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Analysis of Capsule Y from the Tennessee Valley Authority Sequoyah Unit 2 Reactor Vessel Radiation Surveillance Program

Westinghouse Electric Company LLC

WCAP-15320

Analysis of Capsule Y from the Tennessee Valley Authority Sequoyah Unit 2 Reactor Vessel Radiation Surveillance Program

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PREFACE

This report has been technically reviewed and verified by:

Reviewer:

Sections 1 through 5, 7, 8, Appendices A, B and C	Ed Terek	
Section 6	J.D. Perock	

EXECUTIVE SUMMARY

The purpose of this report is to document the results of the testing of surveillance capsule Y from the Sequoyah Unit 2 reactor vessel. Capsule Y was removed at 10.54 EFPY and post irradiation mechanical tests of the Charpy V-notch and tensile specimens was performed, along with a fluence evaluation. The peak clad base/metal vessel fluence after 10.54 EFPY of plant operation was 6.37 x 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. Based on the examination results, all reactor vessel beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are expected to maintain an upper shelf energy greater than 50 ft-lb throughout the life of the vessel (32 EFPY) as required by 10CFR50, Appendix G.. No changes to the reactor vessel surveillance capsule removal schedule are required to support 32 EFPY of operation.

1 SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance capsule Y, the fourth capsule to be removed from the Sequoyah Unit 2 reactor pressure vessel, led to the following conclusions:

- The Charpy V-notch data presented in WCAP-8513[1], WCAP-10509[2], SwRI Report 17-8851[3], and WCAP-13545[4] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1. which is a hyperbolic tangent curve-fitting program. Appendix B presents a comparison of the Charpy V-Notch test results for each capsule based on hand fit vs. hyperbolic tangent fit. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

- Fluence projections for future operation were based on the assumption that the exposure rates averaged over Cycle 5 through 9 (low-leakage loading pattern) would continue to be applicable throughout plant life.

- The capsule received an average fast neutron fluence (E> 1.0 MeV) of 2.14 x 10^{19} n/cm^2 after 10.54 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel intermediate shell forging 05 Charpy specimens, oriented with the longitudinal axis of the specimen normal to the major working direction (tangential orientation), to 2.14 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 134.12°F and a 50 ft-lb transition temperature increase of 135.35°F. This results in an irradiated 30 ft-lb transition temperature of 71.42°F and an irradiated 50 ft-lb transition temperature of 110.97°F for the tangential oriented specimens.

- Irradiation of the reactor vessel intermediate shell forging 05 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction of the forging (axial orientation), to 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 89.21°F and a 50 ft-lb transition temperature increase of 130.97°F. This results in an irradiated 30 ft-lb transition temperature of 77.13°F and an irradiated 50 ft-lb transition temperature of 172.87°F for axial oriented specimens.

- Irradiation of the weld metal Charpy specimens to 2.14 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 86.91°F and a 50 ft-lb transition temperature increase of 93.45°F. This results in an irradiated 30 ft-lb transition temperature of -1.18°F and an irradiated 50 ft-lb transition temperature of 52.32°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 50.32°F and a 50 ft-lb transition temperature increase of 71.76°F. This results in an irradiated 30 ft-lb transition temperature of -20.75°F and an irradiated 50 ft-lb transition temperature of 41.07°F.

- The average upper shelf energy of the Intermediate shell forging 05 (tangential orientation) resulted in an average energy decrease of 30 ft-lb after irradiation to 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV). This results in an irradiated average upper shelf energy of 104 ft-lb for the tangentially oriented specimens.

- The average upper shelf energy of the Intermediate shell forging 05 (Axial orientation) resulted in an average energy decrease of 19 ft-lb after irradiation to 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 69 ft-lb for the axially oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted an average energy decrease of 3 ft-lb after irradiation to 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 109 ft-lb for the weld metal specimens.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in an average energy decrease of 47 ft-lb after irradiation to 2.14 x 10^{19} n/cm^2 (E> 1.0MeV). This results in an irradiated average upper shelf energy of 75 ft-lb for the weld HAZ metal.

- A comparison of the Sequoyah Unit 2 reactor vessel beltline material test results with the Regulatory Guide 1.99, Revision 2[5] predictions led to the following conclusions:

  — The measured 30 ft-lb shift in transition temperature of the tangential oriented surveillance forging material contained in capsule Y is greater than the Regulatory Guide 1.99, Revision 2, prediction. However, the shift value is less than the two-sigma allowance required by Regulatory Guide 1.99, Revision 2.

  — The measured 30 ft-lb shift in transition temperature of the axial oriented surveillance forging material contained in capsule Y is less than the Regulatory Guide 1.99, Revision 2, prediction.

  — The measured 30 ft-lb shift in transition temperature value of the weld material contained in capsule Y is greater than the Regulatory Guide 1.99, Revision 2, prediction. However, the shift value is less than the two-sigma allowance required by Regulatory Guide 1.99, Revision 2.

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

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

  Calculated: Vessel inner radius* = 1.82×10^{19} n/cm^2
  Vessel 1/4 thickness = 1.10×10^{19} n/cm^2
  Vessel 3/4 thickness = 3.98×10^{18} n/cm^2

  Best Estimate: Vessel inner radius* = 1.70×10^{19} n/cm^2
  Vessel 1/4 thickness = 1.02×10^{19} n/cm^2
  Vessel 3/4 thickness = 3.71×10^{18} n/cm^2

  *Clad/base metal interface

- The evaluation of the Sequoyah Unit 2 surveillance program presented in Appendix D of this report indicates that the surveillance results for Intermediate shell forging 05 and the weld material do not meet the nominal credibility requirements of Regulatory Guide 1.99, Revision 2.

- All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are expected to maintain an upper shelf energy greater than 50 ft-lb throughout the life of the vessel (32 EFPY) as required by 10CFR50, Appendix G[6].

- Section 7 contains a recommended surveillance capsule removal schedule based on E185-82. The recommended removal schedule is valid for up to 32 EFPY of operation

2 INTRODUCTION

This report presents the results of the examination of Capsule Y, the fourth capsule removed from the reactor in the continuing surveillance program which monitors the effects of neutron irradiation on the Tennessee Valley Authority Sequoyah Unit 2 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the Sequoyah Unit 2 reactor pressure vessel materials was designed and recommended by the Westinghouse Electric Company. A description of the surveillance program and the preirradiation mechanical properties of the reactor vessel materials is presented in WCAP-8513, "Tennessee Valley Authority Sequoyah Unit No. 2 Reactor Vessel Radiation Surveillance Program[1]. The surveillance program was planned to cover the 40-year design life of the reactor pressure vessel and was based on ASTM E185-73, "Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels"[7]. Capsule Y was removed from the reactor after 10.54 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.

The Charpy V-notch data presented in WCAP-8513[1], WCAP-10509[2], SwRI Report 17-8851[3], and WCAP-13545[4] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1, which is a hyperbolic tangent curve-fitting program. Appendix B presents a comparison of the Charpy V-Notch test results for each capsule based on hand fit vs. hyperbolic tangent fit. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

This report summarizes the testing of and the post-irradiation data obtained from surveillance capsule Y removed from the Tennessee Valley Authority Sequoyah Unit 2 reactor vessel and discusses the analysis of the data.

3 BACKGROUND

The ability of the large steel pressure vessel containing the reactor core and its primary coolant to resist fracture constitutes an important factor in ensuring safety in the nuclear industry. The beltline region of the reactor pressure vessel is the most critical region of the vessel because it is subjected to significant fast neutron bombardment. The overall effects of fast neutron irradiation on the mechanical properties of low alloy, ferritic pressure vessel steels such as SA508 Class 2 forging (base material of the Sequoyah Unit 2 reactor pressure vessel beltline) are well documented in the literature. Generally, low alloy ferritic materials show an increase in hardness and tensile properties and a decrease in ductility and toughness during high-energy irradiation.

A method for ensuring the integrity of reactor pressure vessels has been presented in "Fracture Toughness Criteria for Protection Against Failure," Appendix G to Section XI of the ASME Boiler and Pressure Vessel Code[8]. 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[9]) or the temperature 60°F less than the 50 ft-lb (and 35-mil lateral expansion) temperature as determined from Charpy specimens oriented perpendicular (axial) to the major rolling direction of the forging. The RT_{NDT} of a given material is used to index that material to a reference stress intensity factor curve (K_{Ia} curve) which appears in Appendix G to the ASME Code[8]. The K_{Ia} curve is a lower bound of dynamic, crack arrest, and static fracture toughness results obtained from several heats of pressure vessel steel. When a given material is indexed to the K_{Ia} curve, allowable stress intensity factors can be obtained for this material as a function of temperature. Allowable operating limits can then be determined using these allowable stress intensity factors.

RT_{NDT} and, in turn, the operating limits of nuclear power plants can be adjusted to account for the effects of radiation on the reactor vessel material properties. The changes in mechanical properties of a given reactor pressure vessel steel, due to irradiation, can be monitored by a reactor surveillance program, such as the Sequoyah Unit 2 reactor vessel radiation surveillance program[1], in which a surveillance capsule is periodically removed from the operating nuclear reactor and the encapsulated specimens tested. The increase in the average Charpy V-notch 30 ft-lb temperature (ΔRT_{NDT}) due to irradiation is added to the initial RT_{NDT}, along with a margin (M) to cover uncertainties, to adjust the RT_{NDT} (ART) for radiation embrittlement. This ART (RT_{NDT} initial + M + ΔRT_{NDT}) is used to index the material to the K_{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

Eight surveillance capsules for monitoring the effects of neutron exposure on the Sequoyah Unit 2 reactor pressure vessel core region (beltline) materials were inserted in the reactor vessel prior to initial plant start-up. The eight capsules were positioned in the reactor vessel between the thermal shield and the vessel wall as shown in Figure 4-1. The vertical center of the capsules is opposite the vertical center of the core. The capsules contain specimens made from intermediate shell forging 05 (Heat No. 288757/981057) and weld metal fabricated with weld wire SMIT 89, Heat # 4278, which is identical to that used in the actual fabrication of the intermediate to lower shell circumferential weld.

Capsule Y was removed after 10.54 effective full power years (EFPY) of plant operation. This capsule contained Charpy V-notch, tensile, and WOL fracture mechanics specimens made from Intermediate shell forging 05 and manual arc weld metal identical to that used in the actual fabrication of the intermediate to lower shell circumferential weld. In addition, this capsule contained Charpy V-notch specimens from the weld Heat-Affected-Zone (HAZ) of Intermediate shell forging 05.

Test material obtained from Intermediate shell forging 05 (after the thermal heat treatment and forming of the forging) was taken at least one forging thickness from the quenched ends of the forging. All test specimens were machined from the ¼ and ¾ thickness locations of the forging after performing a simulated post-weld stress-relieving treatment on the test material. Specimens from weld metal and heat-affected-zone metal were machined from a stress-relieved weldment joining intermediate shell forging 05 and lower shell forging 04. All heat-affected-zone specimens were obtained from the weld heat-affected-zone of Intermediate shell forging 05.

Charpy V-notch impact specimens from Intermediate shell forging 05 were machined both in the tangential orientation (longitudinal axis of the specimen parallel to the major working direction) and axial orientation (longitudinal axis of the specimen perpendicular to the major working direction). The core region weld Charpy impact specimens were machined from the weldment such that the long dimension of each Charpy specimen was perpendicular to the weld direction. The notch of the weld metal Charpy specimens was machined such that the direction of crack propagation in the specimen was in the welding direction.

Tensile specimens from Intermediate shell forging 05 were machined in the axial orientation. Tensile specimens from the weld metal were oriented with the long dimension of the specimen perpendicular to the weld direction.

Wedge Opening Loading (WOL) test specimens from the weld metal were machined such that the direction of crack propagation in the specimen was in the welding direction. All specimens were fatigue precracked according to ASTM E399-70T.

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

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

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

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

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

Table 4-1 Chemical Composition (wt %) of the Sequoyah Unit 2 Reactor Vessel Surveillance Materials

Element	Weld Metal	Intermediate shell forging 05	
	Westinghouse Analysis	Westinghouse Analysis	Rotterdam Analysis
C	0.095	0.180	0.19
S	0.013	0.018	0.013
N	0.012	0.009	- -
Co	0.001	0.001	- -
Cu	0.130	0.130	- -
Si	0.410	0.270	0.220
Mo	0.530	0.640	0.570
Ni	0.110	0.740	0.780
Mn	1.500	0.720	0.700
Cr	0.085	0.330	0.340
V	0.002	0.022	<0.010
P	0.016	0.018	0.014
Sn	0.002	0.002	- -
Al	0.009	0.027	- -

Table 4-2 Heat Treatment of the Sequoyah Unit 2 Reactor Vessel Surveillance Material[1]			
Material	**Temperature (°F)**	**Time (hrs.)**	**Coolant**
Intermediate shell forging 05 Heat # 288757 / 981057	1675 ± 25	3 1/2	Water-quenched
	1225 ± 25	9	Furnace Cooled to 815°F
	1130 ± 25	20 1/2	Furnace Cooled
Weld Metal	1130 ± 25	14 3/4	Furnace Cooled

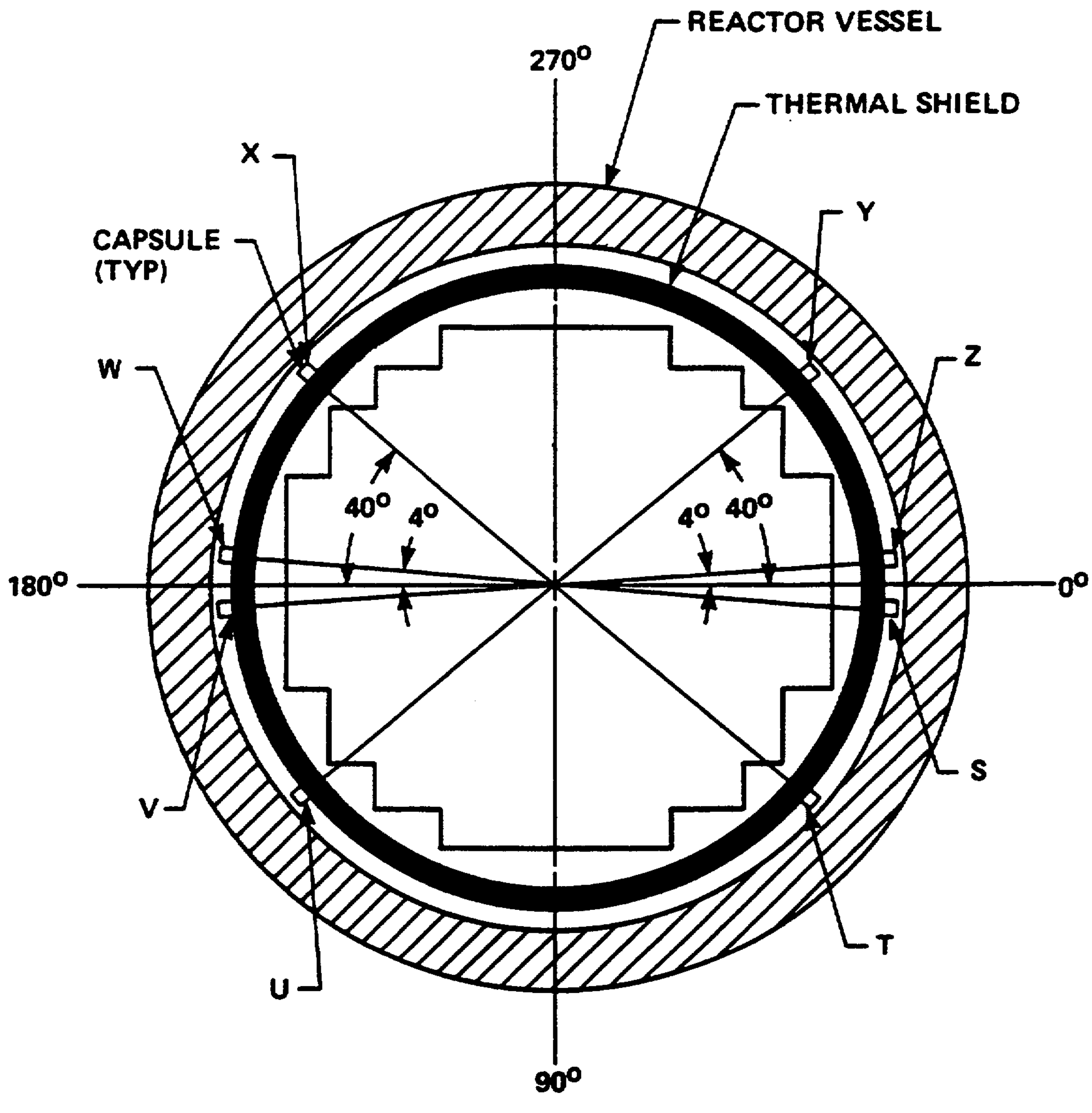


Figure 4-1 Arrangement of Surveillance Capsules in the Sequoyah Unit 2 Reactor Vessel

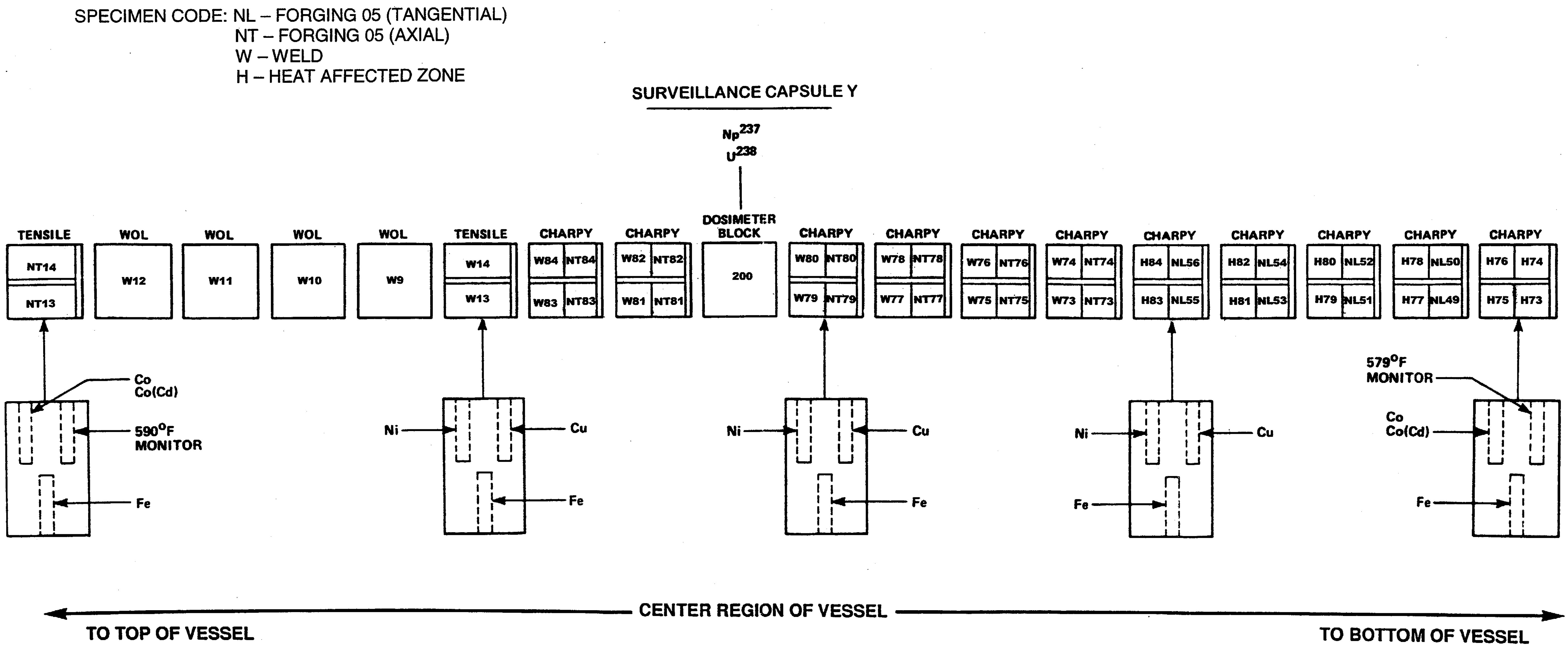


Figure 4-2 Capsule Y Diagram Showing the Location of Specimens, Thermal Monitors, and Dosimeters

5 TESTING OF SPECIMENS FROM CAPSULE Y

5.1 OVERVIEW

The post-irradiation mechanical testing of the Charpy V-notch impact specimens and tensile specimens was performed in the Remote Metallographic Facility (RMF) at the Westinghouse Science and Technology Center. Testing was performed in accordance with 10CFR50, Appendices G[6] and H[10], ASTM Specification E185-82[11], and Westinghouse Procedure RMF 8402, Revision 2 as modified by Westinghouse RMF Procedures 8102, Revision 1, and 8103, Revision 1.

Upon receipt of the capsule at the hot cell laboratory, the specimens and spacer blocks were carefully removed, inspected for identification number, and checked against the master list in WCAP-8513[1]. No discrepancies were found.

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

The Charpy impact tests were performed per ASTM Specification E23-96a[12] 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:

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

where:

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

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

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

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

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

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

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

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

Percent shear was determined from post-fracture photographs using the ratio-of-areas methods in compliance with ASTM Specification A370-97[13]. 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 E8-98[14] and E21-92[15], 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 [16].

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 $\pm$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 Y, which received a fluence of 2.14 x 10^{19} n/cm^2(E> 1.0 MeV) in 10.54 EFPY of operation, are presented in Tables 5-1 through 5-8 and are compared with unirradiated results[1] as shown in Figures 5-1 through 5-12.

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

- Irradiation of the reactor vessel intermediate shell forging 05 Charpy specimens, oriented with the longitudinal axis of the specimen normal to the major working direction (tangential orientation), to 2.14 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 134.12°F and a 50 ft-lb transition temperature increase of 135.35°F. This results in an irradiated 30 ft-lb transition temperature of 71.42°F and an irradiated 50 ft-lb transition temperature of 110.97°F for the tangential oriented specimens.

- Irradiation of the reactor vessel intermediate shell forging 05 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction of the forging (axial orientation), to 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 89.21°F and a 50 ft-lb transition temperature increase of 130.97°F. This results in an irradiated 30 ft-lb transition temperature of 77.13°F and an irradiated 50 ft-lb transition temperature of 172.87°F for axial oriented specimens.

- Irradiation of the weld metal Charpy specimens to 2.14 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 86.91°F and a 50 ft-lb transition temperature increase of 93.45°F. This results in an irradiated 30 ft-lb transition temperature of -1.18°F and an irradiated 50 ft-lb transition temperature of 52.32°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 50.32°F and a 50 ft-lb transition temperature increase of 71.76°F. This results in an irradiated 30 ft-lb transition temperature of -20.75°F and an irradiated 50 ft-lb transition temperature of 41.07°F.

- The average upper shelf energy of the Intermediate shell forging 05 (tangential orientation) resulted in an average energy decrease of 30 ft-lb after irradiation to 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV). This results in an irradiated average upper shelf energy of 104 ft-lb for the tangentially oriented specimens.

- The average upper shelf energy of the Intermediate shell forging 05 (Axial orientation) resulted in an average energy decrease of 19 ft-lb after irradiation to 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 69 ft-lb for the axially oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted an average energy decrease of 3 ft-lb after irradiation to 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 109 ft-lb for the weld metal specimens.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in an average energy decrease of 47 ft-lb after irradiation to 2.14 x 10^{19} n/cm^2 (E> 1.0MeV). This results in an irradiated average upper shelf energy of 75 ft-lb for the weld HAZ metal.

- Table 5-10 contains a comparison of the Sequoyah Unit 2 reactor vessel beltline material test results with the Regulatory Guide 1.99, Revision 2[5] predictions and led to the following conclusions:

  — The measured 30 ft-lb shift in transition temperature of the tangential oriented surveillance forging material contained in capsule Y is greater than the Regulatory Guide 1.99, Revision 2, prediction. However, the shift value is less than the two-sigma allowance required by Regulatory Guide 1.99, Revision 2.

  — The measured 30 ft-lb shift in transition temperature of the axial oriented surveillance forging material contained in capsule Y is less than the Regulatory Guide 1.99, Revision 2, prediction.

  — The measured 30 ft-lb shift in transition temperature value of the weld material contained in capsule Y is greater than the Regulatory Guide 1.99, Revision 2, prediction. However, the shift value is less than the two-sigma allowance required by Regulatory Guide 1.99, Revision 2.

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

All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are expected to maintain an upper shelf energy of no less than 50 ft-lb throughout the life of the vessel (32 EFPY) as required by 10CFR50, Appendix G[6].

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

The Charpy V-notch data presented WCAP-8513[1], WCAP-10509[2], SwRI Report 17-8851[3], and WCAP-13545[4] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1. which is a hyperbolic tangent curve-fitting program. Appendix B presents a comparison of the Charpy V-Notch test results for each capsule based on hand fit vs. hyperbolic tangent fit. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

5.3 TENSILE TEST RESULTS

The results of the tensile tests performed on the various materials contained in capsule Y irradiated to 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV) are presented in Table 5-11 and are compared with unirradiated results[1] as shown in Figures 5-17 and 5-18.

The results of the tensile tests performed on the Intermediate shell forging 05 (axial orientation) indicated that irradiation to 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV) caused an approximate increase of 13 to 16 ksi in the 0.2 percent offset yield strength and approximately a 12 to 20 ksi increase in the ultimate tensile strength when compared to unirradiated data[1] (Figure 5-17).

The results of the tensile tests performed on the surveillance weld metal indicated that irradiation to 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 10 to 14 ksi increase in the 0.2 percent offset yield strength and approximately a 6 to 9 ksi increase in the ultimate tensile strength when compared to unirradiated data[1] (Figure 5-18).

The fractured tensile specimens for the intermediate shell forging 05 material are shown in Figure 5-19, while the fractured tensile specimens for the surveillance weld metal are shown in Figure 5-20. The engineering stress-strain curves for the tensile tests are shown in Figures 5-21 and 5-22.

5.4 WEDGE OPENING LOADING (WOL) TESTS

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

Table 5-1 Charpy V-notch Data for the Sequoyah Unit 2 Intermediate Shell Forging 05 Irradiated to a Fluence of 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV) (Tangential Orientation)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	ft-lbs	Joules	mils	mm	%
NL55	-25	-32	7	9	1	0.03	5
NL56	25	-4	21	28	12	0.30	10
NL54	72	22	24	33	17	0.43	15
NL49	85	29	31	42	27	0.69	25
NL50	100	38	52	71	35	0.89	30
NL51	125	52	58	79	44	1.12	40
NL53	200	93	86	117	63	1.60	80
NL52	250	121	104	141	75	1.91	100

Table 5-2 Charpy V-notch Data for the Sequoyah Unit 2 Intermediate Shell Forging 05 Irradiated to a Fluence of 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV) (Axial Orientation)							
Sample	**Temperature**		**Impact Energy**		**Lateral Expansion**		**Shear**
Number	**F**	**C**	**ft-lbs**	**Joules**	**mils**	**mm**	**%**
NT84	-60	-51	13	18	7	0.18	2
NT83	0	-18	23	31	12	0.30	5
NT81	25	-4	22	30	14	0.36	10
NT76	50	10	22	30	13	0.33	20
NT73	72	22	27	37	17	0.43	20
NT82	90	32	31	42	28	0.71	25
NT75	110	43	41	56	34	0.86	40
NT74	150	66	34	46	27	0.69	50
NT79	165	74	46	62	31	0.79	70
NT77	225	107	58	79	41	1.04	100
NT78	275	135	77	104	60	1.52	100
NT80	300	149	73	99	59	1.50	100

Table 5-3 Charpy V-notch Data for the Sequoyah Unit 2 Surveillance Weld Metal Irradiated to a Fluence of 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	ft-lbs	Joules	mils	mm	%
W80	-75	-59	10	14	3	0.08	2
W73	-50	-46	16	22	7	0.18	2
W76	-25	-32	32	43	21	0.53	10
W78	0	-18	26	35	16	0.41	5
W74	50	10	63	85	45	1.14	40
W75	72	22	55	75	39	0.99	30
W79	100	38	31	42	24	0.61	40
W84	100	38	88	119	68	1.73	75
W83	150	66	89	121	69	1.75	85
W82	200	93	106	144	79	2.01	90
W81	250	121	114	155	81	2.06	100
W77	275	135	104	141	79	2.01	100

Table 5-4 Charpy V-notch Data for the Sequoyah Unit 2 Heat Affected Zone Material Irradiated to a Fluence of 2.14 x 10^{19} n/cm^2 (E> 1.0 MeV)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	ft-lbs	Joules	mils	mm	%
H78	-100	-73	22	30	7	0.18	10
H80	-75	-59	17	23	9	0.23	5
H76	-50	-46	23	31	9	0.23	10
H75	-25	-32	39	53	17	0.43	15
H82	0	-18	15	20	5	0.13	5
H83	40	4	31	42	16	0.41	65
H81	60	16	57	77	33	0.84	70
H73	72	22	88	119	45	1.14	85
H77	100	38	68	92	50	1.27	85
H74	175	79	57	77	39	0.99	90
H84	225	107	101	137	54	1.37	100
H79	250	121	48	65	33	0.84	100

Table 5-5 Instrumented Charpy Impact Test Results for the Sequoyah Unit 2 Intermediate Shell Forging 05 Irradiated to a Fluence of 2.14 x 10^{19} n/cm^2 (E>1.0 MeV) (Tangential 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								
NL55	-25	7	56	29	27	3126	0.15	3142	0.15	0	0	104	104
NL56	25	21	169	66	103	3846	0.17	4209	0.22	4164	0	128	134
NL54	72	24	193	65	128	3676	0.17	3999	0.22	3983	147	122	128
NL49	85	31	250	135	115	3804	0.17	4262	0.35	4156	497	127	134
NL50	100	52	419	233	186	3737	0.17	4545	0.52	4469	322	124	138
NL51	125	58	467	304	163	3439	0.17	4424	0.68	4373	736	115	131
NL53	200	86	693	291	402	3391	0.17	4260	0.67	3836	2324	113	127
NL52	250	104	838	274	564	3227	0.17	3989	0.66	N/A	N/A	107	120

Table 5-6 Instrumented Charpy Impact Test Results for the Sequoyah Unit 2 Intermediate Shell Forging 05 Irradiated to a Fluence of 2.14 x 10^{19} n/cm^2 (E>1.0 MeV)(Axial Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2) Charpy E_D/A	Max. E_M/A	Prop. E_p/A	Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
NT84	-60	13	105	62	43	4050	0.17	4473	0.21	4471	0	135	142
NT83	0	23	185	71	114	4050	0.17	4427	0.23	4355	0	135	141
NT81	25	22	177	138	39	3612	0.17	4228	0.36	4152	0	120	131
NT76	50	22	177	70	107	3856	0.17	4194	0.23	3998	233	128	134
NT73	72	27	218	137	80	3734	0.17	4194	0.35	4149	217	124	132
NT82	90	31	250	146	103	3735	0.17	4228	0.37	4210	563	124	133
NT75	110	41	330	209	121	3689	0.17	4280	0.49	4193	468	123	133
NT74	150	34	274	118	156	3630	0.17	3980	0.33	3957	1033	121	127
NT79	165	46	371	193	178	3385	0.17	4301	0.48	4274	1842	113	128
NT77	225	58	467	145	323	3504	0.17	3950	0.38	N/A	N/A	117	124
NT78	275	77	620	207	413	3357	0.17	4121	0.51	N/A	N/A	112	125
NT80	300	73	588	169	419	3303	0.17	3936	0.45	N/A	N/A	110	121

Table 5-7 Instrumented Charpy Impact Test Results for the Sequoyah Unit 2 Surveillance Weld Metal Irradiated to a Fluence of 2.14 x 10^{19} n/cm^2 (E>1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in²) Charpy E_D/A	Max. E_M/A	Prop. E_p/A	Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
W80	-75	10	81	50	30	4010	0.2	4010	0.19	0	0	134	134
W73	-50	16	129	67	62	3649	0.17	4049	0.23	3951	0	121	128
W76	-25	32	258	209	49	3678	0.17	4191	0.50	4124	0	122	131
W78	0	26	209	162	48	3636	0.17	4096	0.41	3938	0	121	129
W74	50	63	508	291	216	3409	0.17	4112	0.68	3734	399	114	125
W75	72	55	443	298	145	3218	0.21	4116	0.73	4021	162	107	122
W79	100	31	250	162	88	3450	0.17	3883	0.43	3869	814	115	122
W84	100	88	709	284	425	3349	0.17	4011	0.68	2840	177	112	123
W83	150	89	717	274	443	3228	0.17	3903	0.67	3289	1974	107	119
W82	200	106	854	272	582	3027	0.17	3801	0.70	3041	2229	101	114
W81	250	114	919	262	657	2972	0.17	3715	0.68	N/A	N/A	99	111
W77	275	104	838	261	577	2976	0.17	3725	0.68	N/A	N/A	99	112

Table 5-8 Instrumented Charpy Impact Test Results for the Sequoyah Unit 2 Heat-Affected-Zone (HAZ) Metal Irradiated to a Fluence of 2.14 x 10^{19} n/cm^2 (E>1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2)			Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_p/A								
H78	-100	22	177	76	101	4440	0.18	4826	0.23	4649	0	148	154
H80	-75	17	137	75	62	4295	0.17	4761	0.23	4759	0	143	151
H76	-50	23	185	68	117	4163	0.17	4539	0.22	4400	0	139	145
H75	-25	39	314	242	72	4111	0.17	4751	0.51	4751	0	137	148
H82	0	15	121	68	53	4098	0.17	4527	0.22	4527	0	136	144
H83	40	31	250	146	104	3913	0.17	4362	0.36	4298	695	130	138
H81	60	57	459	235	224	3814	0.17	4515	0.52	4303	1787	127	139
H73	72	88	709	324	385	3763	0.17	4600	0.68	4221	2359	125	139
H77	100	68	548	317	231	3715	0.17	4435	0.68	4304	1031	124	136
H74	175	57	459	215	244	3528	0.17	4315	0.51	4162	2747	117	131
H84	225	101	814	313	500	3549	0.17	4431	0.69	N/A	N/A	118	133
H79	250	48	387	191	195	3546	0.17	4175	0.47	N/A	N/A	118	129

Table 5-9 Effect of Irradiation to 2.14 x 10^{19} n/cm^2 (E>1.0 MeV) on the Notch Toughness Properties of the Sequoyah Unit 2 Reactor Vessel Surveillance Materials

Material	Average 30 (ft-lb)[(a)] Transition Temperature (°F)			Average 35 mil Lateral[(b)] Expansion Temperature (°F)			Average 50 ft-lb[(a)] Transition Temperature (°F)			Average Energy Absorption[(a)] at Full Shear (ft-lb)		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT
Inter. Shell Forging 05 (Tangential)	-62.7	71.42	134.12	-37.83	106.41	144.24	-24.37	110.97	135.35	134	104	-30
Inter. Shell Forging 05 (Axial)	-12.08	77.13	89.21	18.0	173.87	155.86	41.9	172.87	130.97	88	69	-19
Weld Metal	-88.1	-1.18	86.91	-48.9	52.6	101.51	-41.12	52.32	93.45	112	109	-3
HAZ Metal	-71.08	-20.75	50.32	-6.5	59.55	66.06	-30.69	41.07	71.76	122	75	-47

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

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

Table 5-10 Comparison of the Sequoyah Unit 2 Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper Shelf Energy Decreases with Regulatory Guide 1.99, Revision 2, Predictions

Material	Capsule	Fluence (x 10^{19} n/cm^2)	30 ft-lb Transition Temperature Shift		Upper Shelf Energy Decrease	
			Predicted (°F) [(a)]	Measured (°F) [(b)]	Predicted (%) [(a)]	Measured (%)[(c)]
Intermediate Shell Forging 05 (Tangential)	T	0.261	60.33	63.65	17	12
	U	0.692	85.22	79.31	21	16
	X	1.22	100.23	85.7	23	8
	Y	2.14	114.67	134.12	26	22
Intermediate Shell Forging 05 (Axial)	T	0.261	60.33	48.73	17	7
	U	0.692	85.22	66.06	21	9
	X	1.22	100.23	110.04	23	2
	Y	2.14	114.67	89.21	26	22
Weld Metal	T	0.261	43.12	74.56	20	2
	U	0.692	60.91	130.38	25	6
	X	1.22	71.63	44.22	29	35
	Y	2.14	81.96	86.91	33	3
HAZ Metal	T	0.261	--	24.58	--	2
	U	0.692	--	64.03	--	14
	X	1.22	--	28.29	--	19
	Y	2.14	--	50.32	--	39

Notes:

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

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

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

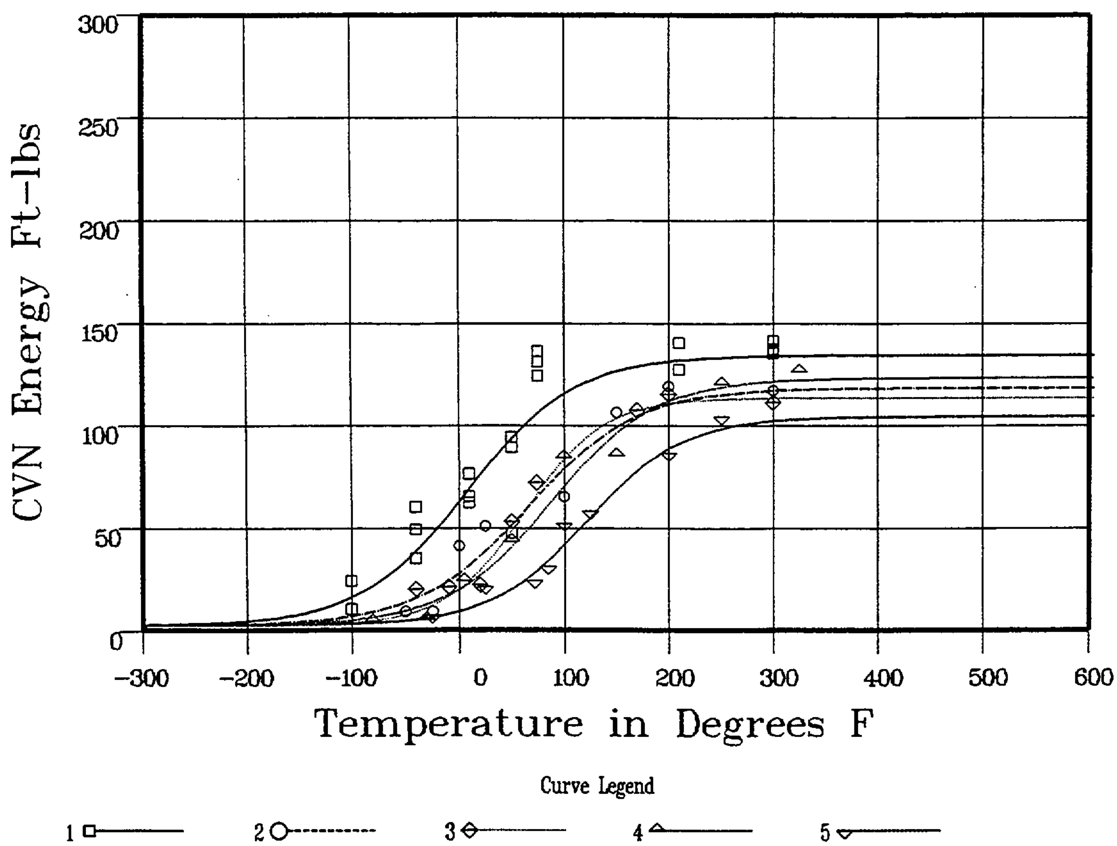
Table 5-11 Tensile Properties of the Sequoyah Unit 2 Reactor Vessel Surveillance Materials Irradiated to 2.14 x 10^{19} n/cm^2 (E > 1.0 MeV)										
Material	**Sample Number**	**Test Temp. (°F)**	**0.2% Yield Strength (ksi)**	**Ultimate Strength (ksi)**	**Fracture Load (kip)**	**Fracture Stress (ksi)**	**Fracture Strength (ksi)**	**Uniform Elongation (%)**	**Total Elongation (%)**	**Reduction in Area (%)**
Intermediate Forging 05 (Axial)	NT13	150	77.4	97.2	3.96	115.5	63.5	9.9	14.0	30
	NT14	550	70.8	95.9	3.94	143.5	51.6	10.5	18.0	44
Weld Metal	W13	125	72.9	88.4	2.85	161.3	59.3	9.3	23.0	64
	W14	550	67.7	85.6	3.24	139.5	66.7	7.5	16.8	53

INTERMEDIATE SHELL FORGING (05) TANGENTIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:22:18 on 09-30-1999

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	134	0	-62.7	0	-24.37	0
2	0	2.19	0	118	-16	.95	63.65	42.58	66.95
3	0	2.19	0	113	-21	16.61	79.31	47.29	71.67
4	0	2.19	0	123	-11	23	85.7	62.09	86.47
5	0	2.19	0	104	-30	71.42	134.12	110.97	135.35



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	SQ2	UNIRR	FORGING SA508CL2	LT	288757/981057(05)
2	SQ2	T	FORGING SA508CL2	LT	288757/981057(05)
3	SQ2	U	FORGING SA508CL2	LT	288757/981057(05)
4	SQ2	X	FORGING SA508CL2	LT	288757/981057(05)
5	SQ2	Y	FORGING SA508CL2	LT	288757/981057(05)

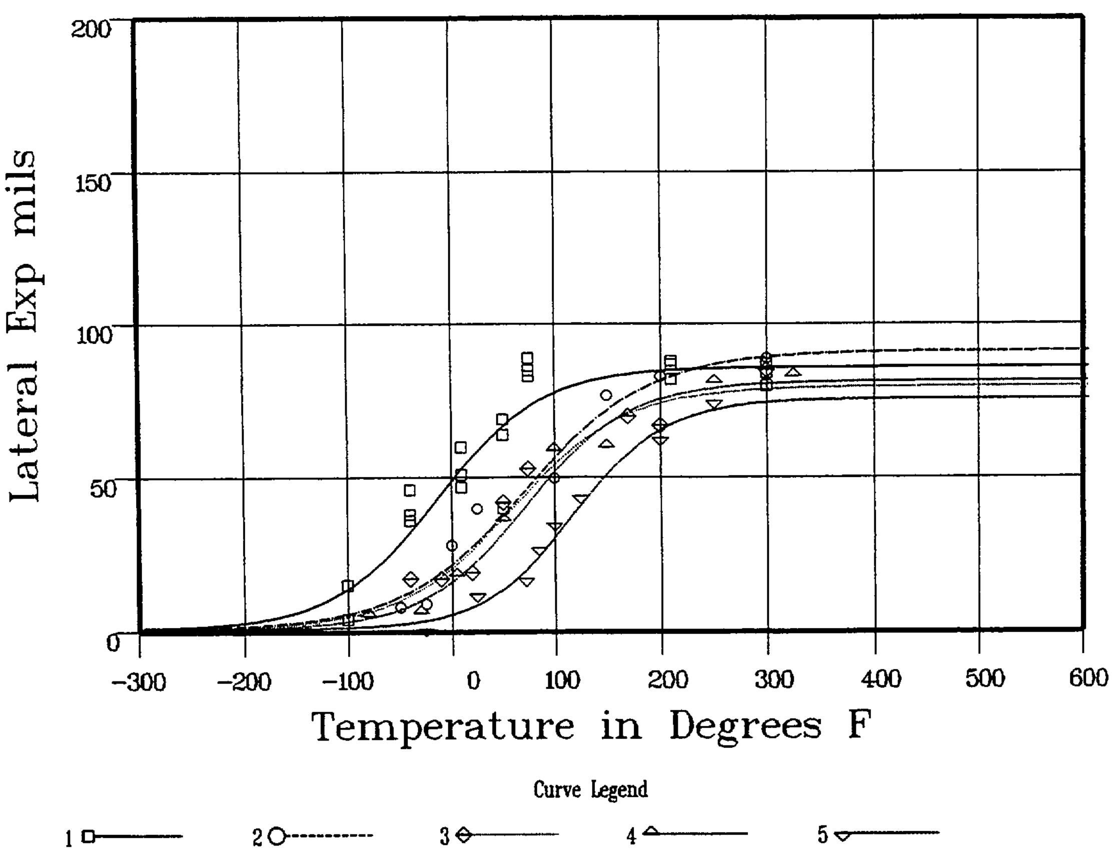
Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Sequoyah Unit 2 Reactor Vessel Intermediate Shell Forging 05 (Tangential Orientation)

INTERMEDIATE SHELL FORGING (05) TANGENTIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:27:00 on 09-30-1999

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	86.01	0	-37.83	0
2	0	91.25	5.23	37.44	75.27
3	0	79.81	-6.2	40.36	78.2
4	0	81.48	-4.52	52.87	90.7
5	0	75.61	-10.39	106.41	144.24



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	SQ2	UNIRR	FORGING SA508CL2	LT	288757/981057(05)
2	SQ2	T	FORGING SA508CL2	LT	288757/981057(05)
3	SQ2	U	FORGING SA508CL2	LT	288757/981057(05)
4	SQ2	X	FORGING SA508CL2	LT	288757/981057(05)
5	SQ2	Y	FORGING SA508CL2	LT	288757/981057(05)

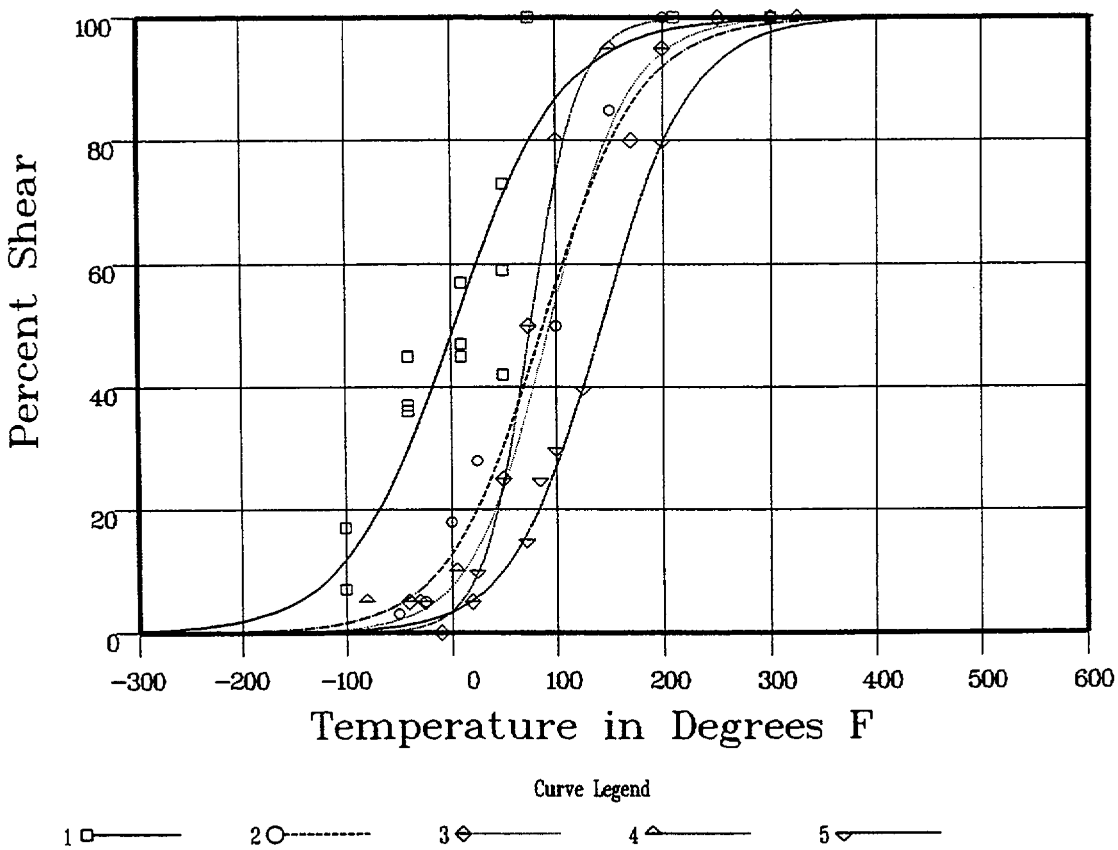
Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Sequoyah Unit 2 Reactor Vessel Intermediate Shell Forging 05 (Tangential Orientation)

INTERMEDIATE SHELL FORGING (05) TANGENTIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:31:12 on 09-30-1999

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	-1.05	0
2	0	83.2	84.25
3	0	89.35	90.41
4	0	71.52	72.58
5	0	137.4	138.45



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	SQ2	UNIRR	FORGING SA508CL2	LT	288757/981057(05)
2	SQ2	T	FORGING SA508CL2	LT	288757/981057(05)
3	SQ2	U.	FORGING SA508CL2	LT	288757/981057(05)
4	SQ2	X	FORGING SA508CL2	LT	288757/981057(05)
5	SQ2	Y	FORGING SA508CL2	LT	288757/981057(05)

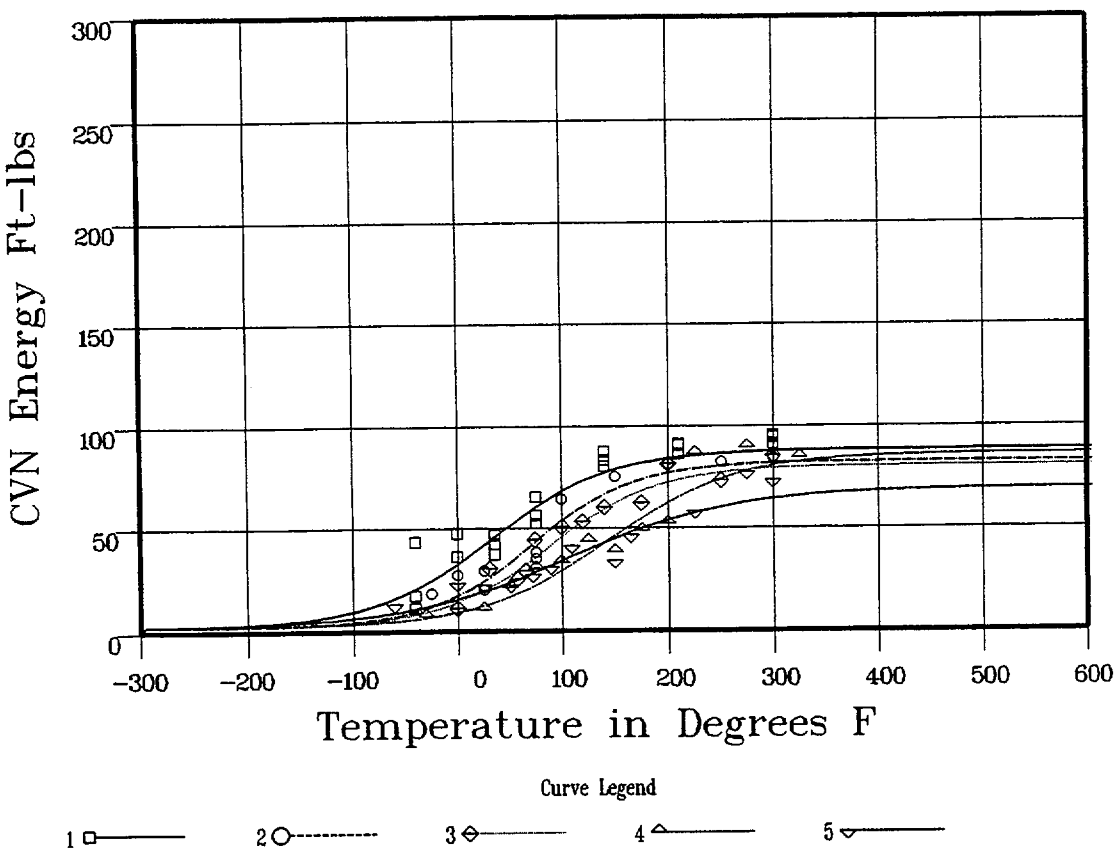
Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Sequoyah Unit 2 Reactor Vessel Intermediate Shell Forging 05 (Tangential Orientation)

INTERMEDIATE SHELL FORGING (05) AXIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:53:12 on 10-18-1999

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	88	0	-12.08	0	41.9	0
2	0	2.19	0	82	-6	36.64	48.73	86.5	44.6
3	0	2.19	0	80	-8	53.98	66.06	107.65	65.75
4	0	2.19	0	86	-2	97.95	110.04	156.66	114.76
5	0	2.19	0	69	-19	77.13	89.21	172.87	130.97



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	SQ2	UNIRR	FORGING SA508CL2	TL	288757/981057(05)
2	SQ2	T	FORGING SA508CL2	TL	288757/981057(05)
3	SQ2	U	FORGING SA508CL2	TL	288757/981057(05)
4	SQ2	X	FORGING SA508CL2	TL	288757/981057(05)
5	SQ2	Y	FORGING SA508CL2	TL	288757/981057(05)

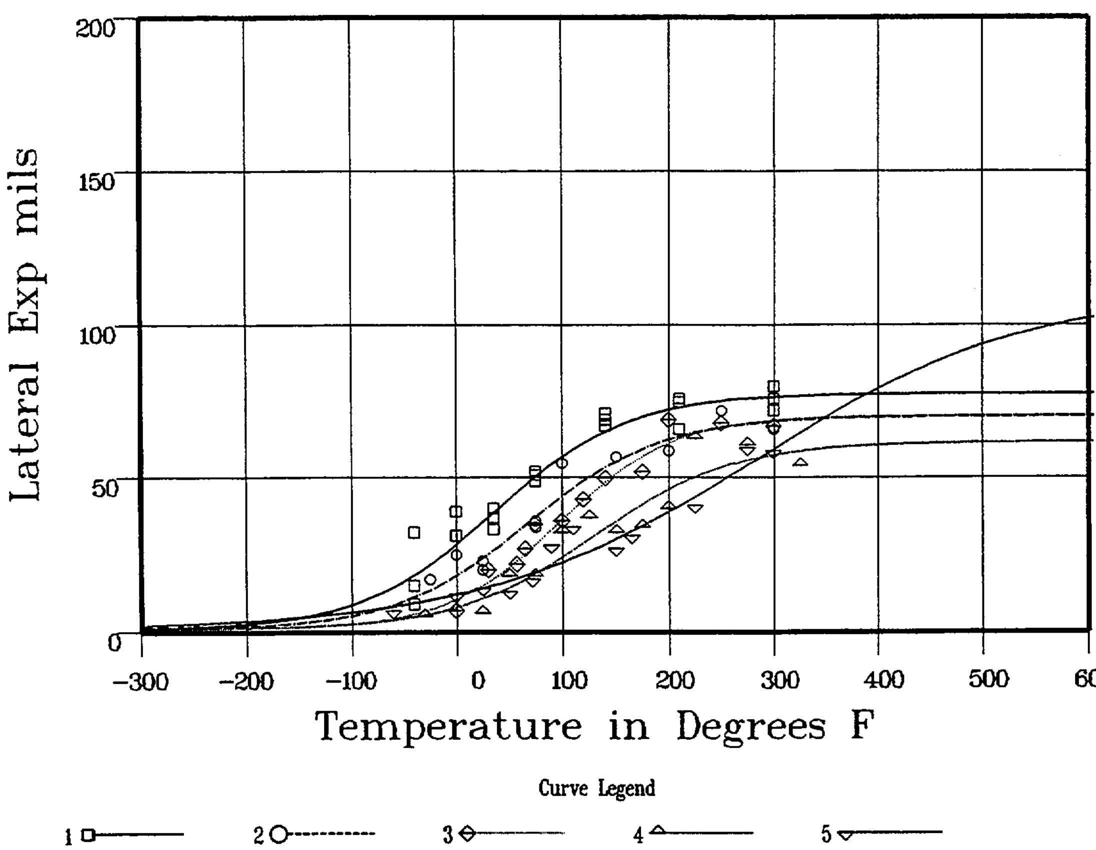
Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Sequoyah Unit 2 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)

INTERMEDIATE SHELL FORGING (05) AXIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:11:14 on 09-30-1999

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	77.7	0	18	0
2	0	70.15	-7.55	61.66	43.66
3	0	70.35	-7.35	90.93	72.92
4	0	61.8	-15.9	141.36	123.35
5	0	110.9	33.19	173.87	155.86



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	SQ2	UNIRR	FORGING SA508CL2	TL	288757/981057(05)
2	SQ2	T	FORGING SA508CL2	TL	288757/981057(05)
3	SQ2	U	FORGING SA508CL2	TL	288757/981057(05)
4	SQ2	X	FORGING SA508CL2	TL	288757/981057(05)
5	SQ2	Y	FORGING SA508CL2	TL	288757/981057(05)

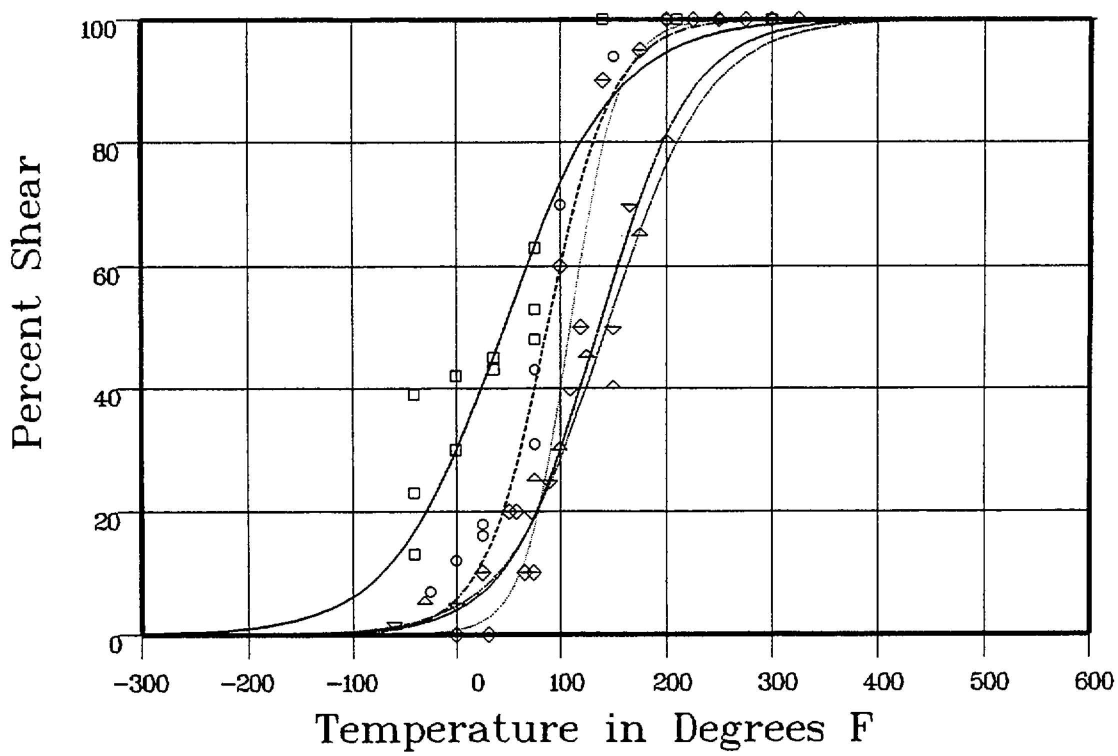
Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Sequoyah Unit 2 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)

INTERMEDIATE SHELL FORGING (05) AXIAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:25:38 on 09-30-1999

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	40.78	0
2	0	82.91	42.12
3	0	105.17	64.39
4	0	139.16	98.37
5	0	131.83	91.05



Curve Legend

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

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	SQ2	UNIRR	FORGING SA508CL2	TL	288757/981057(05)
2	SQ2	T	FORGING SA508CL2	TL	288757/981057(05)
3	SQ2	U	FORGING SA508CL2	TL	288757/981057(05)
4	SQ2	X	FORGING SA508CL2	TL	288757/981057(05)
5	SQ2	Y	FORGING SA508CL2	TL	288757/981057(05)

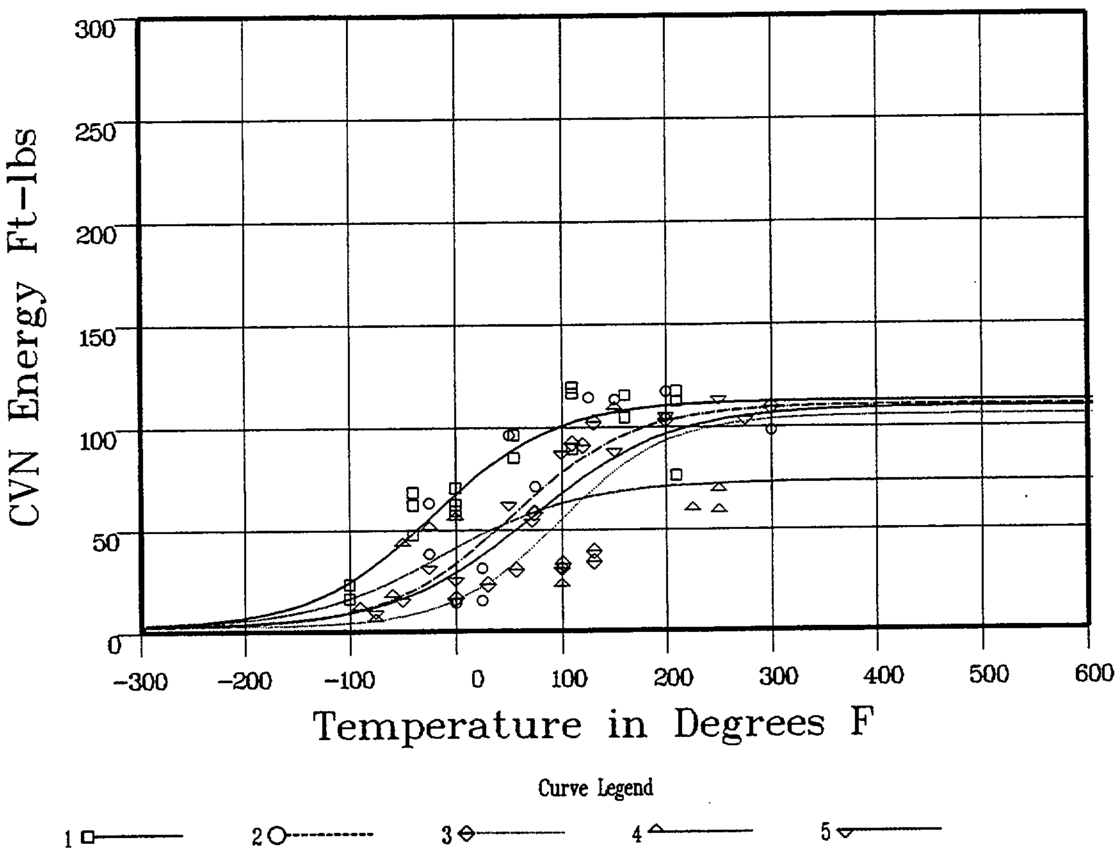
Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Sequoyah Unit 2 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:34:50 on 09-30-1999

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	112	0	-88.1	0	-41.12	0
2	0	2.19	0	110	-2	-13.54	74.56	33.79	74.92
3	0	2.19	0	105	-7	42.27	130.38	85.26	126.39
4	0	2.19	0	73	-39	-43.88	44.22	29.67	70.79
5	0	2.19	0	109	-3	-1.18	86.91	52.32	93.45



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	SQ2	UNIRR	WELD		WIRE HEAT:4278
2	SQ2	T	WELD		WIRE HEAT:4278
3	SQ2	U	WELD		WIRE HEAT:4278
4	SQ2	X	WELD		WIRE HEAT:4278
5	SQ2	Y	WELD		WIRE HEAT:4278

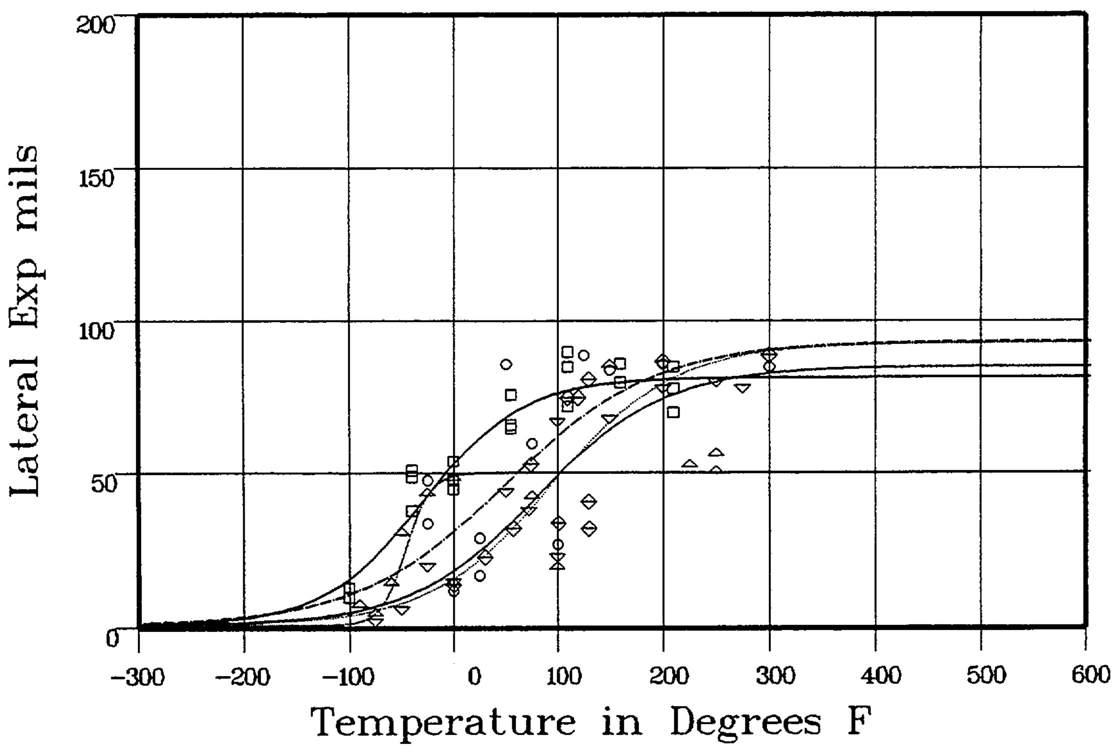
Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for Sequoyah Unit 2 Reactor Vessel Weld Metal

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:37:25 on 09-30-1999

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	81.61	0	-48.9	0
2	0	93.39	11.77	7.72	56.62
3	0	92.82	11.2	59.3	108.2
4	0	50.24	-31.36	-41.1	7.79
5	0	85.26	3.65	52.6	101.51



Curve Legend

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

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	SQ2	UNIRR	WELD		WIRE HEAT:4278
2	SQ2	T	WELD		WIRE HEAT:4278
3	SQ2	U	WELD		WIRE HEAT:4278
4	SQ2	X	WELD		WIRE HEAT:4278
5	SQ2	Y	WELD		WIRE HEAT:4278

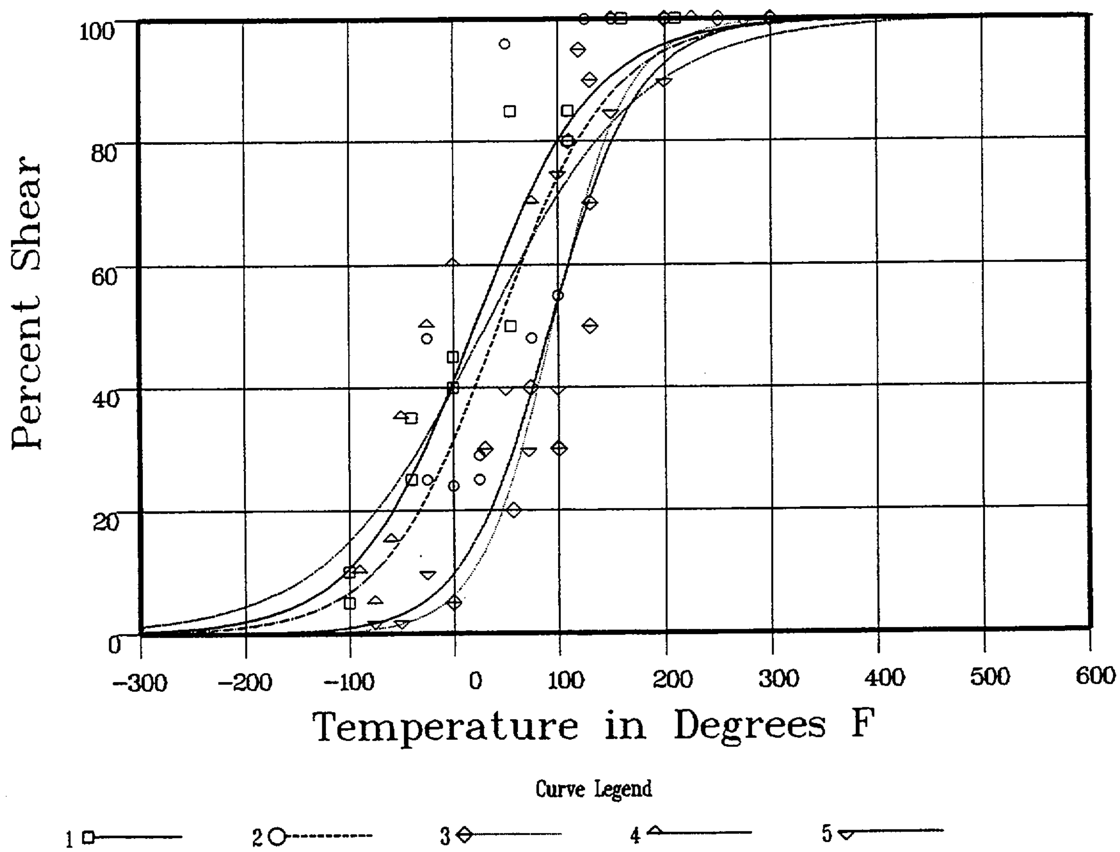
Figure 5-8 Charpy V-Notch Lateral Expansion vs. Temperature for Sequoyah Unit 2 Reactor Vessel Weld Metal

