WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-14779

ANALYSIS OF CAPSULE S FROM THE NORTHERN STATES POWER COMPANY PRAIRIE ISLAND UNIT 1 REACTOR VESSEL RADIATION SURVEILLANCE PROGRAM

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PREFACE

This report has been technically reviewed and verified.

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Sections 1 through 5, 7, 8 Appendices A, B, and C	P. A. Grendys P. A. Grendys
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1.0 SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance Capsule S, the fourth capsule to be removed from the Northern States Power Company Prairie Island Unit 1 reactor pressure vessel, led to the following conclusions:

- The capsule received an average fast neutron fluence (E > 1.0 MeV) of 4.017 x 10^{19} n/cm^2 after 18.12 Effective Full Power Years (EFPY) of plant operation.

- Irradiation of the reactor vessel Intermediate Shell Forging C Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major rolling direction (tangential orientation), to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 101.46°F and a 50 ft-lb transition temperature increase of 105.15°F. This results in an irradiated 30 ft-lb transition temperature of 62.55°F and an irradiated 50 ft-lb transition temperature of 98.80°F for the tangentially-oriented specimens.

- Irradiation of the reactor vessel Intermediate Shell Forging C Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major rolling direction (axial orientation), to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 74.27°F and a 50 ft-lb transition temperature increase of 76.68°F. This results in an irradiated 30 ft-lb transition temperature of 42.95°F and an irradiated 50 ft-lb transition temperature of 80.63°F for the axially-oriented specimens.

- Irradiation of the weld metal Charpy specimens to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 160.43°F and a 50 ft-lb transition temperature increase of 170.84°F. This results in an irradiated 30 ft-lb transition temperature of 95.98°F and an irradiated 50 ft-lb transition temperature of 143.91°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 137.11°F and a 50 ft-lb transition temperature increase of 98.20°F. This results in an irradiated 30 ft-lb transition temperature of -62.89°F and an irradiated 50 ft-lb transition temperature of -26.80°F.

- Irradiation of the correlation monitor material Charpy specimens to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 166.08°F and a 50 ft-lb transition temperature increase of 159.58°F. This results in an irradiated 30 ft-lb transition temperature of 212.29°F and an irradiated 50 ft-lb transition temperature of 237.98°F.

- The average upper shelf energy of Intermediate Shell Forging C (tangential orientation) resulted in an energy decrease of 15.5 ft-lb after irradiation to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 142.5 ft-lb for the tangentially-oriented specimens.

- The average upper shelf energy of Intermediate Shell Forging C (axial orientation) resulted in an energy decrease of 8 ft-lb after irradiation to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 135 ft-lb for the axially-oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted in an energy increase of 6 ft-lb after irradiation to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated upper shelf energy of 84.5 ft-lb for the weld metal specimens.

- The average upper shelf energy of the weld HAZ metal decreased 75 ft-lb after irradiation to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated upper shelf energy of 136 ft-lb for the weld HAZ metal.

- The average upper shelf energy of the correlation monitor material decreased 41 ft-lb after irradiation to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated upper shelf energy of 82.5 ft-lb for the correlation monitor material.

- The surveillance Capsule S test results indicate that all 30 ft-lb transition temperature shifts are greater than the Regulatory Guide 1.99, Revision 2[1], predictions. However, the shift values are less than the two-sigma allowance required by Regulatory Guide 1.99, Revision 2 for all of the materials except intermediate shell forging C (tangential orientation) and the weld metal.

- The surveillance Capsule S test results indicate that all average upper shelf energy decreases of the surveillance materials are less than the Regulatory Guide 1.99, Revision 2, with exception of the correlation monitor material.

- The surveillance capsule 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 (35 EFPY) as required by 10 CFR Part 50, Appendix G[2].

- The calculated 35 EFPY maximum neutron fluence (E > 1.0 MeV) for the Prairie Island Unit 1 reactor vessel is as follows:

  Vessel inner radius* = 3.07×10^{19} n/cm^2
  Vessel 1/4 thickness = 1.96×10^{19} n/cm^2
  Vessel 3/4 thickness = 6.02×10^{18} n/cm^2
  * Clad/base metal interface

2.0 INTRODUCTION

This report presents the results of the examination of Capsule S, the fourth capsule to be removed from the reactor in the continuing surveillance program which monitors the effects of neutron irradiation on the Northern States Power Company Prairie Island Unit 1 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the Northern States Power Company Prairie Island Unit 1 reactor pressure vessel materials was designed and recommended by the Westinghouse Electric Corporation. A description of the surveillance program and the pre-irradiation mechanical properties of the reactor vessel materials is presented in WCAP-8086 entitled "Northern States Power Co. Prairie Island Unit No. 1 Reactor Vessel Radiation Surveillance Program"[3]. The surveillance program was planned to cover the 40-year design life of the reactor pressure vessel and was based on ASTM E185-70, "Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels". Westinghouse personnel were contracted to aid in the preparation of procedures for removing Capsule S from the reactor and its shipment to the Westinghouse Science and Technology Center Hot Cell Facility, where the post-irradiation mechanical testing of the Charpy V-notch impact and tensile surveillance specimens was performed.

This report summarizes the testing of and the post-irradiation data obtained from surveillance Capsule S removed from the Northern States Power Company Prairie Island Unit 1 reactor vessel and discusses the analysis of the data.

3.0 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 A508 Class 3 (base material of the Prairie Island Unit 1 reactor pressure vessel) 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 performing analyses to guard against fast fracture in reactor pressure vessels has been presented in Appendix G to Section XI of the ASME Boiler and Pressure Vessel Code[4]. The method uses fracture mechanics concepts and is based on the reference nil-ductility temperature (RT_{NDT}).

RT_{NDT} is defined as the greater of either the drop weight nil-ductility transition temperature (NDTT per ASTM E208[5]) or the temperature 60°F less than the 50 ft-lb (and 35-mil lateral expansion) temperature as determined from Charpy specimens oriented normal (tangential) to the major working direction of the forging. The RT_{NDT} of a given material is used to index that material to a reference stress intensity factor curve (K_{Ia} curve) which appears in Appendix G to the ASME Code. 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 radiation embrittlement changes in mechanical properties of a given reactor pressure vessel steel can be monitored by a reactor surveillance program, such as the Prairie Island Unit 1 Reactor Vessel Radiation Surveillance Program[3], in which a surveillance capsule is periodically removed from the operating nuclear reactor and the encapsulated specimens tested. The increase in the average Charpy V-notch 30 ft-lb temperature (ΔRT_{NDT}) due to irradiation is added to the initial RT_{NDT} to adjust the RT_{NDT} for radiation embrittlement. This adjusted reference temperature (ART = initial RT_{NDT} +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 which take into account the effects of irradiation on the reactor vessel materials.

4.0 DESCRIPTION OF PROGRAM

Six surveillance capsules for monitoring the effects of neutron exposure on the Prairie Island Unit 1 reactor pressure vessel core region materials were inserted in the reactor vessel prior to initial plant start-up. The six capsules were positioned in the reactor vessel between the thermal shield and the vessel wall as shown in Figure 4-1. The test capsules are in baskets attached to the thermal shield. The vertical center of the capsules is opposite the vertical center of the core.

Capsule S was removed after 18.12 Effective Full Power Years (EFPY) of plant operation. The capsule contained Charpy V-notch impact specimens made from Intermediate Shell Forging C and weld metal which joined sections of material from the intermediate and lower shell rings, heat-affected-zone, and ASTM correlation monitor material. Additionally, tensile and Wedge Opening Loading (WOL) specimens were included in the capsule (Figure 4-2).

Test material obtained from the Intermediate Shell Forging (heat-treated with the shell) was taken at least one forging thickness (6.692 inches) from the quenched edges of the forging. All test specimens were machined from the 1/4-thickness location of the forging after performing a simulated postweld, stress-relieving treatment. Specimens were machined from weld metal and the heat-affected-zone (HAZ) metal of a stress-relieved weldment joining sections of the intermediate and lower shell forgings. All heat-affected-zone specimens were obtained from the weld heat-affected-zone of Intermediate Shell Forging C. The A533 Grade B Class 1 material (HSST Plate 02) for the correlation monitor plate specimens was supplied by the Oak Ridge National Laboratory from a 12-inch-thick plate.

Charpy V-notch impact specimens from Intermediate Shell Forging C were machined in both the axial orientation (longitudinal axis of specimen normal to major working direction) and tangential orientation (longitudinal axis of specimen parallel to major working direction). The core region weld Charpy impact specimens were machined from the weldment such that the long dimension of the Charpy was normal to the weld direction; the notch was machined such that the direction of crack propagation in the specimen was in the weld direction.

Tensile specimens were machined with the longitudinal axis of the specimen in the major working direction (tangential) and also normal to the major working direction (axial) of the shell ring forging.

WOL test specimens were machined in a tangential direction so that the loading of the specimen would be in the major working direction of the forging with the simulated crack propagating in the axal direction. In addition, axial specimens were machined so that the loading of the specimens would be in the axial direction of the forging with the simulated crack propagating in the major working direction. All specimens were fatigue pre-cracked per ASTM E399-70T.

The heat treatment of the beltline region materials is presented in Table 4-1. The results of the chemical analyses on the unirradiated beltline region materials are presented in Table 4-2, which were obtained from the surveillance program report[3]. Additionally, a chemical analysis using Inductively Coupled Plasma Spectrometry (ICPS) was performed on four irradiated Charpy specimens, three weld metal and one base metal, and is reported in Table 4-3. The chemistry results from the NBS certified reference standards are reported in Table 4-4. The results were obtained from the Westinghouse Electric Corporation Nuclear Services Division CMT Analytical Laboratory[7]. Table 4-5 provides the calculations of the average Cu and Ni weight percent values of the reactor vessel beltline materials, which were used in the Prairie Island Unit 1 surveillance Capsule S calculations.

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

Thermal monitors made of two low-melting eutectic alloys and sealed in Pyrex tubes were included in the capsule. These thermal monitors were used to define the maximum temperature attained by the test specimens during irradiation. The composition of the two 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 S is shown in Figure 4-2.

