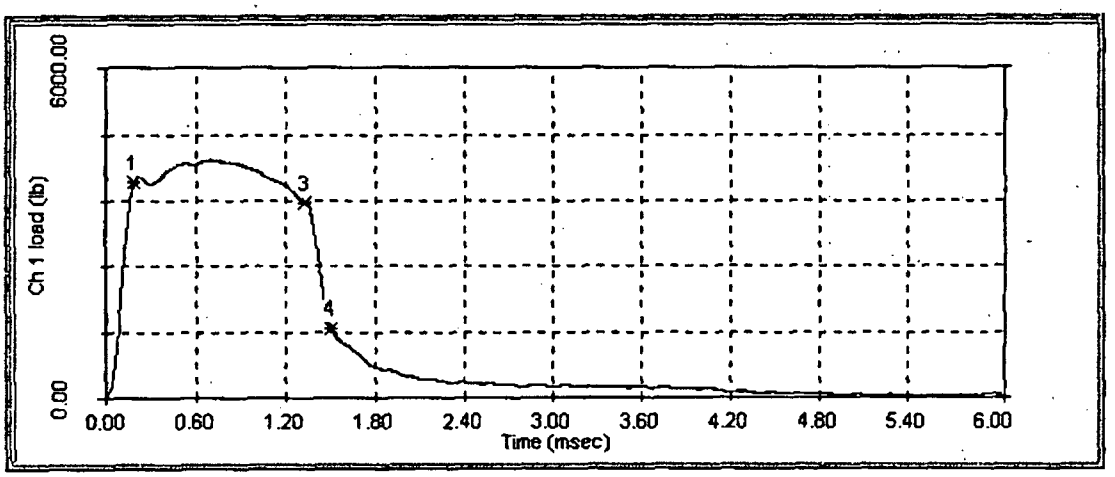
1A372, -25°F



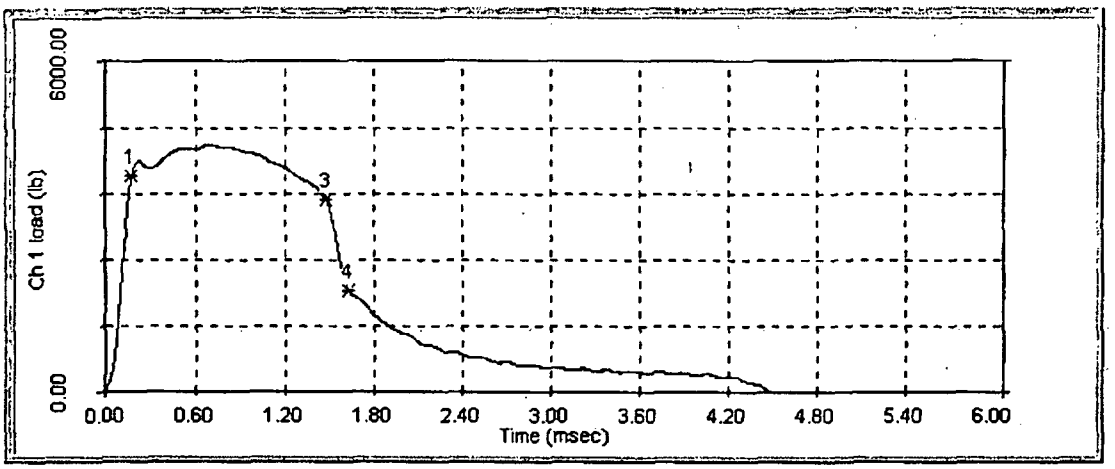
1A33K, -10°F



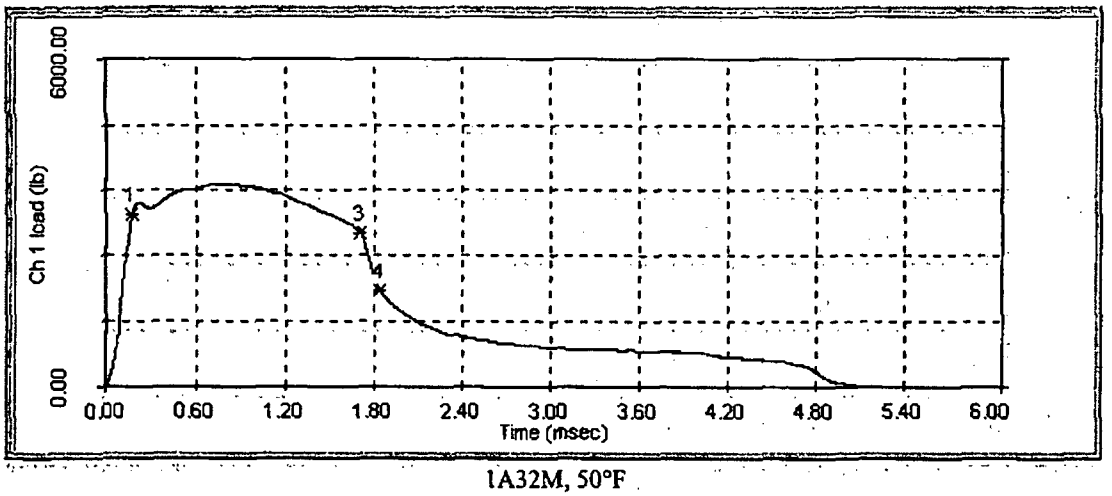
1A32U, 0°F



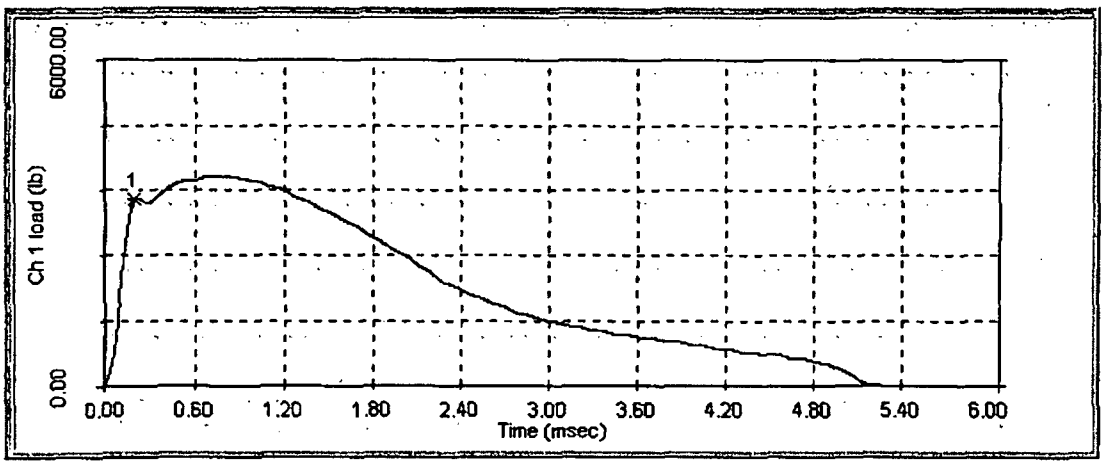
1A342, 15°F



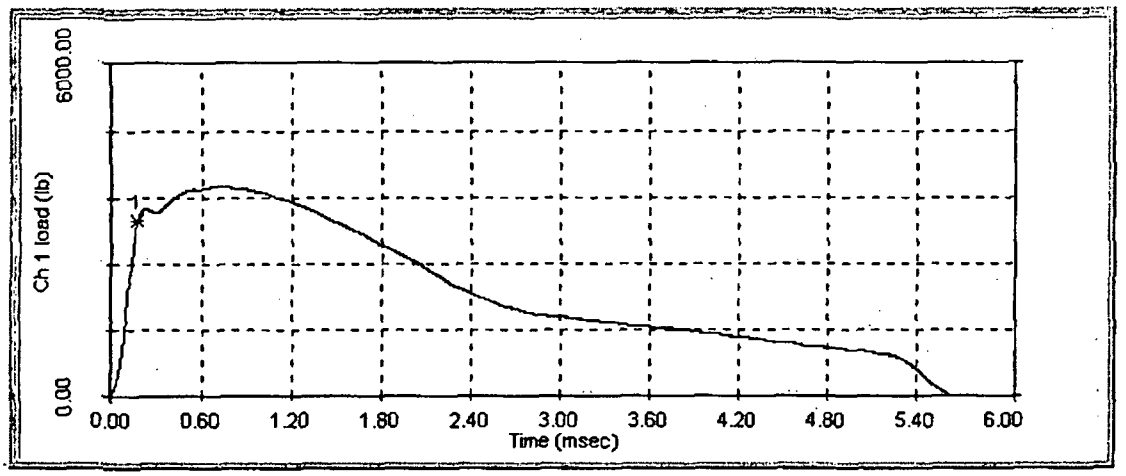
1A35E, 25°F



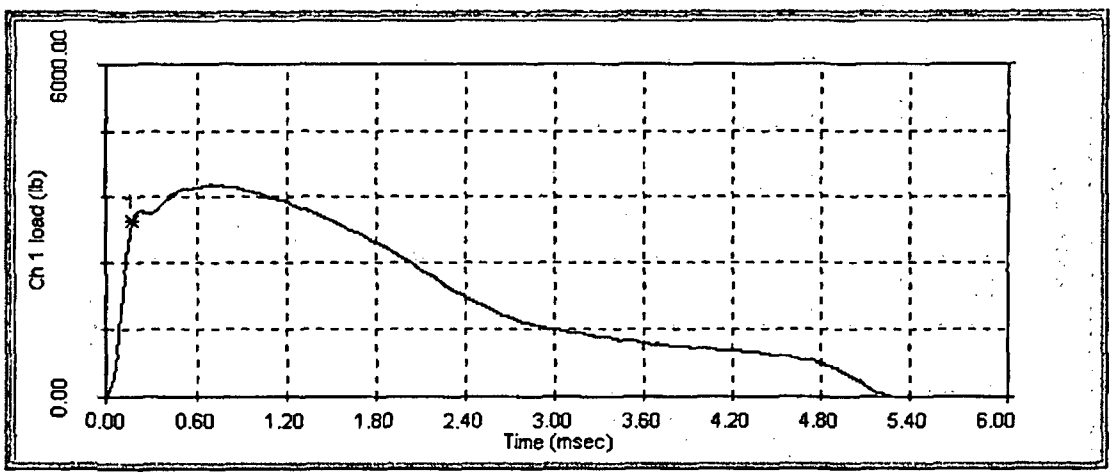
1A32M, 50°F



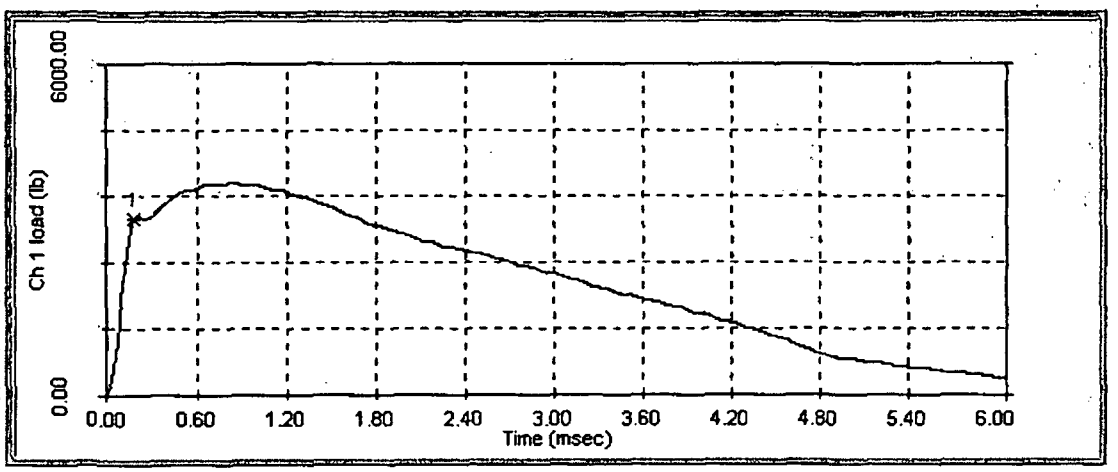
1A323, 100°F



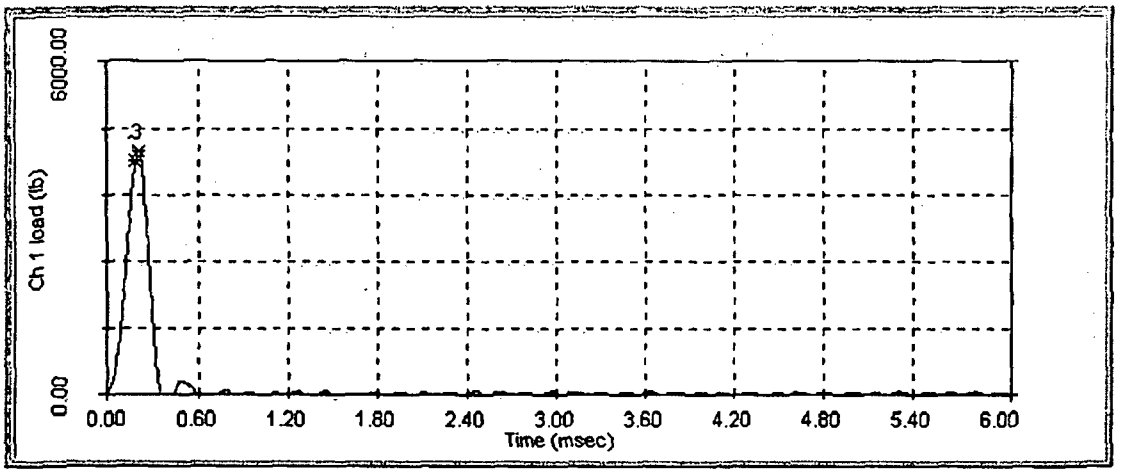
1A35U, 150°F



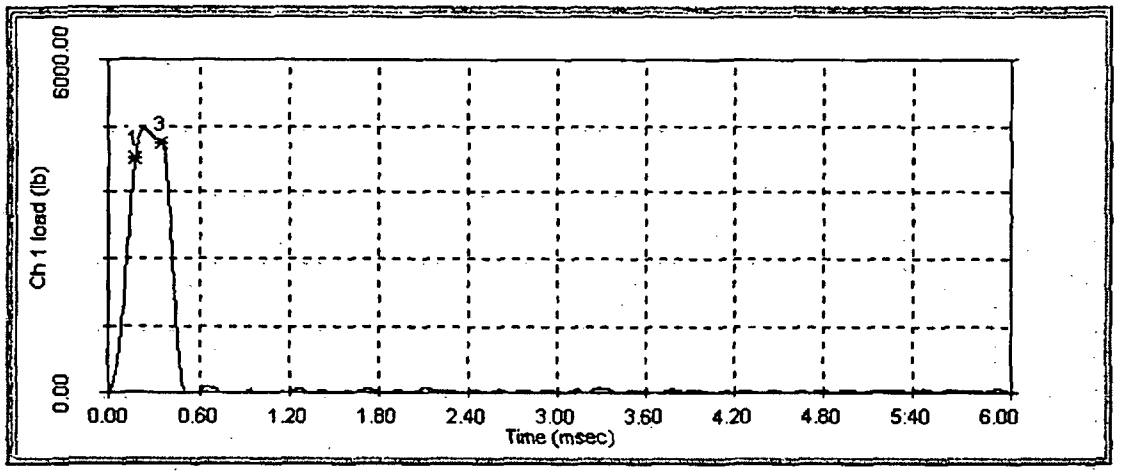
1A331, 200°F



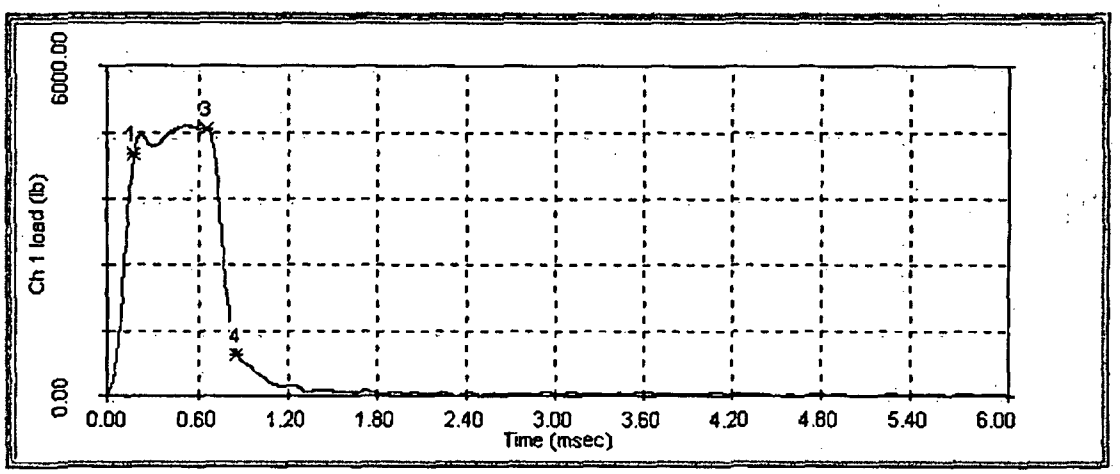
1A33B, 250°F



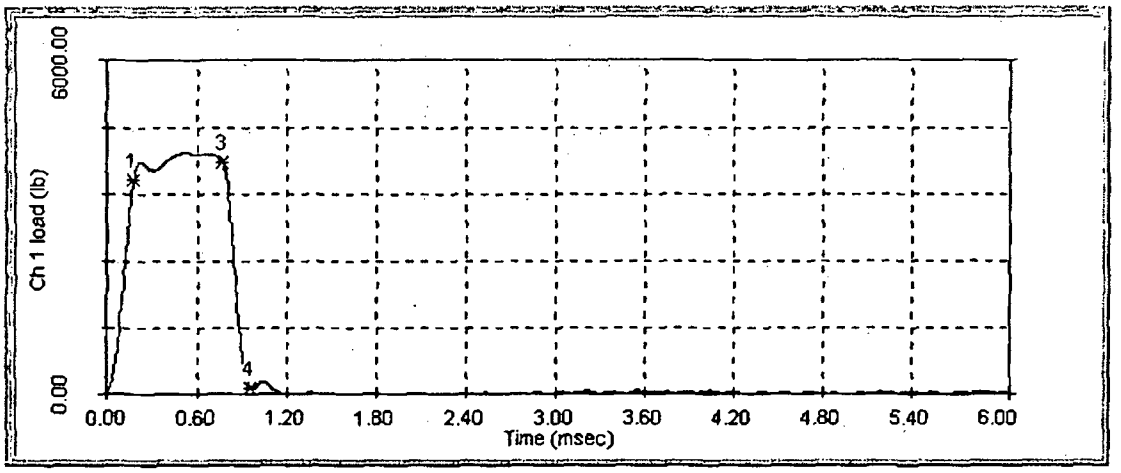
1A441, -175°F



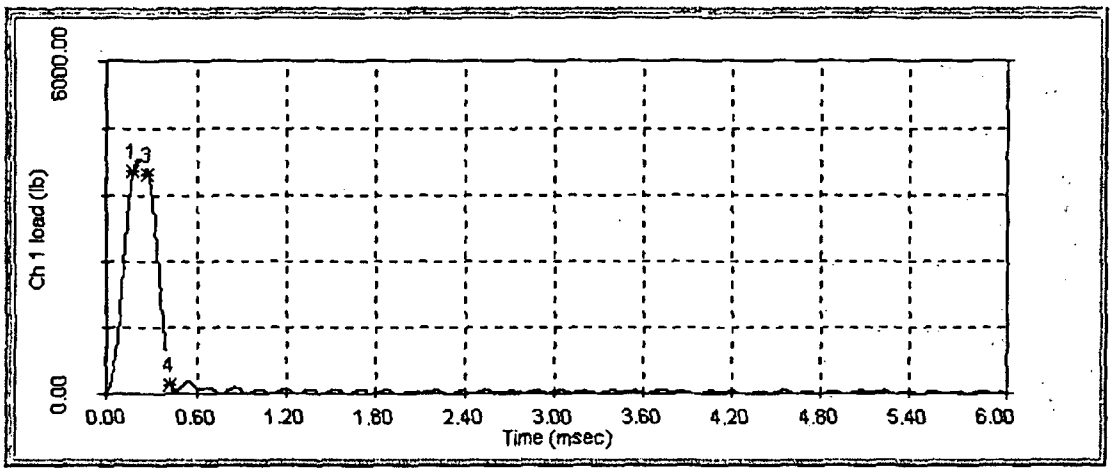
1A442, -120°F



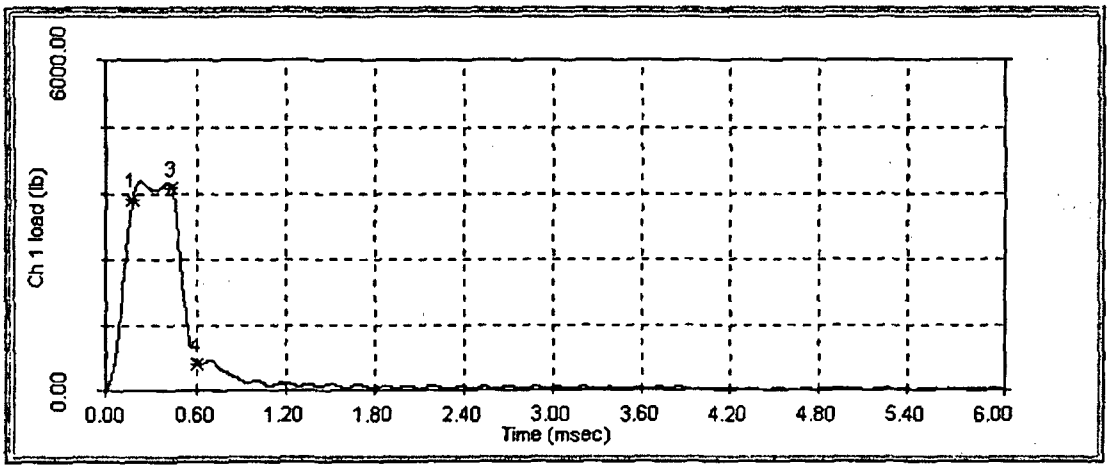
1A43D, -90°F



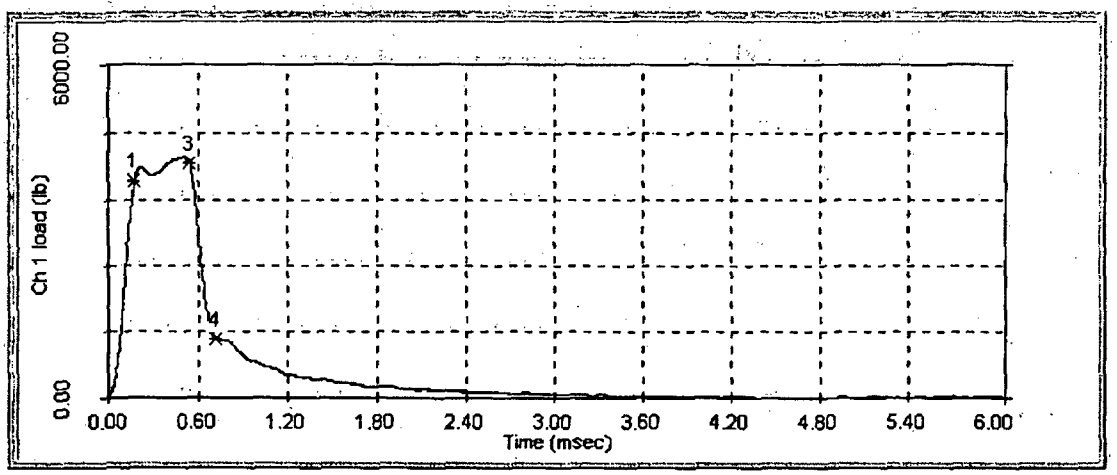
1A41U, -75°F



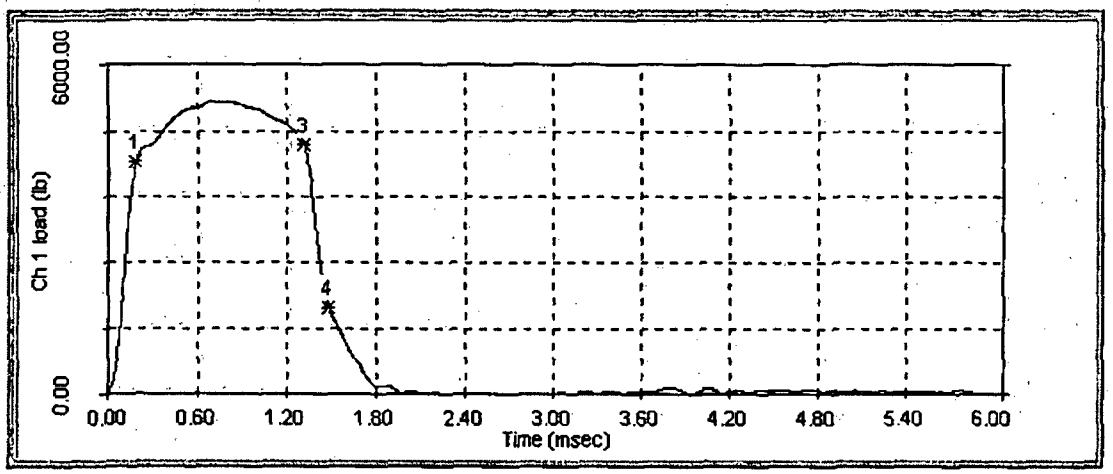
1A44Y, -50°F



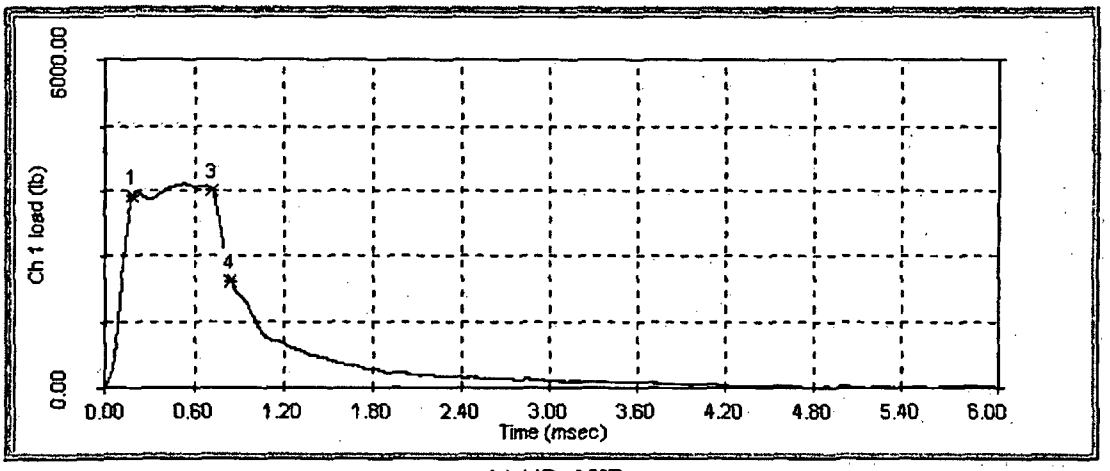
1A453, -30°F



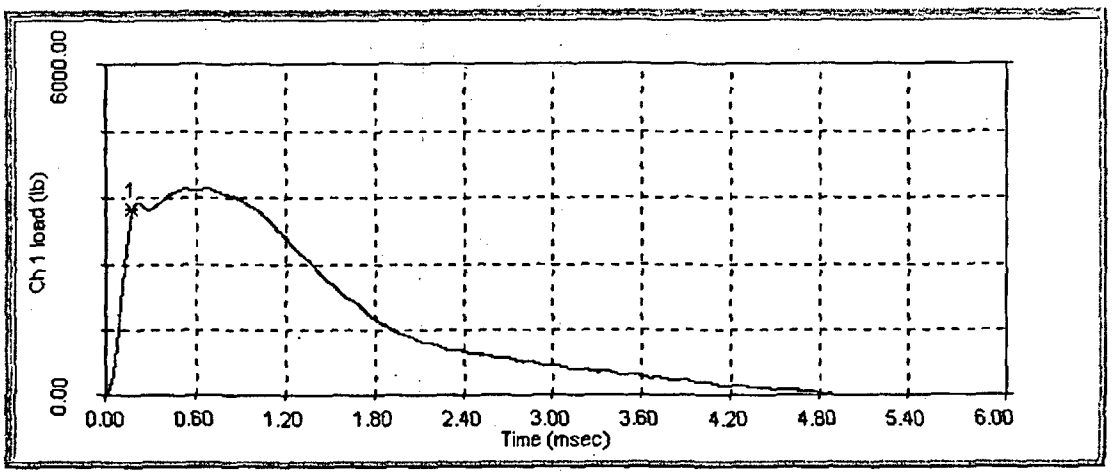
1A416, -25°F



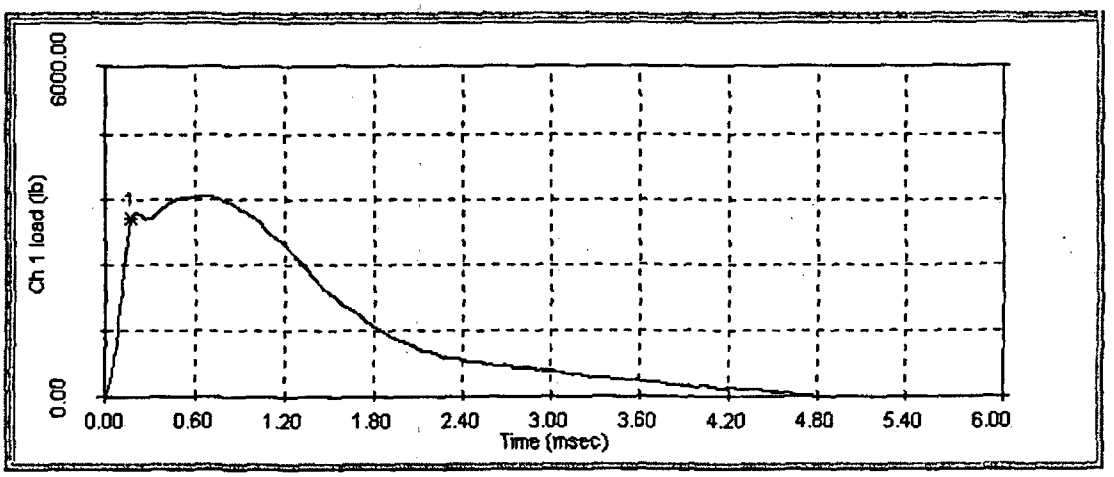
1A443, 0°F



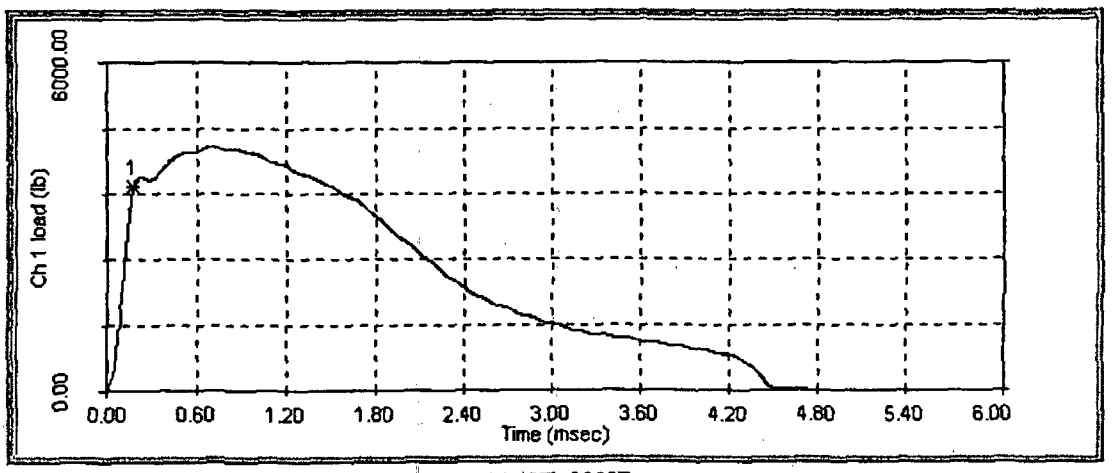
1A44D, 25°F



1A41M, 70°F



1A42B, 130°F



1A43T, 200°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 137°	Capsule 38°
Lower Shell Plate M-4311-1 (Longitudinal)	147 ft-lb	**	141 ft-lb
Lower Shell Plate M-4311-1 (Transverse)	168 ft-lb	**	115
Surveillance Weld (Heat # 90071)	164 ft-lb	162 ft-lb	158 ft-lb
HAZ Material	135 ft-lb	124 ft-lb	119 ft-lb
Standard Reference Material	129 ft-lb	105 ft-lb	105 ft-lb