SURVEILLANCE PROGRAM WELD METTAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:40:30 on 09-30-1999

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	16.14	0
2	0	37.96	21.81
3	0	90.46	74.31
4	0	26.28	10.13
5	0	88.18	72.03



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	SQ2	UNIRR	WELD		WIRE HEAT:4278
2	SQ2	T	WELD		WIRE HEAT:4278
3	SQ2	U	WELD		WIRE HEAT:4278
4	SQ2	X	WELD		WIRE HEAT:4278
5	SQ2	Y	WELD		WIRE HEAT:4278

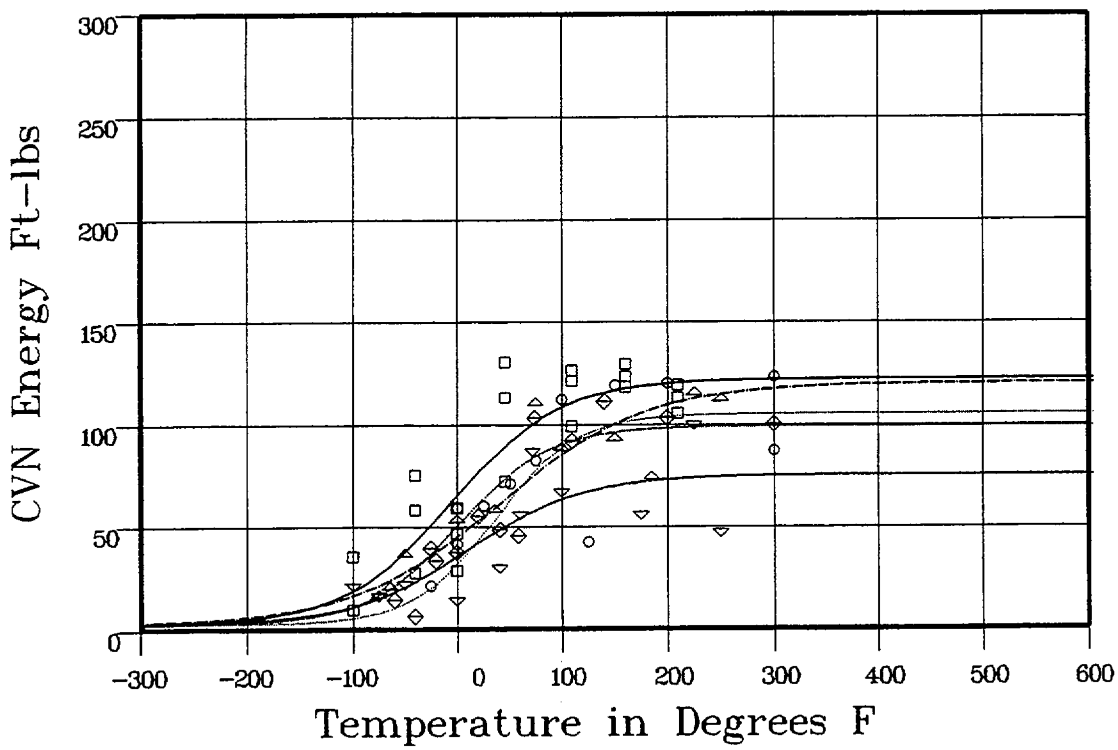
Figure 5-9 Charpy V-Notch Percent Shear vs Temperature for Sequoyah Unit 2 Reactor Vessel Weld Metal

HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:45:02 on 09-30-1999

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	122	0	-71.08	0	-30.69	0
2	0	2.19	0	120	-2	-46.49	24.58	8.64	39.33
3	0	2.19	0	105	-17	-7.05	64.03	25.96	56.65
4	0	2.19	0	99	-23	-42.78	28.29	-4.75	25.93
5	0	2.19	0	75	-47	-20.75	50.32	41.07	71.76



Curve Legend

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

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	SQ2	UNIRR	HEAT AFFD ZONE		SHELL (05) SIDE OF WELD
2	SQ2	T	HEAT AFFD ZONE		SHELL (05) SIDE OF WELD
3	SQ2	U	HEAT AFFD ZONE		SHELL (05) SIDE OF WELD
4	SQ2	X	HEAT AFFD ZONE		SHELL (05) SIDE OF WELD
5	SQ2	Y	HEAT AFFD ZONE		SHELL(05) SIDE OF WELD

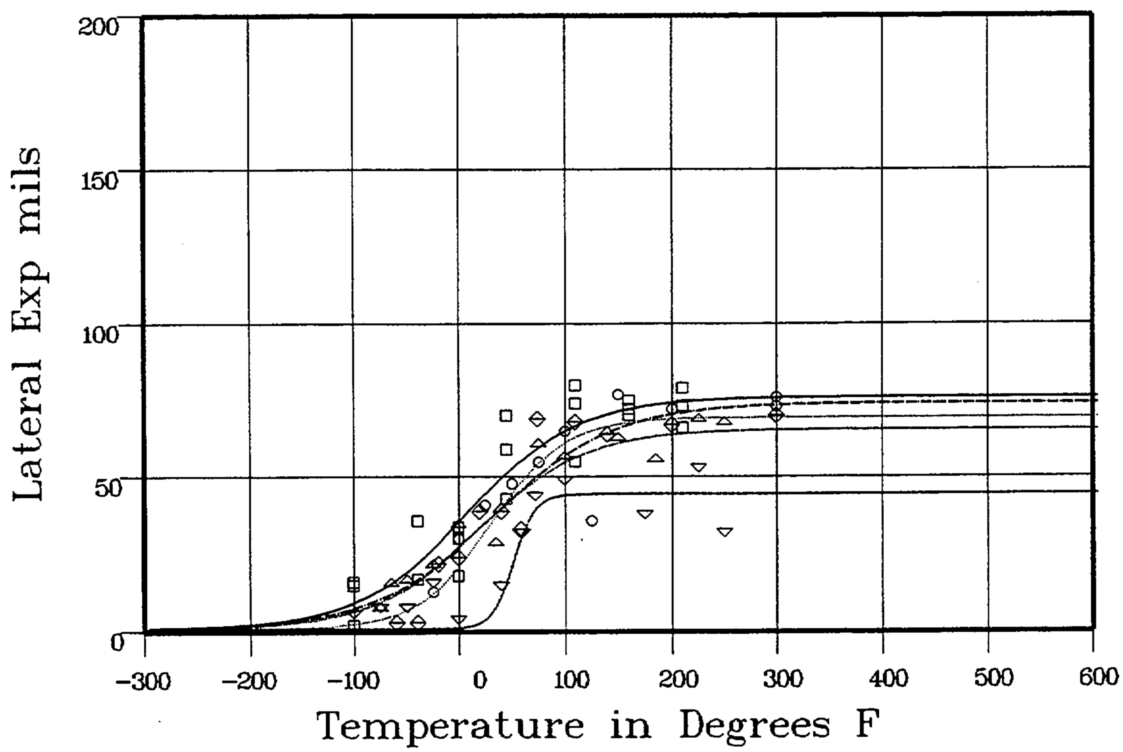
Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for Sequoyah Unit 2 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:48:50 on 09-30-1999

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	75.95	0	-6.5	0
2	0	74	-1.94	19.38	25.89
3	0	69.33	-6.61	25.43	31.94
4	0	65.54	-10.41	19.47	25.98
5	0	44.5	-31.45	59.55	66.06



Curve Legend

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

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	SQ2	UNIRR	HEAT AFFD ZONE	SHELL (05) SIDE OF WELD	
2	SQ2	T	HEAT AFFD ZONE	SHELL (05) SIDE OF WELD	
3	SQ2	U	HEAT AFFD ZONE	SHELL (05) SIDE OF WELD	
4	SQ2	X	HEAT AFFD ZONE	SHELL (05) SIDE OF WELD	
5	SQ2	Y	HEAT AFFD ZONE	SHELL(05) SIDE OF WELD	

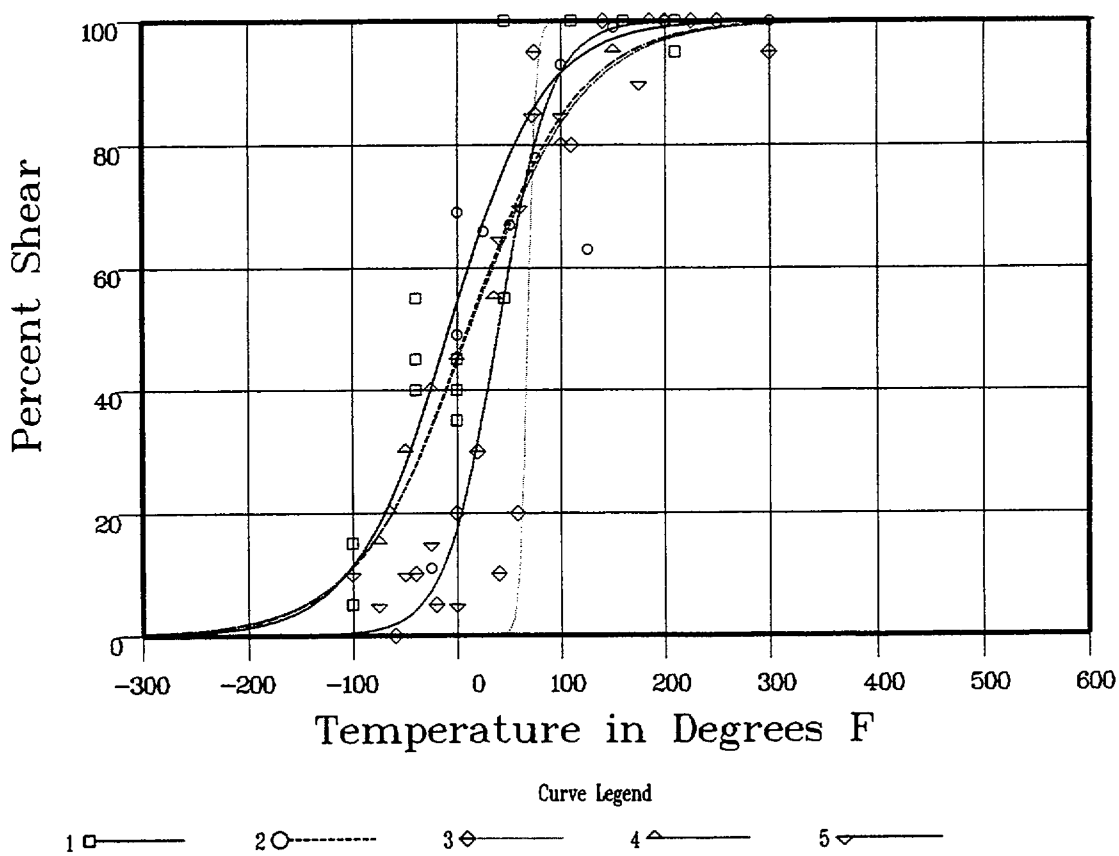
Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for Sequoyah Unit 2 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:52:28 on 09-30-1999

Results

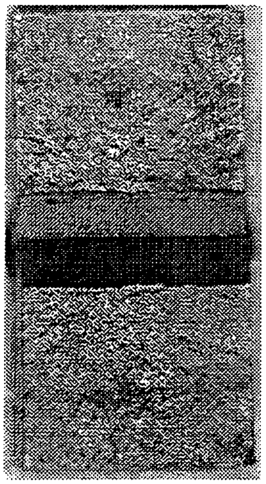
Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	-12.18	0
2	0	5.62	17.81
3	0	63.28	75.46
4	0	7.47	19.65
5	0	34.68	46.87



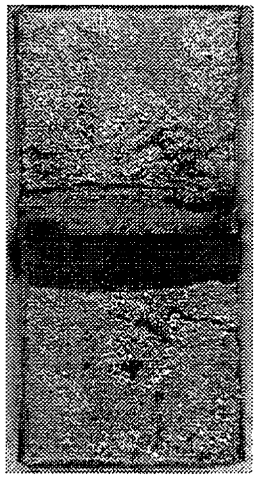
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	SQ2	UNIRR	HEAT AFFD ZONE	SHELL (05) SIDE OF WELD	
2	SQ2	T	HEAT AFFD ZONE	SHELL (05) SIDE OF WELD	
3	SQ2	U	HEAT AFFD ZONE	SHELL (05) SIDE OF WELD	
4	SQ2	X	HEAT AFFD ZONE	SHELL (05) SIDE OF WELD	
5	SQ2	Y	HEAT AFFD ZONE	SHELL(05) SIDE OF WELD	

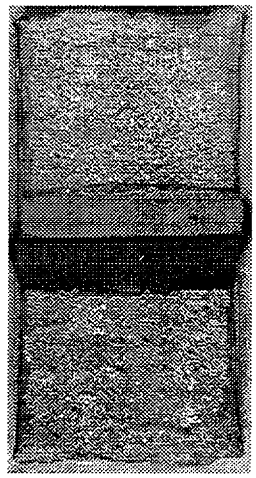
Figure 5-12 Charpy V-Notch Percent Shear vs. Temperature for Sequoyah Unit 2 Reactor Vessel Heat-Affected-Zone Material



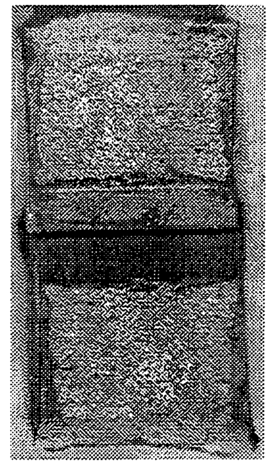
NL55, -25°F



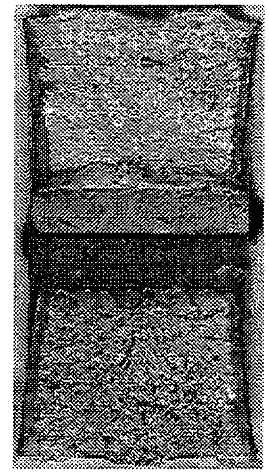
NL56, 25°F



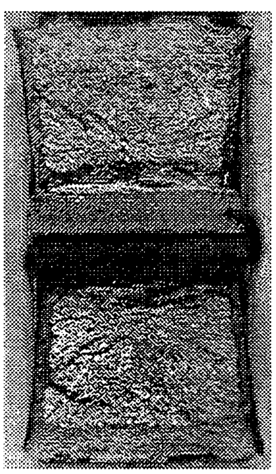
NL54, 72°F



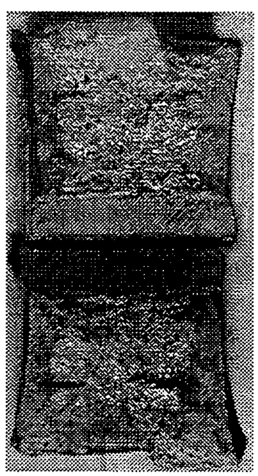
NL49, 85°F



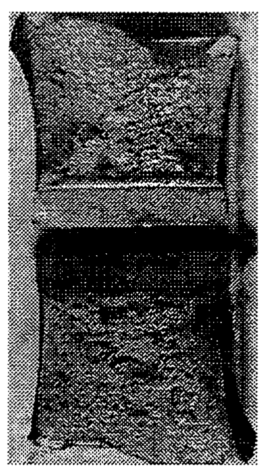
NL50, 100°F



NL51, 125°F



NL53, 200°F



NL52, 250°F

Figure 5-13 Charpy Impact Specimen Fracture Surfaces for Sequoyah Unit 2 Reactor Vessel Intermediate Shell Forging 05 (Tangential Orientation)

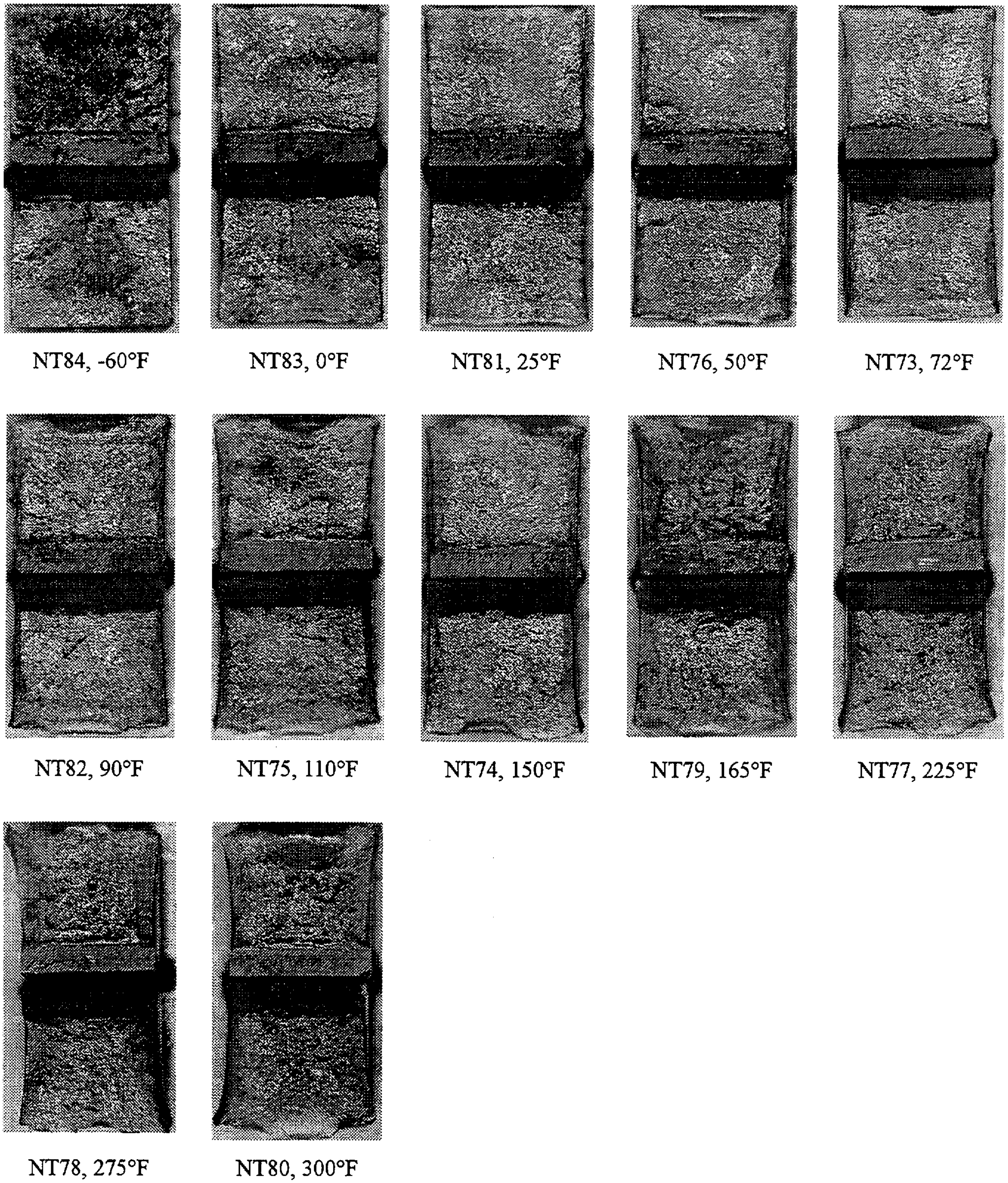
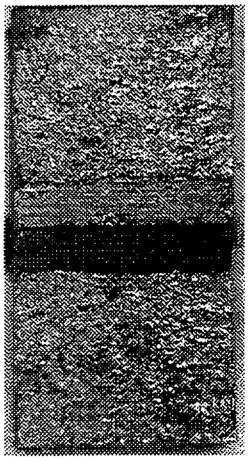
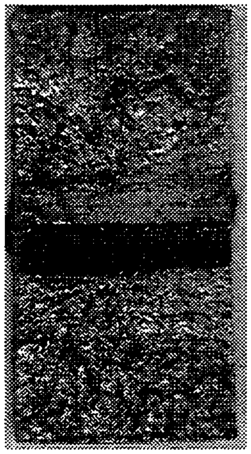
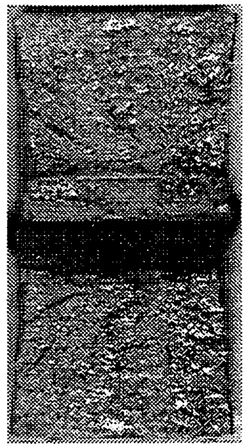
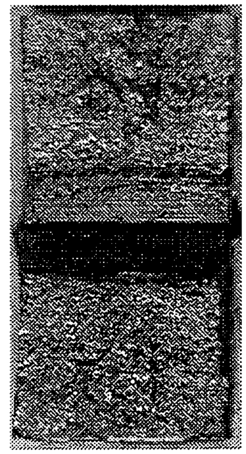


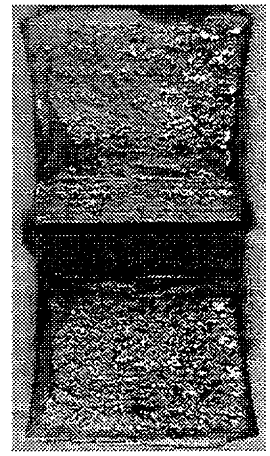
Figure 5-14 Charpy Impact Specimen Fracture Surfaces for Sequoyah Unit 2 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)

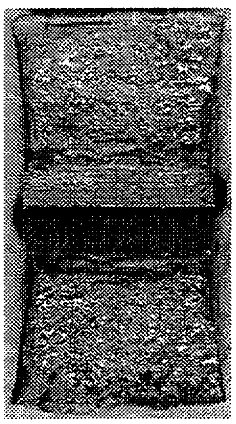

W80, -75°F

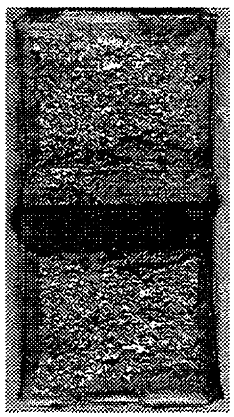

W73, -50°F

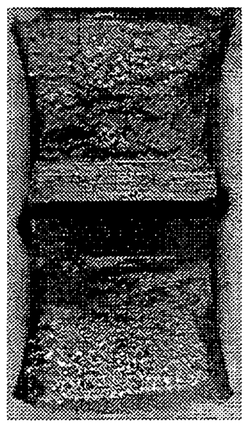

W76, -25°F

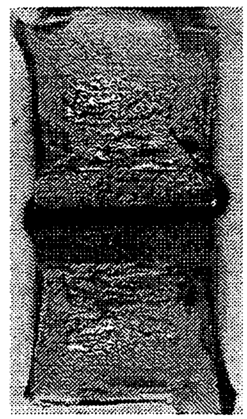

W78, 0°F

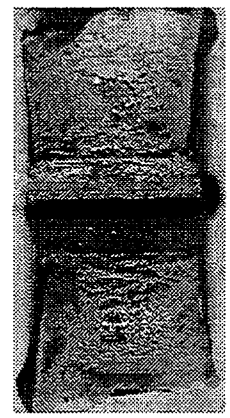

W74, 50°F

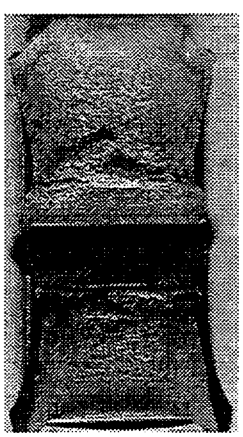

W75, 72°F


W79, 100°F


W84, 100°F


W83, 150°F


W82, 200°F


W81, 250°F

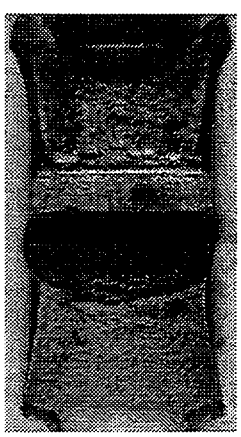

W77, 275°F

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

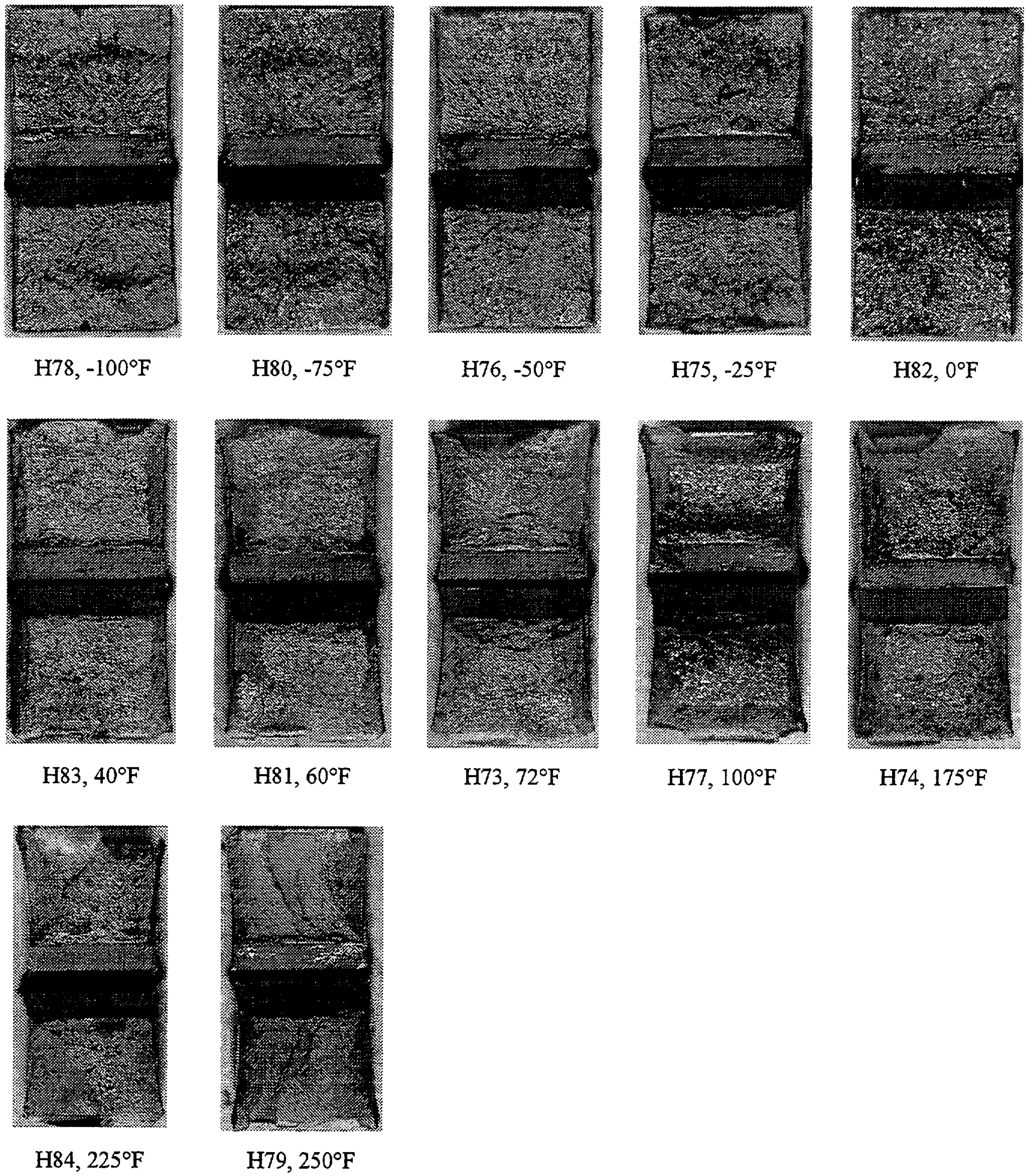


Figure 5-16 Charpy Impact Specimen Fracture Surfaces for Sequoyah Unit 2 Reactor Vessel Heat-Affected-Zone Metal

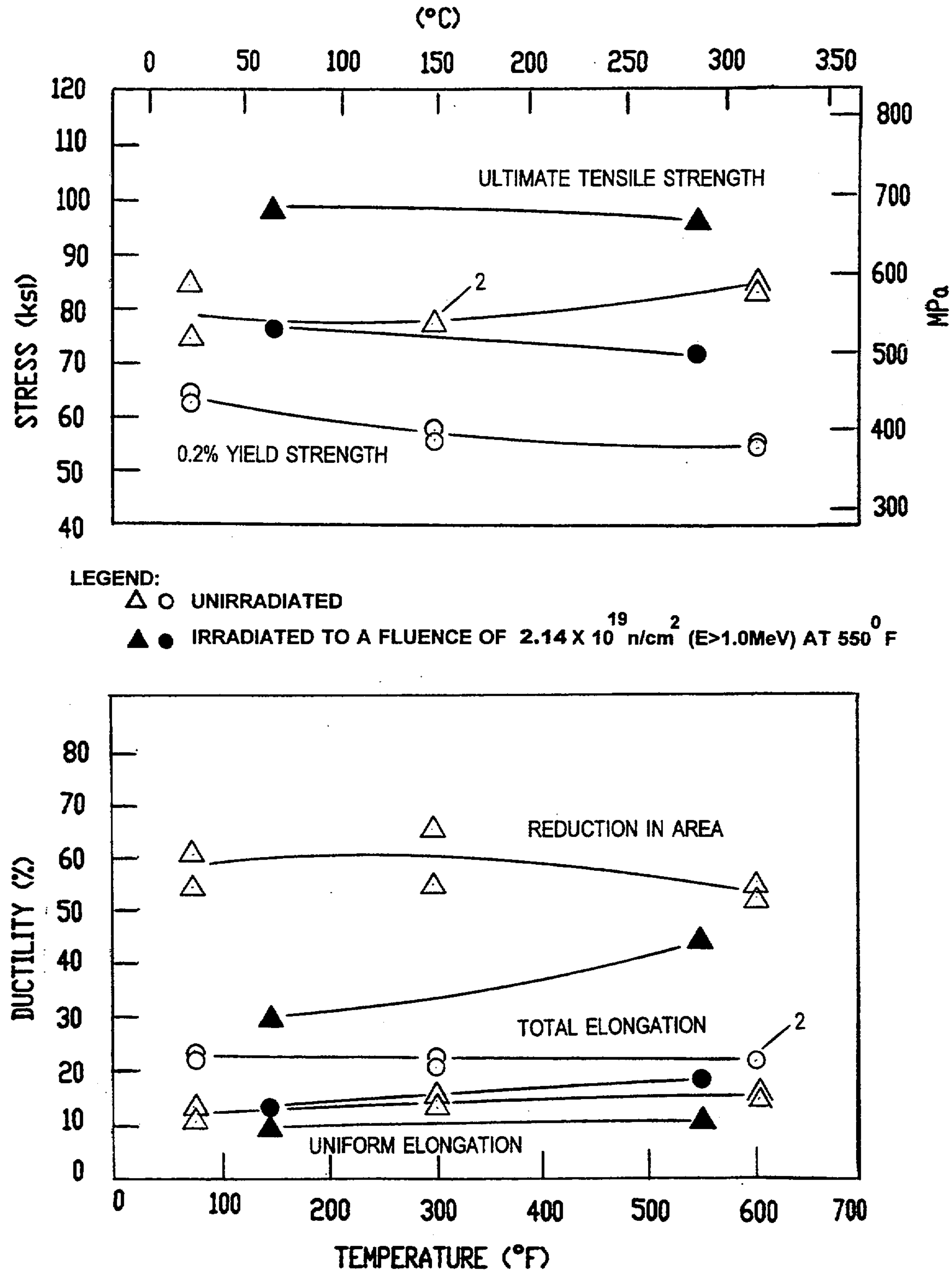


Figure 5-17 Tensile Properties for Sequoyah Unit 2 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)

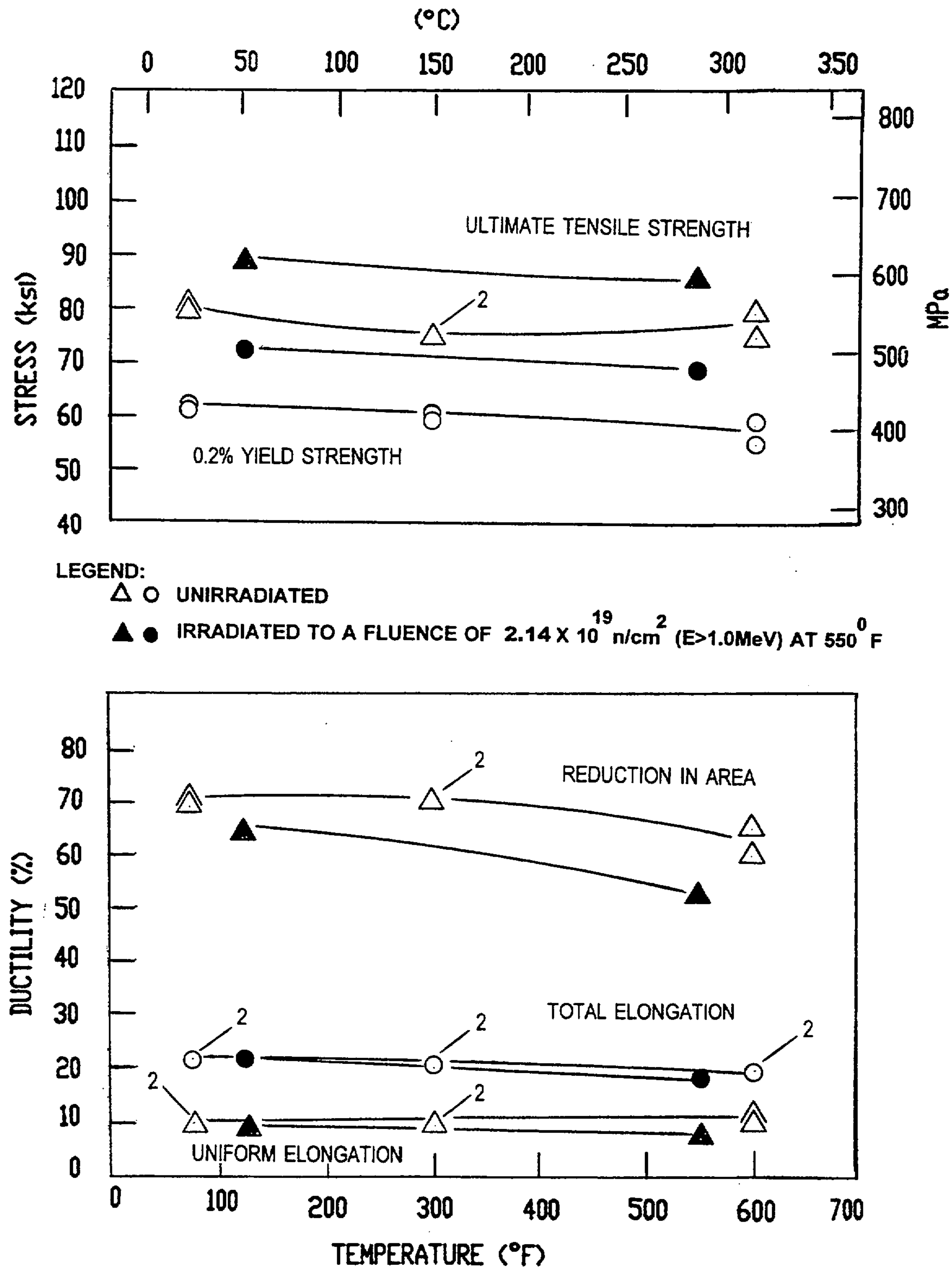
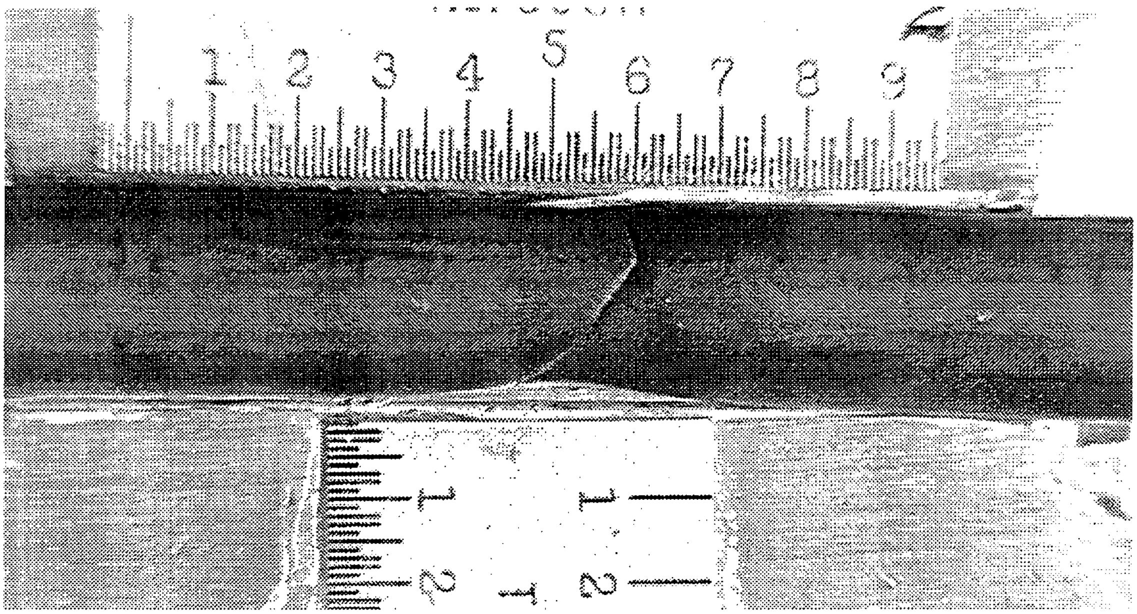
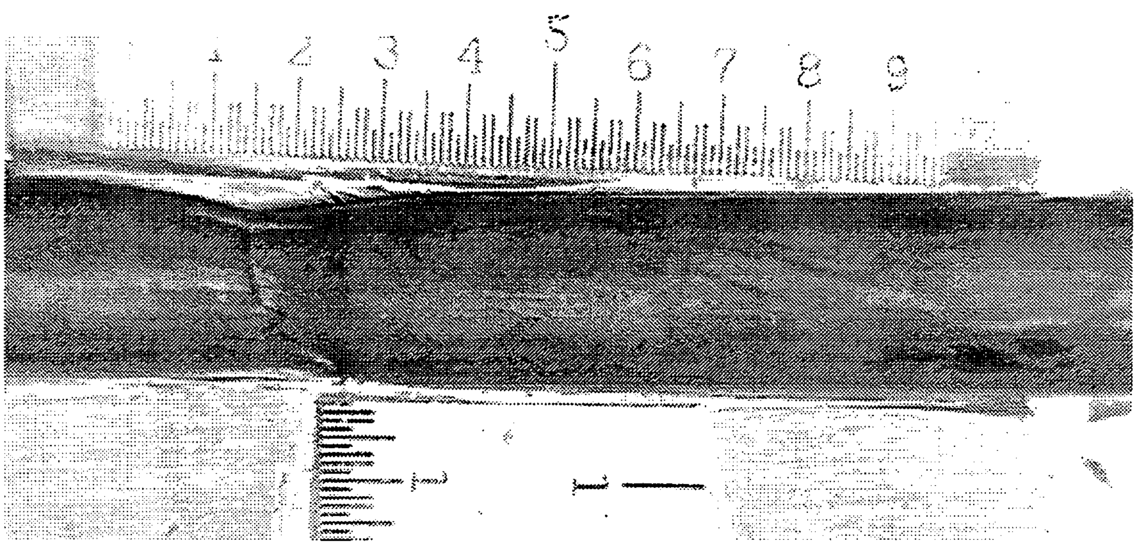


Figure 5-18 Tensile Properties for Sequoyah Unit 2 Reactor Vessel Weld Metal

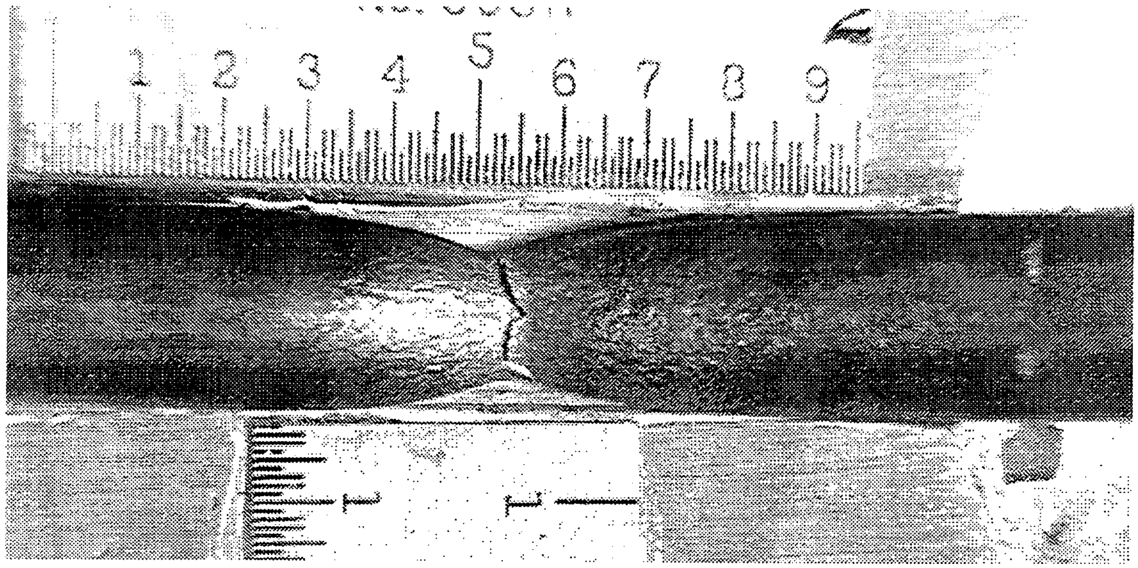


Specimen NT 13 Tested at 150°F

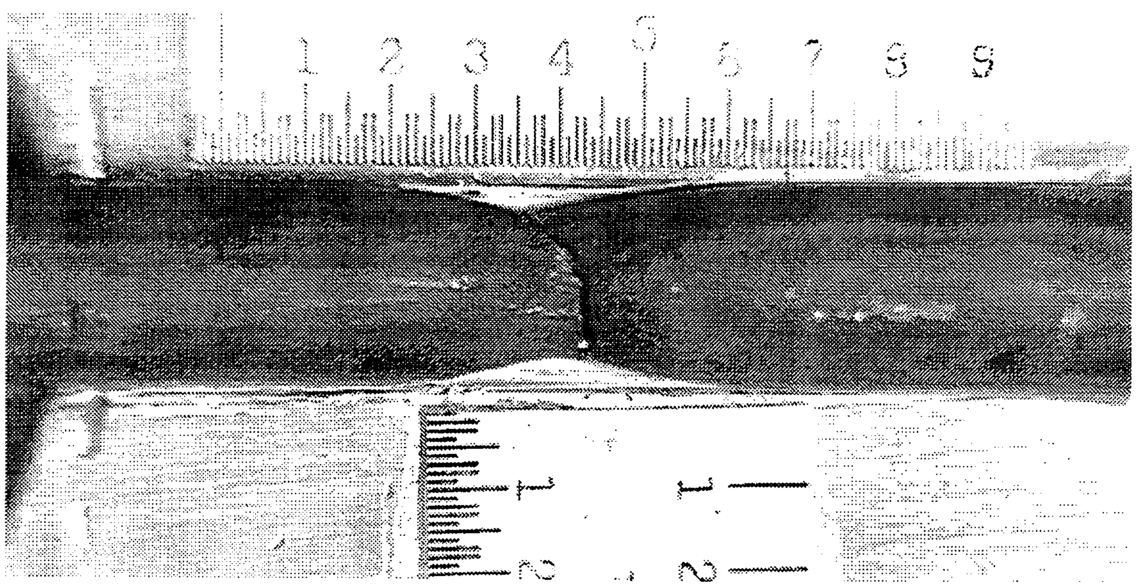


Specimen NT 14 Tested at 550°F

Figure 5-19 Fractured Tensile Specimens from Sequoyah Unit 2 Reactor Vessel Intermediate Shell Forging 05 (Axial Orientation)

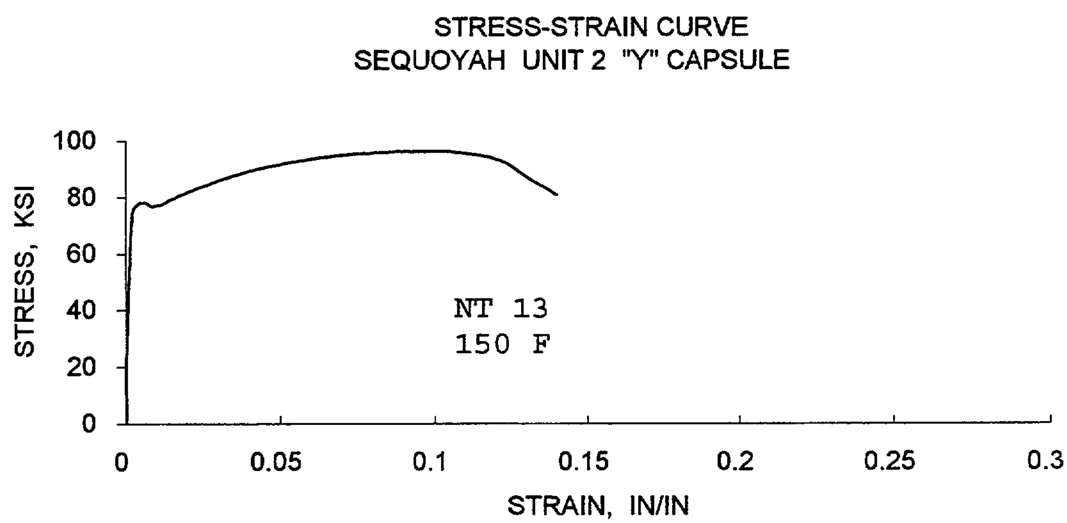


Specimen W13 Tested at 125°F



Specimen W14 Tested at 550°F

Figure 5-20 Fractured Tensile Specimens from Sequoyah Unit 2 Reactor Vessel Weld Metal



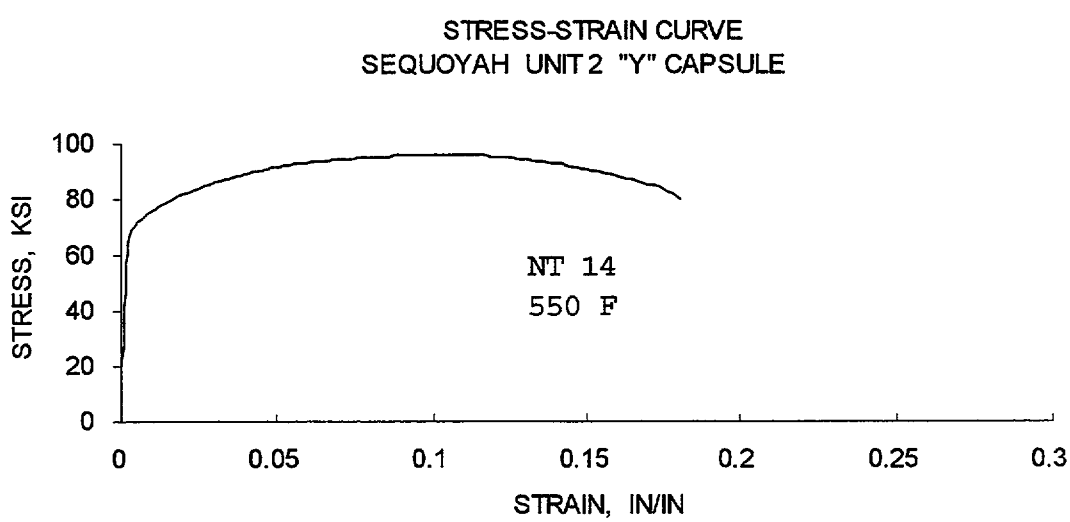
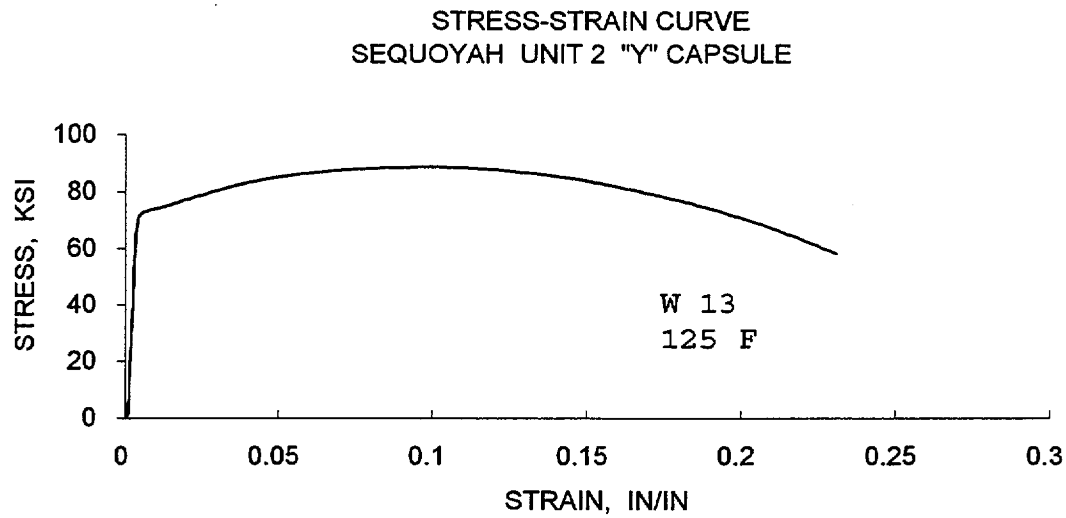


Figure 5-21 Engineering Stress-Strain Curves for Intermediate Shell Forging 05Tensile Specimens NT13 and NT14 (Axial Orientation)



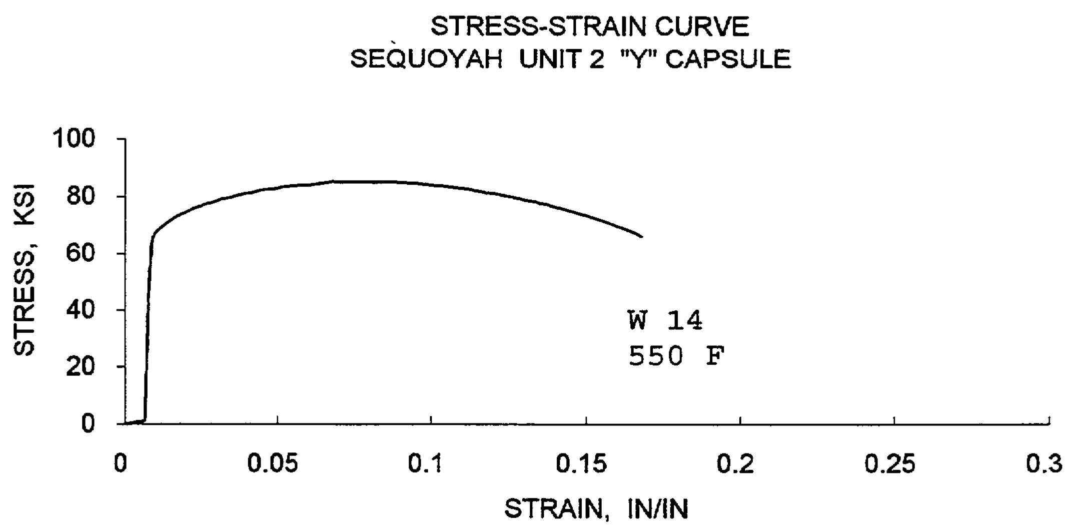


Figure 5-22 Engineering Stress-Strain Curves for Weld Metal Tensile Specimens W13 and W14

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 T, U, X, and Y which were withdrawn after the first, third, fifth, and ninth fuel cycles. This evaluation is based on current state-of-the-art methodology and nuclear data including neutron transport and dosimetry cross-section libraries derived from the ENDF/B-VI data base. This report provides a consistent up-to-date neutron exposure data base for use in evaluating the material properties of the Sequoyah Unit 2 reactor vessel.

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

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

6.2 Discrete Ordinates Analysis

A plan view of the reactor geometry at the core midplane is shown in Figure 4-1. Eight irradiation capsules attached to the thermal shield are included in the reactor design to constitute the reactor vessel surveillance program. The capsules are located at azimuthal angles of 4°, 40°, 140°, 176°, 184°, 220°, 320°, and 356° relative to the core cardinal axis as shown in Figure 4-1.

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

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

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

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

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

1. Evaluate neutron dosimetry obtained from surveillance capsules,

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

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

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

The two-dimensional r,θ forward transport calculation for the reactor model summarized in Figures 4-1 and 6-1 was carried out using the DORT two-dimensional discrete ordinates code Version 3.1[17] and the BUGLE-96 cross-section library [18]. The BUGLE-96 library is a 47 energy group ENDF/B-VI based data set produced specifically for light water reactor applications. In these analyses, anisotropic scattering was treated with a P_3 expansion of the scattering cross-sections and the angular discretization was modeled with an S_8 order of angular quadrature.

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

All adjoint calculations were also carried out using an S_8 order of angular quadrature and the P_3 cross-section approximation from the BUGLE-96 library. Adjoint source locations were chosen at several azimuthal locations along the reactor vessel inner radius as well as at the geometric center of each surveillance capsule. Again, these calculations were run in r,θ geometry to provide neutron source distribution importance functions for the exposure parameter of interest, in this case $\phi(E > 1.0 \text{ MeV})$.

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

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

where:

$R(r,\theta)$ = $\phi(E > 1.0 \text{ MeV})$ at radius r and azimuthal angle θ.

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

$S(r,\theta,E)$= Neutron source strength at core location r,θ and energy E.

Although the adjoint importance functions used in this analysis were based on a response function defined by the threshold neutron flux $\phi(E > 1.0 \text{ MeV})$, prior calculations [19] have shown that, while the implementation of low leakage loading patterns significantly impacts both the magnitude and spatial distribution of the neutron field, changes in the relative neutron energy spectrum are of second order. Thus, for a given location, the ratio of [dpa/sec]/[$\phi(E > 1.0 \text{ MeV})$] is insensitive to changing core source distributions. In the application of these adjoint importance functions to the Sequoyah Unit 2 reactor, therefore, the iron atom displacement rates (dpa/sec) and the neutron flux $\phi(E > 0.1 \text{ MeV})$ were computed on a cycle-specific basis by using [dpa/sec]/[$\phi(E > 1.0 \text{ MeV})$] and [$\phi(E > 0.1 \text{ MeV})$]/[$\phi(E > 1.0 \text{ MeV})$] ratios from the forward analysis in conjunction with the cycle specific $\phi(E > 1.0 \text{ MeV})$ solutions from the individual adjoint evaluations.

The reactor core power distributions used in the plant specific adjoint calculations were taken from fuel cycle design data for the first nine operating cycles of Sequoyah Unit 2 [20 through 28].

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 T, U, X, and Y irradiation periods and provide the means to correlate dosimetry results with the corresponding exposure of the reactor vessel wall.

In Table 6-1, the calculated exposure parameters [$\phi(E > 1.0 \text{ MeV})$, $\phi(E > 0.1 \text{ MeV})$, and dpa/sec] are given at the geometric center of the two azimuthally symmetric surveillance capsule positions (4° and 40°) for both the reference and the plant specific core power distributions. The plant-specific data, based on the adjoint transport analysis, are meant to establish the absolute comparison of measurement with analysis. The reference data derived from the forward calculation are provided as a conservative exposure evaluation against which plant specific fluence calculations can be compared. Similar data are given in Table 6-2 for the reactor vessel inner radius. Again, the three pertinent exposure parameters are listed for the reference and Cycles 1 to 9 plant specific power distributions.

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

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

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

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

where:

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

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

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

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

6.3 Neutron Dosimetry

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

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

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

The specific activity of each of the neutron monitors was determined using established ASTM procedures [29 through 42]. Following sample preparation and weighing, the activity of each monitor was determined by means of a lithium-drifted germanium, Ge(Li), gamma spectrometer. The irradiation history of the Sequoyah Unit 2 reactor was obtained from plant personnel[28] and data reported in NUREG-0020, "Licensed Operating Reactors Status Summary Report," for the Cycles 1 to 9 operating periods. The irradiation history applicable to the exposure of Capsules T, U, X, and Y is given in Table 6-7.

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

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

where:

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

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

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

For the irradiation history of Capsule T, U, X, and Y the flux level term in the reaction rate calculations was set to 1.0 for Capsule T only. Measured and saturated reaction product specific activities as well as the derived full power reaction rates are listed in Table 6-8. The measured values for Capsule T were taken from the previous Westinghouse report[2], and for Capsule U from a Southwest Research Institute report[3]. The measurements for Capsule X were corrected from those in the Capsule X report[4]. 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 include corrections for ^{235}U impurities, plutonium build-in, and gamma ray induced fissions. Corrections for gamma ray induced fissions were also included in the reaction rates for the ^{237}Np sensors.

Values of key fast neutron exposure parameters were derived from the measured reaction rates using the FERRET least squares adjustment code [43]. 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[44]. 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[45], were also collapsed into the 53 energy group structure using the SAND-II code. In this instance, the trial spectrum, as expanded to 620 groups, was employed as a weighting function in the cross-section collapsing procedure. Reaction cross-section uncertainties in the form of a 53 × 53 covariance matrix for each sensor reaction were also constructed from the information contained on the ENDF/B-VI data files. These matrices included energy group to energy group uncertainty correlations for each of the individual reactions. However, correlations between cross-sections for different sensor reactions were not included. The omission of this additional uncertainty information does not significantly impact the results of the adjustment.

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

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

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[46]. 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 T, U, X, and Y dosimetry are given in Table 6-9. The data summarized in this table include fast neutron exposure evaluations in terms of $\Phi(E > 1.0\ \text{MeV})$, $\Phi(E > 0.1\ \text{MeV})$, and dpa. In general, excellent results were achieved in the fits of the best estimate spectra to the individual measured reaction rates. The measured, calculated and best estimate reaction rates for each reaction are given in Table 6-10. An examination of Table 6-10 shows that, in all cases, reaction rates calculated with the best estimate spectra match the measured reaction rates to better than 15%. 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 T, U, X, and Y are presented. The results for the Capsules T, U, X, and Y dosimetry evaluation (BE/C ratio of 0.93 for $\Phi(E > 1.0\text{ MeV})$) 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 Sequoyah Unit 2 reactor vessel was developed using a combination of absolute plant specific transport calculations and all available plant specific measurement data. In the case of Sequoyah Unit 2, the measurement data base contains measurements from the four surveillance capsules discussed in this report.

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

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

where:

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

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

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

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

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

For Sequoyah Unit 2, the derived plant specific bias factors were 0.93, 0.98, 0.96 for $\Phi(E > 1.0\text{ MeV})$, $\Phi(E > 0.1\text{ MeV})$, 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 Sequoyah Unit 2, the derived uncertainties in the bias factor, K, and the additional uncertainty from the analytical sensitivity studies combine to yield a net uncertainty of $\pm$ 12.6%.

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 (10.54 EFPY) exposure, projections are also provided for exposure periods of 20, 32, and 48 EFPY. Projections for future operation were based on the assumption that the Cycles 5 through 9 exposure rates based on low leakage fuel management 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 Sequoyah Unit 2 reactor vessel, exposure projections to 20, 32, and 48 EFPY were also employed. Data based on both a $\Phi(E > 1.0\ MeV)$ slope and a plant-specific dpa slope through the vessel wall are provided in Table 6-14.

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

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

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

In Table 6-15, updated lead factors are listed for each of the Sequoyah Unit 2 surveillance capsules.

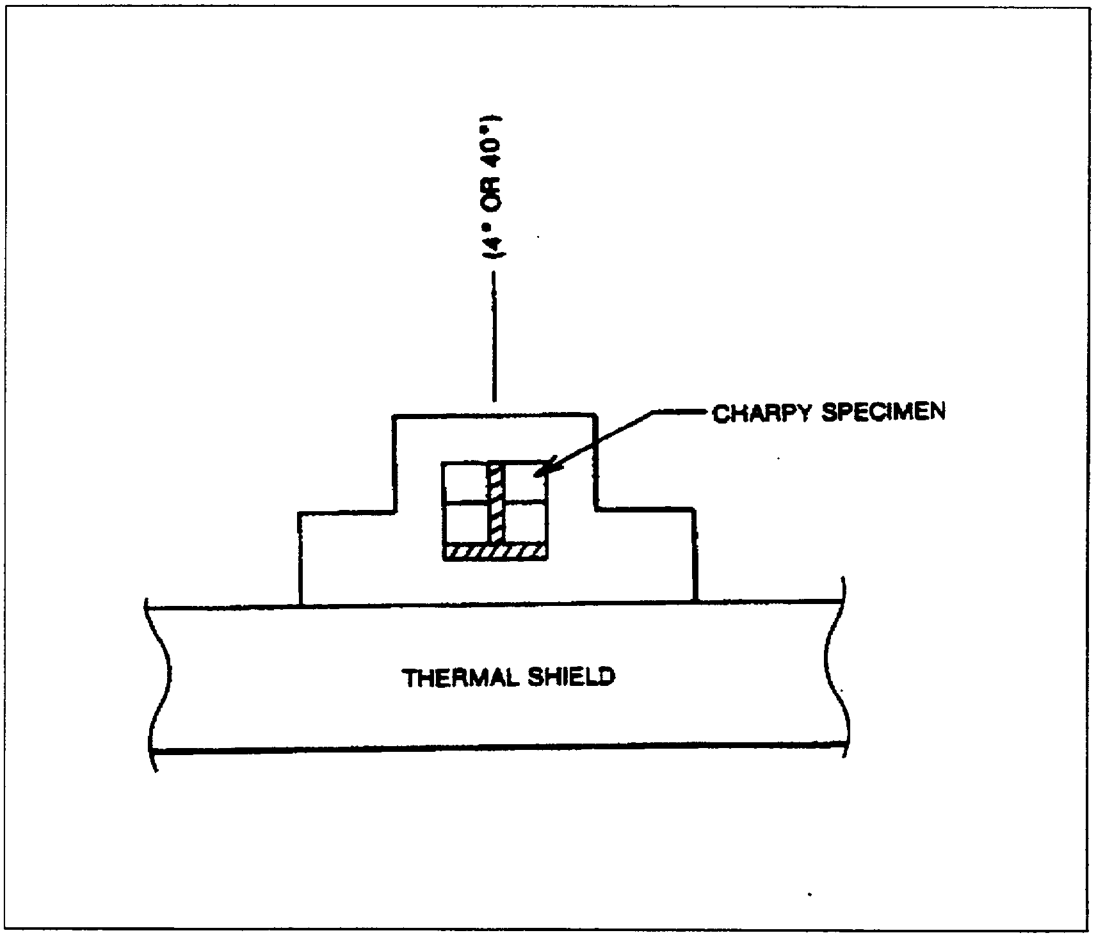


Figure 6-1. Reactor Vessel Surveillance Capsule

Table 6-1

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

	$\phi(E > 1.0\ MeV)$ (n/cm^2-sec)	
Cycle No.	4°	40°
Reference	3.23E+10	1.01E+11
1	2.46E+10	7.78E+10
2	2.49E+10	9.32E+10
3	3.01E+10	5.89E+10
4	2.08E+10	7.06E+10
5	2.04E+10	6.68E+10
6	2.08E+10	6.30E+10
7	1.84E+10	4.54E+10
8	1.65E+10	5.82E+10
9	1.51E+10	5.69E+10

	$\phi(E > 0.1\ MeV)$ (n/cm^2-sec)	
Cycle No.	4°	40°
Reference	9.29E+10	3.39E+11
1	7.07E+10	2.60E+11
2	7.17E+10	3.12E+11
3	8.68E+10	1.97E+11
4	5.99E+10	2.36E+11
5	5.87E+10	2.23E+11
6	5.99E+10	2.11E+11
7	5.29E+10	1.52E+11
8	4.75E+10	1.94E+11
9	4.34E+10	1.90E+11

	Iron Atom Displacement Rate (dpa/sec)	
Cycle No.	4°	40°
Reference	5.10E-11	1.68E-10
1	3.88E-11	1.29E-10
2	3.93E-11	1.55E-10
3	4.76E-11	9.77E-11
4	3.29E-11	1.17E-10
5	3.22E-11	1.11E-10
6	3.29E-11	1.05E-10
7	2.90E-11	7.53E-11
8	2.61E-11	9.65E-11
9	2.38E-11	9.43E-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

		ϕ(E > 1.0 MeV) (n/cm^2-sec)		
Cycle No.	0°	15°	30°	45°
Reference	9.55E+09	1.53E+10	1.89E+10	2.90E+10
1	7.59E+09	1.19E+10	1.52E+10	2.34E+10
2	7.41E+09	1.32E+10	1.71E+10	2.73E+10
3	8.94E+09	1.32E+10	1.34E+10	1.70E+10
4	6.23E+09	1.06E+10	1.36E+10	2.07E+10
5	6.14E+09	1.11E+10	1.38E+10	1.98E+10
6	6.49E+09	9.11E+09	1.22E+10	1.90E+10
7	5.71E+09	8.90E+09	1.02E+10	1.37E+10
8	5.15E+09	7.51E+09	1.06E+10	1.77E+10
9	4.69E+09	7.57E+09	1.13E+10	1.72E+10
		ϕ(E > 0.1 MeV) (n/cm^2-sec)		
Cycle No.	0°	15°	30°	45°
Reference	2.43E+10	3.86E+10	4.92E+10	7.76E+10
1	1.93E+10	3.01E+10	3.96E+10	6.25E+10
2	1.88E+10	3.35E+10	4.44E+10	7.29E+10
3	2.27E+10	3.34E+10	3.49E+10	4.54E+10
4	1.58E+10	2.67E+10	3.55E+10	5.55E+10
5	1.56E+10	2.80E+10	3.59E+10	5.31E+10
6	1.65E+10	2.30E+10	3.18E+10	5.08E+10
7	1.45E+10	2.25E+10	2.66E+10	3.68E+10
8	1.31E+10	1.90E+10	2.75E+10	4.74E+10
9	1.19E+10	1.92E+10	2.94E+10	4.61E+10
		Iron Atom Displacement Rate (dpa/sec)		
Cycle No.	0°	15°	30°	45°
Reference	1.55E-11	2.45E-11	3.05E-11	4.70E-11
1	1.23E-11	1.91E-11	2.46E-11	3.78E-11
2	1.20E-11	2.12E-11	2.75E-11	4.41E-11
3	1.45E-11	2.12E-11	2.17E-11	2.75E-11
4	1.01E-11	1.69E-11	2.20E-11	3.36E-11
5	9.96E-12	1.77E-11	2.23E-11	3.21E-11
6	1.05E-11	1.46E-11	1.97E-11	3.07E-11
7	9.27E-12	1.43E-11	1.65E-11	2.22E-11
8	8.36E-12	1.20E-11	1.71E-11	2.87E-11
9	7.61E-12	1.21E-11	1.82E-11	2.79E-11

Table 6-3

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

Radius	Azimuthal Angle			
(cm)	0°	15°	30°	45°
220.35	1.000	1.000	1.000	1.000
221.00	0.955	0.956	0.957	0.955
222.30	0.842	0.846	0.848	0.842
223.60	0.727	0.730	0.734	0.724
224.89	0.621	0.623	0.628	0.617
225.87	0.547	0.549	0.554	0.542
227.01	0.472	0.475	0.480	0.467
228.63	0.382	0.383	0.389	0.376
230.09	0.314	0.315	0.320	0.308
231.39	0.263	0.264	0.269	0.257
232.68	0.220	0.221	0.225	0.214
234.14	0.180	0.181	0.184	0.174
235.76	0.144	0.144	0.147	0.138
236.90	0.122	0.122	0.125	0.116
237.88	0.106	0.106	0.109	0.100
239.18	0.088	0.087	0.090	0.082
240.47	0.072	0.072	0.074	0.067
241.77	0.059	0.058	0.060	0.053
242.42	0.057	0.055	0.057	0.050

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

Table 6-4

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

Radius	Azimuthal Angle			
(cm)	0°	15°	30°	45°
220.35	1.000	1.000	1.000	1.000
221.00	1.010	1.007	1.010	1.006
222.30	0.993	0.987	0.994	0.982
223.60	0.955	0.945	0.957	0.937
224.89	0.908	0.894	0.910	0.884
225.87	0.869	0.854	0.873	0.842
227.01	0.822	0.807	0.827	0.792
228.63	0.757	0.740	0.762	0.723
230.09	0.699	0.681	0.705	0.662
231.39	0.648	0.630	0.654	0.608
232.68	0.597	0.581	0.605	0.556
234.14	0.542	0.527	0.550	0.500
235.76	0.484	0.470	0.492	0.441
236.90	0.444	0.431	0.453	0.400
237.88	0.409	0.398	0.418	0.364
239.18	0.364	0.355	0.374	0.319
240.47	0.322	0.313	0.330	0.275
241.77	0.280	0.269	0.284	0.229
242.42	0.272	0.259	0.274	0.219

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

Table 6-5

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

Radius (cm)	Azimuthal Angle 0°	15°	30°	45°
220.35	1.000	1.000	1.000	1.000
221.00	0.965	0.964	0.967	0.965
222.30	0.877	0.878	0.884	0.877
223.60	0.788	0.787	0.797	0.787
224.89	0.705	0.703	0.715	0.702
225.87	0.646	0.644	0.658	0.643
227.01	0.585	0.583	0.597	0.581
228.63	0.509	0.505	0.521	0.502
230.09	0.448	0.443	0.460	0.440
231.39	0.400	0.395	0.412	0.391
232.68	0.357	0.352	0.368	0.347
234.14	0.314	0.309	0.325	0.302
235.76	0.271	0.267	0.282	0.259
236.90	0.244	0.240	0.254	0.230
237.88	0.221	0.218	0.231	0.207
239.18	0.194	0.191	0.204	0.179
240.47	0.169	0.166	0.177	0.152
241.77	0.147	0.143	0.152	0.126
242.42	0.142	0.137	0.147	0.120

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

Table 6-6

Nuclear Parameters Used In The Evaluation Of Neutron Sensors

Monitor Material	Reaction of Interest	Target Atom Fraction	Response Range	Product Half-life	Fission Yield (%)
Copper	^{63}Cu (n,α)	0.6917	E > 4.7 MeV	5.271 y	
Iron	^{54}Fe (n,p)	0.0585	E > 1.0 MeV	312.3 d	
Nickel	^{58}Ni (n,p)	0.6808	E > 1.0 MeV	70.82 d	
Uranium-238	^{238}U (n,f)	0.9996	E > 0.4 MeV	30.07 y	6.02
Neptunium-237	^{237}Np (n,f)	1.0000	E > 0.08 MeV	30.07 y	6.17
Cobalt-Al	^{59}Co (n,γ)	0.0015	non-threshold	5.271 y	

Notes:
1. ^{238}U and ^{237}Np monitors are cadmium shielded.