TABLE 4-1

Heat Treatment of the Prairie Island Unit 1 Reactor Vessel Surveillance Materials[3]

Material	Temperature (°F)	Time (hours)	Coolant
Intermediate Shell Forging C	Heated to 1652/1715	5	Water-quenched
	Tempered at 1175/1238	5	Furnace-cooled
	Heated to 1652/1724	5 1/2	Water-quenched
	Tempered at 1202/1238	5	Furnace-cooled
	Stress Relieved at 1022	8	Furnace-cooled
	Stress Relieved at 1112	14	Furnace-cooled
Weldment	Stress Relieved at 1022	5	Furnace-cooled
	Stress Relieved at 1112	7	Furnace-cooled
Correlation Monitor Material	1675 ± 25	4	Air-cooled
	1600 ± 25	4	Water-quenched
	1125 ± 25	4	Furnace-cooled
	1150 ± 25	40	Furnace-cooled to 600°F

TABLE 4-2

Chemical Composition (wt%) of the Unirradiated Prairie Island Unit 1 Reactor Vessel Surveillance Materials[3]

Element	Intermediate Shell Forging C	Weld Metal	Correlation Monitor Material	
			Ladle	Check
C	0.17	0.052	0.22	0.22
Mn	1.41	1.30	1.45	1.48
P	0.013	0.017	0.011	0.012
S	0.005	0.014	0.019	0.018
Si	0.28	0.36	0.22	0.25
Mo	0.48	0.51	0.53	0.52
Ni	0.72	--	0.62	0.68
Cr	0.17	0.015	--	--
V	<0.002	0.001	--	--
Cu	0.06	0.13	--	0.14
Co	0.010	0.001[a]	--	--
Al	0.033	0.015	--	--
N_2	0.006	0.014	--	--
Sn	0.007	0.007	--	--
Zn	0.001	0.001[a]	--	--
Ti	0.001[a]	0.001	--	--
Zr	0.001	0.001	--	--
As	0.011	0.061	--	--
Sb	0.001	0.001	--	--
B	0.003[a]	0.003[a]	--	--

NOTES:

(a) Not detected. The number indicates the minimum limit of detection.

TABLE 4-3

Chemical Composition of the Prairie Island Unit 1 Charpy Specimens Removed from Surveillance Capsule S

Element	Base Metal	Weld Metal		
	S-25	W-18	W-22	W-23
Al	0.03	<0.02	<0.02	<0.02
As	0.03	0.14	0.13	0.12
B	<0.004	<0.004	<0.004	<0.004
Co	0.014	0.022	0.021	0.019
Cr	0.217	0.024	0.018	0.014
Cu	0.078	0.149	0.138	0.143
Mn	1.97	1.67	1.60	1.42
Mo	0.71	0.67	0.64	0.58
Ni	0.956	0.138	0.118	0.091
P	0.018	0.025	0.024	0.022
Si	0.350	0.334	0.325	0.338
Sn	<0.01	<0.01	<0.01	<0.01
Ti	0.005	<0.002	<0.002	0.017
V	<0.004	<0.004	<0.004	<0.004
Zr	<0.01	<0.01	<0.01	<0.01
Carbon	0.182	0.067	0.072	0.060
Sulfur	0.012	0.015	0.016	0.016

TABLE 4-4

Chemistry Results from the Low Alloy Steel NBS Certified Reference Standards

Element	Concentration in Weight Percent			
	NBS-362		NBS-121d	
	Measured	Certified	Measured	Certified
Al	0.06	0.09	--	--
As	0.10	0.09	--	--
B	--	0.003	--	--
Co	0.32	0.30	--	--
Cr	0.29	0.30	--	--
Cu	0.50	0.50	--	--
Mn	1.17	1.04	--	--
Mo	0.069	0.068	--	--
Ni	0.62	0.59	--	--
P	0.03	0.04	--	--
Si	0.410	0.39	--	--
Sn	0.017	0.016	--	--
Ti	0.030	0.08	--	--
V	0.042	0.040	--	--
Zr	0.22	0.19	--	--
	NBS-362		NBS-121d	
C	0.161	0.160	--	--
S	--	--	0.013	0.013

TABLE 4-5

Calculation of Average Cu and Ni Weight Percent Values for Beltline Materials

Ref.	Intermediate Shell Forging C[a]		Lower Shell Forging D		Inter. to Lower Shell Circumferential Weld[a, b]		A533 Gr. B, CL1 Correlation Monitor Material (HSST Plate 02)	
	Cu %	Ni %	Cu %	Ni %	Cu %	Ni %	Cu %	Ni %
8	0.06	0.72						
8	0.06	0.72						
9			0.07	0.66				
9			0.065	0.66				
3					0.13	--	0.14	0.68
6					0.13	0.09		
7	0.078	0.956			0.149	0.138		
7					0.138	0.118		
7					0.143	0.091		
Avg.	0.07	0.80	0.07	0.66	0.14	0.11	0.14	0.68

NOTES:

(a) Surveillance program material

(b) The surveillance weld specimens were made of the same wire and flux as the intermediate to lower shell circular seam (Wire UM 89, Heat Number 1752, UM 89 Flux, Batch Number 1230).

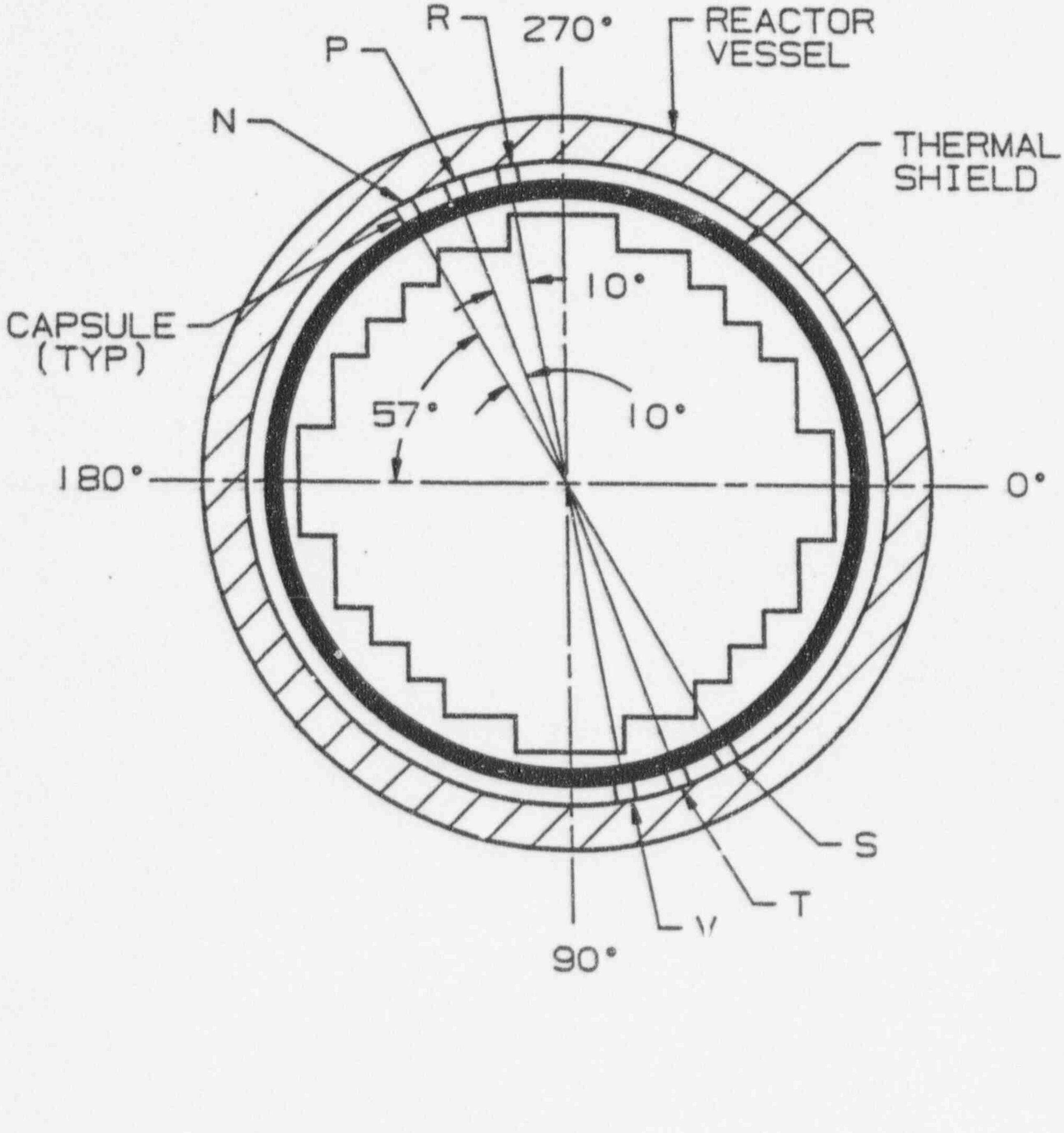


Figure 4-1 Arrangement of Surveillance Capsules in the Prairie Island Unit 1 Reactor Vessel

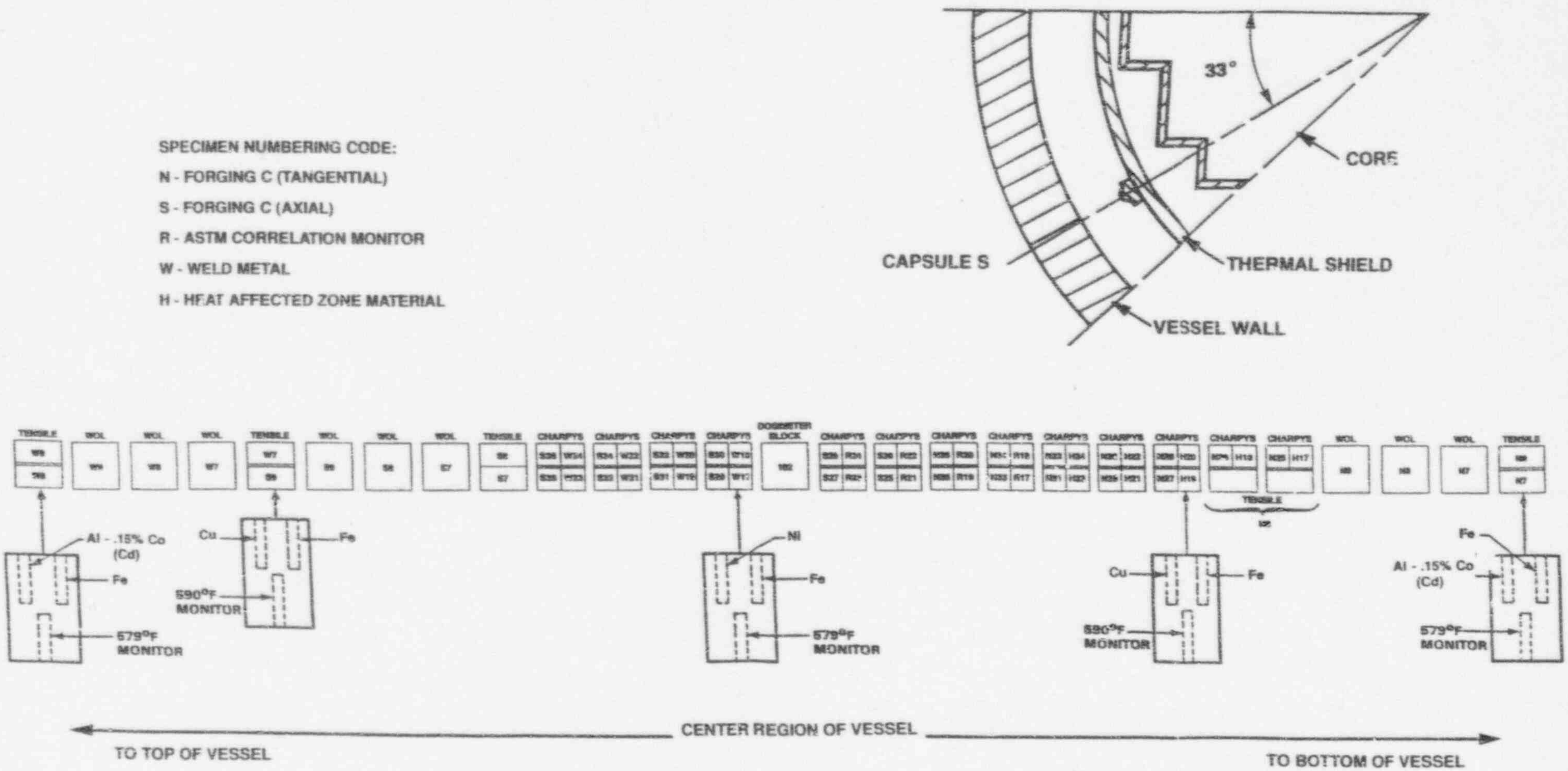


Figure 4-2 Capsule S Diagram Showing the Location of Specimens, Thermal Monitors and Dosimeters