** No Lower Shell Material in Capsule 137°.

UNIRRADIATED (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:59:37 on 01-29-2001

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Coefficients of Curve 1

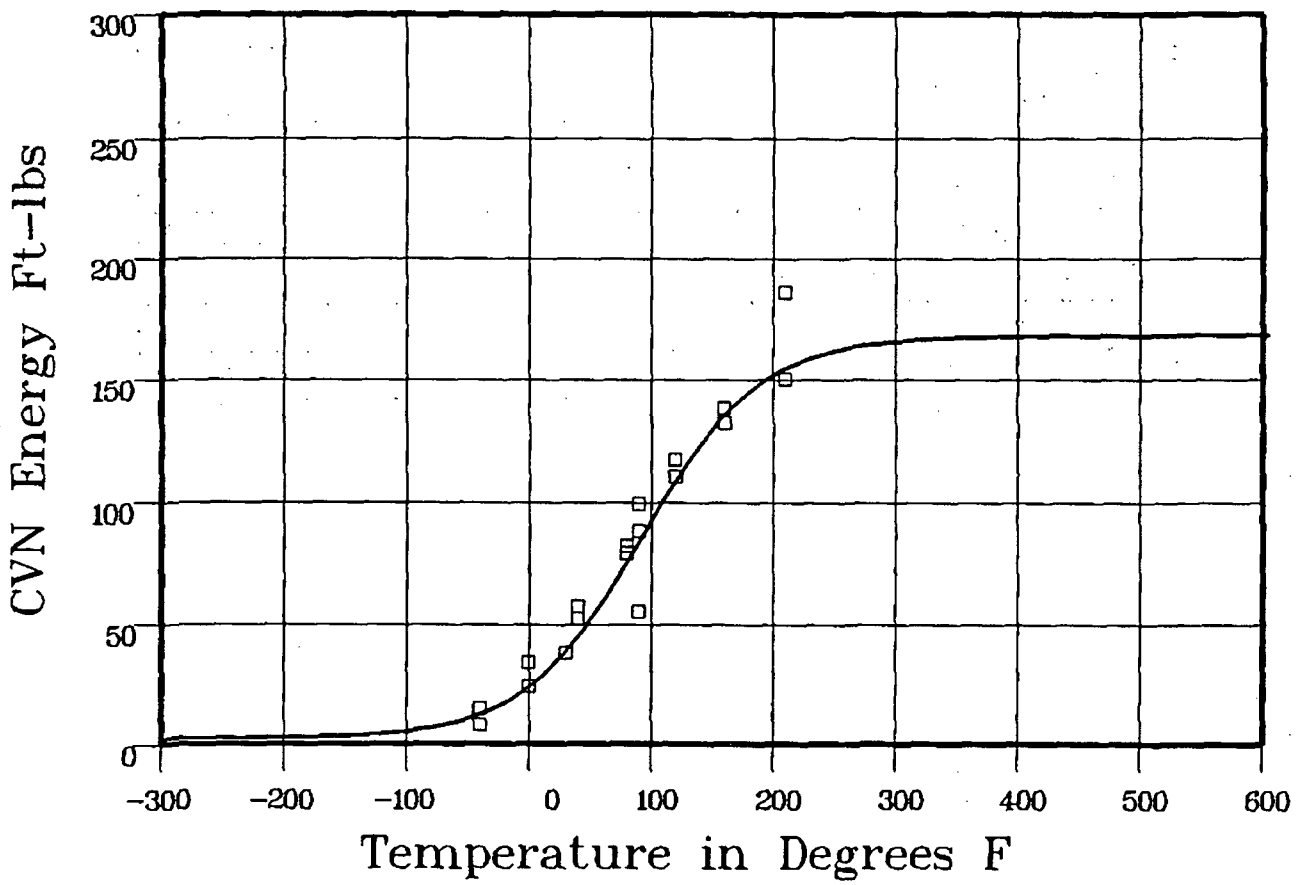
A = 85.09	B = 82.9	C = 97.54	T0 = 87.18

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

Upper Shelf Energy: 168 Fixed Temp. at 30 ft-lbs: 9 Temp. at 50 ft-lbs: 43.1 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: UNIRR Material: PLATE SA533B1 Ori: TL Heat #: M-4311-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-40	8	13.58	-5.58
-40	15	13.58	1.41
0	24	25.96	-1.96
0	34	25.96	8.03
30	38	41.39	-3.39
40	52	47.85	4.14
40	57	47.85	9.14
80	82	79	2.99
80	79	79	0

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

UNIRRADIATED (TRANSVERSE)

Page 2

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
90	99	87.48	11.51
90	88	87.48	.51
90	55	87.48	-32.48
120	110	111.97	-1.97
120	117	111.97	5.02
160	138	137.57	.42
160	132	137.57	-5.57
210	186	155.63	30.36
210	150	155.63	-5.63

SUM of RESIDUALS = 16.93

UNIRRADIATED (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:04:29 on 01-29-2001

Page 1

Coefficients of Curve 1

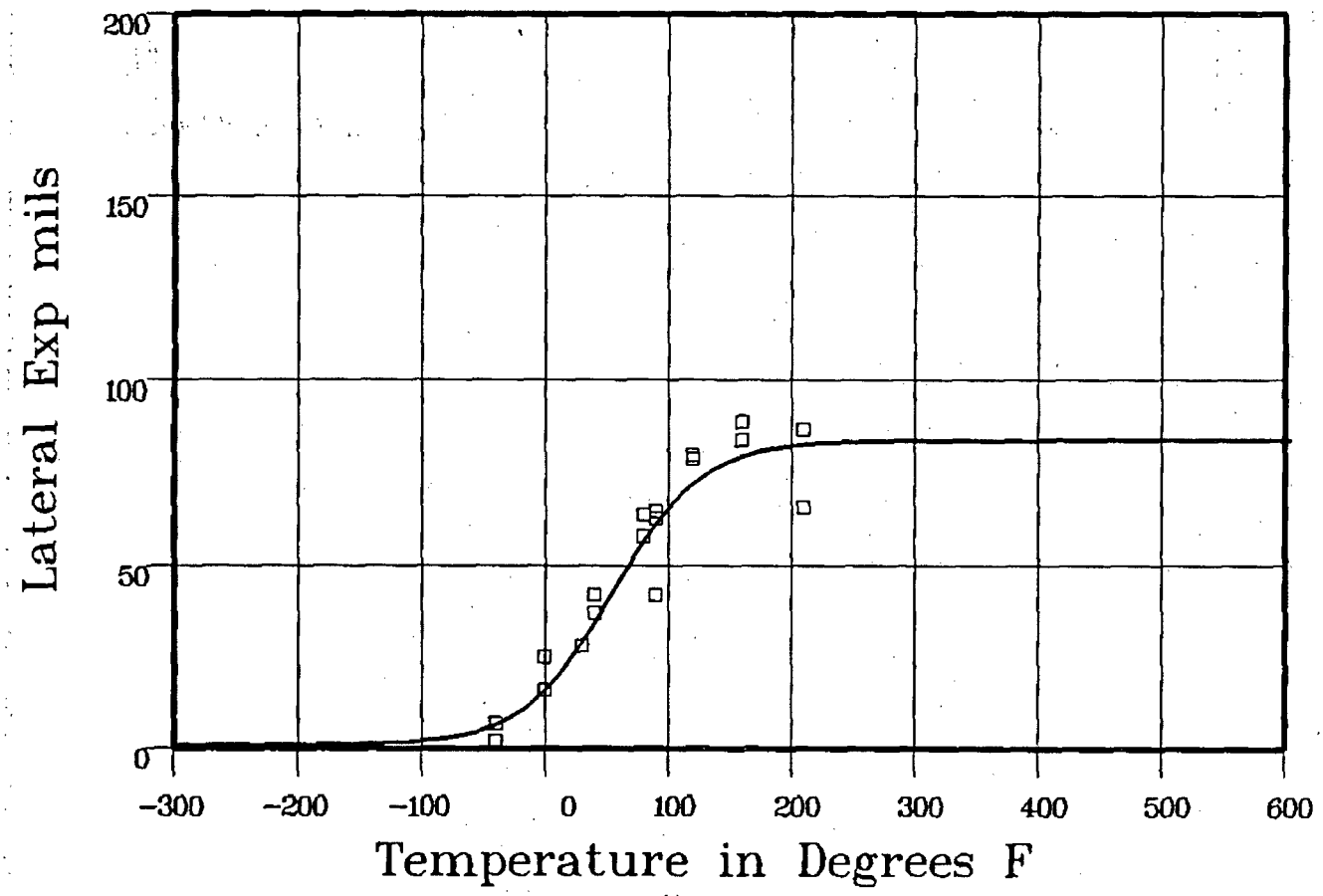
A = 42.48	B = 41.48	C = 72.22	T0 = 49.68

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

Upper Shelf L.E.: 83.97 Temperature at L.E. 35: 36.5 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: UNIRR Material: PLATE SA533B1 Ori: TL Heat #: M-4311-1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-40	2	7.39	-5.39
-40	7	7.39	-.39
0	16	17.73	-1.73
0	25	17.73	7.26
30	28	31.44	-3.44
40	37	36.95	.04
40	42	36.95	5.04
80	64	58.94	5.05
80	58	58.94	-.94

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

UNIRRADIATED (TRANSVERSE)

Page 2

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
90	65	63.5	1.49
90	63	63.5	-5
90	42	63.5	-21.5
120	79	73.61	5.38
120	80	73.61	6.38
160	89	80.23	8.76
160	84	80.23	3.76
210	87	83	3.99
210	66	83	-17

SUM of RESIDUALS = -3.69

UNIRRADIATED (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:07:42 on 01-29-2001

Page 1

Coefficients of Curve 1

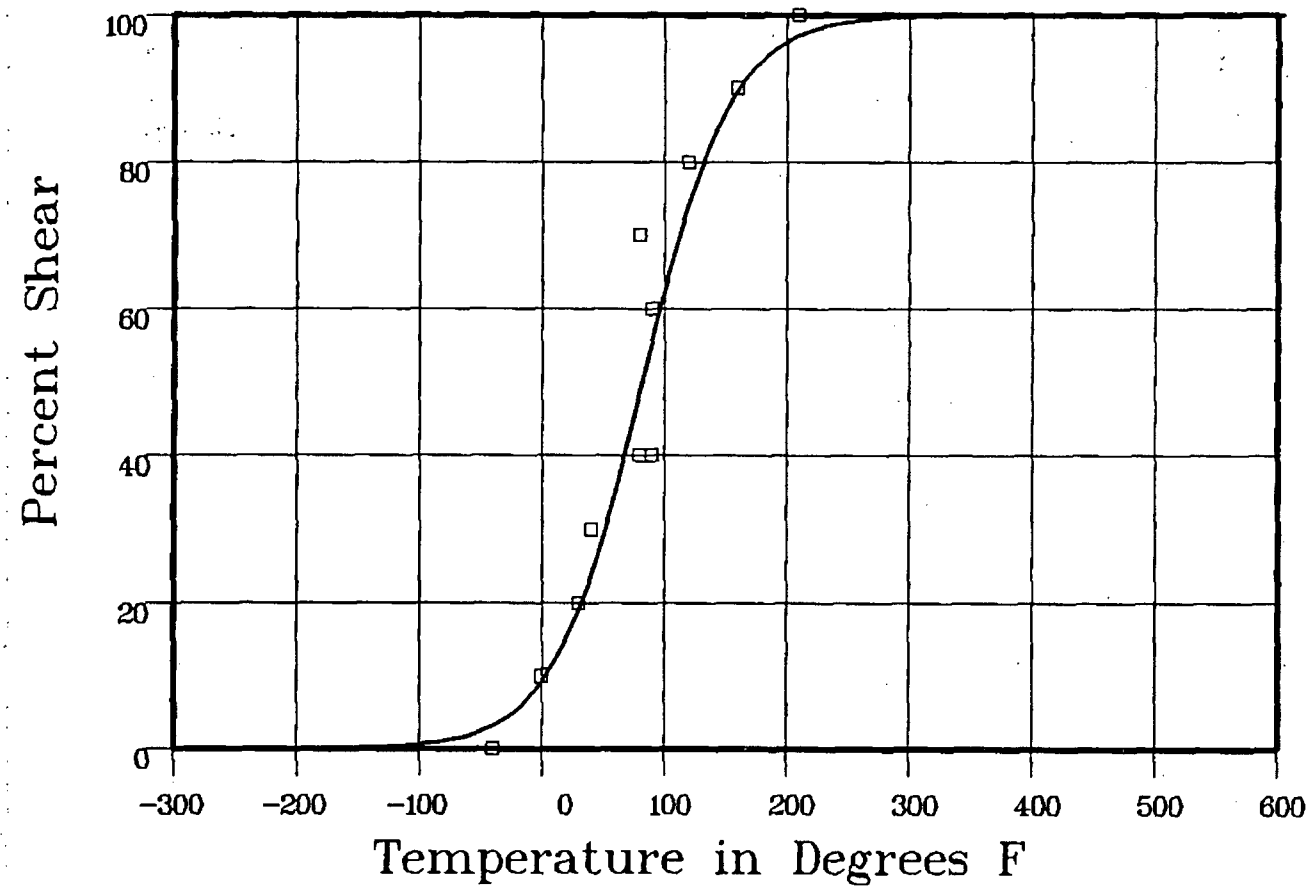
A = 50	B = 50	C = 72.02	T0 = 77.34

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

Temperature at 50% Shear: 77.3

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: UNIRR Material: PLATE SA533B1 Ori.: TL Heat #: M-4311-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40	0	3.7	-3.7
-40	0	3.7	-3.7
0	10	10.45	-.45
0	10	10.45	-.45
30	20	21.17	-1.17
40	30	26.17	3.82
40	30	26.17	3.82
80	70	51.84	18.15
80	40	51.84	-11.84

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

UNIRRADIATED (TRANSVERSE)

Page 2

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
90	60	58.69	1.3
90	60	58.69	1.3
90	40	58.69	-18.69
120	80	76.57	3.42
120	80	76.57	3.42
160	90	90.84	-.84
160	90	90.84	-.84
210	100	97.54	2.45
210	100	97.54	2.45

SUM of RESIDUALS = -1.55

CAPSULE 137 (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:40:18 on 08-03-2000

Page 1

Coefficients of Curve 2

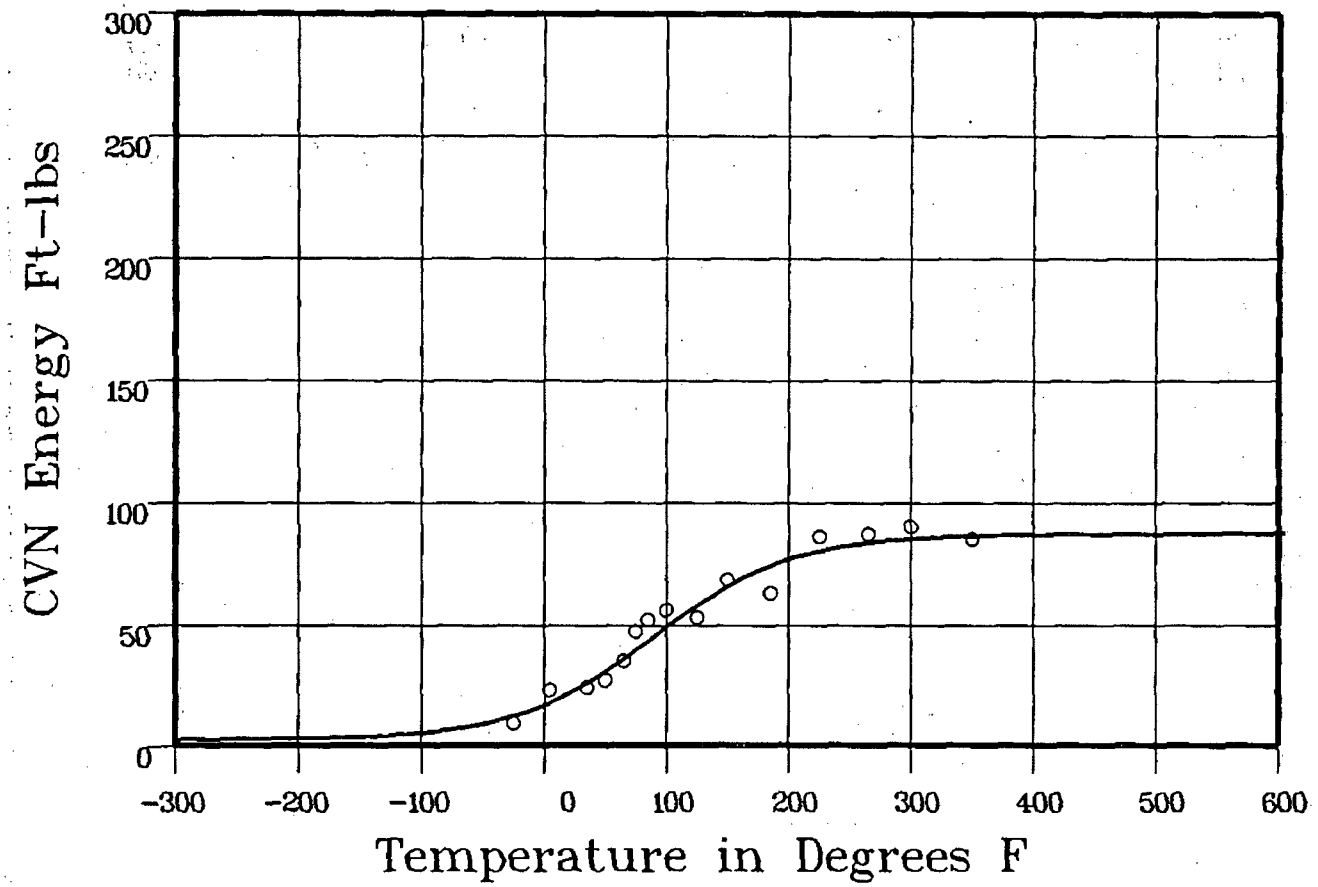
A = 44.59	B = 42.4	C = 112.77	T0 = 83.9

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

Upper Shelf Energy: 87 Fixed Temp. at 30 ft-lbs: 43.4 Temp. at 50 ft-lbs: 98.3 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: M-6701-2 Orientation: TL

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 137 Material: PLATE SA533B1 Ori.: TL Heat #: M-6701-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	9	12.93	-3.93
5	23	18.98	4.01
35	24	27.28	-3.28
50	27	32.22	-5.22
65	35	37.55	-2.55
75	47	41.25	5.74
85	52	45.01	6.98
100	56	50.61	5.38

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

CAPSULE 137 (TRANSVERSE)

Page 2

Material: PLATE SA533B1 Heat Number: M-6701-2 Orientation: TL

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
125	53	59.4	-6.4
150	68	66.94	1.05
185	63	74.89	-11.89
225	86	80.58	5.41
265	87	83.71	3.28
300	90	85.2	4.79
350	85	86.25	-1.25

SUM of RESIDUALS = 2.13

CAPSULE 137 (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:59:59 on 08-03-2000

Page 1

Coefficients of Curve 2

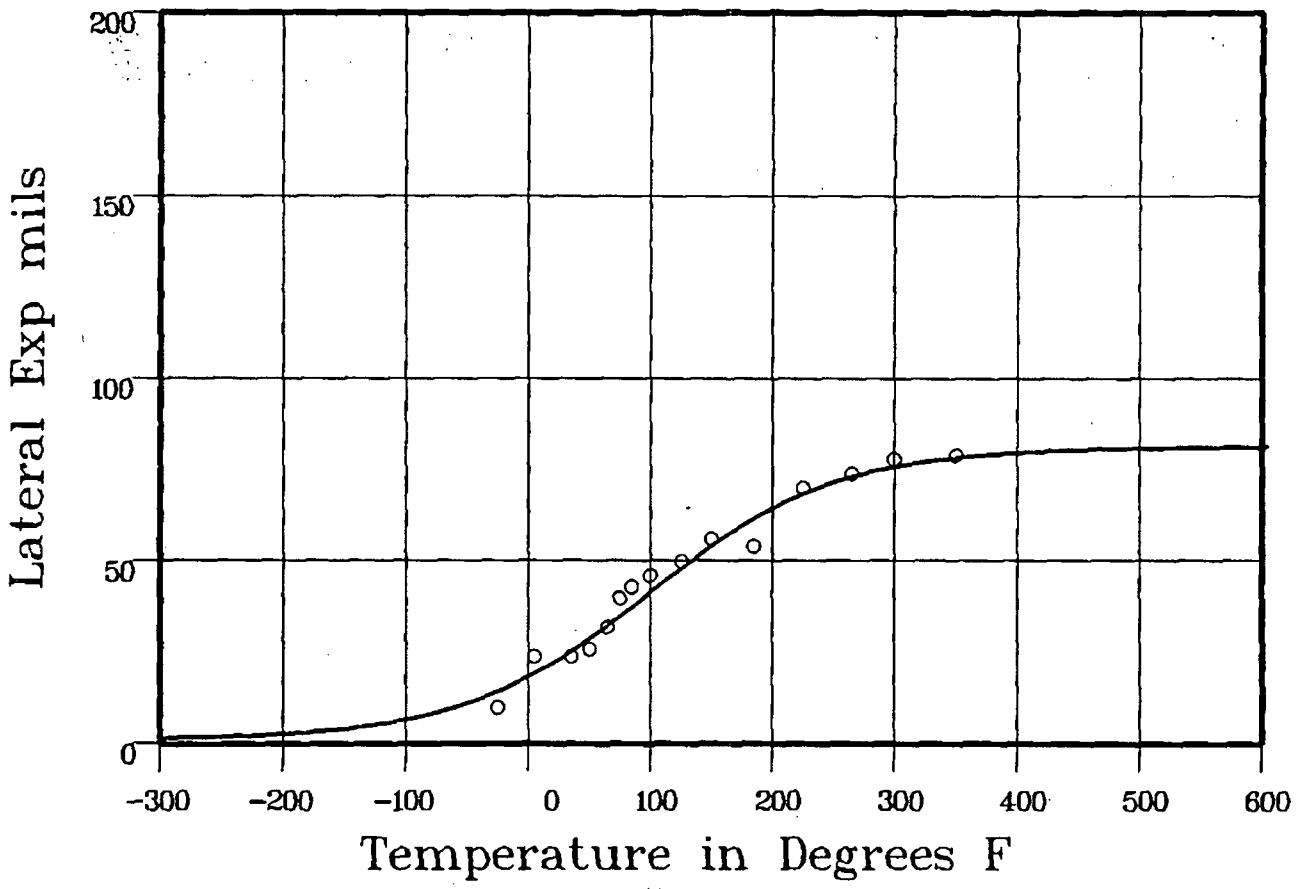
A = 41.13	B = 40.13	C = 153.26	T0 = 93.75

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

Upper Shelf L.E.: 81.27 Temperature at L.E. 35: 70.1 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: M-6701-2 Orientation: TL

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 137 Material: PLATE SA533B1 Ori.: TL Heat #: M-6701-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	10	15.05	-5.05
5	24	20.18	3.81
35	24	26.46	-2.46
50	26	29.98	-3.98
65	32	33.69	-1.69
75	40	36.25	3.74
85	43	38.84	4.15
100	46	42.77	3.22

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

CAPSULE 137 (TRANSVERSE)

Page 2

Material: PLATE SA533B1 Heat Number: M-6701-2 Orientation: TL

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
125	50	49.2	.79
150	56	55.23	.76
185	54	62.55	-8.55
225	70	69	.99
265	74	73.51	.48
300	78	76.17	1.82
350	79	78.53	.46

SUM of RESIDUALS = -1.48

CAPSULE 137 (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:05:35 on 08-03-2000

Page 1

Coefficients of Curve 2

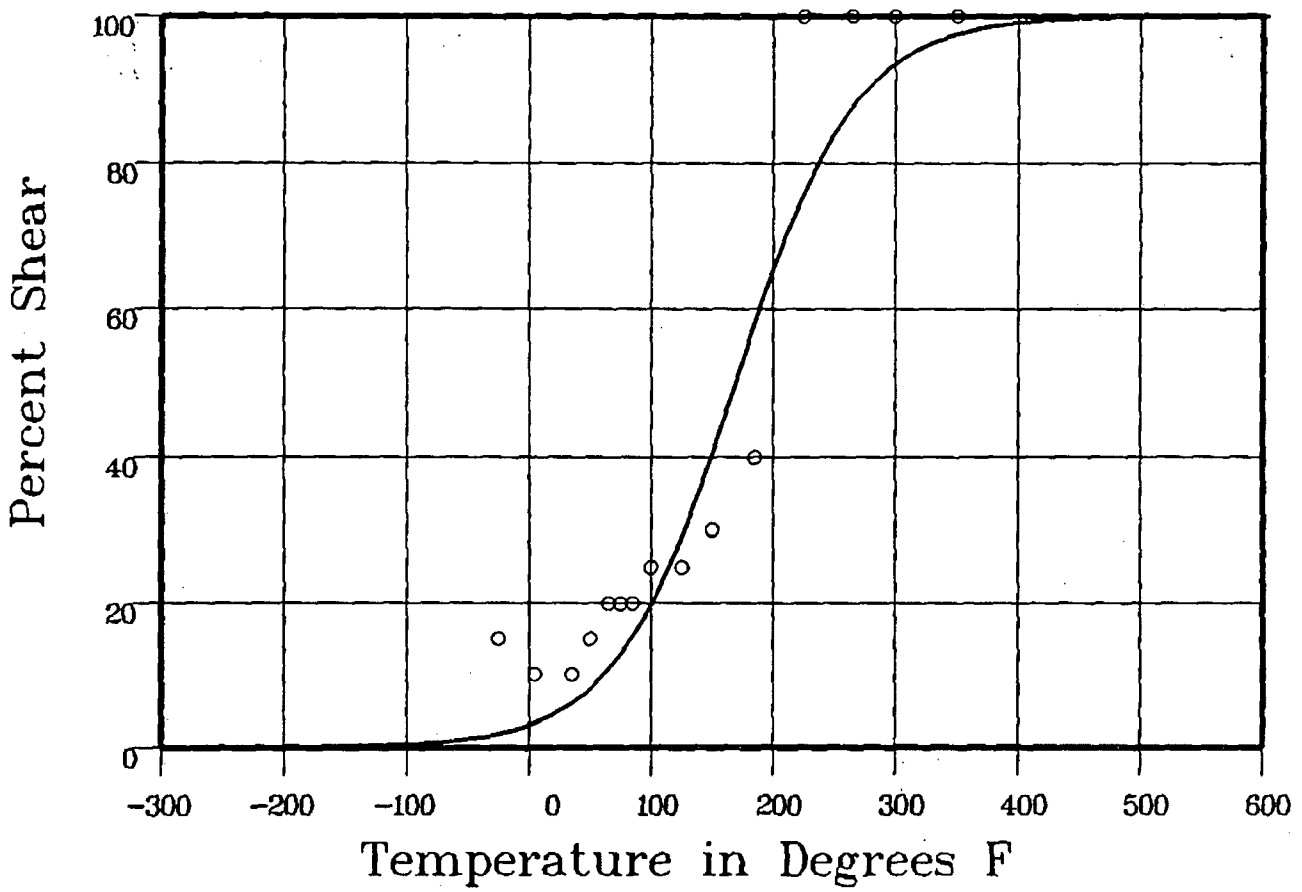
A = 50	B = 50	C = 98.32	T0 = 164.35

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

Temperature at 50% Shear: 164.3

Material: PLATE SA533B1 Heat Number: M-6701-2 Orientation: TL

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: 137 Material: PLATE SA533B1 Ori: TL Heat #: M-6701-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	15	2.08	12.91
5	10	3.76	6.23
35	10	6.71	3.28
50	15	8.89	6.1
65	20	11.7	8.29
75	20	13.97	6.02
85	20	16.6	3.39
100	25	21.26	3.73