Table 6-7

Monthly Thermal Generation During The First Nine Fuel Cycles
Of The Sequoyah Unit 2 Reactor
(Reactor Power of 3411 MWt)

Year	Month	Thermal Generat. (MW-hr)	Year	Month	Thermal Generat. (MW-hr)	Year	Month	Thermal Generat. (MW-hr)
1981	11	3200	1985	1	2002236	1988	3	0
1981	12	12713	1985	2	2069227	1988	4	0
1982	1	244601	1985	3	2532201	1988	5	780704.0
1982	2	544637	1985	4	2449796	1988	6	820272.0
1982	3	942115	1985	5	1401909	1988	7	2050019.0
1982	4	1611435	1985	6	2444832	1988	8	2459410.0
1982	5	943376	1985	7	2535401	1988	9	1870207.0
1982	6	1918281	1985	8	1693363	1988	10	1625160.0
1982	7	2498077	1985	9	0	1988	11	1533273.0
1982	8	2386212	1985	10	0	1988	12	1458074.0
1982	9	2079585	1985	11	0	1989	1	1014187.0
1982	10	2282698	1985	12	0	1989	2	0.0
1982	11	957633	1986	1	0	1989	3	0.0
1982	12	32105	1986	2	0	1989	4	98400.0
1983	1	2203657	1986	3	0	1989	5	2208995.0
1983	2	2240493	1986	4	0	1989	6	2433673.0
1983	3	2422686	1986	5	0	1989	7	1959789.0
1983	4	2411559	1986	6	0	1989	8	2532338.0
1983	5	2490822	1986	7	0	1989	9	2451049.0
1983	6	2216622	1986	8	0	1989	10	2122206.0
1983	7	1415930	1986	9	0	1989	11	1474580.0
1983	8	0	1986	10	0	1989	12	2390942.0
1983	9	0	1986	11	0	1990	1	2369133.0
1983	10	950094	1986	12	0	1990	2	2287291.0
1983	11	1375955	1987	1	0	1990	3	2491759.0
1983	12	2535658	1987	2	0	1990	4	2242121.0
1984	1	2535537	1987	3	0	1990	5	2509824.0
1984	2	2077520	1987	4	0	1990	6	2437716.0
1984	3	2535289	1987	5	0	1990	7	2487333.0
1984	4	2449814	1987	6	0	1990	8	2046158.0
1984	5	2287795	1987	7	0	1990	9	397459.0
1984	6	2360139	1987	8	0	1990	10	0.0
1984	7	2105415	1987	9	0	1990	11	180336.0
1984	8	1626829	1987	10	0	1990	12	2415061.0
1984	9	1471238	1987	11	0	1991	1	2316660.0
1984	10	0	1987	12	0	1991	2	2287530.0
1984	11	0	1988	1	0	1991	3	2525809.0
1984	12	131366	1988	2	0	1991	4	2449233.0

Table 6-7 Cont'd

Monthly Thermal Generation During The First Seven Fuel Cycles
Of The Sequoyah Unit 2 Reactor
(Reactor Power of 3411 MWt)

Year	Month	Thermal Generat. (MW-hr)	Year	Month	Thermal Generat. (MW-hr)	Year	Month	Thermal Generat. (MW-hr)
1991	5	2534992.0	1994	7	243427.2	1997	9	2017336.8
1991	6	2414990.0	1994	8	0.0	1997	10	236974.7
1991	7	2533273.0	1994	9	0.0	1997	11	1624643.1
1991	8	2533075.0	1994	10	0.0	1997	12	2536141.2
1991	9	2452746.0	1994	11	944910.6	1998	1	2536128.0
1991	10	2538138.0	1994	12	2533659.8	1998	2	2290303.2
1991	11	1567577.0	1995	1	2198286.6	1998	3	2536159.2
1991	12	2498839.0	1995	2	2275606.6	1998	4	2450780.7
1992	1	2526794.0	1995	3	2500844.1	1998	5	2534445.6
1992	2	1840863.0	1995	4	675051.7	1998	6	2451816.0
1992	3	793075.0	1995	5	2374780.1	1998	7	2536041.6
1992	4	0.0	1995	6	2276770.1	1998	8	2228728.9
1992	5	870008.0	1995	7	2522066.4	1998	9	2453376.0
1992	6	2311008.0	1995	8	2522935.2	1998	10	2422529.9
1992	7	2532047.0	1995	9	2446665.6	1998	11	2454100.8
1992	8	2177489.0	1995	10	2540266.6	1998	12	2535727.2
1992	9	2110368.0	1995	11	2453022.6	1999	1	2535712.8
1992	10	2252338.0	1995	12	2227837.1	1999	2	2261901.6
1992	11	2377580.0	1996	1	2535347.7	1999	3	2064134.4
1992	12	2462897.0	1996	2	2369838.7	1999	4	925462.8
1993	1	1516520.0	1996	3	2532090.0			
1993	2	2208422.0	1996	4	1515095.1			
1993	3	48365.0	1996	5	0.0			
1993	4	0.0	1996	6	1497931.7			
1993	5	0.0	1996	7	2535257.0			
1993	6	0.0	1996	8	2535479.4			
1993	7	0.0	1996	9	2451437.8			
1993	8	0.0	1996	10	843363.6			
1993	9	0.0	1996	11	2093736.4			
1993	10	137773.5	1996	12	2288480.3			
1993	11	1401901.4	1997	1	2535876.0			
1993	12	1268193.4	1997	2	2279443.2			
1994	1	2081774.4	1997	3	2504371.2			
1994	2	2270829.8	1997	4	2449341.5			
1994	3	2530829.3	1997	5	2535176.0			
1994	4	2444780.5	1997	6	2315918.4			
1994	5	2535186.2	1997	7	2405695.2			
1994	6	2179111.9	1997	8	2496364.8			

Table 6-8

Measured Sensor Activities And Reaction Rates

Surveillance Capsule T

Reaction	Location	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	Top-Mid	3.88E+04	3.14E+05	4.58E-17
	Middle	3.91E+04	3.16E+05	4.61E-17
	Bot-Mid	4.06E+04	3.29E+05	4.79E-17
^{54}Fe (n,p) ^{54}Mn	Top	1.23E+06	2.95E+06	4.92E-15
	Top-Mid	1.24E+06	2.98E+06	4.96E-15
	Middle	1.23E+06	2.95E+06	4.92E-15
	Bot-Mid	1.26E+06	3.02E+06	5.04E-15
	Bottom	1.27E+06	3.05E+06	5.08E-15
^{58}Ni (n,p) ^{58}Co	Top-Mid	1.16E+07	4.08E+07	6.76E-15
	Middle	1.14E+07	4.03E+07	6.67E-15
	Bot-Mid	1.19E+07	4.19E+07	6.94E-15
^{59}Co (n,γ) ^{60}Co	Top	7.37E+06	5.97E+07	3.79E-12
	Bottom	7.29E+06	5.90E+07	3.75E-12
^{59}Co (n,γ) ^{60}Co (Cd)	Top	2.93E+06	2.37E+07	1.78E-12
	Bottom	2.86E+06	2.32E+07	1.74E-12
^{238}U (n,f) ^{137}Cs	Middle	1.17E+05	4.87E+06	3.20E-14
^{238}U (n,f) ^{137}Cs	Including ^{235}U, ^{239}Pu, and γ,fission corrections			2.68E-14
^{237}Np (n,f) ^{137}Cs	Middle	9.22E+05	3.84E+07	2.45E-13
^{237}Np (n,f) ^{137}Cs	Including γ,fission correction			2.41E-13

Table 6-8 cont'd

Measured Sensor Activities And Reaction Rates

Surveillance Capsule U

Reaction	Location	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	Top-Mid	6.93E+04	3.21E+05	4.68E-17
	Middle	6.81E+04	3.15E+05	4.59E-17
	Bot-Mid	6.97E+04	3.23E+05	4.70E-17
^{54}Fe (n,p) ^{54}Mn	Top	7.15E+05	2.72E+06	4.52E-15
	Top-Mid	7.10E+05	2.70E+06	4.49E-15
	Middle	6.94E+05	2.64E+06	4.39E-15
	Bot-Mid	7.05E+05	2.68E+06	4.46E-15
	Bottom	6.90E+05	2.62E+06	4.37E-15
^{58}Ni (n,p) ^{58}Co	Top-Mid	1.77E+07	3.76E+07	6.22E-15
	Middle	1.69E+07	3.59E+07	5.94E-15
	Bot-Mid	1.77E+07	3.76E+07	6.22E-15
^{59}Co (n,γ) ^{60}Co	Top	8.13E+09	3.77E+10	3.59E-12
	Bottom	7.40E+09	3.43E+10	3.27E-12
^{59}Co (n,γ) ^{60}Co (Cd)	Top	3.35E+09	1.55E+10	1.75E-12
	Bottom	3.12E+09	1.45E+10	1.63E-12
^{238}U (n,f) ^{137}Cs	Middle	2.13E+05	3.53E+06	2.32E-14
^{238}U (n,f) ^{137}Cs	Including ^{235}U, ^{239}Pu, and γ,fission corrections			2.22E-14
^{237}Np (n,f) ^{137}Cs	Middle	1.91E+06	3.16E+07	2.02E-13
^{237}Np (n,f) ^{137}Cs	Including γ,fission correction			1.99E-13

Table 6-8 cont'd

Measured Sensor Activities And Reaction Rates

Surveillance Capsule X

Reaction	Location	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	Top-Mid	1.12E+05	2.84E+05	4.14E-17
	Middle	1.13E+05	2.86E+05	4.17E-17
	Bot-Mid	1.15E+05	2.92E+05	4.25E-17
^{54}Fe (n,p) ^{54}Mn	Top	1.63E+06	2.49E+06	4.15E-15
	Middle	1.61E+06	2.46E+06	4.10E-15
	Bot-Mid	1.65E+06	2.52E+06	4.20E-15
	Bottom	1.64E+06	2.50E+06	4.17E-15
^{58}Ni (n,p) ^{58}Co	Top-Mid	1.46E+07	3.34E+07	5.52E-15
	Middle	1.45E+07	3.31E+07	5.49E-15
	Bot-Mid	1.52E+07	3.47E+07	5.75E-15
^{59}Co (n,γ) ^{60}Co	Top	1.88E+07	4.77E+07	3.03E-12
	Bottom	1.86E+07	4.72E+07	3.00E-12
^{59}Co (n,γ) ^{60}Co (Cd)	Top	7.82E+06	1.98E+07	1.49E-12
	Bottom	7.43E+06	1.88E+07	1.42E-12
^{238}U (n,f) ^{137}Cs	Middle	4.41E+05	4.01E+06	2.63E-14
^{238}U (n,f) ^{137}Cs	Including ^{235}U, ^{239}Pu, and γ,fission corrections			2.11E-14
^{237}Np (n,f) ^{137}Cs	Middle	3.21E+06	2.92E+07	1.86E-13
^{237}Np (n,f) ^{137}Cs	Including γ,fission correction			1.83E-13

Table 6-8 cont'd

Measured Sensor Activities And Reaction Rates

Surveillance Capsule Y

Reaction	Location	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	Top-Mid	1.46E+05	2.59E+05	3.77E-17
	Middle	1.42E+05	2.52E+05	3.67E-17
	Bot-Mid	1.50E+05	2.66E+05	3.87E-17
$^{54}Fe\ (n,p)\ ^{54}Mn$	Top	1.51E+06	2.39E+06	3.97E-15
	Top-Mid	1.53E+06	2.42E+06	4.03E-15
	Middle	1.45E+06	2.29E+06	3.82E-15
	Bot-Mid	1.52E+06	2.40E+06	4.00E-15
	Bottom	1.49E+06	2.35E+06	3.92E-15
$^{58}Ni\ (n,p)\ ^{58}Co$	Top-Mid	9.83E+06	3.29E+07	5.45E-15
	Middle	9.34E+06	3.13E+07	5.18E-15
	Bot-Mid	9.82E+06	3.29E+07	5.44E-15
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Top	2.32E+07	4.11E+07	2.61E-12
	Bottom	2.36E+07	4.18E+07	2.66E-12
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)	Top	9.51E+06	1.69E+07	1.27E-12
	Bottom	9.40E+06	1.67E+07	1.25E-12
$^{238}U\ (n,f)\ ^{137}Cs$	Middle	1.03E+06	5.12E+06	3.37E-14
$^{238}U\ (n,f)\ ^{137}Cs$	Including ^{235}U, ^{239}Pu, and γ,fission corrections			2.59E-14
$^{237}Np\ (n,f)\ ^{137}Cs$	Middle	7.03E+06	3.50E+07	2.23E-13
$^{237}Np\ (n,f)\ ^{137}Cs$	Including γ,fission correction			2.20E-13

Table 6-9

Summary Of Neutron Dosimetry Results
Surveillance Capsules T, U, X, and Y

Best Estimate Flux and Fluence for Capsule T

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	Uncertainty
ϕ (E > 1.0 MeV)	7.64E+10	Φ (E > 1.0 MeV)	2.57E+18	6%
ϕ (E > 0.1 MeV)	2.67E+11	Φ (E > 0.1 MeV)	8.98E+18	10%
ϕ (E < 0.414 eV)	7.68E+10	Φ (E < 0.414 eV)	2.58E+18	13%
dpa/sec	1.30E-10	dpa	4.36E-03	7%

Best Estimate Flux and Fluence for Capsule U

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	Uncertainty
ϕ (E > 1.0 MeV)	6.57E+10	Φ (E > 1.0 MeV)	6.03E+18	6%
ϕ (E > 0.1 MeV)	2.30E+11	Φ (E > 0.1 MeV)	2.11E+19	10%
ϕ (E < 0.414 eV)	6.73E+10	Φ (E < 0.414 eV)	6.18E+18	14%
dpa/sec	1.12E-10	dpa	1.03E-02	7%

Best Estimate Flux and Fluence for Capsule X

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	Uncertainty
ϕ (E > 1.0 MeV)	6.12E+10	Φ (E > 1.0 MeV)	1.04E+19	6%
ϕ (E > 0.1 MeV)	2.14E+11	Φ (E > 0.1 MeV)	3.63E+19	10%
ϕ (E < 0.414 eV)	6.05E+10	Φ (E < 0.414 eV)	1.02E+19	14%
dpa/sec	1.05E-10	dpa	1.77E-02	7%

Best Estimate Flux and Fluence for Capsule Y

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	Uncertainty
ϕ (E > 1.0 MeV)	6.54E+10	Φ (E > 1.0 MeV)	2.18E+19	6%
ϕ (E > 0.1 MeV)	2.32E+11	Φ (E > 0.1 MeV)	7.72E+19	10%
ϕ (E < 0.414 eV)	5.38E+10	Φ (E < 0.414 eV)	1.79E+19	14%
dpa/sec	1.11E-10	dpa	3.70E-02	7%

Table 6-10

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

Surveillance Capsule T

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,α)	4.66E-17	4.72E-17	4.57E-17	0.98	0.97	0.99
^{54}Fe (n,p)	4.98E-15	5.37E-15	5.08E-15	1.02	0.95	0.93
^{58}Ni (n,p)	6.79E-15	7.40E-15	6.99E-15	1.03	0.94	0.92
^{238}U (n,f) (Cd)	2.68E-14	2.68E-14	2.60E-14	0.97	0.97	1.00
^{237}Np (n,f) (Cd)	2.41E-13	2.11E-13	2.25E-13	0.93	1.07	1.14
^{59}Co (n,γ)	3.77E-12	3.33E-12	3.76E-12	1.00	1.13	1.13
^{59}Co (n,γ) (Cd)	1.76E-12	1.63E-12	1.76E-12	1.00	1.08	1.08

Surveillance Capsule U

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,α)	4.66E-17	4.58E-17	4.45E-17	0.95	0.97	1.02
^{54}Fe (n,p)	4.45E-15	5.20E-15	4.59E-15	1.03	0.88	0.86
^{58}Ni (n,p)	6.13E-15	7.17E-15	6.30E-15	1.03	0.88	0.85
^{238}U (n,f) (Cd)	2.22E-14	2.60E-14	2.27E-14	1.02	0.87	0.85
^{237}Np (n,f) (Cd)	1.99E-13	2.04E-13	1.89E-13	0.95	0.93	0.98
^{59}Co (n,γ)	3.43E-12	3.23E-12	3.42E-12	1.00	1.06	1.06
^{59}Co (n,γ) (Cd)	1.69E-12	1.58E-12	1.69E-12	1.00	1.07	1.07

Surveillance Capsule X

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,α)	4.18E-17	4.39E-17	4.03E-17	0.96	0.92	0.95
^{54}Fe (n,p)	4.15E-15	4.99E-15	4.24E-15	1.02	0.85	0.83
^{58}Ni (n,p)	5.59E-15	6.88E-15	5.79E-15	1.04	0.84	0.81
^{238}U (n,f) (Cd)	2.11E-14	2.49E-14	2.11E-14	1.00	0.85	0.85
^{237}Np (n,f) (Cd)	1.83E-13	1.96E-13	1.75E-13	0.96	0.89	0.93
^{59}Co (n,γ)	3.01E-12	3.10E-12	3.01E-12	1.00	0.97	0.97
^{59}Co (n,γ) (Cd)	1.45E-12	1.52E-12	1.45E-12	1.00	0.95	0.95

Surveillance Capsule Y

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,α)	3.77E-17	3.90E-17	3.66E-17	0.97	0.94	0.97
^{54}Fe (n,p)	3.95E-15	4.43E-15	4.12E-15	1.04	0.93	0.89
^{58}Ni (n,p)	5.36E-15	6.11E-15	5.67E-15	1.06	0.93	0.88
^{238}U (n,f) (Cd)	2.59E-14	2.21E-14	2.19E-14	0.85	0.99	1.17
^{237}Np (n,f) (Cd)	2.20E-13	1.74E-13	2.00E-13	0.91	1.15	1.26
^{59}Co (n,γ)	2.63E-12	2.75E-12	2.64E-12	1.00	0.96	0.96
^{59}Co (n,γ) (Cd)	1.26E-12	1.35E-12	1.26E-12	1.00	0.93	0.93

Table 6-11

Best Estimate Neutron Energy Spectrum At The
Center Of Surveillance Capsules

Capsule T

Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	5.72E+06	28	9.12E-03	1.23E+10
2	1.49E+01	1.23E+07	29	5.53E-03	1.27E+10
3	1.35E+01	4.53E+07	30	3.36E-03	4.02E+09
4	1.16E+01	1.25E+08	31	2.84E-03	3.91E+09
5	1.00E+01	2.87E+08	32	2.40E-03	3.88E+09
6	8.61E+00	5.10E+08	33	2.04E-03	1.19E+10
7	7.41E+00	1.26E+09	34	1.23E-03	1.25E+10
8	6.07E+00	1.98E+09	35	7.49E-04	1.21E+10
9	4.97E+00	4.17E+09	36	4.54E-04	1.03E+10
10	3.68E+00	4.91E+09	37	2.75E-04	1.18E+10
11	2.87E+00	9.43E+09	38	1.67E-04	1.27E+10
12	2.23E+00	1.21E+10	39	1.01E-04	1.24E+10
13	1.74E+00	1.59E+10	40	6.14E-05	1.24E+10
14	1.35E+00	1.61E+10	41	3.73E-05	1.22E+10
15	1.11E+00	2.80E+10	42	2.26E-05	1.18E+10
16	8.21E-01	2.83E+10	43	1.37E-05	1.14E+10
17	6.39E-01	3.06E+10	44	8.32E-06	1.09E+10
18	4.98E-01	1.93E+10	45	5.04E-06	1.03E+10
19	3.88E-01	2.73E+10	46	3.06E-06	1.00E+10
20	3.02E-01	3.20E+10	47	1.86E-06	9.51E+09
21	1.83E-01	3.04E+10	48	1.13E-06	6.70E+09
22	1.11E-01	2.04E+10	49	6.83E-07	7.04E+09
23	6.74E-02	1.86E+10	50	4.14E-07	1.30E+10
24	4.09E-02	1.06E+10	51	2.51E-07	1.22E+10
25	2.55E-02	1.12E+10	52	1.52E-07	1.14E+10
26	1.99E-02	6.30E+09	53	9.24E-08	4.02E+10
27	1.50E-02	1.15E+10			

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

Table 6-11 cont'd

Best Estimate Neutron Energy Spectrum At The Center Of Surveillance Capsules

Capsule U

Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	5.73E+06	28	9.12E-03	1.15E+10
2	1.49E+01	1.23E+07	29	5.53E-03	1.18E+10
3	1.35E+01	4.53E+07	30	3.36E-03	3.75E+09
4	1.16E+01	1.24E+08	31	2.84E-03	3.66E+09
5	1.00E+01	2.82E+08	32	2.40E-03	3.64E+09
6	8.61E+00	4.93E+08	33	2.04E-03	1.12E+10
7	7.41E+00	1.20E+09	34	1.23E-03	1.18E+10
8	6.07E+00	1.83E+09	35	7.49E-04	1.14E+10
9	4.97E+00	3.76E+09	36	4.54E-04	9.75E+09
10	3.68E+00	4.34E+09	37	2.75E-04	1.12E+10
11	2.87E+00	8.17E+09	38	1.67E-04	1.22E+10
12	2.23E+00	1.03E+10	39	1.01E-04	1.18E+10
13	1.74E+00	1.35E+10	40	6.14E-05	1.17E+10
14	1.35E+00	1.36E+10	41	3.73E-05	1.15E+10
15	1.11E+00	2.35E+10	42	2.26E-05	1.12E+10
16	8.21E-01	2.39E+10	43	1.37E-05	1.07E+10
17	6.39E-01	2.60E+10	44	8.32E-06	1.02E+10
18	4.98E-01	1.65E+10	45	5.04E-06	9.66E+09
19	3.88E-01	2.36E+10	46	3.06E-06	9.38E+09
20	3.02E-01	2.80E+10	47	1.86E-06	8.88E+09
21	1.83E-01	2.70E+10	48	1.13E-06	6.25E+09
22	1.11E-01	1.82E+10	49	6.83E-07	6.48E+09
23	6.74E-02	1.68E+10	50	4.14E-07	1.18E+10
24	4.09E-02	9.68E+09	51	2.51E-07	1.09E+10
25	2.55E-02	1.03E+10	52	1.52E-07	1.01E+10
26	1.99E-02	5.81E+09	53	9.24E-08	3.45E+10
27	1.50E-02	1.06E+10			

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

Table 6-11 cont'd

Best Estimate Neutron Energy Spectrum At The
Center Of Surveillance Capsules

Capsule X

Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	5.17E+06	28	9.12E-03	1.05E+10
2	1.49E+01	1.11E+07	29	5.53E-03	1.08E+10
3	1.35E+01	4.09E+07	30	3.36E-03	3.44E+09
4	1.16E+01	1.12E+08	31	2.84E-03	3.34E+09
5	1.00E+01	2.55E+08	32	2.40E-03	3.31E+09
6	8.61E+00	4.48E+08	33	2.04E-03	1.02E+10
7	7.41E+00	1.09E+09	34	1.23E-03	1.06E+10
8	6.07E+00	1.68E+09	35	7.49E-04	1.02E+10
9	4.97E+00	3.47E+09	36	4.54E-04	8.63E+09
10	3.68E+00	4.02E+09	37	2.75E-04	9.88E+09
11	2.87E+00	7.61E+09	38	1.67E-04	1.04E+10
12	2.23E+00	9.64E+09	39	1.01E-04	1.04E+10
13	1.74E+00	1.26E+10	40	6.14E-05	1.03E+10
14	1.35E+00	1.27E+10	41	3.73E-05	1.02E+10
15	1.11E+00	2.20E+10	42	2.26E-05	9.96E+09
16	8.21E-01	2.24E+10	43	1.37E-05	9.63E+09
17	6.39E-01	2.43E+10	44	8.32E-06	9.20E+09
18	4.98E-01	1.54E+10	45	5.04E-06	8.73E+09
19	3.88E-01	2.20E+10	46	3.06E-06	8.50E+09
20	3.02E-01	2.60E+10	47	1.86E-06	8.08E+09
21	1.83E-01	2.50E+10	48	1.13E-06	5.69E+09
22	1.11E-01	1.69E+10	49	6.83E-07	5.88E+09
23	6.74E-02	1.56E+10	50	4.14E-07	1.07E+10
24	4.09E-02	8.94E+09	51	2.51E-07	9.87E+09
25	2.55E-02	9.50E+09	52	1.52E-07	9.13E+09
26	1.99E-02	5.36E+09	53	9.24E-08	3.08E+10
27	1.50E-02	9.78E+09			

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

Table 6-11 cont'd

Best Estimate Neutron Energy Spectrum At The Center Of Surveillance Capsules

Capsule Y

Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	4.56E+06	28	9.12E-03	1.01E+10
2	1.49E+01	9.73E+06	29	5.53E-03	1.03E+10
3	1.35E+01	3.59E+07	30	3.36E-03	3.24E+09
4	1.16E+01	9.89E+07	31	2.84E-03	3.12E+09
5	1.00E+01	2.27E+08	32	2.40E-03	3.08E+09
6	8.61E+00	4.05E+08	33	2.04E-03	9.38E+09
7	7.41E+00	1.01E+09	34	1.23E-03	9.66E+09
8	6.07E+00	1.59E+09	35	7.49E-04	9.24E+09
9	4.97E+00	3.38E+09	36	4.54E-04	7.76E+09
10	3.68E+00	4.05E+09	37	2.75E-04	8.81E+09
11	2.87E+00	7.92E+09	38	1.67E-04	8.92E+09
12	2.23E+00	1.04E+10	39	1.01E-04	9.20E+09
13	1.74E+00	1.38E+10	40	6.14E-05	9.24E+09
14	1.35E+00	1.41E+10	41	3.73E-05	9.19E+09
15	1.11E+00	2.46E+10	42	2.26E-05	9.02E+09
16	8.21E-01	2.50E+10	43	1.37E-05	8.78E+09
17	6.39E-01	2.70E+10	44	8.32E-06	8.42E+09
18	4.98E-01	1.70E+10	45	5.04E-06	8.03E+09
19	3.88E-01	2.39E+10	46	3.06E-06	7.83E+09
20	3.02E-01	2.78E+10	47	1.86E-06	7.45E+09
21	1.83E-01	2.62E+10	48	1.13E-06	5.27E+09
22	1.11E-01	1.74E+10	49	6.83E-07	5.37E+09
23	6.74E-02	1.57E+10	50	4.14E-07	9.69E+09
24	4.09E-02	8.91E+09	51	2.51E-07	8.90E+09
25	2.55E-02	9.33E+09	52	1.52E-07	8.19E+09
26	1.99E-02	5.20E+09	53	9.24E-08	2.70E+10
27	1.50E-02	9.41E+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 Sequoyah Unit 2 Surveillance Capsules T, U, X, and Y

CAPSULE T

	Calculated	Best Estimate	BE/C
Φ(E > 1.0 MeV) [n/cm^2]	2.61E+18	2.57E+18	0.98
Φ(E > 0.1 MeV) [n/cm^2]	8.74E+18	8.98E+18	1.03
dpa	4.34E-03	4.36E-03	1.01

CAPSULE U

	Calculated	Best Estimate	BE/C
Φ(E > 1.0 MeV) [n/cm^2]	6.92E+18	6.03E+18	0.87
Φ(E > 0.1 MeV) [n/cm^2]	2.31E+19	2.11E+19	0.91
dpa	1.15E-02	1.03E-02	0.90

CAPSULE X

	Calculated	Best Estimate	BE/C
Φ(E > 1.0 MeV) [n/cm^2]	1.22E+19	1.04E+19	0.85
Φ(E > 0.1 MeV) [n/cm^2]	4.09E+19	3.63E+19	0.89
dpa	2.03E-02	1.77E-02	0.87

CAPSULE Y

	Calculated	Best Estimate	BE/C
Φ(E > 1.0 MeV) [n/cm^2]	2.14E+19	2.18E+19	1.02
Φ(E > 0.1 MeV) [n/cm^2]	7.14E+19	7.72E+19	1.08
dpa	3.54E-02	3.70E-02	1.05

AVERAGE BE/C RATIOS

	BE/C
Φ(E > 1.0 MeV) [n/cm^2]	0.93
Φ(E > 0.1 MeV) [n/cm^2]	0.98
dpa	0.96

Table 6-13

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

Best Estimate

	0°	15°	30°	45°[a]
10.54 EFPY				
E>1.0 MeV	1.97E+18	3.12E+18	3.96E+18	5.92E+18
E>0.1 MeV	5.25E+18	8.31E+18	1.08E+19	1.67E+19
dpa	3.28E-03	5.14E-03	6.56E-03	9.84E-03
20 EFPY				
E>1.0 MeV	3.53E+18	5.58E+18	7.18E+18	1.08E+19
E>0.1 MeV	9.43E+18	1.48E+19	1.97E+19	3.03E+19
dpa	5.88E-03	9.18E-03	1.19E-02	1.79E-02
32 EFPY				
E>1.0 MeV	5.52E+18	8.69E+18	1.13E+19	1.70E+19
E>0.1 MeV	1.47E+19	2.31E+19	3.08E+19	4.77E+19
dpa	9.19E-03	1.43E-02	1.87E-02	2.82E-02
48 EFPY				
E>1.0 MeV	8.16E+18	1.28E+19	1.67E+19	2.52E+19
E>0.1 MeV	2.18E+19	3.41E+19	4.58E+19	7.08E+19
dpa	1.36E-02	2.11E-02	2.77E-02	4.18E-02

Note:
a) Maximum neutron exposure projection

Table 6-13, cont'd

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

Calculated

	0°	15°	30°	45°[a]
10.54 EFPY				
E>1.0 MeV	2.11E+18	3.36E+18	4.26E+18	6.37E+18
E>0.1 MeV	5.37E+18	8.50E+18	1.11E+19	1.70E+19
dpa	3.43E-03	5.39E-03	6.88E-03	1.03E-02
20 EFPY				
E>1.0 MeV	3.80E+18	6.00E+18	7.73E+18	1.16E+19
E>0.1 MeV	9.65E+18	1.52E+19	2.01E+19	3.10E+19
dpa	6.16E-03	9.61E-03	1.25E-02	1.88E-02
32 EFPY				
E>1.0 MeV	5.93E+18	9.34E+18	1.21E+19	1.82E+19
E>0.1 MeV	1.51E+19	2.36E+19	3.16E+19	4.88E+19
dpa	9.63E-03	1.50E-02	1.96E-02	2.95E-02
48 EFPY				
E>1.0 MeV	8.78E+18	1.38E+19	1.80E+19	2.71E+19
E>0.1 MeV	2.23E+19	3.49E+19	4.68E+19	7.24E+19
dpa	1.42E-02	2.21E-02	2.91E-02	4.38E-02

Note:
a) Maximum neutron exposure projection

Table 6-14

Neutron Exposure Values Within The
Sequoyah Unit 2 Reactor Vessel

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

	0°	15°	30°	45°[a]
10.54 EFPY				
Surface	1.97E+18	3.12E+18	3.96E+18	5.92E+18
¼ T	1.08E+18	1.71E+18	2.20E+18	3.21E+18
¾ T	2.40E+17	3.80E+17	4.96E+17	6.90E+17
20 EFPY				
Surface	3.53E+18	5.58E+18	7.18E+18	1.08E+19
¼ T	1.93E+18	3.06E+18	3.98E+18	5.85E+18
¾ T	4.32E+17	6.79E+17	9.00E+17	1.26E+18
32 EFPY				
Surface	5.52E+18	8.69E+18	1.13E+19	1.70E+19
¼ T	3.02E+18	4.77E+18	6.25E+18	9.20E+18
¾ T	6.75E+17	1.06E+18	1.41E+18	1.97E+18
48 EFPY				
Surface	8.16E+18	1.28E+19	1.67E+19	2.52E+19
¼ T	4.46E+18	7.04E+18	9.28E+18	1.37E+19
¾ T	9.98E+17	1.56E+18	2.10E+18	2.93E+18

Notes:

a) Maximum neutron exposure projection.
b) 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 Sequoyah Unit 2 Reactor Vessel

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

	0°	15°	30°	45°[a]
10.54 EFPY				
Surface	1.97E+18	3.12E+18	3.96E+18	5.92E+18
¼ T	1.27E+18	2.01E+18	2.60E+18	3.81E+18
¾ T	4.79E+17	7.49E+17	1.01E+18	1.36E+18
20 EFPY				
Surface	3.53E+18	5.58E+18	7.18E+18	1.08E+19
¼ T	2.28E+18	3.59E+18	4.72E+18	6.93E+18
¾ T	8.60E+17	1.34E+18	1.82E+18	2.48E+18
32 EFPY				
Surface	5.52E+18	8.69E+18	1.13E+19	1.70E+19
¼ T	3.57E+18	5.59E+18	7.42E+18	1.09E+19
¾ T	1.34E+18	2.08E+18	2.86E+18	3.91E+18
48 EFPY				
Surface	8.16E+18	1.28E+19	1.67E+19	2.52E+19
¼ T	5.28E+18	8.26E+18	1.10E+19	1.62E+19
¾ T	1.99E+18	3.08E+18	4.25E+18	5.80E+18

Notes:

a) Maximum neutron exposure projection.

b) 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
Sequoyah Unit 2 Reactor Vessel

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

	0°	15°	30°	45°[a]
10.54 EFPY				
Surface	2.11E+18	3.36E+18	4.26E+18	6.37E+18
¼ T	1.16E+18	1.84E+18	2.36E+18	3.46E+18
¾ T	2.59E+17	4.09E+17	5.34E+17	7.42E+17
20 EFPY				
Surface	3.80E+18	6.00E+18	7.73E+18	1.16E+19
¼ T	2.08E+18	3.29E+18	4.28E+18	6.29E+18
¾ T	4.64E+17	7.30E+17	9.68E+17	1.35E+18
32 EFPY				
Surface	5.93E+18	9.34E+18	1.21E+19	1.82E+19
¼ T	3.24E+18	5.13E+18	6.72E+18	9.889E+18
¾ T	7.26E+17	1.14E+18	1.52E+18	2.122E+18
48 EFPY				
Surface	8.78E+18	1.38E+19	1.80E+19	2.71E+19
¼ T	4.80E+18	7.58E+18	9.98E+18	1.47E+19
¾ T	1.07E+18	1.68E+18	2.25E+18	3.15E+18

Notes:

a) Maximum neutron exposure projection.

b) 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
Sequoyah Unit 2 Reactor Vessel

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

	0°	15°	30°	45°[a]
10.54 EFPY				
Surface	2.11E+18	3.36E+18	4.26E+18	6.37E+18
¼ T	1.37E+18	2.16E+18	2.80E+18	4.10E+18
¾ T	5.15E+17	8.05E+17	1.08E+18	1.47E+18
20 EFPY				
Surface	3.80E+18	6.00E+18	7.73E+18	1.16E+19
¼ T	2.45E+18	3.86E+18	5.08E+18	7.46E+18
¾ T	9.25E+17	1.44E+18	1.96E+18	2.67E+18
32 EFPY				
Surface	5.93E+18	9.34E+18	1.21E+19	1.82E+19
¼ T	3.83E+18	6.01E+18	7.97E+18	1.17E+19
¾ T	1.45E+18	2.24E+18	3.08E+18	4.20E+18
48 EFPY				
Surface	8.78E+18	1.38E+19	1.80E+19	2.71E+19
¼ T	5.67E+18	8.88E+18	1.18E+19	1.74E+19
¾ T	2.14E+18	3.31E+18	4.57E+18	6.24E+18

Notes:

a) Maximum neutron exposure projection.
b) 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 Sequoyah Unit 2
Surveillance Capsules

Capsule	Location	Lead Factor
T[a]	40°	3.33
U[b]	40°	3.40
X[c]	40°	3.39
Y[d]	40°	3.35
S[e]	4°	1.09
V[e]	4°	1.09
W[e]	4°	1.09
Z[e]	4°	1.09

[a] - Withdrawn at the end of Cycle 1.
[b] - Withdrawn at the end of Cycle 3.
[c] - Withdrawn at the end of Cycle 5.
[d] - Withdrawn at the end of Cycle 9.
[e] - Not withdrawn; standby.

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 requirements of ASTM E185-82 and is recommended for future capsules to be removed from the Sequoyah Unit 2 reactor vessel. This recommended removal schedule is applicable to 32 EFPY of operation.

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

Capsule	Location	Lead Factor[(a)]	Removal Time (EFPY)[(b)]	Fluence (n/cm^2,E>1.0 MeV)[(a)]
T	40°	3.33	1.04	2.61×10^{18} (c)
U	140°	3.40	2.93	6.92×10^{18} (c)
X	220°	3.39	5.36	1.22×10^{19} (c)
Y	320°	3.35	10.54	2.14×10^{19} (c,d)
S	4°	1.09	Standby	(e)
V	176°	1.09	Standby	(e)
W	184°	1.09	Standby	(e)
Z	356°	1.09	Standby	(e)

Notes:

(a) Updated in Capsule Y dosimetry analysis, see Section 6 of this report.

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

(c) Plant specific evaluation.

(d) This fluence is not less than once or greater than twice the peak end of license (32 EFPY) fluence

(e) Capsules S, V, W and Z will reach a fluence of 2.71×10^{19} (E > 1.0 MeV), the 48 EFPY peak vessel fluence at approximately 44 EFPY. If vessel fluence data is needed at EOL for Life Extension, it is recommended that one or more of the Standby Capsules be moved to a higher flux location within the next few cycles of operation.

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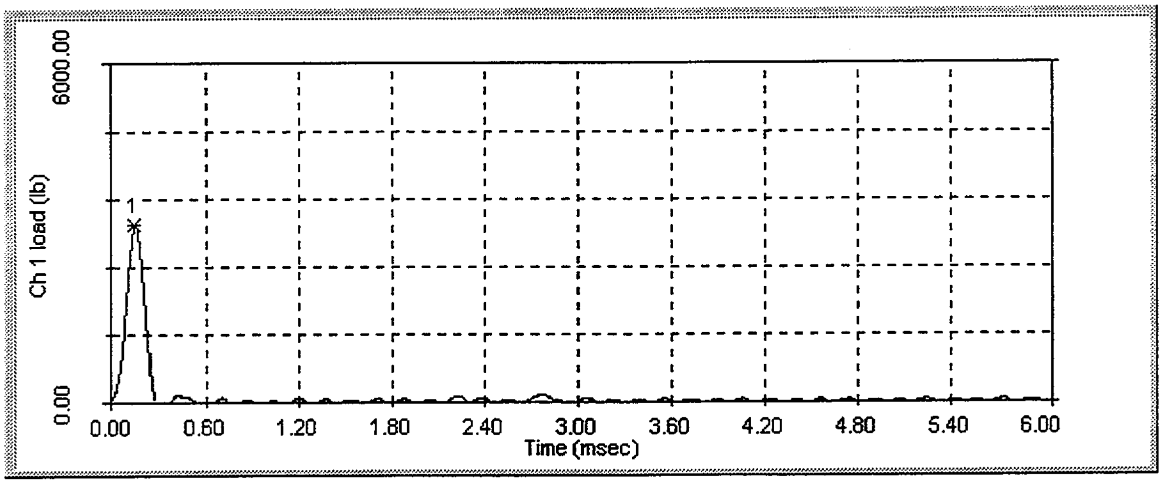
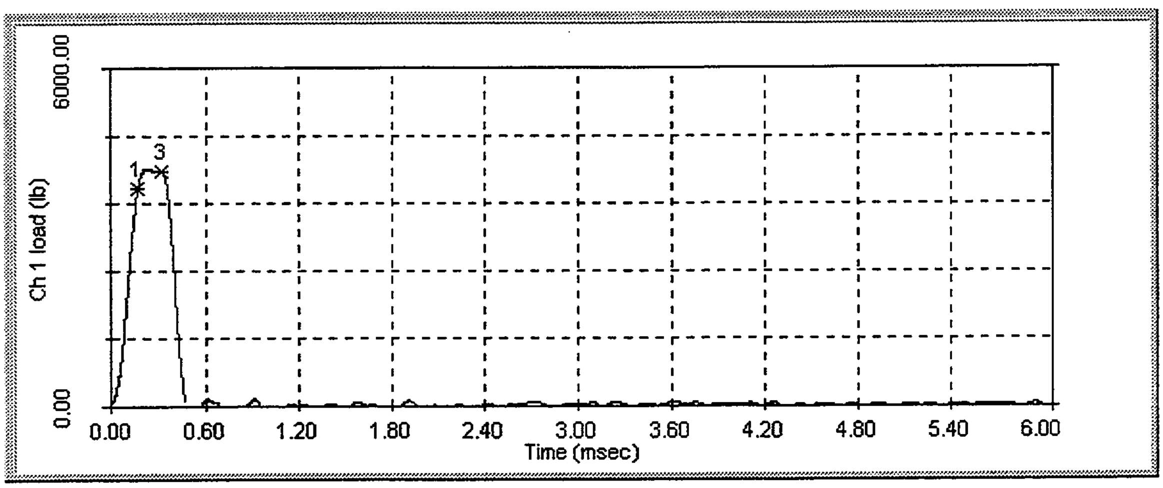
APPENDIX A

LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS



NL55, -25°F



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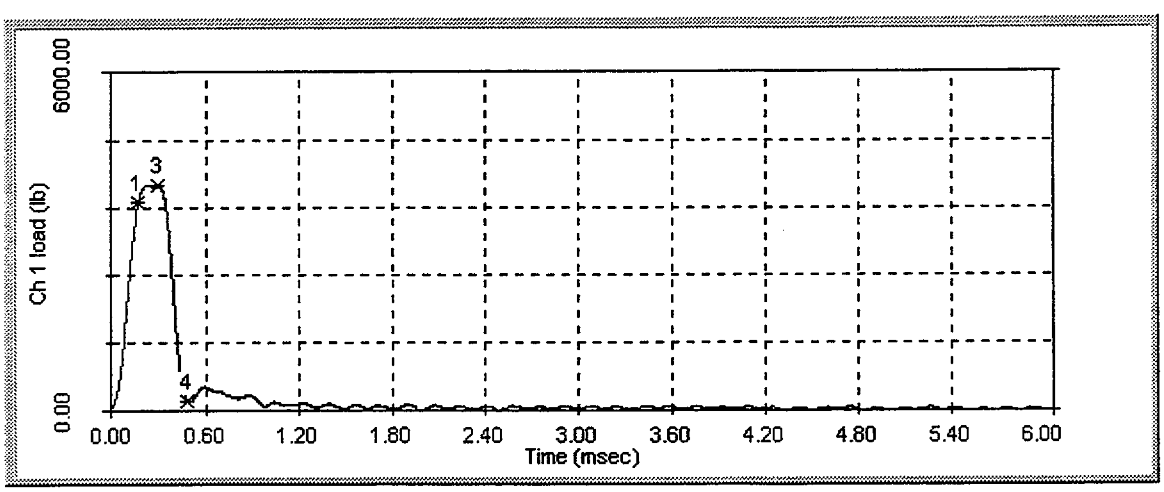

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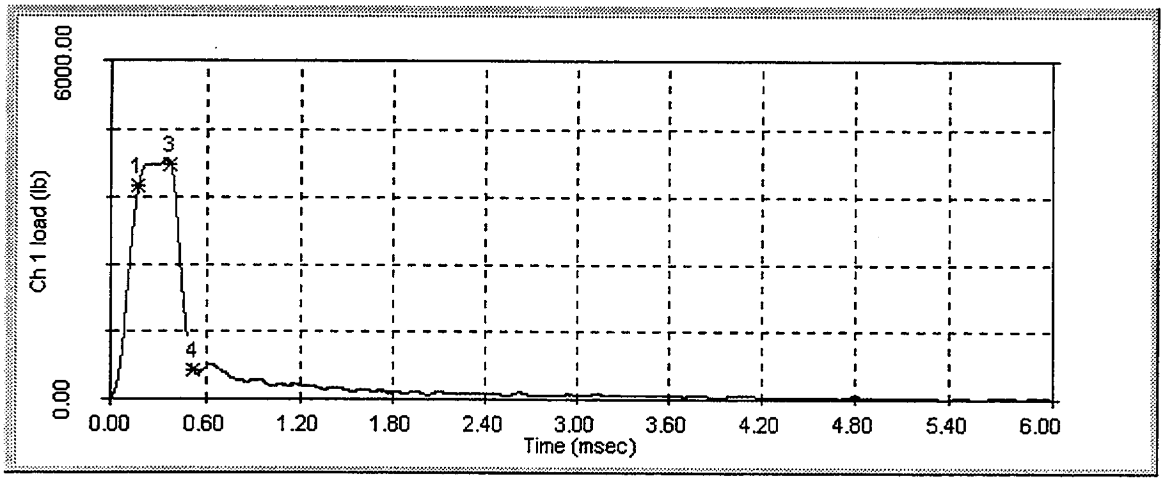
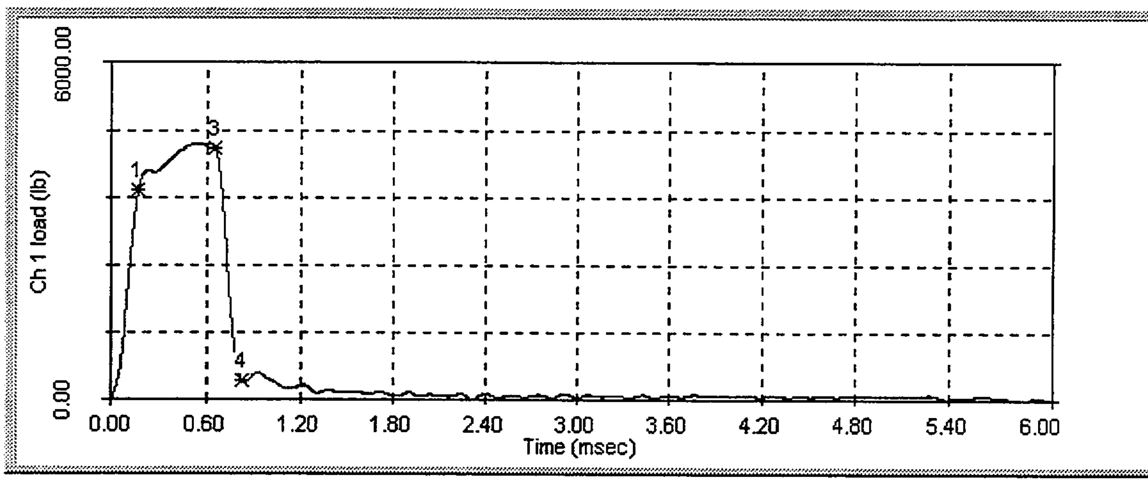
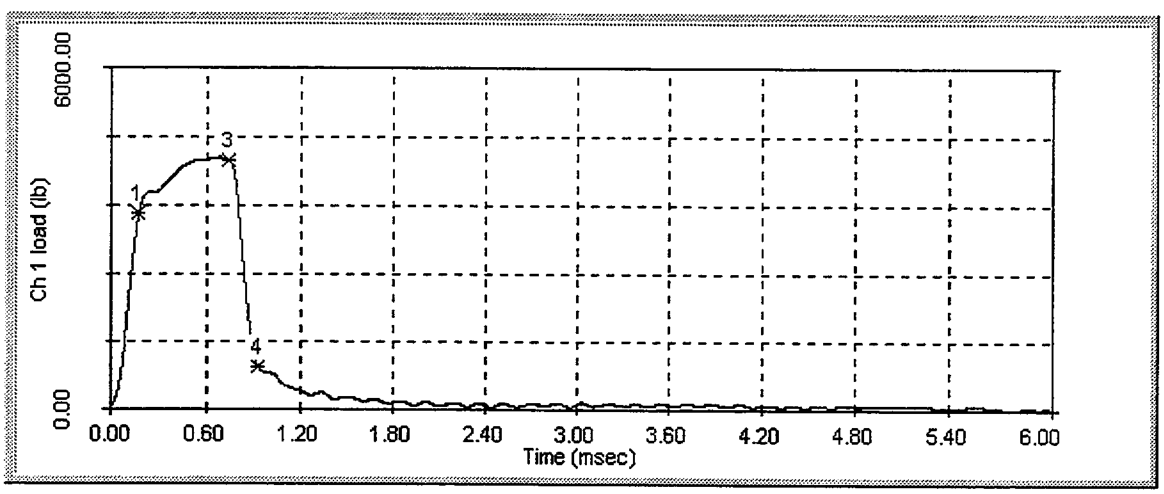


NL49, 85°F



NL50, 100°F



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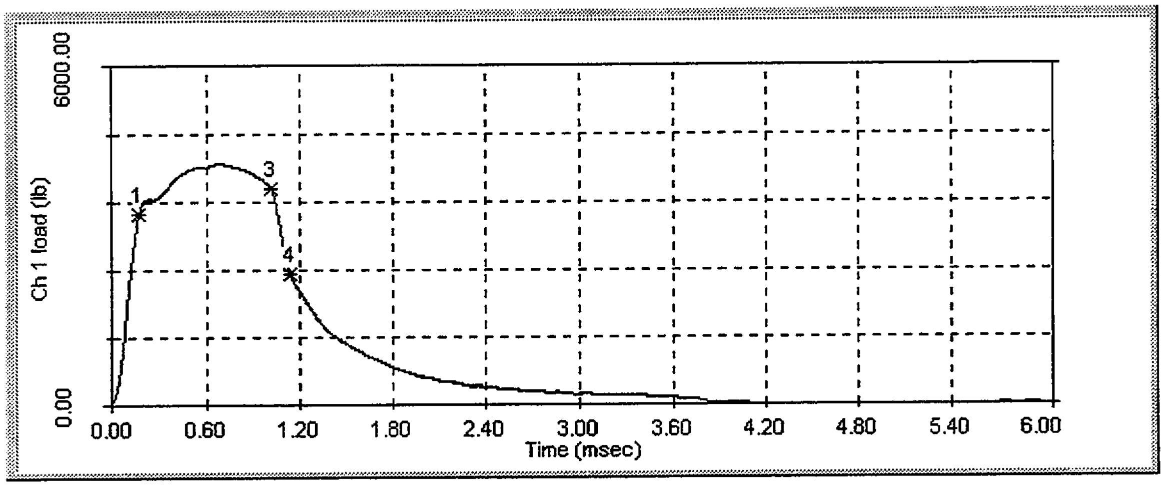
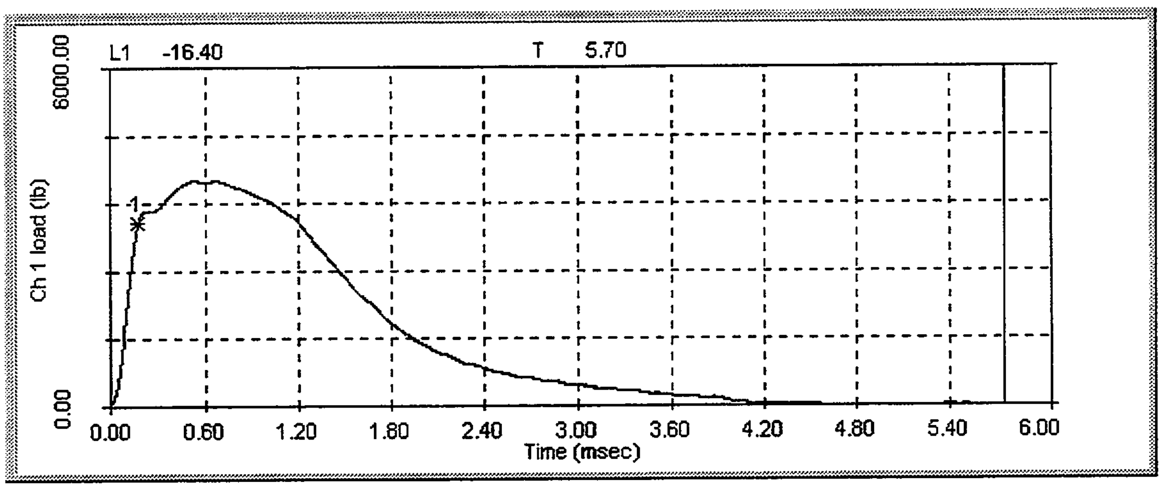


NL53, 200°F



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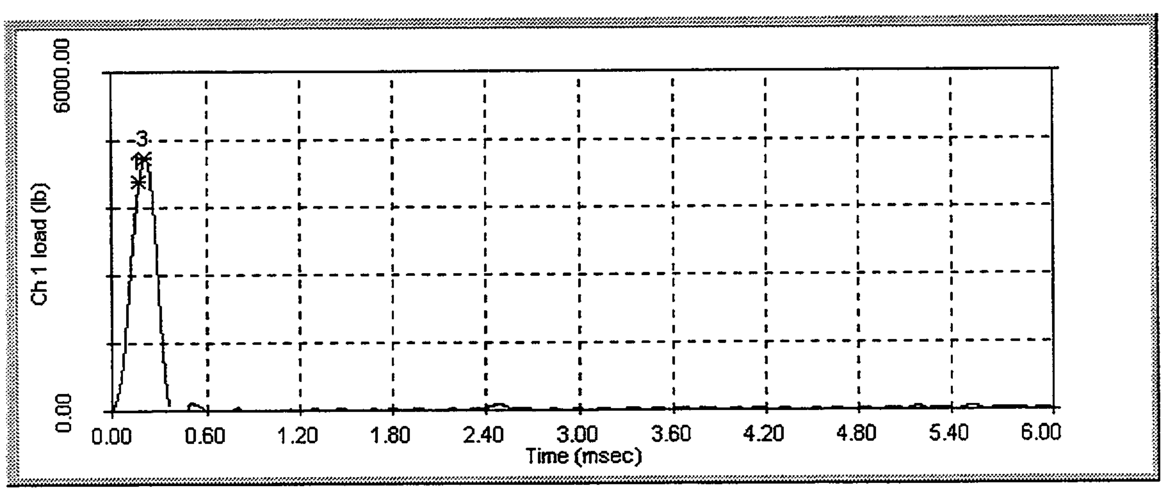
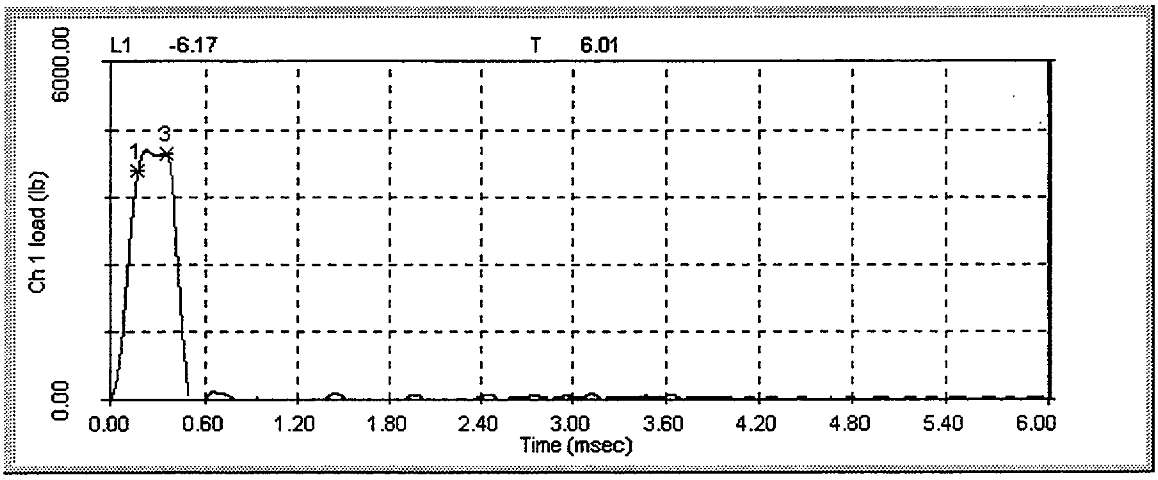
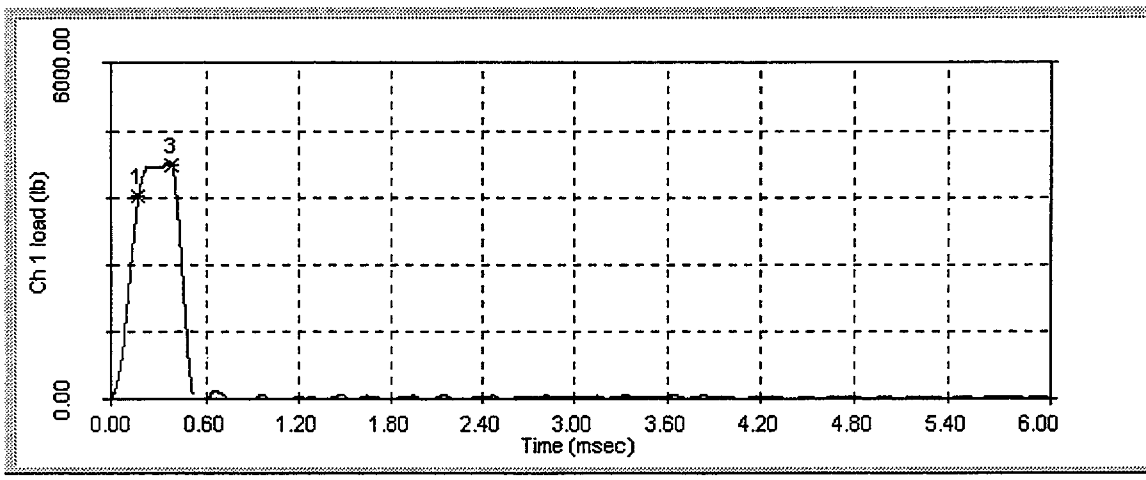


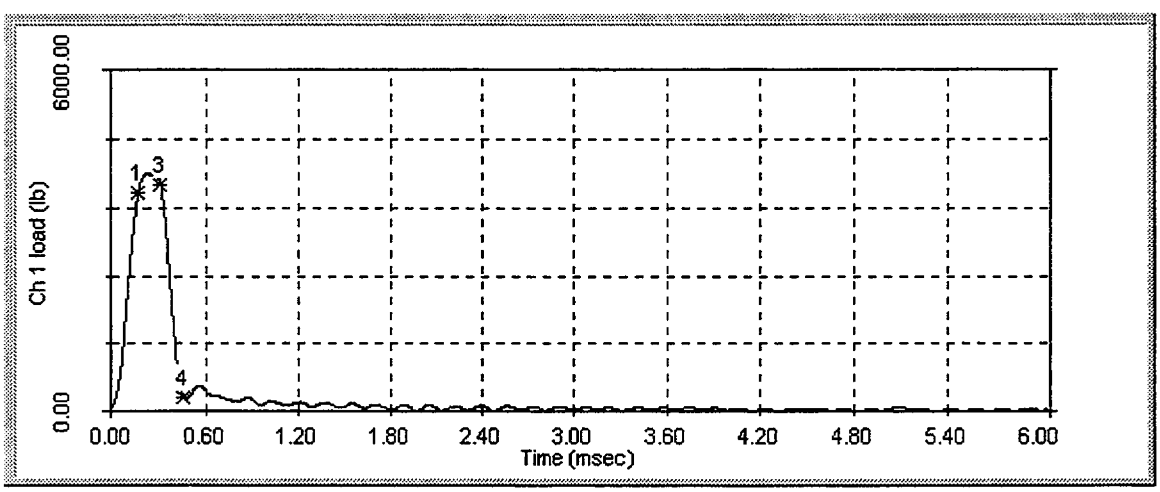
NT84, -60°F



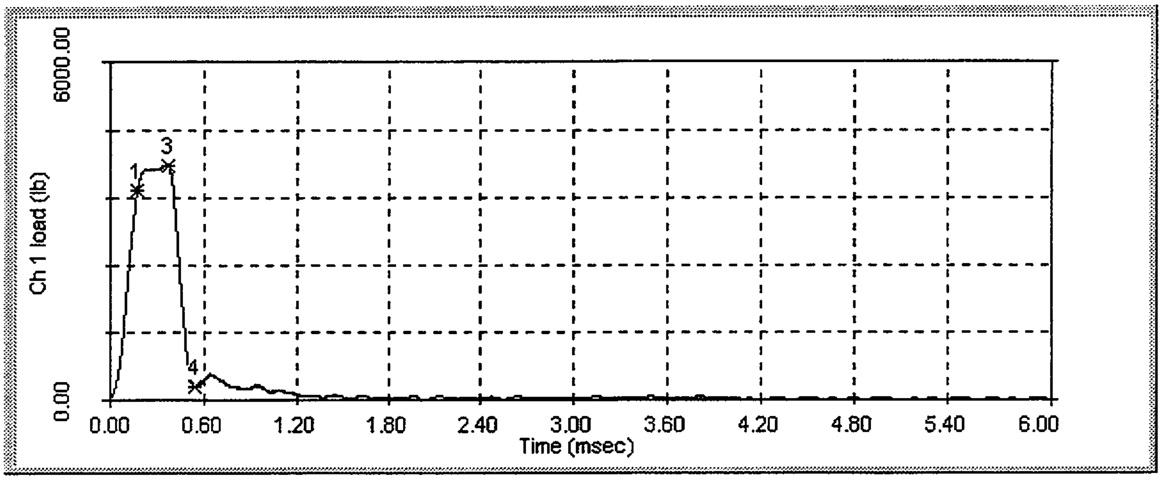
NT83, 0°F



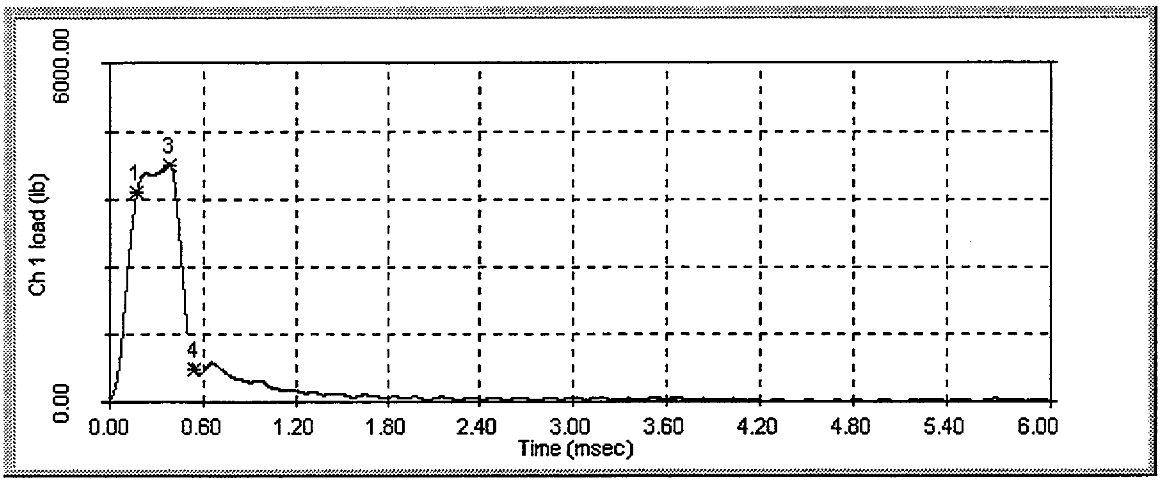
NT81, 25°F



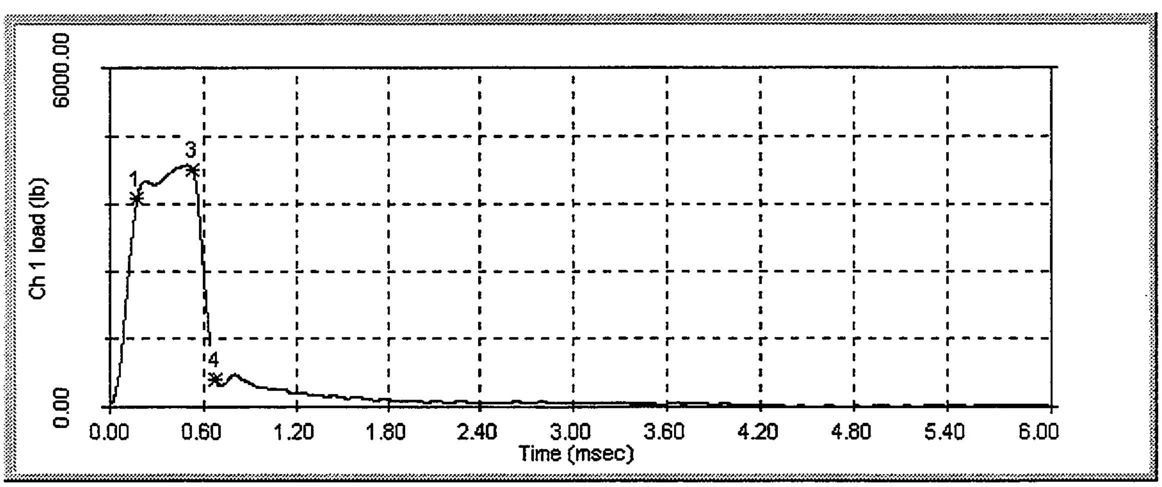
NT76, 50°F



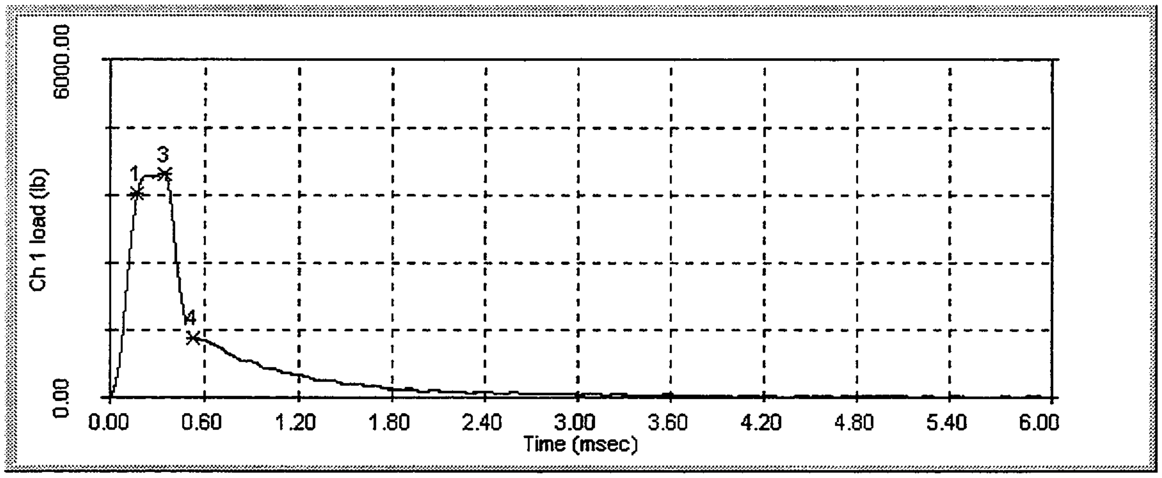
NT73, 72°F



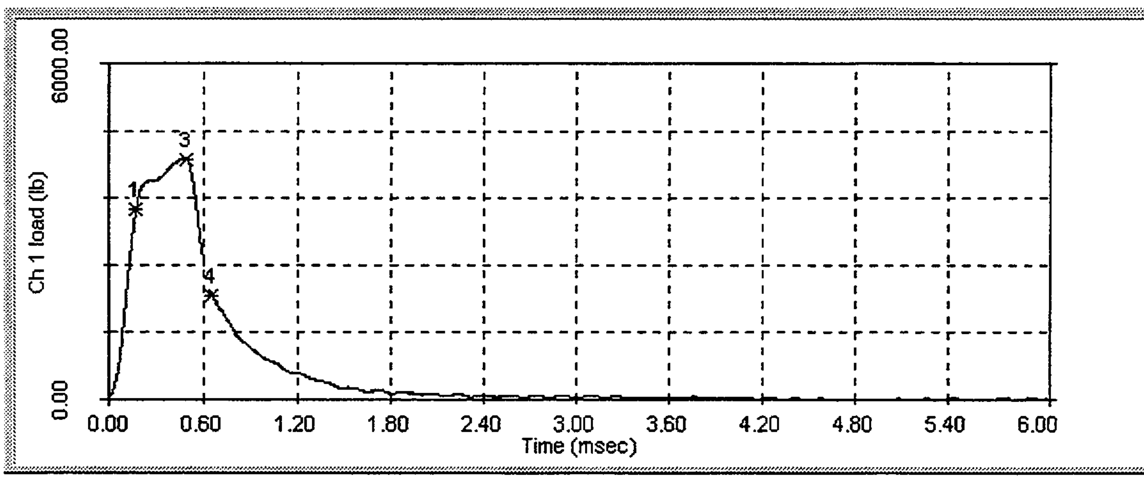
NT82, 90°F



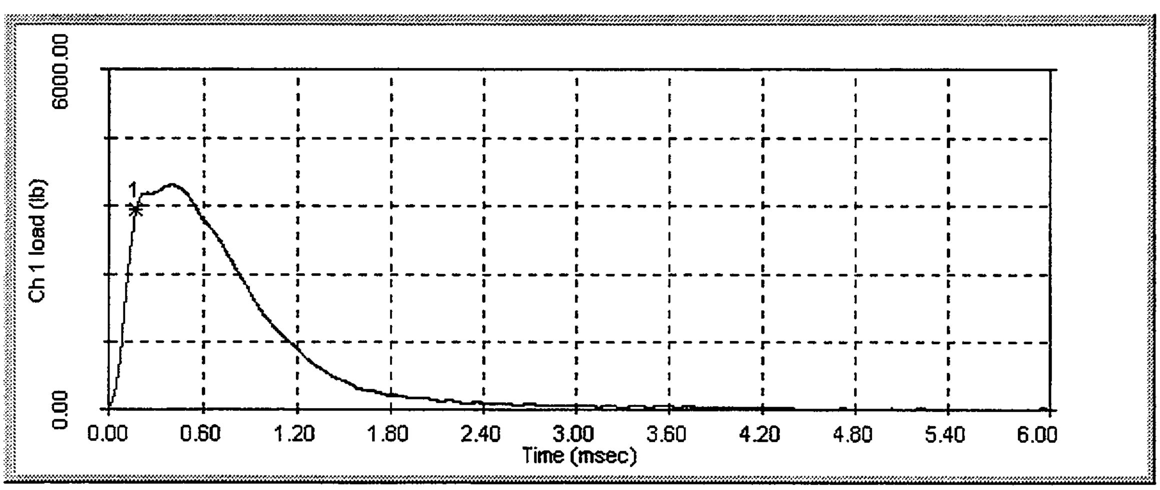
NT75, 110°F



NT74, 150°F



NT79, 165°F



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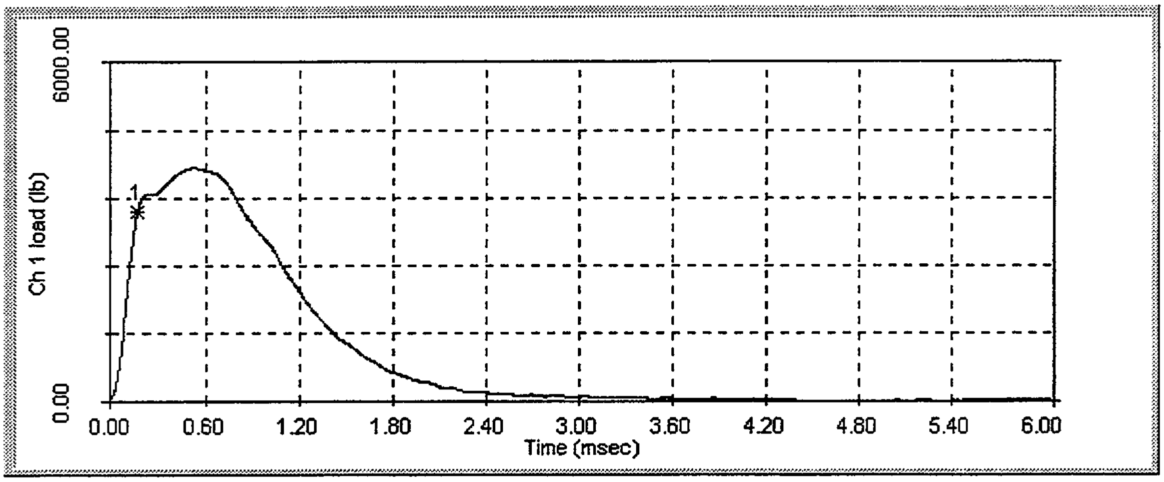
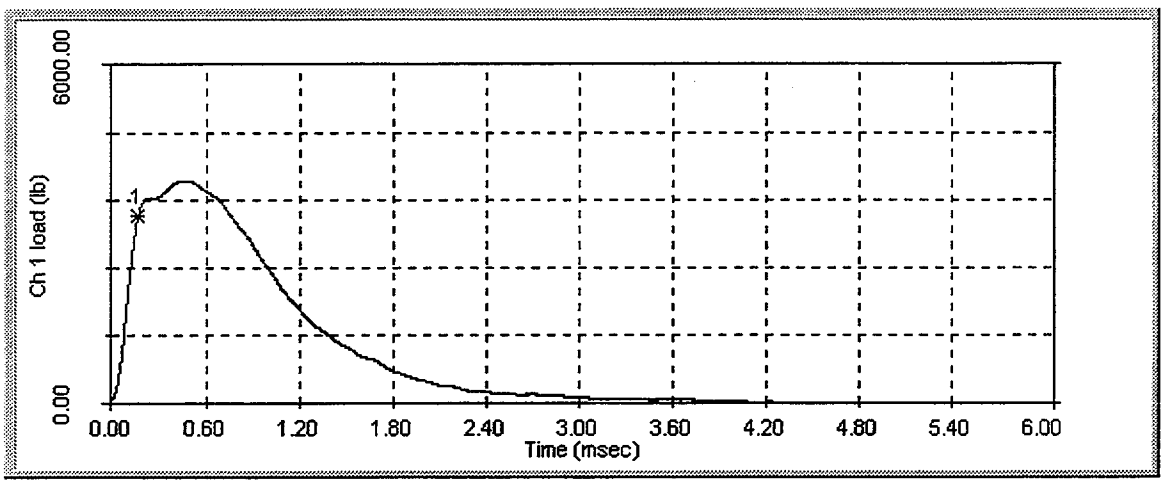
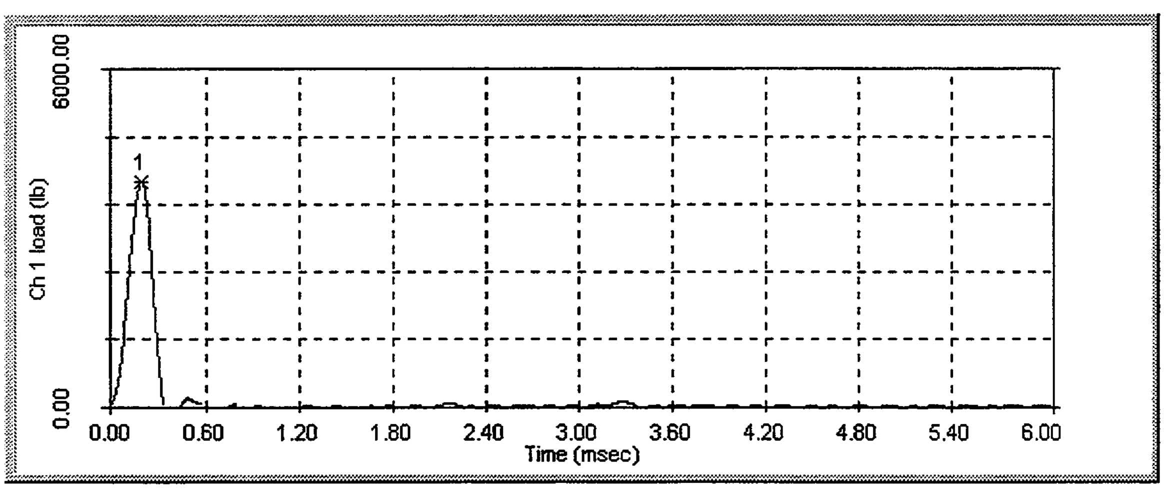