5.0 TESTING OF SPECIMENS FROM CAPSULE S

5.1 Overview

The post-irradiation mechanical testing of the Charpy V-notch and tensile specimens was performed at the Remote Metallographic Facility (RMF) at the Westinghouse Science and Technology Center (STC). Testing was performed in accordance with 10 CFR Part 50, Appendix 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-8086[3]. No discrepancies were found.

Thermal monitors made from two low-melting point eutectic alloys sealed in Pyrex tubes were included in the capsule. 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 specimens were exposed was less than 579°F (304°C).

The Charpy impact tests were performed per ASTM Specification E23-93a[12] and RMF Procedure 8103, Revision 1, on a Tinius-Olsen Model 74, 358J machine. The tup (striker) of the Charpy machine is instrumented with a GRC 830-I instrumentation system, feeding into an IBM compatible 486 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}), time to general yielding (t_{GY}), maximum load (P_M), and 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:

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

where ***L*** is the distance between the specimen supports in the impact testing machine; ***B*** is the width of the specimen measured parallel to the notch; ***W*** is the height of the specimen, measured perpendicularly to the notch; and ***a*** is the 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 a Charpy specimen in which ϕ = 45° and ρ = 0.010 inches, Equation 1 is valid with C = 1.21. Therefore (for L = 4W),

$$\sigma_Y = P_{GY} \frac{L}{B(W-a)^2 1.21} = \frac{3.33 P_{GY} W}{B(W-a)^2} \tag{2}$$

For the Charpy specimens, ***B*** is 0.394 in., ***W*** is 0.394 in., and ***a*** is 0.079 in. 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 lb. The flow stress was calculated from the average of the yield and maximum loads, also using the three-point bend formula.

Symbol A is columns 4, 5, and 6 of Tables 5-6 through 5-10 is the cross-sectional area under the notch of the Charpy specimens:

$$A = B*(W-a) = 0.1241 \quad \text{square inches} \tag{4}$$

Percent shear was determined from post-fracture photographs using the ratio-of-areas methods in compliance with ASTM Specification A370-92[13]. The lateral expansion was measured using a dial gage rig similar to that shown in the same specification.

Tension tests were performed on a 20,000-pound Instron Model 1115, split-console test machine, per ASTM Specification E8-93[14] and E21-92[15], and RMF Procedure 8102, Revision 1. The upper pull rod of the test machine 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 (LVDT) extensometer. The extensometer knife edges were spring-loaded to the specimen and operated through specimen failure. The extensometer gage length is 1.00 inch. The extensometer is rated as Class B-2 per ASTM E83-93[16].

Elevated test temperatures were obtained with a three-zone electric resistance split-tube furnace with a nine-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 temperature. Chromel-Alumel thermocouples were inserted in shallow holes in the center, each end of the gage section of a dummy specimen, and in each grip. In the test configuration, with a slight load on the specimen, a plot of specimen temperature versus upper and lower grip and controller temperatures was developed over the range of room temperature to 550°F (288°C). The upper grip was used to control the furnace temperature. During the actual testing, the grip temperatures were used to obtain desired specimen temperatures. Experiments indicate that this method is accurate to ±2°F.

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

5.2 Charpy V-Notch Impact Test Results

The results of the Charpy V-notch impact tests performed on the various materials contained in Capsule S, which was irradiated to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV), are presented in Tables 5-1 through 5-10. The unirradiated and Capsule S results, as well as the results from previously tested capsules, are presented in Figures 5-1 through 5-15. These figures were generated using the hyperbolic tangent curve-fitting program CVGRAPH, Version 4.1. The transition temperature increases and upper shelf energy decreases for the Capsule S materials are summarized in Table 5-11.

Irradiation of the reactor vessel intermediate Shell Forging C Charpy specimens oriented with the longitudinal axis of the specimen parallel to the major rolling direction of the forging (tangential orientation) to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV) (Figure 5-1) resulted in a 30 ft-lb transition temperature increase of 101.46°F and a 50 ft-lb transition temperature increase of 105.15°F. This resulted in an irradiated 30 ft-lb transition temperature of 62.55°F and an irradiated 50 ft-lb transition temperature of 98.80°F (tangential orientation).

The average upper shelf energy (USE) of the Intermediate Shell Forging C Charpy specimens (tangential orientation) resulted in a energy decrease of 15.5 ft-lb after irradiation to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average USE of 142.5 ft-lb (Figure 5-1).

Irradiation of the reactor vessel Intermediate Shell Forging C Charpy specimens oriented with the longitudinal axis of the specimen perpendicular to the major rolling direction of the forging (axial orientation) to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV) (Figure 5-4) resulted in a 30 ft-lb transition temperature increase of 74.27°F and a 50 ft-lb transition temperature increase of 76.68°F. This resulted in an irradiated 30 ft-lb transition temperature of 42.95°F and an irradiated 50 ft-lb transition temperature of 80.63°F (axial orientation).

The average upper shelf energy (USE) of the Intemediate Shell Forging C Charpy specimens (axial orientation) resulted in a energy decrease of 8 ft-lb after irradiation to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV). This results in an irradiated average USE of 135 ft-lb (Figure 5-4).

Irradiation of the surveillance weld metal Charpy specimens to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV) (Figure 5-7) resulted in a 30 ft-lb transition temperature shift of 160.43°F and a 50 ft-lb transition temperature increase of 170.84°F. This results in an irradiated 30 ft-lb transition temperature of 95.98°F and an irradiated 50 ft-lb transition temperature of 143.91°F.

The average upper shelf energy (USE) of the surveillance weld metal resulted in an energy increase of 6 ft-lb after irradiation to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV). This resulted in an irradiated average USE of 84.5 ft-lb (Figure 5-7).

Irradiation of the reactor vessel weld HAZ metal Charpy specimens to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV) (Figure 5-10) resulted in a 30 ft-lb transition temperature increase of 127.11°F and a 50 ft-lb transition temperature increase of 98.20°F. This resulted in an irradiated 30 ft-lb transition temperature of -62.89°F and an irradiated 50 ft-lb transition temperature of -26.80°F.

The average upper shelf energy (USE) of the weld HAZ metal resulted in an energy decrease of 75 ft-lb after irradiation to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV). This resulted in an irradiated average USE of 136 ft-lb (Figure 5-10).

Irradiation of the reactor vessel correlation monitor material Charpy specimens to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV) (Figure 5-13) resulted in a 30 ft-lb transition temperature increase of 166.08°F and a 50 ft-lb transition temperature increase of 159.58°F. This resulted in an irradiated 30 ft-lb transition temperature of 212.29°F and an irradiated 50 ft-lb transition temperature of 237.98°F.

The average upper shelf energy (USE) of the correlation monitor material resulted in an energy decrease of 41 ft-lb after irradiation to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV). This resulted in an irradiated average USE of 82.5 ft-lb (Figure 5-13).

The fracture appearance of each irradiated Charpy specimen from the various materials is shown in Figures 5-16 through 5-20 and show an increasingly ductile or tougher appearance with increasing test temperature.

A comparison of the measured 30 ft-lb transition temperature increases and upper shelf energy decreases for the various Prairie Island Unit 1 surveillance materials with predicted values using the methods of NRC Regulatory Guide 1.99, Revision 2[1], is presented in Table 5-12 and led to the following conclusions:

- The surveillance Capsule S test results indicate that all 30 ft-lb transition temperature shifts are greater than the Regulatory Guide 1.99, Revision 2, predictions. However, the shift values are less than the two-sigma allowance required by Regulatory Guide 1.99, Revision 2 for all of the materials except intermediate shell forging C (tangential orientation) and the weld metal.

- The surveillance Capsule S test results indicate that all average upper shelf energy decreases of the surveillance materials are less than the Regulatory Guide 1.99, Revision 2, predictions with exception of the correlation monitor material.

The Charpy V-notch property changes presented in WCAP-8086, WCAP-8916, WCAP-10102, and WCAP-11006 are based on hand-fit Charpy curves using engineering judgement. However, the results presented in this report are based on a re-plot of the capsule data using CVGRAPH, Version 4.1, a hyperbolic tangent curve-fitting program. Hence, Appendix B contains a comparison of the Charpy V-notch shift results for each surveillance material, hand-fit versus hyperbolic tangent curve-fitting. Additionally, Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and program input data.

The load-time records for the Capsule S individual instrumented Charpy specimen tests are presented in Appendix A.

5.3 Tensile Test Results

The results of the tensile tests performed on the various materials contained in Capsule S, irradiated to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV), are presented in Table 5-13 and are compared with unirradiated results as shown in Figures 5-21 through 5-23.

The results of the tensile tests performed on the Intermediate Shell Forging C (tangential orientation) indicated that irradiation to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV) caused a 12 to 14 ksi increase in the 0.2 percent offset yield strength and a 9 to 10 ksi increase in the ultimate tensile strength when compared to unirradiated data (Figure 5-21).

The results of the tensile tests performed on the Intermediate Shell Forging C (axial orientation) indicated that irradiation to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV) caused a 10 to 14 ksi increase in the 0.2 percent offset yield strength and a 8 to 12 ksi increase in the ultimate tensile strength when compared to unirradiated data (Figure 5-22).