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

CAPSULE 137 (TRANSVERSE)

Page 2

Material: PLATE SA533B1 Heat Number: M-6701-2 Orientation: TL

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
125	25	30.99	-5.99
150	30	42.75	-12.75
185	40	60.34	-20.34
225	100	77.44	22.55
265	100	88.56	11.43
300	100	94.04	5.95
350	100	97.76	2.23

SUM of RESIDUALS = 53.09

CAPSULE 38 (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:59:37 on 01-29-2001

Page 1

Coefficients of Curve 2

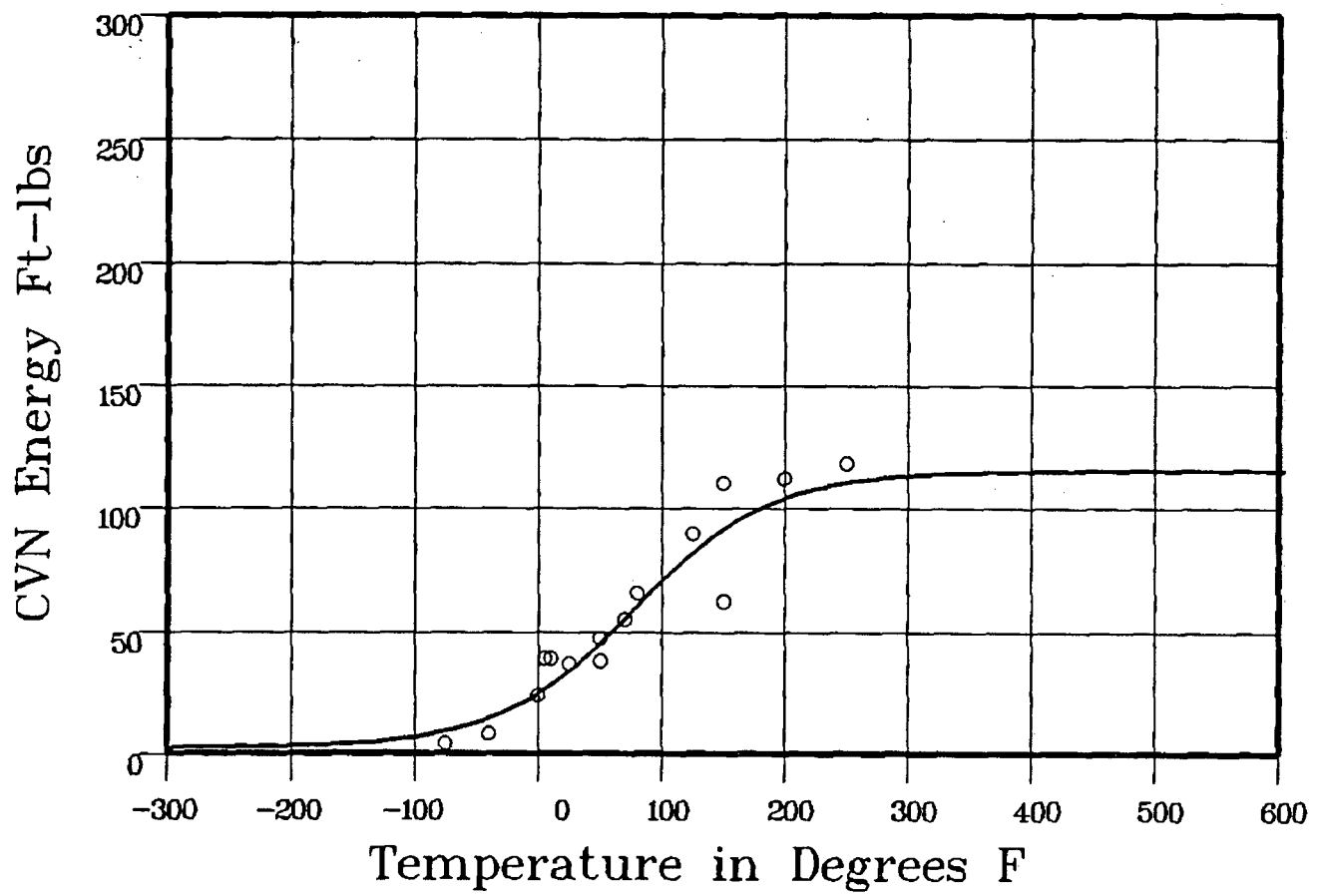
A = 58.59	B = 56.4	C = 111.35	T0 = 72.37

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

Upper Shelf Energy: 115 Fixed Temp. at 30 ft-lbs: 10.1 Temp. at 50 ft-lbs: 55.2 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: TL

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 38 Material: PLATE SA533B1 Ori.: TL Heat #: M-4311-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-75	4	9.66	-5.66
-40	8	15.43	-7.43
0	24	26.36	-2.36
5	39	28.1	10.89
10	39	29.94	9.05
25	37	35.95	1.04
50	47	47.41	-.41
50	38	47.41	-9.41

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

CAPSULE 38 (TRANSVERSE)

Page 2

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: TL

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
70	55	57.39	-2.39
80	65	62.45	2.54
125	89	83.43	5.56
150	110	92.58	17.41
150	62	92.58	-30.58
200	112	104.64	7.35
250	118	110.54	7.45

SUM of RESIDUALS = 3.05

CAPSULE 38 (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:04:29 on 01-29-2001

Page 1

Coefficients of Curve 2

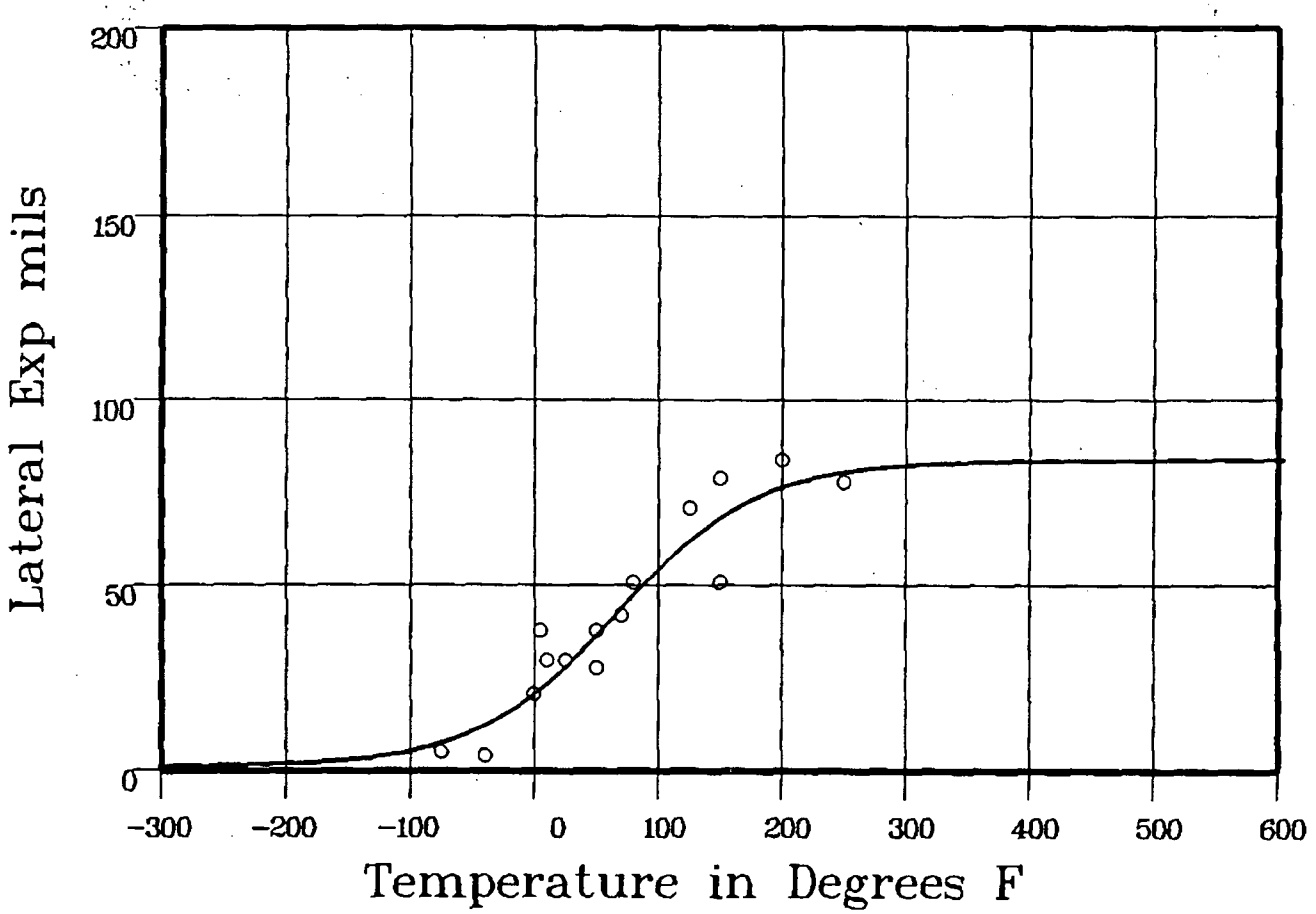
A = 42.42	B = 41.42	C = 114.49	T0 = 61.39

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

Upper Shelf L.E.: 83.84 Temperature at L.E. 35: 40.6 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: TL

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 38 Material: PLATE SA533B1 Ori.: TL Heat #: M-4311-1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-75	5	8	-3
-40	4	13.04	-9.04
0	21	22.12	-1.12
5	38	23.52	14.47
10	30	24.98	5.01
25	30	29.68	.31
50	38	38.31	-.31
50	28	38.31	-10.31

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

CAPSULE 38 (TRANSVERSE)

Page 2

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: TL

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
70	42	45.52	-3.52
80	51	49.09	1.9
125	71	63.32	7.67
150	79	69.31	9.68
150	51	69.31	-18.31
200	84	77.08	6.91
250	78	80.87	-2.87

SUM of RESIDUALS = -2.51

CAPSULE 38 (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:07:42 on 01-29-2001

Page 1

Coefficients of Curve 2

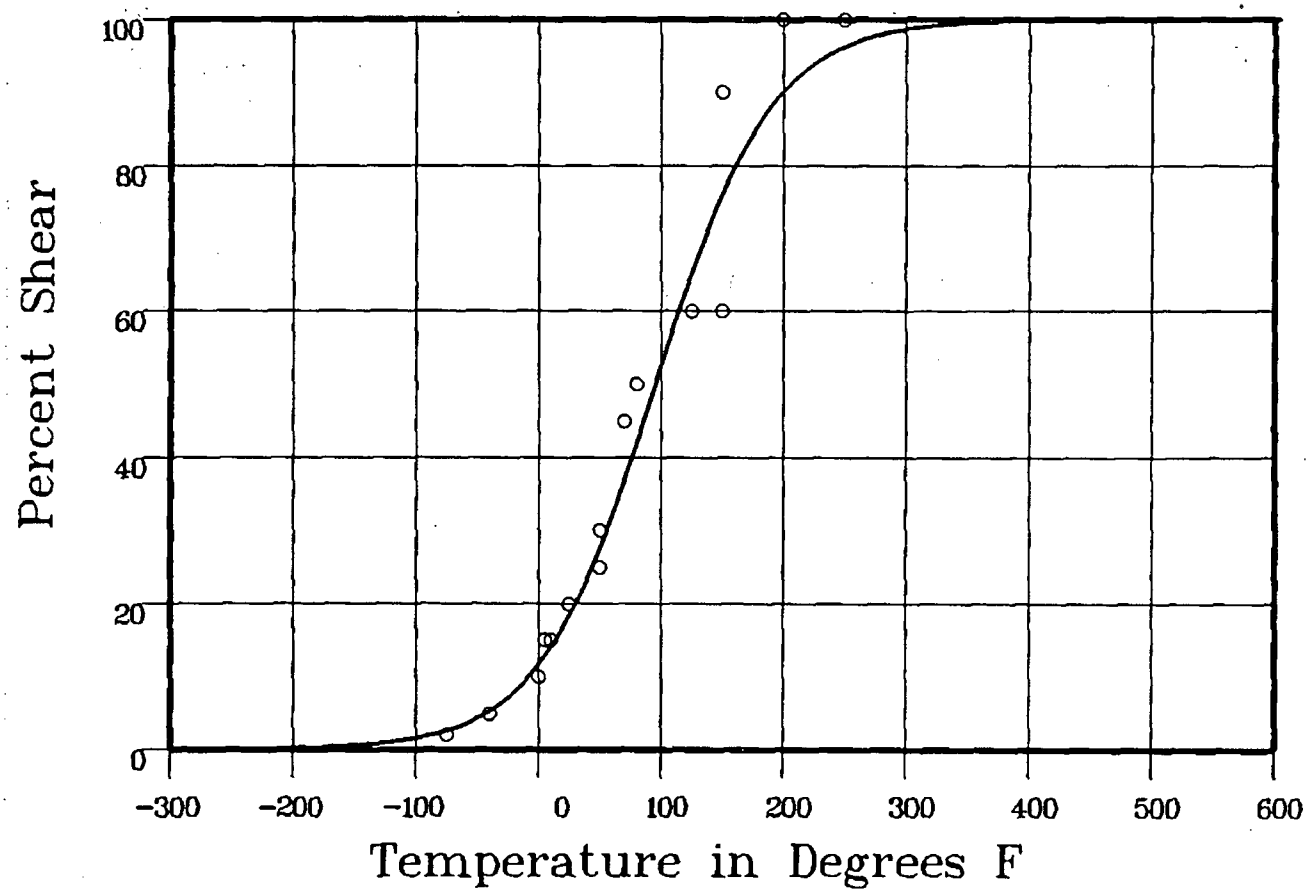
A = 50	B = 50	C = 94.51	T0 = 90.82

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

Temperature at 50% Shear: 90.8

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: TL

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: 38 Material: PLATE SA533B1 Ori: TL Heat #: M-4311-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75	2	2.9	-.9
-40	5	5.9	-.9
0	10	12.76	-2.76
5	15	13.99	1
10	15	15.31	-.31
25	20	19.89	.1
50	30	29.65	.34
50	25	29.65	-4.65

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

CAPSULE 38 (TRANSVERSE)

Page 2

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: TL

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
70	45	39.16	5.83
80	50	44.3	5.69
125	60	67.33	-7.33
150	90	77.76	12.23
150	60	77.76	-17.76
200	100	90.97	9.02
250	100	96.66	3.33

SUM of RESIDUALS = 2.93

UNIRRADIATED (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:35:25 on 01-29-2001

Page 1

Coefficients of Curve 1

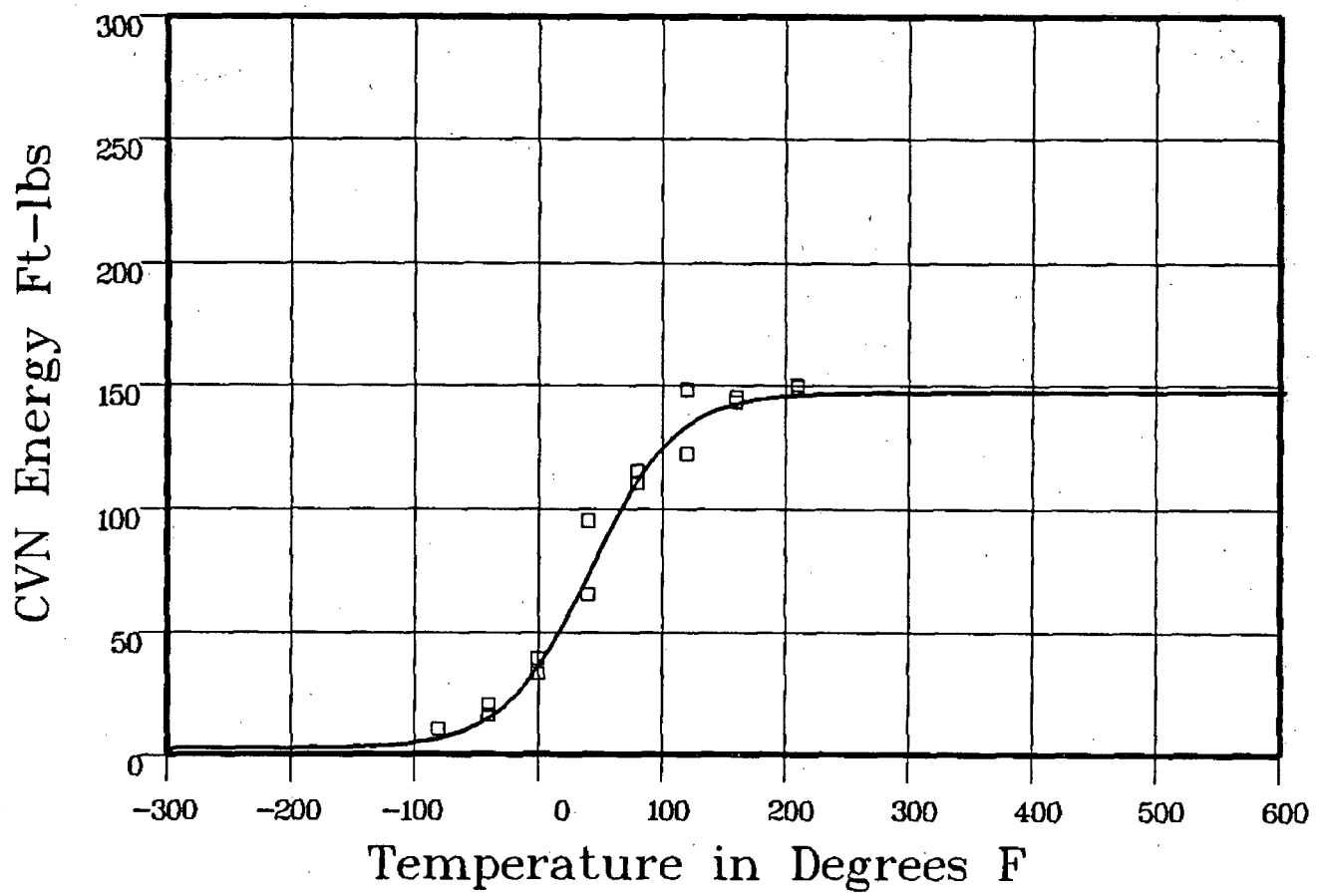
A = 74.59	B = 72.4	C = 69.42	T0 = 37.03

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

Upper Shelf Energy: 147 Fixed Temp. at 30 ft-lbs: -12.8 Temp. at 50 ft-lbs: 12.4 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: UNIRR Material: PLATE SA533B1 Ori.: LT Heat #: M-4311-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-80	10	7	2.99
-80	10	7	2.99
-40	20	16.39	3.6
-40	16	16.39	-.39
0	39	39.27	-.27
0	33	39.27	-6.27
40	95	77.69	17.3
40	65	77.69	-12.69
80	110	114.44	-4.44

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

UNIRRADIATED (LONGITUDINAL)

Page 2

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
80	115	114.44	.55
120	148	134.84	13.15
120	122	134.84	-12.84
160	145	142.92	2.07
160	143	142.92	.07
210	150	146.01	3.98
210	149	146.01	2.98

SUM of RESIDUALS = 12.78

UNIRRADIATED (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:45:51 on 01-29-2001

Page 1

Coefficients of Curve 1

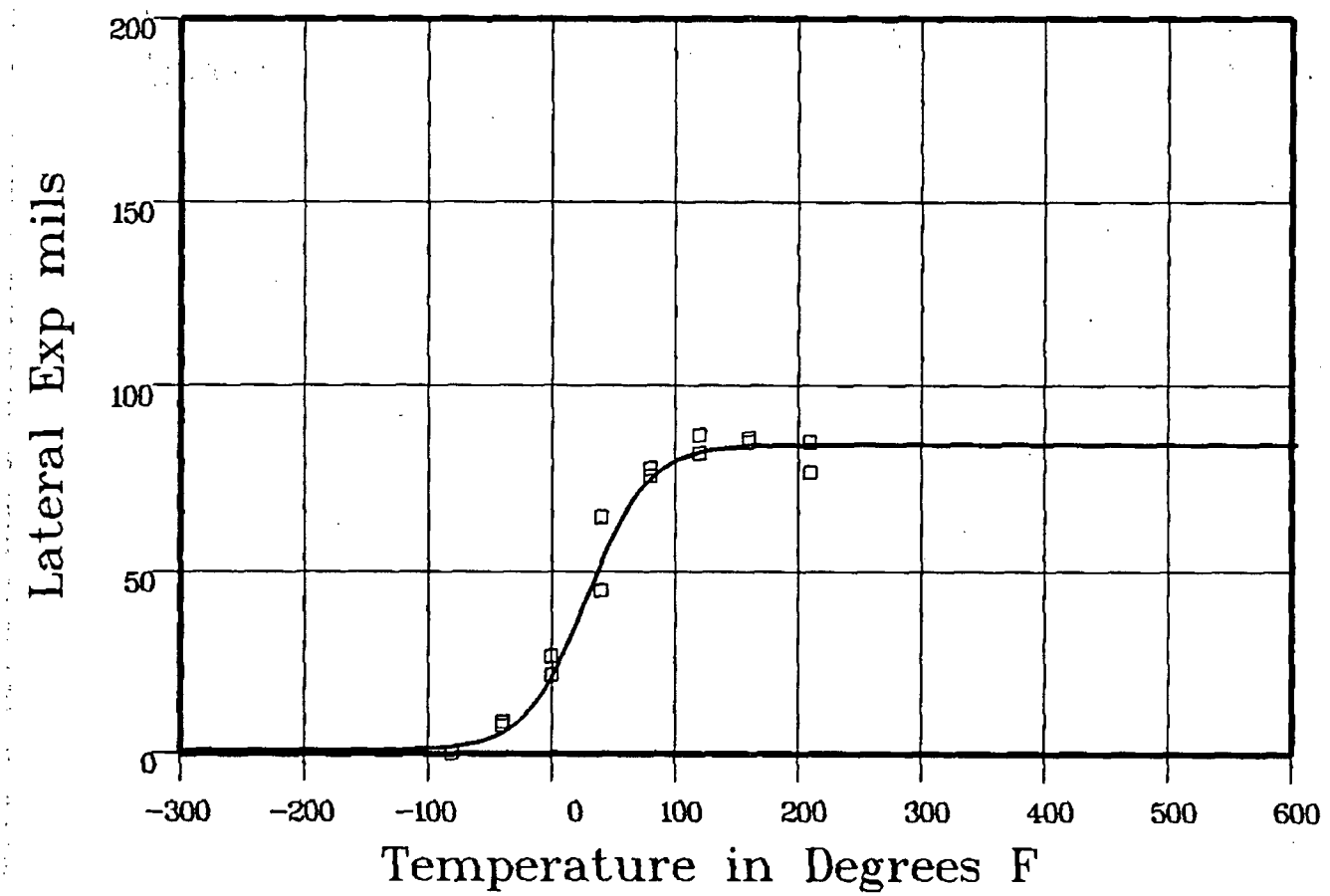
A = 42.66	B = 41.66	C = 49.4	T0 = 23.43

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

Upper Shelf L.E.: 84.32 Temperature at L.E. 35: 14.2 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: UNIRR Material: PLATE SA533B1 Ori.: LT Heat #: M-4311-1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-80	0	2.24	-2.24
-80	0	2.24	-2.24
-40	9	6.93	2.06
-40	8	6.93	1.06
0	27	24.25	2.74
0	22	24.25	-2.25
40	65	56.13	8.86
40	45	56.13	-11.13
80	76	76.66	-.66

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

UNIRRADIATED (LONGITUDINAL)

Page 2

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
80	78	76.66	1.33
120	87	82.69	4.3
120	82	82.69	-.69
160	86	83.99	2
160	85	83.99	1
210	85	84.28	.71
210	77	84.28	-7.28

SUM of RESIDUALS = -2.42

UNIRRADIATED (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:49:09 on 01-29-2001

Page 1

Coefficients of Curve 1

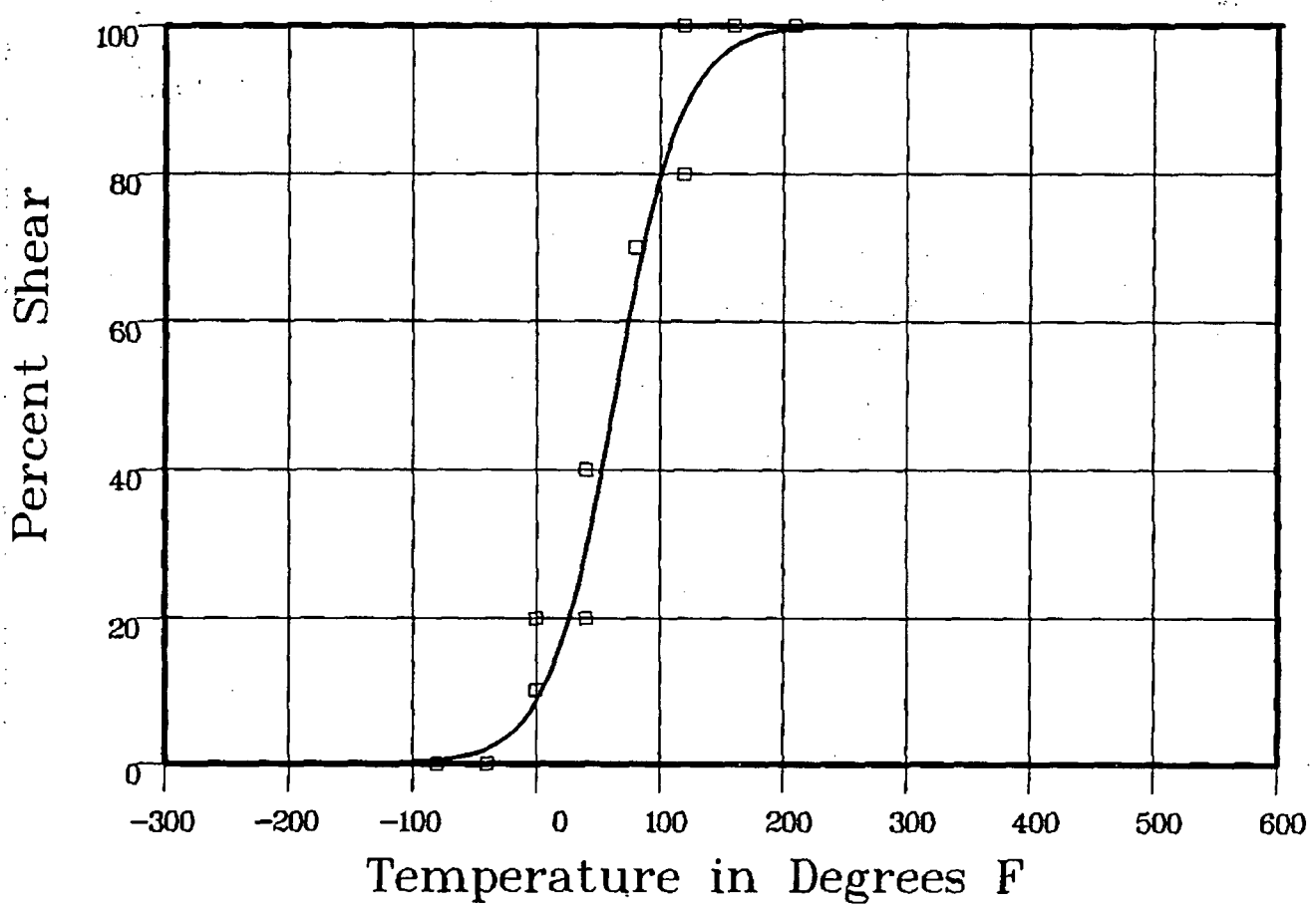
A = 50	B = 50	C = 53.77	T0 = 59.06

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

Temperature at 50% Shear: 59

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: UNIRR Material: PLATE SA533B1 Ori.: LT Heat #: M-4311-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-80	0	.56	-.56
-80	0	.56	-.56
-40	0	2.44	-2.44
-40	0	2.44	-2.44
0	20	10	9.99
0	10	10	0
40	40	32.98	7.01
40	20	32.98	-12.98
80	70	68.54	1.45

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

UNIRRADIATED (LONGITUDINAL)

Page 2

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
80	70	68.54	1.45
120	100	90.6	9.39
120	80	90.6	-10.6
160	100	97.71	2.28
160	100	97.71	2.28
210	100	99.63	.36
210	100	99.63	.36

SUM of RESIDUALS = 5

CAPSULE 137 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:11:17 on 08-03-2000