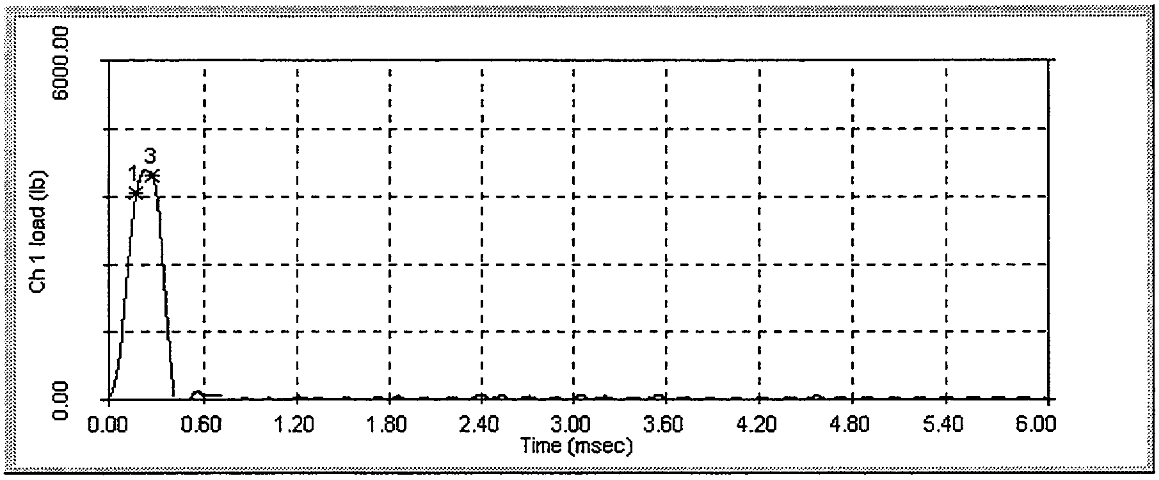
NT78, 275°F



NT80, 300°F



W80, -75°F



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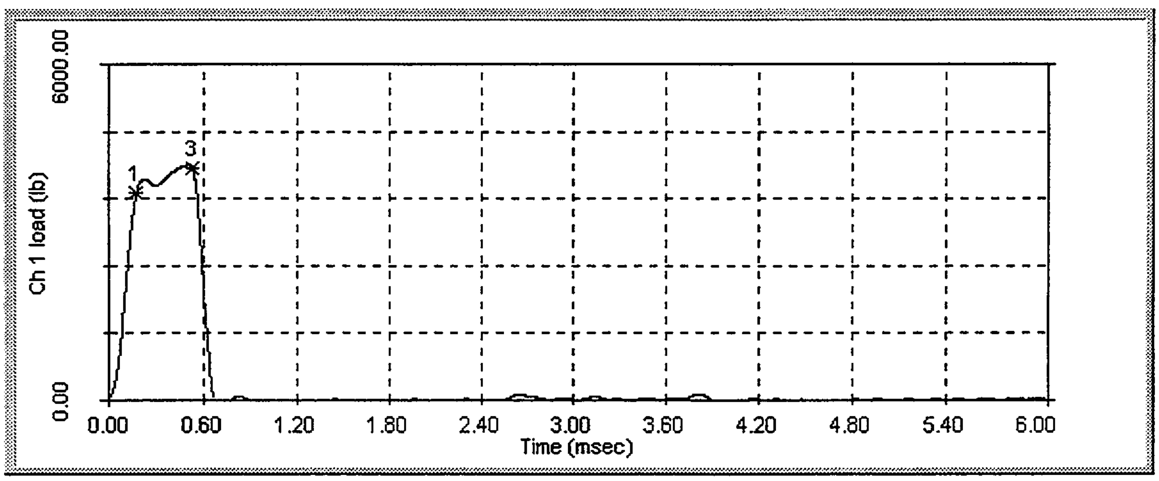

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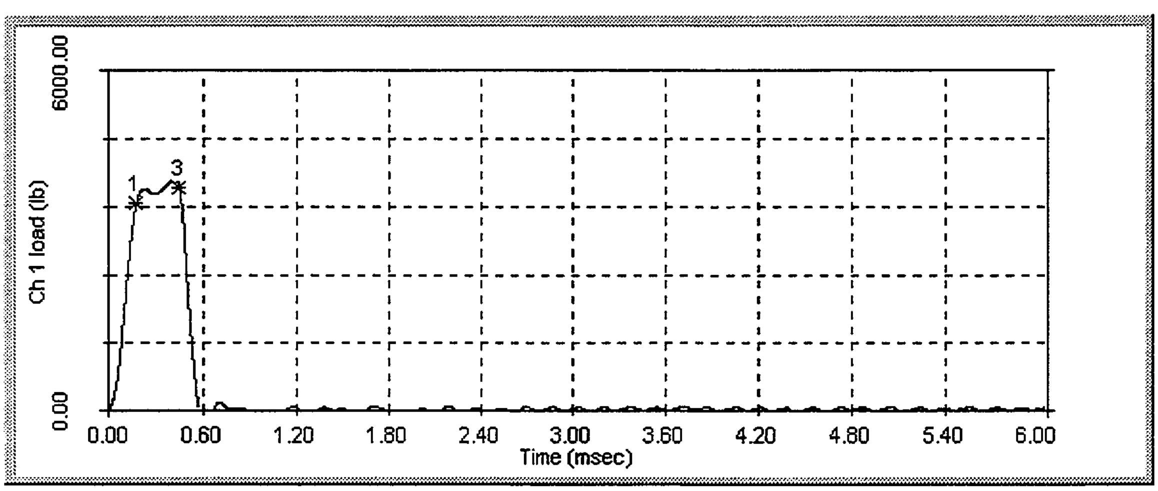

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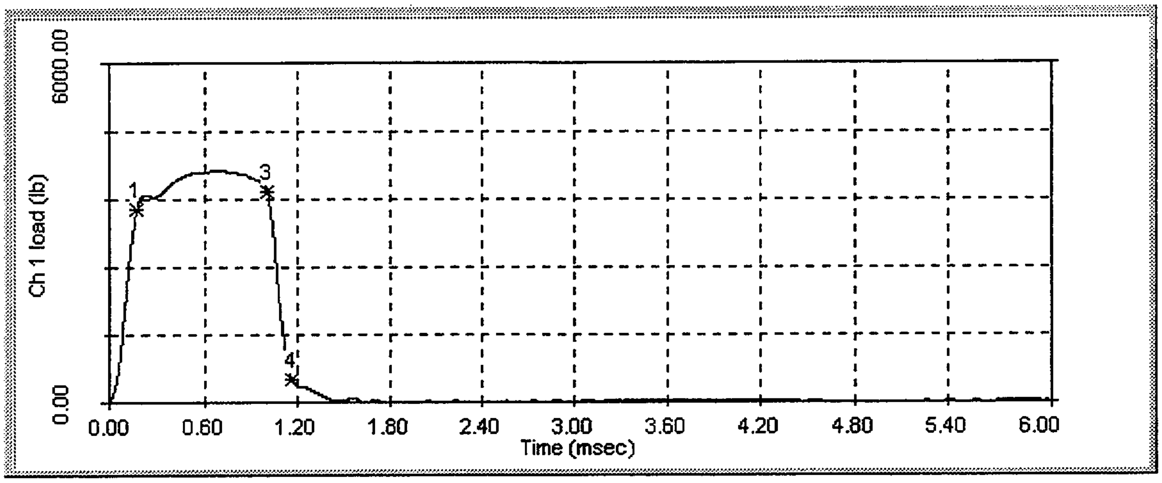
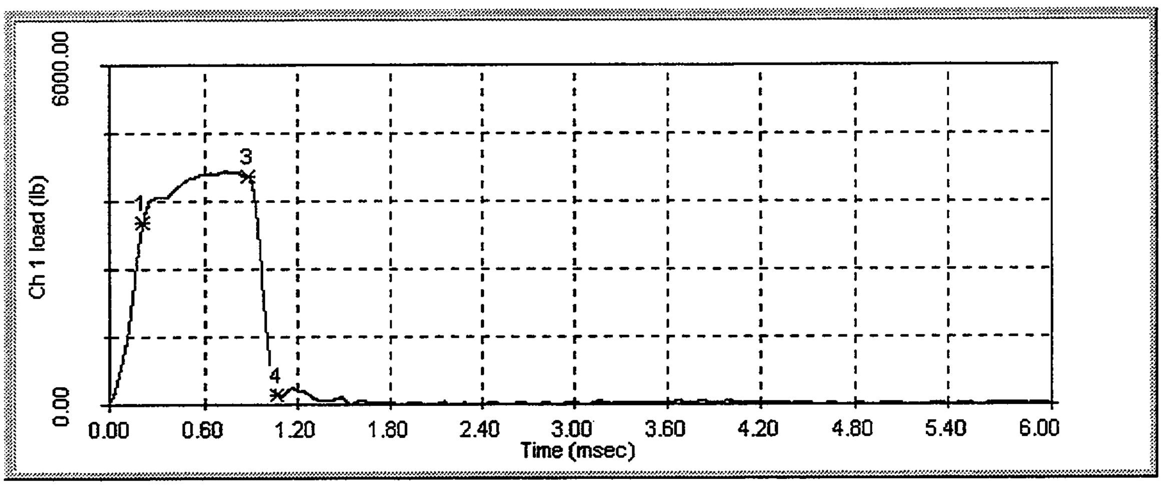


W74, 50°F



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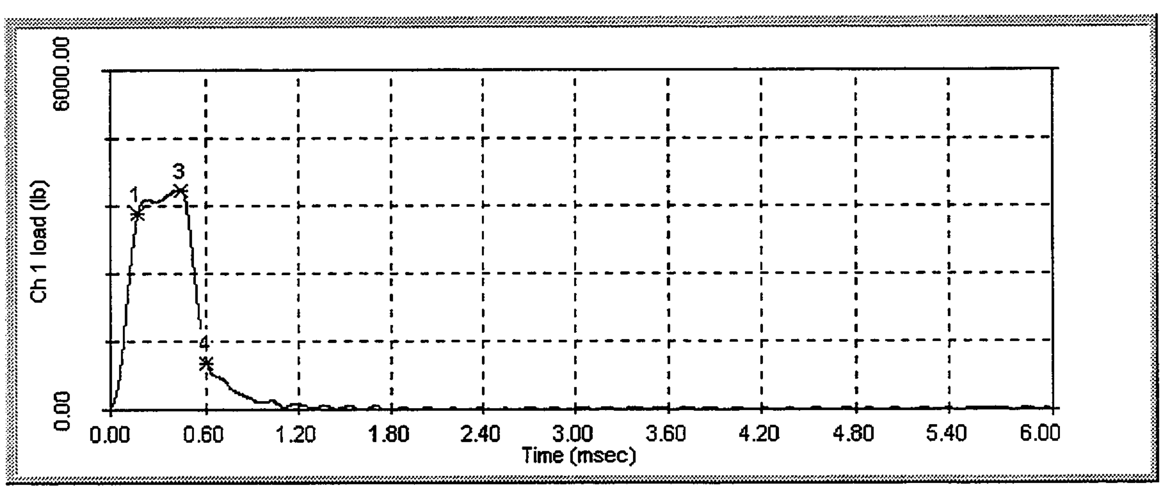
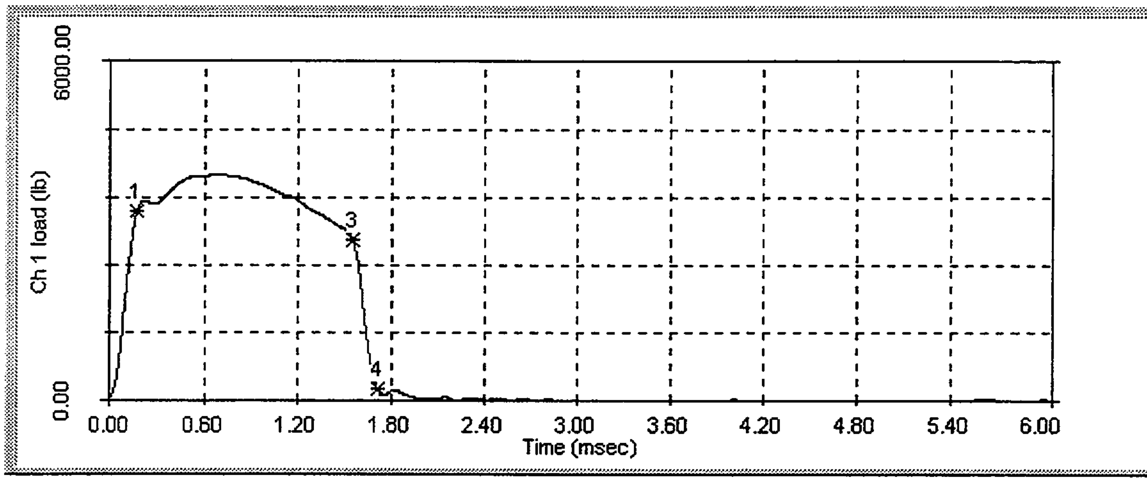
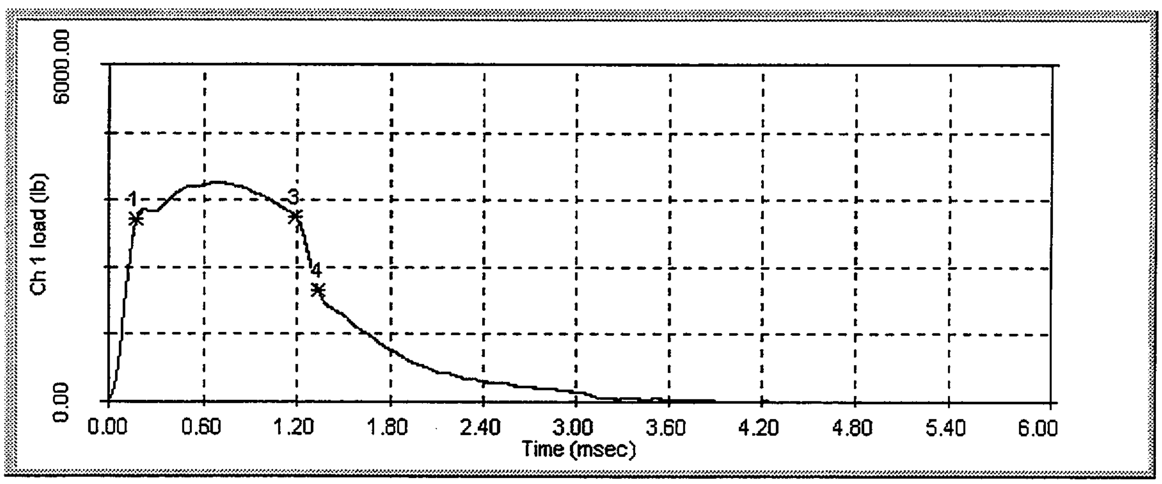


W79, 100°F



W84, 100°F



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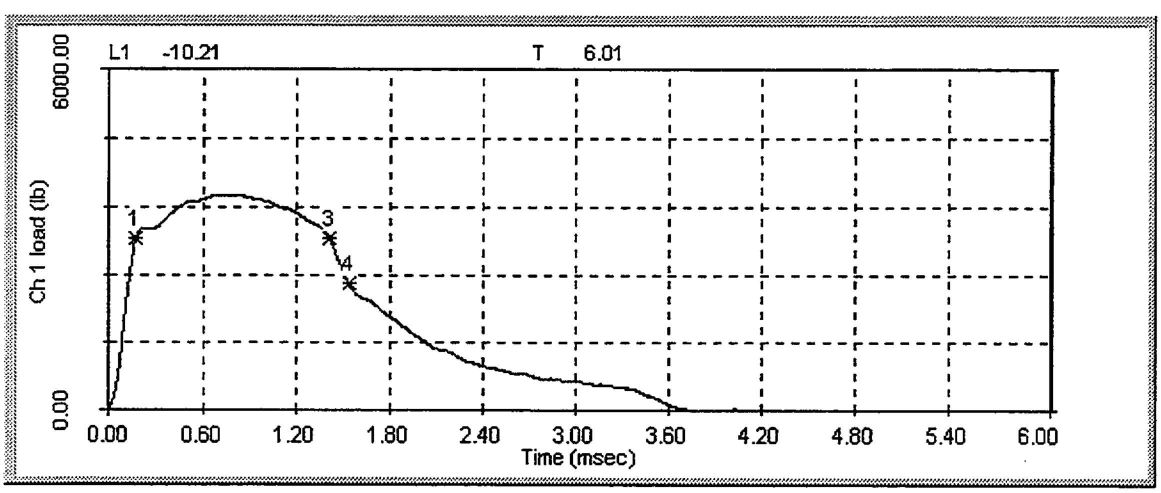
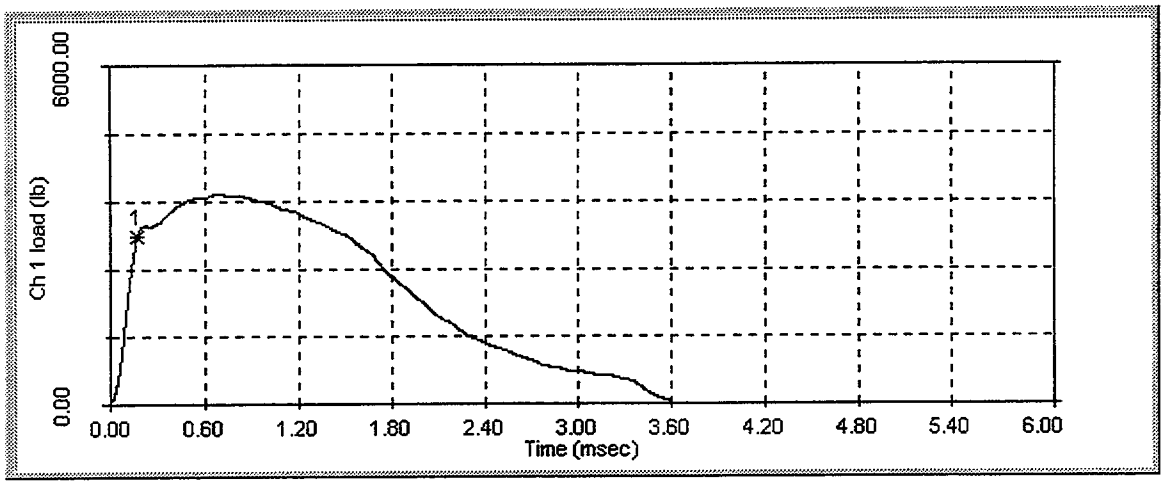
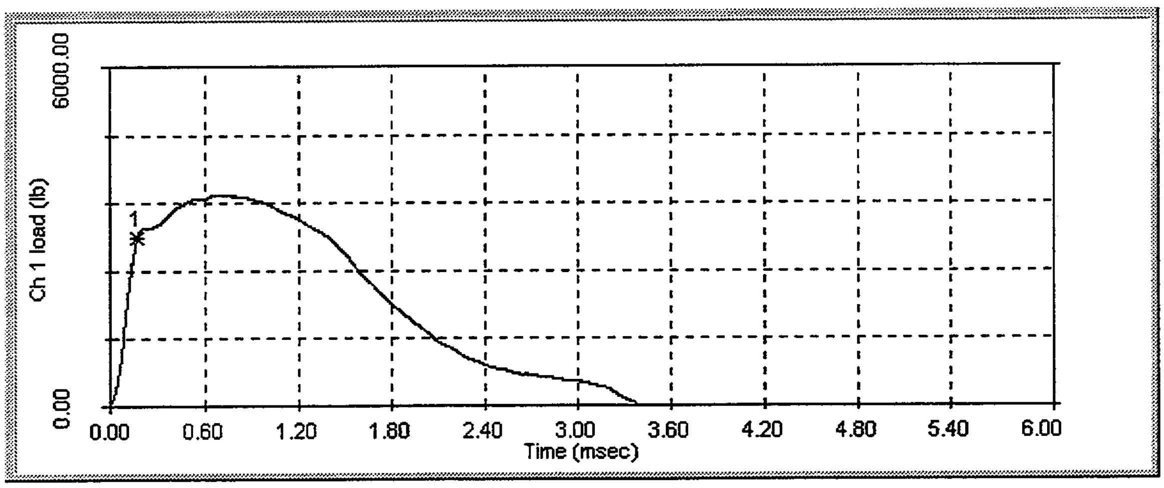


W82, 200°F



W81, 250°F



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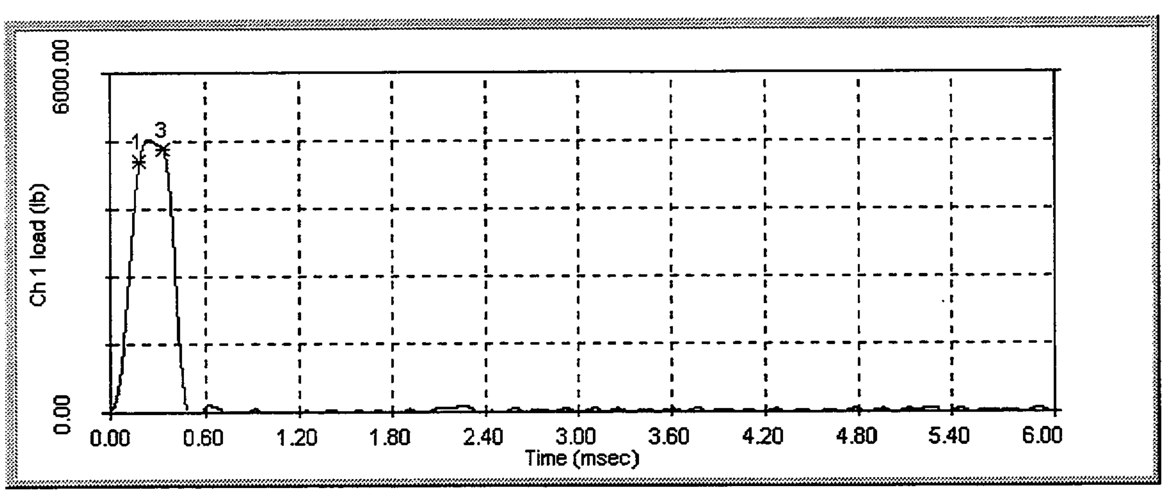
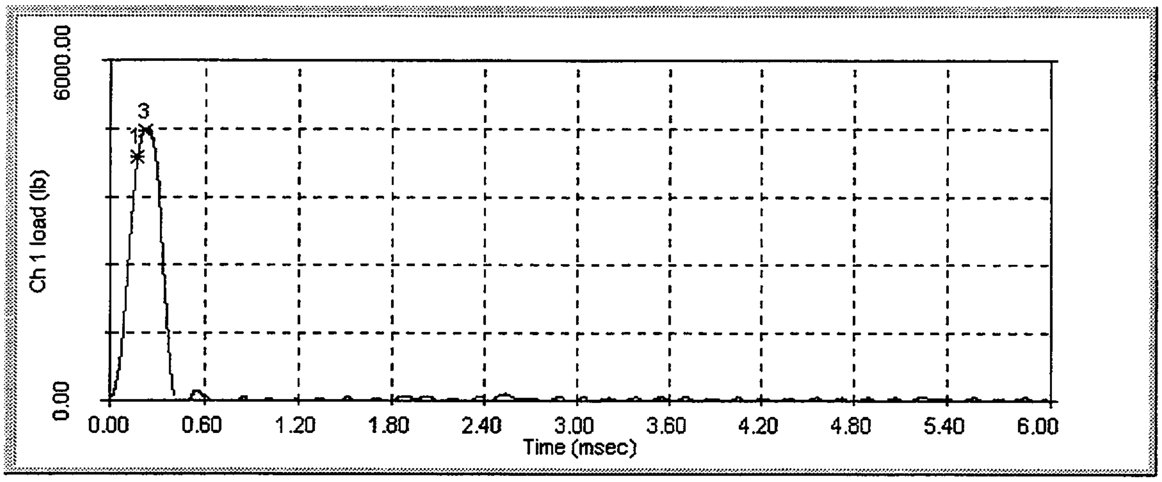
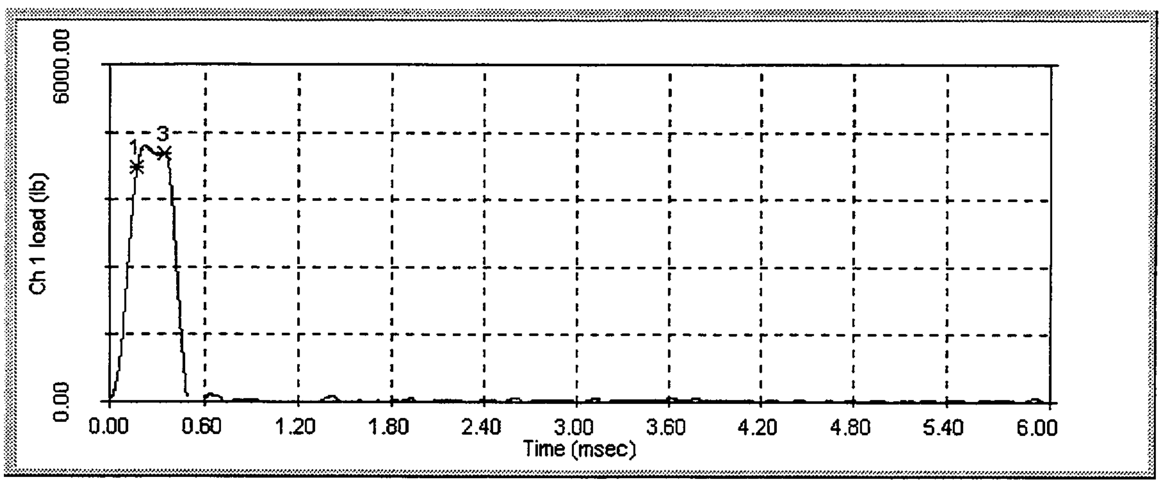


H78, -100°F



H80, -75°F



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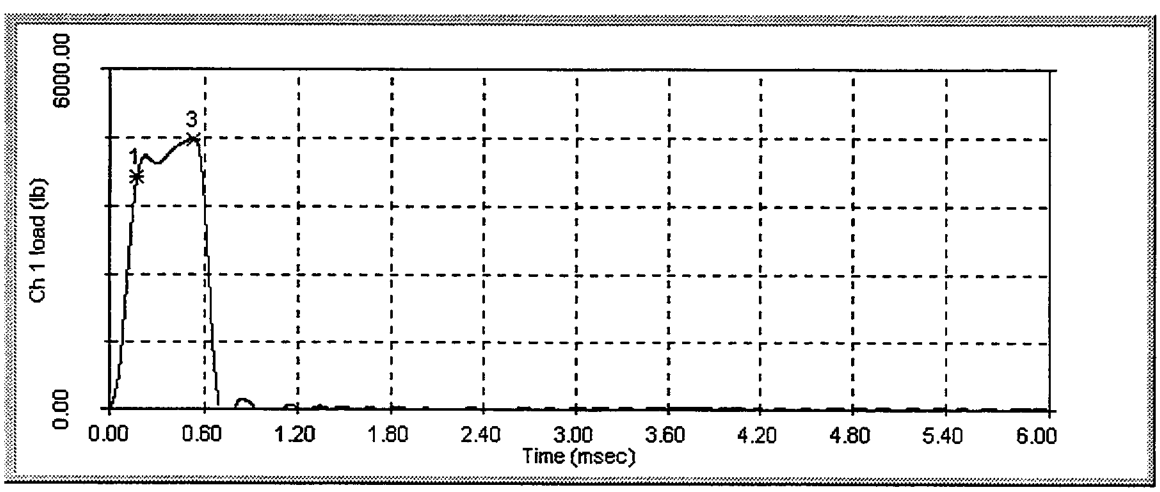

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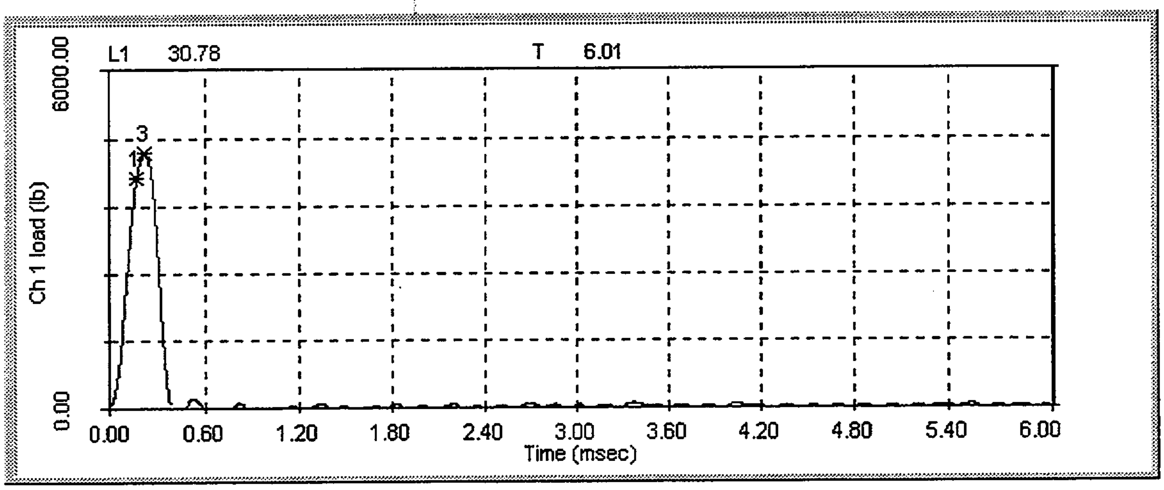

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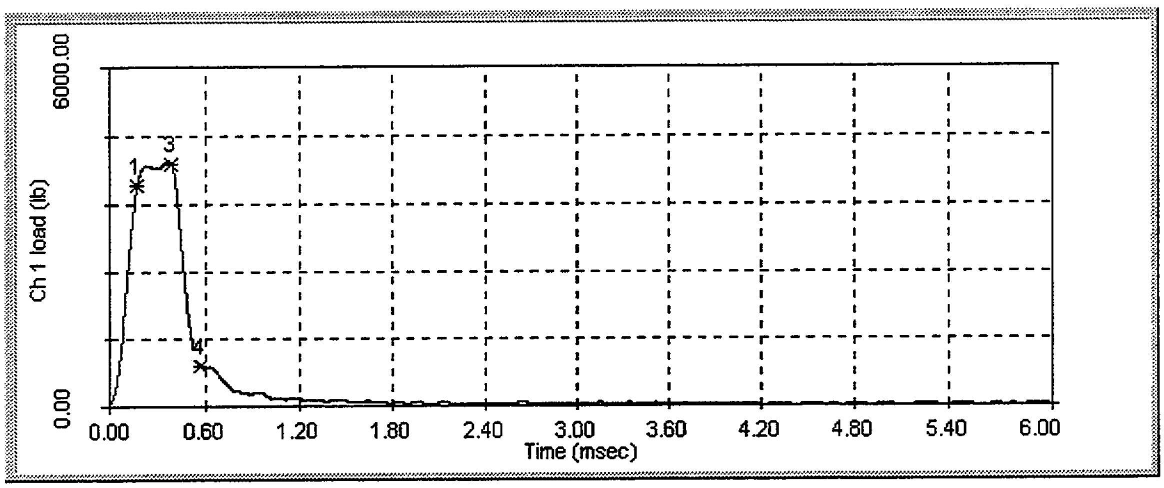
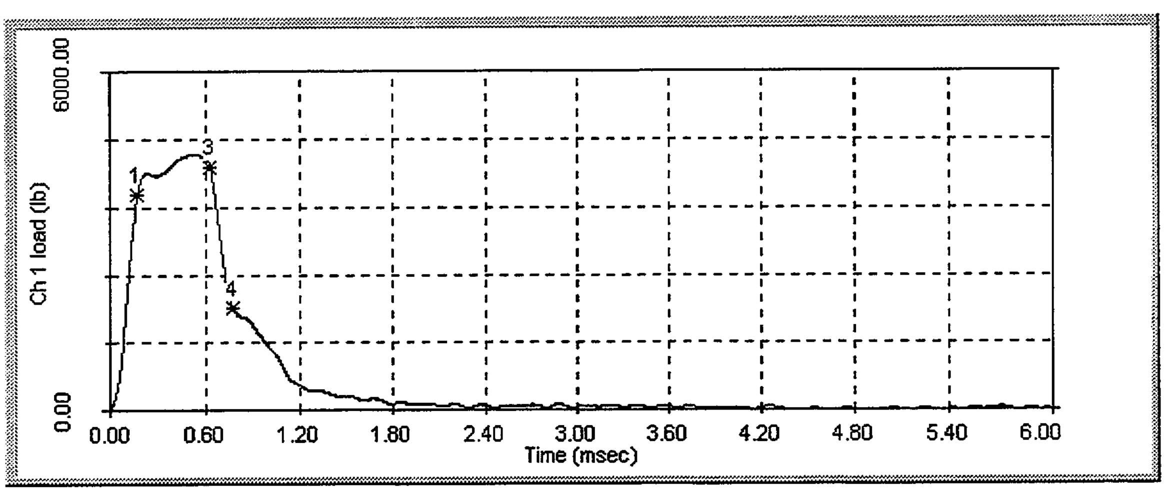
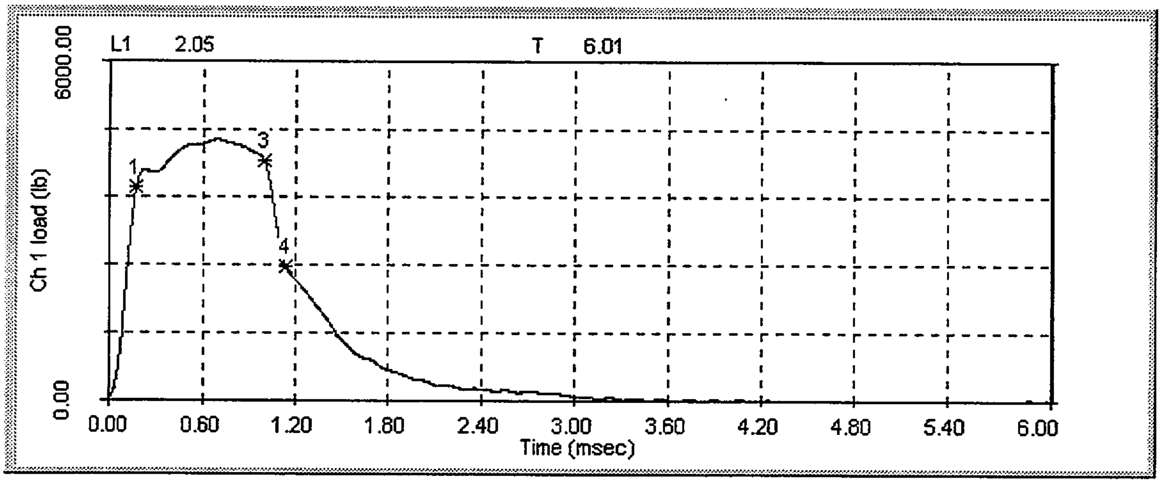


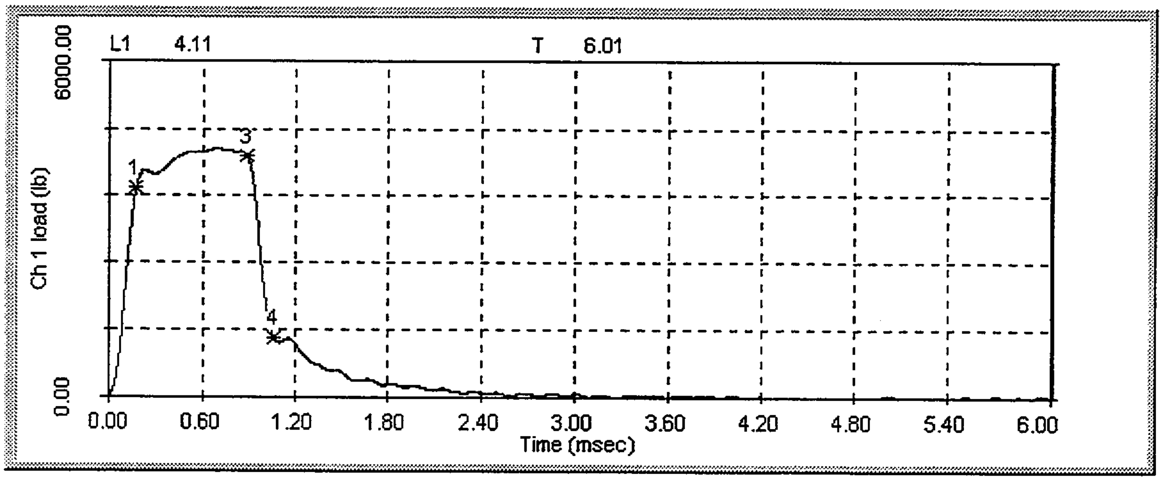
H83, 40°F



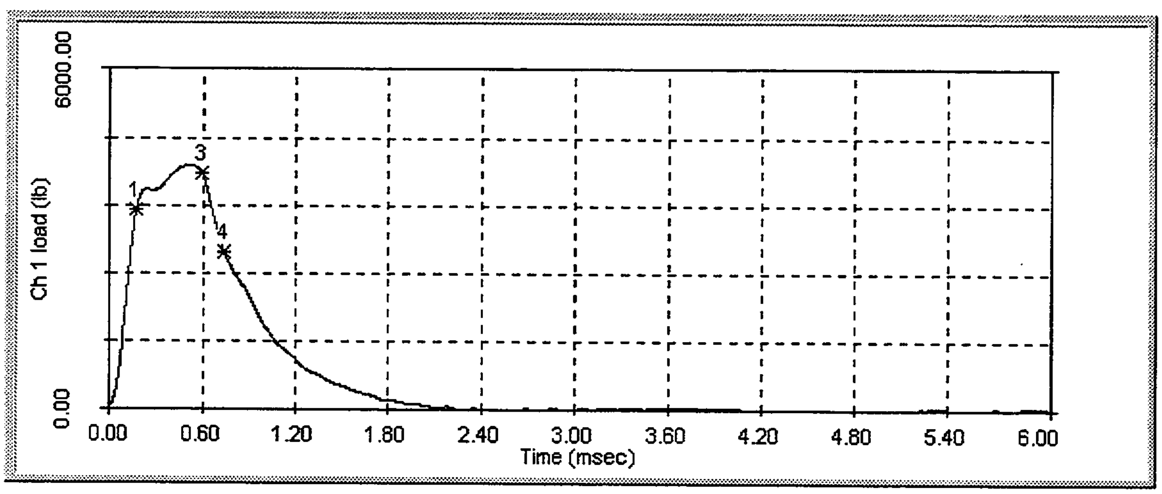
H81, 60°F



H73, 72°F



H77, 100°F



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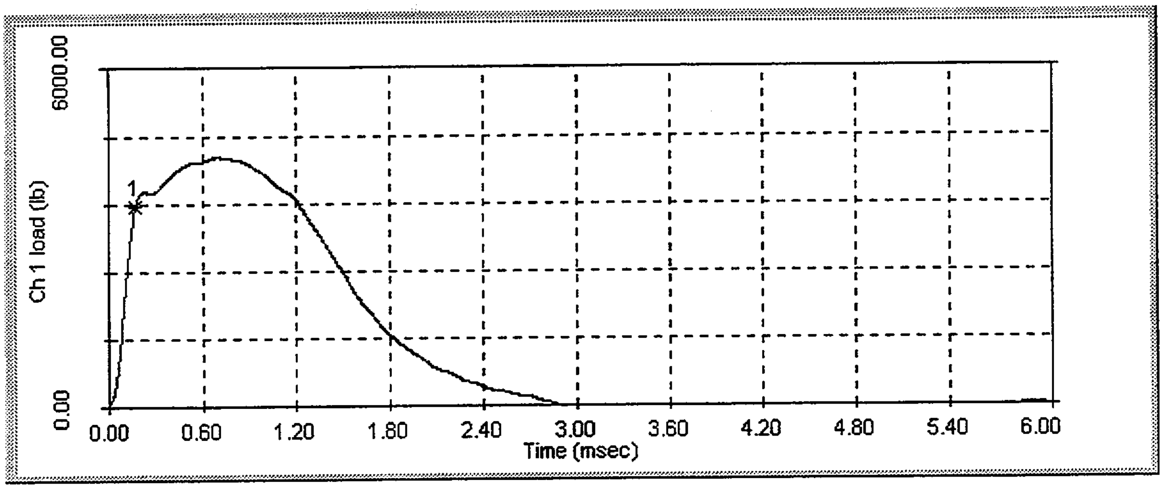
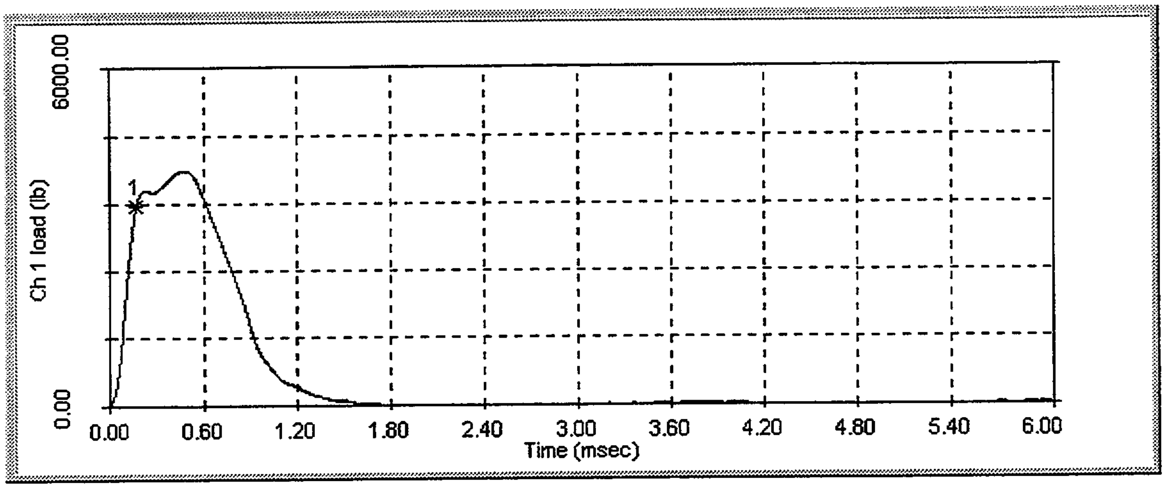


H84, 225°F



H79, 250°F

APPENDIX B

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

TABLE B-1

Changes in Average 30 ft-lb Temperatures for Intermediate Shell Forging 05 (Tangential Orientation) Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{30}	Unirradiated	CVGRAPH Fit	ΔT_{30}
T	- 70°F	-10°F	60°F	- 62.7°F	0.95°F	63.65°F
U	- 70°F	23°F	93°F	- 62.7°F	16.61°F	79.31°F
X	- 70°F	35°F	105°F	- 62.7°F	23.00	85.70°F
Y	- 70°F	- -	- -	- 62.7°F	71.42°F	134.12°F

TABLE B-2

Changes in Average 50 ft-lb Temperatures for Intermediate Shell Forging 05 (Tangential Orientation) Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{50}	Unirradiated	CVGRAPH Fit	ΔT_{50}
T	-25°F	35°F	60°F	-24.37°F	42.58°F	66.95°F
U	-25°F	48°F	73°F	-24.37°F	47.29°F	71.67°F
X	-25°F	70°F	95°F	-24.37°F	62.09°F	86.47F
Y	-25°F	- -	- -	-24.37°F	110.97°F	135.35°F

TABLE B-3
Changes in Average 35 mil Lateral Expansion Temperatures for Intermediate Shell Forging 05 (Tangential Orientation)
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{35}	Unirradiated	CVGRAPH Fit	ΔT_{35}
T	-45°F	20°F	65°F	- 37.83°F	37.44°F	75.27°F
U	-45°F	41°F	86°F	- 37.83°F	40.36°F	78.20°F
X	-45°F	60°F	105°F	- 37.83°F	52.87°F	90.70°F
Y	-45°F	- -	- -	- 37.83°F	106.41°F	144.24°F

TABLE B-4
Changes in Average Energy Absorption at Full Shear for Lower Shell Forging 05 (Tangential Orientation)
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔE	Unirradiated	CVGRAPH Fit	ΔE
T	134 ft-lb	118 ft-lb	- 16 ft-lb	134 ft-lb	118 ft-lb	- 16 ft-lb
U	134 ft-lb	110 ft-lb	- 24 ft-lb	134 ft-lb	113 ft-lb	- 21 ft-lb
X	134 ft-lb	123 ft-lb	- 11 ft-lb	134 ft-lb	123 ft-lb	- 11 ft-lb
Y	134 ft-lb	- -	- -	134 ft-lb	104 ft-lb	- 30 ft-lb

TABLE B-5
Changes in Average 30 ft-lb Temperatures for Intermediate Shell
Forging 05 (Axial Orientation)
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{30}	Unirradiated	CVGRAPH Fit	ΔT_{30}
T	0°F	25°F	25°F	-12.08°F	36.64°F	48.73°F
U	0°F	62°F	62°F	-12.08°F	53.98°F	66.06°F
X	0°F	115°F	115°F	-12.08°F	97.95°F	110.04°F
Y	0°F	--	--	-12.08°F	77.13°F	89.21°F

TABLE B-6
Changes in Average 50 ft-lb Temperatures for Intermediate Shell
Forging 05 (Axial Orientation)
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{50}	Unirradiated	CVGRAPH Fit	ΔT_{50}
T	60°F	85°F	25°F	41.9°F	86.5°F	44.6°F
U	60°F	102°F	42°F	41.9°F	107.65°F	65.75°F
X	60°F	150°F	90°F	41.9°F	156.66°F	114.76°F
Y	60°F	--	--	41.9°F	172.87°F	130.97°F

TABLE B-7
Changes in Average 35 mil Lateral Expansion Temperatures for Intermediate Shell
Forging 05 (Axial Orientation)
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{35}	Unirradiated	CVGRAPH Fit	ΔT_{35}
T	20°F	50°F	30°F	18.0	61.66°F	43.66°F
U	20°F	97°F	77°F	18.0	90.93°F	72.92F
X	20°F	135°F	115°F	18.0	141.36°F	123.35°F
Y	20°F	- -	- -	18.0	173.87°F	155.86°F

TABLE B-8
Changes in Average Energy Absorption at Full Shear for Intermediate Shell
Forging 05 (Axial Orientation)
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔE	Unirradiated	CVGRAPH Fit	ΔE
T	88 ft-lb	82 ft-lb	-6 ft-lb	88 ft-lb	82 ft-lb	-6 ft-lb
U	88 ft-lb	80 ft-lb	- 8 ft-lb	88 ft-lb	80 ft-lb	- 8 ft-lb
X	88 ft-lb	86 ft-lb	- 2 ft-lb	88 ft-lb	86 ft-lb	- 2 ft-lb
Y	88 ft-lb	- -	- -	88 ft-lb	69 ft-lb	- 19 ft-lb

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

Capsule	Unirradiated	Hand Fit	ΔT_{30}	Unirradiated	CVGRAPH Fit	ΔT_{30}
T	- 75°F	5°F	80°F	- 88.1°F	-13.54°F	74.56°F
U	- 75°F	55°F	130°F	- 88.1°F	42.27°F	130.38°F
X	- 75°F	-20°F	55°F	- 88.1°F	-43.88°F	44.22°F
Y	- 75°F	- -	- -	- 88.1°F	-1.18°F	86.91°F

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

Capsule	Unirradiated	Hand Fit	ΔT_{50}	Unirradiated	CVGRAPH Fit	ΔT_{50}
T	- 40°F	35°F	75°F	- 41.12°F	33.79°F	74.92°F
U	- 40°F	98°F	138°F	- 41.12°F	85.26°F	126.39°F
X	- 40°F	35°F	75°F	- 41.12°F	29.67°F	70.79°F
Y	- 40°F	- -	- -	- 41.12°F	52.32°F	93.45°F

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

Capsule	Unirradiated	Hand Fit	ΔT_{35}	Unirradiated	CVGRAPH Fit	ΔT_{35}
T	- 50°F	15°F	65°F	- 48.9°F	7.72°F	56.62°F
U	- 50°F	62°F	122°F	- 48.9°F	59.3°F	108.2°F
X	- 50°F	-20°F	30°F	- 48.9°F	-41.1°F	7.79°F
Y	- 50°F	- -	- -	- 48.9°F	52.6°F	101.51°F

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

Capsule	Unirradiated	Hand Fit	ΔE	Unirradiated	CVGRAPH Fit	ΔE
T	112 ft-lb	110 ft-lb	- 2 ft-lb	112 ft-lb	110 ft-lb	- 2 ft-lb
U	112 ft-lb	109 ft-lb	- 3 ft-lb	112 ft-lb	105 ft-lb	- 7 ft-lb
X	112 ft-lb	73 ft-lb	- 39 ft-lb	112 ft-lb	73 ft-lb	- 39 ft-lb
Y	112 ft-lb	- -	- -	112 ft-lb	109 ft-lb	- 3 ft-lb

TABLE B-13
Changes in Average 30 ft-lb Temperatures for the Weld Heat-Affected-Zone Material
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{30}	Unirradiated	CVGRAPH Fit	ΔT_{30}
T	- 60°F	-10°F	50°F	- 71.08°F	-46.49°F	24.58°F
U	- 60°F	-2°F	58°F	- 71.08°F	-7.05°F	64.03°F
X	- 60°F	-35°F	25°F	- 71.08°F	-42.78°F	28.29°F
Y	- 60°F	- -	- -	- 71.08°F	-20.75°F	50.32°F

TABLE B-14
Changes in Average 50 ft-lb Temperatures for the Weld Heat-Affected-Zone Material
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{50}	Unirradiated	CVGRAPH Fit	ΔT_{50}
T	- 30°F	20°F	50°F	- 30.69°F	8.64°F	39.33°F
U	- 30°F	28°F	58°F	- 30.69°F	25.96°F	56.65°F
X	- 30°F	5°F	35°F	- 30.69°F	-4.75°F	25.93°F
Y	- 30°F	- -	- -	- 30.69°F	41.07°F	71.76°F

TABLE B-15
Changes in Average 35 mil Lateral Expansion Temperatures for the Weld
Heat-Affected-Zone Material
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔT_{35}	Unirradiated	CVGRAPH Fit	ΔT_{35}
T	- 25°F	15°F	40°F	- 6.5°F	19.38°F	25.89°F
U	- 25°F	30°F	55°F	- 6.5°F	25.43°F	31.94°F
X	- 25°F	40°F	65°F	- 6.5°F	19.47°F	25.98°F
Y	- 25°F	- -	- -	- 6.5°F	59.55°F	66.06°F

TABLE B-16
Changes in Average Energy Absorption at Full Shear for the Weld
Heat-Affected-Zone Material
Hand Fit vs. CVGRAPH 4.1

Capsule	Unirradiated	Hand Fit	ΔE	Unirradiated	CVGRAPH Fit	ΔE
T	122 ft-lb	120 ft-lb	- 2 ft-lb	122 ft-lb	120 ft-lb	- 2 ft-lb
U	122 ft-lb	105 ft-lb	- 17 ft-lb	122 ft-lb	105 ft-lb	- 17 ft-lb
X	122 ft-lb	99 ft-lb	- 23 ft-lb	122 ft-lb	99 ft-lb	- 23 ft-lb
Y	122 ft-lb	- -	- -	122 ft-lb	75 ft-lb	- 47 ft-lb

APPENDIX C

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

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

Table C-1 Upper Shelf Energy Values Fixed in CVGRAPH

Material	Unirradiated	Capsule T	Capsule U	Capsule X	Capsule Y
Intermediate Shell Forging 05 (Tangential)	134 ft-lb	118 ft-lb	113 ft-lb	123 ft-lb	104 ft-lb
Intermediate Shell Forging 05 (Axial)	88 ft-lb	82 ft-lb	80 ft-lb	86 ft-lb	69 ft-lb
Circumferential Weld (Heat # 4278)	112 ft-lb	110 ft-lb	105 ft-lb	73 ft-lb	109 ft-lb
HAZ Material	122 ft-lb	120 ft-lb	105 ft-lb	99 ft-lb	75 ft-lb

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:20:10 on 09-15-1999

Page 1

Coefficients of Curve 1

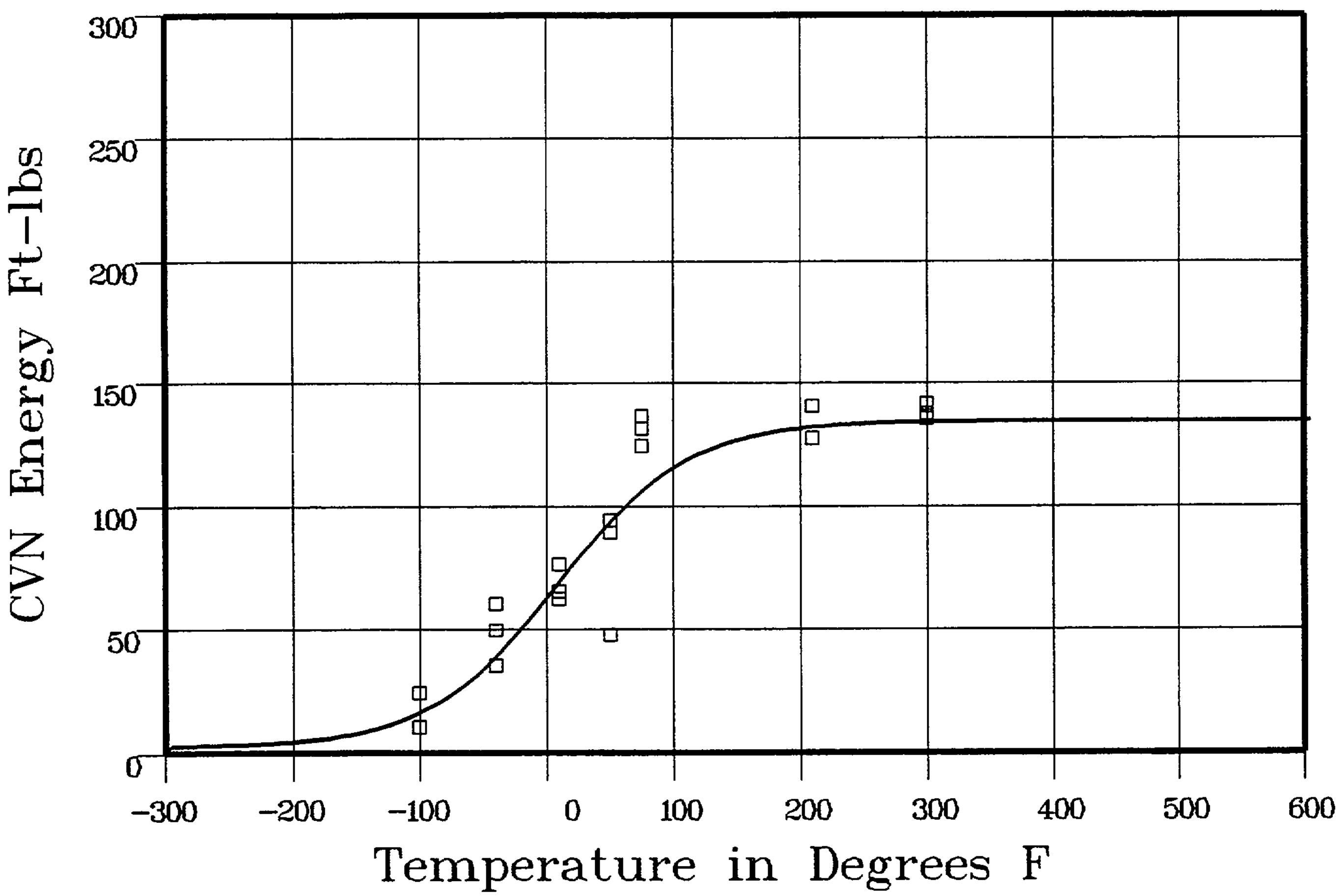
A = 68.09	B = 65.9	C = 101.44	T0 = 4.21

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

Upper Shelf Energy: 134 Fixed Temp. at 30 ft-lbs: -62.7 Temp. at 50 ft-lbs: -24.3 Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: UNIRR Material: FORGING SA508CL2 Ori.: LT Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	10.	17.17	-7.17
-100	24	17.17	6.82
-40	49	41.06	7.93
-40	35	41.06	-6.06
-40	60	41.06	18.93
10	76	71.85	4.14
10	62	71.85	-9.85
10	65	71.85	-6.85
50	47	95.97	-48.97

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

UNIRRADIATED

Page 2

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
50	89	95.97	-6.97
50	94	95.97	-1.97
75	124	107.83	16.16
75	131	107.83	23.16
75	136	107.83	28.16
210	140	131.75	8.24
210	127	131.75	-4.75
210	127	131.75	-4.75
300	137	133.61	3.38
300	135	133.61	1.38
300	141	133.61	7.38

SUM of RESIDUALS = 28.37

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:22:50 on 09-15-1999

Page 1

Coefficients of Curve 1

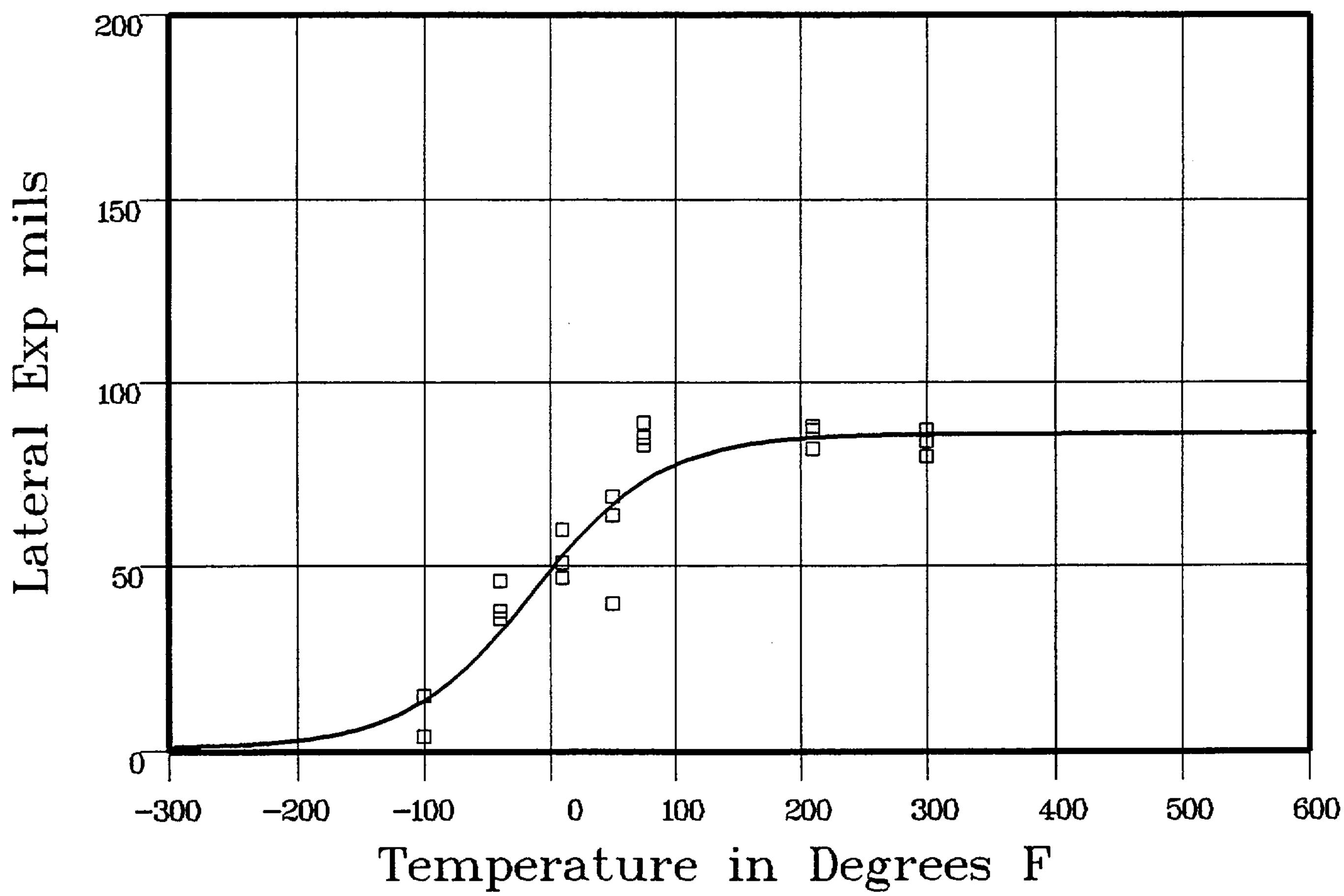
A = 43.5	B = 42.5	C = 100.99	T0 = -17.34

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

Upper Shelf L.E.: 86.01 Temperature at L.E. 35: -37.8 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: UNIRR Material: FORGING SA508CL2 Ori.: LT Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	4	14.84	-10.84
-100	15	14.84	.15
-40	36	34.12	1.87
-40	38	34.12	3.87
-40	46	34.12	11.87
10	60	54.74	5.25
10	47	54.74	-7.74
10	51	54.74	-3.74
50	40	68.28	-28.28

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

UNIRRADIATED

Page 2

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V–Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
50	64	68.28	−4.28
50	69	68.28	.71
75	83	74.24	8.75
75	85	74.24	10.75
75	89	74.24	14.75
210	88	85.08	2.91
210	87	85.08	1.91
210	82	85.08	−3.08
300	84	85.85	−1.85
300	87	85.85	1.14
300	80	85.85	−5.85