The results of the tensile tests performed on the surveillance weld metal indicated that irradiation to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV) caused a 9 to 16 ksi increase in the 0.2 percent offset yield strength and a 5 to 10 ksi increase in the ultimate tensile strength when compared to unirradiated data (Figure 5-23).

The fractured tensile specimens for the Intermediate Shell Forging C material are shown in Figures 5-24 and 5-25, while the fractured specimens for the surveillance weld metal are shown in Figure 5-26. The engineering stress-strain curves for the tensile tests are shown in Figures 5-27 through 5-32.

5.4 Wedge Opening Loading (WOL) Specimens

Per the surveillance capsule testing contract with the Northern States Power Company, WOL specimens will not be tested. The specimens will be stored at the Westinghouse Science and Technology Center Hot Cell.

TABLE 5-1

Charpy V-notch Data for the Prairie Island Unit 1 Intermediate Shell Forging C Irradiated to a Fluence of 4.017×10^{19} n/cm^2 (E > 1.0 MeV) (Tangential Orientation)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	(°F)	(°C)	(ft-lb)	(J)	(mils)	(mm)	(%)
N27	-25	-32	9	12	4	0.10	5
N28	25	-4	10	14	10	0.25	5
N32	26	-3	33	45	26	0.66	10
N25	72	22	35	47	29	0.74	10
N31	100	38	51	69	37	0.94	15
N29	125	52	68	92	51	1.30	30
N35	150	66	74	100	54	1.37	35
N34	175	79	106	144	77	1.96	60
N26	250	121	136	184	93	2.36	100
N36	300	149	150	203	80	2.03	100
N30	350	177	151	205	90	2.29	100
N33	400	204	133	180	94	2.39	100

TABLE 5-2

Charpy V-notch Data for the Prairie Island Unit 1 Intermediate Shell Forging C
Irradiated to a Fluence of 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV)
(Axial Orientation)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	(°F)	(°C)	(ft-lb)	(J)	(mils)	(mm)	(%)
S25	-25	-32	7	9	2	0.05	0
S34	25	-4	22	30	14	0.36	5
S29	50	10	19	26	14	0.36	10
S28	60	16	49	66	36	0.91	20
S30	72	22	63	85	45	1.14	25
S27	100	38	59	80	46	1.17	30
S33	125	52	69	94	50	1.27	40
S36	175	79	97	132	66	1.68	65
S26	225	107	135	183	90	2.29	100
S31*	250	121	---	---	---	---	---
S35	250	121	138	187	85	2.16	100
S32	300	149	132	179	70	1.78	100

NOTE:

* Specimen alignment error. Data is not valid.

TABLE 5-3

Charpy V-notch Data for the Prairie Island Unit 1 Surveillance Weld Medal Irradiated to a Fluence of 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	(°F)	(°C)	(ft-lb)	(J)	(mils)	(mm)	(%)
W23	-25	-32	8	11	3	0.08	10
W18	25	-4	17	23	12	0.30	10
W22	72	22	24	33	16	0.41	40
W21	100	38	28	38	24	0.61	60
W19	150	66	45	61	37	0.94	80
W24	175	79	67	91	53	1.35	90
W17	225	107	77	104	64	1.63	100
W20	300	149	92	125	71	1.80	100

TABLE 5-4							
Charpy V-notch Data for the Prairie Island Unit 1 Heat-Affected-Zone (HAZ) Metal Irradiated to a Fluence of 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV)							
Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	(°F)	(°C)	(ft-lb)	(J)	(mils)	(mm)	(%)
H17*	-100	-73	---	---	---	---	---
H21	-100	-73	20	27	8	0.20	10
H24	-50	-46	32	43	16	0.41	25
H22	0	-18	82	111	50	1.27	30
H20	50	10	58	79	40	1.02	50
H23	72	22	143	194	71	1.80	60
H19	175	79	149	202	74	1.88	100
H18	300	149	123	167	82	2.08	100

* Specimen alignment error. Data is not valid.

TABLE 5-5

Charpy V-notch Data for the Prairie Island Unit 1 Correlation Monitor Material Irradiated to a Fluence of 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV)

Sample Number	Temperature (°F)	Temperature (°C)	Impact Energy (ft-lb)	Impact Energy (J)	Lateral Expansion (mils)	Lateral Expansion (mm)	Shear (%)
R17	150	66	9	12	9	0.23	15
R22	200	93	21	28	14	0.36	20
R24	206	97	19	26	13	0.33	15
R18	225	107	47	64	29	0.74	30
R21	250	121	57	77	41	1.04	55
R23	300	149	76	103	57	1.45	80
R19	350	177	78	106	64	1.63	95
R20	400	204	87	118	54	1.37	100

TABLE 5-6
Instrumented Charpy Impact Test Results for the Prairie Island Unit 1 Intermediate Shell Forging C
Irradiated to a Fluence of 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV)
(Tangential Orientation)

Sample Number	Test Temp (°F)	Charpy Energy (ft-lb)	Normalized Energies ft-lb/in^2 Charpy E_d/A	Max. E_m/A	Prop. E_p/A	Yield Load (lb)	Time to Yield (msec)	Max. Load (lb)	Time to Max. (msec)	Fracture Load (lb)	Arrest Load (lb)	Yield Stress (ksi)	Flow Stress (ksi)
N27	-25	9	72	48	24	3724	0.14	3881	0.17	3881	0	124	126
N28	25	10	81	60	20	3520	0.15	3737	0.2	3723	77	117	121
N32	26	33	266	219	47	3361	0.16	4427	0.51	4427	0	112	129
N25	72	35	282	231	51	3607	0.15	4640	0.51	4640	0	120	137
N31	100	51	411	309	101	3426	0.15	4482	0.67	4413	505	114	131
N29	125	68	548	299	249	3254	0.14	4328	0.67	4175	1172	108	126
N35	150	74	596	300	296	3251	0.14	4336	0.67	4182	1732	108	126
N34	175	106	854	383	470	3198	0.14	4323	0.84	3222	1899	106	125
N26	250	136	1095	371	724	3209	0.17	4252	0.83	N/A	N/A	107	124
N36	300	150	1208	374	834	3118	0.16	4233	0.83	N/A	N/A	104	122
N30	350	151	1216	279	936	2933	0.14	4096	0.67	N/A	N/A	97	117
N33	400	133	1071	267	804	2556	0.14	3902	0.67	N/A	N/A	85	107

TABLE 5-7
Instrumented Charpy Impact Test Results for the Prairie Island Unit 1 Intermediate Shell Forging C
Irradiated to a Fluence of 4.017×10^{19} n/cm^2 (E > 1.0 MeV)
(Axial Orientation)

Sample Number	Test Temp (°F)	Charpy Energy (ft-lb)	Normalized Energies ft-lb/in² Charpy E_d/A	Max. E_m/A	Prop. E_p/A	Yield Load (lb)	Time to Yield (msec)	Max. Load (lb)	Time to Max. (msec)	Fracture Load (lb)	Arrest Load (lb)	Yield Stress (ksi)	Flow Stress (ksi)
S25	-25	7	56	29	27	3590	0.13	3590	0.13	3590	0	119	119
S34	25	22	177	145	32	3608	0.14	4225	0.36	4225	0	120	130
S29	50	19	153	97	56	3458	0.14	3857	0.28	3857	175	115	121
S28	60	49	395	316	78	3538	0.15	4552	0.67	4510	0	118	134
S30	72	63	507	308	200	3431	0.14	4467	0.67	4324	101	114	131
S27	100	59	475	304	171	3363	0.15	4385	0.67	4336	931	112	129
S33	125	69	556	297	258	3346	0.15	4367	0.67	4179	1045	111	128
S36	175	97	781	291	490	3211	0.14	4256	0.67	3622	2111	107	124
S26	225	135	1087	375	712	3179	0.16	4214	0.84	N/A	N/A	106	123
S31*	250	---	---	---	---	---	---	---	---	---	---	---	---
S35	250	138	1111	377	734	3227	0.19	4320	0.83	N/A	N/A	107	125
S32	300	132	1063	287	775	3046	0.14	4217	0.67	N/A	N/A	101	121

* Specimen Alignment Error. Data is not valid.

TABLE 5-8

Instrumented Charpy Impact Test Results for the Prairie Island Unit 1 Weld Metal Irradiated to a Fluence of 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV)

Sample Number	Test Temp (°F)	Charpy Energy (ft-lb)	Normalized Energies ft-lb/in^2 Charpy E_d/A	Max. E_m/A	Prop. E_p/A	Yield Load (lb)	Time to Yield (msec)	Max. Load (lb)	Time to Max. (msec)	Fracture Load (lb)	Arrest Load (lb)	Yield Stress (ksi)	Flow Stress (ksi)
W23	-25	8	164	26	39	3273	0.13	3273	0.13	3273	561	109	109
W18	25	17	137	102	35	3719	0.16	3956	0.28	3956	300	124	127
W22	72	24	193	129	64	3329	0.15	4058	0.34	4058	1322	111	123
W21	100	28	225	138	87	3470	0.14	3964	0.36	3964	1949	115	123
W19	150	45	362	235	127	3185	0.2	3926	0.61	3926	2436	106	118
W24	175	67	540	280	259	3231	0.14	4029	0.66	3576	2497	107	121
W17	225	77	620	271	349	2998	0.13	4001	0.64	N/A	N/A	100	116
W20	300	92	741	275	465	3072	0.14	3981	0.66	N/A	N/A	102	117

TABLE 5-9
Instrumented Charpy Impact Test Results for the Prairie Island Unit 1 Heat-Affected Zone (HAZ) Metal Irradiated to a Fluence of 4.017×10^{19} n/cm^2 (E > 1.0 MeV)

Sample Number	Test Temp (°F)	Charpy Energy (ft-lb)	Normalized Energies ft-lb/in^2 Charpy E_d/A	Max. E_m/A	Prop. E_p/A	Yield Load (lb)	Time to Yield (msec)	Max. Load (lb)	Time to Max. (msec)	Fracture Load (lb)	Arrest Load (lb)	Yield Stress (ksi)	Flow Stress (ksi)
H17*	-100	---	---	---	---	---	---	---	---	---	---	---	---
H21	-100	20	161	136	25	4522	0.19	4780	0.31	4780	0	150	154
H24	-50	32	258	159	99	4170	0.16	4640	0.36	4612	1321	139	146
H22	0	82	660	334	326	3870	0.16	4808	0.67	4366	0	129	144
H20	50	58	467	89	378	3911	0.19	3998	0.27	1405	269	130	131
H23	72	143	1151	437	714	3748	0.16	4970	0.84	2823	1344	124	145
H19	175	149	1200	409	791	3523	0.14	4599	0.84	N/A	N/A	117	135
H18	300	123	990	297	693	3269	0.14	4419	0.67	N/A	N/A	109	128

* Specimen Alignment Error. Data is not valid.