Page 1

Coefficients of Curve 2

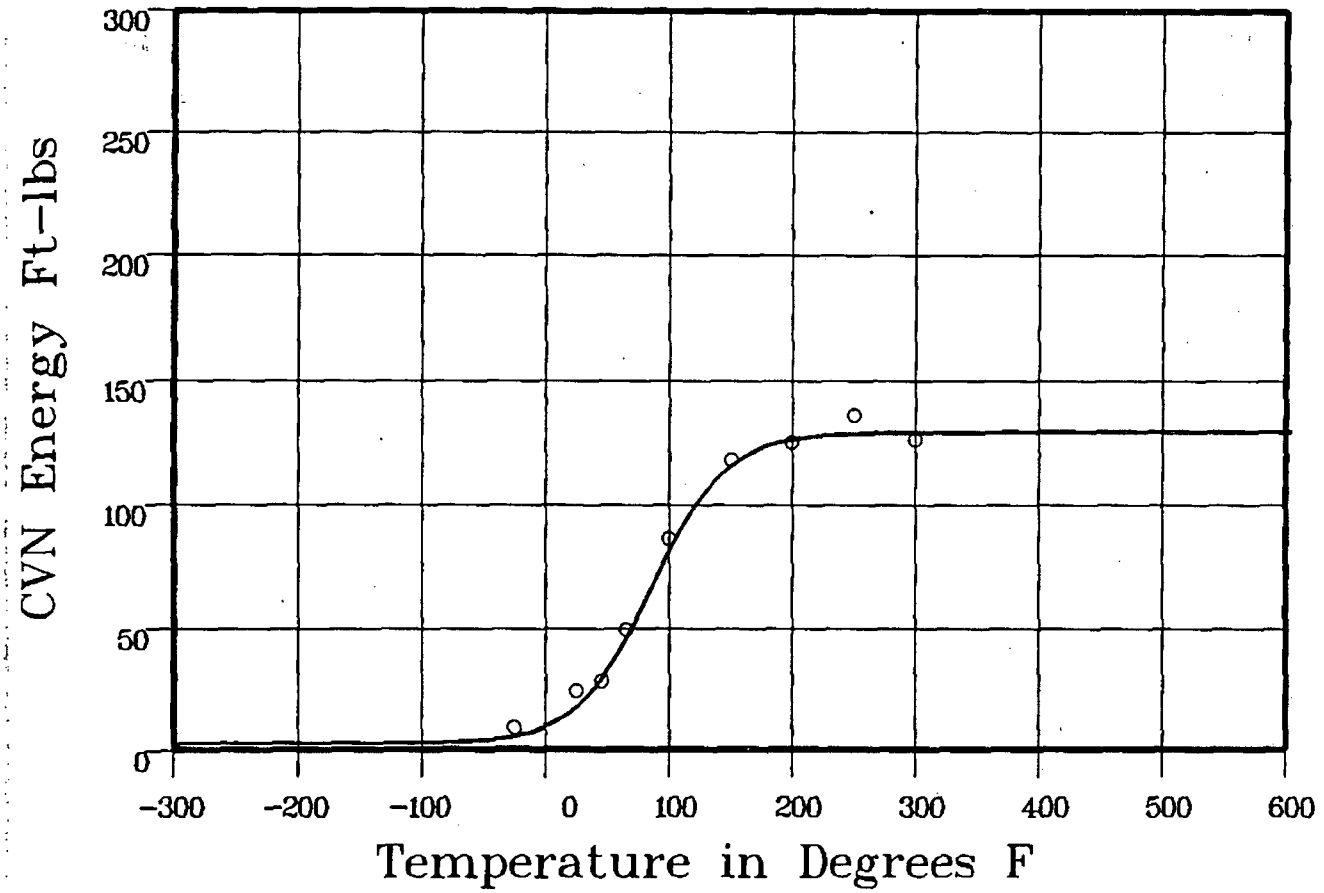
A = 65.59	B = 63.4	C = 60.68	T0 = 80.62

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

Upper Shelf Energy: 129 Fixed Temp. at 30 ft-lbs: 42 Temp. at 50 ft-lbs: 65.3 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: M-6701-2 Orientation: LT

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 137 Material: PLATE SA533B1 Ori.: LT Heat #: M-6701-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	9	5.98	3.01
25	24	19.67	4.32
45	28	32.13	-4.13
65	49	49.62	-.62
100	86	85.18	.81
150	118	117.3	.69
200	125	126.56	-1.56
250	136	128.52	7.47

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

CAPSULE 137 (LONGITUDINAL)

Page 2

Material: PLATE SA533B1 Heat Number: M-6701-2 Orientation: LT

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
300	126	128.9	-2.9

SUM of RESIDUALS = 7.08

CAPSULE 137 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:19:44 on 08-03-2000

Page 1

Coefficients of Curve 2

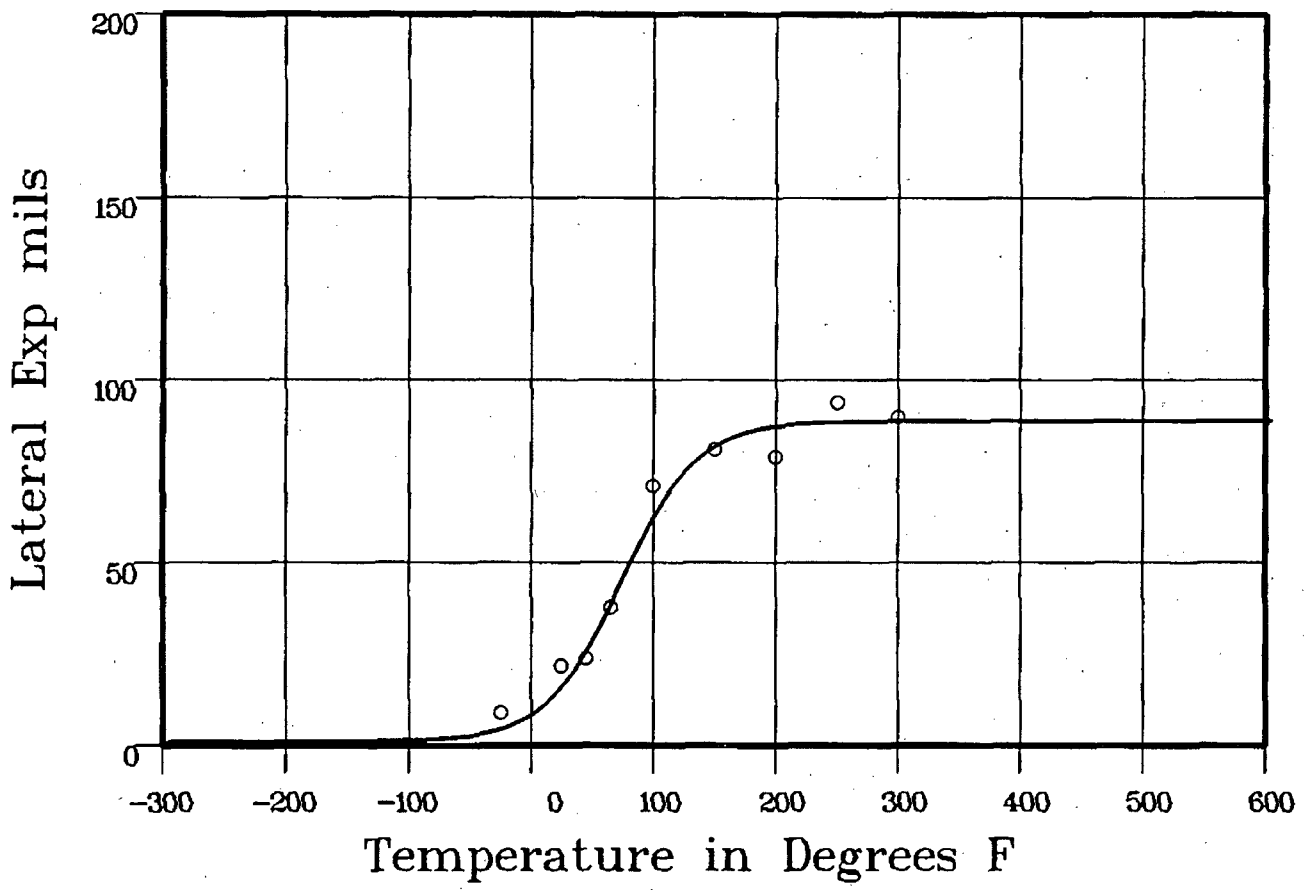
A = 44.88	B = 43.88	C = 61.91	T0 = 69.37

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

Upper Shelf L.E.: 88.77 Temperature at L.E. 35: 55.1 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: M-6701-2 Orientation: LT

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 137 Material: PLATE SA533B1 Ori.: LT Heat #: M-6701-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	9	4.97	4.02
25	22	17.9	4.09
45	24	28.45	-4.45
65	38	41.79	-3.79
100	71	64.98	6.01
150	81	82.73	-1.73
200	79	87.5	-8.5
250	94	88.52	5.47

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

CAPSULE 137 (LONGITUDINAL)

Page 2

Material: PLATE SA533B1 Heat Number: M-6701-2 Orientation: LT

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
300	90	88.72	1.27

SUM of RESIDUALS = 2.4

CAPSULE 137 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:27:38 on 08-03-2000

Page 1

Coefficients of Curve 2

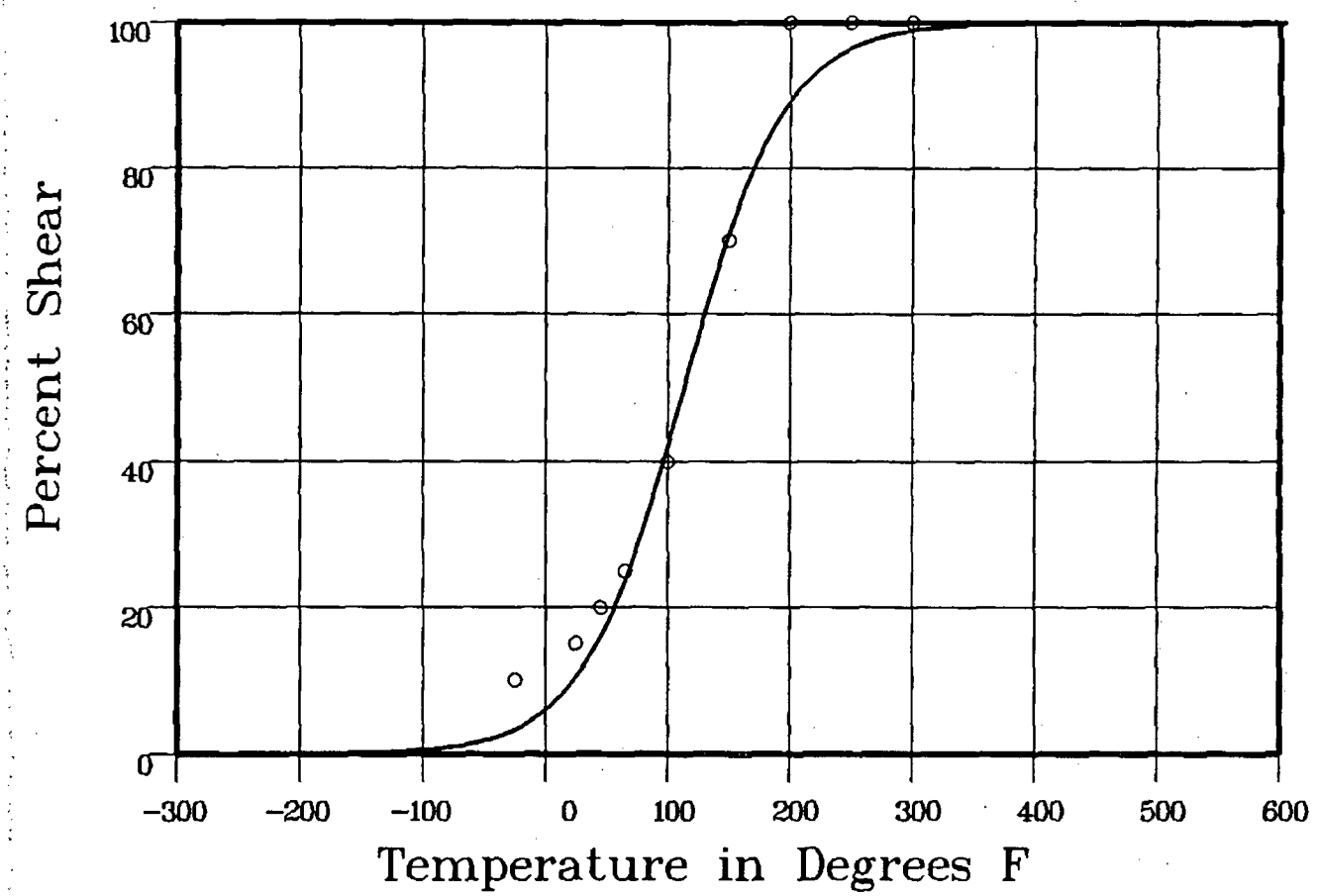
A = 50	B = 50	C = 82.14	T0 = 108.69

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

Temperature at 50% Shear: 108.6

Material: PLATE SA533B1 Heat Number: M-6701-2 Orientation: LT

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 137 Material: PLATE SA533B1 Ori.: LT Heat #: M-6701-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	10	3.71	6.28
25	15	11.53	3.46
45	20	17.49	2.5
65	25	25.65	-.65
100	40	44.72	-4.72
150	70	73.21	-3.21
200	100	90.23	9.76
250	100	96.89	3.1

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

CAPSULE 137 (LONGITUDINAL)

Material: PLATE SA533B1 Heat Number: M-6701-2 Orientation: LT

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
300	100	99.06	.93

SUM of RESIDUALS = 17.46

CAPSULE 38 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:35:25 on 01-29-2001

Page 1

Coefficients of Curve 2

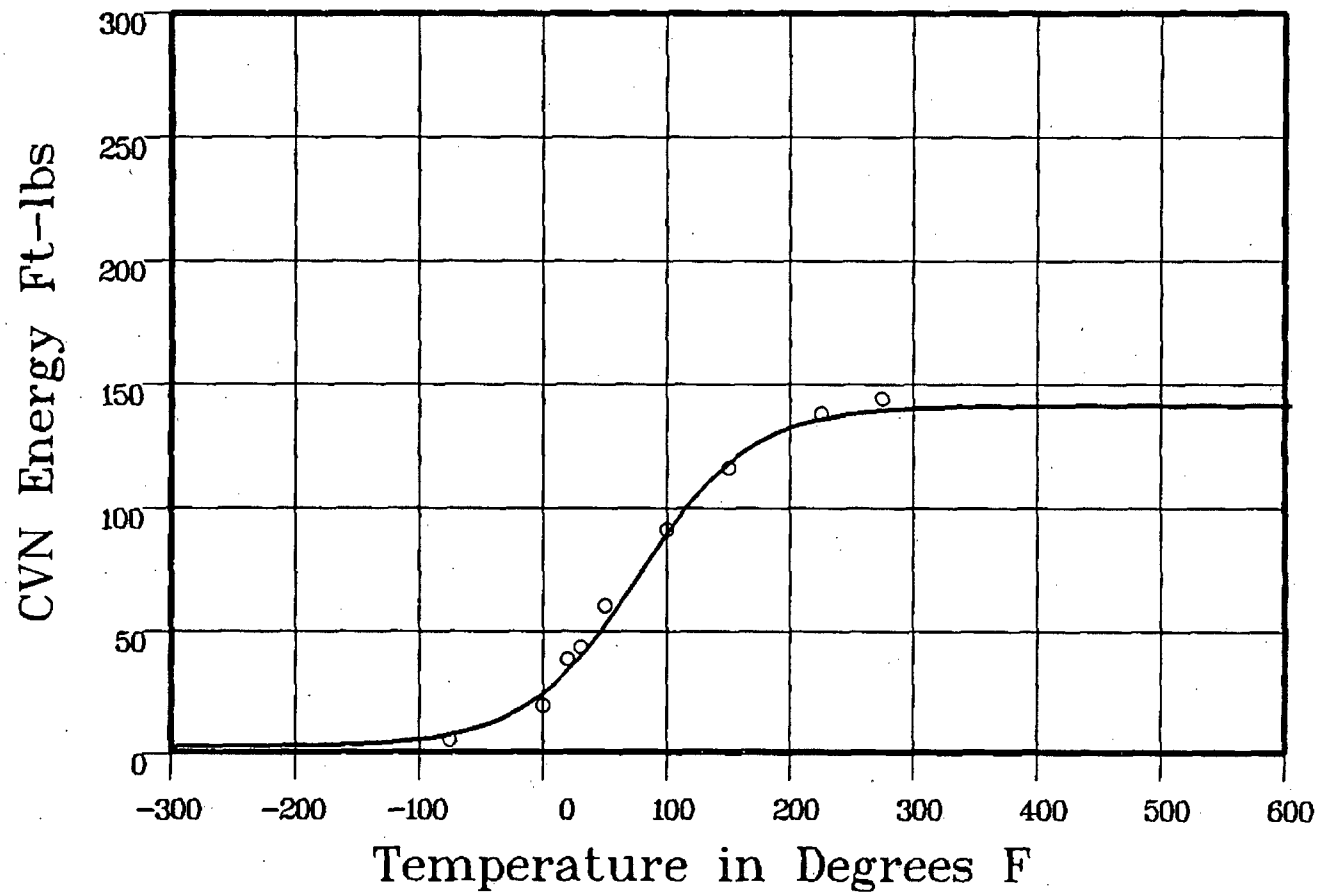
A = 71.59	B = 69.4	C = 91.26	T0 = 71.9

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

Upper Shelf Energy: 141 Fixed Temp. at 30 ft-lbs: 8.7 Temp. at 50 ft-lbs: 42.5 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: LT

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 38 Material: PLATE SA533B1 Ori.: LT Heat #: M-4311-1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-75	5	7.53	-2.53
0	19	25.98	-6.98
20	38	35.89	2.1
30	43	41.79	1.2
50	60	55.25	4.74
100	91	92.31	-1.31
150	116	119.76	-3.76
225	138	136.31	1.68

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

CAPSULE 38 (LONGITUDINAL)

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: LT

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
275	144	139.39	4.6

SUM of RESIDUALS = -27

CAPSULE 38 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:45:51 on 01-29-2001

Page 1

Coefficients of Curve 2

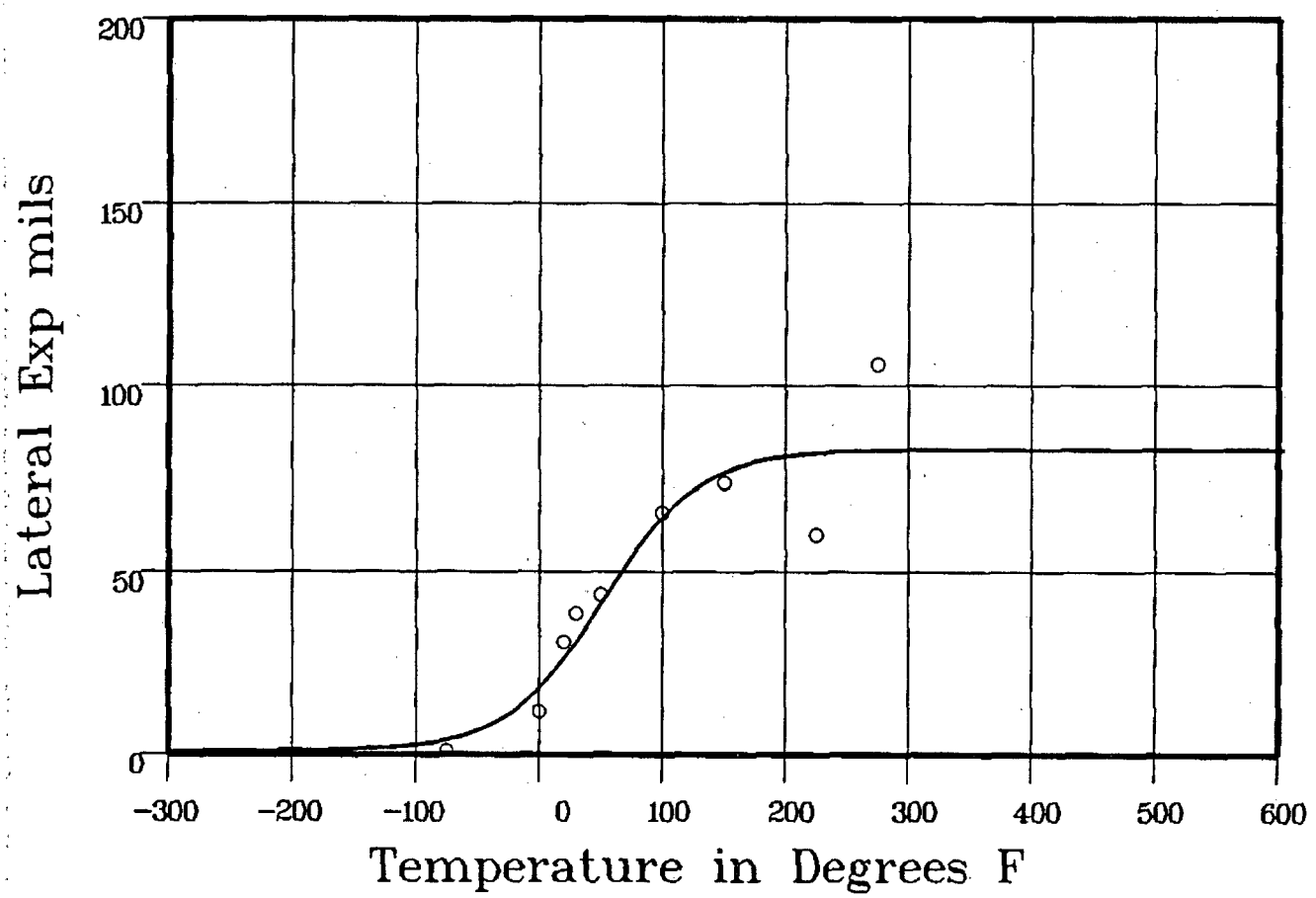
A = 41.89	B = 40.89	C = 78.24	T0 = 46.5

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

Upper Shelf L.E.: 82.78 Temperature at L.E. 35: 33.1 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: LT

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 38 Material: PLATE SA533B1 Ori.: LT Heat #: M-4311-1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-75	1	4.5	-3.5
0	12	20.09	-8.09
20	31	28.54	2.45
30	39	33.38	5.61
50	44	43.71	.28
100	66	66.17	-.17
150	74	77.36	-3.36
225	60	81.93	-21.93

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

CAPSULE 38 (LONGITUDINAL)

Page 2

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: LT

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
275	106	82.54	23.45

SUM of RESIDUALS = -5.26

CAPSULE 38 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:49:09 on 01-29-2001

Page 1

Coefficients of Curve 2

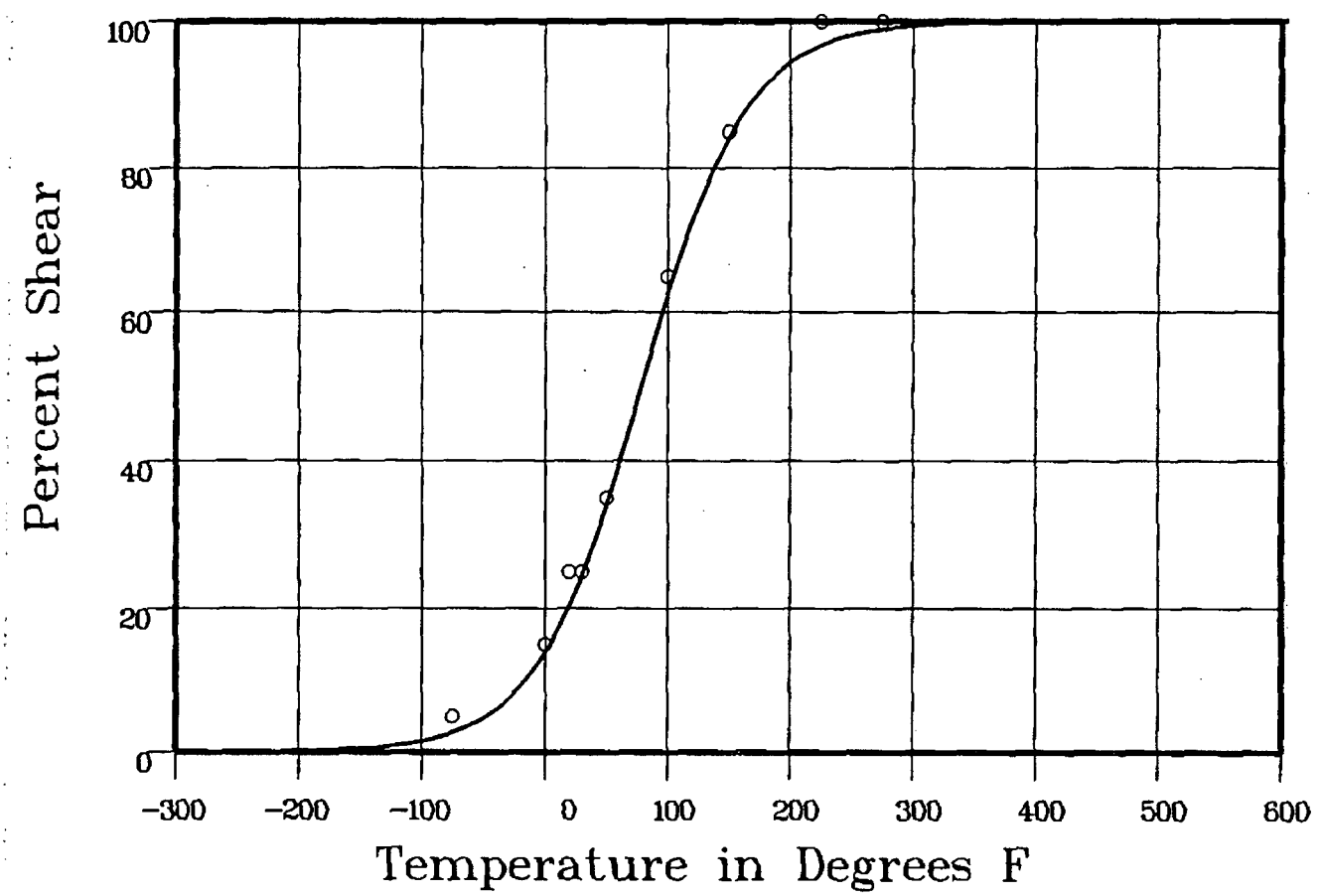
A = 50	B = 50	C = 85.82	T0 = 73.77

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

Temperature at 50% Shear: 73.7

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: LT

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 38 Material: PLATE SA533B1 Ori.: LT Heat #: M-4311-1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75	5	3.02	1.97
0	15	15.19	-.19
20	25	22.21	2.78
30	25	26.5	-1.5
50	35	36.49	-1.49
100	65	64.82	.17
150	85	85.52	-.52
225	100	97.13	2.86

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

CAPSULE 38 (LONGITUDINAL)

Page 2

Material: PLATE SA533B1 Heat Number: M-4311-1 Orientation: LT

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
275	100	99.08	.91

SUM of RESIDUALS = 4.99

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:42:36 on 08-03-2000

Page 1

Coefficients of Curve 1

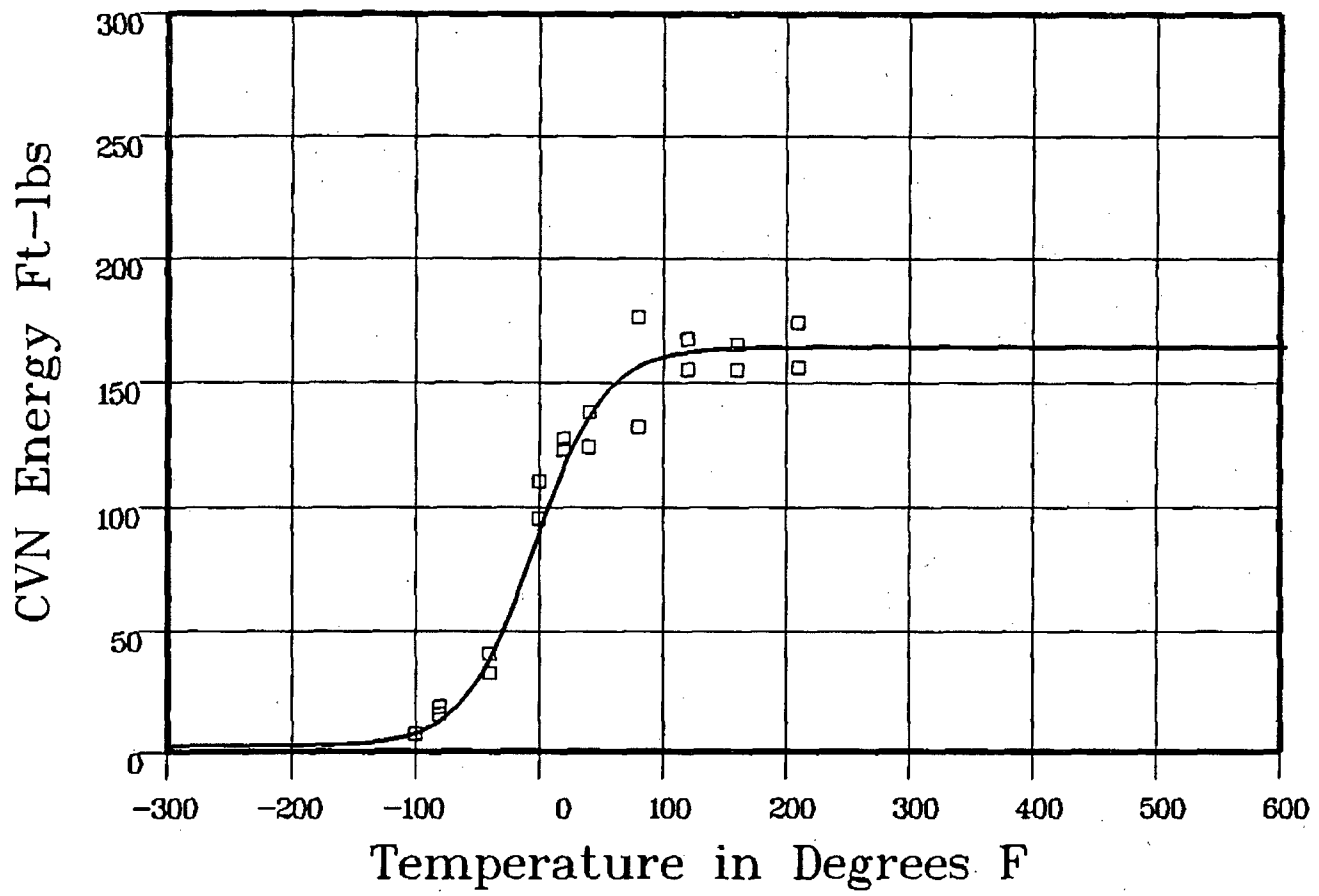
A = 83.09	B = 80.9	C = 56.43	T0 = -8.9

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

Upper Shelf Energy: 164 Fixed Temp. at 30 ft-lbs: -53.2 Temp. at 50 ft-lbs: -33.4 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: UNIRR Material: WELD Ori: Heat #: M-4311-1/M-4311-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	7	8.36	-1.36
-80	15	14.25	.74
-80	18	14.25	3.74
-40	32	42.54	-10.54
-40	40	42.54	-2.54
0	110	95.76	14.23
0	95	95.76	-.76
20	123	121.25	1.74
20	127	121.25	5.74

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

UNIRRADIATED

Page 2

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
20	123	121.25	1.74
40	138	139.7	-1.7
40	124	139.7	-15.7
80	132	157.35	-25.35
80	176	157.35	18.64
120	155	162.33	-7.33
120	167	162.33	4.66
160	165	163.59	1.4
160	155	163.59	-8.59
210	174	163.93	10.06
210	156	163.93	-7.93
		SUM of RESIDUALS =	-19.12