SUM of RESIDUALS = −1.69

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:34:22 on 09-15-1999

Page 1

Coefficients of Curve 1

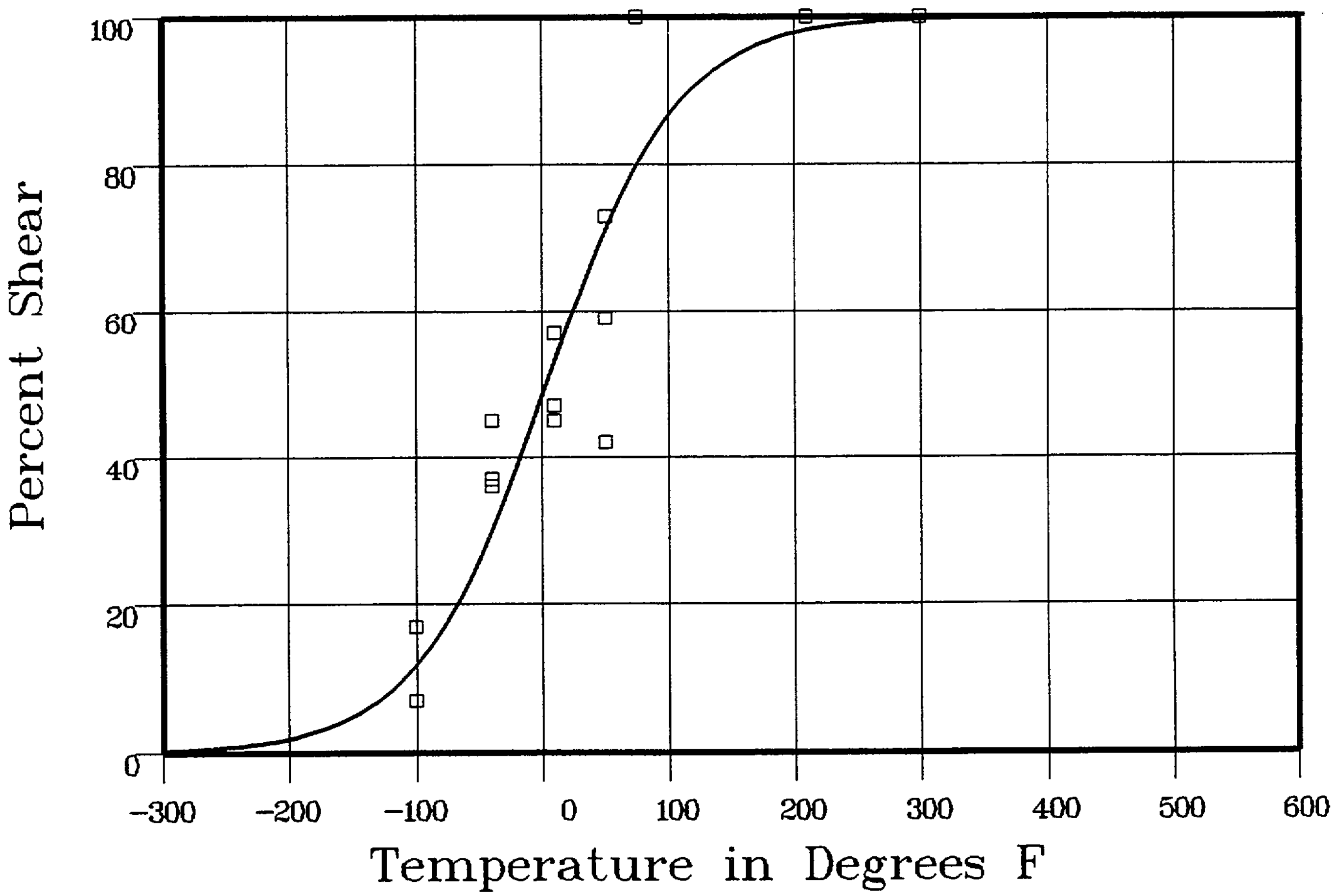
A = 50	B = 50	C = 103.1	T0 = -1.05

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

Temperature at 50% Shear: -1

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: UNIRR Material: FORGING SA508CL2 Ori.: LT Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	7	12.79	-5.79
-100	17	12.79	4.2
-40	37	31.96	5.03
-40	36	31.96	4.03
-40	45	31.96	13.03
10	57	55.34	1.65
10	45	55.34	-10.34
10	47	55.34	-8.34
50	42	72.91	-30.91

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

UNIRRADIATED

Page 2

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50	73	72.91	.08
50	59	72.91	-13.91
75	100	81.38	18.61
75	100	81.38	18.61
75	100	81.38	18.61
210	100	98.36	1.63
210	100	98.36	1.63
210	100	98.36	1.63
300	100	99.7	.29
300	100	99.7	.29
300	100	99.7	.29

SUM of RESIDUALS = 20.38

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:39:29 on 09-15-1999

Page 1

Coefficients of Curve 1

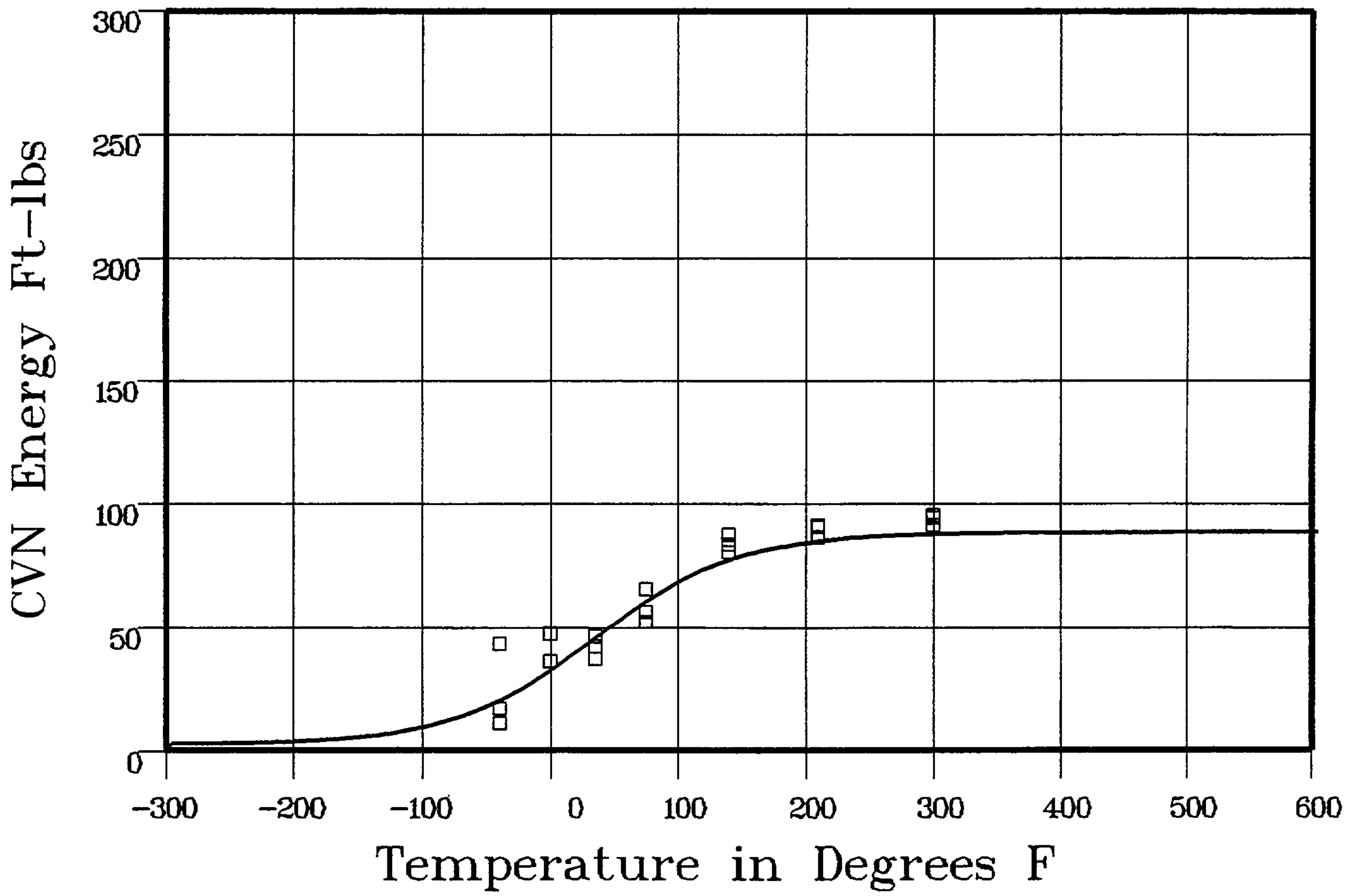
A = 45.09	B = 42.9	C = 111.9	T0 = 29.06

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

Upper Shelf Energy: 88 Fixed   Temp. at 30 ft-lbs: -12   Temp. at 50 ft-lbs: 41.9   Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA508CL2   Heat Number: 288757/981057(05)   Orientation: TL

Capsule: UNIRR   Total Fluence:



Data Set(s) Plotted

Plant: SQ2   Cap.: UNIRR   Material: FORGING SA508CL2   Ori.: TL   Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-40	17	21.54	-4.54
-40	11	21.54	-10.54
-40	43	21.54	21.45
0	36	34.2	1.79
0	47	34.2	12.79
35	37	47.37	-10.37
35	42	47.37	-5.37
35	46	47.37	-1.37
75	52	61.78	-9.78

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

UNIRRADIATED

Page 2

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
75	65	61.78	3.21
75	56	61.78	-5.78
140	87	77.61	9.38
140	83	77.61	5.38
140	80	77.61	2.38
210	90	84.74	5.25
210	91	84.74	6.25
210	86	84.74	1.25
300	94	87.32	6.67
300	91	87.32	3.67
300	95	87.32	7.67

SUM of RESIDUALS = 39.42

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:46:14 on 09-15-1999

Page 1

Coefficients of Curve 1

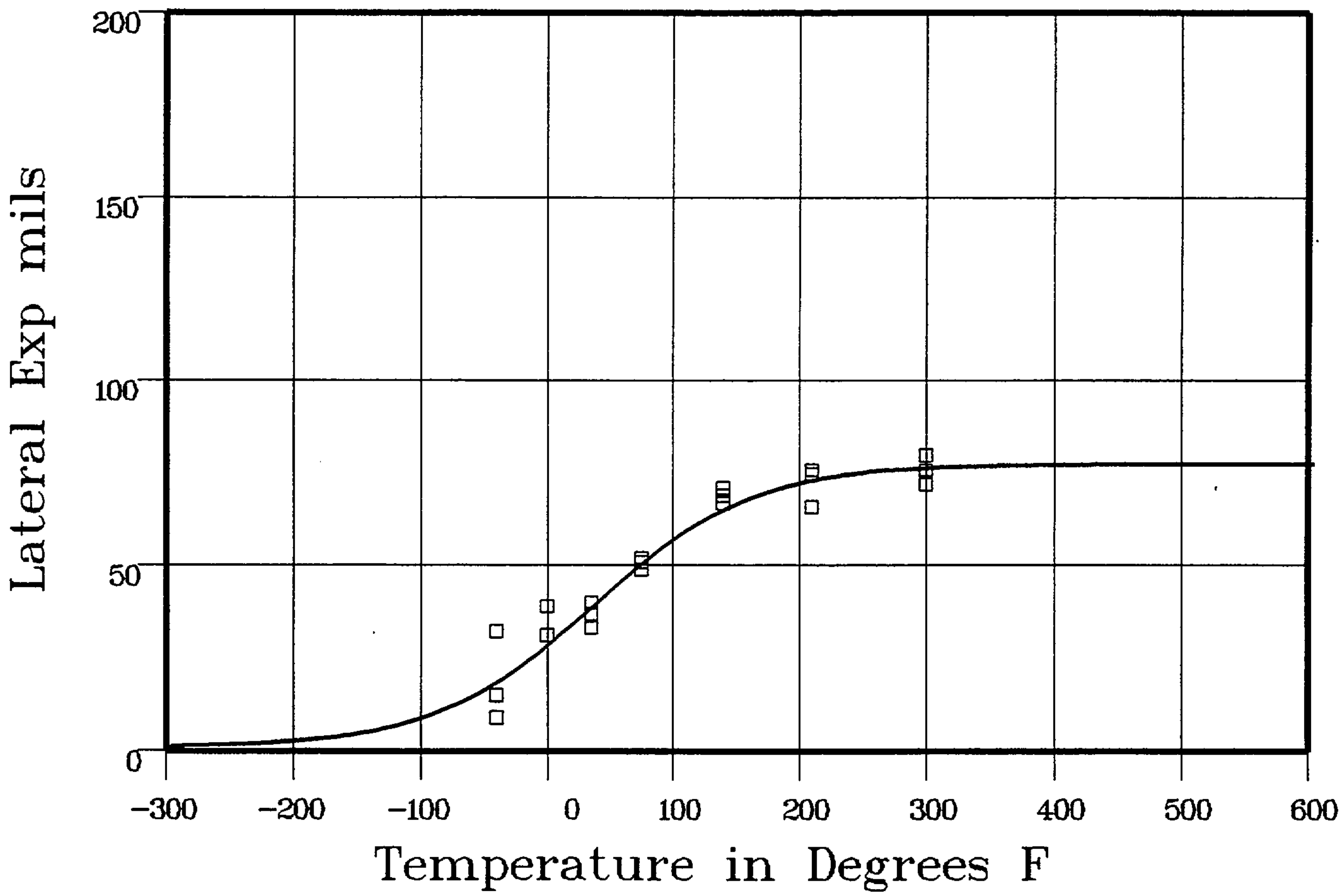
A = 39.35	B = 38.35	C = 125.74	T0 = 32.34

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

Upper Shelf L.E.: 77.7 Temperature at L.E. 35: 18 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: UNIRR Material: FORGING SA508CL2 Ori.: TL Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-40	15	19.43	-4.43
-40	9	19.43	-10.43
-40	32	19.43	12.56
0	31	29.7	1.29
0	39	29.7	9.29
35	33	40.16	-7.16
35	37	40.16	-3.16
35	40	40.16	-.16
75	49	51.88	-2.88

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

UNIRRADIATED

Page 2

Material: FORGING SA508CL2   Heat Number: 288757/981057(05)   Orientation: TL

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
75	52	51.88	.11
75	51	51.88	-.88
140	71	65.98	5.01
140	67	65.98	1.01
140	69	65.98	3.01
210	76	73.41	2.58
210	75	73.41	1.58
210	66	73.41	-7.41
300	72	76.63	-4.63
300	76	76.63	-.63
300	80	76.63	3.36

SUM of RESIDUALS = -1.96

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:54:20 on 09-15-1999

Page 1

Coefficients of Curve 1

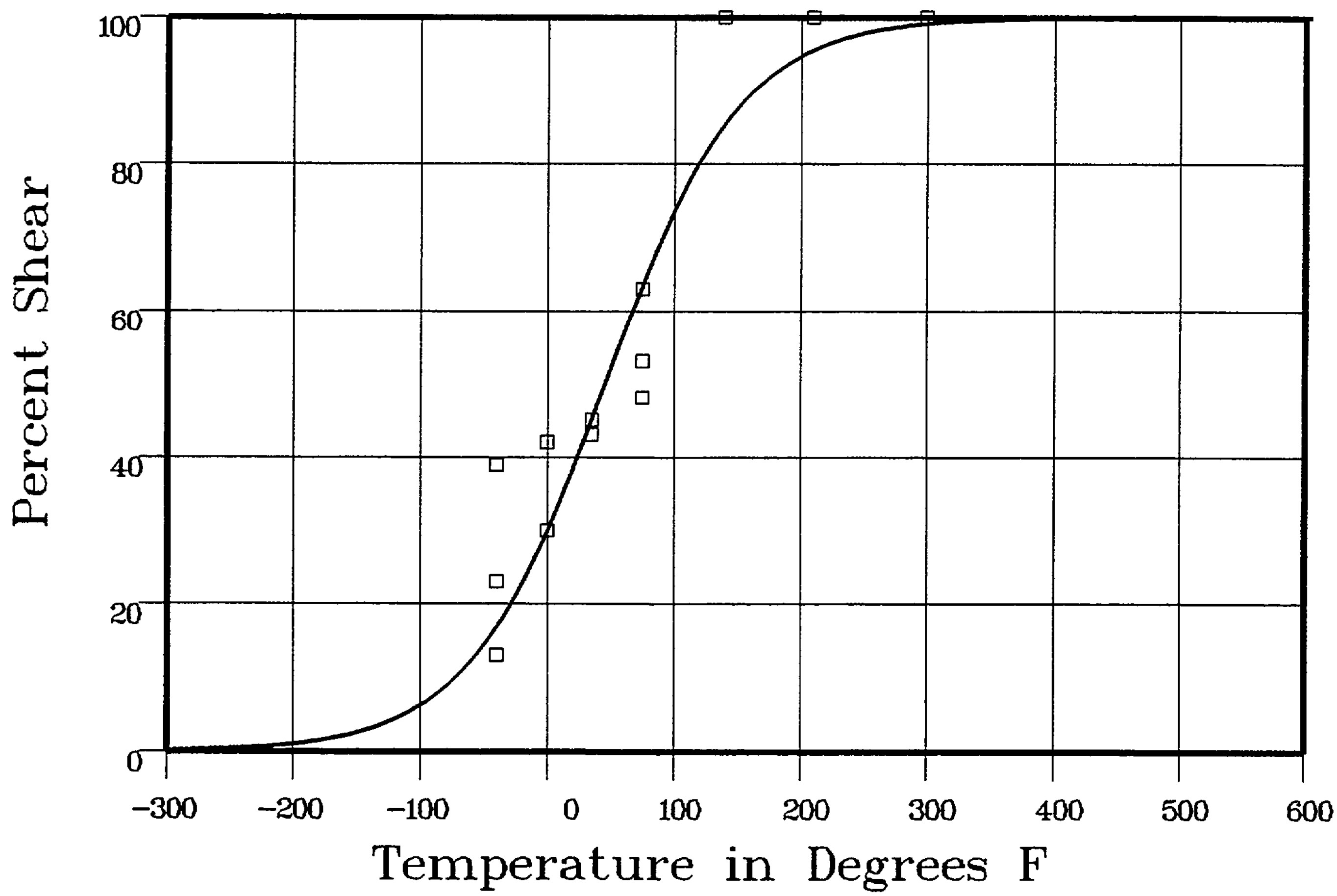
A = 50	B = 50	C = 106.95	T0 = 40.78

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

Temperature at 50% Shear: 40.7

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: UNIRR Material: FORGING SA508CL2 Ori.: TL Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40	23	18.08	4.91
-40	13	18.08	-5.08
-40	39	18.08	20.91
0	30	31.8	-1.8
0	42	31.8	10.19
35	43	47.29	-4.29
35	43	47.29	-4.29
35	45	47.29	-2.29
75	48	65.47	-17.47

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

UNIRRADIATED

Page 2

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
75	63	65.47	-2.47
75	53	65.47	-12.47
140	100	86.47	13.52
140	100	86.47	13.52
140	100	86.47	13.52
210	100	95.94	4.05
210	100	95.94	4.05
210	100	95.94	4.05
300	100	99.22	.77
300	100	99.22	.77
300	100	99.22	.77

SUM of RESIDUALS = 40.87

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:11:06 on 09-15-1999

Page 1

Coefficients of Curve 1

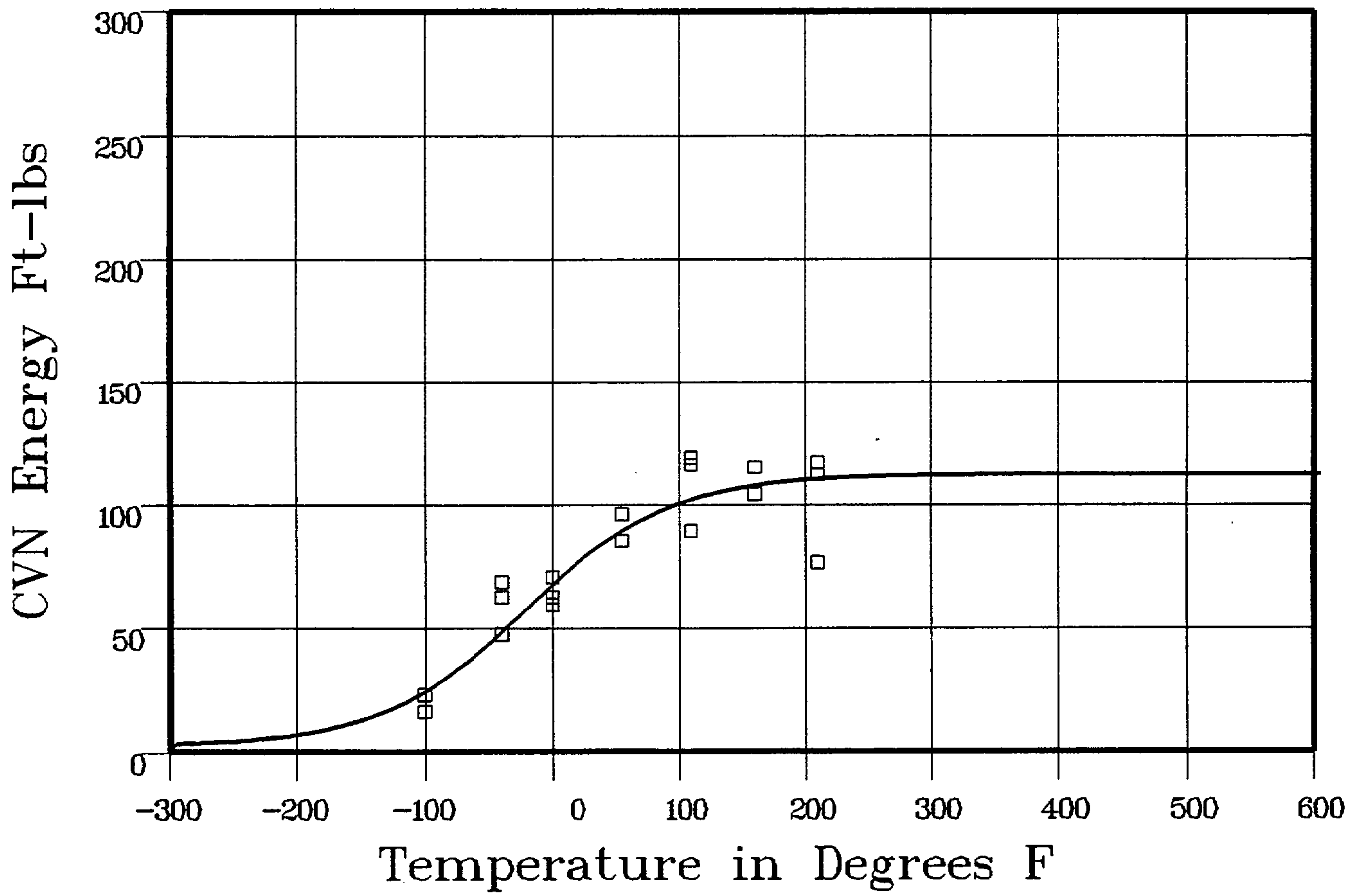
A = 57.09	B = 54.9	C = 114.36	T0 = -26.25

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

Upper Shelf Energy: 112 Fixed Temp. at 30 ft-lbs: -88.1 Temp. at 50 ft-lbs: -41.1 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: UNIRR Material: WELD Ori.: Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	16	25.9	-9.9
-100	23	25.9	-2.9
-40	68	50.53	17.46
-40	47	50.53	-3.53
-40	62	50.53	11.46
0	59	69.48	-10.48
0	62	69.48	-7.48
0	70	69.48	.51
55	85	90.64	-5.64

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

UNIRRADIATED

Page 2

Material: WELD   Heat Number: WIRE HEAT:4278   Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
55	96	90.64	5.35
55	85	90.64	-5.64
110	89	102.72	-13.72
110	116	102.72	13.27
110	119	102.72	16.27
160	104	107.92	-3.92
160	115	107.92	7.07
210	112	110.26	1.73
210	76	110.26	-34.26
210	117	110.26	6.73

SUM of RESIDUALS = -17.59

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:15:09 on 09-15-1999

Page 1

Coefficients of Curve 1

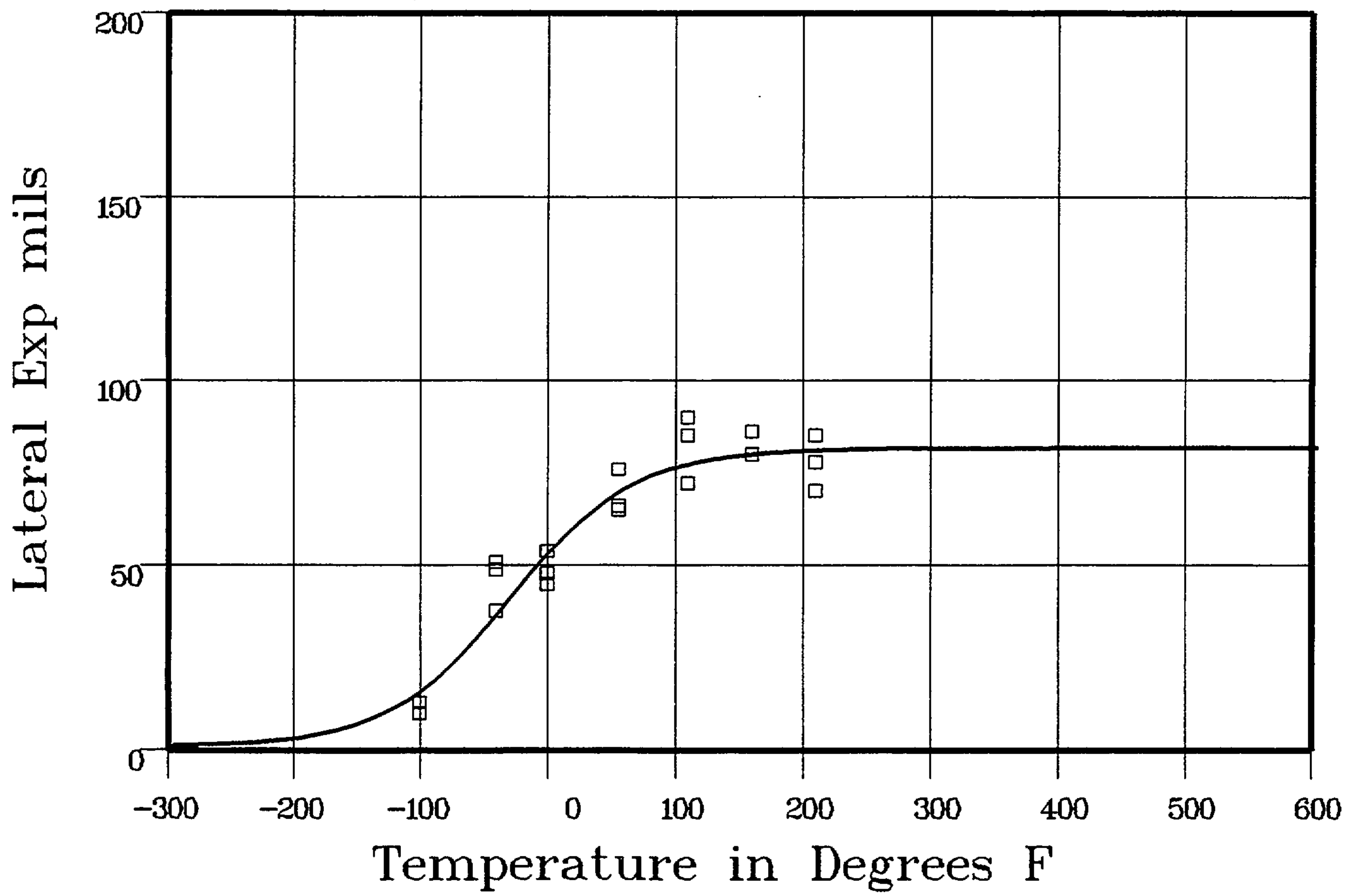
A = 41.3	B = 40.3	C = 96.03	T0 = -33.75

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

Upper Shelf L.E.: 81.61 Temperature at L.E. 35: -48.9 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: UNIRR Material: WELD Ori.: Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	10	17.2	-7.2
-100	13	17.2	-4.2
-40	51	38.68	12.31
-40	38	38.68	-.68
-40	49	38.68	10.31
0	48	54.91	-6.91
0	45	54.91	-9.91
0	54	54.91	-.91
55	65	70.64	-5.64

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

UNIRRADIATED

Page 2

Material: WELD　　Heat Number: WIRE HEAT:4278　　Orientation:

Capsule: UNIRR　　Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
55	76	70.64	5.35
55	66	70.64	-4.64
110	72	77.76	-5.76
110	90	77.76	12.23
110	85	77.76	7.23
160	80	80.21	-.21
160	86	80.21	5.78
210	78	81.11	-3.11
210	70	81.11	-11.11
210	85	81.11	3.88

SUM of RESIDUALS = -3.23

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:18:57 on 09-15-1999
Page 1
Coefficients of Curve 1

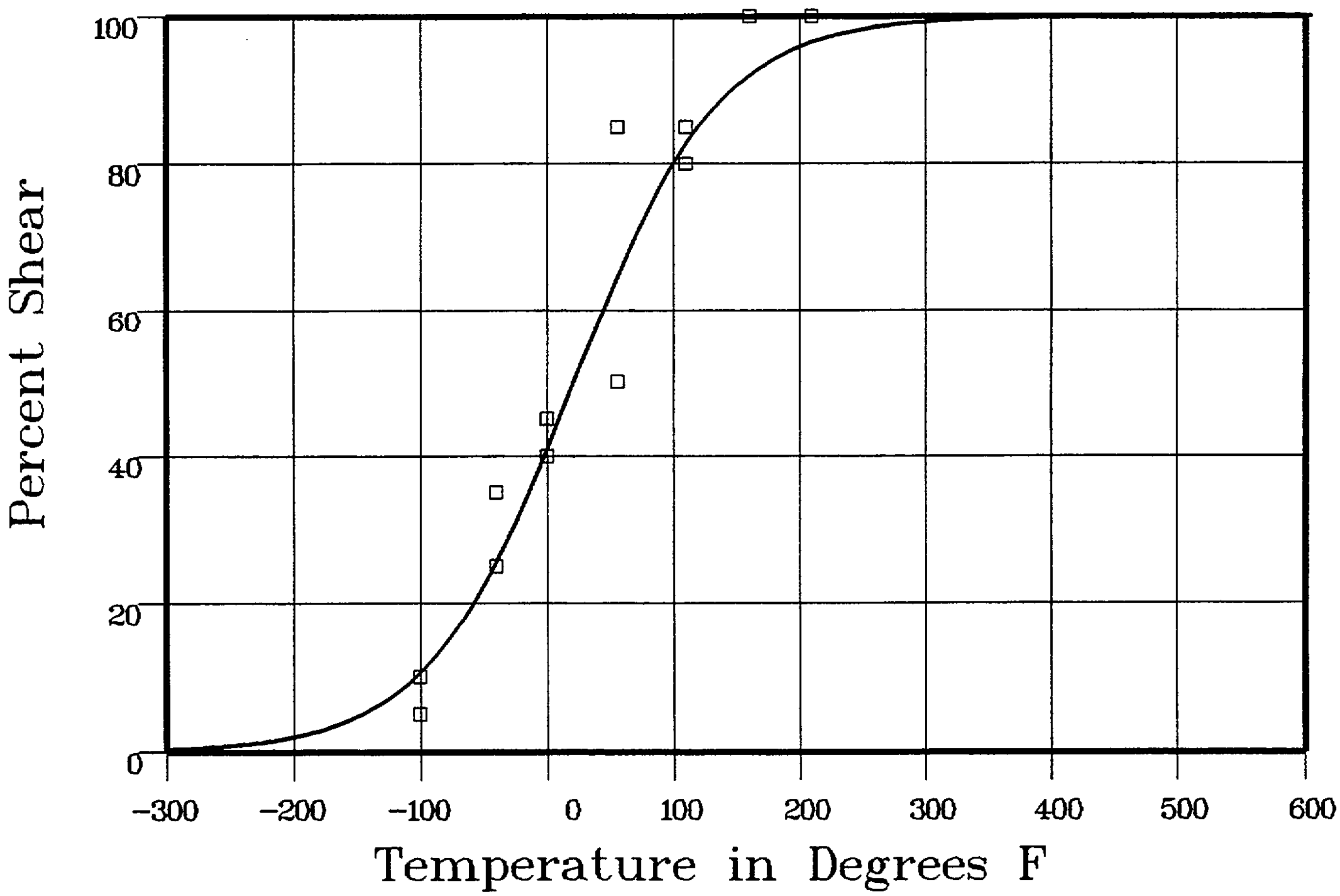
A = 50	B = 50	C = 113.68	T0 = 16.14

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

Temperature at 50% Shear: 16.1

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted
Plant: SQ2 Cap.: UNIRR Material: WELD Ori.: Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	5	11.47	-6.47
-100	10	11.47	-1.47
-40	35	27.13	7.86
-40	25	27.13	-2.13
-40	35	27.13	7.86
0	45	42.94	2.05
0	40	42.94	-2.94
0	45	42.94	2.05
55	50	66.45	-16.45

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

UNIRRADIATED

Page 2

Material: WELD   Heat Number: WIRE HEAT:4278   Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
55	85	66.45	18.54
55	50	66.45	-16.45
110	80	83.9	-3.9
110	85	83.9	1.09
110	85	83.9	1.09
160	100	92.62	7.37
160	100	92.62	7.37
210	100	96.8	3.19
210	100	96.8	3.19
210	100	96.8	3.19

SUM of RESIDUALS = 15.09

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:24:36 on 09-15-1999

Page 1

Coefficients of Curve 1

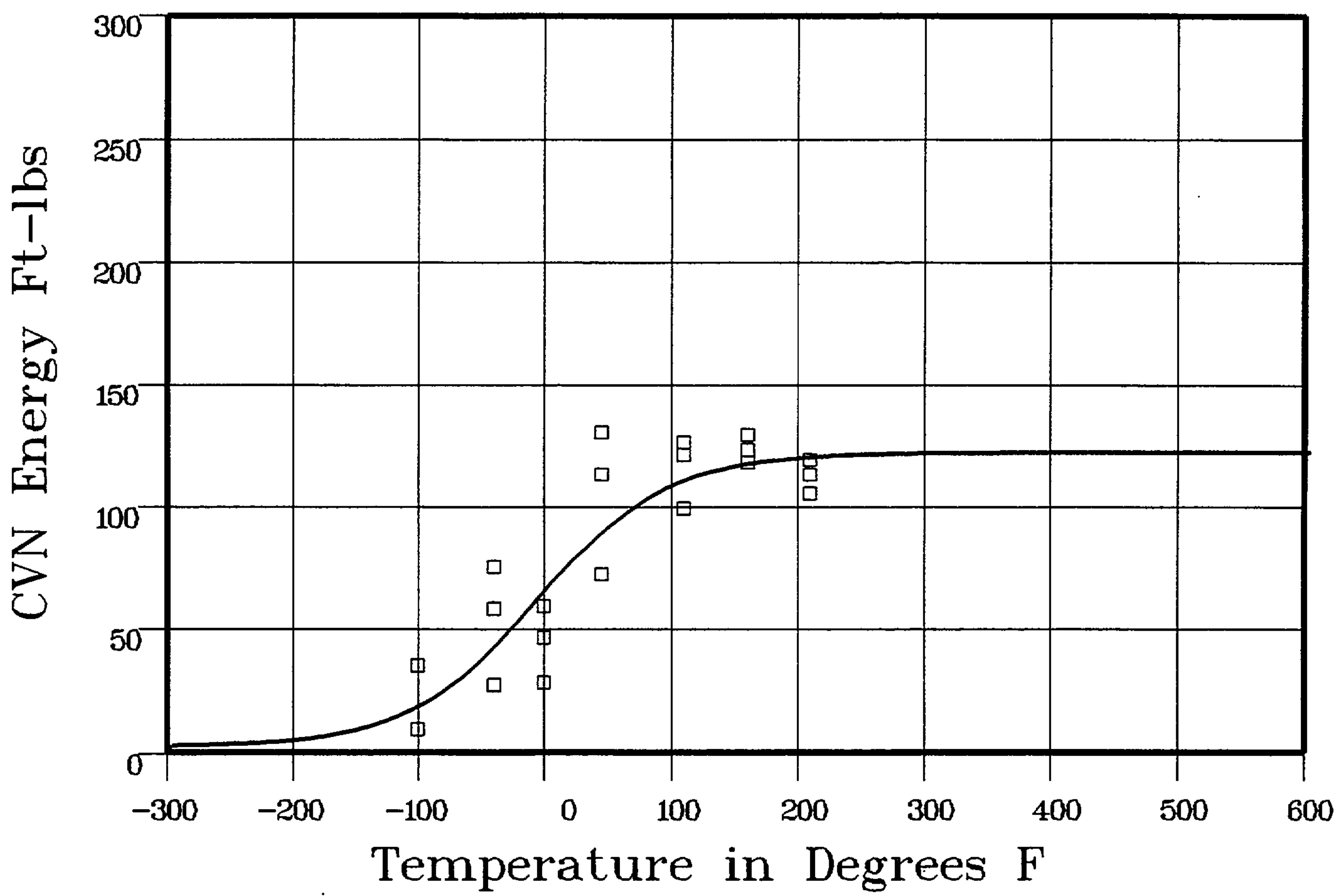
A = 62.09	B = 59.9	C = 102.63	T0 = -9.66

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

Upper Shelf Energy: 122 Fixed Temp. at 30 ft-lbs: -71 Temp. at 50 ft-lbs: -30.6 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: SHELL (05) SIDE OF WELD Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: UNIRR Material: HEAT AFFD ZONE Ori.: Heat #: SHELL (05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	9	19.78	-10.78
-100	35	19.78	15.21
-100	35	19.78	15.21
-40	27	44.89	-17.89
-40	75	44.89	30.1
-40	58	44.89	13.1
0	46	67.72	-21.72
0	59	67.72	-8.72
0	28	67.72	-39.72

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

UNIRRADIATED

Page 2

Material: HEAT AFF'D ZONE   Heat Number: SHELL (05) SIDE OF WELD   Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V–Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
45	72	91.29	–19.29
45	130	91.29	38.7
45	113	91.29	21.7
110	99	111.39	–12.39
110	126	111.39	14.6
110	121	111.39	9.6
160	123	117.76	5.23
160	118	117.76	.23
160	129	117.76	11.23
210	105	120.36	–15.36
210	113	120.36	–7.36
210	119	120.36	–1.36

SUM of RESIDUALS = 20.33

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:28:29 on 09-15-1999

Page 1

Coefficients of Curve 1

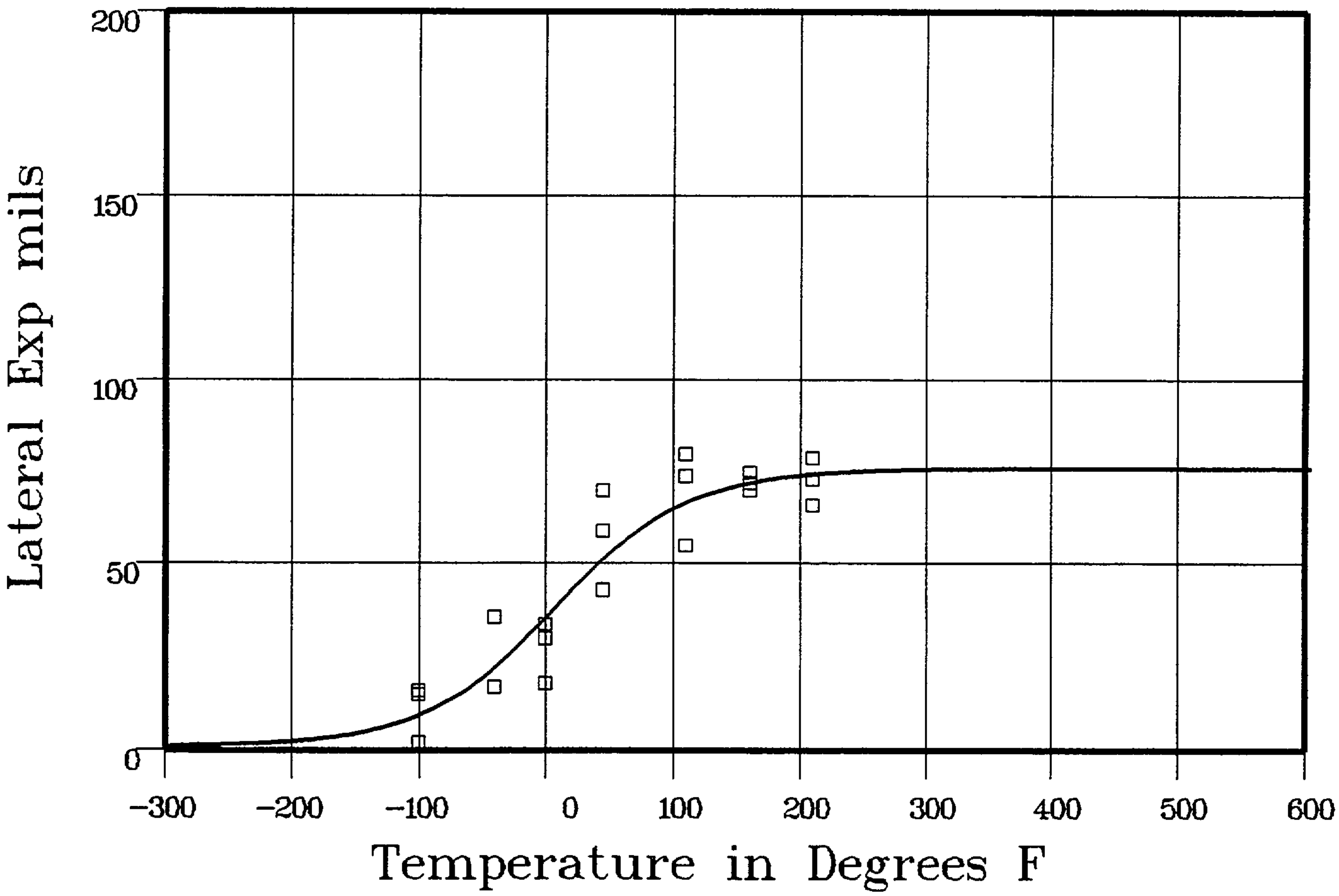
A = 38.47	B = 37.47	C = 103.96	T0 = 3.16

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

Upper Shelf L.E.: 75.95 Temperature at L.E. 35: -6.5 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: SHELL (05) SIDE OF WELD Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: UNIRR Material: HEAT AFFD ZONE Ori.: Heat #: SHELL (05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	2	10.05	-8.05
-100	16	10.05	5.94
-100	15	10.05	4.94
-40	17	23.75	-6.75
-40	36	23.75	12.24
-40	36	23.75	12.24
0	30	37.33	-7.33
0	34	37.33	-3.33
0	18	37.33	-19.33

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

UNIRRADIATED

Page 2

Material: HEAT AFF'D ZONE Heat Number: SHELL (05) SIDE OF WELD Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
45	43	52.79	-9.79
45	70	52.79	17.2
45	59	52.79	6.2
110	55	67.44	-12.44
110	80	67.44	12.55
110	74	67.44	6.55
160	72	72.45	-.45
160	75	72.45	2.54
160	70	72.45	-2.45
210	66	74.57	-8.57
210	73	74.57	-1.57
210	79	74.57	4.42

SUM of RESIDUALS = 4.73

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:31:40 on 09-15-1999

Page 1

Coefficients of Curve 1

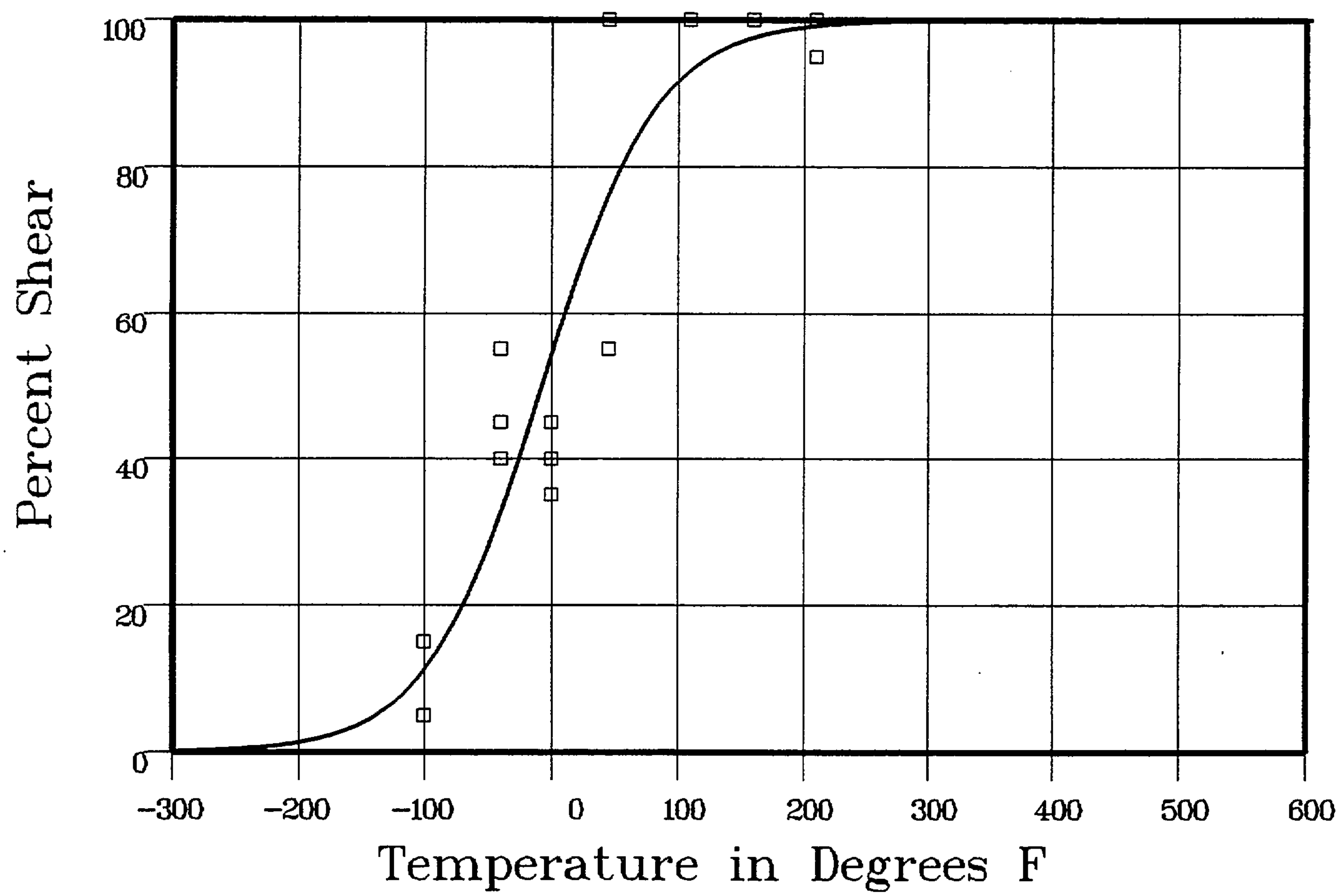
A = 50	B = 50	C = 89.68	T0 = -12.18

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

Temperature at 50% Shear: -12.1

Material: HEAT AFFD ZONE   Heat Number: SHELL (05) SIDE OF WELD   Orientation:

Capsule: UNIRR   Total Fluence:



Data Set(s) Plotted

Plant: SQ2   Cap.: UNIRR   Material: HEAT AFFD ZONE   Ori.:   Heat #: SHELL (05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	5	12.36	-7.36
-100	15	12.36	2.63
-100	15	12.36	2.63
-40	40	34.97	5.02
-40	55	34.97	20.02
-40	45	34.97	10.02
0	35	56.75	-21.75
0	45	56.75	-11.75
0	40	56.75	-16.75

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

UNIRRADIATED

Page 2

Material: HEAT AFF'D ZONE Heat Number: SHELL (05) SIDE OF WELD Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
45	55	78.16	-23.16
45	100	78.16	21.83
45	100	78.16	21.83
110	100	93.84	6.15
110	100	93.84	6.15
110	100	93.84	6.15
160	100	97.89	2.1
160	100	97.89	2.1
160	100	97.89	2.1
210	95	99.3	-4.3
210	100	99.3	.69
210	100	99.3	.69

SUM of RESIDUALS = 25.09

IRRADIATED CAPSULE T

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:35:29 on 09-24-1999

Page 1

Coefficients of Curve 1

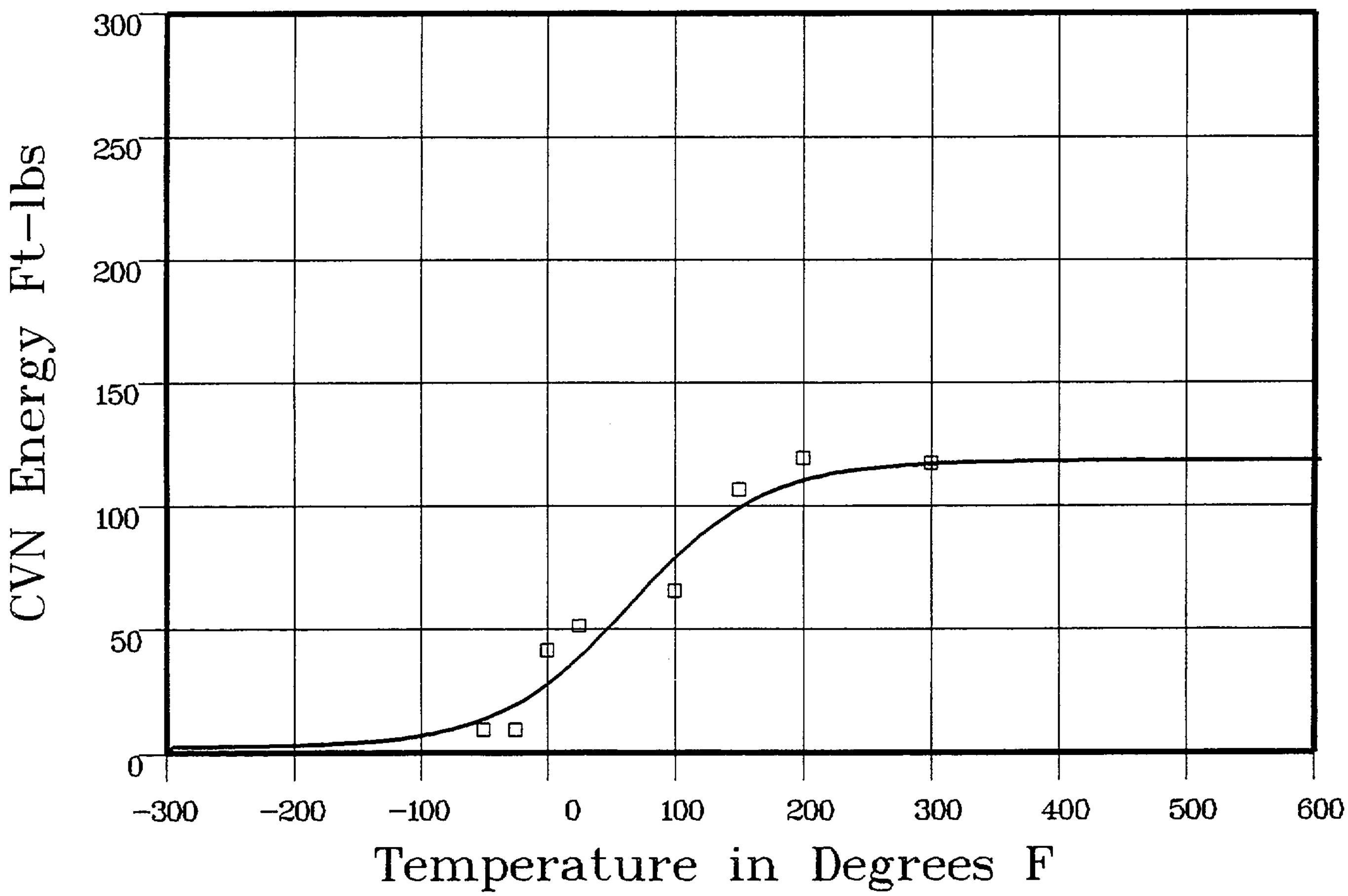
A = 60.09	B = 57.9	C = 104.09	T0 = 60.92

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

Upper Shelf Energy: 118 Fixed Temp. at 30 ft-lbs: .9 Temp. at 50 ft-lbs: 42.5 Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: T Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: T Material: FORGING SA508CL2 Ori.: LT Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	9	14.48	-5.48
-25	9	20.84	-11.84
0	41	29.61	11.38
25	51	40.87	10.12
100	65	80.86	-15.86
150	106	100.28	5.71
200	119	110.51	8.48
300	117	116.84	.15

SUM of RESIDUALS = 2.67

IRRADIATED CAPSULE T

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:37:27 on 09-24-1999

Page 1

Coefficients of Curve 1

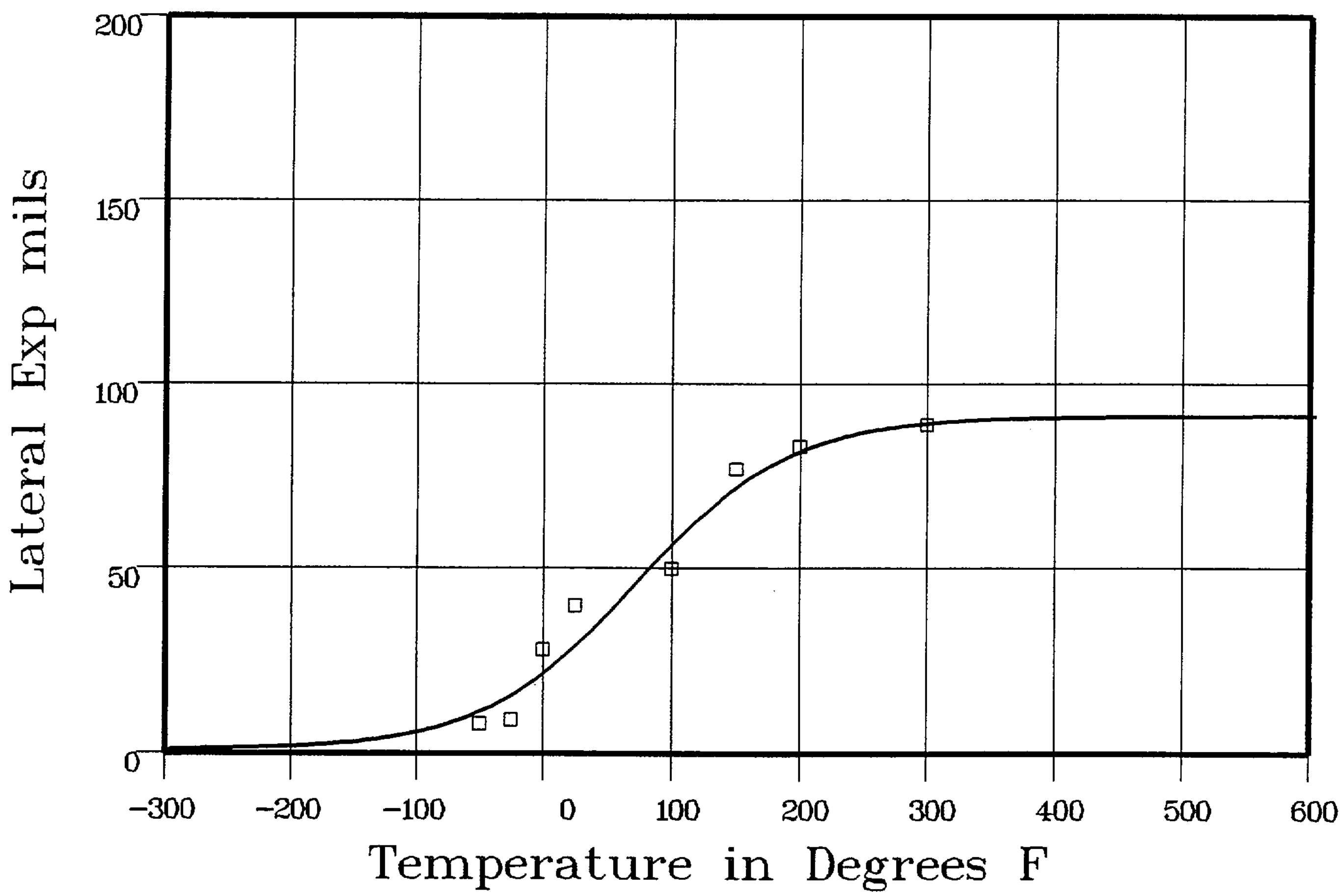
A = 46.12	B = 45.12	C = 119.14	T0 = 67.43

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

Upper Shelf L.E.: 91.25 Temperature at L.E. 35: 37.4 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: T Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: T Material: FORGING SA508CL2 Ori.: LT Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	8	12.03	-4.03
-25	9	16.77	-7.77
0	28	23	4.99
25	40	30.69	9.3
100	50	58.16	-8.16
150	77	73.19	3.8
200	83	82.45	.54
300	89	89.46	-.46

SUM of RESIDUALS = -1.78

IRRADIATED CAPSULE T

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:40:12 on 09-24-1999

Page 1

Coefficients of Curve 1

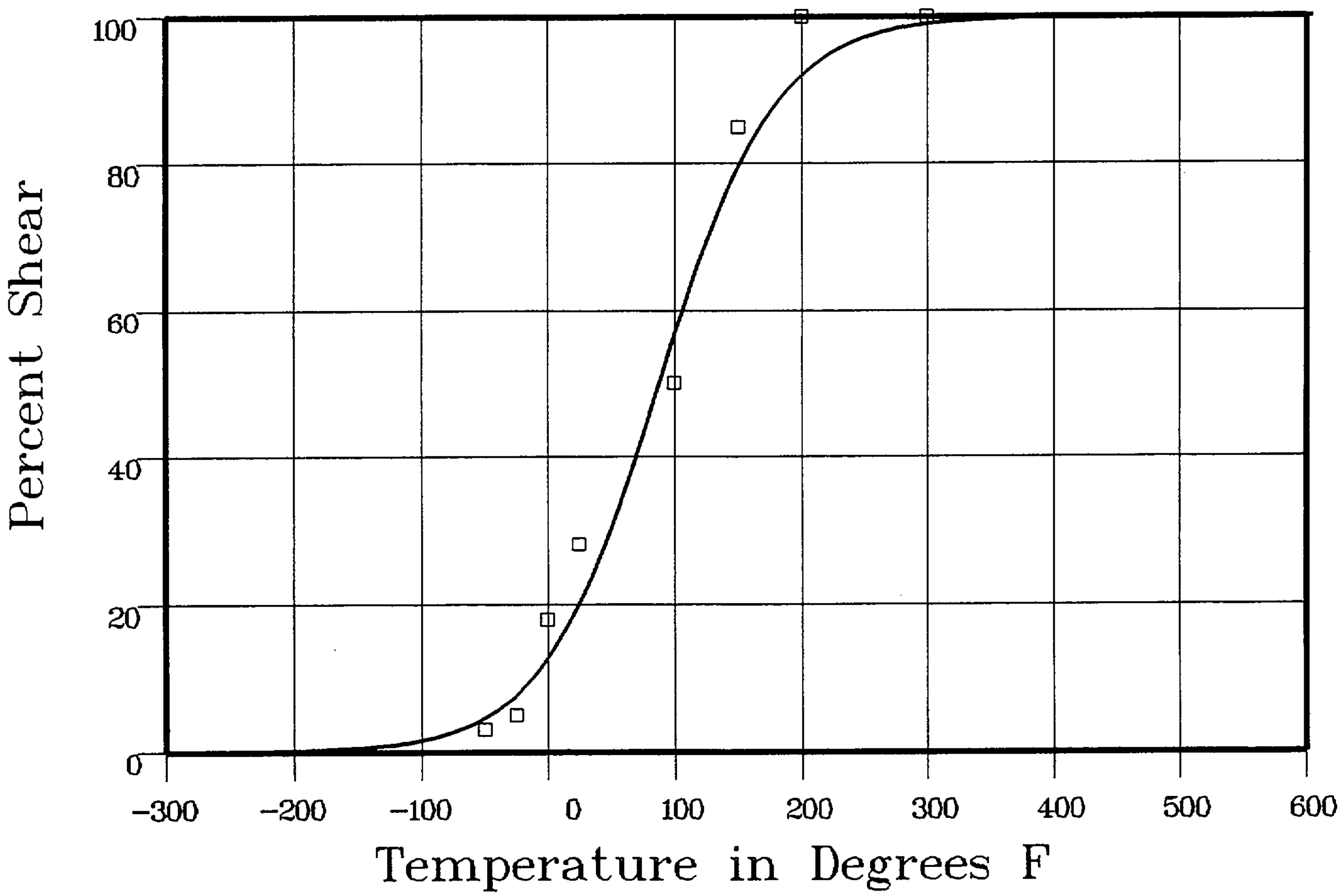
A = 50	B = 50	C = 91.21	T0 = 83.2

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

Temperature at 50% Shear: 83.2

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: T Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: T Material: FORGING SA508CL2 Ori.: LT Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	3	5.11	-2.11
-25	5	8.52	-3.52
0	18	13.89	4.1
25	28	21.81	6.18
100	50	59.1	-9.1
150	85	81.22	3.77
200	100	92.83	7.16
300	100	99.14	.85

SUM of RESIDUALS = 7.34

IRRADIATED CAPSULE T

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:45:06 on 09-24-1999

Page 1

Coefficients of Curve 1

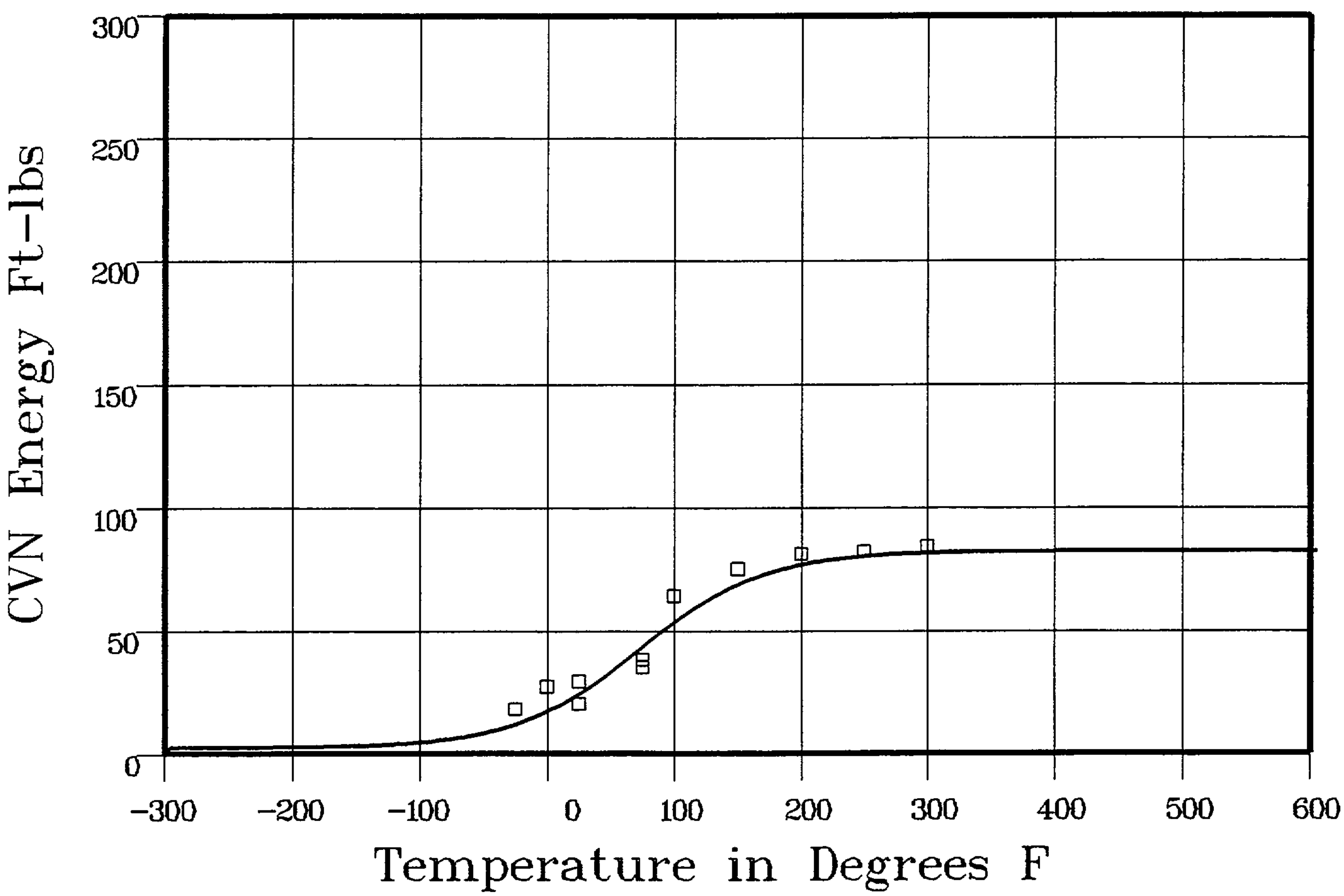
A = 42.09	B = 39.9	C = 97.03	T0 = 67.03

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

Upper Shelf Energy: 82 Fixed   Temp. at 30 ft-lbs: 36.6   Temp. at 50 ft-lbs: 86.5   Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA508CL2   Heat Number: 288757/981057(05)   Orientation: TL

Capsule: T   Total Fluence:



Data Set(s) Plotted

Plant: SQ2   Cap.: T   Material: FORGING SA508CL2   Ori.: TL   Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	18	12.61	5.38
0	27	18.22	8.77
25	20	25.82	-5.82
25	29	25.82	3.17
75	35	45.36	-10.36
75	38	45.36	-7.36
100	64	55.15	8.84
150	75	69.77	5.22
200	81	77.16	3.83

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

IRRADIATED CAPSULE T

Page 2

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: T Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
250	82	80.2	1.79
300	84	81.34	2.65

SUM of RESIDUALS = 16.13

IRRADIATED CAPSULE T

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:01:42 on 09-24-1999

Page 1

Coefficients of Curve 1

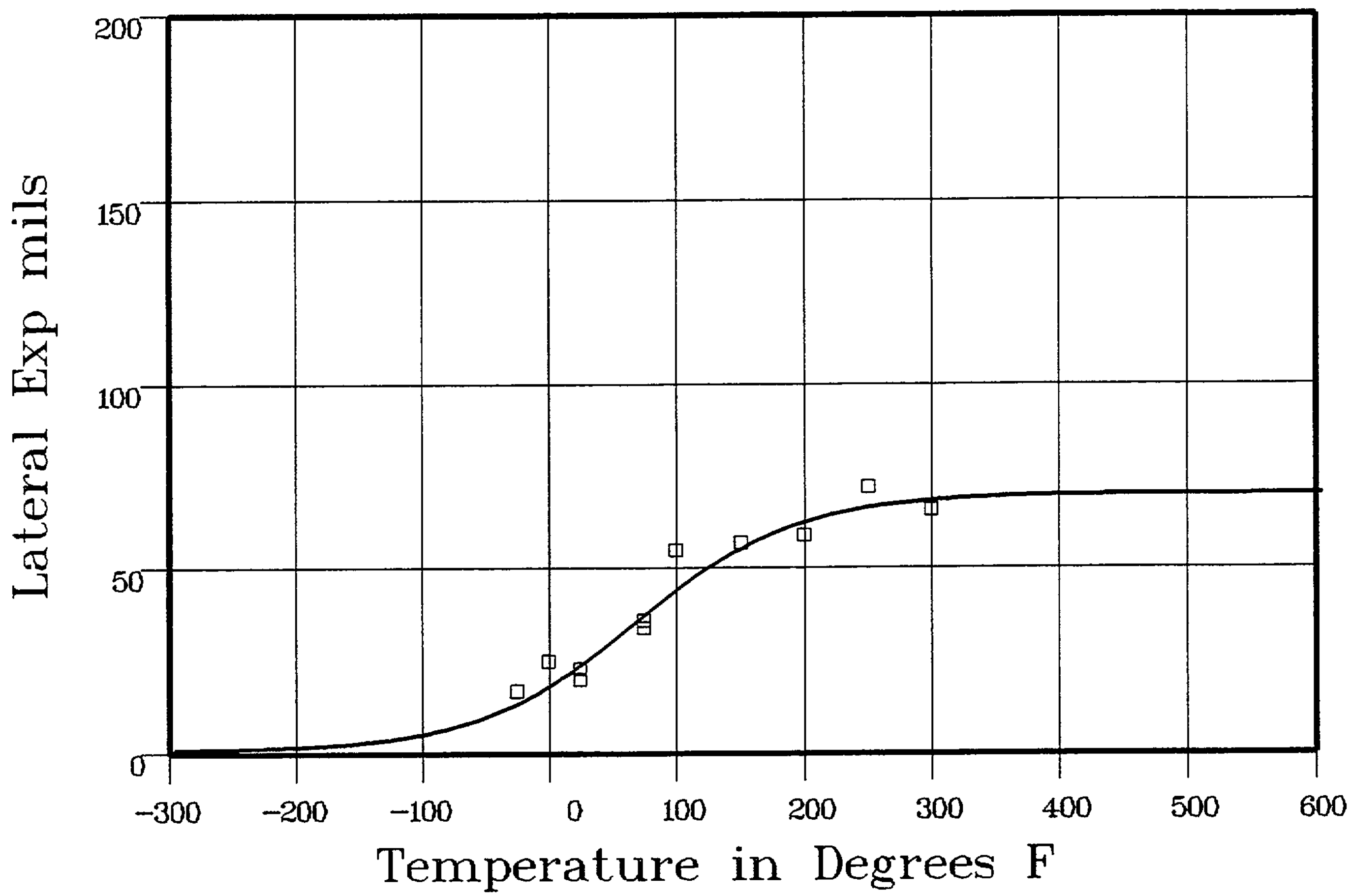
A = 35.57	B = 34.57	C = 124.5	T0 = 63.75

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

Upper Shelf L.E.: 70.15 Temperature at L.E. 35: 61.6 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: T Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: T Material: FORGING SA508CL2 Ori.: TL Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	17	14.4	2.59
0	25	19.27	5.72
25	20	25.15	-5.15
25	23	25.15	-2.15
75	34	38.69	-4.69
75	36	38.69	-2.69
100	55	45.37	9.62
150	57	56.31	.68
200	59	63.18	-4.18