TABLE 5-10

Instrumented Charpy Impact Test Results for the Prairie Island Unit 1 Correlation Monitor Material Irradiated to a Fluence of 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV)

Sample Number	Test Temp (°F)	Charpy Energy (ft-lb)	Normalized Energies (ft-lb/in²) Charpy E_d/A	Max. E_m/A	Prop. E_p/A	Yield Load (lb)	Time to Yield (msec)	Max. Load (lb)	Time to Max. (msec)	Fracture Load (lb)	Arrest Load (lb)	Yield Stress (ksi)	Flow Stress (ksi)
R17	150	9	72	40	32	3795	0.16	3795	0.16	3795	74	126	126
R22	200	21	169	119	50	3527	0.15	4087	0.32	4087	759	117	126
R24	206	19	153	104	49	3527	0.14	3992	0.29	3992	545	117	125
R18	225	47	378	243	135	3623	0.14	4734	0.51	4633	1700	120	139
R21	250	57	459	293	166	3449	0.14	4518	0.63	4498	2494	115	132
R23	300	76	612	295	317	3322	0.14	4300	0.65	3721	2495	110	127
R19	350	78	628	305	323	3379	0.14	4419	0.65	3253	2479	112	130
R20	400	87	701	306	395	3466	0.15	4474	0.65	N/A	N/A	115	132

TABLE 5-11
Effect of Irradiation to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV) on the Notch Toughness Properties of the Prairie Island Unit 1 Capsule S Reactor Vessel Surveillance Materials[a]

Material	Average 30 ft-lb Transition Temperature (°F)			Average 35-mil Lateral Expansion Temperature (°F)			Average 50 ft-lb Transition Temperature (°F)			Average Energy Absorption at Full Shear (ft-lb)		
	Unirr.[b]	Irrad.	ΔT	Unirr.[b]	Irrad.	ΔT	Unirr.[b]	Irrad.	ΔT	Unirr.[c]	Irrad.[c]	ΔE
Intermediate Shell Forging C (Axial)	-31.31	42.95	74.27	-13.05	75.02	88.07	3.95	80.63	76.68	143	135	-8
Intermediate Shell Forging C (Tangential)	-38.91	62.55	101.46	-24.28	88.08	112.37	-6.35	98.80	105.15	158	142.5	-15.5
Weld Metal	-64.44	95.98	160.43	-50.79	132.74	183.54	-26.93	143.91	170.84	78.5	84.5	6
HAZ Metal	-200.00[d]	-62.89	127.11	-152.00[d]	-7.49	144.51	-125.00[d]	-26.80	98.20	211	136	-75
Correlation Monitor Material	46.20	212.29	166.08	58.63	238.47	179.83	78.39	237.98	159.58	123.5	82.5	-41

NOTES:

(a) All values obtained from CVGRAPH Version 4.1 results.

(b) These values differ from those reported in WCAP-11006. Those reported in WCAP-11006 were developed from hand-fit curves using engineering judgement while the values reported here were determined from curves generated by CVGRAPH, Version 4.1.

(c) Values determined per the definition of "upper shelf energy" given in ASTM E185-82.

(d) Because the hyperbolic tangent curve fitting process did not provide a smooth S-shaped curve for the unirradiated data, these values have been retained from the original unirradiated Charpy V-notch hand fit curves (WCAP-8086).

TABLE 5-12

Comparison of the Prairie Island Unit 1 Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper Shelf Energy Decreases with Regulatory Guide 1.99, Revision 2, Predictions

MATERIAL	CAPSULE	Capsule Fluence (10^{19} n/cm², E>1.0MeV)	30 ft-lb Transition Temperature Shift		Upper Shelf Energy Decrease	
			Predicted[a] (°F)	Measured[b] (°F)	Predicted[a] (%)	Measured (%)
INTER. SHELL FORGING C (Axial Orientation)	V	0.5630	36.9	24.07	16.5	0
	P	1.318	47.4	33.98	20.5	5
	R	4.478	60.7	84.18	27	10
	S	4.017	59.7	74.27	26.5	6
INTER. SHELL FORGING C (Tangential Orientation)	V	0.5630	36.9	56.36	16.5	9
	P	1.318	47.4	23.11	20.5	10
	R	4.478	60.7	95.85	27	8
	S	4.017	59.7	101.46	26.5	10
WELD METAL	V	0.5630	59.5	34.38	25	0
	P	1.318	76.4	45.15	30	0
	R	4.478	91.8	122.47	40	4
	S	4.017	96.2	160.43	39	0
Heat Affected Zone Material	V	0.5630	--	0.00	--	(c)
	P	1.318	--	74.65	--	32
	R	4.478	--	149.69	--	54
	S	4.017	--	137.11	--	36
Correlation Monitor Material (HSST Plate 02) (Longitudinal Orientation)	V	0.5630	85.6	102.84	20	26
	P	1.318	109.9	161.40	24.5	31
	R	4.478	140.8	193.72	33	30
	S	4.017	138.4	166.08	32	33

NOTES:

(a) Based on Regulatory Guide 1.99, Revision 2, methodology using the Cu and Ni weight percent and capsule fluence values.

(b) The Charpy data was fit using the hyperbolic tangent curve fitting program CVGRAPH Version 4.1[57]. (See Figures 5-1, 5-4, 5-7, 5-10 and 5-13.)

(c) Upper Shelf Energy not obtainable due to toughness, per WCAP-8916.

TABLE 5-13

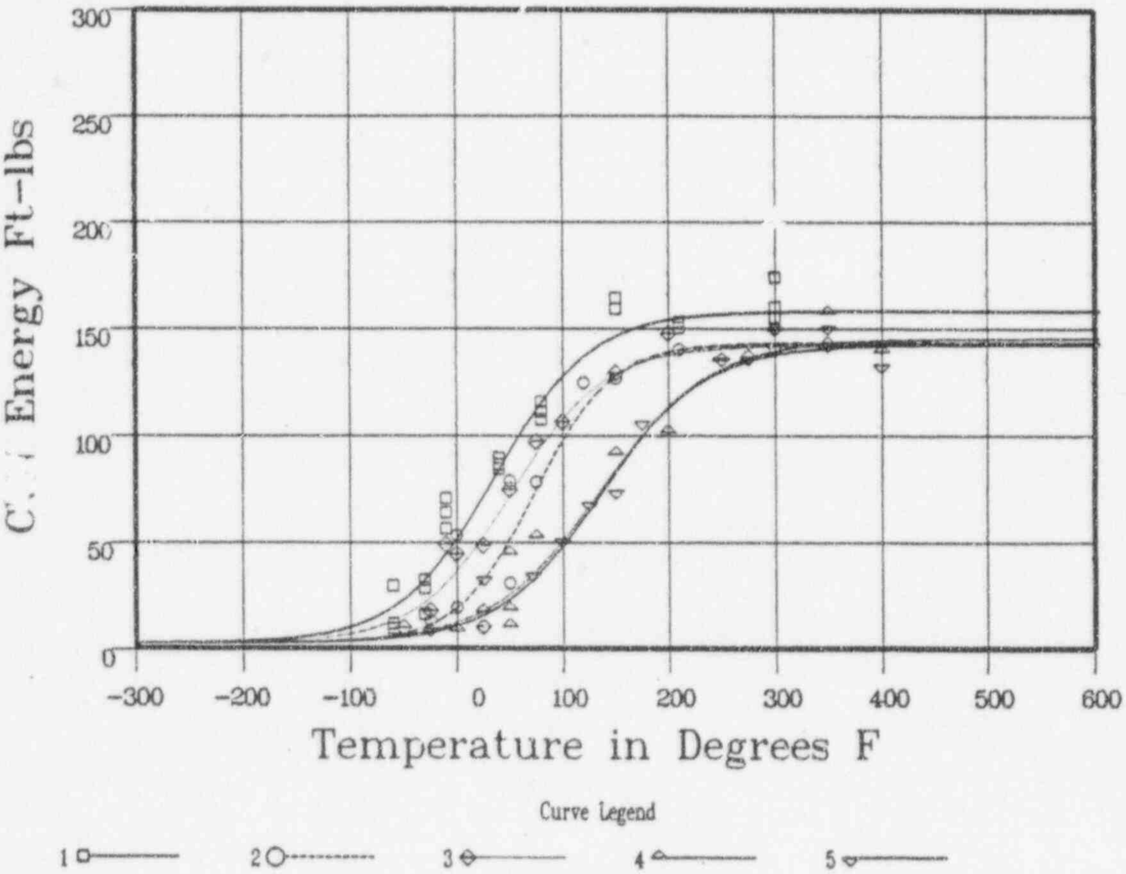
Tensile Properties of the Prairie Island Unit 1 Reactor Vessel Surveillance Materials Irradiated to 4.017 x 10^{19} n/cm^2 (E > 1.0 MeV)

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 (%)
Inter. Shell Forging C (Tangential)	N7	125	77.4	93.7	2.75	166.0	56.0	10.5	26.0	66
	N8	250	75.9	90.7	2.70	186.6	55.0	9.0	22.4	66
	N9	550	69.8	90.7	3.10	178.2	63.2	9.0	21.8	65
Inter. Shell Forging C (Axial)	S7	125	78.2	94.7	3.05	207.2	62.1	10.1	22.8	70
	S8	200	74.4	92.7	3.95	282.9	80.5	9.3	21.5	72
	S9	550	68.8	89.6	2.95	190.3	60.1	8.6	20.3	68
Surveillance Weld Metal	W7	125	78.9	91.7	3.05	210.8	62.1	12.8	26.7	71
	W8	200	83.5	86.6	3.30	212.9	67.2	12.0	25.0	68
	W9	550	75.4	91.7	3.35	195.8	68.2	9.6	21.6	65

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:34:14 on 11-06-1996

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	158	0	-38.91	0	-6.35	0
2	0	2.19	0	143	-15	17.44	56.36	44.34	50.69
3	0	2.19	0	142	-16	-15.8	23.11	16.92	23.27
4	0	2.19	0	145	-13	56.93	95.85	94.84	101.19
5	0	2.19	0	142.5	-15.5	62.55	101.46	98.8	105.15