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:51:31 on 08-03-2000

Page 1

Coefficients of Curve 1

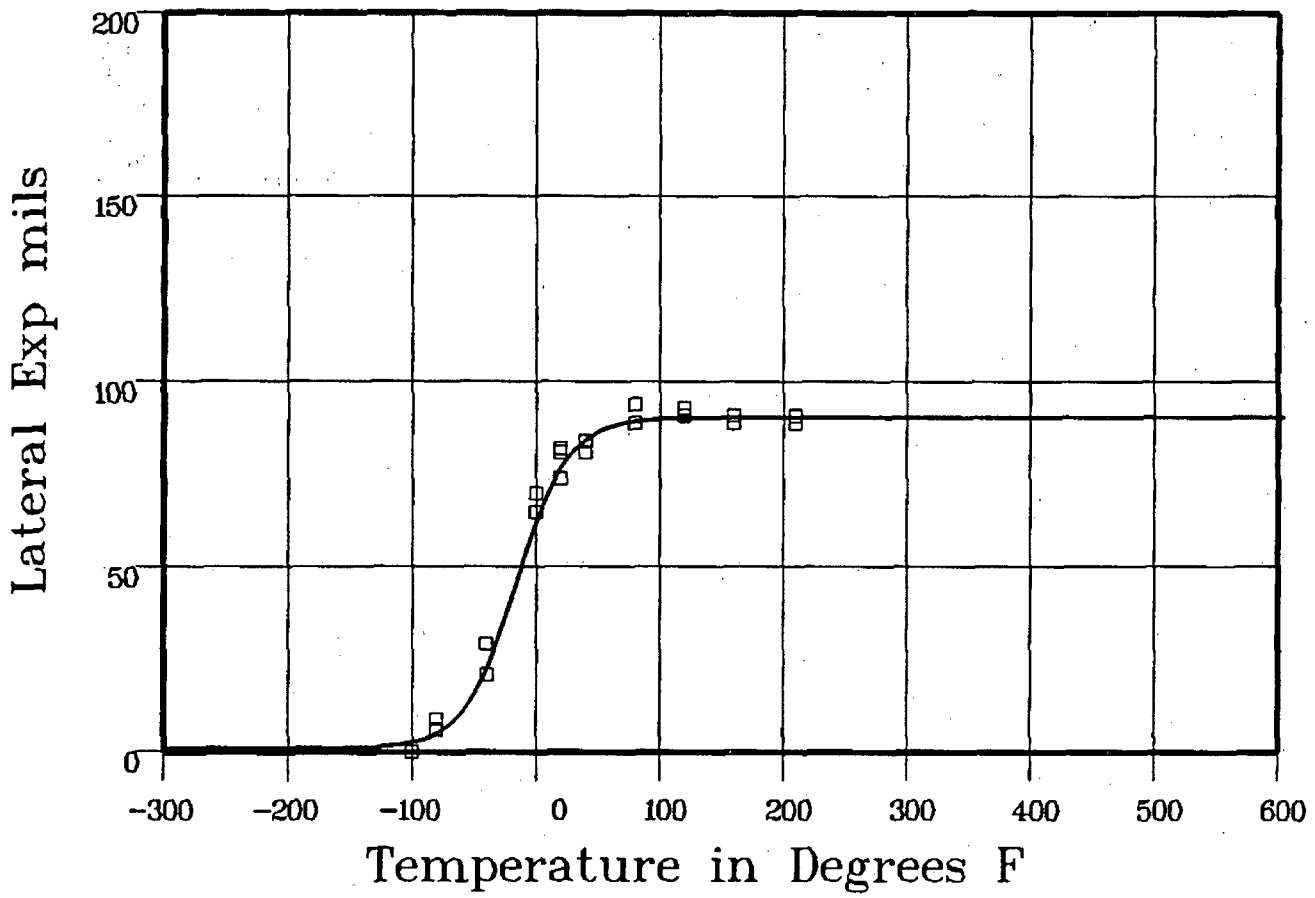
A = 45.71	B = 44.71	C = 42.24	T0 = -20.62

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

Upper Shelf L.E: 90.43 Temperature at L.E. 35: -30.9 Lower Shelf L.E: 1 Fixed

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: UNIRR Material: WELD Ori: Heat #: M-4311-1/M-4311-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	0	3.03	-3.03
-80	6	6.07	-.07
-80	9	6.07	2.92
-40	21	26.53	-5.53
-40	29	26.53	2.46
0	70	65.96	4.03
0	65	65.96	-.96
20	74	79.02	-5.02
20	82	79.02	2.97

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

UNIRRADIATED

Page 2

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
20	81	79.02	1.97
40	81	85.63	-4.63
40	84	85.63	-1.63
80	89	89.67	-.67
80	94	89.67	4.32
120	93	90.31	2.68
120	91	90.31	.68
160	89	90.41	-1.41
160	91	90.41	.58
210	89	90.43	-1.43
210	91	90.43	.56

SUM of RESIDUALS = -1.21

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:59:59 on 08-03-2000

Page 1

Coefficients of Curve 1

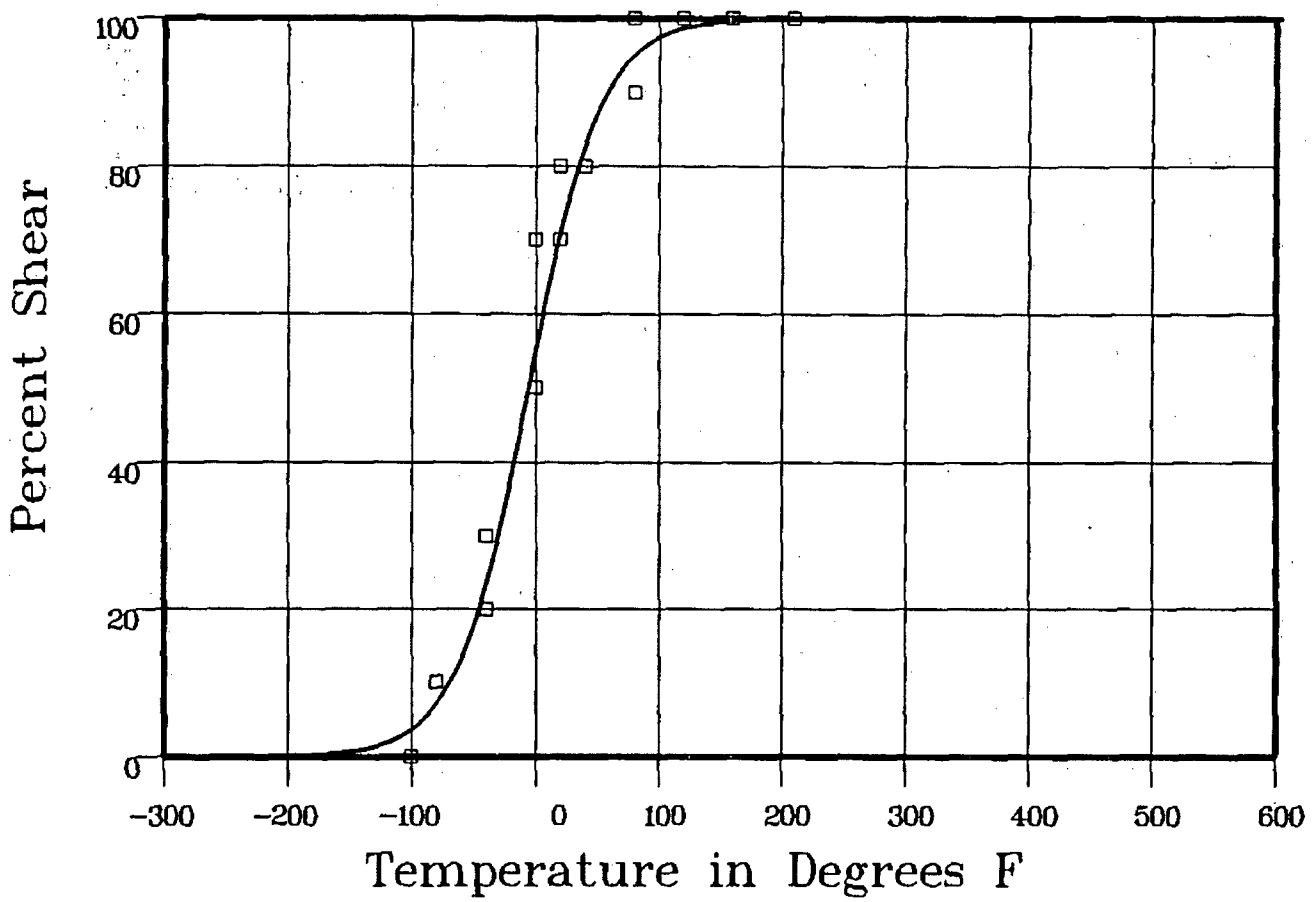
A = 50	B = 50	C = 57.87	T0 = -10.44

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

Temperature at 50% Shear: -10.4

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: UNIRR Material: WELD Ori.: Heat #: M-4311-1/M-4311-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	0	4.33	-4.33
-80	10	8.29	1.7
-80	10	8.29	1.7
-40	20	26.47	-6.47
-40	30	26.47	3.52
0	50	58.92	-8.92
0	70	58.92	11.07
20	70	74.11	-4.11
20	80	74.11	5.88

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

UNIRRADIATED

Page 2

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
20	80	74.11	5.88
40	80	85.1	-5.1
40	80	85.1	-5.1
80	90	95.79	-5.79
80	100	95.79	4.2
120	100	98.9	1.09
120	100	98.9	1.09
160	100	99.72	.27
160	100	99.72	.27
210	100	99.95	.04
210	100	99.95	.04

SUM of RESIDUALS = -3.03

CAPSULE 137

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:48:57 on 08-03-2000

Page 1

Coefficients of Curve 2

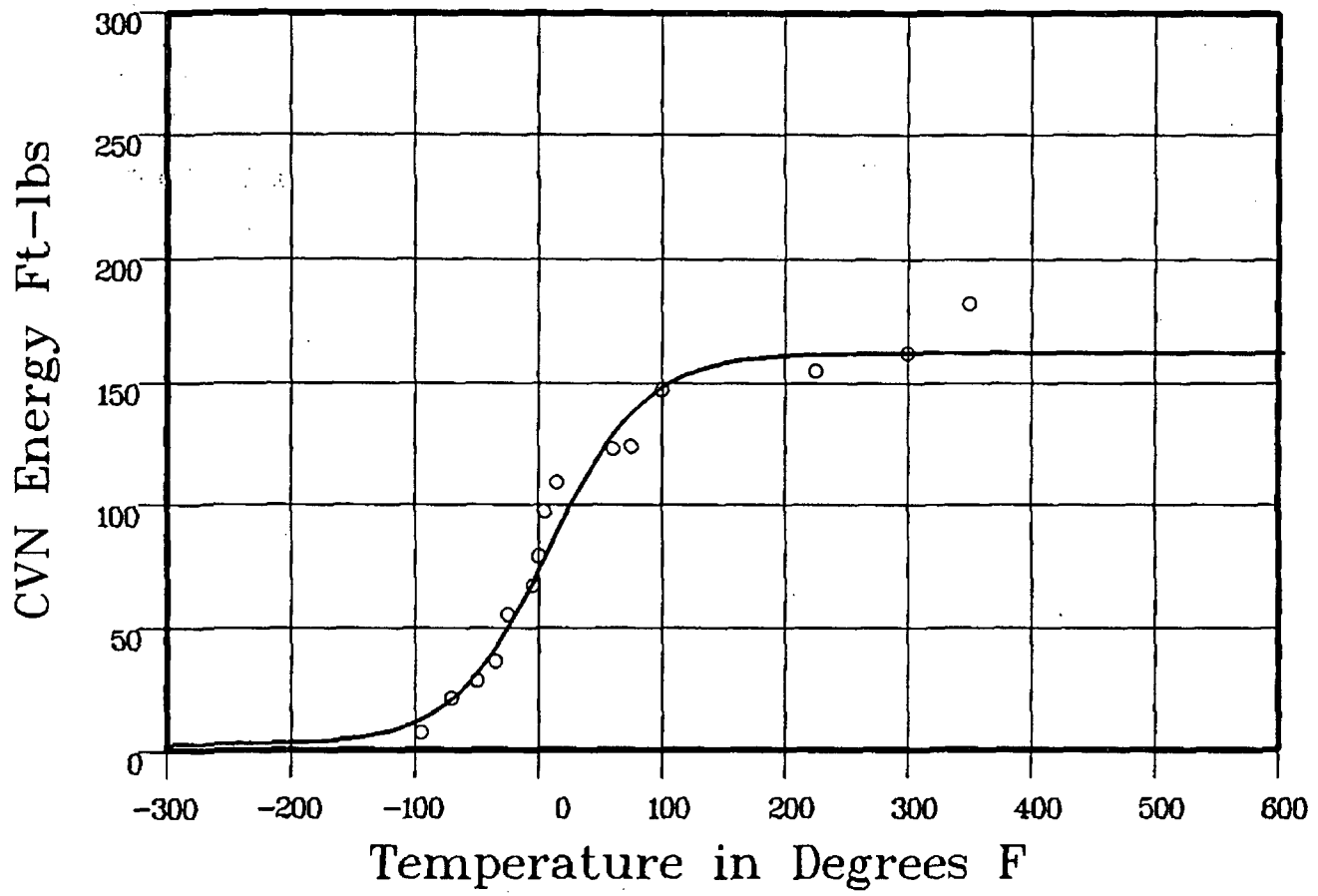
A = 82.09	B = 79.9	C = 77.6	T0 = 4.21

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

Upper Shelf Energy: 162 Fixed Temp. at 30 ft-lbs: -56.2 Temp. at 50 ft-lbs: -28.8 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 137 Material: WELD Ori.: Heat #: M-4311-1/M-4311-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-95	7	13.69	-6.69
-70	21	22.76	-1.76
-50	28	33.87	-5.87
-35	36	44.84	-8.84
-25	55	53.36	1.63
-5	67	72.65	-5.65
0	79	77.76	1.23
5	97	82.9	14.09

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

CAPSULE 137

Page 2

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
15	109	93.12	15.87
60	123	131.33	-8.33
75	124	139.79	-15.79
100	147	149.51	-2.51
225	155	161.46	-6.46
300	162	161.92	.07
350	182	161.97	20.02

SUM of RESIDUALS = -9

CAPSULE 137

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:51:31 on 08-03-2000

Page 1

Coefficients of Curve 2

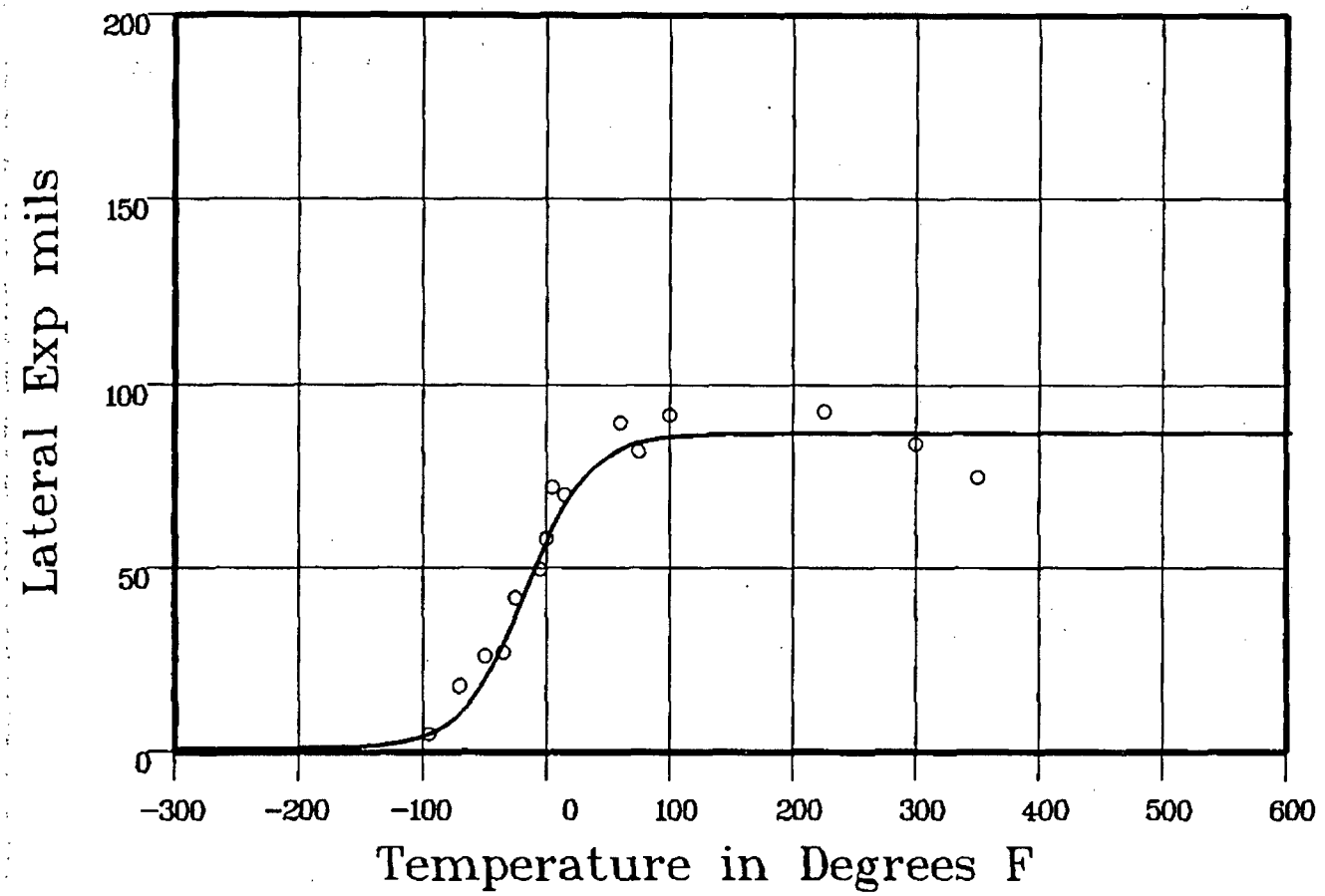
A = 43.93	B = 42.93	C = 52.25	T0 = -21.09

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

Upper Shelf L.E.: 86.87 Temperature at L.E. 35: -32.1 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 137 Material: WELD Ori.: Heat #: M-4311-1/M-4311-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-95	5	5.79	-.79
-70	18	12.45	5.54
-50	26	22.34	3.65
-35	27	32.77	-5.77
-25	42	40.73	1.26
-5	50	56.76	-6.76
0	58	60.38	-2.38
5	72	63.76	8.23

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

CAPSULE 137

Page 2

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
15	70	69.63	.36
60	90	83.19	6.8
75	82	84.76	-2.76
100	92	86.05	5.94
225	93	86.87	6.12
300	84	86.87	-2.87
350	75	86.87	-11.87

SUM of RESIDUALS = 4.71

CAPSULE 137

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:59:59 on 08-03-2000

Page 1

Coefficients of Curve 2

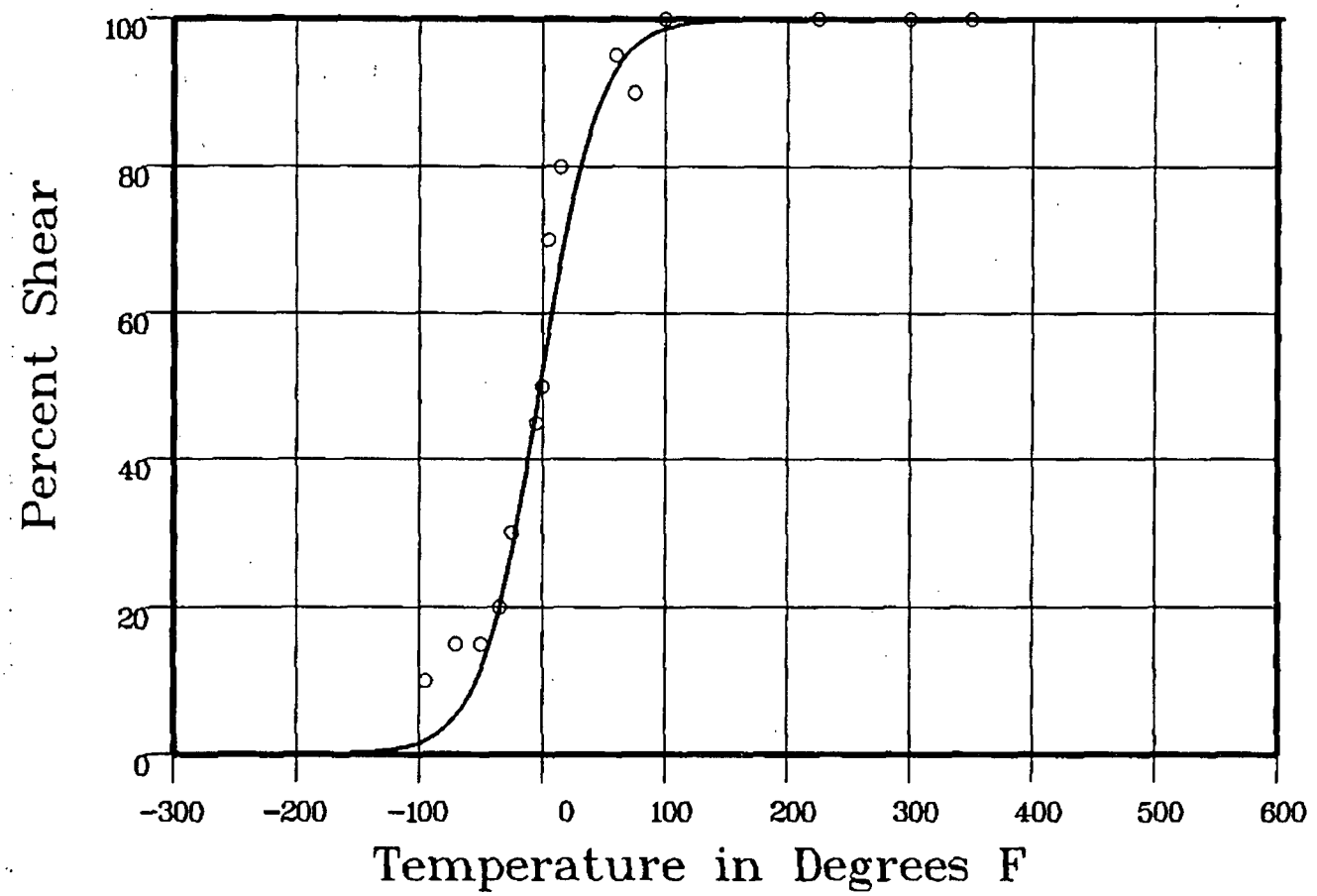
A = 50	B = 50	C = 47.34	T0 = -6.56

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

Temperature at 50% Shear: -6.5

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: 137 Material: WELD Ori: Heat #: M-4311-1/M-4311-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-95	10	2.32	7.67
-70	15	6.41	8.58
-50	15	13.76	1.23
-35	20	23.12	-3.12
-25	30	31.45	-1.45
-5	45	51.64	-6.64
0	50	56.88	-6.88
5	70	61.97	8.02

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

CAPSULE 137

Page 2

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
15	80	71.31	8.68
60	95	94.33	.66
75	90	96.9	-6.9
100	100	98.9	1.09
225	100	99.99	0
300	100	99.99	0
350	100	99.99	0

SUM of RESIDUALS = 10.94

CAPSULE 38

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:42:36 on 08-03-2000

Page 1

Coefficients of Curve 3

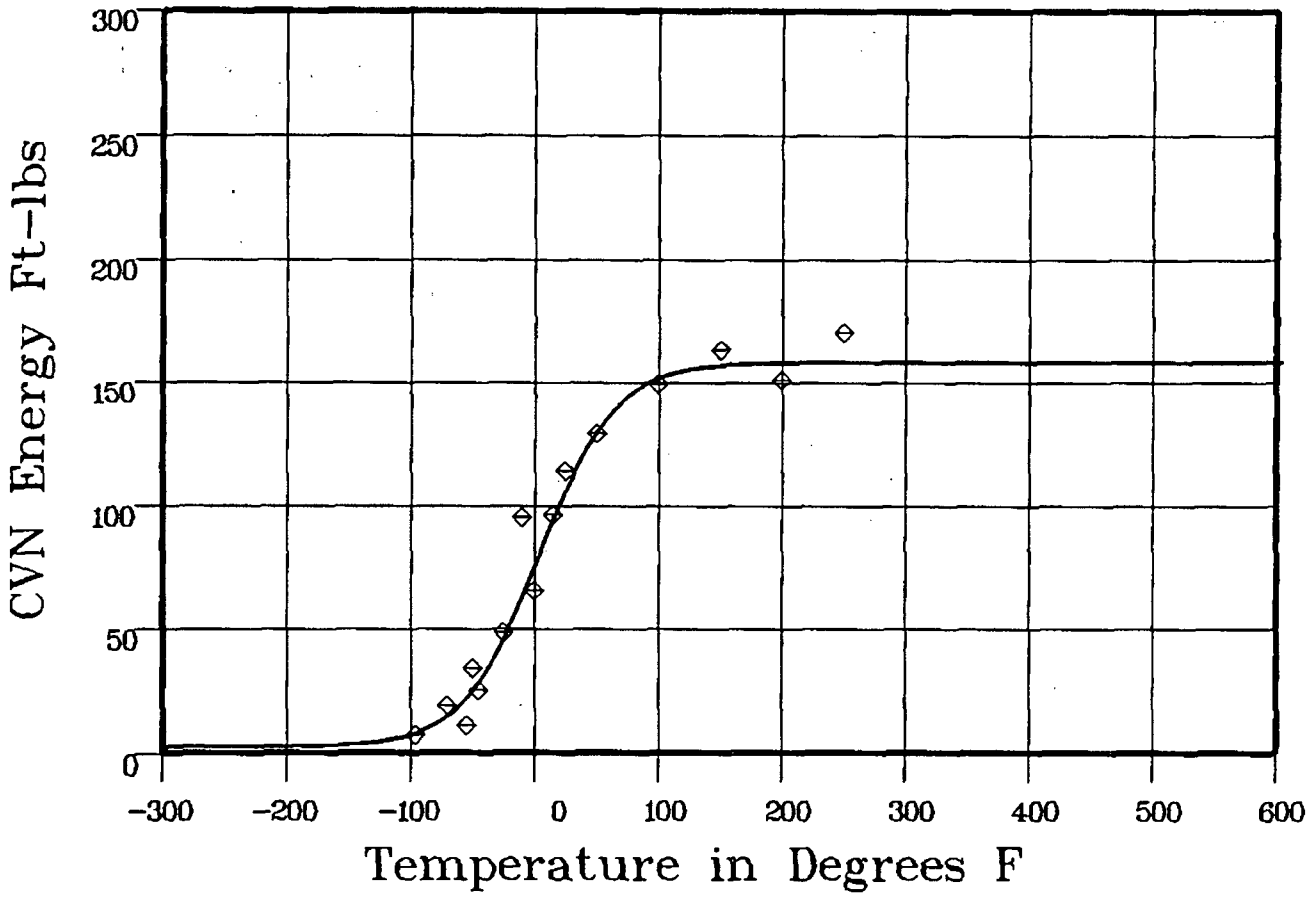
A = 80.09	B = 77.9	C = 60.95	T0 = -.46

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

Upper Shelf Energy: 158 Fixed Temp. at 30 ft-lbs: -47 Temp. at 50 ft-lbs: -25.3 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: 38 Material: WELD Ori: Heat #: M-4311-1/M-4311-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-96	7	8.69	-1.69
-70	19	16.63	2.36
-55	11	24.5	-13.5
-50	34	27.82	6.17
-45	25	31.53	-6.53
-25	48	50.33	-2.33
-10	95	68.01	26.98
0	65	80.69	-15.69

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

CAPSULE 38

Page 2

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
15	96	99.45	-3.45
25	114	110.87	3.12
50	129	133.02	-4.02
100	149	152.44	-3.44
150	163	156.89	6.1
200	151	157.78	-6.78
250	170	157.95	12.04

SUM of RESIDUALS = -.68

CAPSULE 38

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:51:31 on 08-03-2000

Page 1

Coefficients of Curve 3

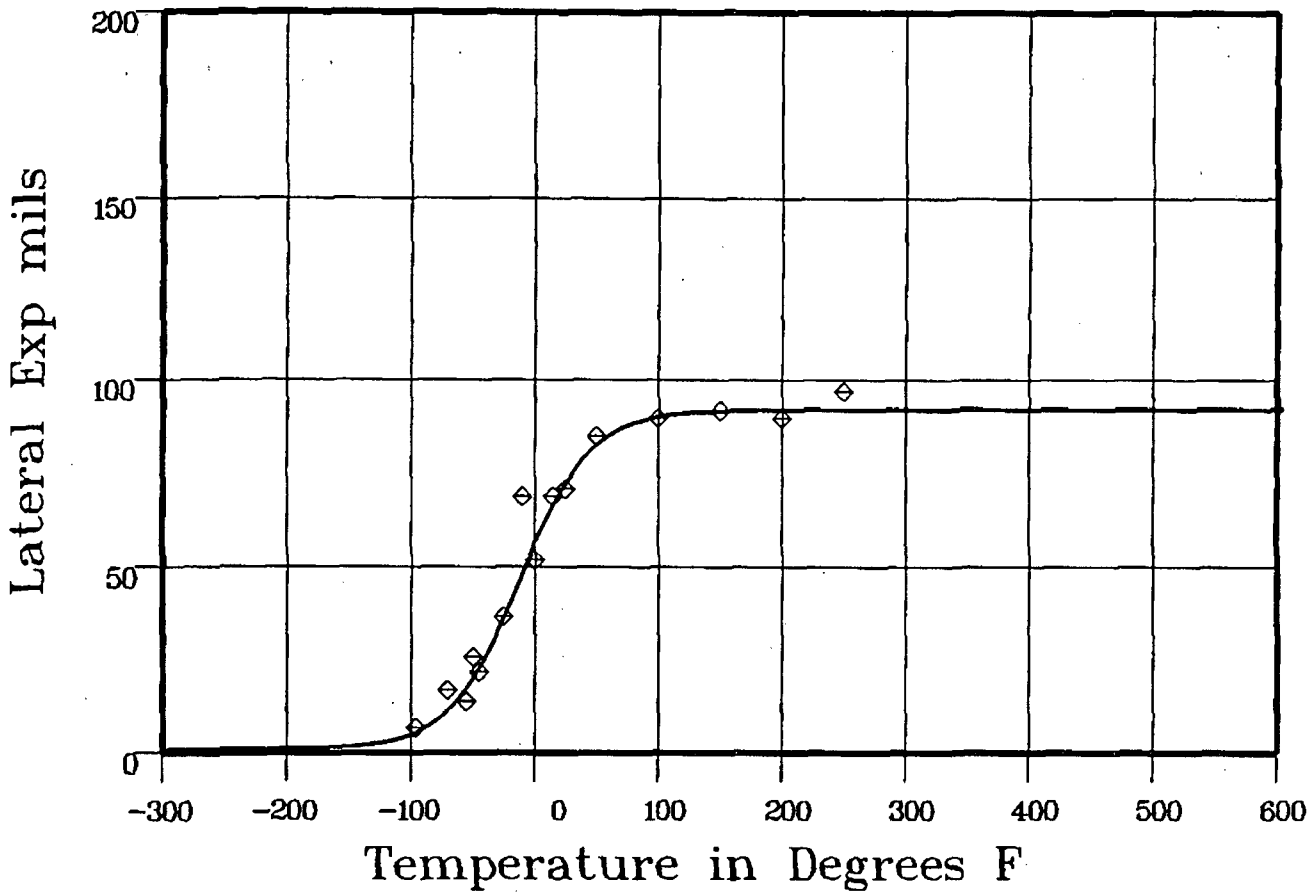
A = 46.59	B = 45.59	C = 57.39	T0 = -16.87