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

IRRADIATED CAPSULE T

Page 2

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: T Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
250	72	66.85	5.14
300	66	68.63	-2.63

SUM of RESIDUALS = 2.27

IRRADIATED CAPSULE T

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:03:03 on 09-24-1999

Page 1

Coefficients of Curve 1

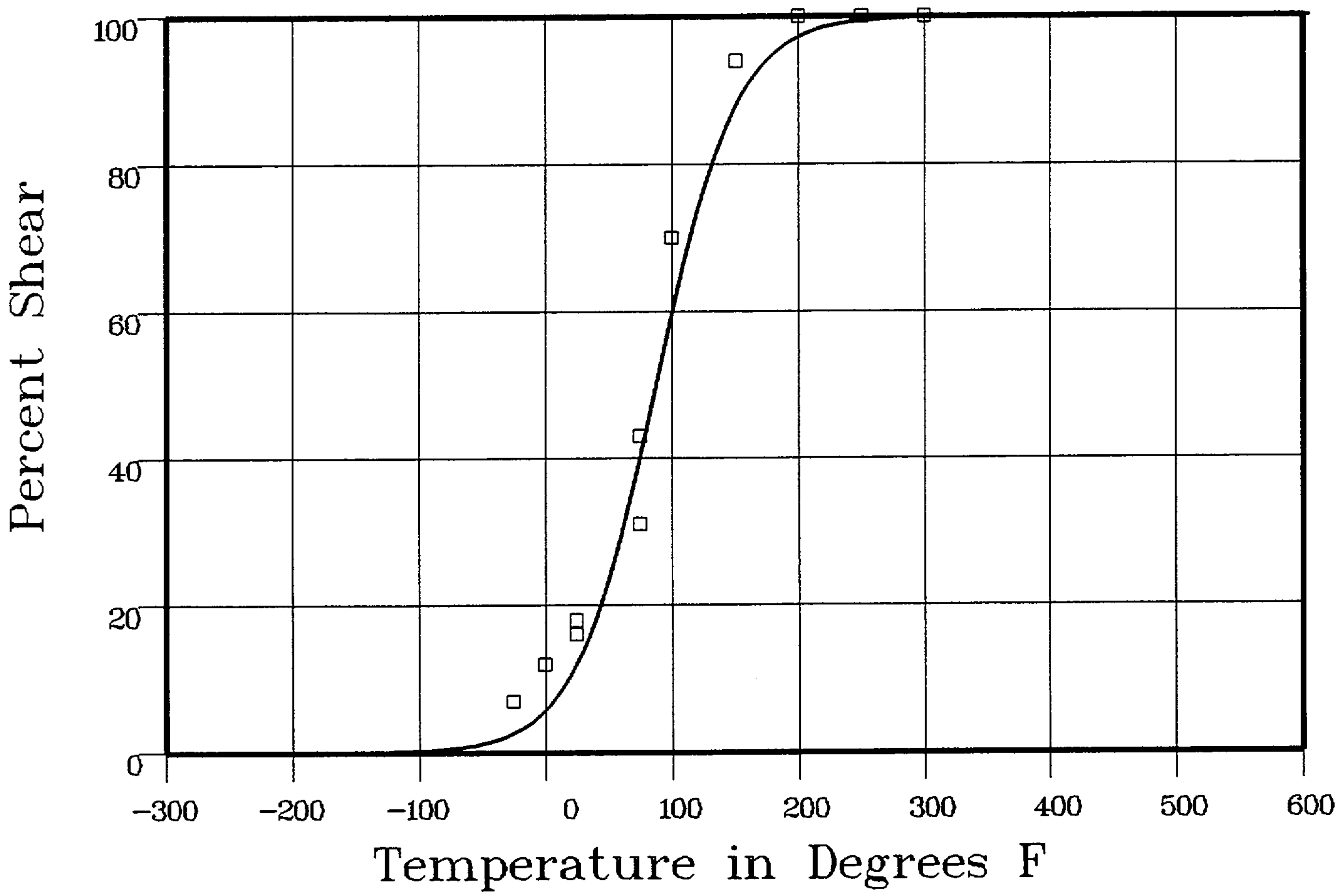
A = 50	B = 50	C = 62.82	T0 = 82.91

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

Temperature at 50% Shear: 82.9

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: T Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: T Material: FORGING SA508CL2 Ori.: TL Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	7	3.12	3.87
0	12	6.66	5.33
25	16	13.66	2.33
25	18	13.66	4.33
75	31	43.73	-12.73
75	43	43.73	-.73
100	70	63.27	6.72
150	94	89.43	4.56
200	100	97.65	2.34

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

IRRADIATED CAPSULE T

Page 2

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: T Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
250	100	99.51	.48
300	100	99.9	.09

SUM of RESIDUALS = 16.63

IRRADIATED CAPSULE T

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:12:37 on 09-24-1999

Page 1

Coefficients of Curve 1

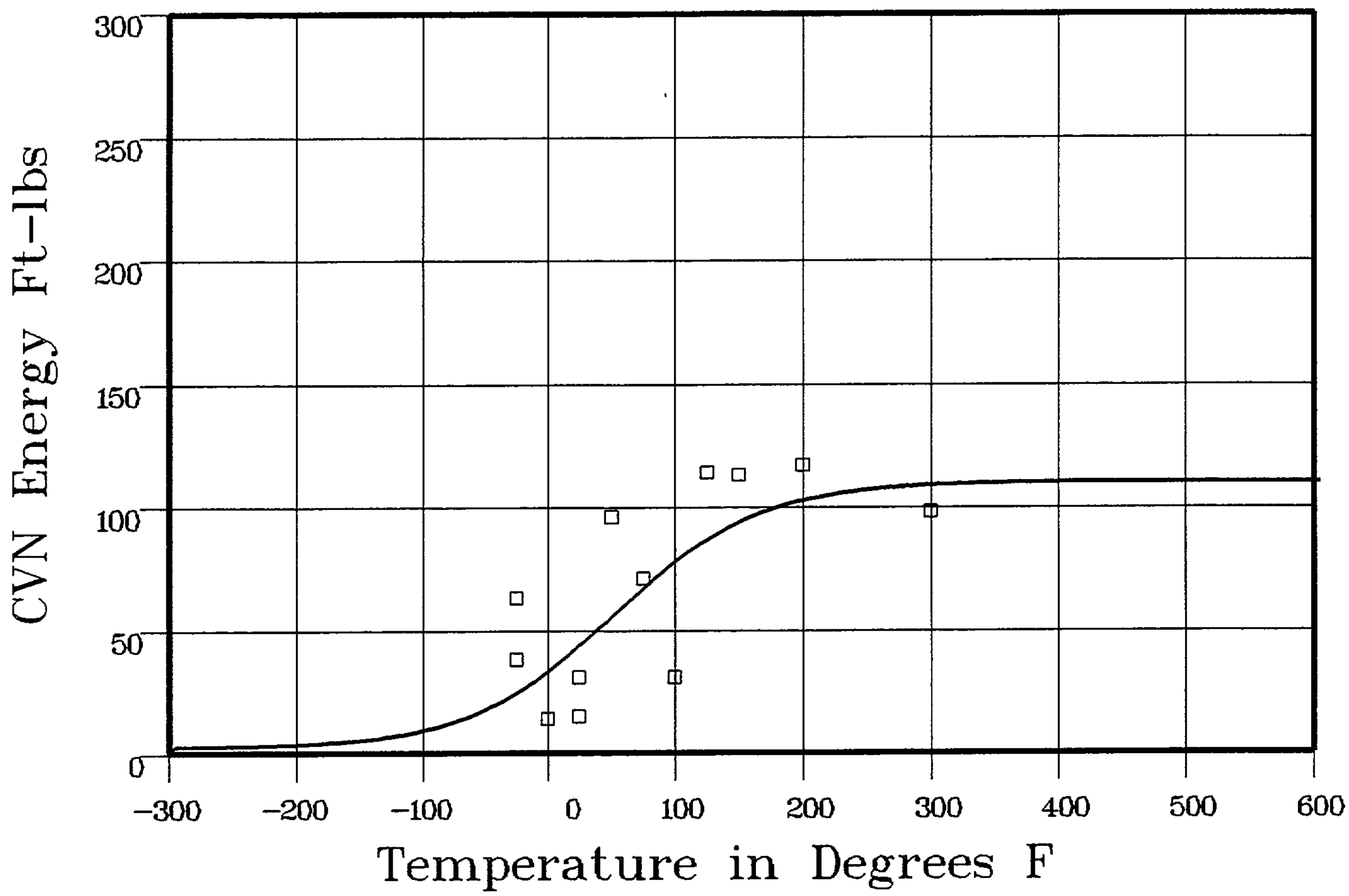
A = 56.09	B = 53.9	C = 114.11	T0 = 46.76

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

Upper Shelf Energy: 110 Fixed Temp. at 30 ft-lbs: -13.5 Temp. at 50 ft-lbs: 33.7 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: T Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: T Material: WELD Ori.: Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	63	26.06	36.93
-25	38	26.06	11.93
0	14	35.16	-21.16
25	15	45.94	-30.94
25	31	45.94	-14.94
50	96	57.62	38.37
75	71	69.16	1.83
100	31	79.56	-48.56
125	114	88.17	25.82

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

IRRADIATED CAPSULE T

Page 2

Material: WELD   Heat Number: WIRE HEAT:4278   Orientation:

Capsule: T   Total Fluence:

Charpy V–Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
150	113	94.82	18.17
200	117	103.11	13.88
300	98	108.74	-10.74

SUM of RESIDUALS = 20.6

IRRADIATED CAPSULE T

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:16:44 on 09-24-1999

Page 1

Coefficients of Curve 1

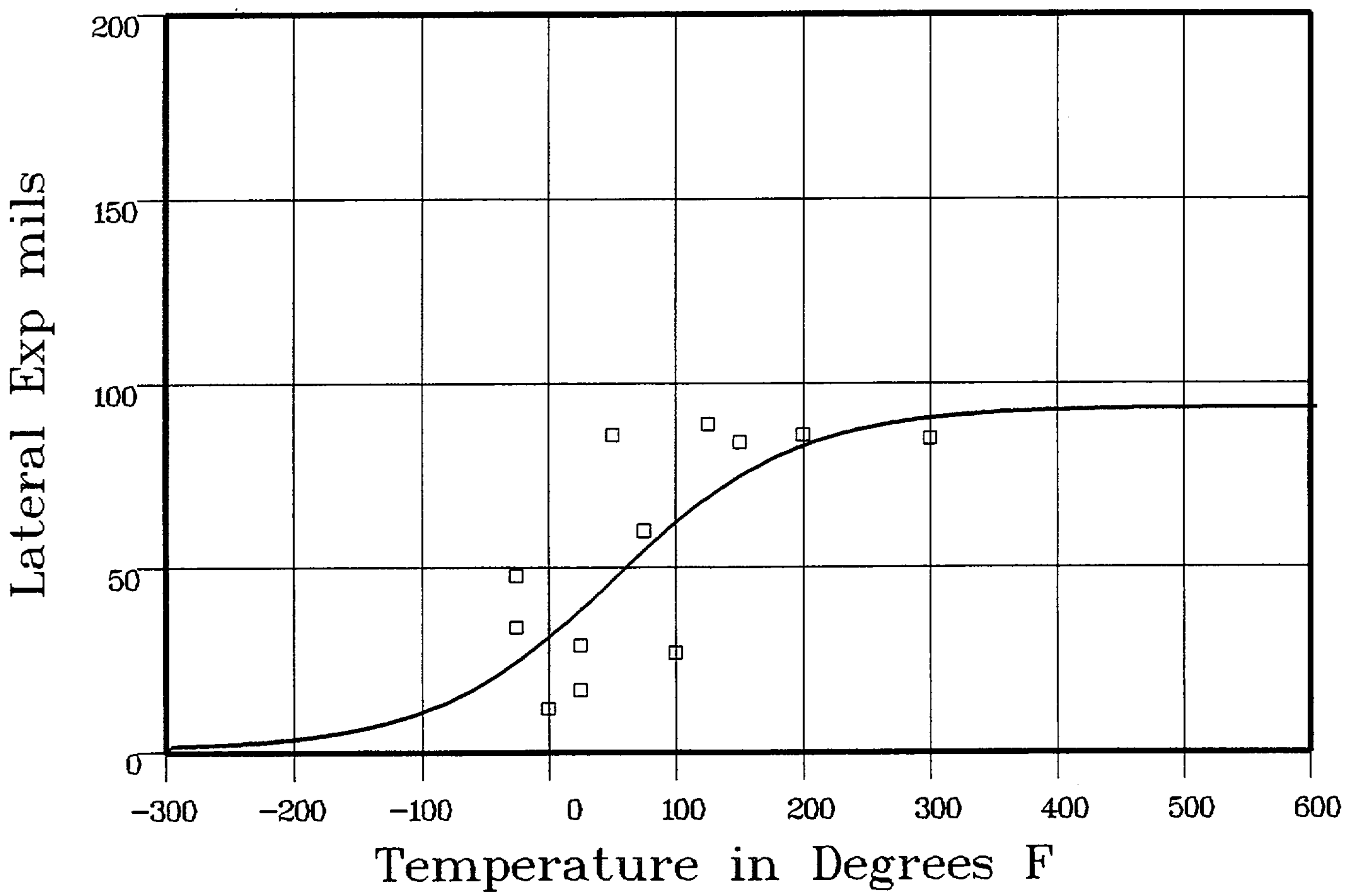
A = 47.19	B = 46.19	C = 143.04	T0 = 46.4

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

Upper Shelf L.E.: 93.39 Temperature at L.E. 35: 7.7 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: T Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: T Material: WELD Ori.: Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	48	25.87	22.12
-25	34	25.87	8.12
0	12	32.71	-20.71
25	17	40.33	-23.33
25	29	40.33	-11.33
50	86	48.35	37.64
75	60	56.3	3.69
100	27	63.73	-36.73
125	89	70.29	18.7

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

IRRADIATED CAPSULE T

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: T Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
150	84	75.81	8.18
200	86	83.73	2.26
300	85	90.8	-5.8

SUM of RESIDUALS = 2.81

IRRADIATED CAPSULE T

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:22:22 on 09-24-1999

Page 1

Coefficients of Curve 1

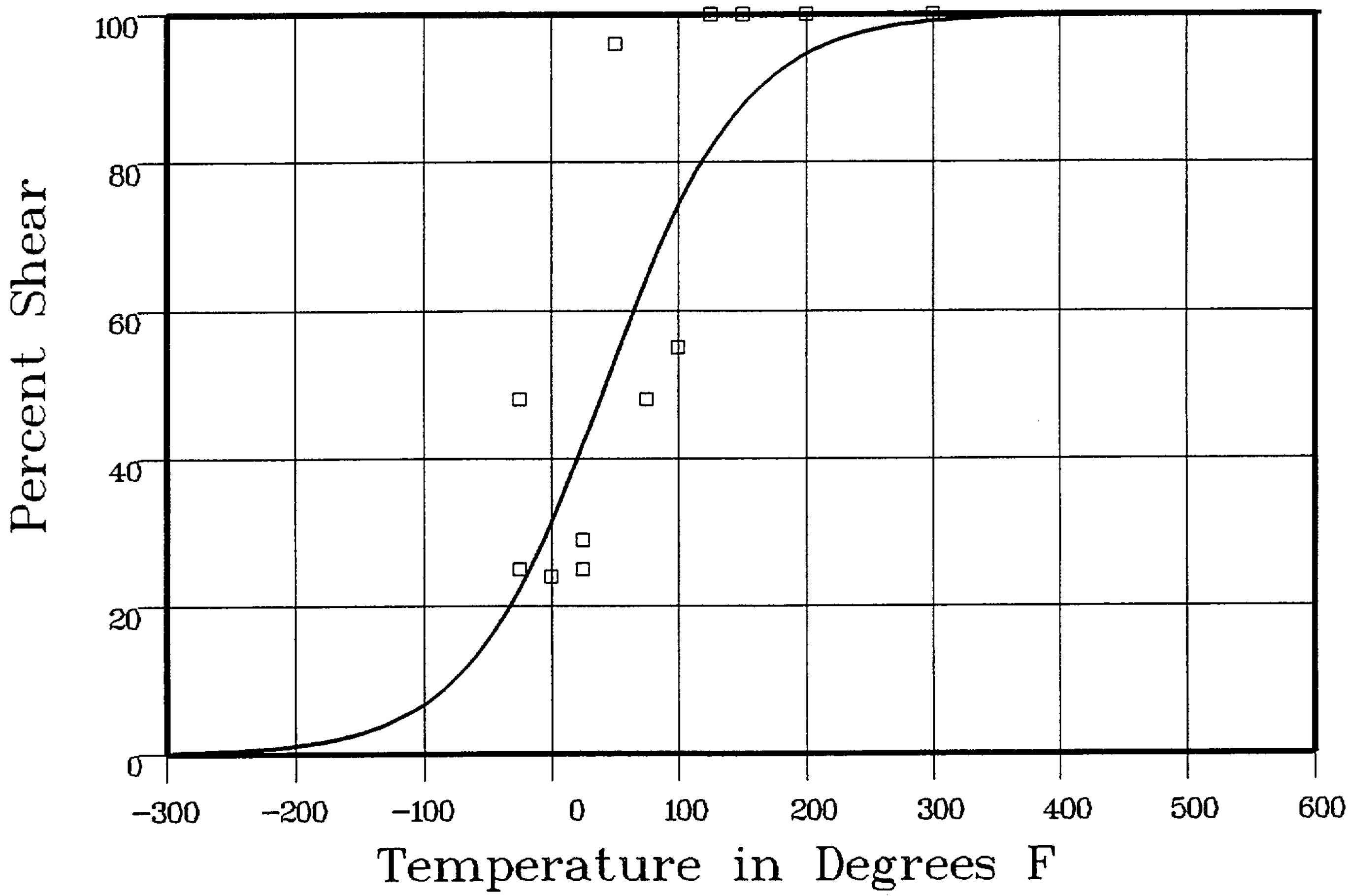
A = 50	B = 50	C = 108.87	T0 = 37.96

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

Temperature at 50% Shear: 37.9

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: T Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: T Material: WELD Ori.: Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	25	23.92	1.07
-25	48	23.92	24.07
0	24	33.23	-9.23
25	25	44.07	-19.07
25	29	44.07	-15.07
50	96	55.5	40.49
75	48	66.37	-18.37
100	55	75.75	-20.75
125	100	83.18	16.81

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

IRRADIATED CAPSULE T

Page 2

Material: WELD   Heat Number: WIRE HEAT:4278   Orientation:

Capsule: T   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
150	100	88.67	11.32
200	100	95.14	4.85
300	100	99.19	.8

SUM of RESIDUALS = 16.92

IRRADIATED CAPSULE T

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:27:23 on 09-24-1999

Page 1

Coefficients of Curve 1

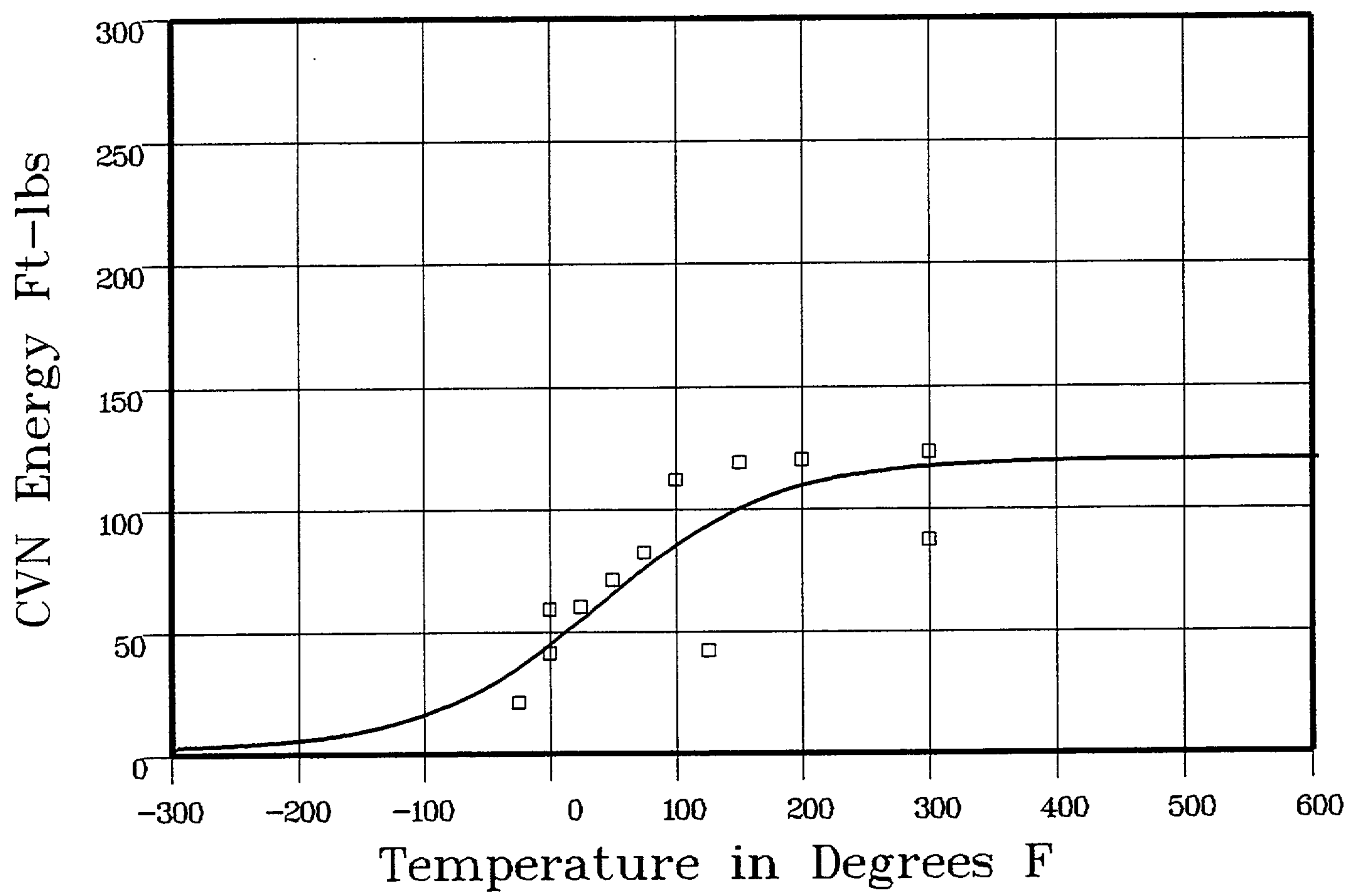
A = 61.09	B = 58.9	C = 139	T0 = 35.15

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

Upper Shelf Energy: 120 Fixed Temp. at 30 ft-lbs: -46.4 Temp. at 50 ft-lbs: 8.6 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFF'D ZONE Heat Number: SHELL (05) SIDE OF WELD Orientation:

Capsule: T Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: T Material: HEAT AFF'D ZONE Ori.: Heat #: SHELL (05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	21	37.09	-16.09
0	59	46.51	12.48
0	41	46.51	-5.51
25	60	56.8	3.19
50	71	67.36	3.63
75	82	77.53	4.46
100	112	86.74	25.25
125	42	94.62	-52.62
150	119	101.05	17.94

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

IRRADIATED CAPSULE T

Page 2

Material: HEAT AFF'D ZONE   Heat Number: SHELL (05) SIDE OF WELD   Orientation:

Capsule: T   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
200	120	109.94	10.05
300	87	117.44	-30.44
300	123	117.44	5.55

SUM of RESIDUALS = -22.09

IRRADIATED CAPSULE T

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:30:23 on 09-24-1999

Page 1

Coefficients of Curve 1

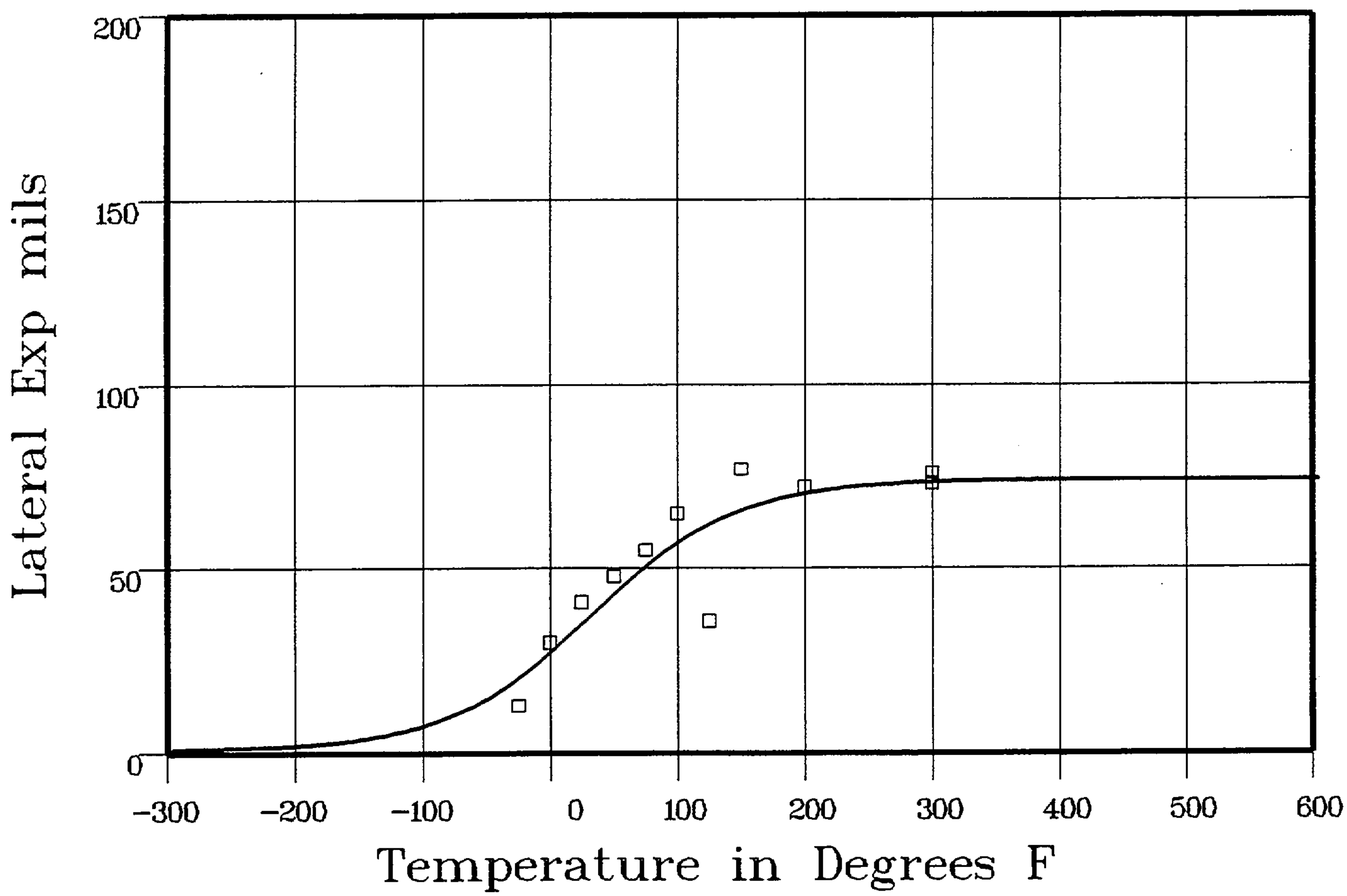
A = 37.5	B = 36.5	C = 113.61	T0 = 27.18

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

Upper Shelf L.E.: 74 Temperature at L.E. 35: 19.3 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: SHELL (05) SIDE OF WELD Orientation:

Capsule: T Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: T Material: HEAT AFFD ZONE Ori.: Heat #: SHELL (05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	13	21.82	-8.82
0	30	28.93	1.06
0	30	28.93	1.06
25	41	36.8	4.19
50	48	44.73	3.26
75	55	52.01	2.98
100	65	58.14	6.85
125	36	62.93	-26.93
150	77	66.47	10.52

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

IRRADIATED CAPSULE T

Page 2

Material: HEAT AFFD ZONE   Heat Number: SHELL (05) SIDE OF WELD   Orientation:

Capsule: T   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
200	72	70.68	1.31
300	73	73.41	-.41
300	76	73.41	2.58

SUM of RESIDUALS = -2.3

IRRADIATED CAPSULE T

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:36:21 on 09-24-1999

Page 1

Coefficients of Curve 1

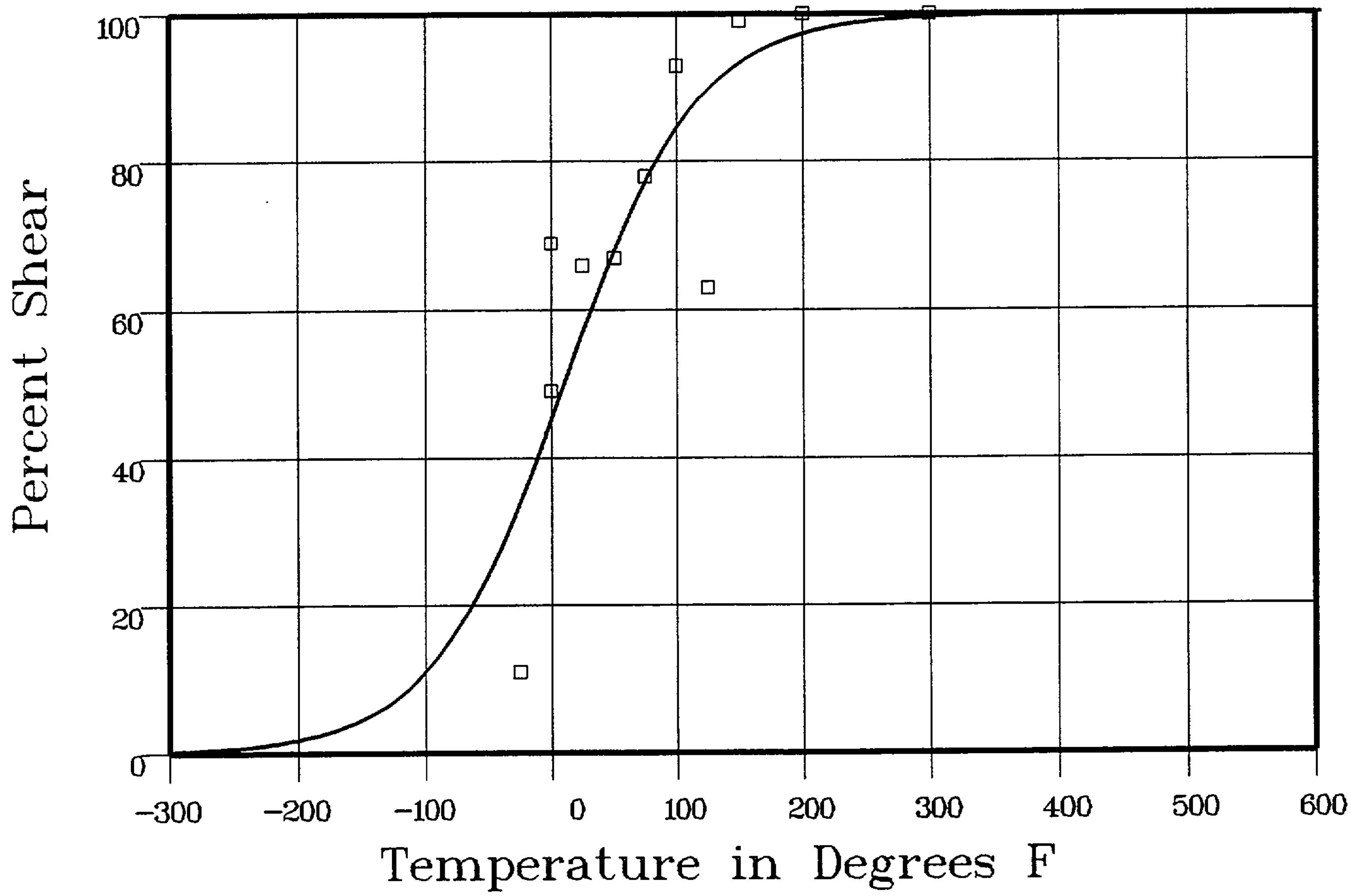
A = 50	B = 50	C = 105.49	T0 = 5.62

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

Temperature at 50% Shear: 5.6

Material: HEAT AFF'D ZONE Heat Number: SHELL (05) SIDE OF WELD Orientation:

Capsule: T Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: T Material: HEAT AFF'D ZONE Ori.: Heat #: SHELL (05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	11	35.88	-24.88
0	69	47.33	21.66
0	49	47.33	1.66
25	66	59.08	6.91
50	67	69.87	-2.87
75	78	78.83	-.83
100	93	85.68	7.31
125	63	90.57	-27.57
150	99	93.91	5.08

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

IRRADIATED CAPSULE T

Page 2

Material: HEAT AFF'D ZONE   Heat Number: SHELL (05) SIDE OF WELD   Orientation:

Capsule: T   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
200	100	97.55	2.44
300	100	99.62	.37
300	100	99.62	.37

SUM of RESIDUALS = -10.32

IRRADIATED CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:16:13 on 09-24-1999
Page 1
Coefficients of Curve 3

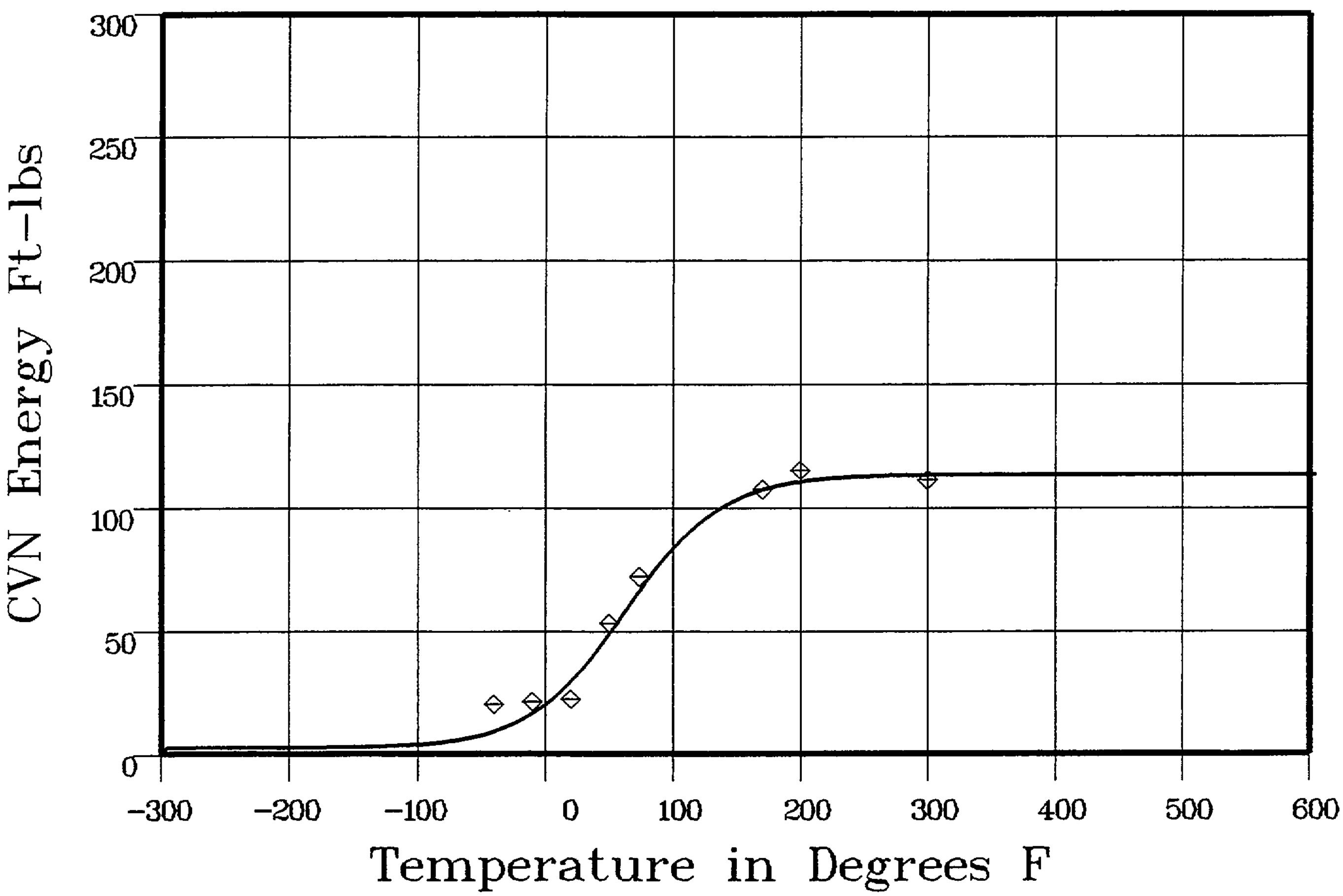
A = 57.59	B = 55.4	C = 75.03	T0 = 57.65

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

Upper Shelf Energy: 113 Fixed Temp. at 30 ft-lbs: 16.6 Temp. at 50 ft-lbs: 47.2 Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: U Total Fluence:



Data Set(s) Plotted
Plant: SQ2 Cap.: U Material: FORGING SA508CL2 Ori.: LT Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-40	20	9.84	10.15
-10	21	17.87	3.12
20	22	31.91	-9.91
50	53	51.96	1.03
74	72	69.47	2.52
170	107	107.71	-.71
200	115	110.56	4.43
300	111	112.82	-1.82

SUM of RESIDUALS = 8.81

IRRADIATED CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:47:04 on 09-24-1999

Page 1

Coefficients of Curve 1

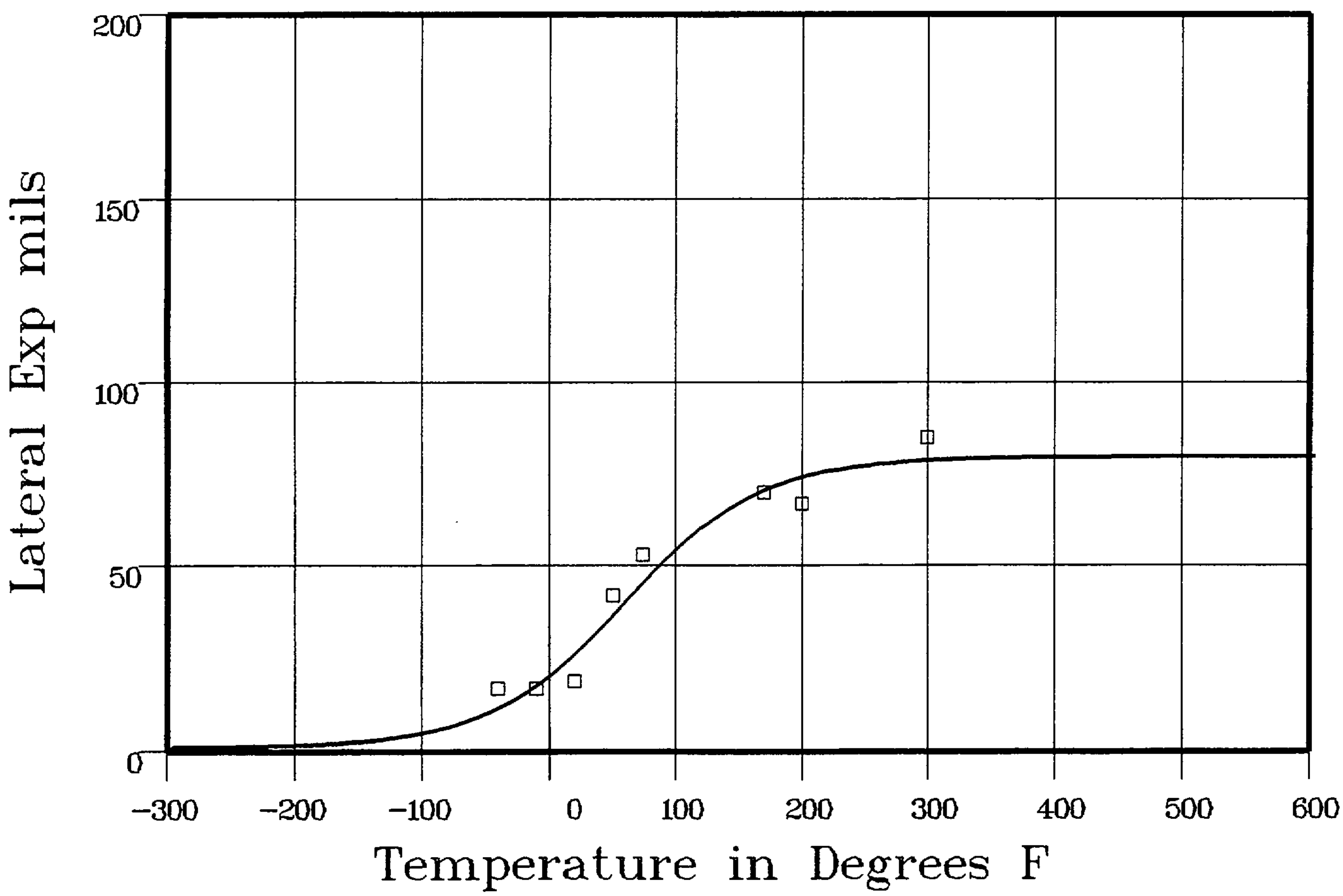
A = 40.4	B = 39.4	C = 108.23	T0 = 55.31

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

Upper Shelf L.E.: 79.81 Temperature at L.E. 35: 40.3 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: U Material: FORGING SA508CL2 Ori.: LT Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-40	17	12.55	4.44
-10	17	19.14	-2.14
20	19	27.98	-8.98
50	42	38.47	3.52
74	53	47.14	5.85
170	70	71.36	-1.36
200	67	74.72	-7.72
300	85	78.96	6.03

SUM of RESIDUALS = -.35

IRRADIATED CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:43:26 on 09-24-1999

Page 1

Coefficients of Curve 1

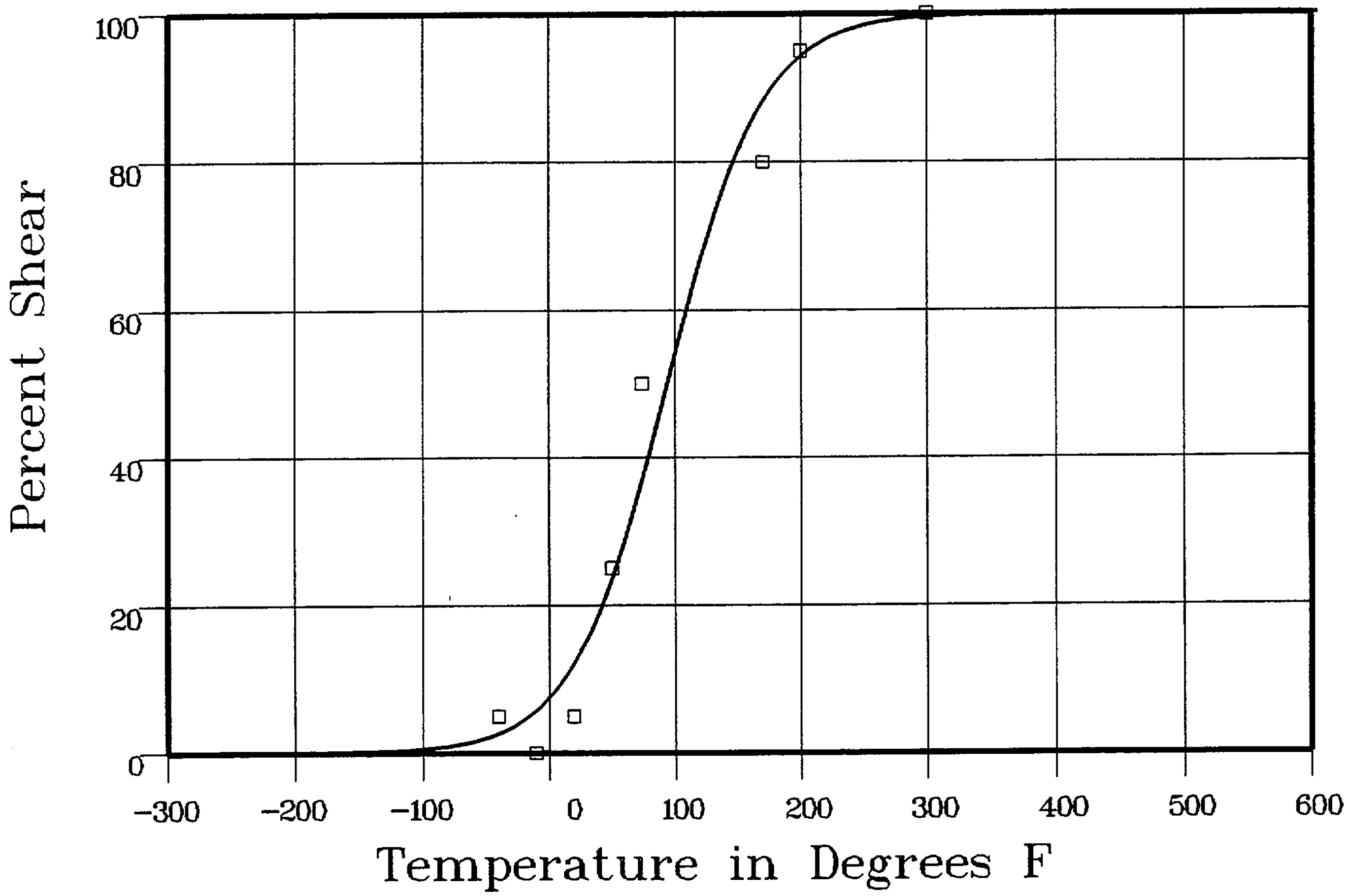
A = 50	B = 50	C = 74.98	T0 = 89.35

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

Temperature at 50% Shear: 89.3

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: U Material: FORGING SA508CL2 Ori.: LT Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40	5	3.07	1.92
-10	0	6.59	-6.59
20	5	13.58	-8.58
50	25	25.92	-.92
74	50	39.9	10.09
170	80	89.57	-9.57
200	95	95.03	-.03
300	100	99.63	.36

SUM of RESIDUALS = -13.34

IRRADIATED CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:48:03 on 09-24-1999

Page 1

Coefficients of Curve 1

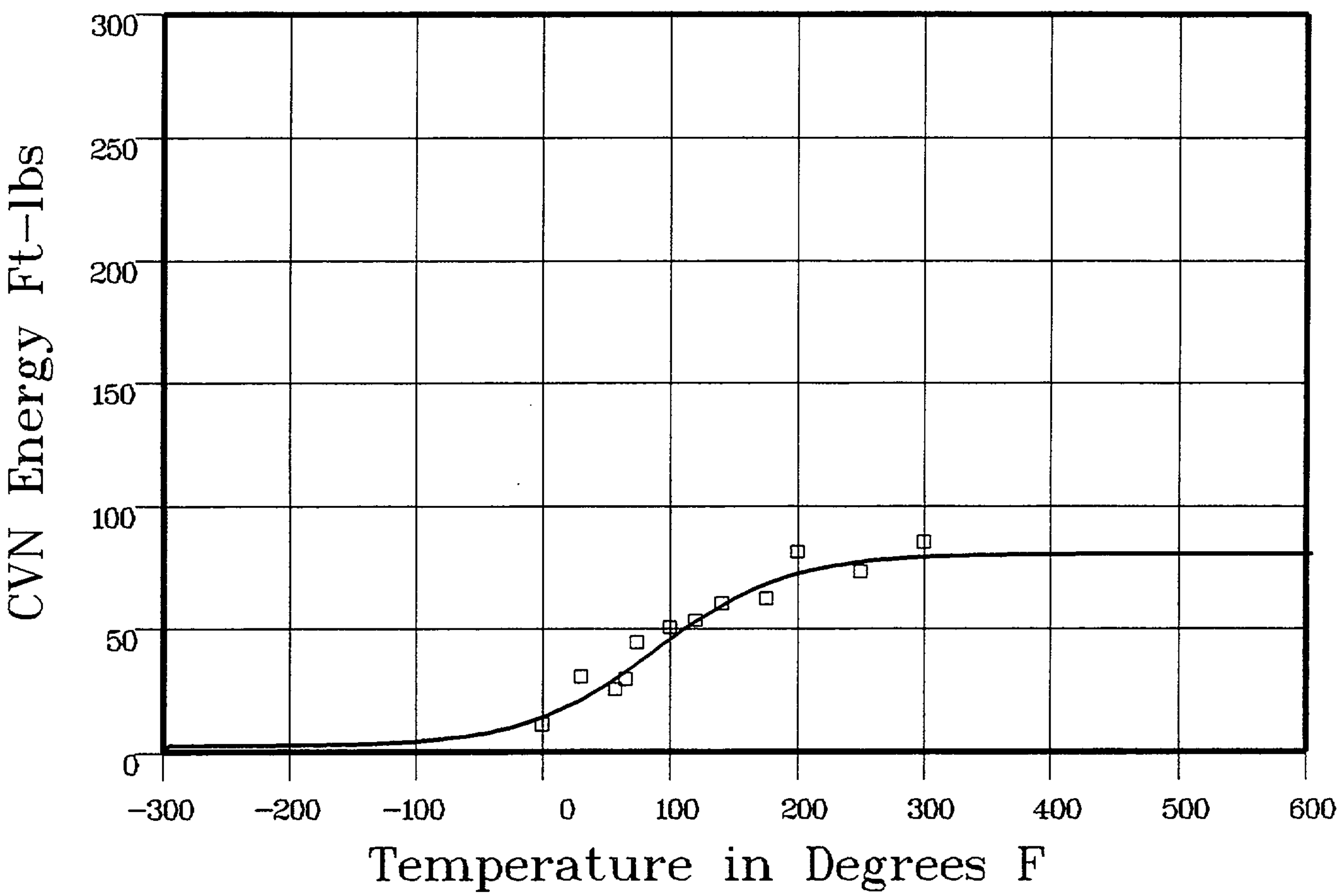
A = 41.09	B = 38.9	C = 101.96	T0 = 83.9

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

Upper Shelf Energy: 80 Fixed Temp. at 30 ft-lbs: 53.9 Temp. at 50 ft-lbs: 107.6 Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: U Material: FORGING SA508CL2 Ori.: TL Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	11	14.77	-3.77
30	30	22.25	7.74
57	25	31.06	-6.06
65	29	33.96	-4.96
74	44	37.33	6.66
100	50	47.18	2.81
120	53	54.32	-1.32
140	60	60.57	-.57
175	62	68.83	-6.83

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

IRRADIATED CAPSULE U

Page 2

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
200	81	72.76	8.23
250	73	77.11	-4.11
300	85	78.89	6.1

SUM of RESIDUALS = 3.89

IRRADIATED CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:51:50 on 09-24-1999

Page 1

Coefficients of Curve 1

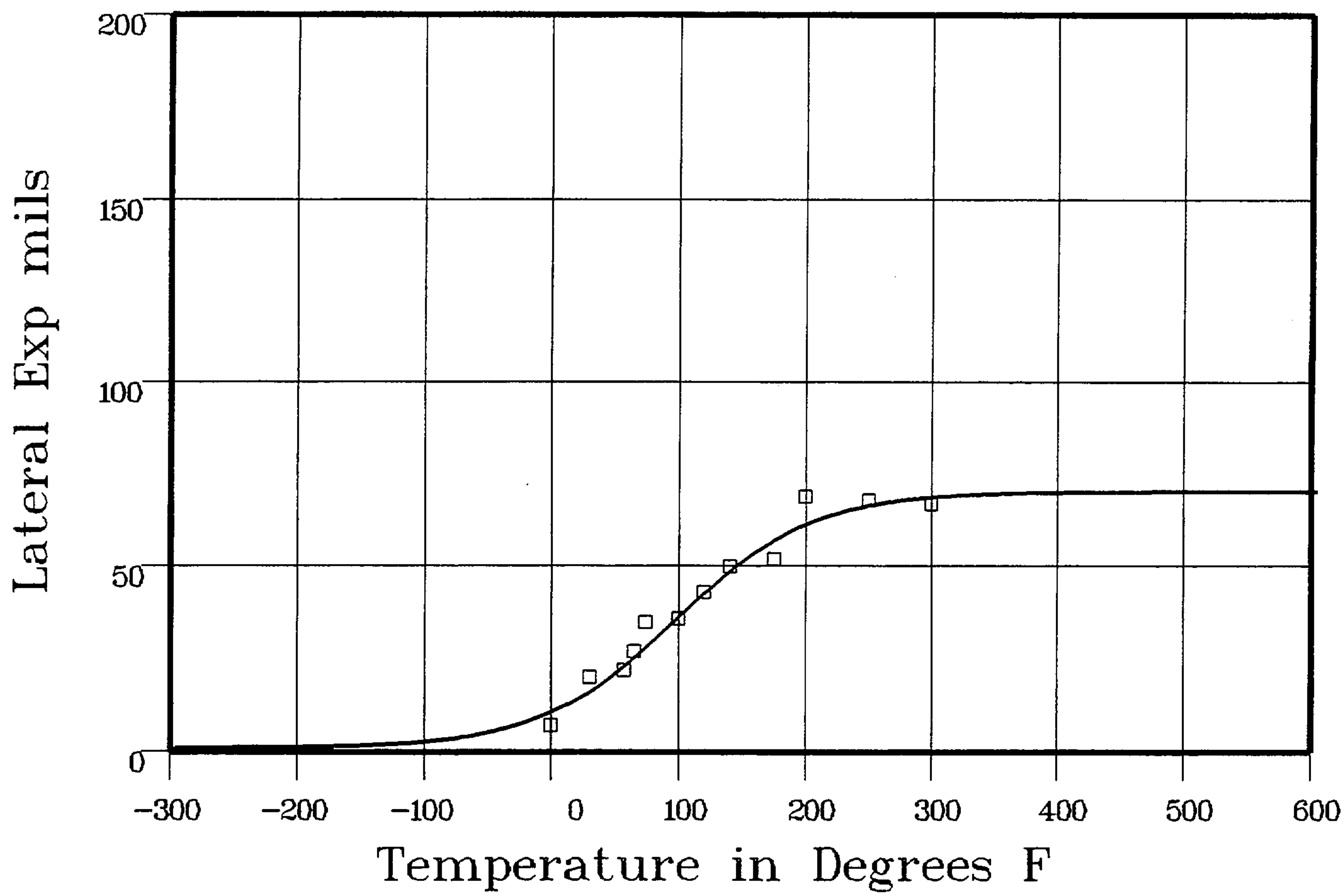
A = 35.67	B = 34.67	C = 106.45	T0 = 93.01

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

Upper Shelf L.E.: 70.35 Temperature at L.E. 35: 90.9 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: U Material: FORGING SA508CL2 Ori.: TL Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	7	11.28	-4.28
30	20	17.25	2.74
57	22	24.37	-2.37
65	27	26.75	.24
74	35	29.54	5.45
100	36	37.94	-1.94
120	43	44.28	-1.28
140	50	50.06	-.06
175	52	58.11	-6.11

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

IRRADIATED CAPSULE U

Page 2

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: U Total Fluence:

Charpy V–Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
200	69	62.16	6.83
250	68	66.9	1.09
300	67	68.96	−1.96

SUM of RESIDUALS = −1.66

IRRADIATED CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:55:02 on 09-24-1999

Page 1

Coefficients of Curve 1

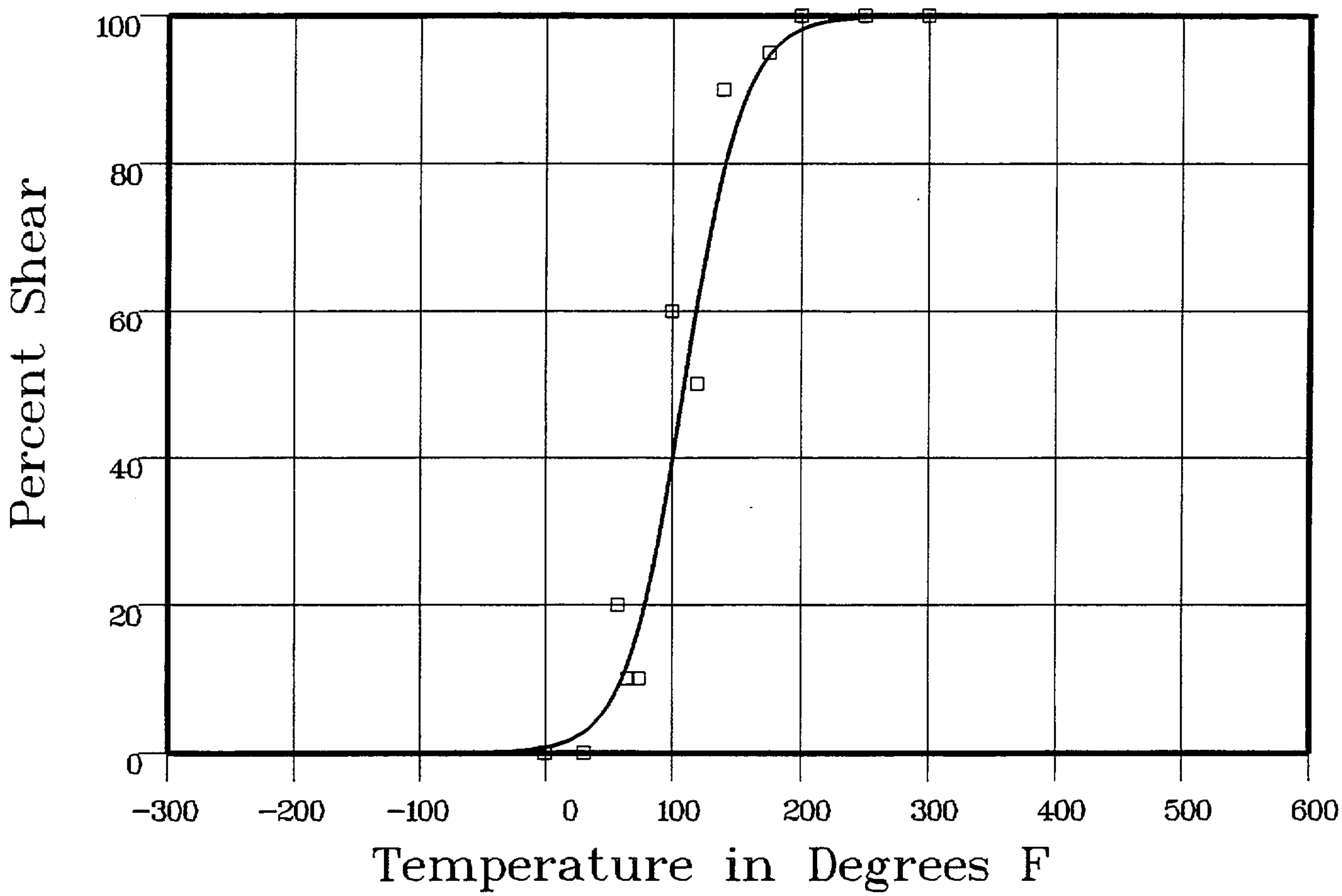
A = 50	B = 50	C = 45.12	T0 = 105.17

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

Temperature at 50% Shear: 105.1

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: U Material: FORGING SA508CL2 Ori.: TL Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	0	.93	-.93
30	0	3.44	-3.44
57	20	10.57	9.42
65	10	14.42	-4.42
74	10	20.07	-10.07
100	60	44.28	15.71
120	50	65.86	-15.86
140	90	82.39	7.6
175	95	95.66	-.66

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

IRRADIATED CAPSULE U

Page 2

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: U Total Fluence:

Charpy V–Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
200	100	98.52	1.47
250	100	99.83	.16
300	100	99.98	.01
		SUM of RESIDUALS =	-1

IRRADIATED CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 12:59:07 on 09-24-1999

Page 1

Coefficients of Curve 1

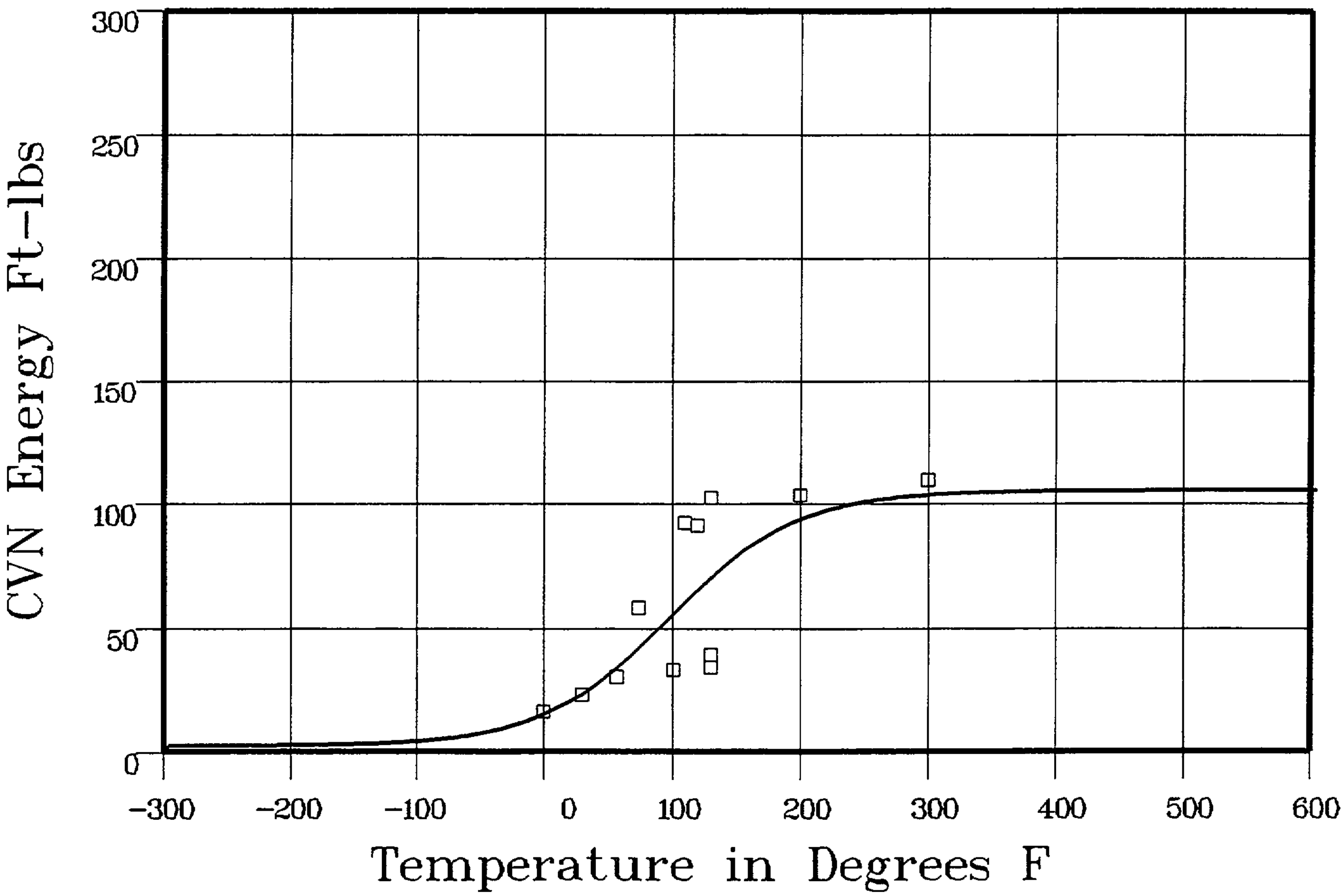
A = 53.59	B = 51.4	C = 99.69	T0 = 92.34

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

Upper Shelf Energy: 105 Fixed   Temp. at 30 ft-lbs: 42.8   Temp. at 50 ft-lbs: 85.3   Lower Shelf Energy: 2.19 Fixed

Material: WELD   Heat Number: WIRE HEAT:4278   Orientation:

Capsule: U   Total Fluence:



Data Set(s) Plotted

Plant: SQ2   Cap.: U   Material: WELD   Ori.:   Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	16	16.13	-.13
30	23	25.08	-2.08
57	30	36.1	-6.1
74	58	44.24	13.75
101	33	58.05	-25.05
110	92	62.6	29.39
120	91	67.5	23.49
130	102	72.14	29.85
130	39	72.14	-33.14

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

IRRADIATED CAPSULE U

Page 2

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
130	34	72.14	-38.14
200	103	94.36	8.63
300	109	103.42	5.57

SUM of RESIDUALS = 6.04

IRRADIATED CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:00:54 on 09-24-1999

Page 1

Coefficients of Curve 1

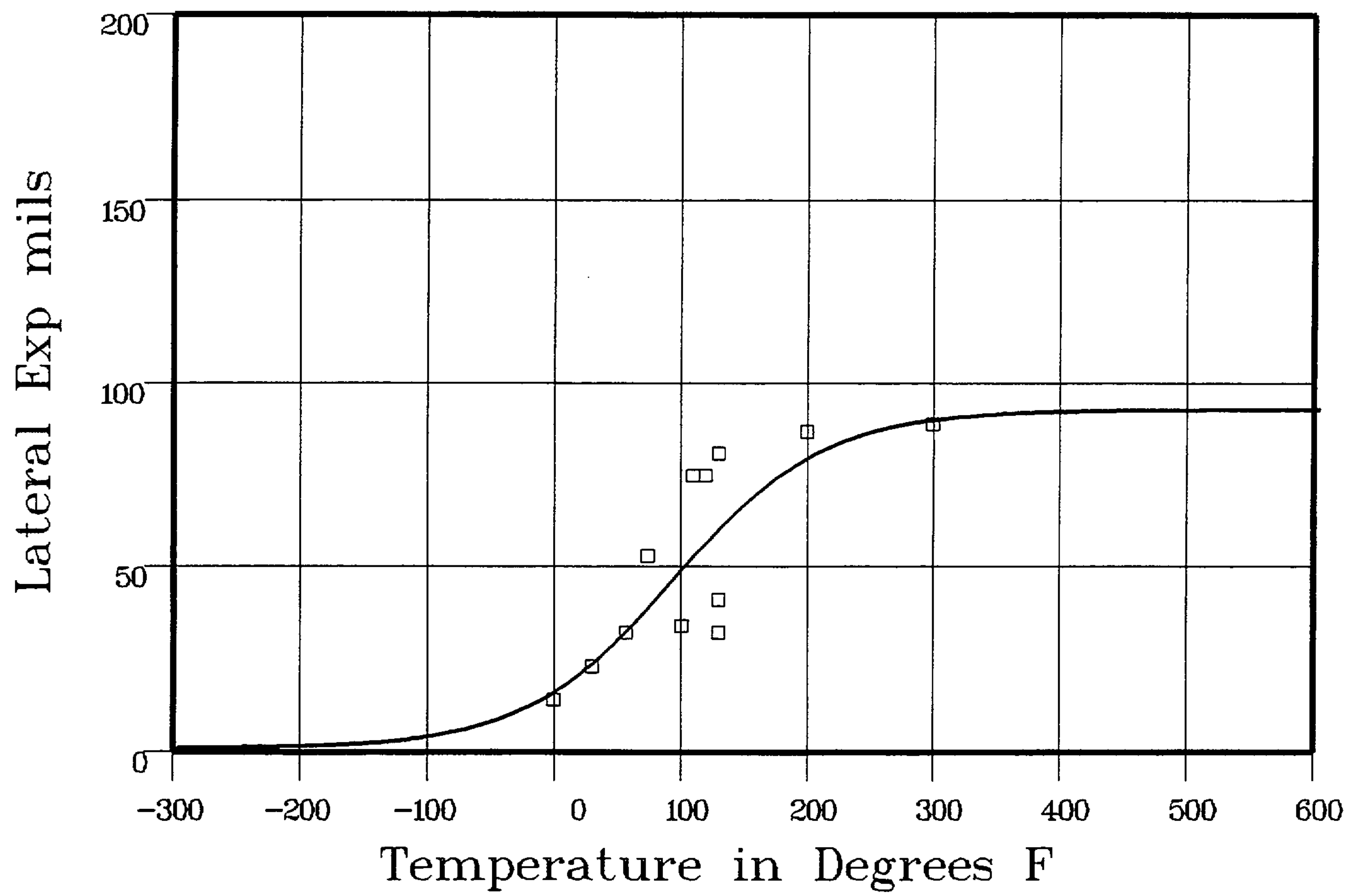
A = 46.91	B = 45.91	C = 116.95	T0 = 90.35

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

Upper Shelf L.E.: 92.82 Temperature at L.E. 35: 59.3 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: U Material: WELD Ori.: Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	14	17.14	-3.14
30	23	25.12	-2.12
57	32	34.16	-2.16
74	53	40.53	12.46
101	34	51.07	-17.07
110	75	54.55	20.44
120	75	58.3	16.69
130	81	61.9	19.09
130	41	61.9	-20.9

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

IRRADIATED CAPSULE U

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: U Total Fluence:

Charpy V–Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
130	32	61.9	−29.9
200	87	80.61	6.38
300	89	90.34	−1.34

SUM of RESIDUALS = −1.55

IRRADIATED CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:02:23 on 09-24-1999