Data Set(s) Plotted

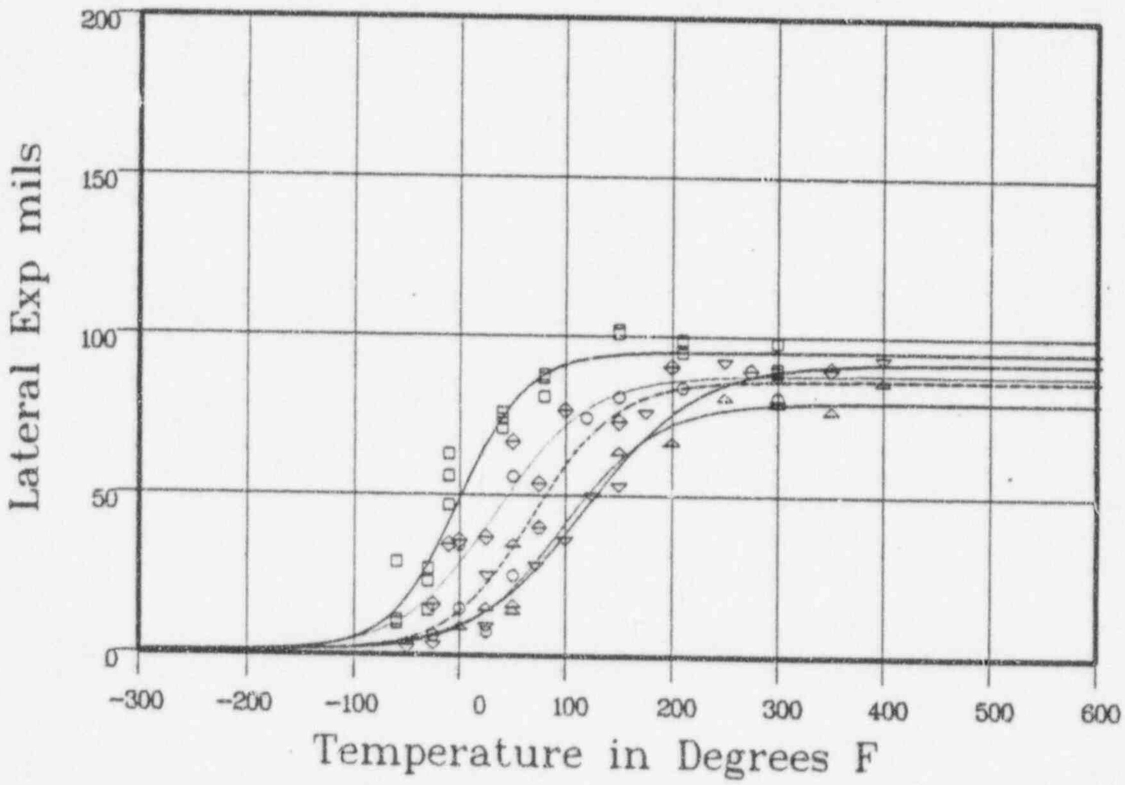
Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	FORGING SA5083	LT	21918/38566
2	PI1	V	FORGING SA5083	LT	21918/38566
3	PI1	P	FORGING SA5083	LT	21918/38566
4	PI1	R	FORGING SA5083	LT	21918/38566
5	PI1	S	FORGING SA5083	LT	21918/38566

Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C (Tangential Orientation)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:40:31 on 11-06-1996

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	95.3	0	-24.28	0
2	0	86.37	-8.93	47.82	72.11
3	0	88.06	-7.24	9.34	33.63
4	0	79.5	-15.8	80.86	105.15
5	0	92.05	-3.25	88.08	112.37



Curve Legend

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

Data Set(s) Plotted

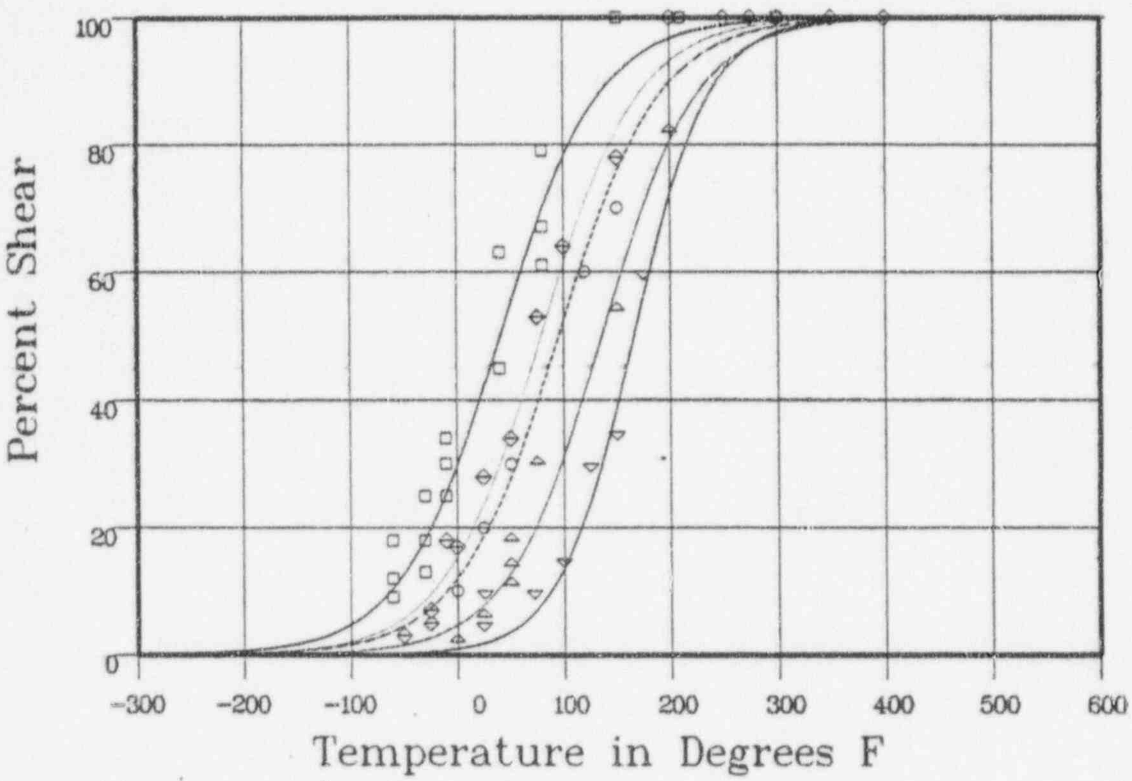
Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	FORGING SA5083	LT	21918/38566
2	PI1	V	FORGING SA5083	LT	21918/38566
3	PI1	P	FORGING SA5083	LT	21918/38566
4	PI1	R	FORGING SA5083	LT	21918/38566
5	PI1	S	FORGING SA5083	LT	21918/38566

Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C (Tangential Orientation)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:43:47 on 11-06-1996

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	35.9	0
2	0	90.82	54.91
3	0	74.12	38.22
4	0	131.25	95.34
5	0	161.25	125.34



Curve Legend

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

Data Set(s) Plotted

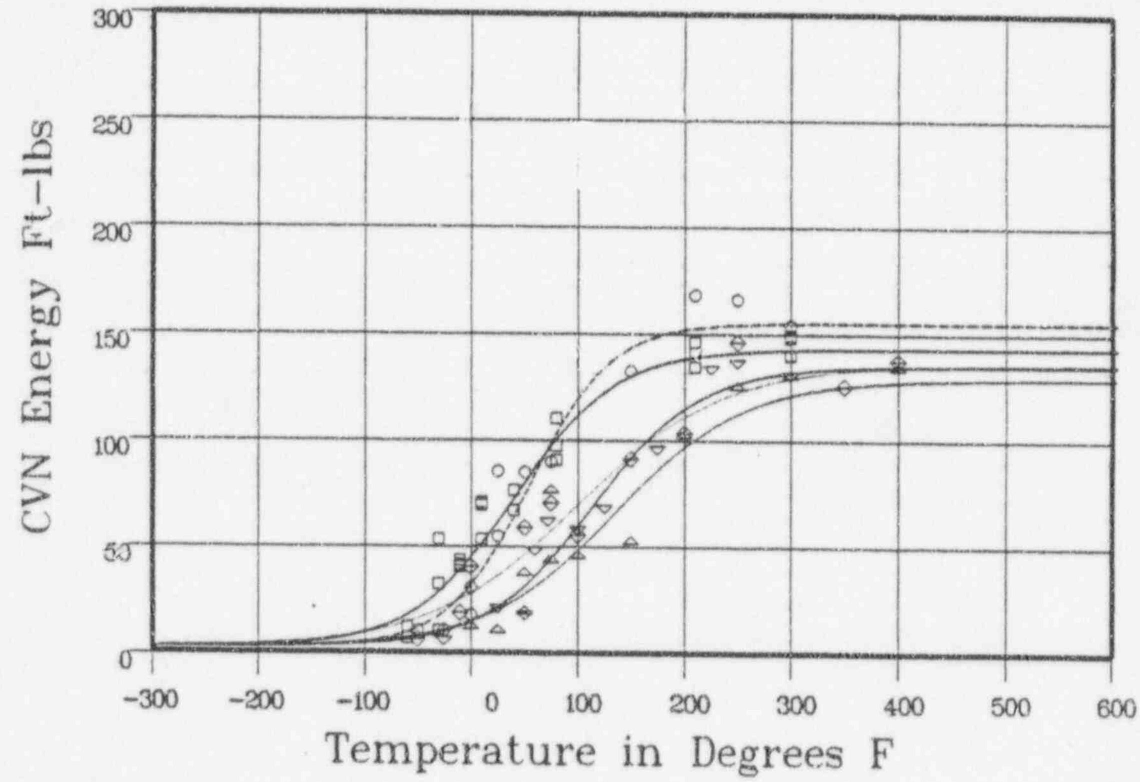
Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	FORGING SA508	LT	21918/38566
2	PI1	V	FORGING SA508	LT	21918/38566
3	PI1	P	FORGING SA508	LT	21918/38566
4	PI1	R	FORGING SA508	LT	21918/38566
5	PI1	S	FORGING SA508	LT	21918/38566

Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C (Tangential Orientation)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:31:17 on 11-07-1996

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	143	0	-31.31	0	3.95	0
2	0	2.19	0	155	12	-7.24	24.07	20.11	16.15
3	0	2.19	0	136	-7	2.66	33.98	54.27	50.32
4	0	2.19	0	129	-14	52.87	84.18	99.55	95.6
5	0	2.19	0	135	-8	42.95	74.27	80.63	76.68