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

Upper Shelf L.E.: 92.18 Temperature at L.E. 35: -31.7 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 38 Material: WELD Ori.: Heat #: M-4311-1/M-4311-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-96	7	6.44	.55
-70	17	13.37	3.62
-55	14	20.09	-6.09
-50	26	22.85	3.14
-45	22	25.88	-3.88
-25	37	40.17	-3.17
-10	69	52.02	16.97
0	52	59.62	-7.62

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

CAPSULE 38

Page 2

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
15	69	69.59	-.59
25	71	74.98	-3.98
50	85	84.09	.9
100	90	90.65	-.65
150	92	91.91	.08
200	90	92.13	-2.13
250	97	92.17	4.82

SUM of RESIDUALS = 1.97

CAPSULE 38

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:59:59 on 08-03-2000

Page 1

Coefficients of Curve 3

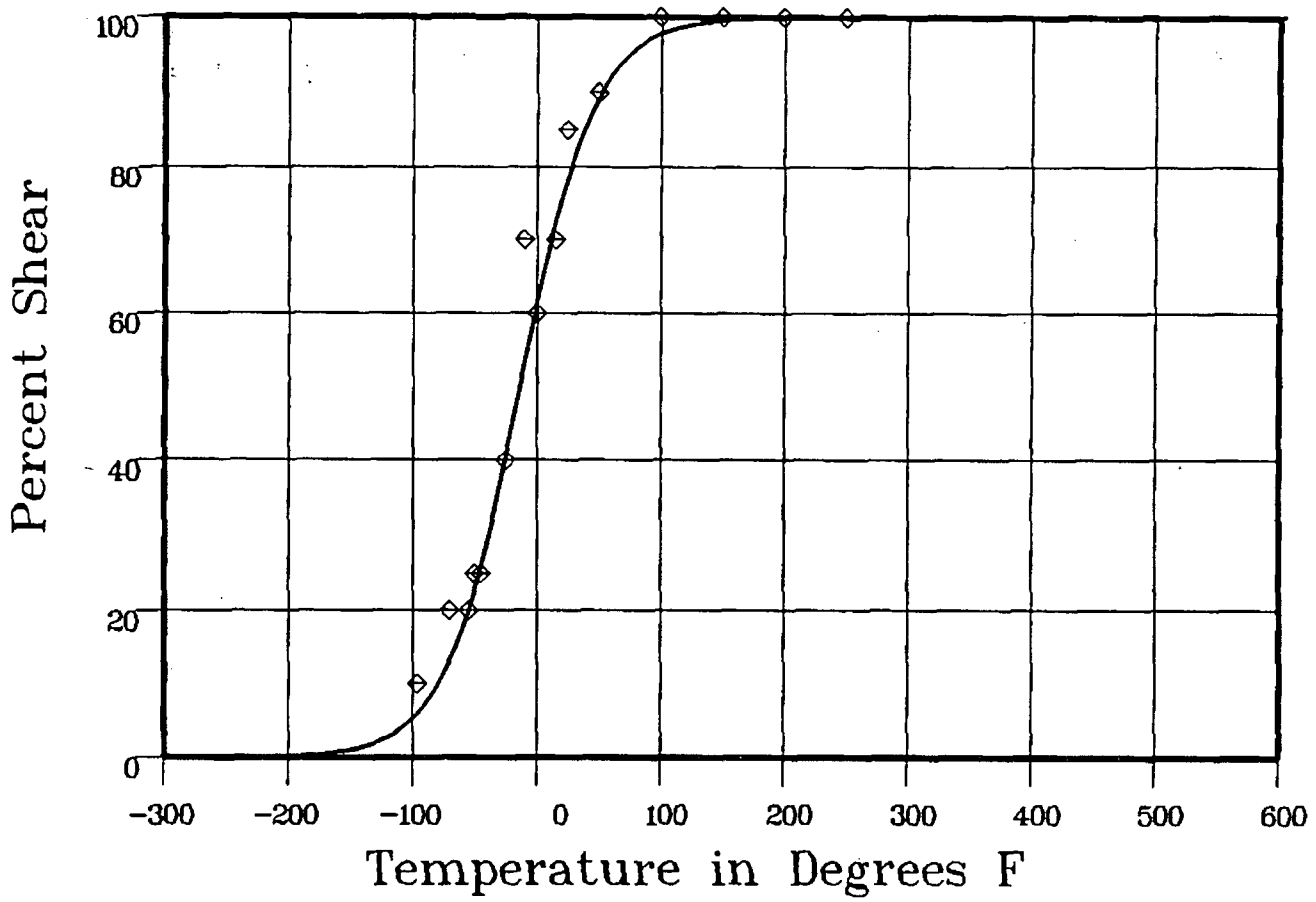
A = 50	B = 50	C = 59.75	T0 = -18.28

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

Temperature at 50% Shear: -18.2

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: 38 Material: WELD Ori: Heat #: M-4311-1/M-4311-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-96	10	6.9	3.09
-70	20	15.04	4.95
-55	20	22.63	-2.63
-50	25	25.7	-.7
-45	25	29.02	-4.02
-25	40	44.4	-4.4
-10	70	56.88	13.11
0	60	64.83	-4.83

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

CAPSULE 38

Page 2

Material: WELD Heat Number: M-4311-1/M-4311-2 Orientation:

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
15	70	75.28	-5.28
25	85	80.97	4.02
50	90	90.76	-.76
100	100	98.12	1.87
150	100	99.64	.35
200	100	99.93	.06
250	100	99.98	.01

SUM of RESIDUALS = 4.84

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:18:01 on 08-03-2000

Page 1

Coefficients of Curve 1

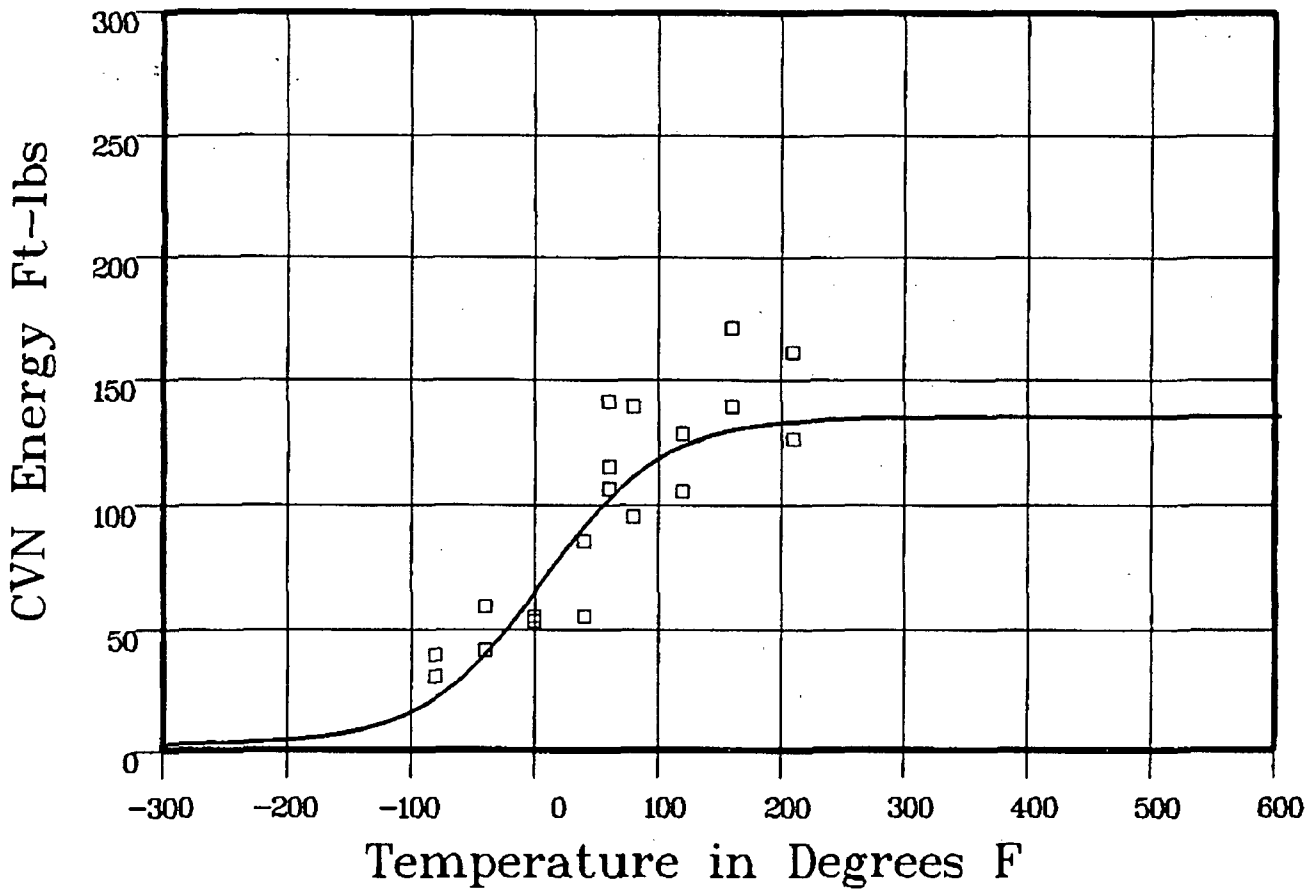
A = 68.59	B = 66.4	C = 97.23	T0 = 1.4

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

Upper Shelf Energy: 135 Fixed Temp. at 30 ft-lbs: -63.2 Temp. at 50 ft-lbs: -26.5 Lower Shelf Energy: 2.19 Fixed

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

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: UNIRR Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-80	39	23.16	15.83
-80	30	23.16	6.83
-40	41	41.91	-.91
-40	59	41.91	17.08
0	55	67.63	-12.63
0	53	67.63	-14.63
40	85	93.65	-8.65
40	55	93.65	-38.65
60	106	104.38	1.61

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

UNIRRADIATED

Page 2

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

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
60	115	104.38	10.61
60	141	104.38	36.61
80	95	112.99	-17.99
80	139	112.99	26
120	128	124.34	3.65
120	105	124.34	-19.34
160	139	130.1	8.89
160	171	130.1	40.89
210	126	133.2	-7.2
210	161	133.2	27.79

SUM of RESIDUALS = 75.8

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:21:56 on 08-03-2000

Page 1

Coefficients of Curve 1

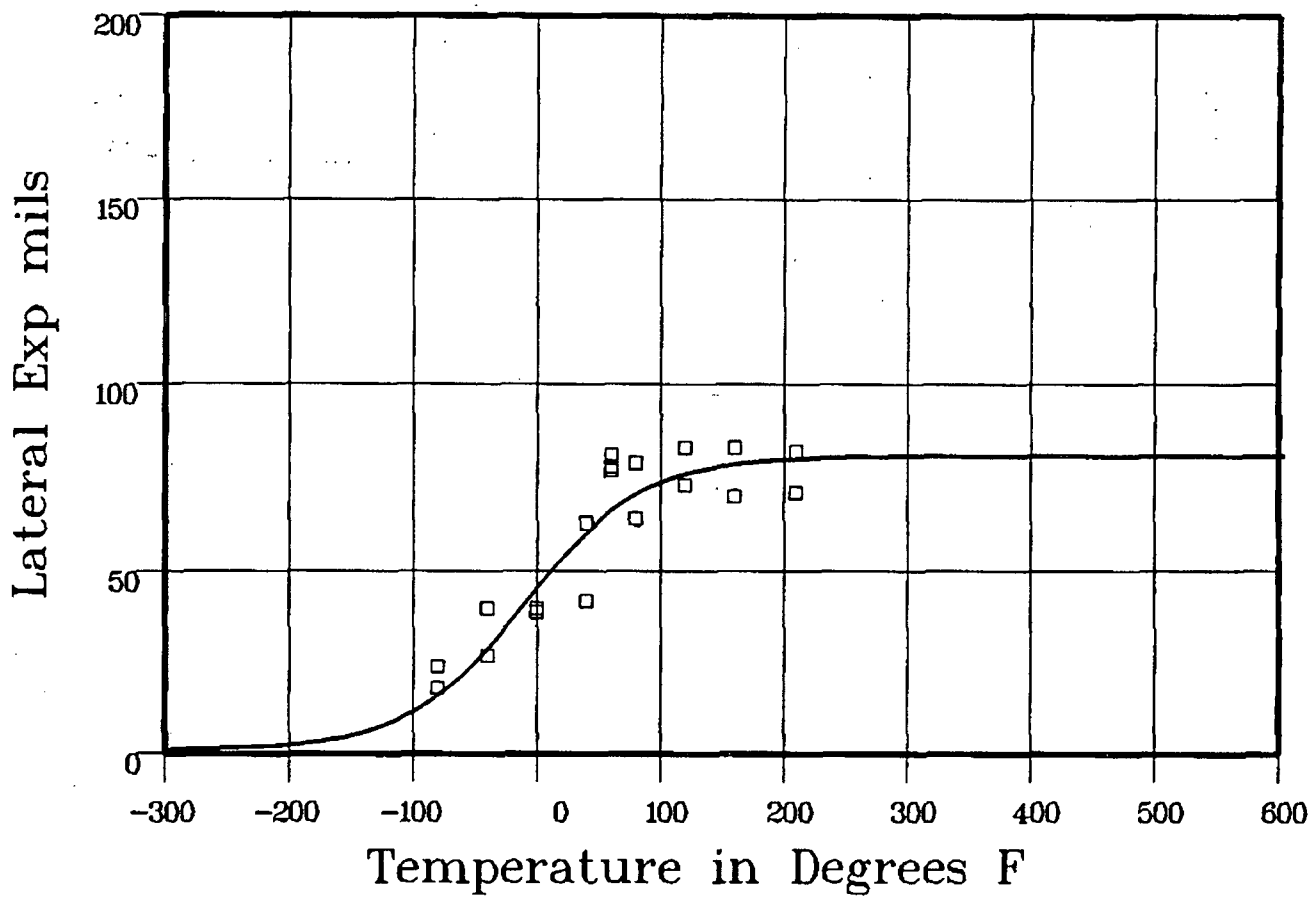
A = 40.96	B = 39.96	C = 94.95	T0 = -15.46

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

Upper Shelf L.E.: 80.92 Temperature at L.E. 35: -29.7 Lower Shelf L.E.: 1 Fixed

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

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: UNIRR Material: HEAT AFF'D ZONE Ori: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-80	18	17.33	.66
-80	24	17.33	6.66
-40	27	30.86	-3.86
-40	40	30.86	9.13
0	39	47.41	-8.41
0	40	47.41	-7.41
40	63	61.97	1.02
40	42	61.97	-19.97
60	77	67.38	9.61

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

UNIRRADIATED

Page 2

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

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
60	81	67.38	13.61
60	78	67.38	10.61
80	64	71.49	-7.49
80	79	71.49	7.5
120	73	76.57	-3.57
120	83	76.57	6.42
160	70	78.99	-8.99
160	83	78.99	4
210	82	80.24	1.75
210	71	80.24	-9.24

SUM of RESIDUALS = 2.08

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:29:47 on 08-03-2000

Page 1

Coefficients of Curve 1

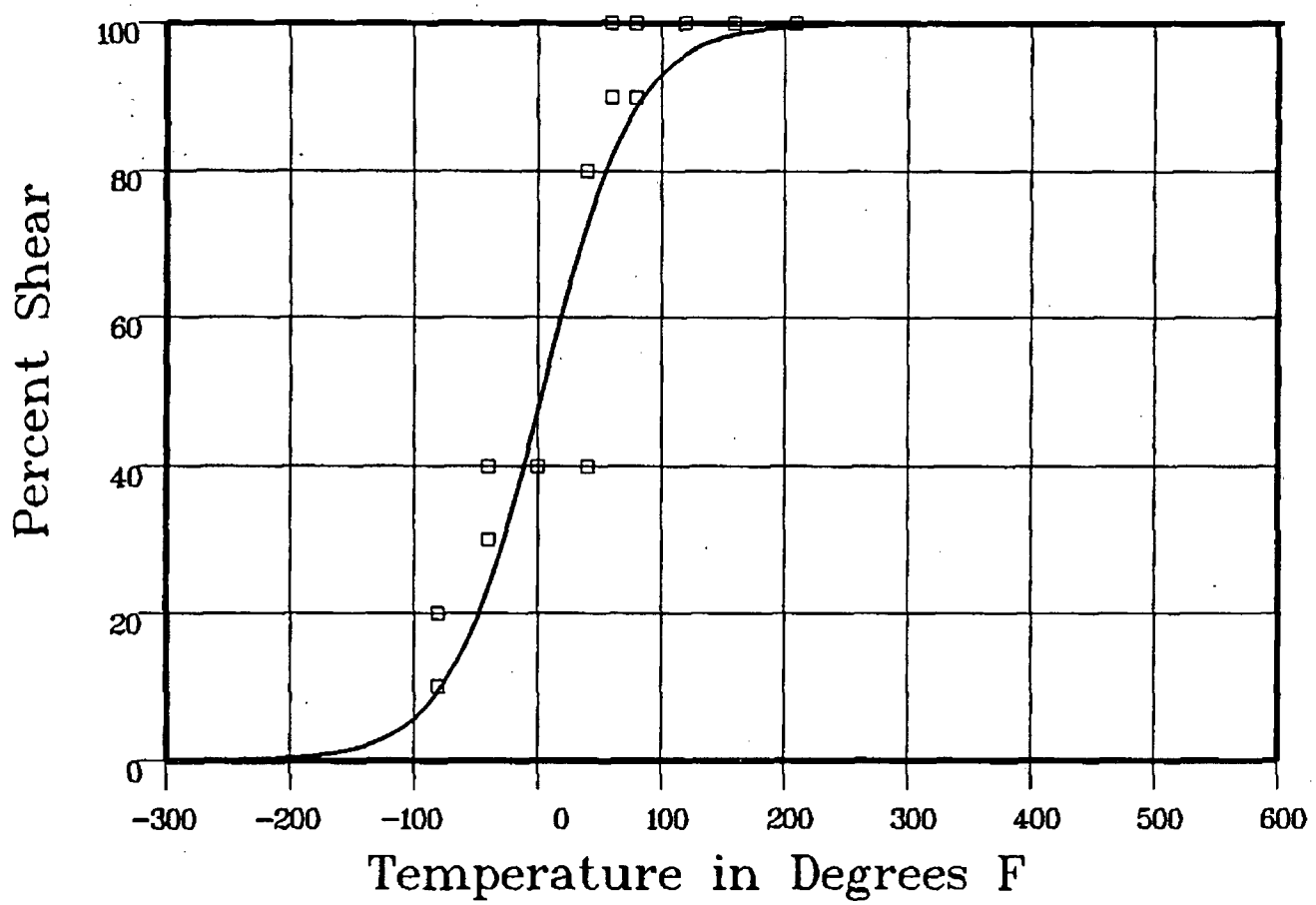
A = 50	B = 50	C = 73.95	T0 = -.93

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

Temperature at 50% Shear: -.9

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: UNIRR Material: HEAT AFFD ZONE Ori: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-80	10	10.54	-.54
-80	20	10.54	9.45
-40	30	25.79	4.2
-40	40	25.79	14.2
0	40	50.63	-10.63
0	40	50.63	-10.63
40	80	75.15	4.84
40	40	75.15	-35.15
60	100	83.86	16.13

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

UNIRRADIATED

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
60	90	83.86	6.13
60	100	83.86	16.13
80	90	89.92	.07
80	100	89.92	10.07
120	100	96.34	3.65
120	100	96.34	3.65
160	100	98.72	1.27
160	100	98.72	1.27
210	100	99.66	.33
210	100	99.66	.33

SUM of RESIDUALS = 34.81

CAPSULE 137

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:48:11 on 08-03-2000

Page 1

Coefficients of Curve 2

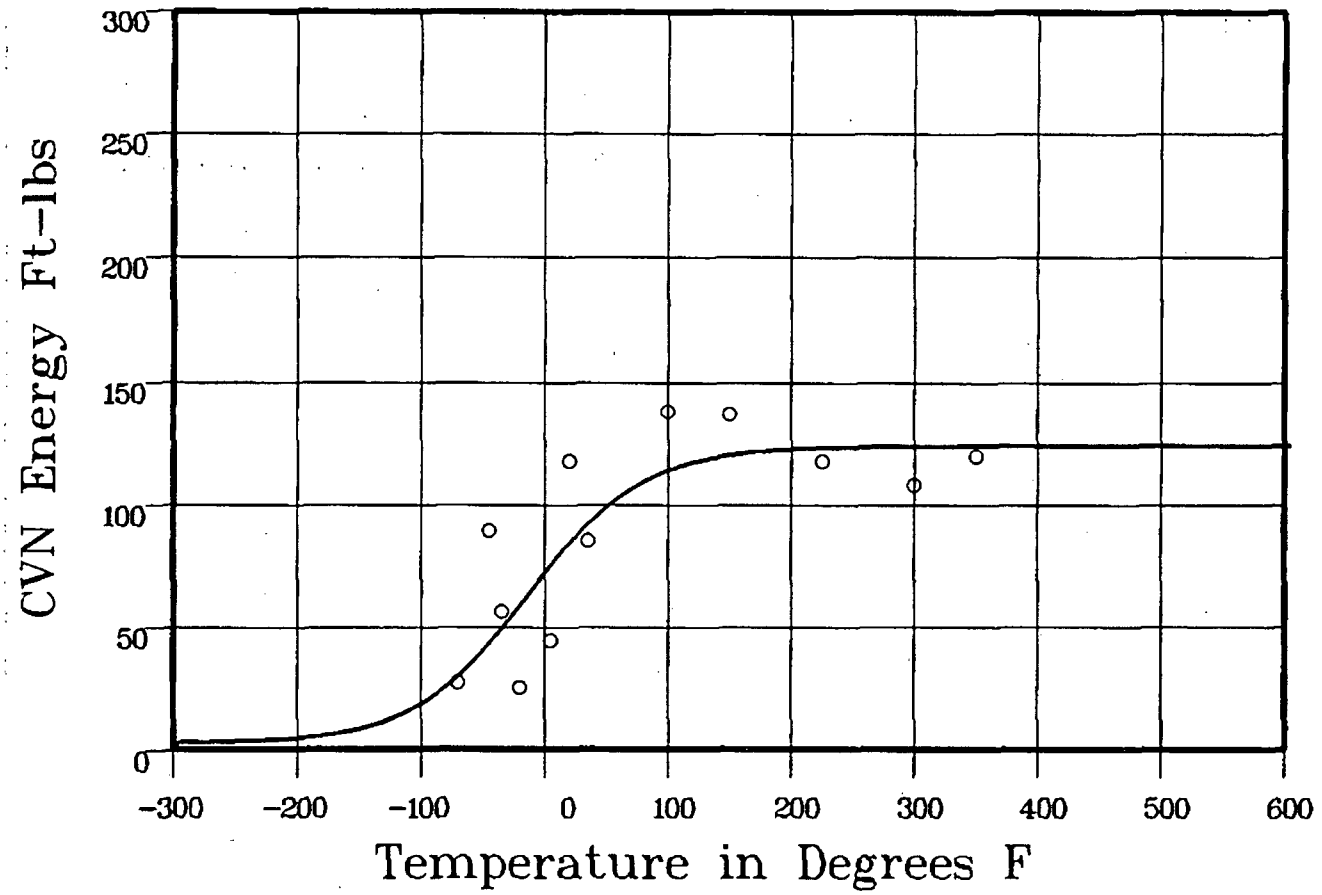
A = 63.09	B = 60.9	C = 92.86	T0 = -17.61

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

Upper Shelf Energy: 124 Fixed Temp. at 30 ft-lbs: -74.1 Temp. at 50 ft-lbs: -37.9 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 137 Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-70	27	31.98	-4.98
-45	89	45.64	43.35
-35	56	51.83	4.16
-20	25	61.53	-36.53
5	44	77.64	-33.64
20	118	86.5	31.49
35	85	94.33	-9.33
100	138	115.03	22.96

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

CAPSULE 137

Page 2

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

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
150	137	120.79	16.2
225	118	123.34	-5.34
300	108	123.86	-15.86
350	120	123.95	-3.95

SUM of RESIDUALS = 8.53

CAPSULE 137

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:21:56 on 08-03-2000

Page 1

Coefficients of Curve 2

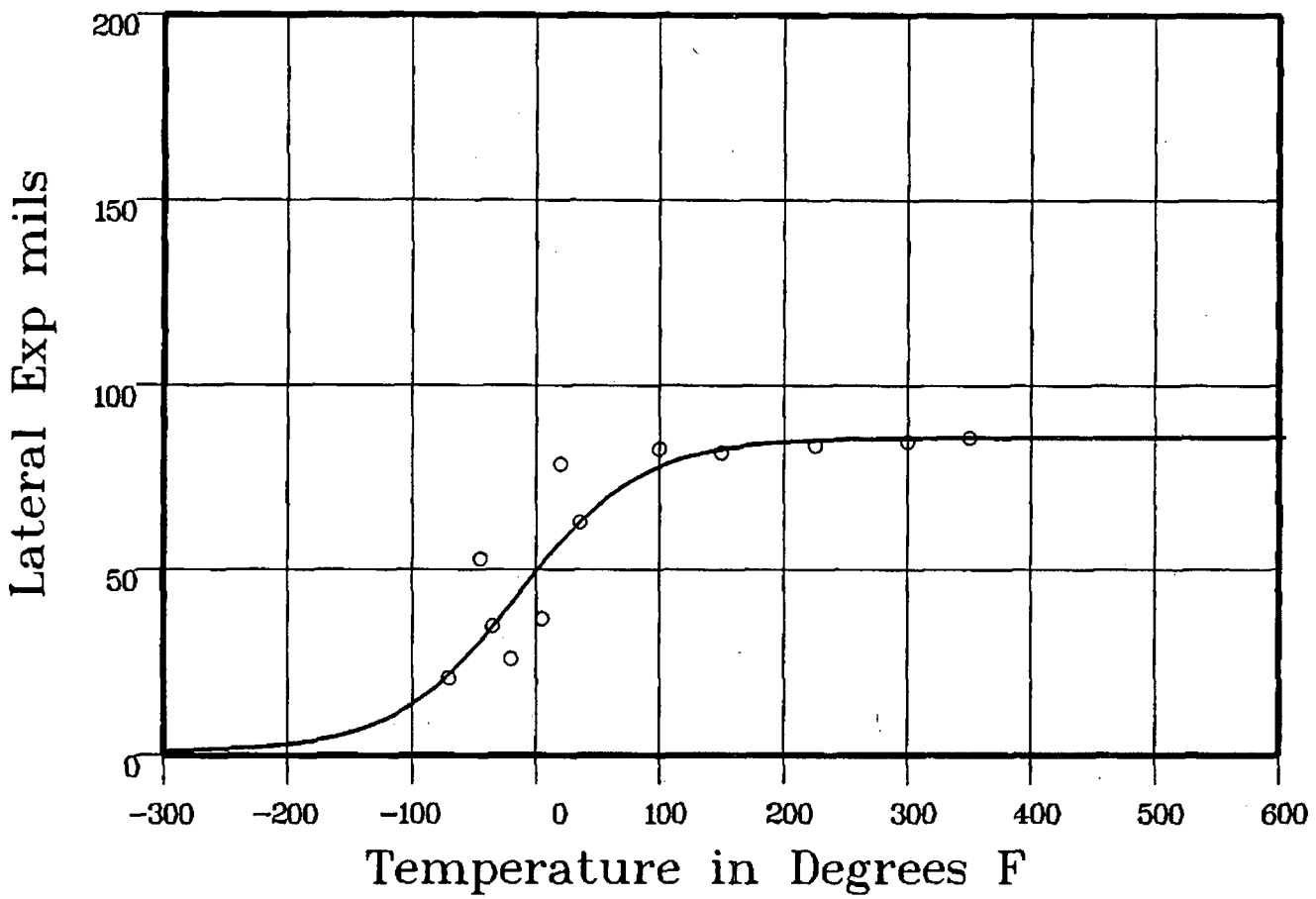
A = 43.54	B = 42.54	C = 99.7	T0 = -18.75

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

Upper Shelf L.E.: 86.08 Temperature at L.E. 35: -39 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 137 Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-70	21	23.41	-2.41
-45	53	32.59	20.4
-35	35	36.67	-1.67
-20	26	43.01	-17.01
5	37	53.49	-16.49
20	79	59.29	19.7
35	63	64.48	-1.48
100	83	78.89	4.1