Page 1

Coefficients of Curve 1

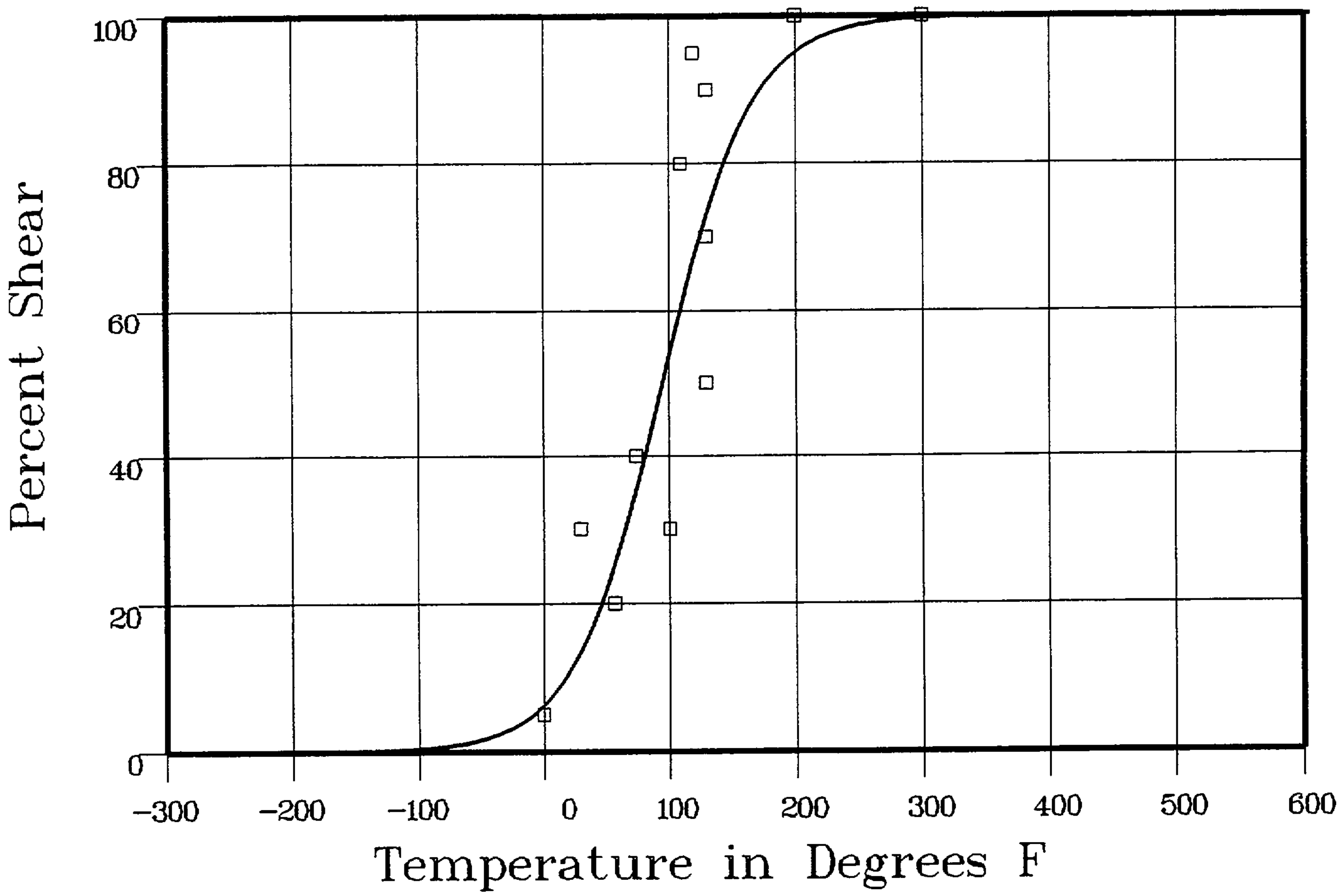
A = 50	B = 50	C = 70.32	T0 = 90.46

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

Temperature at 50% Shear: 90.4

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: U Material: WELD Ori.: Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	5	7.08	-2.08
30	30	15.19	14.8
57	20	27.85	-7.85
74	40	38.5	1.49
101	30	57.43	-27.43
110	80	63.54	16.45
120	95	69.84	25.15
130	90	75.47	14.52
130	70	75.47	-5.47

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

IRRADIATED CAPSULE U

Page 2

Material: WELD   Heat Number: WIRE HEAT:4278   Orientation:

Capsule: U   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
130	50	75.47	-25.47
200	100	95.75	4.24
300	100	99.74	.25

SUM of RESIDUALS = 8.61

IRRADIATED CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:07:14 on 09-24-1999
Page 1
Coefficients of Curve 1

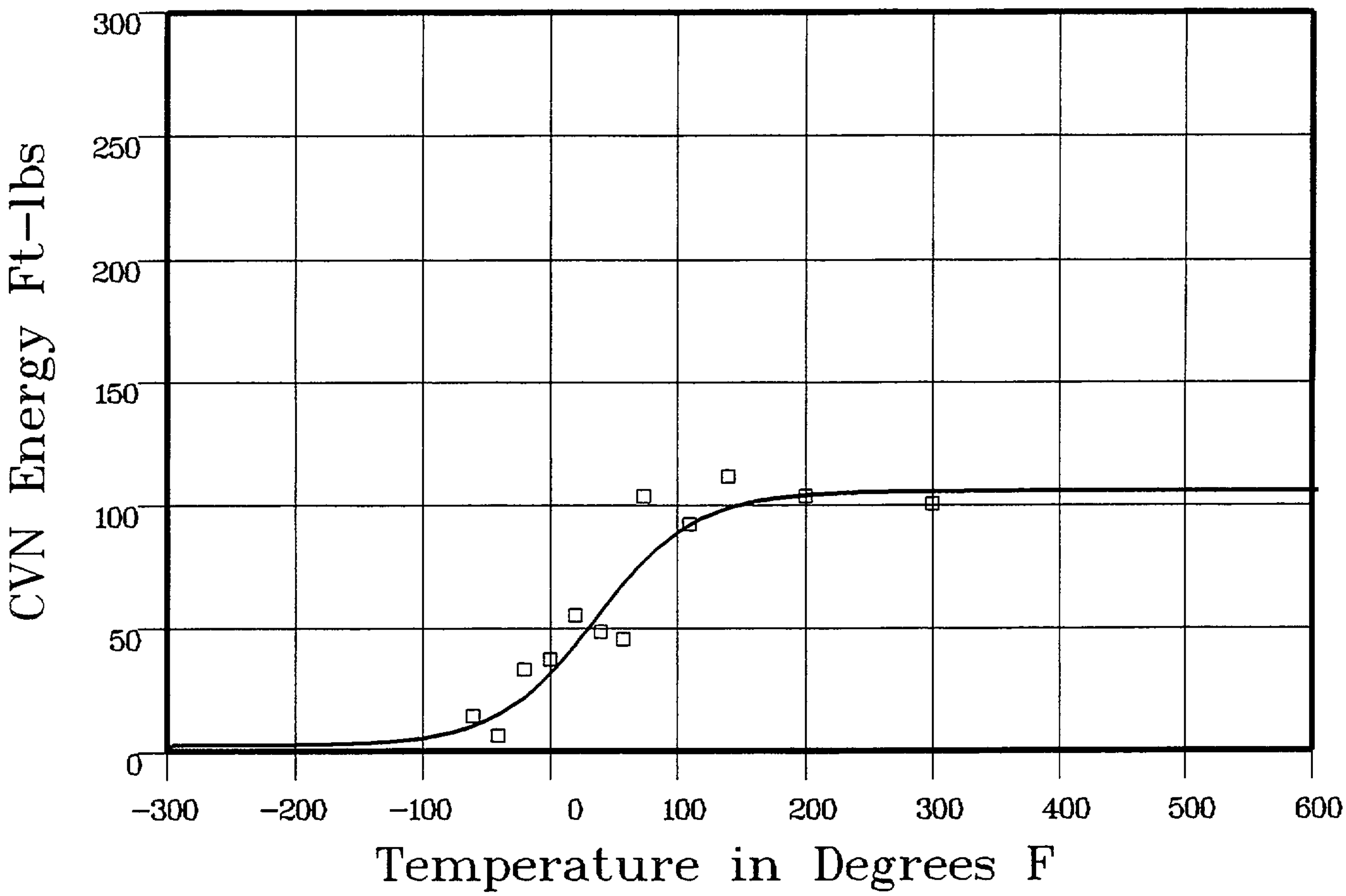
A = 53.59	B = 51.4	C = 77.5	T0 = 31.4

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

Upper Shelf Energy: 105 Fixed   Temp. at 30 ft-lbs: -7   Temp. at 50 ft-lbs: 25.9   Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE   Heat Number: SHELL (05) SIDE OF WELD   Orientation:

Capsule: U   Total Fluence:



Data Set(s) Plotted
Plant: SQ2   Cap.: U   Material: HEAT AFFD ZONE   Ori.:   Heat #: SHELL (05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-60	14	11.07	2.92
-40	6	16.25	-10.25
-20	33	23.75	9.24
0	37	33.84	3.15
20	55	46.08	8.91
40	48	59.27	-11.27
58	45	70.57	-25.57
74	103	79.31	23.68
110	92	93.04	-1.04

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

IRRADIATED CAPSULE U

Page 2

Material: HEAT AFFD ZONE Heat Number: SHELL (05) SIDE OF WELD Orientation:

Capsule: U Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
140	111	99.12	11.87
200	103	103.69	-.69
300	100	104.89	-4.89

SUM of RESIDUALS = 6.05

IRRADIATED CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:09:36 on 09-24-1999

Page 1

Coefficients of Curve 1

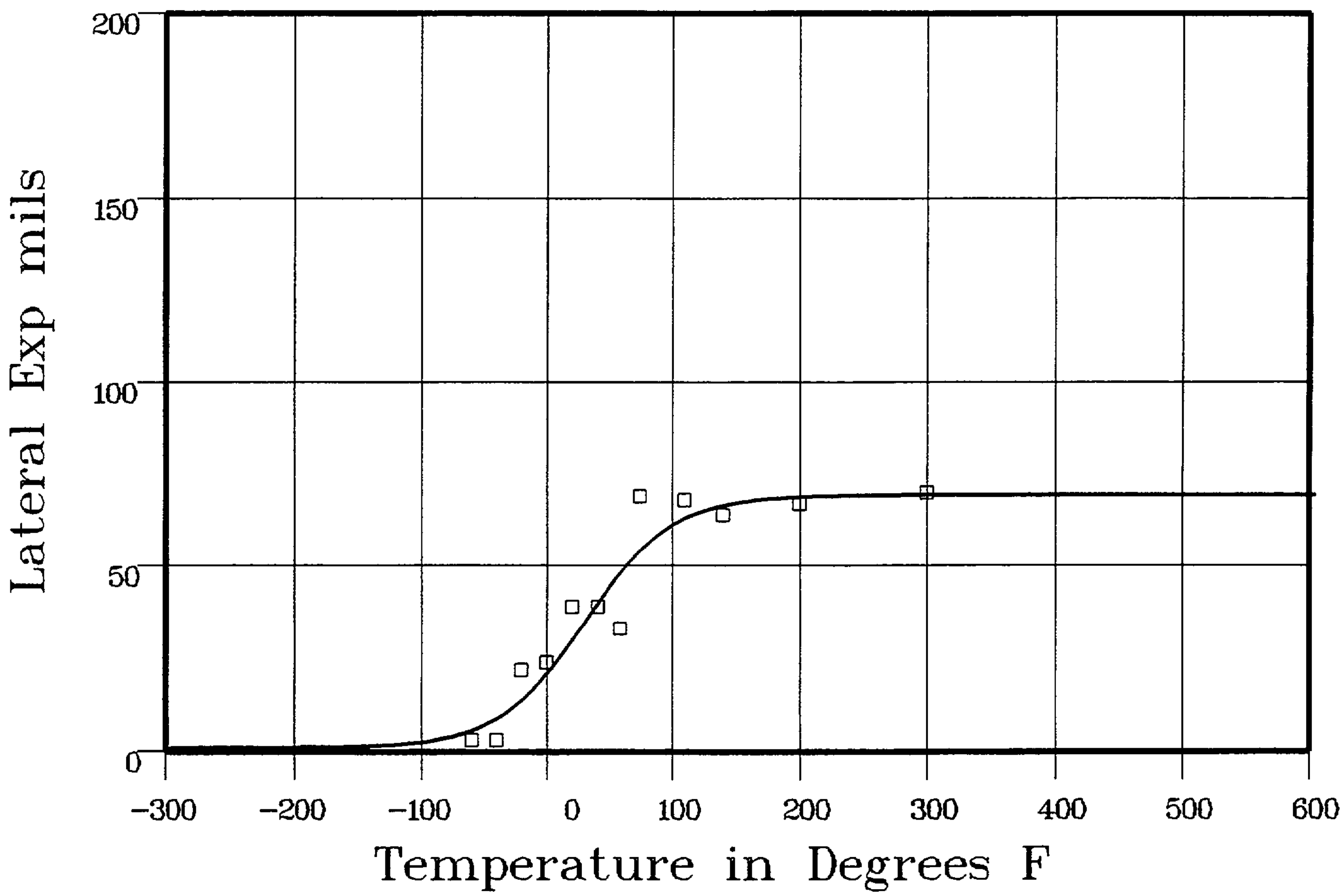
A = 35.16	B = 34.16	C = 69.15	T0 = 25.78

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

Upper Shelf L.E.: 69.33 Temperature at L.E. 35: 25.4 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: SHELL (05) SIDE OF WELD Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: U Material: HEAT AFFD ZONE Ori.: Heat #: SHELL (05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-60	3	6.27	-3.27
-40	3	9.87	-6.87
-20	22	15.36	6.63
0	24	22.98	1.01
20	39	32.31	6.68
40	39	42.09	-3.09
58	33	50.02	-17.02
74	69	55.76	13.23
110	68	63.83	4.16

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

IRRADIATED CAPSULE U

Page 2

Material: HEAT AFF'D ZONE   Heat Number: SHELL (05) SIDE OF WELD   Orientation:

Capsule: U   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
140	64	66.91	-2.91
200	67	68.89	-1.89
300	70	69.31	.68

SUM of RESIDUALS = -2.66

IRRADIATED CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:11:53 on 09-24-1999

Page 1

Coefficients of Curve 1

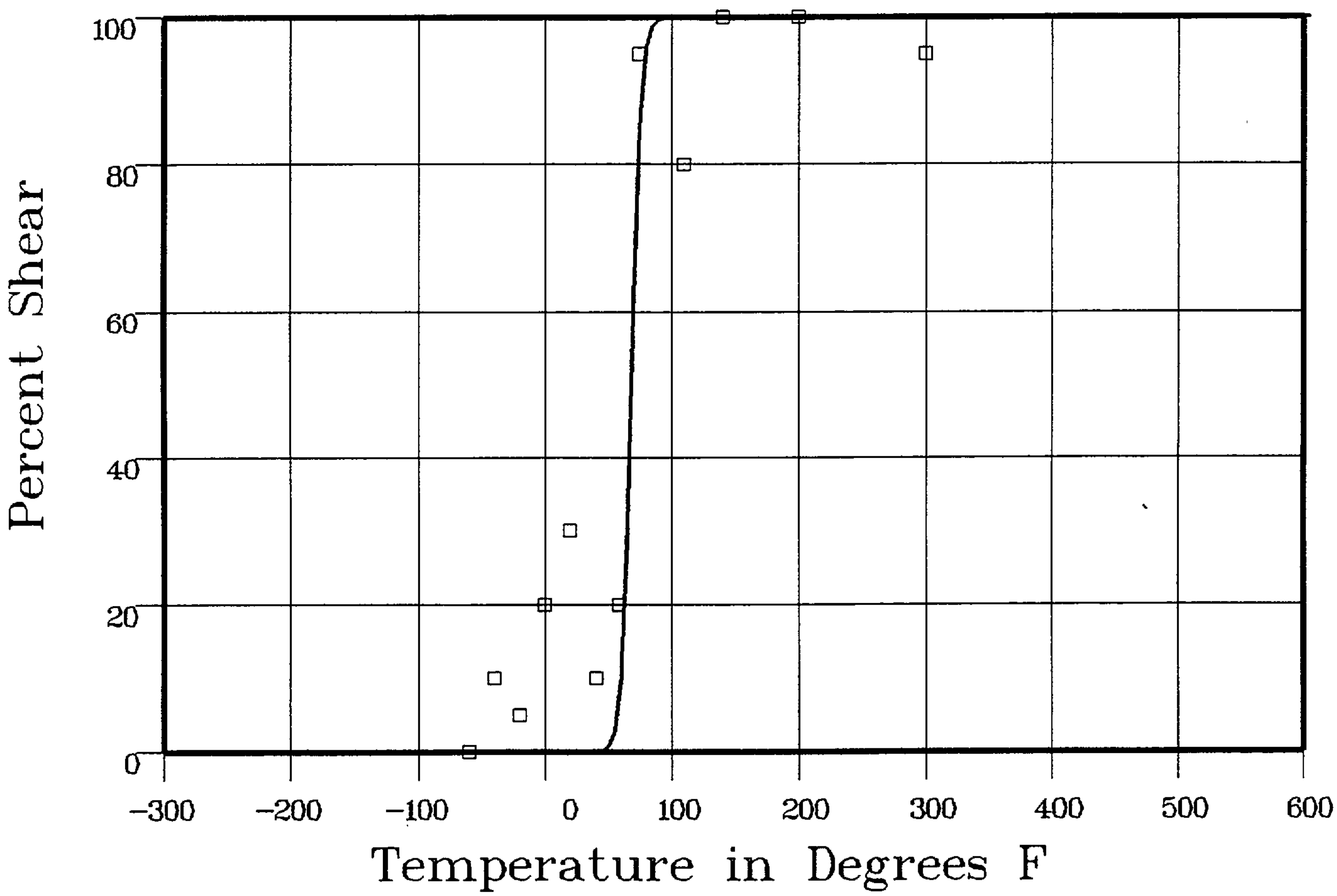
A = 50	B = 50	C = 7.49	T0 = 63.28

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

Temperature at 50% Shear: 63.2

Material: HEAT AFF'D ZONE Heat Number: SHELL (05) SIDE OF WELD Orientation:

Capsule: U Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: U Material: HEAT AFF'D ZONE Ori.: Heat #: SHELL (05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-60	0	0	0
-40	10	0	10
-20	5	0	5
0	20	0	19.99
20	30	0	29.99
40	10	.2	9.79
58	20	19.64	.35
74	95	94.57	.42
110	80	99.99	-19.99

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

IRRADIATED CAPSULE U

Page 2

Material: HEAT AFF'D ZONE　　Heat Number: SHELL (05) SIDE OF WELD　　Orientation:

Capsule: U　　Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
140	100	100	0
200	100	100	0
300	95	100	-5

SUM of RESIDUALS = 50.57

IRRADIATED CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:37:46 on 09-24-1999

Page 1

Coefficients of Curve 1

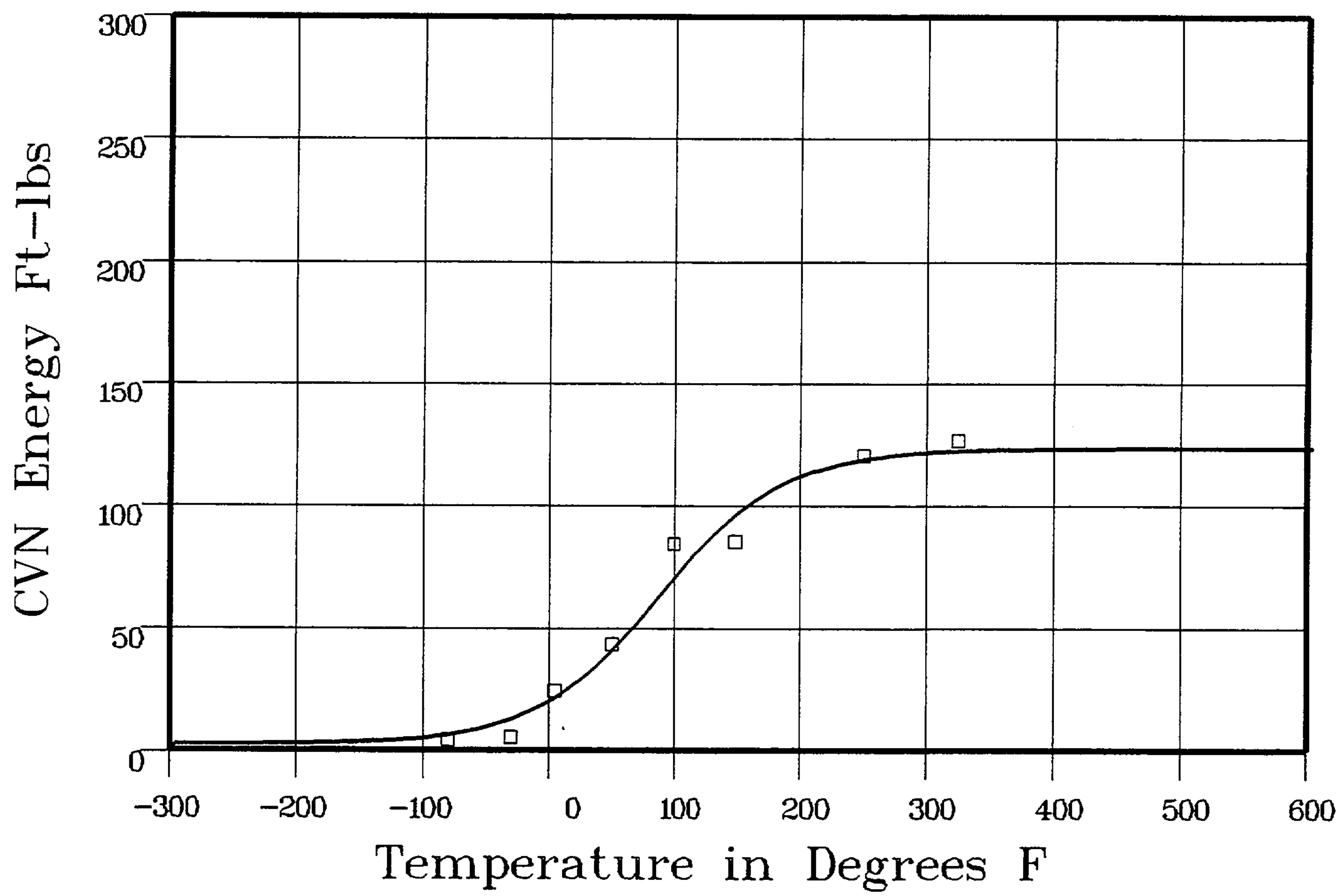
A = 62.59	B = 60.4	C = 99.7	T0 = 83.2

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

Upper Shelf Energy: 123 Fixed   Temp. at 30 ft-lbs: 23   Temp. at 50 ft-lbs: 62   Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA508CL2   Heat Number: 288757/981057(05)   Orientation: LT

Capsule: X   Total Fluence:



Data Set(s) Plotted

Plant: SQ2   Cap.: X   Material: FORGING SA508CL2   Ori.: LT   Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-80	4	6.6	-2.6
-30	5	13.5	-8.5
5	24	23.02	.97
50	43	43.19	-.19
100	84	72.68	11.31
150	85	97.93	-12.93
250	120	118.88	1.11
325	126	122.06	3.93

SUM of RESIDUALS = -6.89

IRRADIATED CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:34:28 on 09-24-1999
Page 1
Coefficients of Curve 1

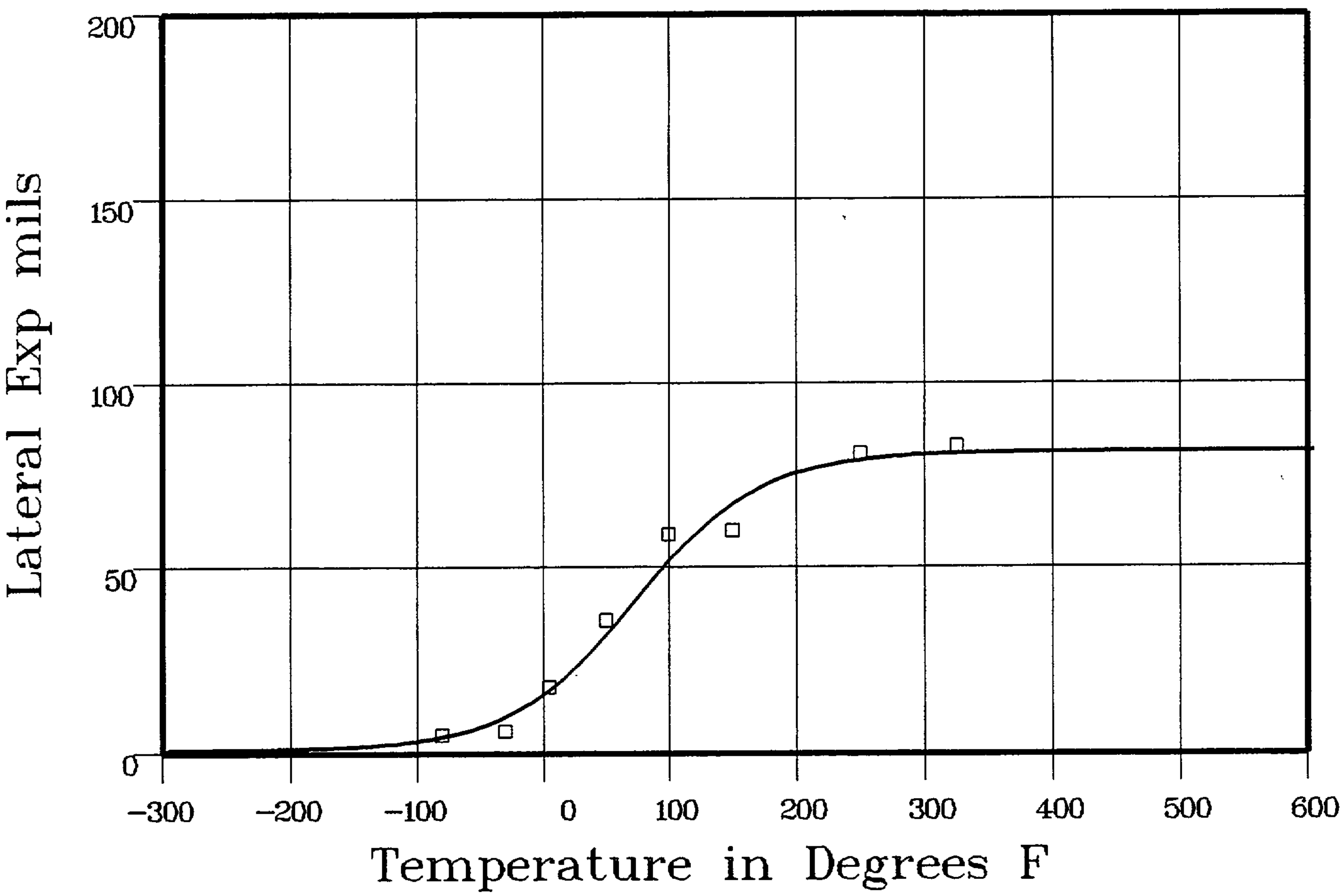
A = 41.24	B = 40.24	C = 99.5	T0 = 68.43

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

Upper Shelf L.E.: 81.48 Temperature at L.E. 35: 52.8 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: X Total Fluence:



Data Set(s) Plotted
Plant: SQ2 Cap.: X Material: FORGING SA508CL2 Ori.: LT Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-80	5	4.87	.12
-30	6	10.77	-4.77
5	18	18.57	-.57
50	36	33.87	2.12
100	59	53.59	5.4
150	60	68.4	-8.4
250	81	79.44	1.55
325	83	81.02	1.97

SUM of RESIDUALS = -2.57

IRRADIATED CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:39:57 on 09-24-1999

Page 1

Coefficients of Curve 1

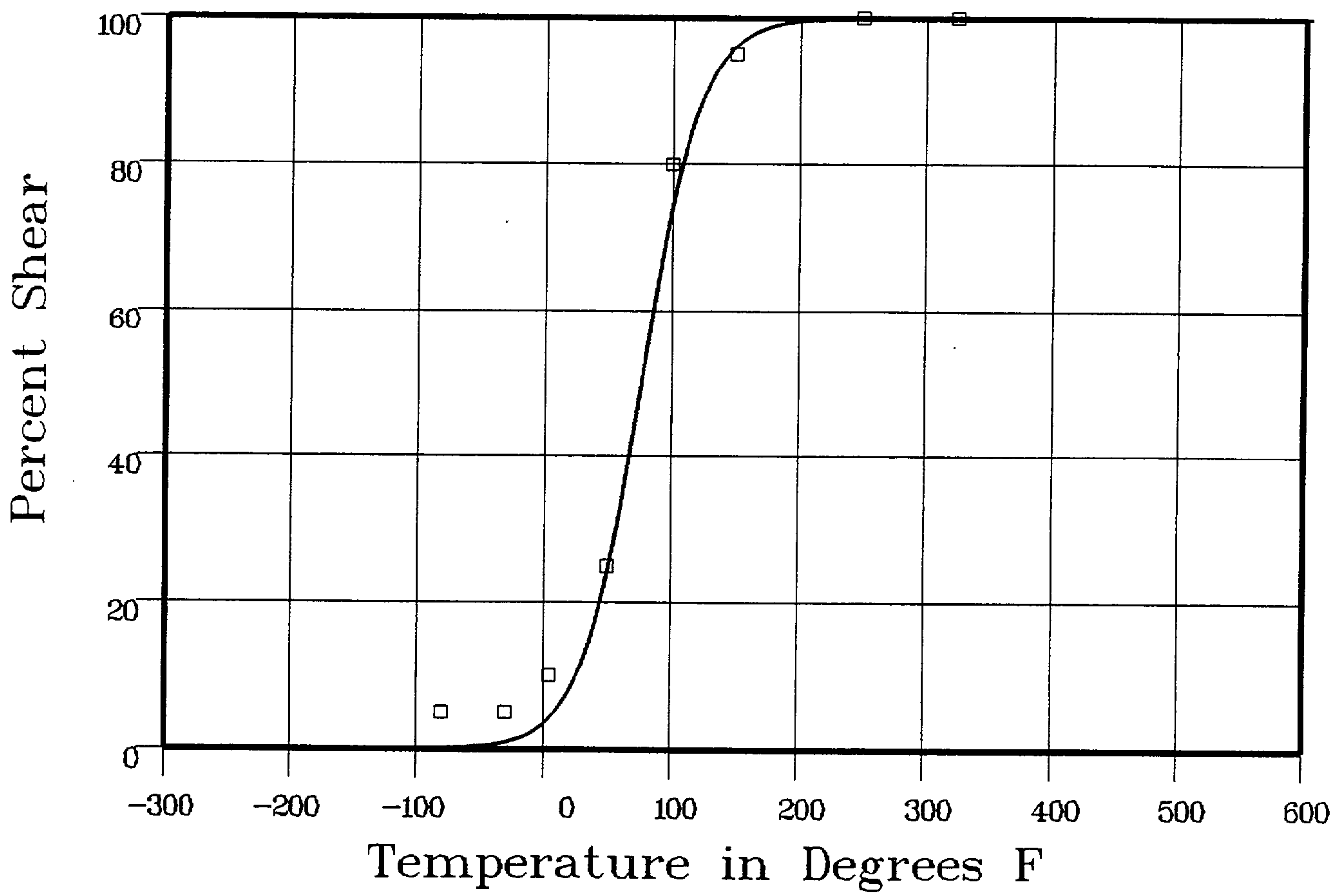
A = 50	B = 50	C = 45.77	T0 = 71.52

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

Temperature at 50% Shear: 71.5

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: X Material: FORGING SA508CL2 Ori.: LT Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-80	5	.13	4.86
-30	5	1.17	3.82
5	10	5.18	4.81
50	25	28.07	-3.07
100	80	77.62	2.37
150	95	96.85	-1.85
250	100	99.95	.04
325	100	99.99	0

SUM of RESIDUALS = 10.99

IRRADIATED CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:43:34 on 09-24-1999

Page 1

Coefficients of Curve 1

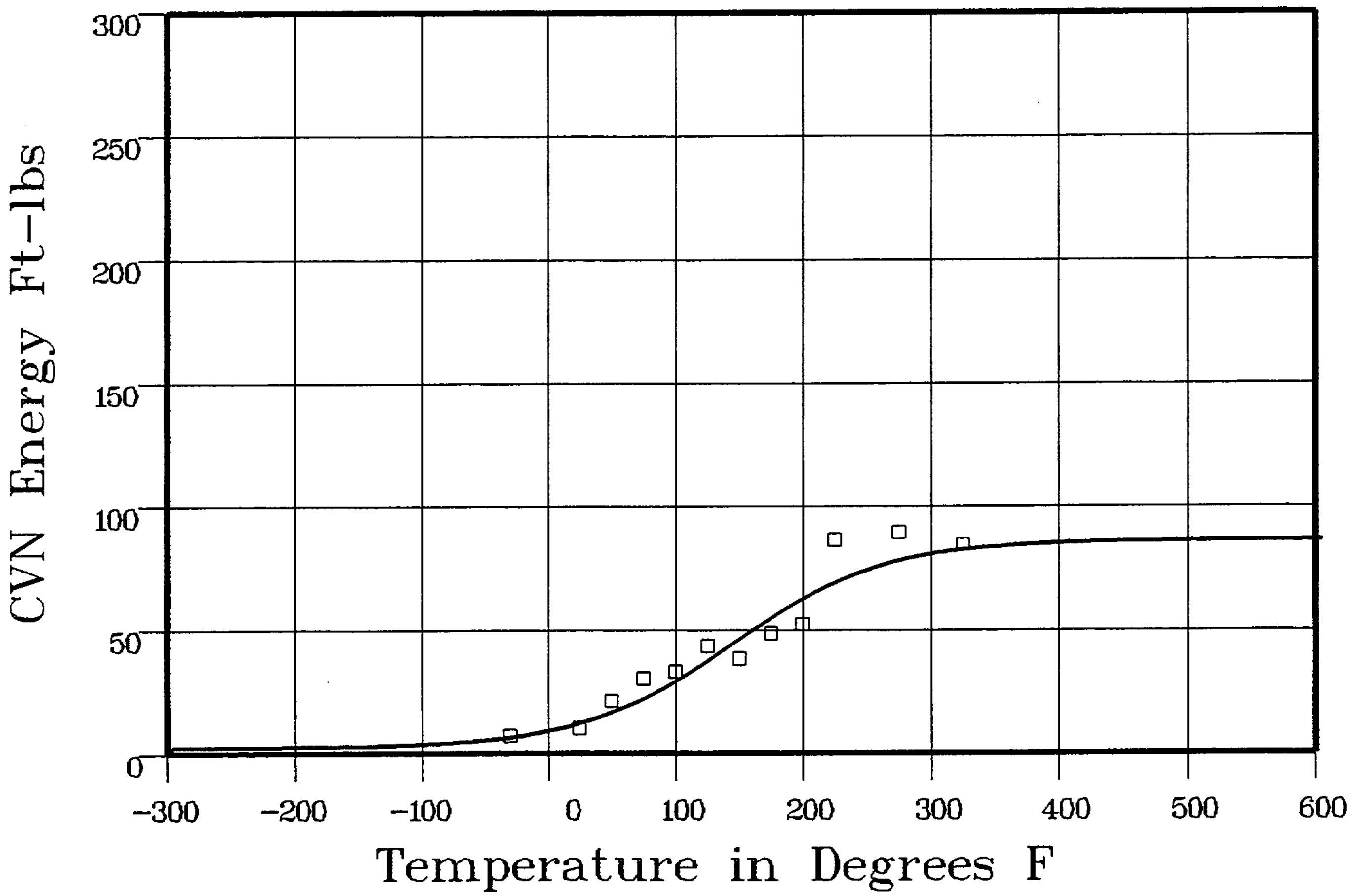
A = 44.09	B = 41.9	C = 119.34	T0 = 139.74

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

Upper Shelf Energy: 86 Fixed Temp. at 30 ft-lbs: 97.9 Temp. at 50 ft-lbs: 156.6 Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: X Material: FORGING SA508CL2 Ori.: TL Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-30	7	6.8	.19
25	10	12.88	-2.88
50	21	17.43	3.56
75	30	23.36	6.63
100	33	30.64	2.35
125	43	38.94	4.05
150	38	47.69	-9.69
175	48	56.12	-8.12
200	52	63.62	-11.62

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

IRRADIATED CAPSULE X

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: X Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
225	86	69.8	16.19
275	89	78.12	10.87
325	84	82.4	1.59

SUM of RESIDUALS = 13.13

IRRADIATED CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:45:14 on 09-24-1999

Page 1

Coefficients of Curve 1

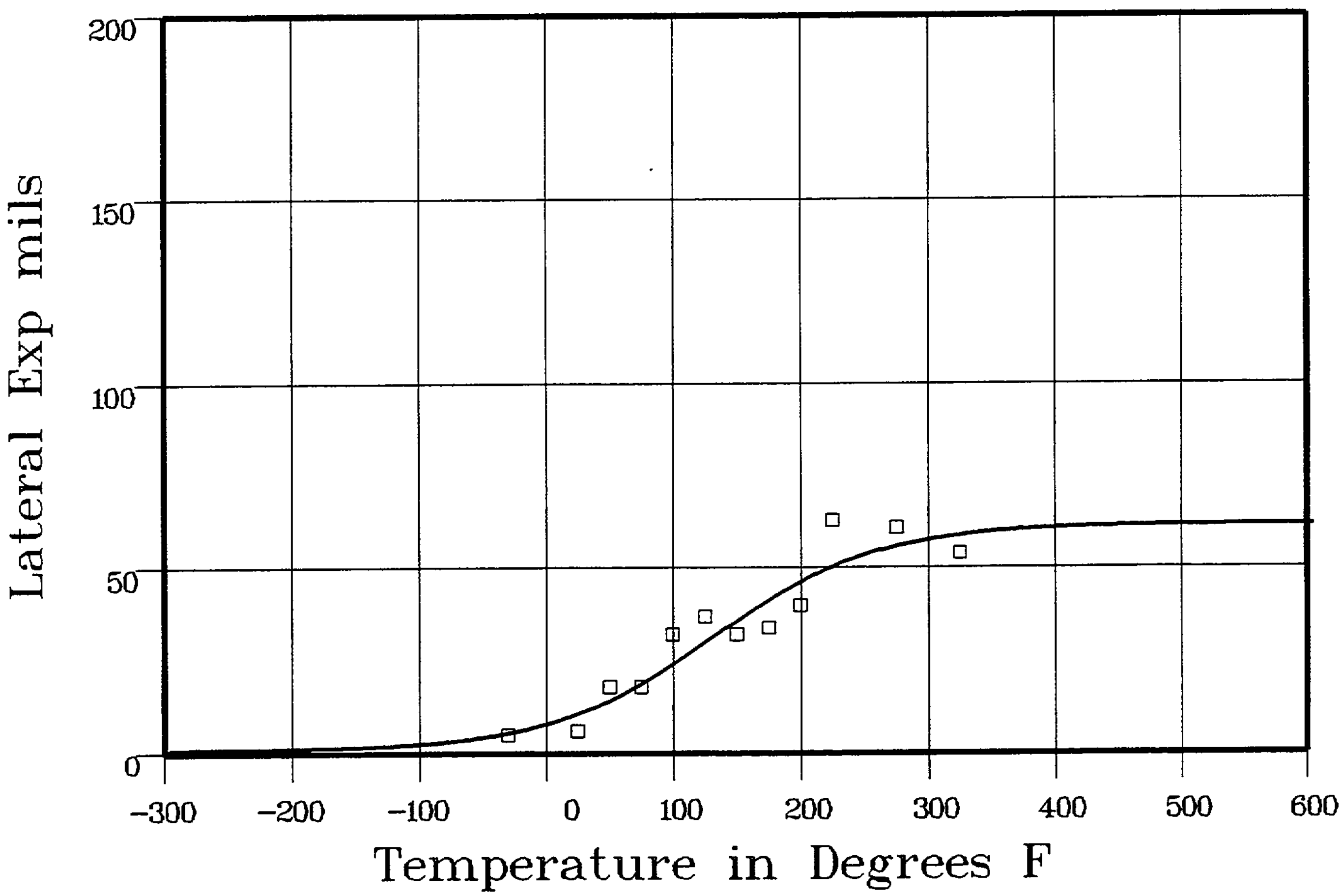
A = 31.4	B = 30.4	C = 128.4	T0 = 126.09

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

Upper Shelf L.E.: 61.8 Temperature at L.E. 35: 141.3 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: X Material: FORGING SA508CL2 Ori.: TL Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-30	5	5.91	-.91
25	6	11.43	-5.43
50	18	15.23	2.76
75	18	19.9	-1.9
100	32	25.3	6.69
125	37	31.14	5.85
150	32	36.99	-4.99
175	34	42.45	-8.45
200	40	47.19	-7.19

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

IRRADIATED CAPSULE X

Page 2

Material: FORGING SA508CL2　　Heat Number: 288757/981057(05)　　Orientation: TL

Capsule: X　　Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
225	63	51.07	11.92
275	61	56.35	4.64
325	54	59.17	-5.17

SUM of RESIDUALS = -2.18

IRRADIATED CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:47:36 on 09-24-1999

Page 1

Coefficients of Curve 1

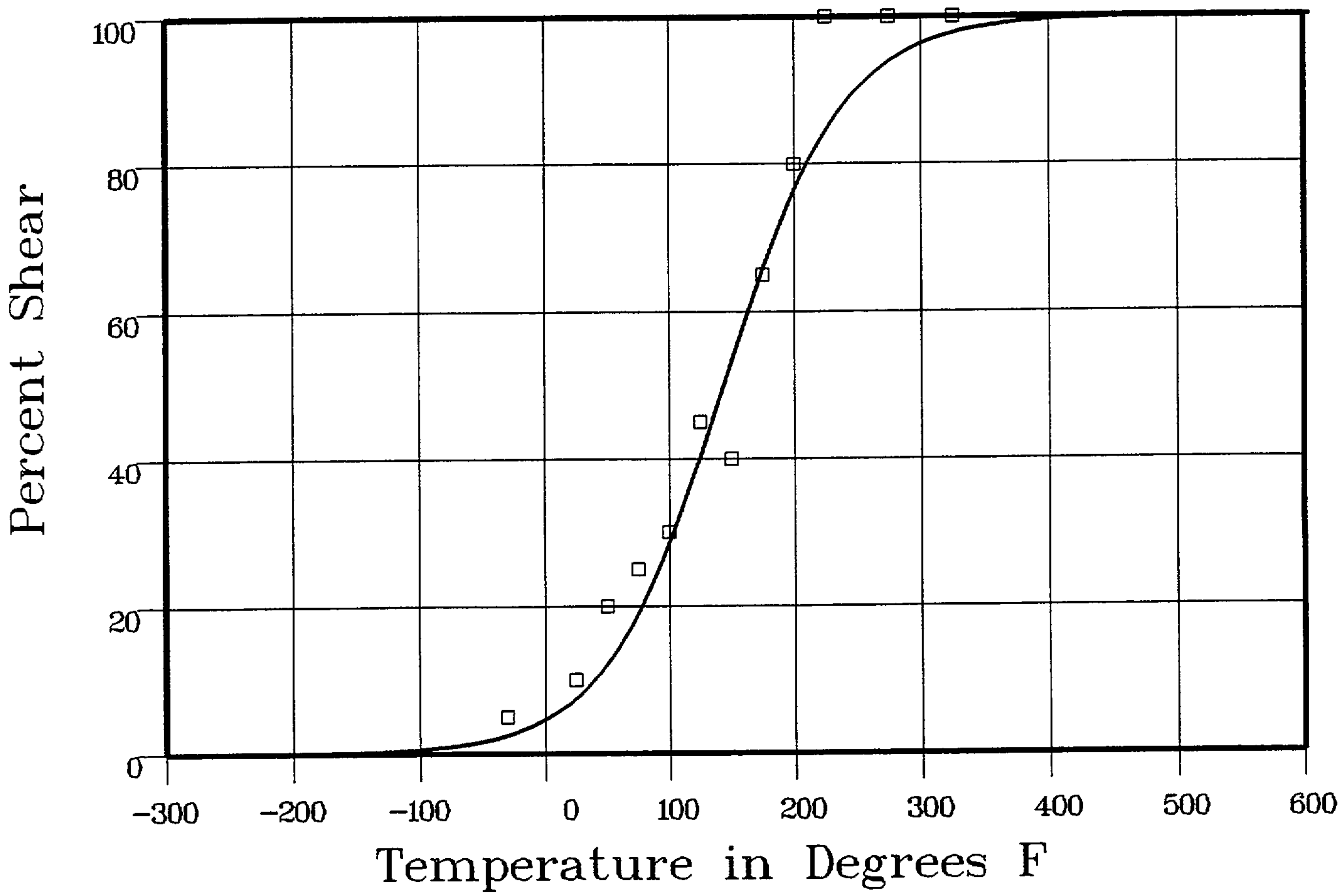
A = 50	B = 50	C = 95.27	T0 = 139.16

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

Temperature at 50% Shear: 139.1

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: X Material: FORGING SA508CL2 Ori.: TL Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-30	5	2.78	2.21
25	10	8.34	1.65
50	20	13.33	6.66
75	25	20.63	4.36
100	30	30.53	-.53
125	45	42.62	2.37
150	40	55.66	-15.66
175	65	67.96	-2.96
200	80	78.19	1.8

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

IRRADIATED CAPSULE X

Page 2

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: TL

Capsule: X Total Fluence:

Charpy V–Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
225	100	85.83	14.16
275	100	94.53	5.46
325	100	98.01	1.98

SUM of RESIDUALS = 21.5

IRRADIATED CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:50:14 on 09-24-1999

Page 1

Coefficients of Curve 1

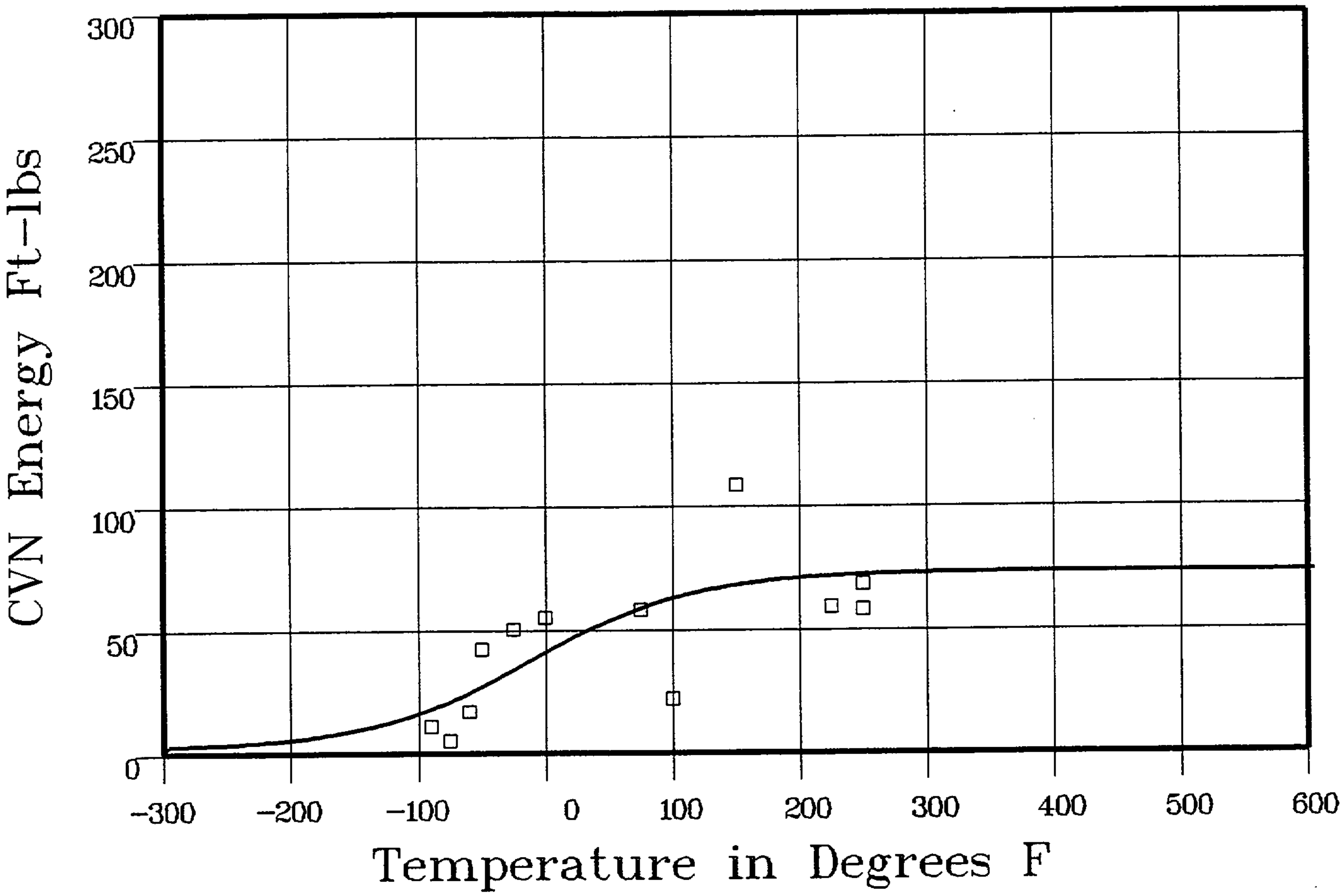
A = 37.59	B = 35.4	C = 125.97	T0 = -16.4

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

Upper Shelf Energy: 73 Fixed Temp. at 30 ft-lbs: -43.8 Temp. at 50 ft-lbs: 29.6 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: X Material: WELD Ori.: Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-90	11	18.99	-7.99
-75	5	22.22	-17.22
-60	17	25.81	-8.81
-50	42	28.37	13.62
-25	50	35.18	14.81
0	55	42.18	12.81
75	58	59.56	-1.56
100	22	63.36	-41.36
150	108	68.29	39.7

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

IRRADIATED CAPSULE X

Material: WELD   Heat Number: WIRE HEAT:4278   Orientation:

Capsule: X   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
225	59	71.49	-12.49
250	68	71.98	-3.98
250	58	71.98	-13.98

SUM of RESIDUALS = -26.46

IRRADIATED CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:53:52 on 09-24-1999

Page 1

Coefficients of Curve 1

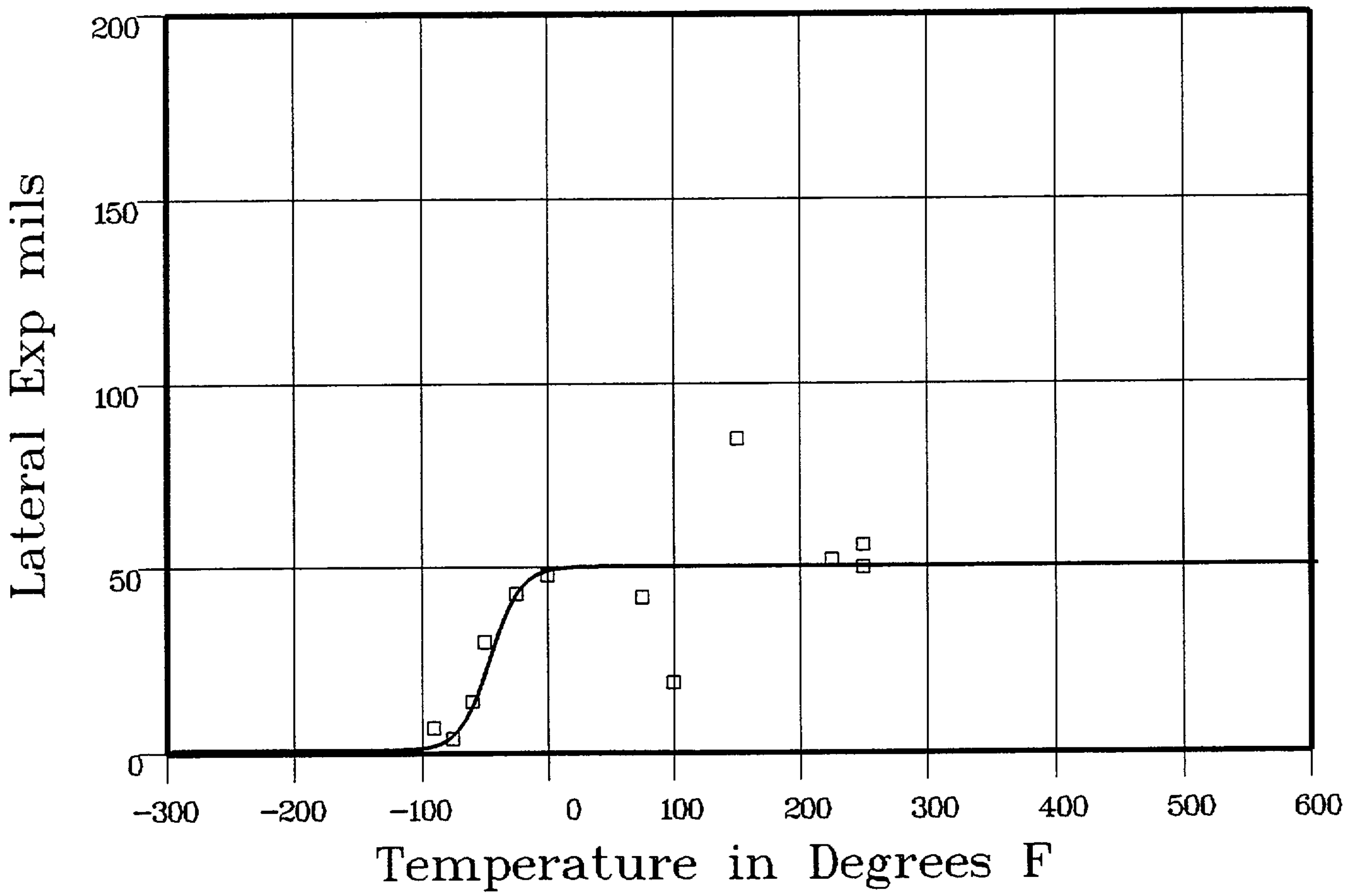
A = 25.62	B = 24.62	C = 23.74	T0 = -50.62

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

Upper Shelf L.E.: 50.24 Temperature at L.E. 35: -41.1 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: X Material: WELD Ori.: Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-90	7	2.72	4.27
-75	4	6.6	-2.6
-60	14	16.37	-2.37
-50	30	26.27	3.72
-25	43	45.14	-2.14
0	48	49.56	-1.56
75	42	50.24	-8.24
100	19	50.24	-31.24
150	85	50.24	34.75

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

IRRADIATED CAPSULE X

Page 2

Material: WELD   Heat Number: WIRE HEAT:4278   Orientation:

Capsule: X   Total Fluence:

Charpy V–Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
225	52	50.24	1.75
250	56	50.24	5.75
250	50	50.24	-.24
			SUM of RESIDUALS = 1.83

IRRADIATED CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:55:21 on 09-24-1999
Page 1
Coefficients of Curve 1

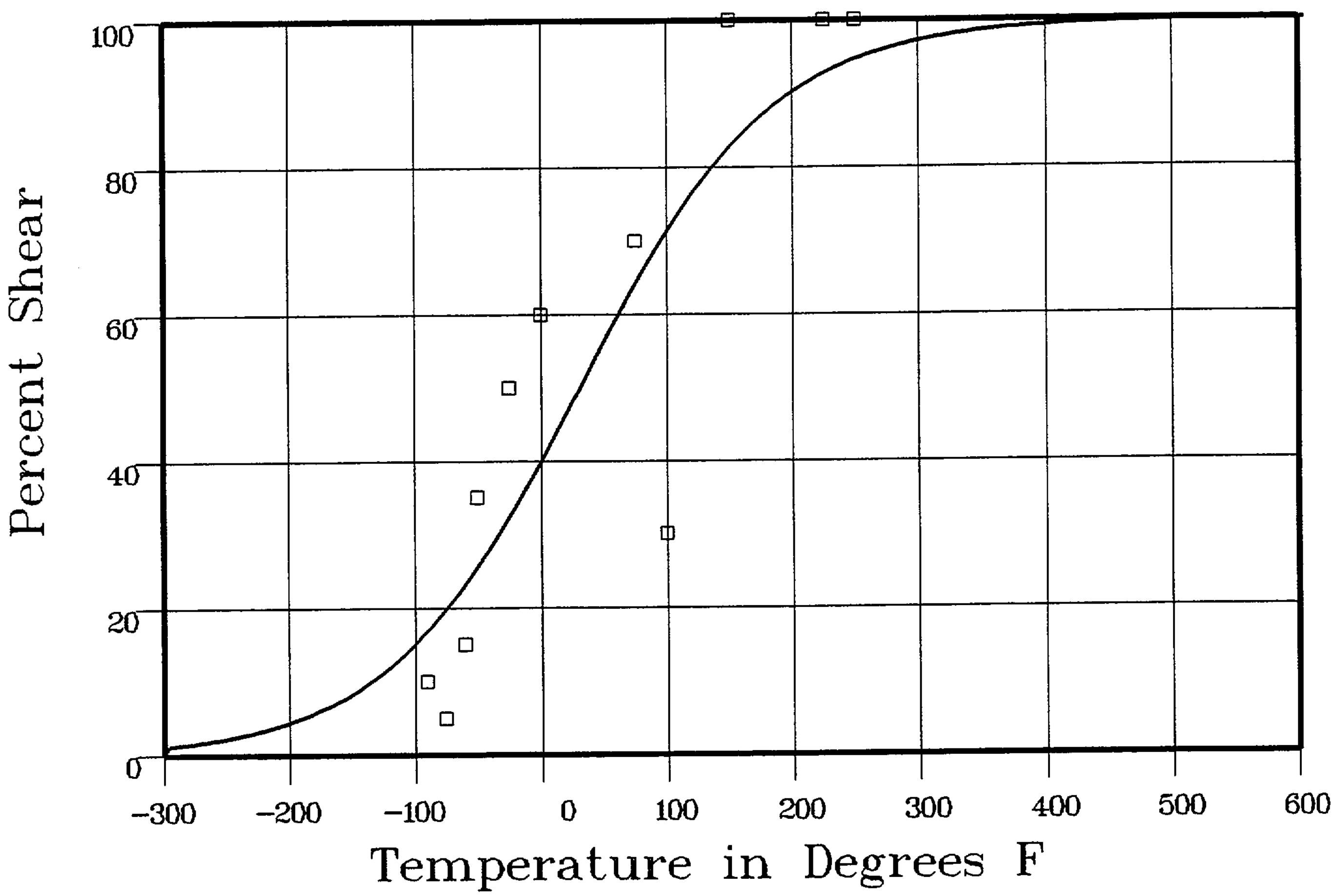
A = 50	B = 50	C = 151.39	T0 = 26.28

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

Temperature at 50% Shear: 26.2

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: X Total Fluence:



Data Set(s) Plotted
Plant: SQ2 Cap.: X Material: WELD Ori.: Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-90	10	17.7	-7.7
-75	5	20.78	-15.78
-60	15	24.23	-9.23
-50	35	26.74	8.25
-25	50	33.68	16.31
0	60	41.4	18.59
75	70	65.55	4.44
100	30	72.58	-42.58
150	100	83.67	16.32

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

IRRADIATED CAPSULE X

Page 2

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: X Total Fluence:

Charpy V–Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
225	100	93.24	6.75
250	100	95.05	4.94
250	100	95.05	4.94

SUM of RESIDUALS = 5.28

IRRADIATED CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:59:41 on 09-24-1999

Page 1

Coefficients of Curve 1

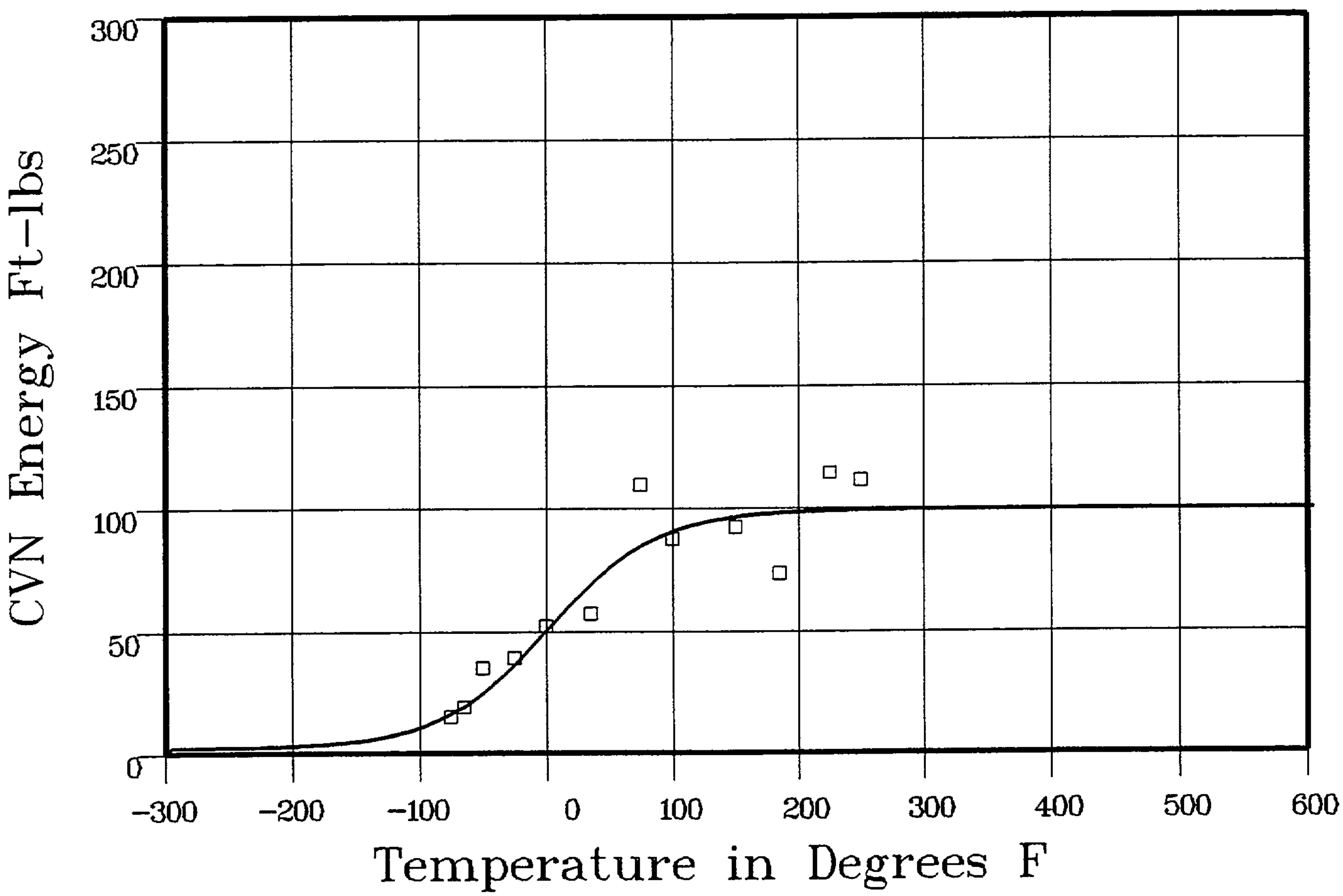
A = 50.59	B = 48.4	C = 86	T0 = -3.69

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

Upper Shelf Energy: 99 Fixed Temp. at 30 ft-lbs: -42.7 Temp. at 50 ft-lbs: -4.7 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFF'D ZONE Heat Number: SHELL (05) SIDE OF WELD Orientation:

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: X Material: HEAT AFFD ZONE Ori.: Heat #: SHELL (05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-75	15	17.68	-2.68
-65	19	20.95	-1.95
-50	35	26.79	8.2
-25	39	38.84	.15
0	52	52.67	-.67
35	57	71.01	-14.01
75	109	85.61	23.38
100	87	91.03	-4.03
150	92	96.35	-4.35

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

IRRADIATED CAPSULE X

Page 2

Material: HEAT AFF'D ZONE   Heat Number: SHELL (05) SIDE OF WELD   Orientation:

Capsule: X   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
185	73	97.81	-24.81
225	114	98.52	15.47
250	111	98.73	12.26

SUM of RESIDUALS = 6.93

IRRADIATED CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:02:59 on 09-24-1999

Page 1

Coefficients of Curve 1

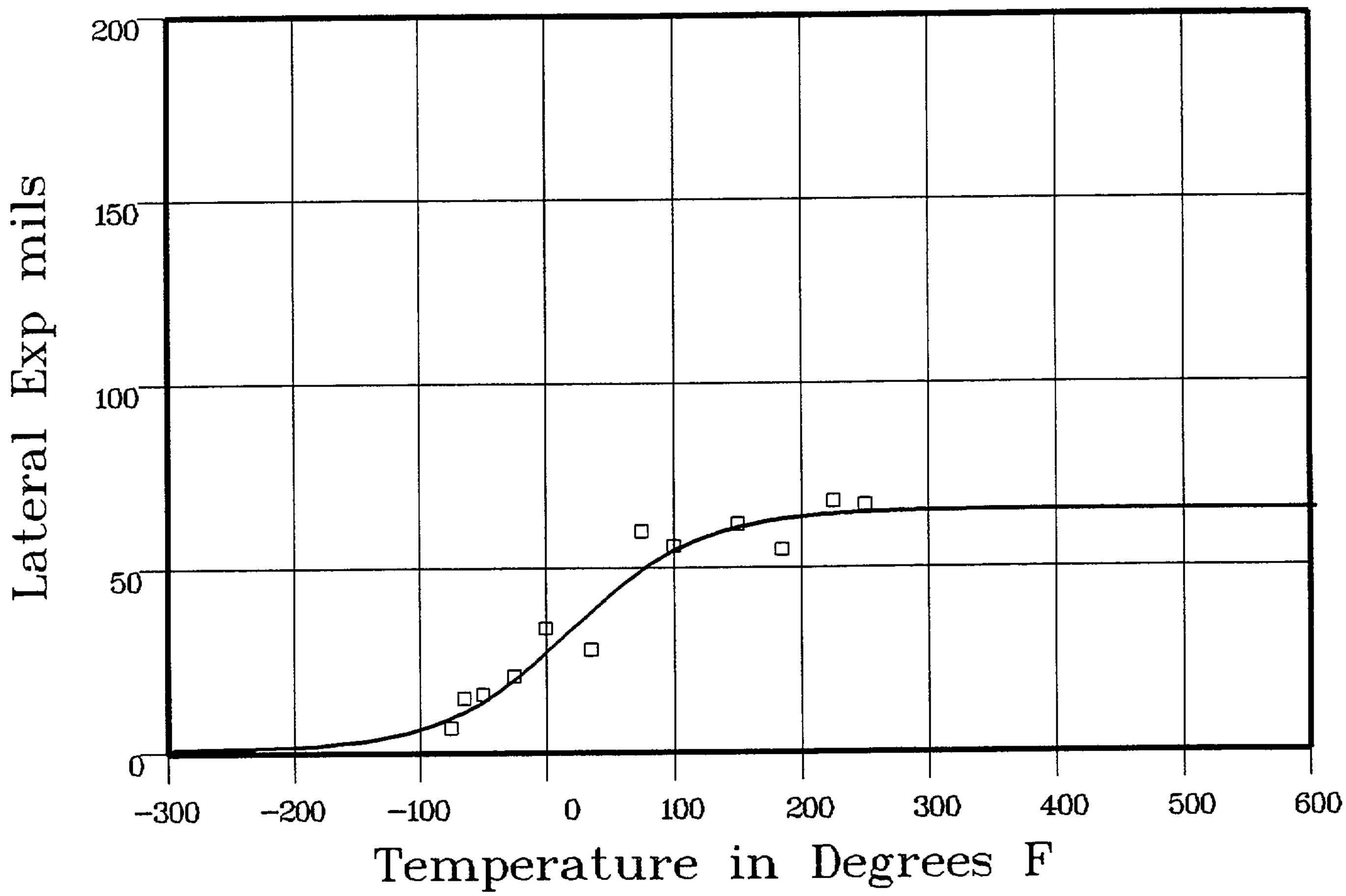
A = 33.27	B = 32.27	C = 100.66	T0 = 14.07

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

Upper Shelf L.E.: 65.54 Temperature at L.E. 35: 19.4 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFF'D ZONE Heat Number: SHELL (05) SIDE OF WELD Orientation:

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: X Material: HEAT AFF'D ZONE Ori.: Heat #: SHELL (05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-75	7	10.39	-3.39
-65	15	12.1	2.89
-50	16	15.11	.88
-25	21	21.33	-.33
0	34	28.78	5.21
35	28	39.88	-11.88
75	60	50.72	9.27
100	56	55.63	.36
150	62	61.47	.52

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

IRRADIATED CAPSULE X

Page 2

Material: HEAT AFF'D ZONE   Heat Number: SHELL (05) SIDE OF WELD   Orientation:

Capsule: X   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
185	55	63.44	-8.44
225	68	64.57	3.42
250	67	64.95	2.04

SUM of RESIDUALS = .56

IRRADIATED CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 11:04:59 on 09-24-1999