Curve Legend

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

Data Set(s) Plotted

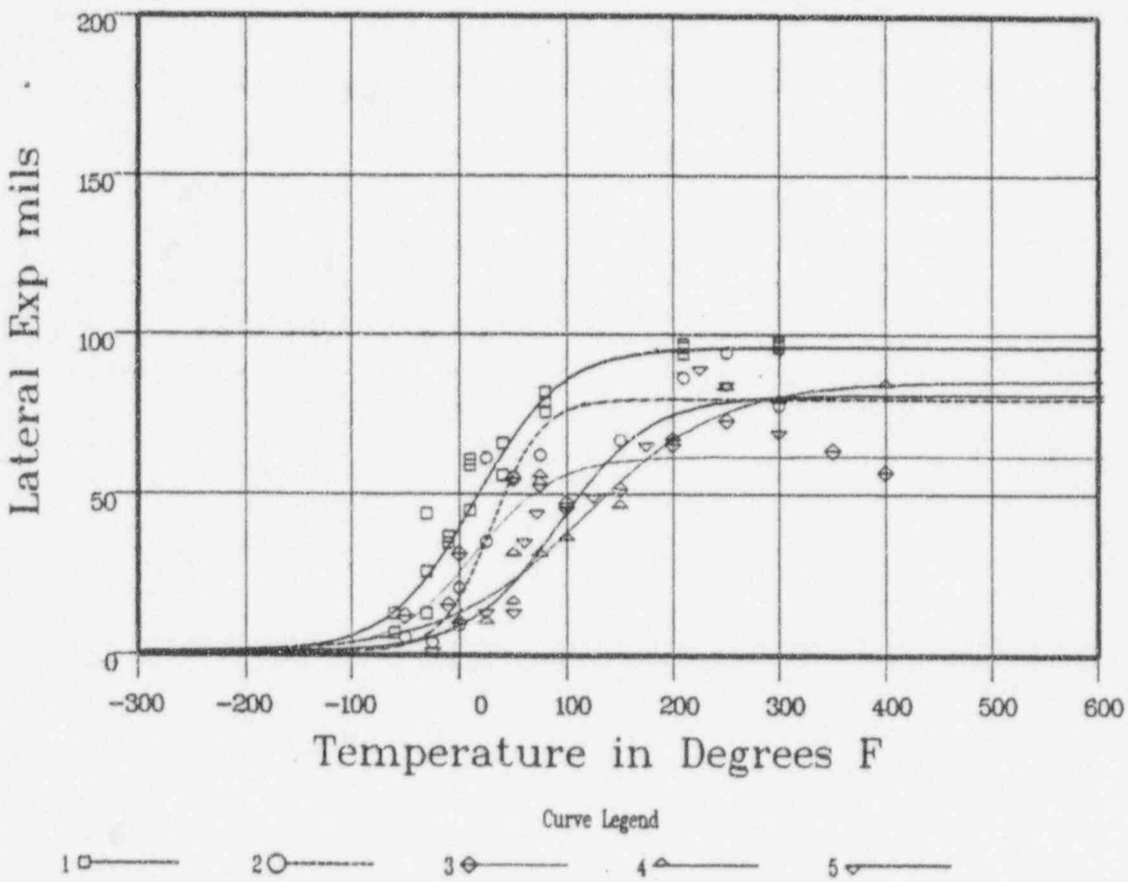
Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	FORGING SA508-3	TL	21918/38566
2	PI1	V	FORGING SA508-3	TL	21918/38566
3	PI1	P	FORGING SA508-3	TL	21918/38566
4	PI1	R	FORGING SA508-3	TL	21918/38566
5	PI1	S	FORGING SA508-3	TL	21918/38566

Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C (Axial Orientation)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:35:10 on 11-07-1996

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	96.01	0	-13.05	0
2	0	79.86	-16.15	18.92	31.97
3	0	61.87	-34.14	18.14	31.2
4	0	85.54	-10.47	85.16	98.21
5	0	81.11	-14.89	75.02	88.07



Data Set(s) Plotted

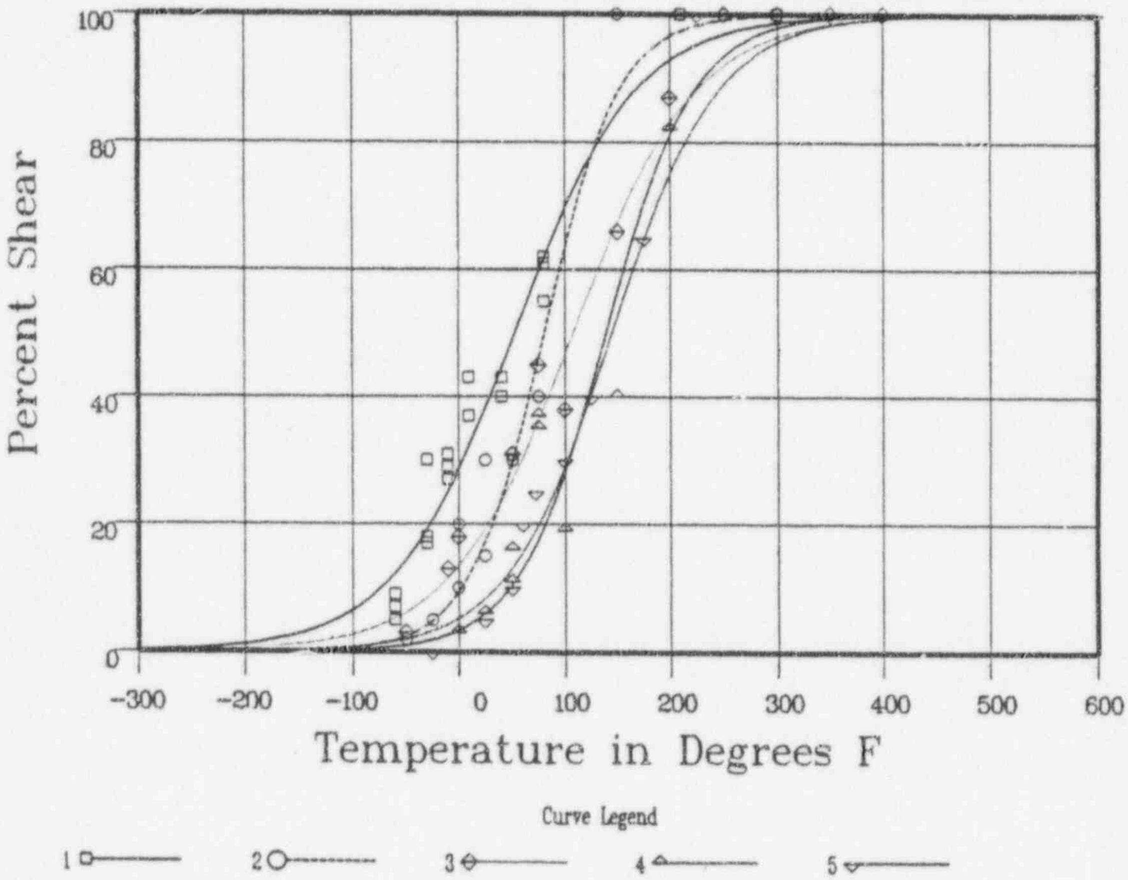
Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	FORGING SA508	TL	21918/38566
2	PI1	V	FORGING SA508	TL	21918/38566
3	PI1	P	FORGING SA508	TL	21918/38566
4	PI1	R	FORGING SA508	TL	21918/38566
5	PI1	S	FORGING SA508	TL	21918/38566

Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging (Axial Orientation)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:37:57 on 11-07-1996

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	47.81	0
2	0	75.87	28.06
3	0	103.12	55.31
4	0	140.03	92.22
5	0	134.47	86.66



Data Set(s) Plotted

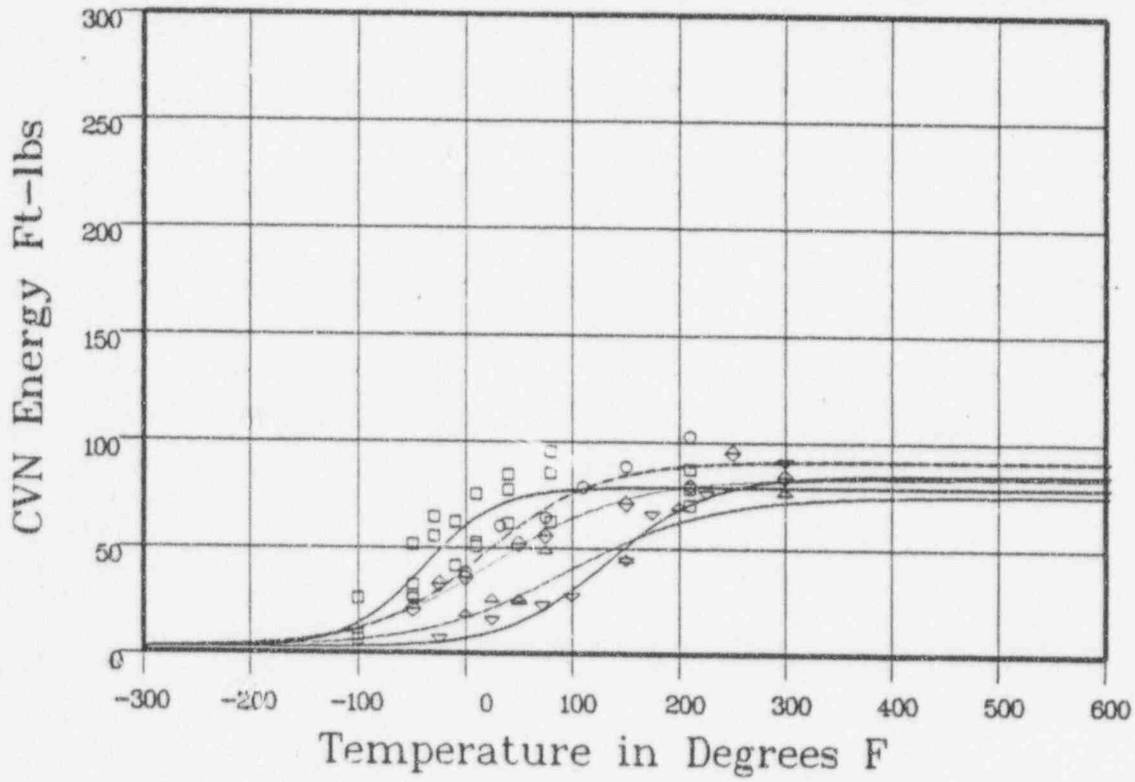
Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	FORGING SA508	TL	21918/38566
2	PI1	V	FORGING SA508	TL	21918/38566
3	PI1	P	FORGING SA508	TL	21918/38566
4	PI1	R	FORGING SA508	TL	21918/38566
5	PI1	S	FORGING SA508	TL	21918/38566

Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C (Axial Orientation)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:03:53 on 11-06-1996

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	78.5	0	-64.44	0	-26.93	0
2	0	2.19	0	91	12.5	-30.05	34.38	20.42	47.35
3	0	2.19	0	83	4.5	-19.28	45.15	45.01	71.94
4	0	2.19	0	75	-3.5	58.02	122.47	134.95	161.88
5	0	2.19	0	84.5	6	95.98	160.43	143.91	170.84