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

CAPSULE 137

Page 2

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
150	82	83.29	-1.29
225	84	85.45	-1.45
300	85	85.94	-.94
350	86	86.03	-.03

SUM of RESIDUALS = 1.41

CAPSULE 137

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:29:47 on 08-03-2000

Page 1

Coefficients of Curve 2

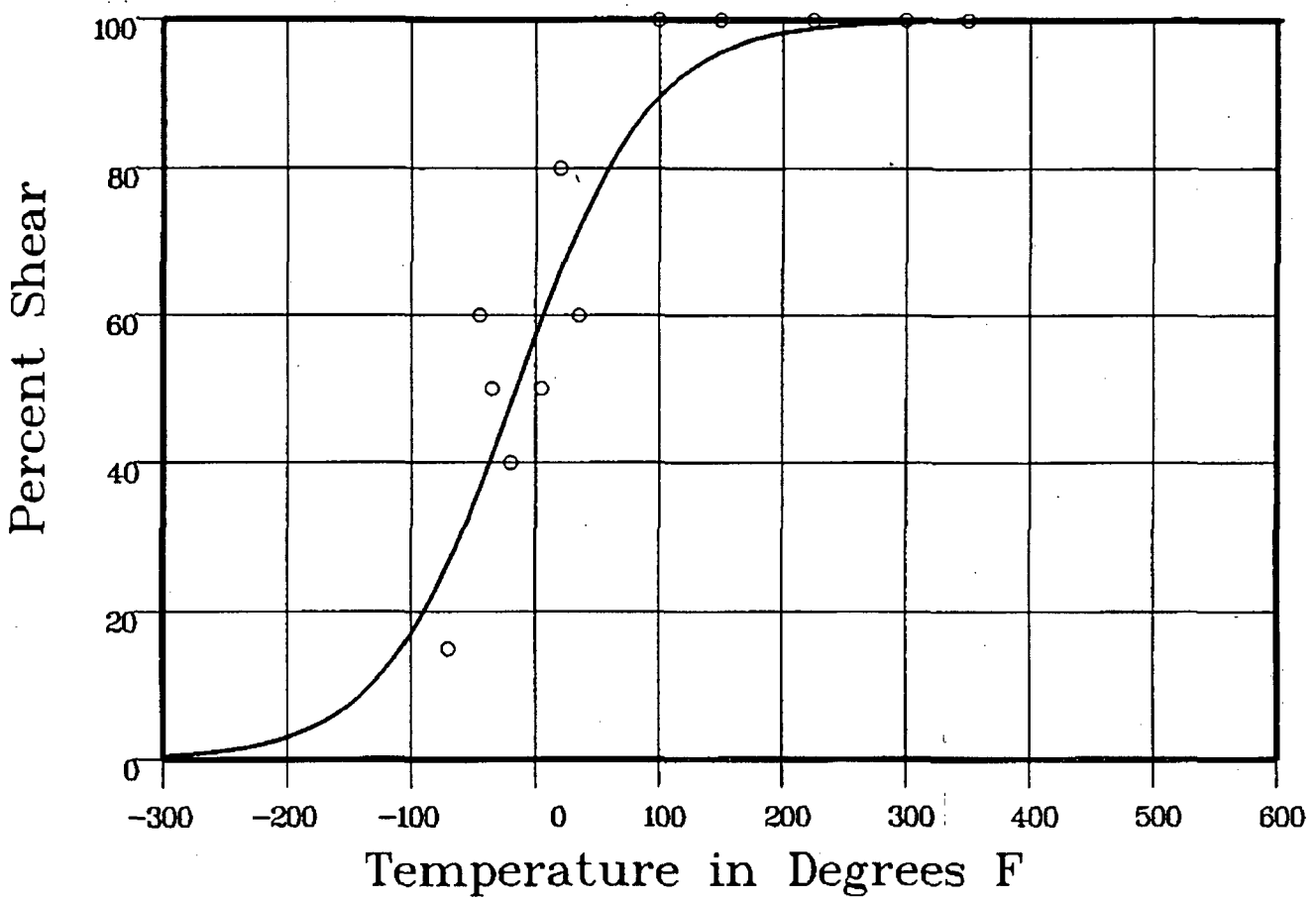
A = 50	B = 50	C = 107.14	T0 = -19.99

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

Temperature at 50% Shear: -19.9

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

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 137 Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-70	15	28.22	-13.22
-45	60	38.53	21.46
-35	50	43.04	6.95
-20	40	49.99	-9.99
5	50	61.45	-11.45
20	80	67.84	12.15
35	60	73.62	-13.62
100	100	90.37	9.62

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

CAPSULE 137

Page 2

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
150	100	95.98	4.01
225	100	98.97	1.02
300	100	99.74	.25
350	100	99.89	.1

SUM of RESIDUALS = 7.29

CAPSULE 38

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:48:11 on 08-03-2000

Page 1

Coefficients of Curve 3

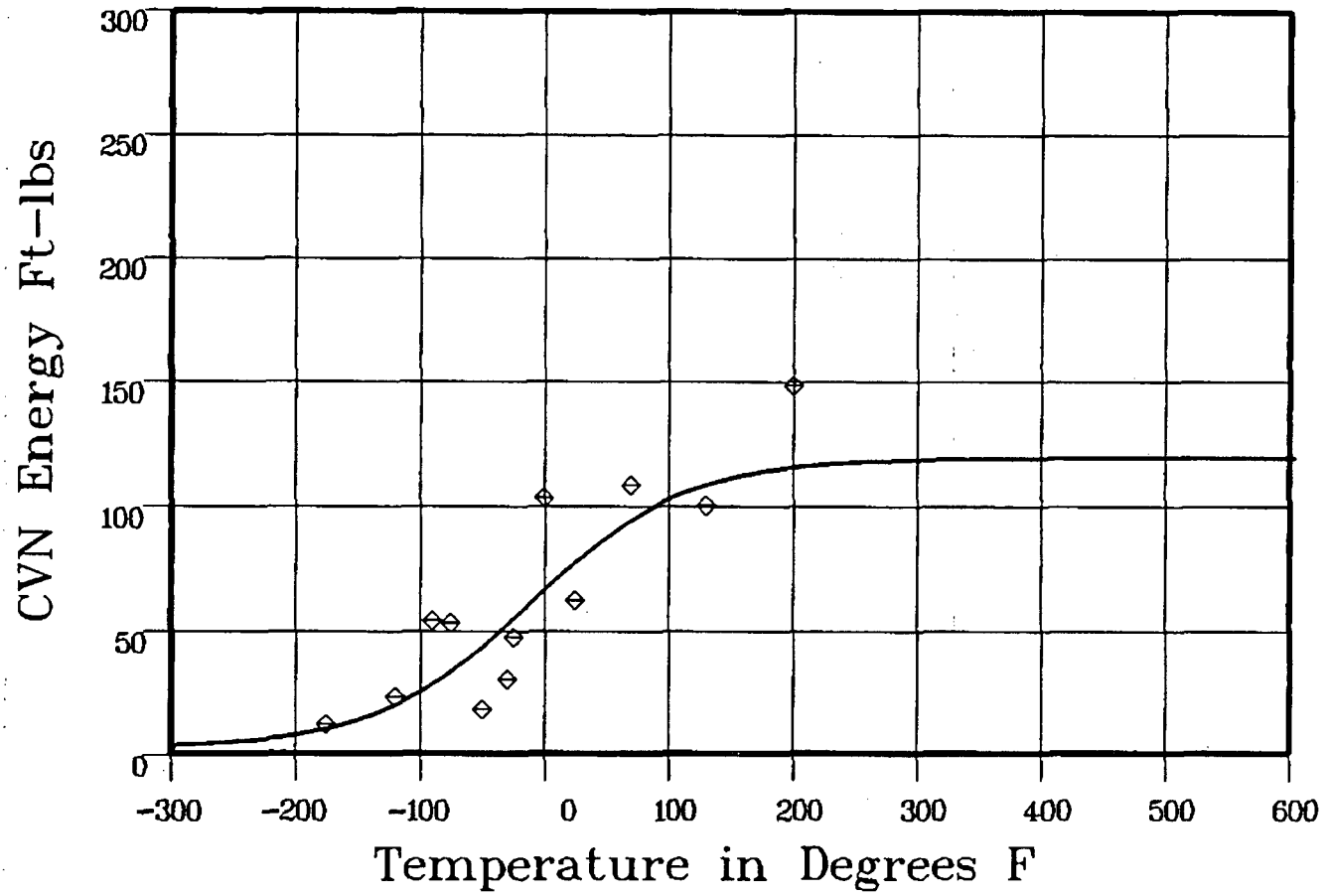
A = 60.59	B = 58.4	C = 125	T0 = -17.07

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

Upper Shelf Energy: 119 Fixed Temp. at 30 ft-lbs: -89.7 Temp. at 50 ft-lbs: -40 Lower Shelf Energy: 2.19 Fixed

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

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: 38 Material: HEAT AFF'D ZONE Ori: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-175	12	10.84	1.15
-120	23	21.06	1.93
-90	54	29.93	24.06
-75	53	35.32	17.67
-50	18	45.56	-27.56
-30	30	54.58	-24.58
-25	47	56.9	-9.9
0	103	68.52	34.47

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

CAPSULE 38

Page 2

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
25	62	79.54	-17.54
70	108	95.76	12.23
130	100	108.85	-8.85
200	148	115.48	32.51

SUM of RESIDUALS = 35.6

CAPSULE 38

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:21:56 on 08-03-2000

Page 1

Coefficients of Curve 3

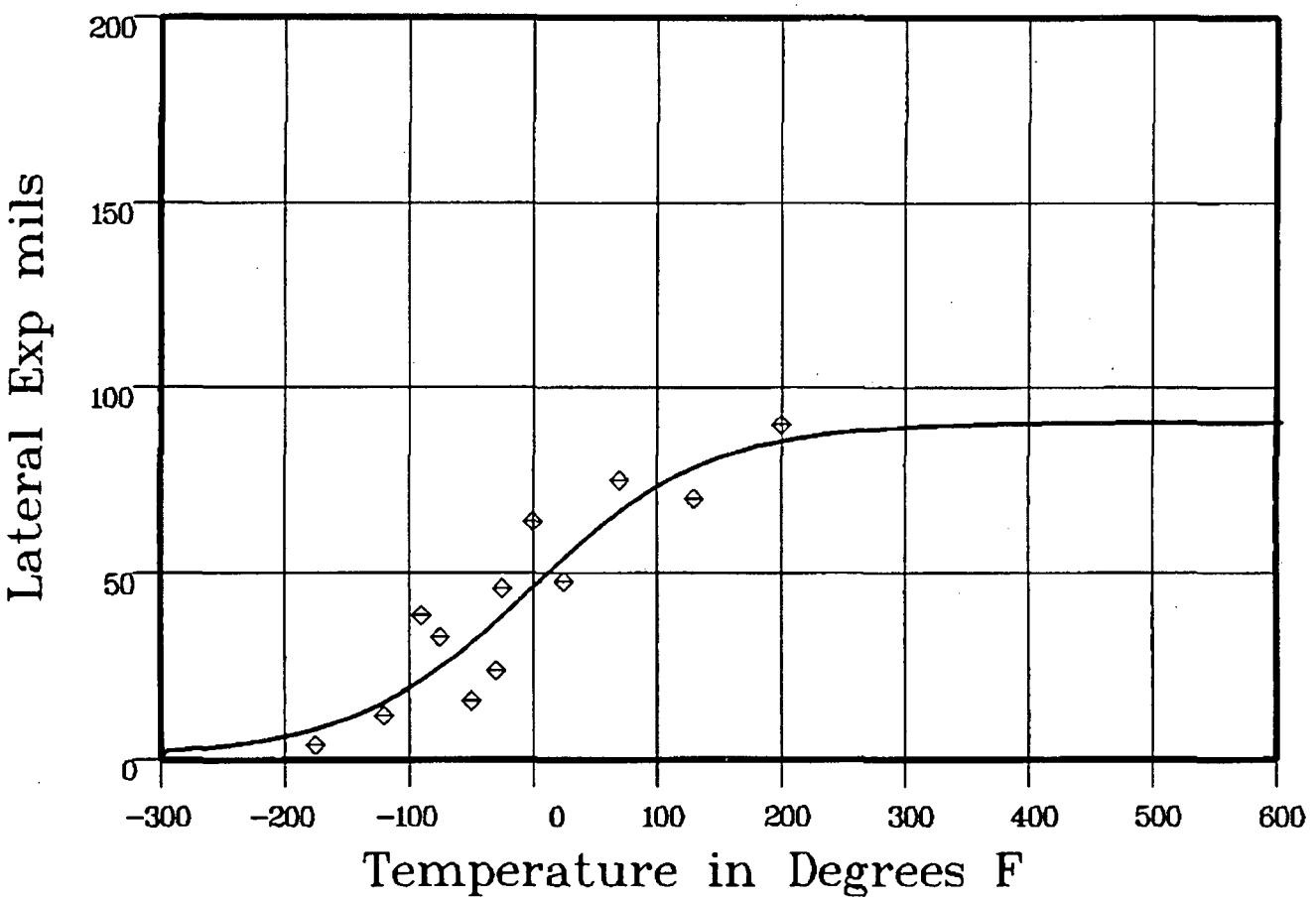
A = 45.75	B = 44.75	C = 143.69	T0 = -7.5

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

Upper Shelf L.E: 90.51 Temperature at L.E. 35: -42.7 Lower Shelf L.E: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 38 Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-175	4	8.92	-4.92
-120	12	16.46	-4.46
-90	39	22.55	16.44
-75	33	26.15	6.84
-50	16	32.89	-16.89
-30	24	38.8	-14.8
-25	46	40.33	5.66
0	64	48.08	15.91

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

CAPSULE 38

Page 2

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
25	48	55.7	-7.7
70	75	67.79	7.2
130	70	79	-9
200	90	85.78	4.21

SUM of RESIDUALS = -1.51

CAPSULE 38

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:29:47 on 08-03-2000

Page 1

Coefficients of Curve 3

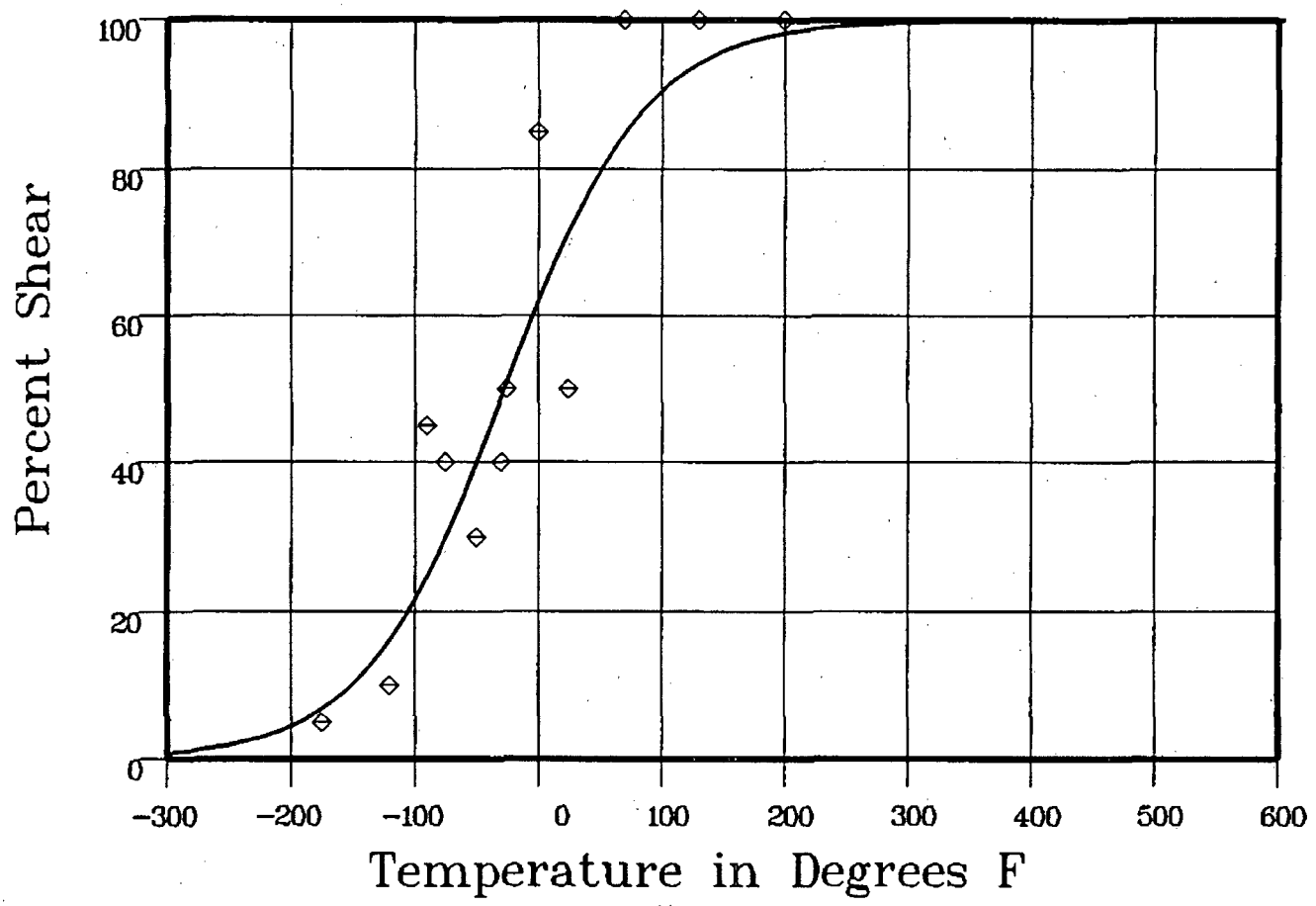
A = 50	B = 50	C = 112.84	T0 = -31.87

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

Temperature at 50% Shear: -31.8

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 38 Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-175	5	7.33	-2.33
-120	10	17.33	-7.33
-90	45	26.3	18.69
-75	40	31.77	8.22
-50	30	42.03	-12.03
-30	40	50.83	-10.83
-25	50	53.04	-3.04
0	85	63.75	21.24

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

CAPSULE 38

Page 2

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25	50	73.26	-23.26
70	100	85.88	14.11
130	100	94.62	5.37
200	100	98.38	1.61

SUM of RESIDUALS = 10.42

UNIRRADIATED STANDARD REFERENCE MATERIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:46:27 on 08-04-2000

Page 1

Coefficients of Curve 1

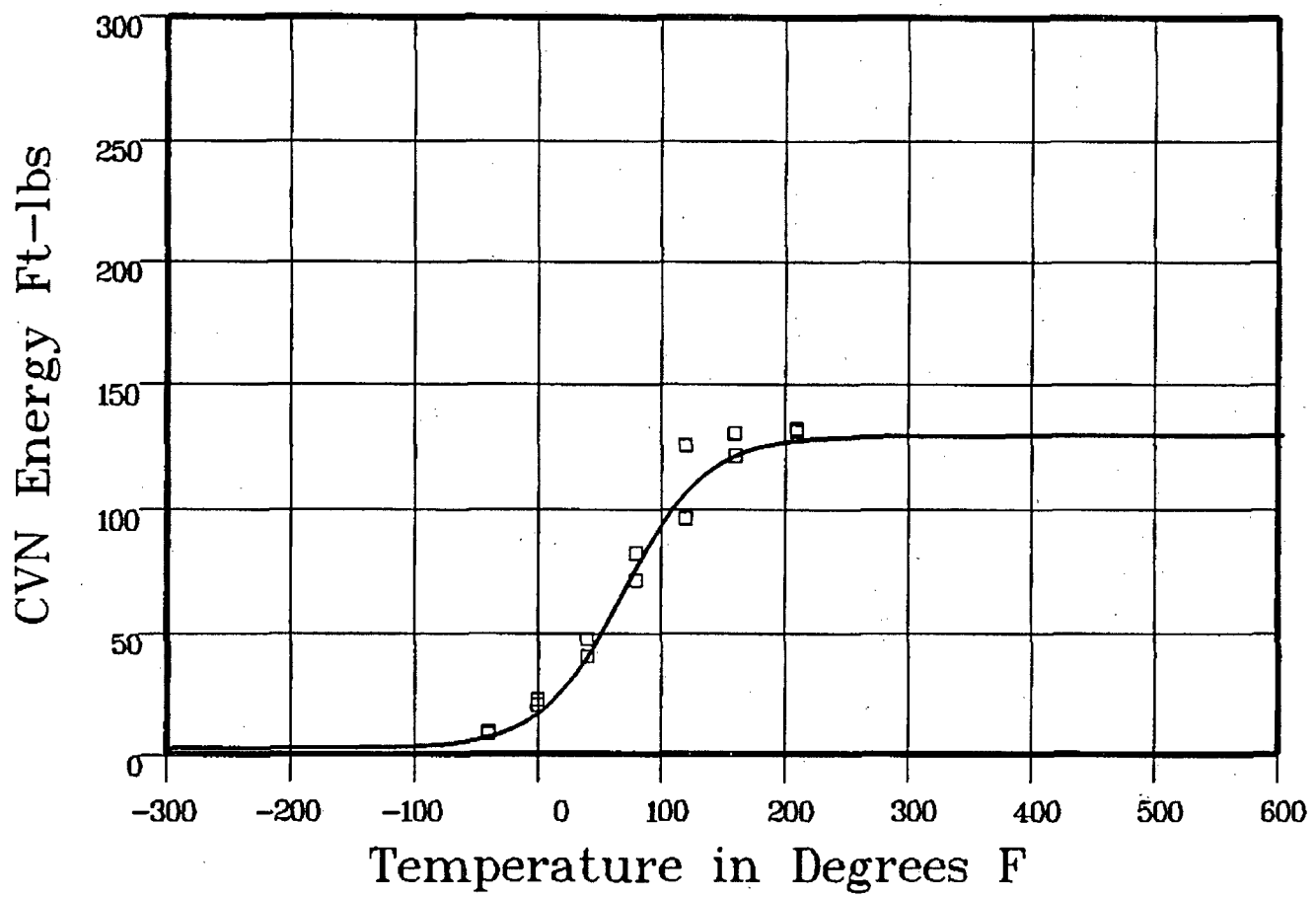
A = 65.59	B = 63.4	C = 66.96	T0 = 64.43

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

Upper Shelf Energy: 129 Fixed Temp. at 30 ft-lbs: 21.9 Temp. at 50 ft-lbs: 47.6 Lower Shelf Energy: 2.19 Fixed

Material: SRM SA533B1 Heat Number: Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: UNIRR Material: SRM SA533B1 Ori.: LT Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-40	9	7.56	1.43
-40	8	7.56	.43
0	20	18.35	1.64
0	22	18.35	3.64
40	47	43.44	3.55
40	40	43.44	-3.44
80	82	80.07	1.92
80	71	80.07	-9.07
120	125	108.73	16.26

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

UNIRRADIATED STANDARD REFERENCE MATERIAL

Material: SRM SA533B1 Heat Number: Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
120	96	108.73	-12.73
160	121	122.09	-1.09
160	130	122.09	7.9
210	131	127.38	3.61
210	132	127.38	4.61

SUM of RESIDUALS = 18.71

UNIRRADIATED STANDARD REFERENCE MATERIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:49:12 on 08-04-2000

Page 1

Coefficients of Curve 1

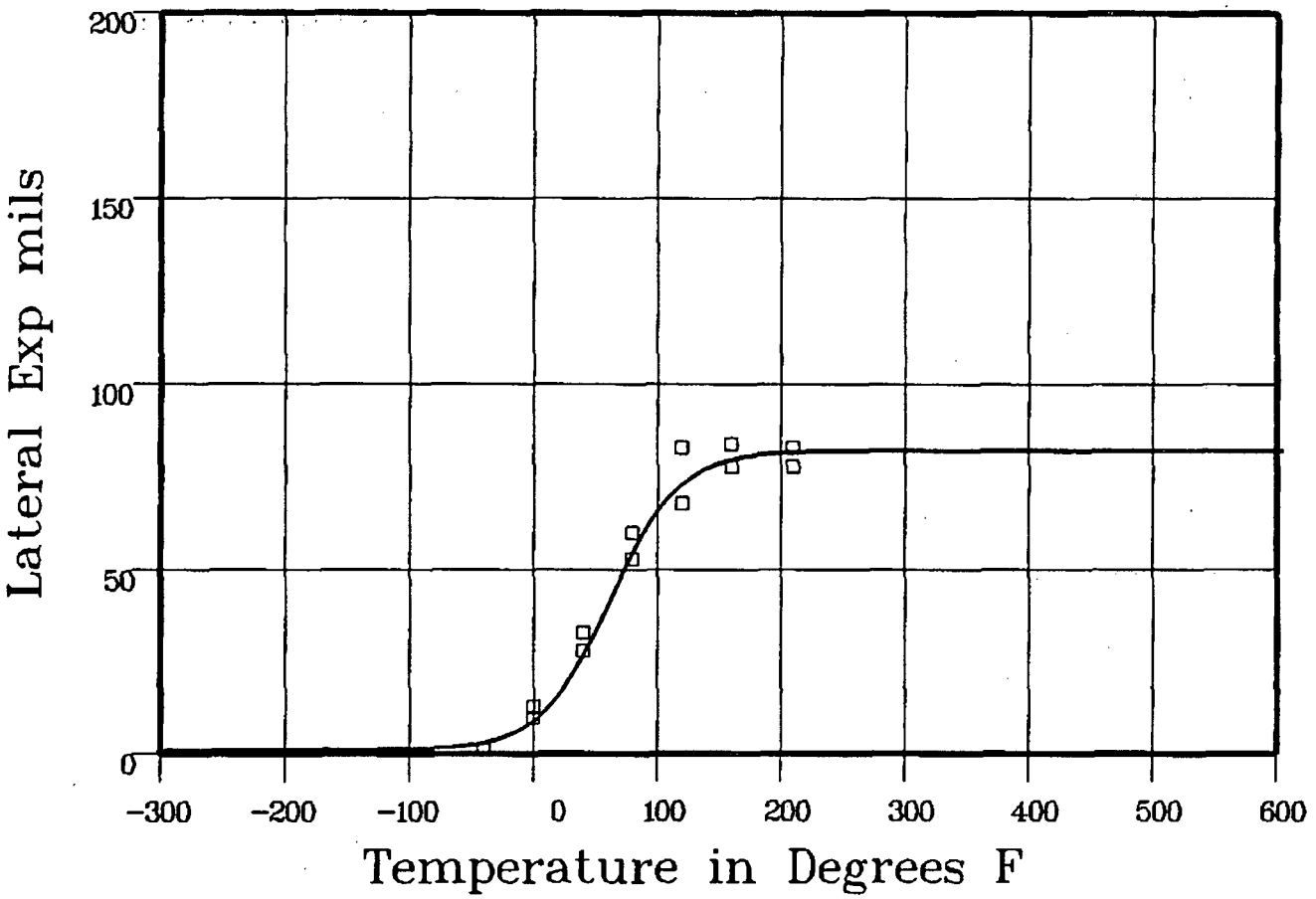
A = 41.63	B = 40.63	C = 56.01	T0 = 56.71

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

Upper Shelf L.E: 82.27 Temperature at L.E. 35: 47.4 Lower Shelf L.E: 1 Fixed

Material: SRM SA533B1 Heat Number: Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: UNIRR Material: SRM SA533B1 Ori.: LT Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-40	1	3.49	-2.49
-40	1	3.49	-2.49
0	10	10.47	-.47
0	13	10.47	2.52
40	33	29.85	3.14
40	28	29.85	-1.85
80	60	57.61	2.38
80	53	57.61	-4.61
120	83	74.58	8.41

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

UNIRRADIATED STANDARD REFERENCE MATERIAL

Material: SRM SA533B1 Heat Number: Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
120	68	74.58	-6.58
160	78	80.28	-2.28
160	84	80.28	3.71
210	83	81.93	1.06
210	78	81.93	-3.93

SUM of RESIDUALS = -3.48

UNIRRADIATED STANDARD REFERENCE MATERIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:51:56 on 08-04-2000

Page 1

Coefficients of Curve 1

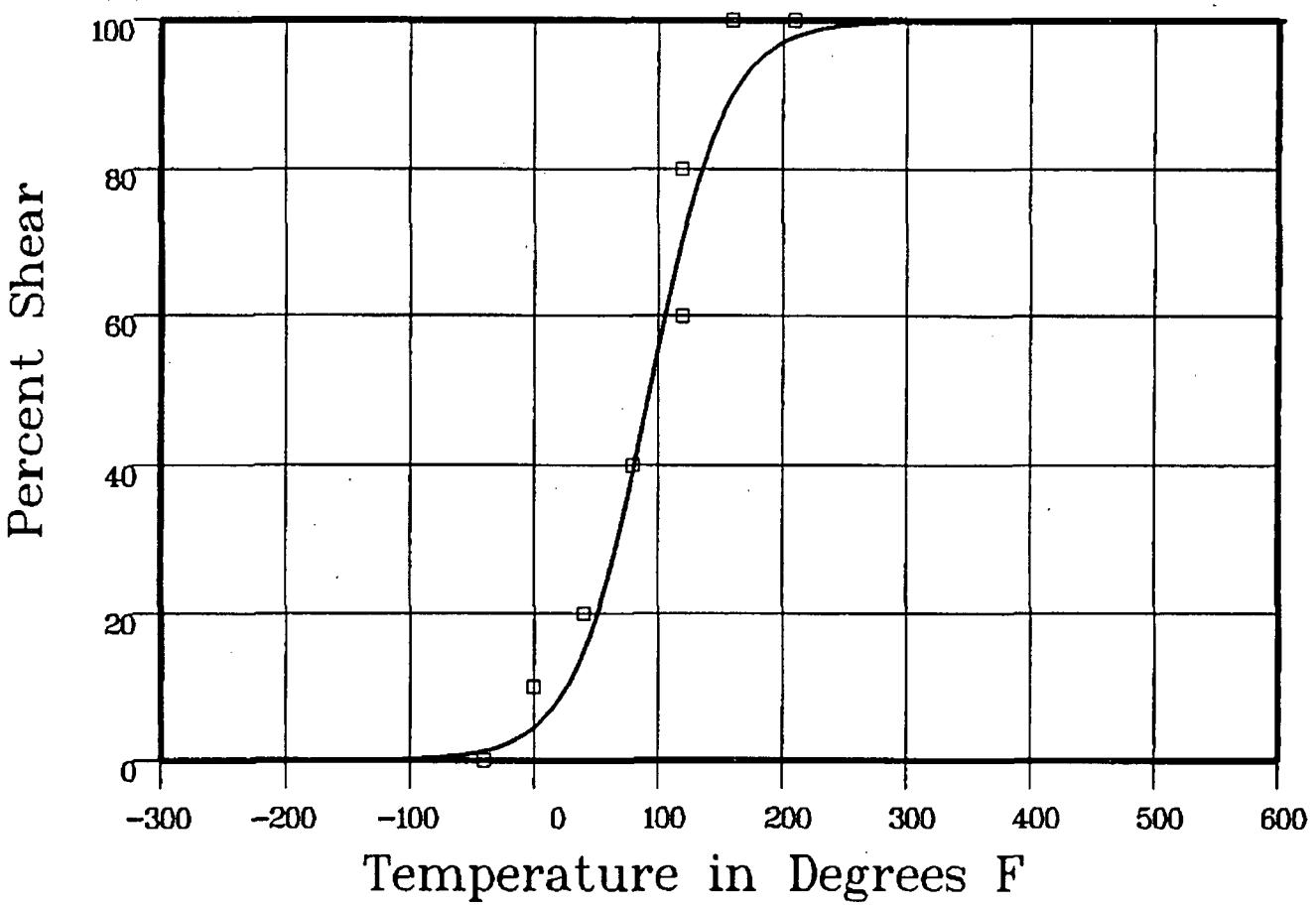
A = 50	B = 50	C = 61.02	T0 = 88.76

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

Temperature at 50% Shear: 88.7

Material: SRM SA533B1 Heat Number: Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: UNIRR Material: SRM SA533B1 Ori.: LT Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40	0	1.44	-1.44
-40	0	1.44	-1.44
0	10	5.16	4.83
0	10	5.16	4.83
40	20	16.82	3.17
40	20	16.82	3.17
80	40	42.86	-2.86
80	40	42.86	-2.86
120	80	73.56	6.43