Page 1

Coefficients of Curve 1

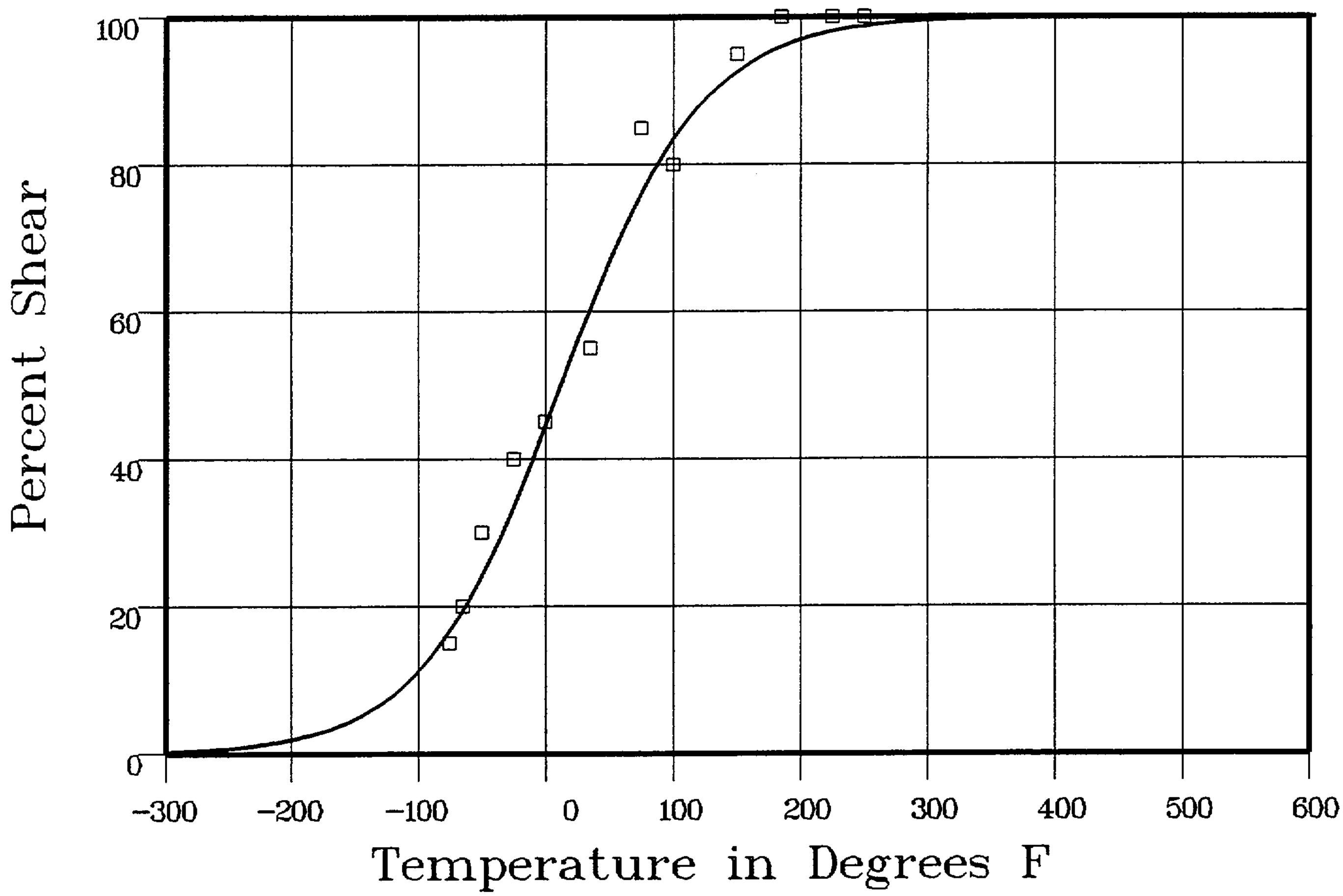
A = 50	B = 50	C = 108.31	T0 = 7.47

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

Temperature at 50% Shear: 7.4

Material: HEAT AFF'D ZONE Heat Number: SHELL (05) SIDE OF WELD Orientation:

Capsule: X Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: X Material: HEAT AFF'D ZONE Ori.: Heat #: SHELL (05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75	15	17.9	-2.9
-65	20	20.78	-.78
-50	30	25.7	4.29
-25	40	35.44	4.55
0	45	46.55	-1.55
35	55	62.44	-7.44
75	85	77.67	7.32
100	80	84.66	-4.66
150	95	93.28	1.71

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

IRRADIATED CAPSULE X

Page 2

Material: HEAT AFFD ZONE   Heat Number: SHELL (05) SIDE OF WELD   Orientation:

Capsule: X   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
185	100	96.36	3.63
225	100	98.23	1.76
250	100	98.87	1.12

SUM of RESIDUALS = 7.05

IRRADIATED CAPSULE Y

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:42:12 on 09-30-1999

Page 1

Coefficients of Curve 1

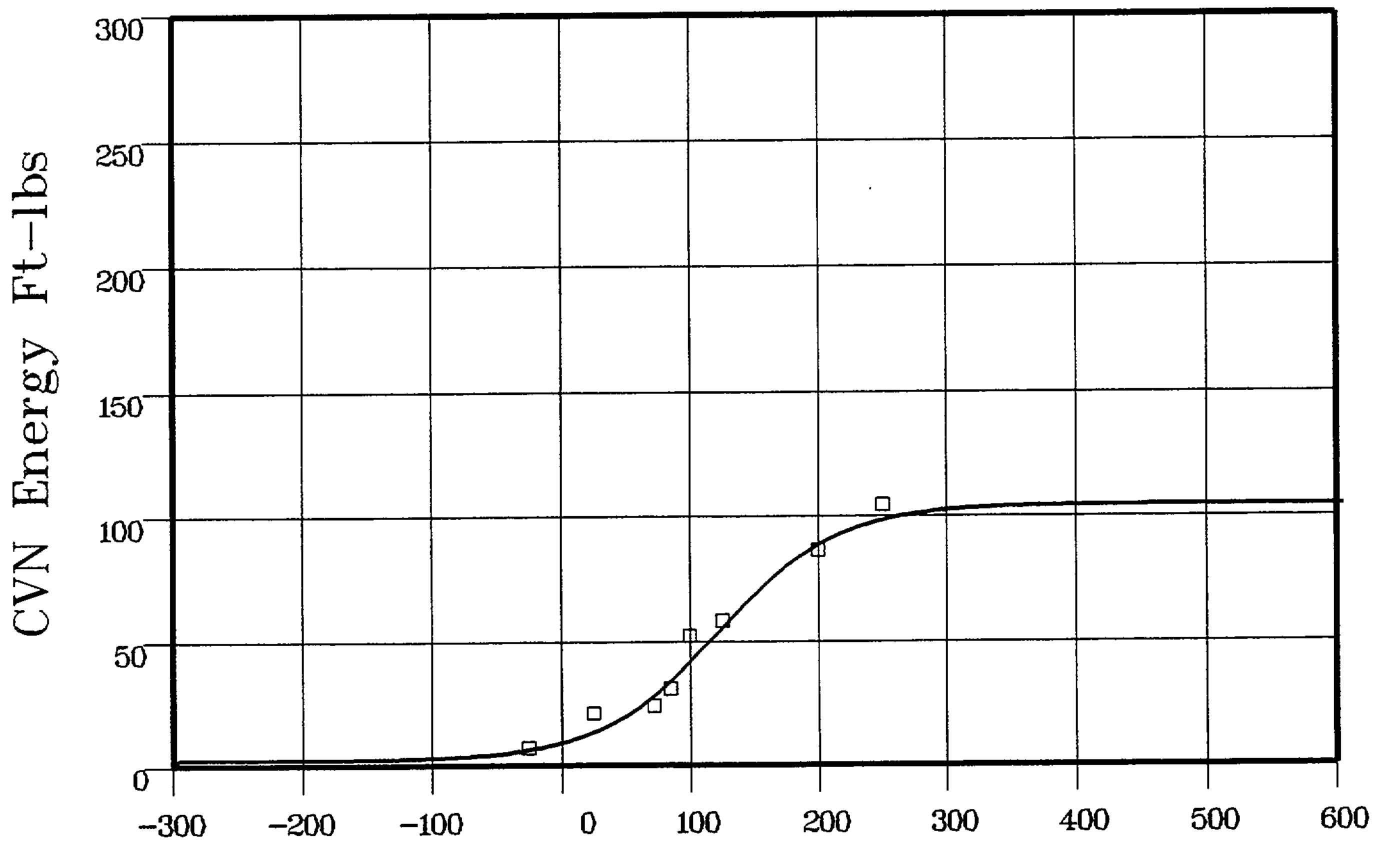
A = 53.09	B = 50.9	C = 92.28	T0 = 116.59

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

Upper Shelf Energy: 104 Fixed Temp. at 30 ft-lbs: 71.4 Temp. at 50 ft-lbs: 110.9 Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: Y Material: FORGING SA508CL2 Ori.: LT Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	7	6.72	.27
25	21	14.49	6.5
72	24	30.25	-6.25
85	31	36.32	-5.32
100	52	44.04	7.95
125	58	57.72	.27
200	86	89.65	-3.65
250	104	98.64	5.35

SUM of RESIDUALS = 5.15

IRRADIATED CAPSULE Y

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:38:06 on 09-30-1999

Page 1

Coefficients of Curve 1

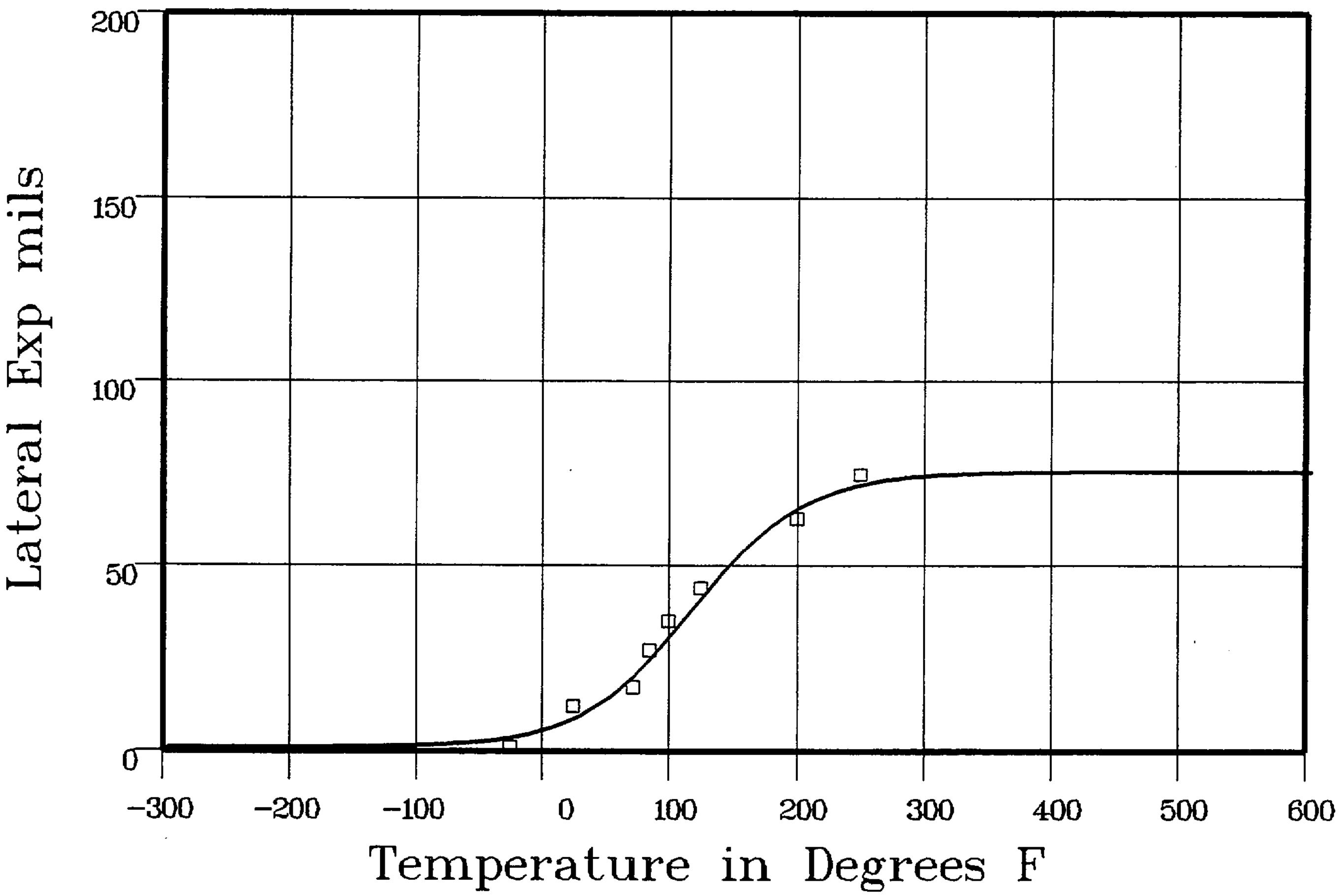
A = 38.3	B = 37.3	C = 86.91	T0 = 114.14

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

Upper Shelf L.E.: 75.61 Temperature at L.E. 35: 106.4 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: Y Material: FORGING SA508CL2 Ori.: LT Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	1	3.91	-2.91
25	12	9.5	2.49
72	17	21.51	-4.51
85	27	26.24	.75
100	35	32.29	2.7
125	44	42.94	1.05
200	63	66.52	-3.52
250	75	72.47	2.52

SUM of RESIDUALS = -1.42

IRRADIATED CAPSULE Y

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:39:21 on 09-30-1999

Page 1

Coefficients of Curve 1

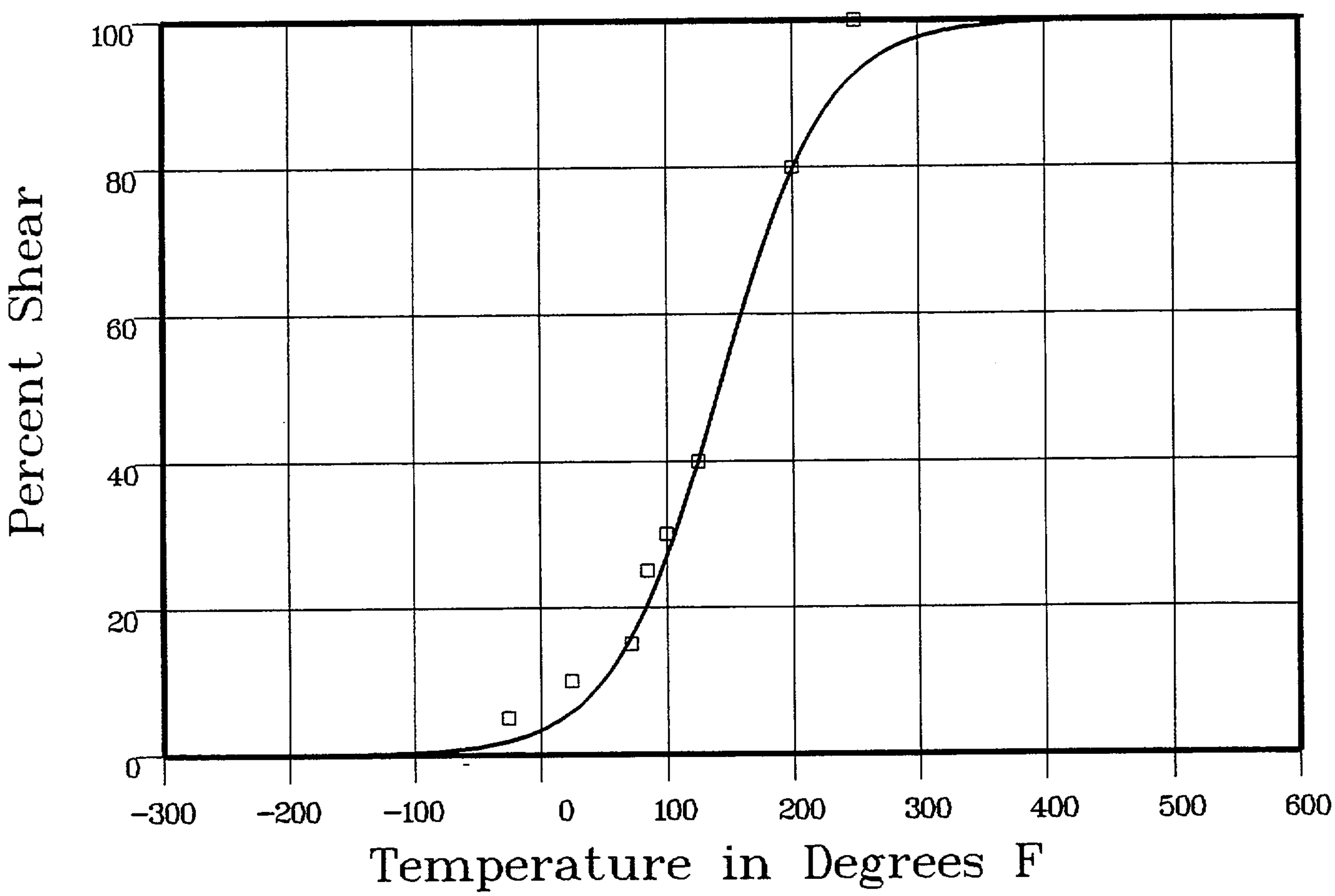
A = 50	B = 50	C = 84.54	T0 = 137.4

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

Temperature at 50% Shear: 137.4

Material: FORGING SA508CL2 Heat Number: 288757/981057(05) Orientation: LT

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: Y Material: FORGING SA508CL2 Ori.: LT Heat #: 288757/981057(05)

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	5	2.1	2.89
25	10	6.54	3.45
72	15	17.54	-2.54
85	25	22.44	2.55
100	30	29.21	.78
125	40	42.71	-2.71
200	80	81.47	-1.47
250	100	93.48	6.51

SUM of RESIDUALS = 9.46

IRRADIATED CAPSULE Y

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:49:11 on 09-30-1999

Page 1

Coefficients of Curve 1

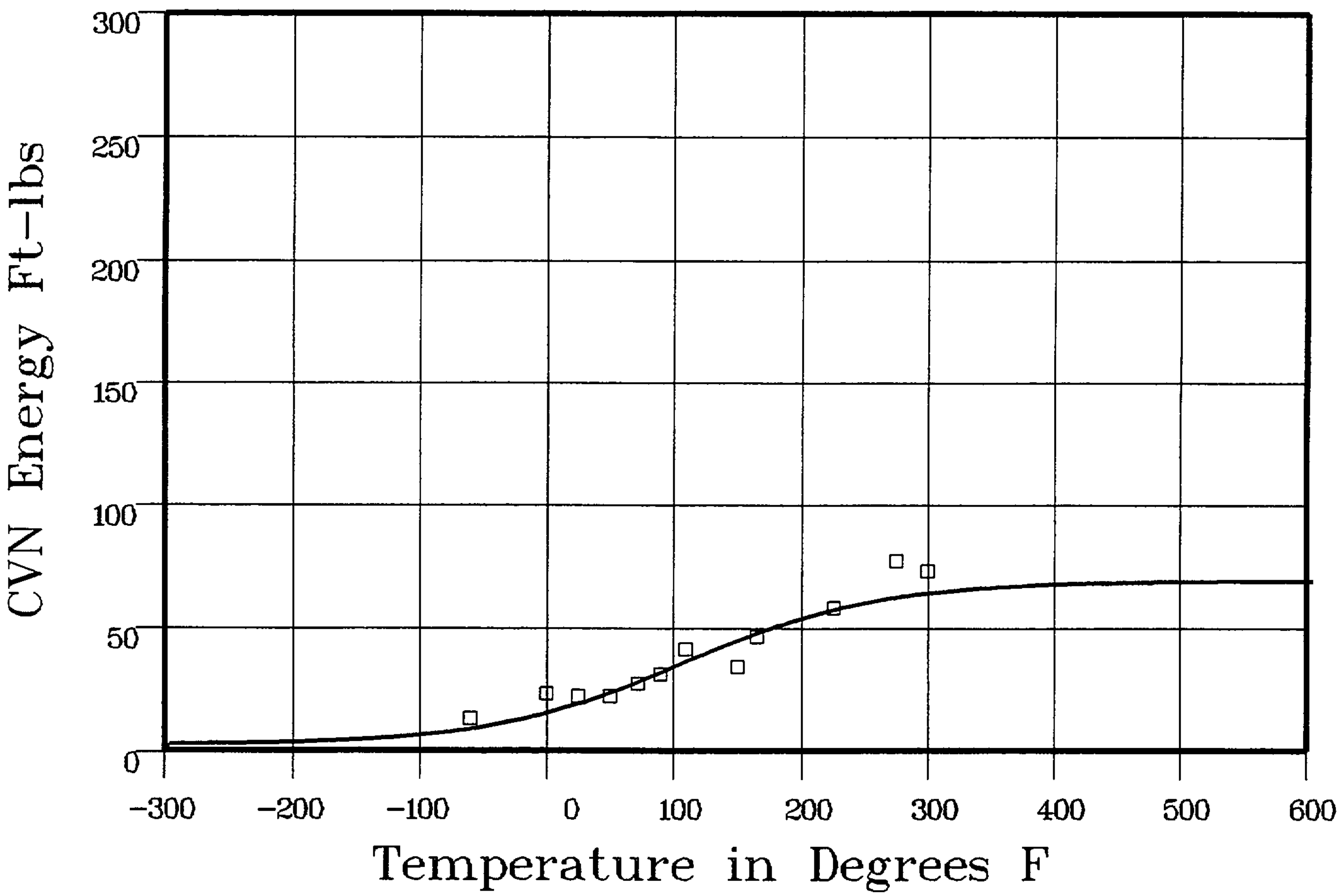
A = 35.59	B = 33.4	C = 151.84	T0 = 102.83

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

Upper Shelf Energy: 69 Fixed   Temp. at 30 ft-lbs: 77.1   Temp. at 50 ft-lbs: 172.8   Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA508CL2   Heat Number: 288757-981057(05)   Orientation: TL

Capsule: Y   Total Fluence:



Data Set(s) Plotted

Plant: SQ2   Cap.: Y   Material: FORGING SA508CL2   Ori.: TL   Heat #: 288757-981057(05)

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-60	13	9.2	3.79
0	23	15.9	7.09
25	22	19.83	2.16
50	22	24.42	-2.42
72	27	28.9	-1.9
90	31	32.78	-1.78
110	41	37.17	3.82
150	34	45.65	-11.65
165	46	48.55	-2.55

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

IRRADIATED CAPSULE Y

Page 2

Material: FORGING SA508CL2 Heat Number: 288757-981057(05) Orientation: TL

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
225	58	57.86	.13
275	77	62.73	14.26
300	73	64.36	8.63

SUM of RESIDUALS = 19.58

IRRADIATED CAPSULE Y

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:54:56 on 09-30-1999

Page 1

Coefficients of Curve 1

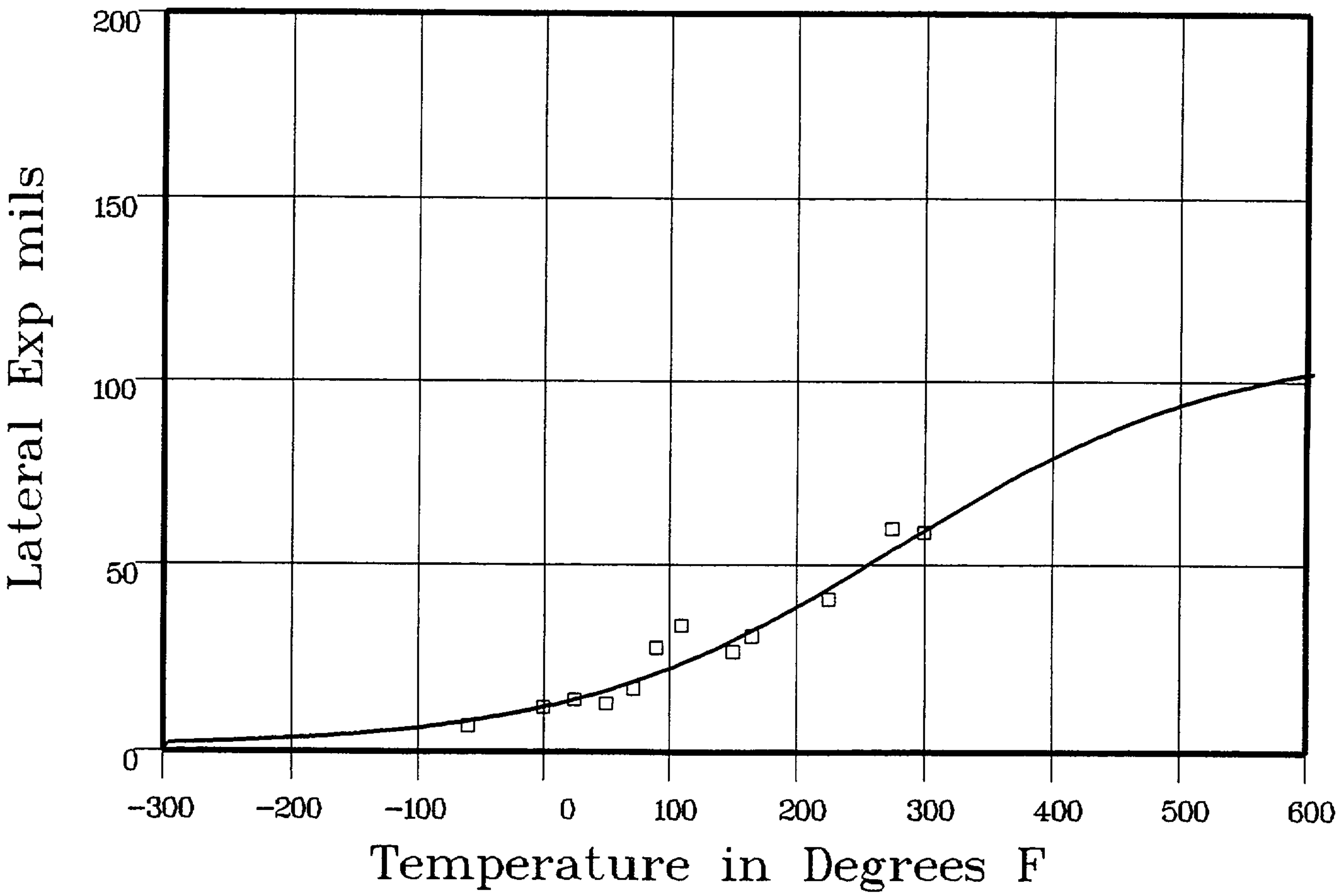
A = 55.95	B = 54.95	C = 258.83	T0 = 277.81

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

Upper Shelf L.E.: 110.9   Temperature at L.E. 35: 173.8   Lower Shelf L.E.: 1 Fixed

Material: FORGING SA508CL2   Heat Number: 288757-981057(05)   Orientation: TL

Capsule: Y   Total Fluence:



Data Set(s) Plotted

Plant: SQ2   Cap.: Y   Material: FORGING SA508CL2   Ori.: TL   Heat #: 288757-981057(05)

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-60	7	8.52	-1.52
0	12	12.5	-.5
25	14	14.64	-.64
50	13	17.12	-4.12
72	17	19.61	-2.61
90	28	21.86	6.13
110	34	24.59	9.4
150	27	30.82	-3.82
165	31	33.41	-2.41

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

IRRADIATED CAPSULE Y

Page 2

Material: FORGING SA508CL2 Heat Number: 288757-981057(05) Orientation: TL

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
225	41	44.89	-3.89
275	60	55.35	4.64
300	59	60.65	-1.65

SUM of RESIDUALS = -1.01

IRRADIATED CAPSULE Y

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:58:15 on 09-30-1999

Page 1

Coefficients of Curve 1

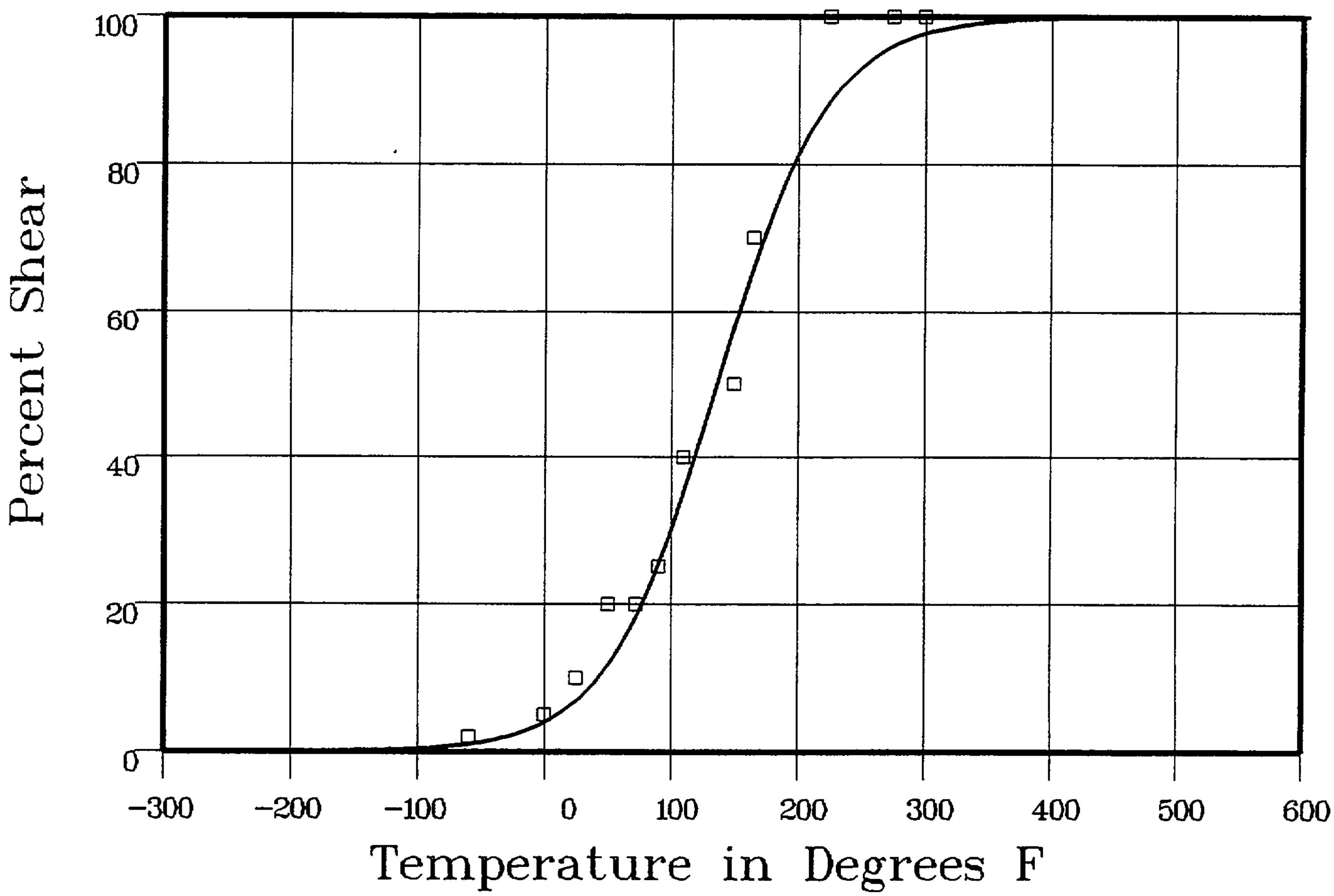
A = 50	B = 50	C = 86.11	T0 = 131.83

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

Temperature at 50% Shear: 131.8

Material: FORGING SA508CL2 Heat Number: 288757-981057(05) Orientation: TL

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: Y Material: FORGING SA508CL2 Ori.: TL Heat #: 288757-981057(05)

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-60	2	1.14	.85
0	5	4.47	.52
25	10	7.71	2.28
50	20	13	6.99
72	20	19.94	.05
90	25	27.45	-2.45
110	40	37.58	2.41
150	50	60.39	-10.39
165	70	68.35	1.64

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

IRRADIATED CAPSULE Y

Page 2

Material: FORGING SA508CL2 Heat Number: 288757-981057(05) Orientation: TL

Capsule: Y Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
225	100	89.69	10.3
275	100	96.52	3.47
300	100	98.02	1.97

SUM of RESIDUALS = 17.66

IRRADIATED CAPSULE Y

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:16:07 on 09-30-1999

Page 1

Coefficients of Curve 1

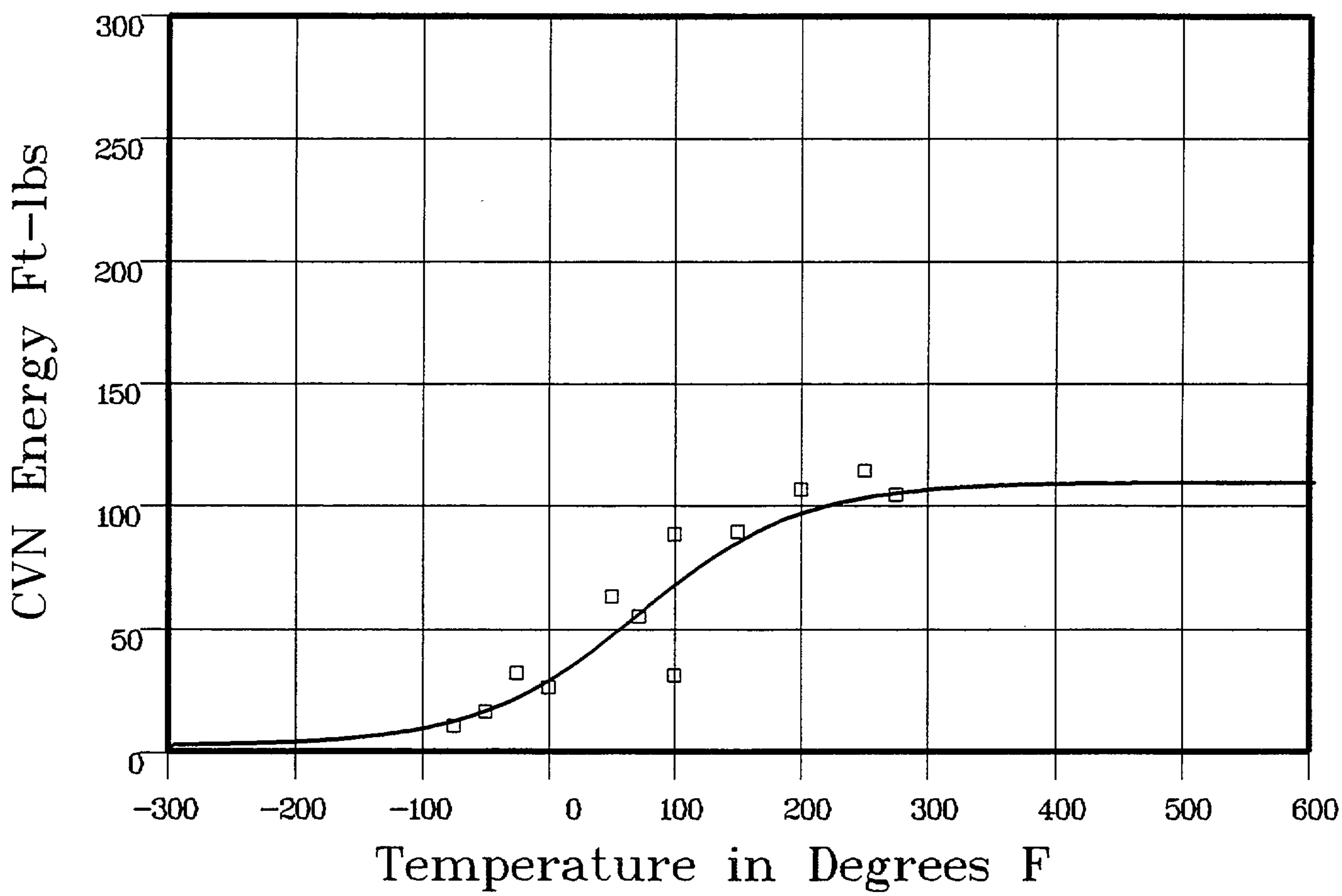
A = 55.59	B = 53.4	C = 128.34	T0 = 65.83

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

Upper Shelf Energy: 109 Fixed Temp. at 30 ft-lbs: -1.1 Temp. at 50 ft-lbs: 52.3 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: Y Material: WELD Ori.: Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-75	10	12.9	-2.9
-50	16	17.28	-1.28
-25	32	23.06	8.93
0	26	30.38	-4.38
50	63	49.04	13.95
72	55	58.16	-3.16
100	88	69.48	18.51
100	31	69.48	-38.48
150	89	86.33	2.66

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

IRRADIATED CAPSULE Y

Page 2

Material: WELD　　Heat Number: WIRE HEAT:4278　　Orientation:

Capsule: Y　　Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
200	106	97.25	8.74
250	114	103.26	10.73
275	104	105.04	-1.04

SUM of RESIDUALS = 12.27

IRRADIATED CAPSULE Y

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:18:57 on 09-30-1999

Page 1

Coefficients of Curve 1

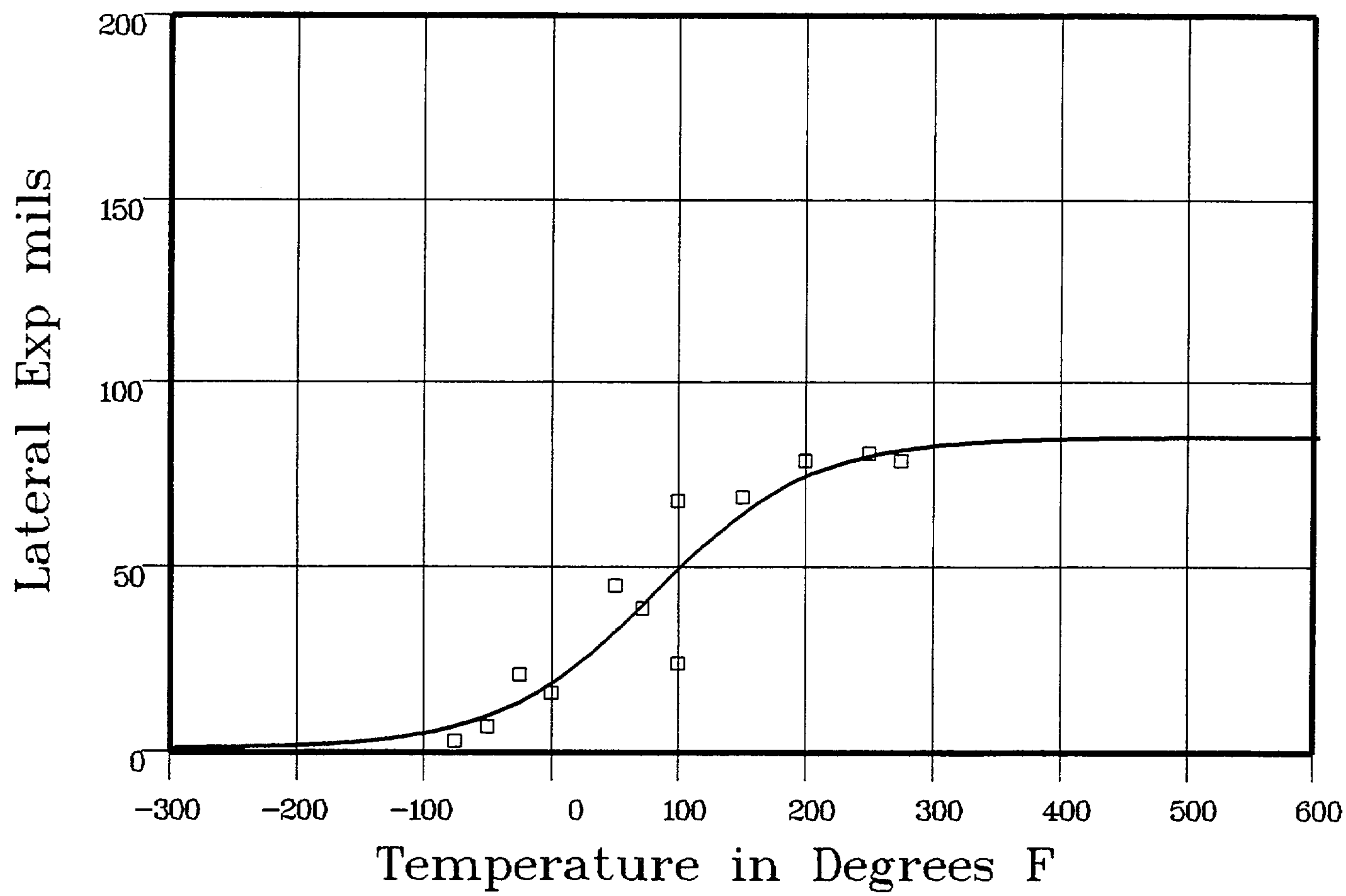
A = 43.13	B = 42.13	C = 122.35	T0 = 76.53

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

Upper Shelf L.E.: 85.26 Temperature at L.E. 35: 52.6 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: Y Material: WELD Ori.: Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-75	3	7.52	-4.52
-50	7	10.45	-3.45
-25	21	14.46	6.53
0	16	19.75	-3.75
50	45	34.13	10.86
72	39	41.57	-2.57
100	68	51.11	16.88
100	24	51.11	-27.11
150	69	65.77	3.22

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

IRRADIATED CAPSULE Y

Page 2

Material: WELD　　Heat Number: WIRE HEAT:4278　　Orientation:

Capsule: Y　　Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
200	79	75.38	3.61
250	81	80.59	.4
275	79	82.1	-3.1

SUM of RESIDUALS = -3.01

IRRADIATED CAPSULE Y

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:23:11 on 09-30-1999

Page 1

Coefficients of Curve 1

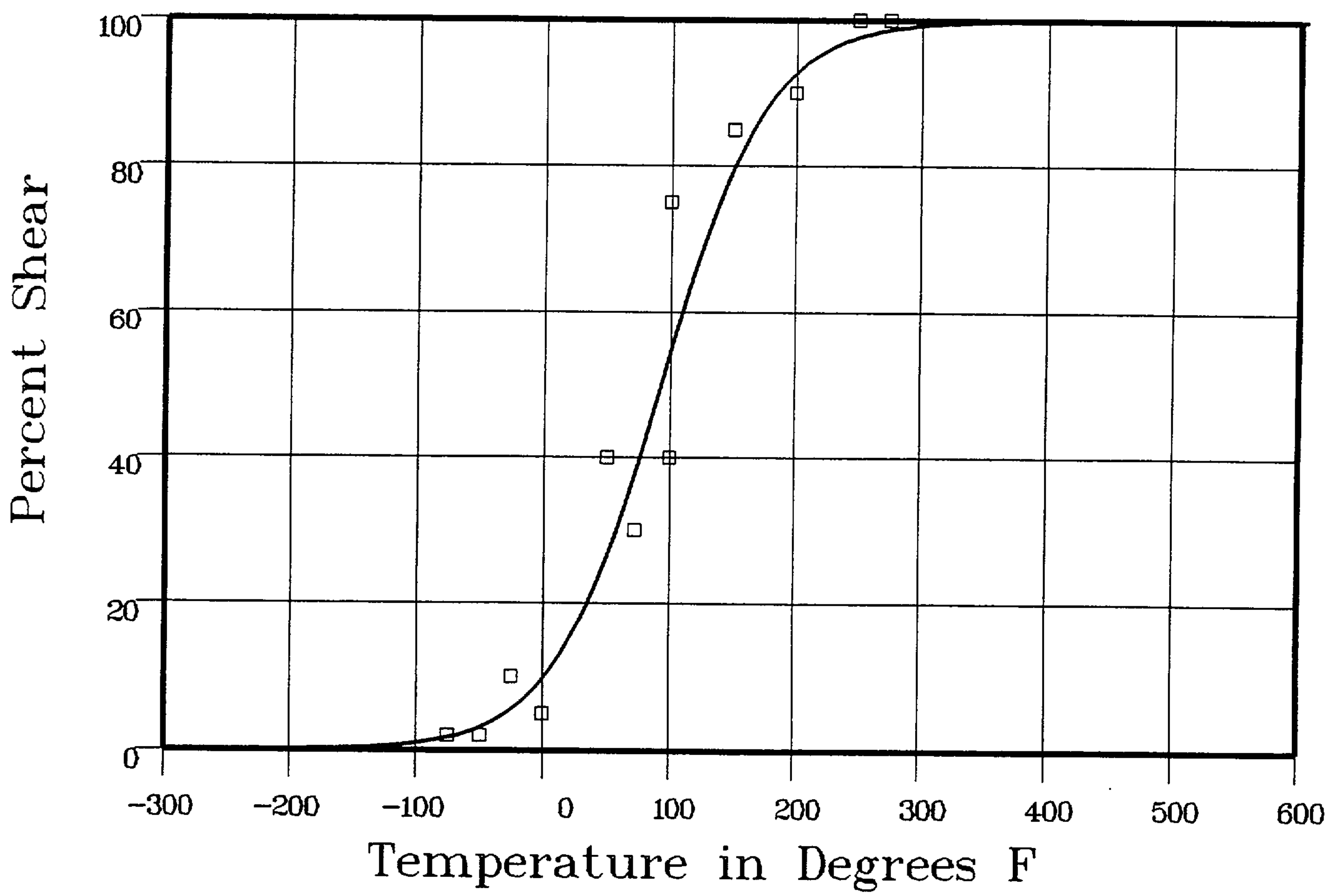
A = 50	B = 50	C = 83.66	T0 = 88.18

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

Temperature at 50% Shear: 88.1

Material: WELD Heat Number: WIRE HEAT:4278 Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: Y Material: WELD Ori.: Heat #: WIRE HEAT:4278

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75	2	1.98	.01
-50	2	3.54	-1.54
-25	10	6.26	3.73
0	5	10.83	-5.83
50	40	28.64	11.35
72	30	40.44	-10.44
100	75	57.01	17.98
100	40	57.01	-17.01
150	85	81.42	3.57

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

IRRADIATED CAPSULE Y

Page 2

Material: WELD   Heat Number: WIRE HEAT:4278   Orientation:

Capsule: Y   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
200	90	93.54	-3.54
250	100	97.95	2.04
275	100	98.86	1.13

SUM of RESIDUALS = 1.47

IRRADIATEDCAPSULE Y

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:45:55 on 09-30-1999

Page 1

Coefficients of Curve 1

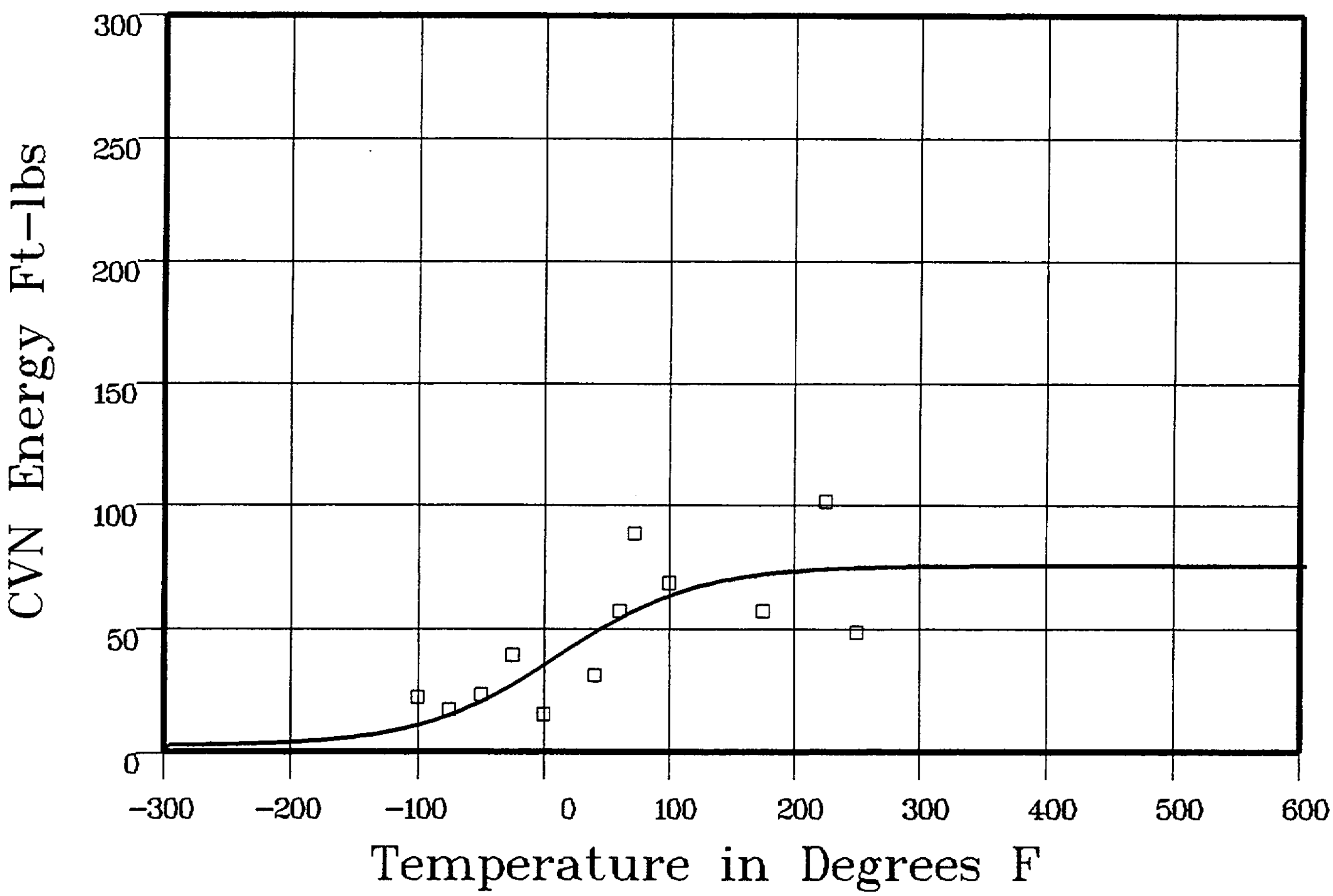
A = 38.59	B = 36.4	C = 109.46	T0 = 5.6

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

Upper Shelf Energy: 75 Fixed   Temp. at 30 ft-lbs: -20.7   Temp. at 50 ft-lbs: 41   Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE   Heat Number: SHELL(05) SIDE OF WELD   Orientation:

Capsule: Y   Total Fluence:



Data Set(s) Plotted

Plant: SQ2   Cap.: Y   Material: HEAT AFFD ZONE   Ori.:   Heat #: SHELL(05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	22	11.43	10.56
-75	17	15.77	1.22
-50	23	21.55	1.44
-25	39	28.68	10.31
0	15	36.73	-21.73
40	31	49.67	-18.67
60	57	55.33	1.66
72	88	58.31	29.68
100	68	63.98	4.01

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

IRRADIATEDCAPSULE Y

Page 2

Material: HEAT AFFD ZONE   Heat Number: SHELL(05) SIDE OF WELD   Orientation:

Capsule: Y   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
175	57	71.84	-14.84
225	101	73.7	27.29
250	48	74.17	-26.17

SUM of RESIDUALS = 4.78

IRRADIATED CAPSULE Y

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:49:12 on 09-30-1999

Page 1

Coefficients of Curve 1

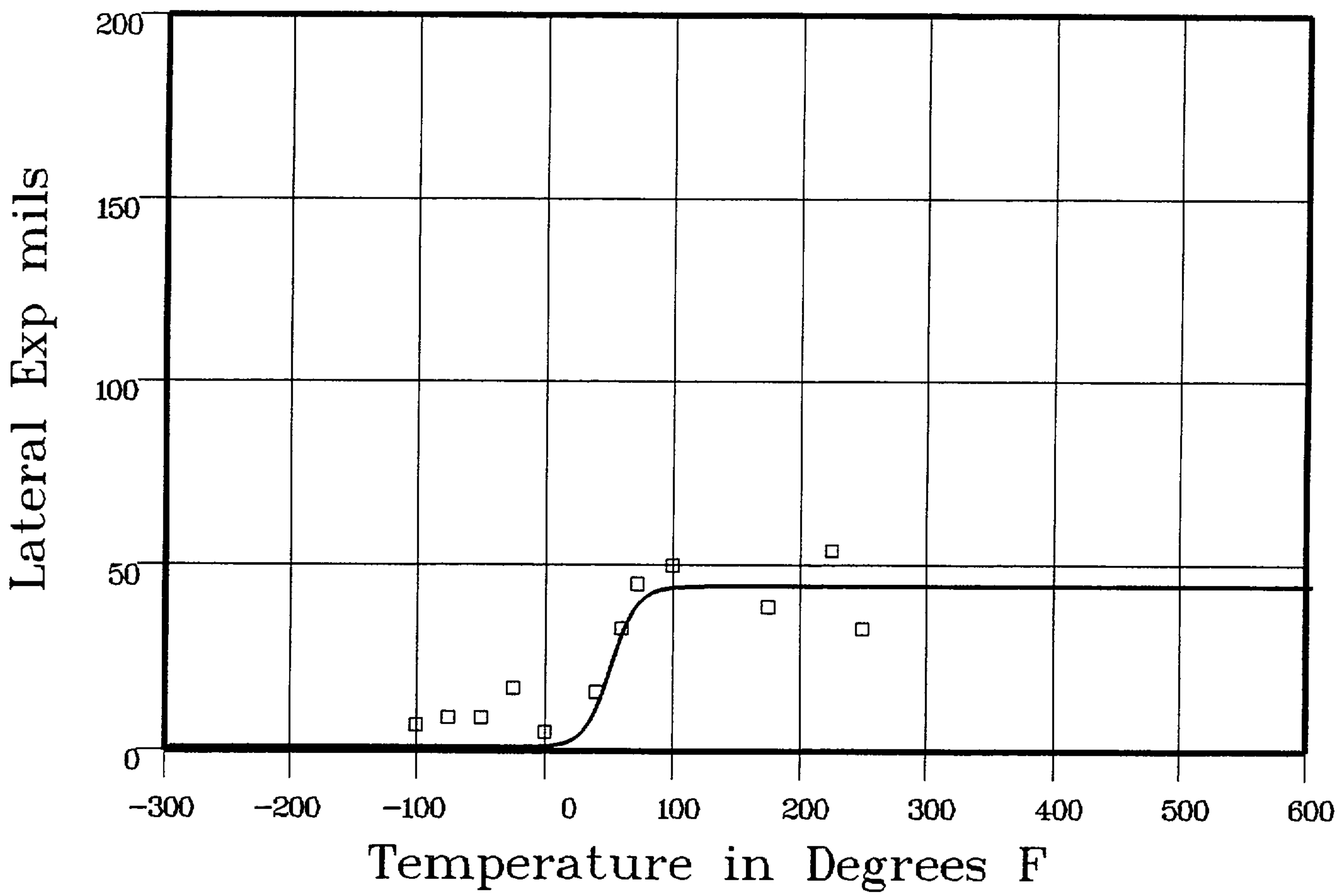
A = 22.75	B = 21.75	C = 19.89	T0 = 46.87

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

Upper Shelf L.E.: 44.5 Temperature at L.E. 35: 59.5 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: SHELL(05) SIDE OF WELD Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: Y Material: HEAT AFFD ZONE Ori.: Heat #: SHELL(05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	7	1	5.99
-75	9	1	7.99
-50	9	1	7.99
-25	17	1.03	15.96
0	5	1.38	3.61
40	16	15.52	.47
60	33	35.32	-2.32
72	45	41.28	3.71
100	50	44.29	5.7

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

IRRADIATED CAPSULE Y

Page 2

Material: HEAT AFF'D ZONE   Heat Number: SHELL(05) SIDE OF WELD   Orientation:

Capsule: Y   Total Fluence:

Charpy V–Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
175	39	44.5	-5.5
225	54	44.5	9.49
250	33	44.5	-11.5

SUM of RESIDUALS = 41.64

IRRADIATED CAPSULE Y

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:51:02 on 09-30-1999

Page 1

Coefficients of Curve 1

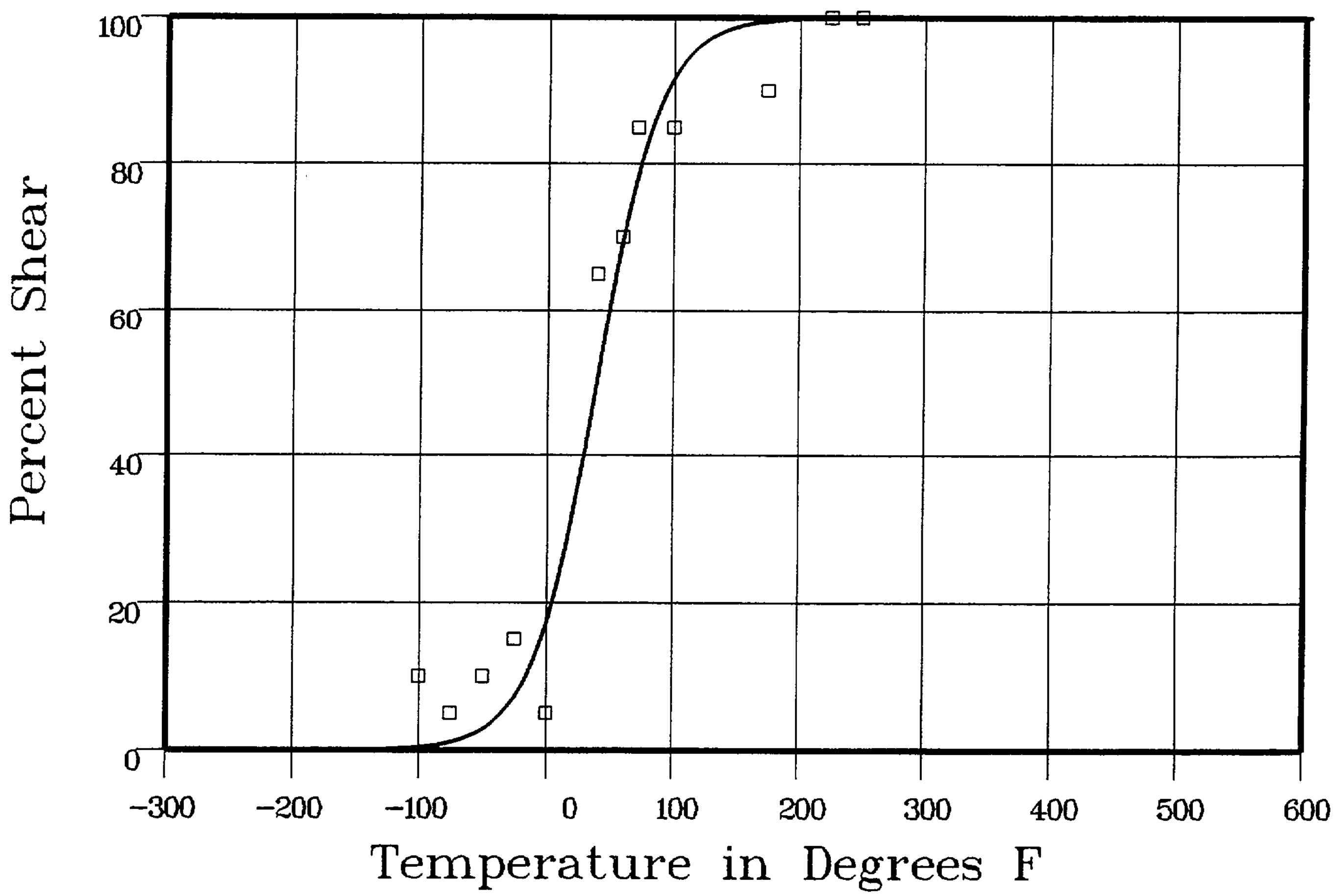
A = 50	B = 50	C = 50.56	T0 = 34.68

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

Temperature at 50% Shear: 34.6

Material: HEAT AFFD ZONE Heat Number: SHELL(05) SIDE OF WELD Orientation:

Capsule: Y Total Fluence:



Data Set(s) Plotted

Plant: SQ2 Cap.: Y Material: HEAT AFFD ZONE Ori.: Heat #: SHELL(05) SIDE OF WELD

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	10	.48	9.51
-75	5	1.28	3.71
-50	10	3.39	6.6
-25	15	8.62	6.37
0	5	20.22	-15.22
40	65	55.23	9.76
60	70	73.12	-3.12
72	85	81.39	3.6
100	85	92.97	-7.97

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

IRRADIATED CAPSULE Y

Material: HEAT AFFD ZONE　　Heat Number: SHELL(05) SIDE OF WELD　　Orientation:

Capsule: Y　　Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
175	90	99.61	-9.61
225	100	99.94	.05
250	100	99.97	.02

SUM of RESIDUALS = 3.71

APPENDIX D

SEQUOYAH UNIT 2 SURVEILLANCE PROGRAM CREDIBILITY ANALYSIS

INTRODUCTION:

Regulatory Guide 1.99, Revision 2, describes general procedures acceptable to the NRC staff for calculating the effects of neutron radiation embrittlement of the low-alloy steels currently used for light-water-cooled reactor vessels. Position C.2 of Regulatory Guide 1.99, Revision 2, describes the method for calculating the adjusted reference temperature and Charpy upper-shelf energy of reactor vessel beltline materials using surveillance capsule data. The methods of Position C.2 can only be applied when two or more credible surveillance data sets become available from the reactor in question.

To date there has been four surveillance capsules removed from the Sequoyah Unit 2 reactor vessel. To use these surveillance data sets, they must be shown to be credible. In accordance with the discussion of Regulatory Guide 1.99, Revision 2, there are five requirements that must be met for the surveillance data to be judged credible.

The purpose of this evaluation is to apply the credibility requirements of Regulatory Guide 1.99, Revision 2, to the Sequoyah Unit 2 reactor vessel surveillance data and determine if the Sequoyah Unit 2 surveillance data is credible.

EVALUATION:

Criterion 1: Materials in the capsules should be those judged most likely to be controlling with regard to radiation embrittlement.

The beltline region of the reactor vessel is defined in Appendix G to 10 CFR Part 50, "FractureToughness Requirements", as follows:

> "the reactor vessel (shell material including welds, heat affected zones, and plates or forgings) that directly surrounds the effective height of the active core and adjacent regions of the reactor vessel that are predicted to experience sufficient neutron radiation damage to be considered in the selection of the most limiting material with regard to radiation damage."

The Sequoyah Unit 2 reactor vessel consists of the following beltline region materials:

- Intermediate shell forging 05,
- Lower shell forging 04, and
- Intermediate to lower shell circumferential weld seam.

Per WCAP-8513, the Sequoyah Unit 2 surveillance program was based on ASTM E185-73, "Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels". Per Section 4.1 of ASTM E185-73, *"The base metal and weld metal to be included in the program should represent the material that may limit the operation of the reactor during its lifetime. The test material should be selected on the basis of initial transition temperature, upper shelf energy level, and estimated increase in transition temperature considering chemical composition (copper (Cu) and phosphorus (P)) and neutron fluence."*

At the time the Sequoyah Unit 2 surveillance capsule program was developed, intermediate shell forging 05 was judged to be most limiting based on the higher initial RT_{NDT} and lower USE. Hence, the intermediate shell forging 05 was therefore utilized in the surveillance program.

The Sequoyah Unit 2 surveillance program weld was fabricated with Wire Heat No. 4278, Flux Type SMIT 89, Flux Lot No. 1211. The Sequoyah Unit 2 intermediate to lower shell circumferential weld seam (the only beltline weld seam) was fabricated with with Wire Heat No. 4278, Flux Type SMIT 89, Flux Lot No. 1211. Hence, the surveillance weld is representative of the beltline weld metal.

Hence, Criterion 1 is met for the Sequoyah Unit 2 reactor vessel.

Criterion 2: Scatter in the plots of Charpy energy versus temperature for the irradiated and unirradiated conditions should be small enough to permit the determination of the 30 ft-lb temperature and upper shelf energy unambiguously.

Plots of Charpy energy versus temperature for the unirradiated and irradiated condition are presented in Appendix B of this calcnote. Based on engineering judgment, the scatter in the data presented in these plots is small enough to permit the determination of the 30 ft-lb temperature and the upper shelf energy of the Sequoyah Unit 2 surveillance materials unambiguously. Hence, the Sequoyah Unit 2 surveillance program meets this criterion.

Criterion 3: When there are two or more sets of surveillance data from one reactor, the scatter of ΔRT_{NDT} values about a best-fit line drawn as described in Regulatory Position 2.1 normally should be less than 28°F for welds and 17°F for base metal. Even if the fluence range is large (two or more orders of magnitude), the scatter should not exceed twice those values. Even if the data fail this criterion for use in shift calculations, they may be credible for determining decrease in upper shelf energy if the upper shelf can be clearly determined, following the definition given in ASTM E185-82.

The functional form of the least squares method as described in Regulatory Position 2.1 will be utilized to determine a best-fit line for this data and to determine if the scatter of these ΔRT_{NDT} values about this line is less than 28°F for welds and less than 17°F for the plate.

Following is the calculation of the best fit line as described in Regulatory Position 2.1 of Regulatory Guide 1.99, Revision 2.

TABLE D-1: Sequoyah Unit 2 Surveillance Capsule Data

Material	Capsule	Capsule f[a]	FF[b]	ΔRT_{NDT}[c]	FF*ΔRT_{NDT}	FF^2
Intermediate Shell Forging 05 (Tangential)	T	2.61E+18	0.635	63.7	40.45	0.403
	U	6.92E+18	0.897	79.3	71.13	0.805
	X	1.22E+19	1.055	85.7	90.41	1.113
	Y	2.14E+19	1.207	134.1	161.86	1.457
Intermediate Shell Forging 05 (Axial)	T	2.61E+18	0.635	48.7	30.92	0.403
	U	6.92E+18	0.897	66.1	59.29	0.805
	X	1.22E+19	1.055	110.0	116.05	1.113
	Y	2.14E+19	1.207	89.2	107.66	1.457
				SUM:	677.77°F	7.556
	$CF_{05} = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (677.77) \div (7.556) =$ **89.7°F**					
Surveillance Weld Material[d]	T	2.61E+18	0.635	74.6	47.37	0.403
	U	6.92E+19	0.897	130.4	116.97	0.805
	X	1.22E+19	1.055	44.2	46.63	1.113
	Y	2.14E+19	1.207	86.9	104.89	1.457
				SUM:	315.86°F	3.778
	$CF_{Surv. Weld} = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (315.86°F) \div (3.778) =$ **83.6°F**					

Notes:

(a) f = Measured fluence from capsule Y dosimetry analysis results [(13)], (x 10^{19} n/cm^2, E > 1.0 MeV).

(b) FF = fluence factor = $f^{(0.28 - 0.1 * \log f)}$.

(c) ΔRT_{NDT} values are the measured 30 ft-lb shift values (See Appendix B).

(d) These measured ΔRT_{NDT} values do not include the adjustment ratio procedure of Reg. Guide 1.99 Revision 2, Position 2.1, since this calculation is based on the actual surveillance weld metal measured shift values and based on the copper and nickel content the ratio would be 1. In addition, the only surveillance data available is from the Sequoyah Unit 2 reactor vessel, therefore, no temperature adjustment is required.

The scatter of ΔRT_{NDT} values about the functional form of a best-fit line drawn as described in Regulatory Position 2.1 is presented in Table D-2.

TABLE D-2
Best Fit Evaluation for Sequoyah Unit 2 Surveillance Materials

Base Material	Capsule	CF (°F)	FF	Measured ΔRT_{NDT} (30 ft-lb) (°F)	Best Fit[(a)] ΔRT_{NDT} (°F)	Scatter of ΔRT_{NDT} (°F)	< 17°F (Base Metals) < 28°F (Weld Metal)
Intermediate Shell Forging 05 (Tangential)	T	89.7	0.635	63.7	56.96	6.74	Yes
	U	89.7	0.897	79.3	80.46	-1.16	Yes
	X	89.7	1.055	85.7	94.6	-8.9	Yes
	Y	89.7	1.207	134.1	108.27	25.83	**No**
Intermediate Shell Forging 05 (Axial)	T	89.7	0.635	48.73	56.96	-8.23	Yes
	U	89.7	0.897	66.06	80.46	-14.4	Yes
	X	89.7	1.055	110.04	94.6	15.44	Yes
	Y	89.7	1.207	89.21	108.27	-19.06	**No**
Surveillance Weld Metal	T	83.6	0.635	74.56	53.09	21.47	Yes
	U	83.6	0.897	130.4	75.00	55.40	**No**
	X	83.6	1.055	44.2	88.20	-44.00	**No**
	Y	83.6	1.207	86.9	100.91	-14.01	Yes

NOTES:
(a) Best Fit Line Per Equation 2 of Reg. Guide 1.99 Rev. 2 Position 1.1.

Table D-2 indicates the entire ΔRT_{NDT} scatter is greater than one standard deviation for both the forging and the weld material. Hence, the surveillance data does not meet this criteria.

Since the surveillance data for both the weld and intermediate shell forging is deemed non-credible, then per the NRC guidelines in their February 12, 1998 Industry Meeting a conservatism check of the Table Chemistry Factor must be performed. [*"Generic Letter 92-01 and RPV Integrity Assessment Status, Schedule and Issues", Attachment 12 of the NRC presentation from the February 12, 1998 meeting, more specifically Case 3.*] This conservatism check follows the NRC guidelines and is presented in Table D-3. Note, only the intermediate shell forging will be checked for conservatism since that is the limiting vessel material.

TABLE D-3
Conservatism Check of the Table Chemistry Factor For Base Metal Only

Capsule	Chemistry Factor	Fluence Factor (FF)	Measured ΔRT_{NDT}	Predicted ΔRT_{NDT}	Measured - Predicted ΔRT_{NDT}
Intermediate Shell Forging 05					
T (Tang.)	95°F	0.635	63.7	60.3°F	3.4
U (Tang.)	95°F	0.897	79.3	85.2°F	-5.9
X (Tang.)	95°F	1.055	85.7	100.2°F	-14.5
Y (Tang.)	95°F	1.207	134.1	114.7°F	20.8
T (Axial.)	95°F	0.635	48.73	60.3°F	-11.57
U (Axial.)	95°F	0.897	66.06	85.2°F	-19.14
X (Axial.)	95°F	1.055	110.04	100.2°F	9.84
Y (Axial.)	95°F	1.207	89.21	114.7°F	-25.49

Since none of the points (Measured - Predicted ΔRT_{NDT}) fall outside the 2σ scatter band of 34°F for base metals, then the Table Chemistry Factor is considered conservative and should be used when calculating ART and RT_{PTS} values.

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

The capsule specimens are located in the reactor between the thermal shield and the vessel wall and are positioned opposite the center of the core. The test capsules are in baskets attached to the thermal shield. The location of the specimens with respect to the reactor vessel beltline provides assurance that the reactor vessel wall and the specimens experience equivalent operating conditions such that the temperatures will not differ by more than 25°F. Hence, this criteria is met.

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

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

CONCLUSION:

Based on the preceding responses to all five criteria of Regulatory Guide 1.99, Revision 2, Section B and 10 CFR 50.61, the Sequoyah Unit 2 surveillance weld data and the intermediate shell forging 05 surveillance data do not meet the nominal credibility requirements of Regulatory Guide 1.99, Revision 2..