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

UNIRRADIATED STANDARD REFERENCE MATERIAL

Material: SRM SA533B1 Heat Number: Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
120	60	73.56	-13.56
160	100	91.16	8.83
160	100	91.16	8.83
210	100	98.15	1.84
210	100	98.15	1.84

SUM of RESIDUALS = 21.61

CAPSULE 137 STANDARD REFERENCE MATERIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:46:27 on 08-04-2000

Page 1

Coefficients of Curve 2

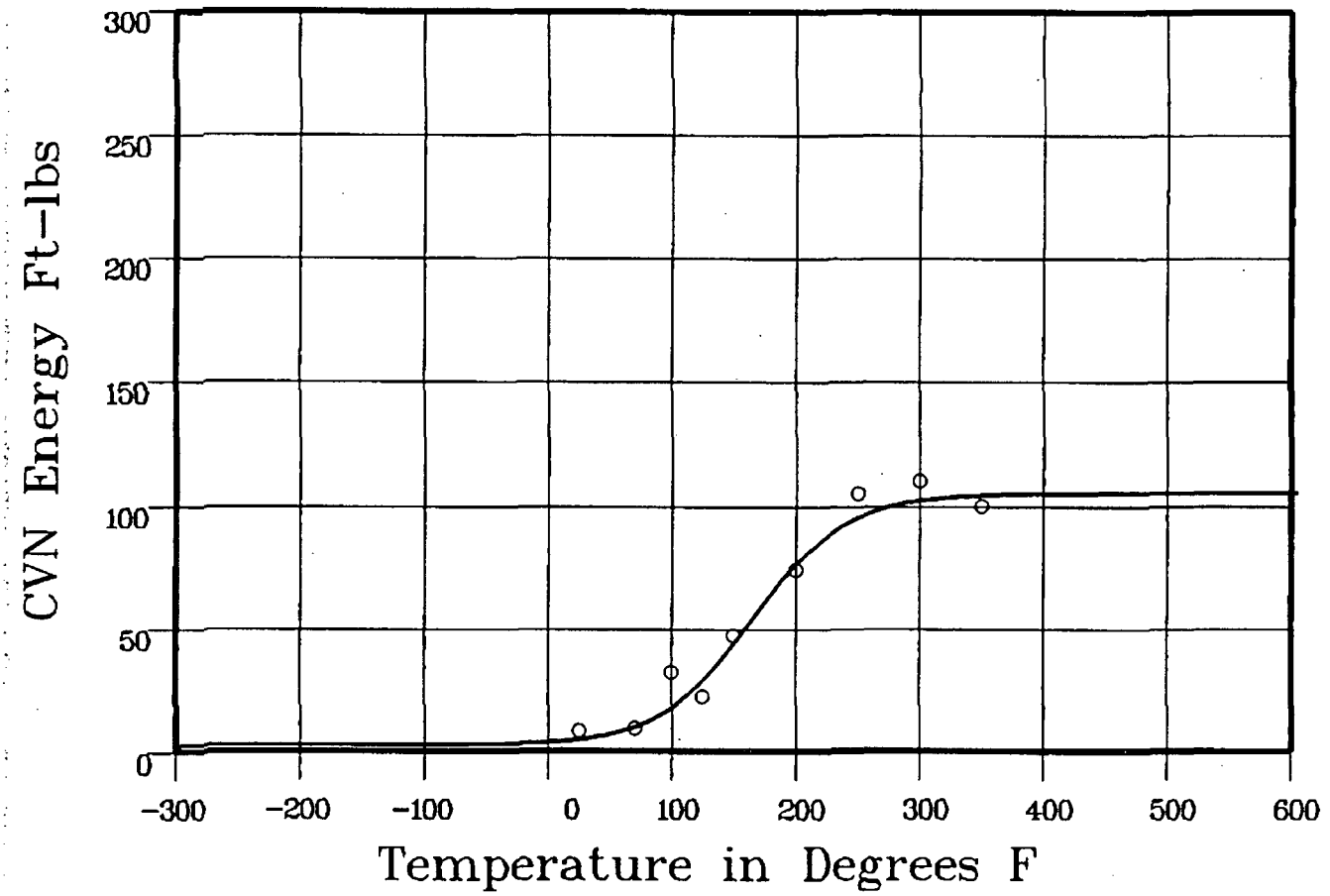
A = 53.59	B = 51.4	C = 75.06	T0 = 160.54

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

Upper Shelf Energy: 105 Fixed Temp. at 30 ft-lbs: 123.2 Temp. at 50 ft-lbs: 155.2 Lower Shelf Energy: 2.19 Fixed

Material: SRM SA533B1 Heat Number: Orientation: LT

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 137 Material: SRM SA533B1 Ori.: LT Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
25	8	4.9	3.09
70	9	10.65	-1.65
100	32	19.27	12.72
125	22	30.92	-8.92
150	47	46.42	.57
200	74	78.37	-4.37
250	105	96.31	8.68
300	110	102.55	7.44

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

CAPSULE 137 STANDARD REFERENCE MATERIAL

Page 2

Material: SRM SA533B1 Heat Number: Orientation: LT

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
350	100	104.34	-4.34

SUM of RESIDUALS = 13.21

CAPSULE 137 STANDARD REFERENCE MATERIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:49:12 on 08-04-2000

Page 1

Coefficients of Curve 2

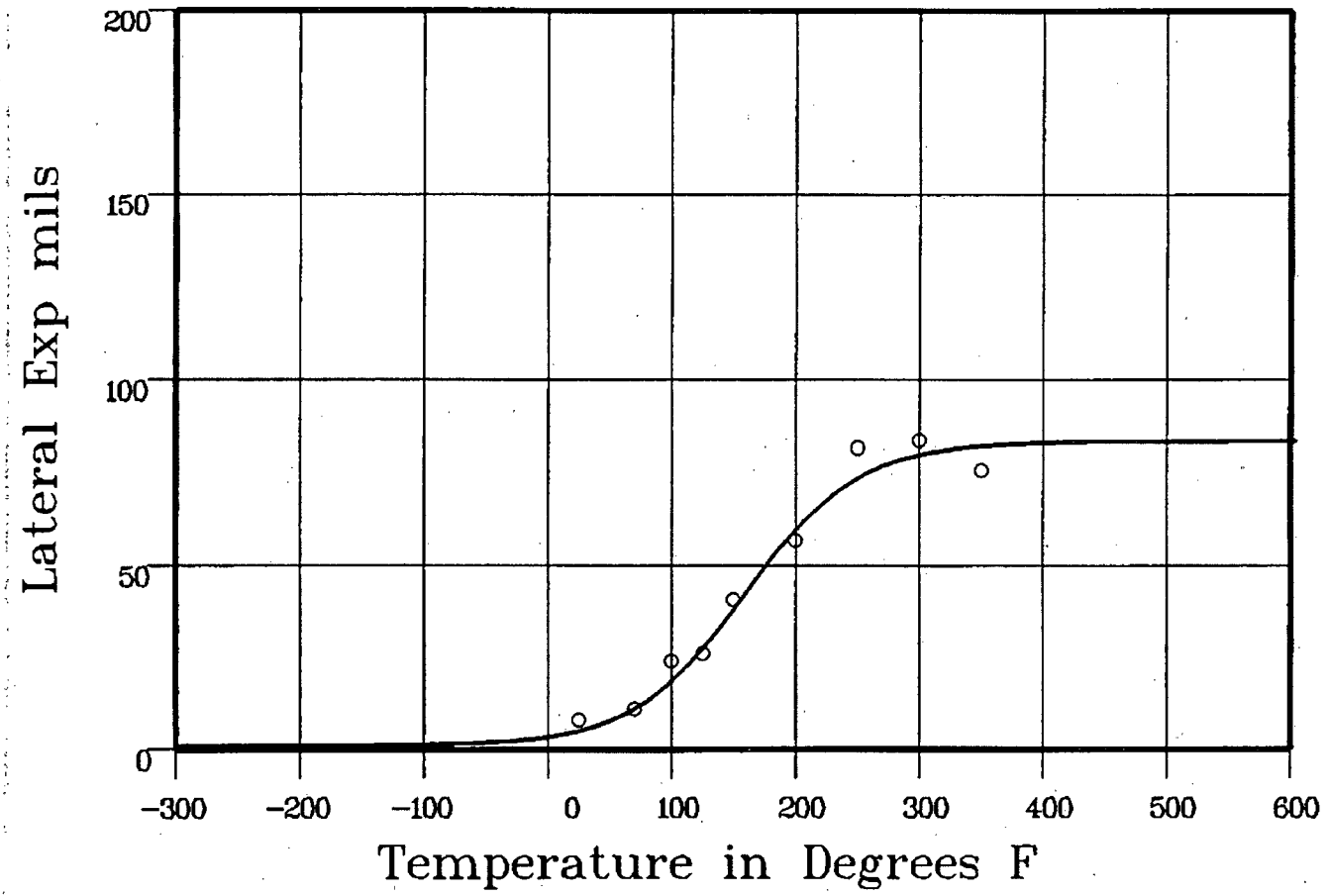
A = 42.32	B = 41.32	C = 90.15	T0 = 154.68

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

Upper Shelf L.E.: 83.64 Temperature at L.E. 35: 138.5 Lower Shelf L.E.: 1 Fixed

Material: SRM SA533B1 Heat Number: Orientation: LT

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: 137 Material: SRM SA533B1 Ori: LT Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
25	8	5.4	2.59
70	11	11.95	-.95
100	24	19.93	4.06
125	26	29.18	-3.18
150	41	40.17	.82
200	57	61.5	-4.5
250	82	74.74	7.25
300	84	80.47	3.52

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

CAPSULE 137 STANDARD REFERENCE MATERIAL

Page 2

Material: SRM SA533B1 Heat Number: Orientation: LT

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
350	76	82.57	-6.57

SUM of RESIDUALS = 3.04

CAPSULE 137 STANDARD REFERENCE MATERIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:51:56 on 08-04-2000

Page 1

Coefficients of Curve 2

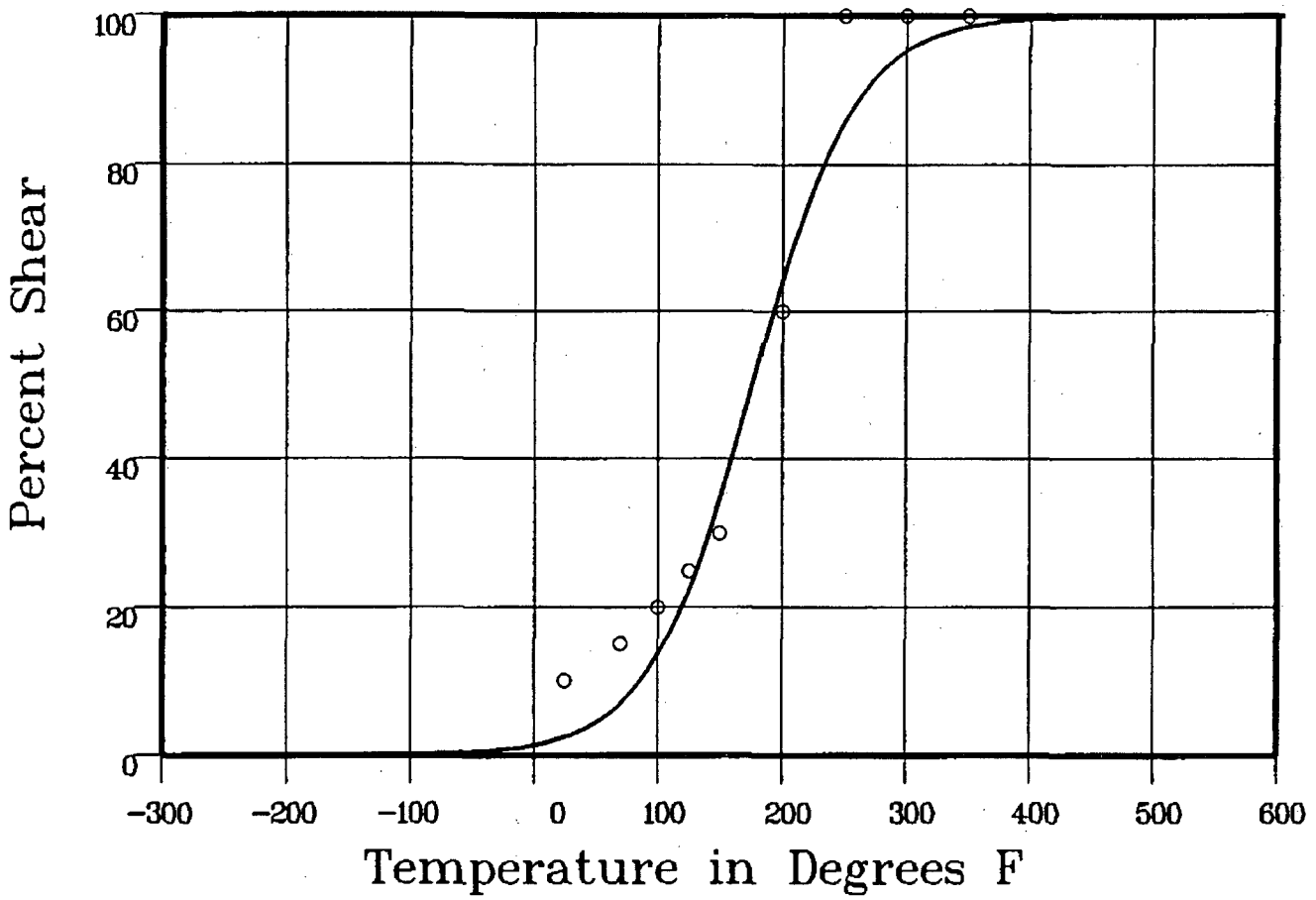
A = 50	B = 50	C = 82.17	T0 = 171.67

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

Temperature at 50% Shear: 171.6

Material: SRM SA533B1 Heat Number: Orientation: LT

Capsule: 137 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: 137 Material: SRM SA533B1 Ori: LT Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25	10	2.73	7.26
70	15	7.76	7.23
100	20	14.87	5.12
125	25	24.3	.69
150	30	37.1	-7.1
200	60	66.58	-6.58
250	100	87.05	12.94
300	100	95.78	4.21

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

CAPSULE 137 STANDARD REFERENCE MATERIAL

Material: SRM SA533B1 Heat Number: Orientation: LT

Capsule: 137 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
350	100	98.71	1.28

SUM of RESIDUALS = 25.07

CAPSULE 38 STANDARD REFERENCE MATERIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:46:27 on 08-04-2000

Page 1

Coefficients of Curve 3

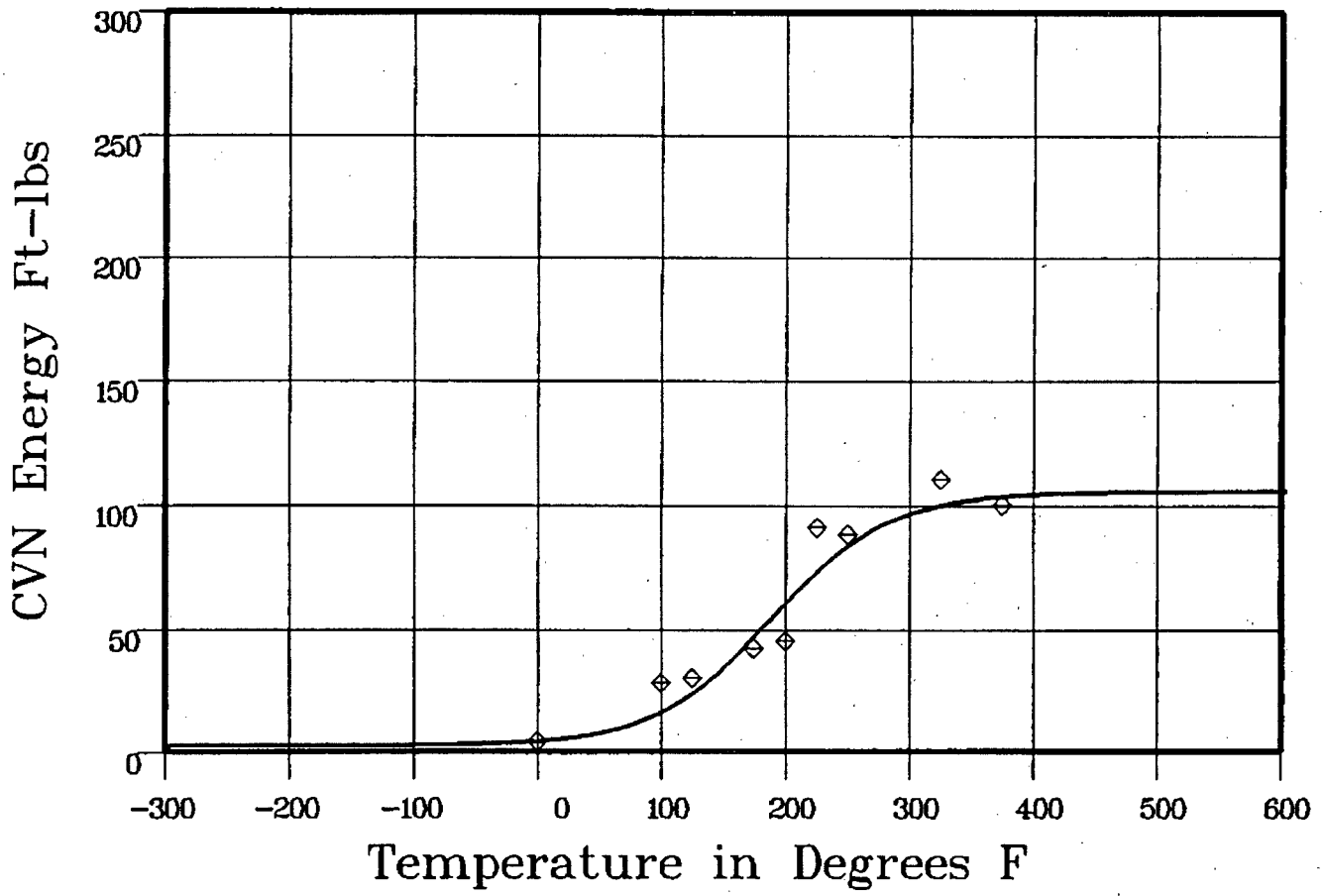
A = 53.59	B = 51.4	C = 94.01	T0 = 182.81

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

Upper Shelf Energy: 105 Fixed Temp. at 30 ft-lbs: 136.1 Temp. at 50 ft-lbs: 176.2 Lower Shelf Energy: 2.19 Fixed

Material: SRM SA533B1 Heat Number: Orientation:

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: 38 Material: SRM SA533B1 Ori: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	4	4.26	-.26
100	28	17.26	10.73
125	30	25.45	4.54
175	42	49.33	-7.33
200	45	62.89	-17.89
225	91	75.23	15.76
250	88	85.13	2.86
325	110	100.23	9.76

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

CAPSULE 38 STANDARD REFERENCE MATERIAL

Material: SRM SA533B1 Heat Number: Orientation:

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
375	100	103.3	-3.3

SUM of RESIDUALS = 14.87

CAPSULE 38 STANDARD REFERENCE MATERIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:49:12 on 08-04-2000

Page 1

Coefficients of Curve 3

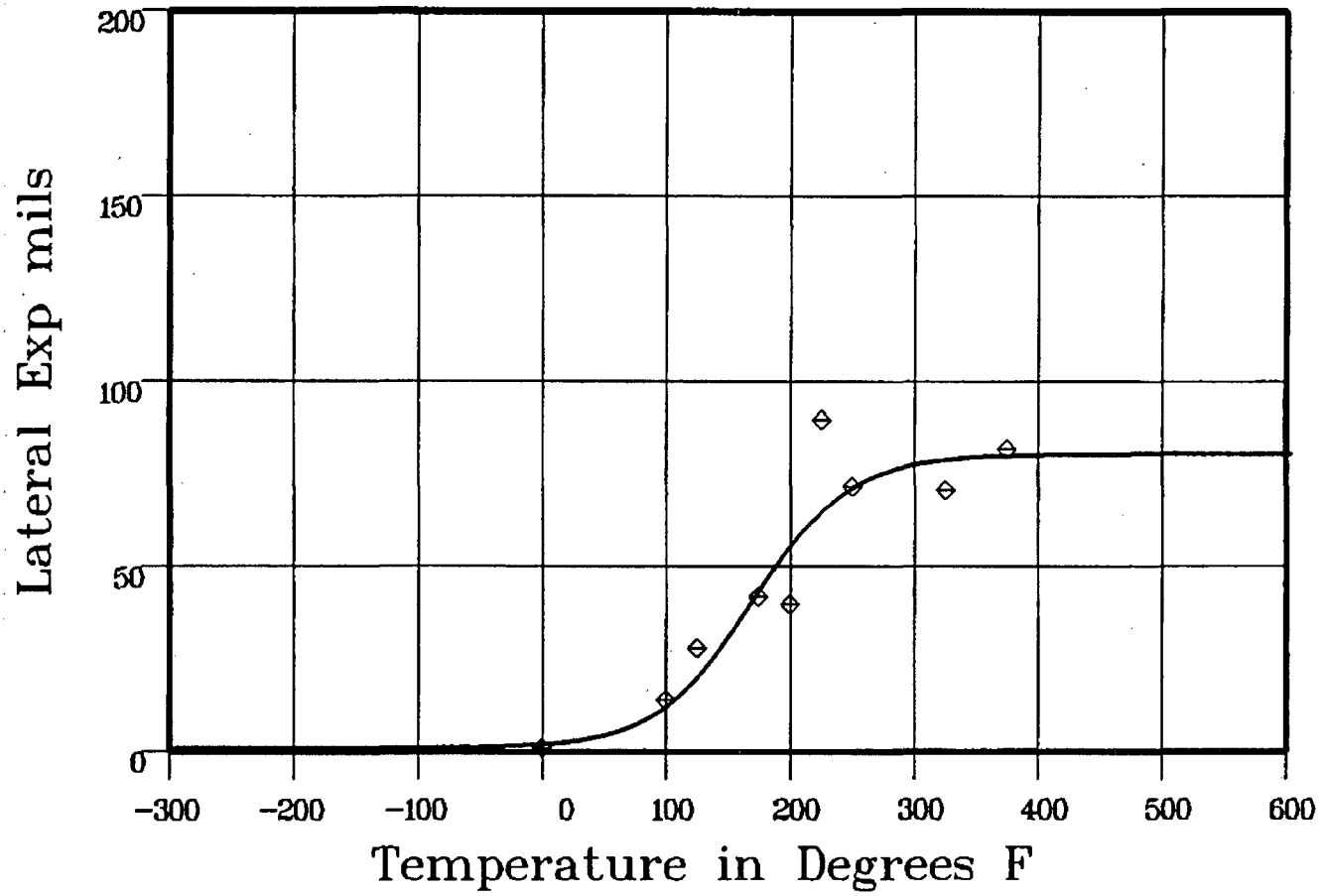
A = 40.81	B = 39.81	C = 77.47	T0 = 165.23

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

Upper Shelf L.E.: 80.62 Temperature at L.E. 35: 153.8 Lower Shelf L.E.: 1 Fixed

Material: SRM SA533B1 Heat Number: Orientation:

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap.: 38 Material: SRM SA533B1 Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	1	2.1	-1.1
100	14	13.46	.53
125	28	21.81	6.18
175	42	45.8	-3.8
200	40	57.56	-17.56
225	90	66.59	23.4
250	72	72.59	-.59
325	71	79.35	-8.35

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

CAPSULE 38 STANDARD REFERENCE MATERIAL

Page 2

Material: SRM SA533B1 Heat Number: Orientation:

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
375	82	80.26	1.73

SUM of RESIDUALS = .43

CAPSULE 38 STANDARD REFERENCE MATERIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:51:56 on 08-04-2000

Page 1

Coefficients of Curve 3

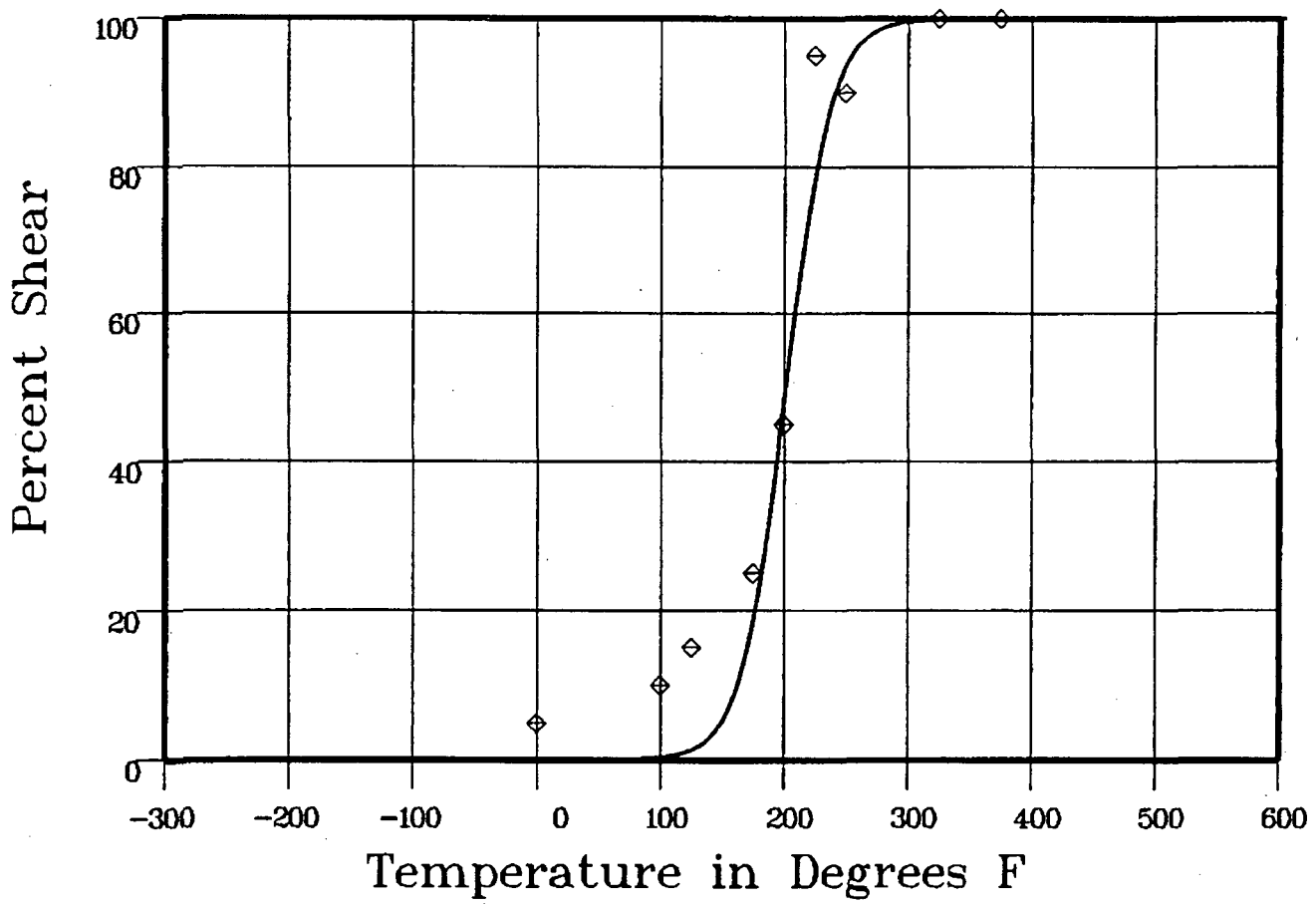
A = 50	B = 50	C = 35.72	T0 = 196.95

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

Temperature at 50% Shear: 196.9

Material: SRM SA533B1 Heat Number: Orientation:

Capsule: 38 Total Fluence:



Data Set(s) Plotted

Plant: PV1 Cap: 38 Material: SRM SA533B1 Ori: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	5	0	4.99
100	10	.43	9.56
125	15	1.74	13.25
175	25	22.62	2.37
200	45	54.24	-9.24
225	95	82.77	12.22
250	90	95.11	-5.11
325	100	99.92	.07

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

CAPSULE 38 STANDARD REFERENCE MATERIAL

Material: SRM SA533B1 Heat Number: Orientation:

Capsule: 38 Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
375	100	99.99	0

SUM of RESIDUALS = 28.12