Curve Legend

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

Data Set(s) Plotted

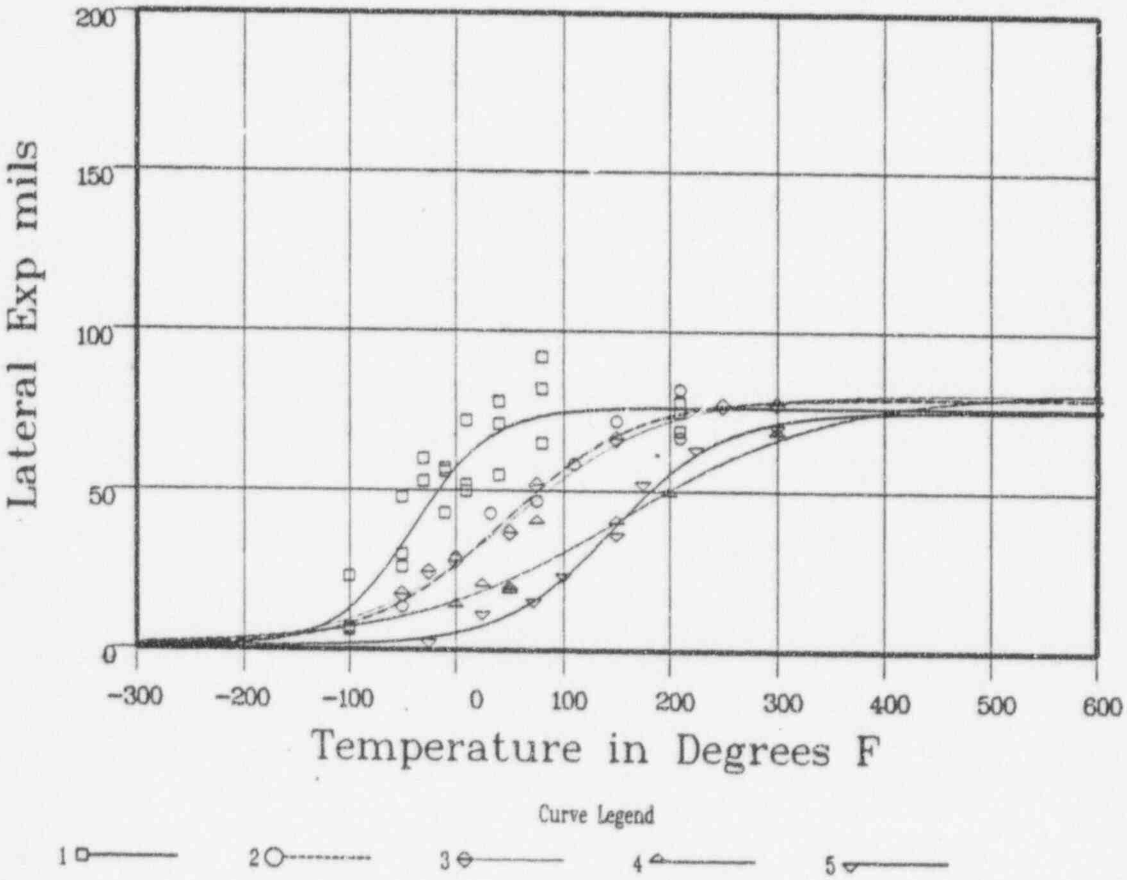
Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	WELD		1752
2	PI1	V	WELD		1752
3	PI1	P	WELD		1752
4	PI1	R	WELD		1752
5	PI1	S	WELD		1752

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

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:07:09 on 11-06-1996

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	76.41	0	-50.79	0
2	0	79.62	3.2	22.58	73.38
3	0	80.92	4.5	25.55	76.34
4	0	82.1	5.68	117.04	167.83
5	0	75.56	-.85	132.74	183.54



Data Set(s) Plotted

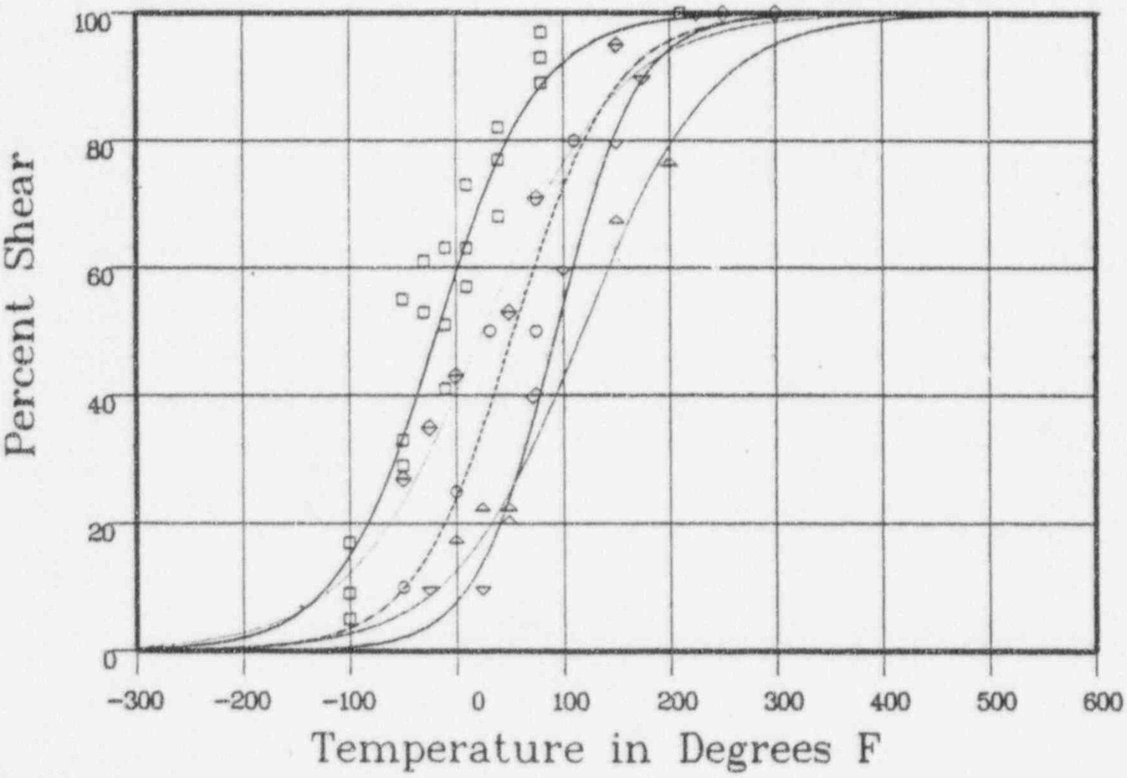
Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	WELD		1752
2	PI1	V	WELD		1752
3	PI1	P	WELD		1752
4	PI1	R	WELD		1752
5	PI1	S	WELD		1752

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

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:10:07 on 11-06-1996

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	-22.03	0
2	0	49.68	71.71
3	0	20.47	42.5
4	0	113.08	135.11
5	0	89.06	111.09



Curve Legend

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

Data Set(s) Plotted

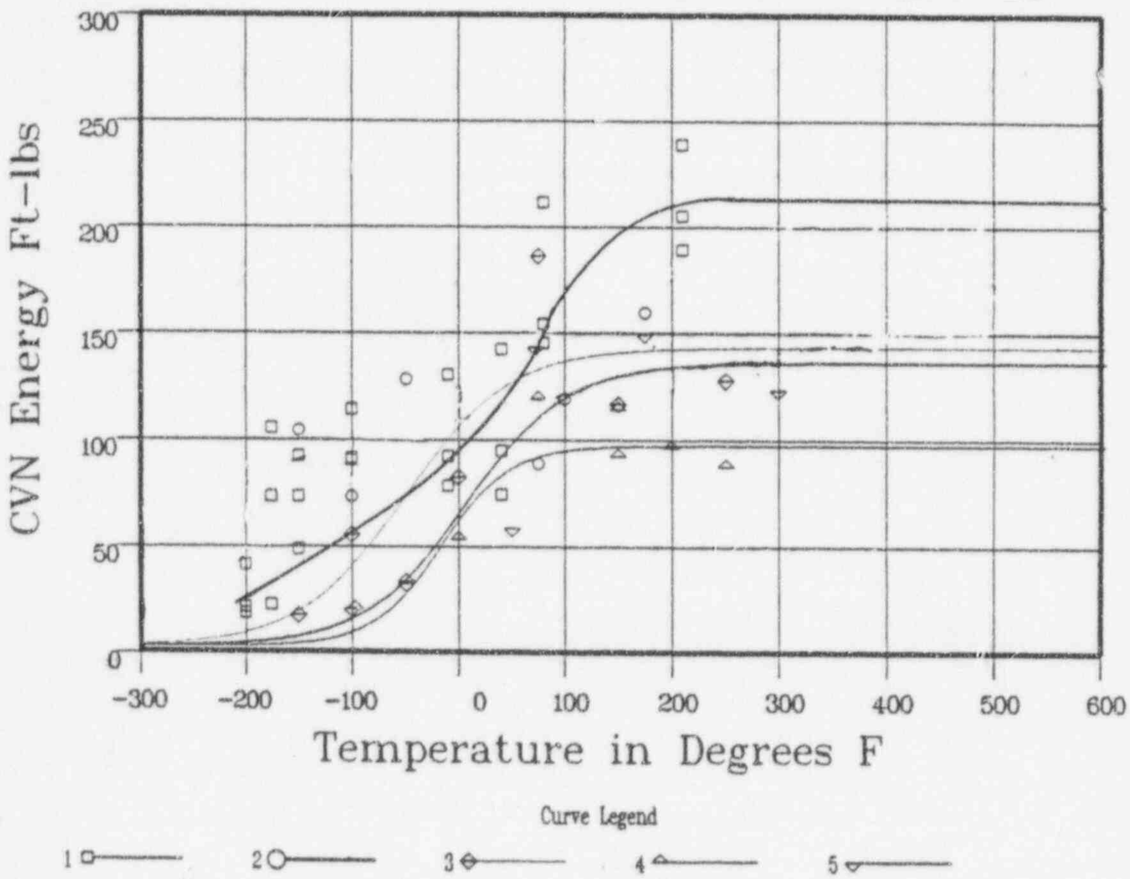
Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	WELD		1752
2	PI1	V	WELD		1752
3	PI1	P	WELD		1752
4	PI1	R	WELD		1752
5	PI1	S	WELD		1752

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

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:44:41 on 11-07-1996

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0		0	211	0	-200	0	-125	0
2	0		0	<211*	0	-200	0	-125	0
3	0	2.19	0	143	-68	-125.35	74.65	-88.8	36.2
4	0	2.19	0	97	-114	-50.31	149.69	-21.13	103.87
5	0	2.19	0	136	-75	-62.89	137.11	-26.8	98.2



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	HEAT AFF'D ZONE		
2	PI1	V	HEAT AFF'D ZONE		
3	PI1	P	HEAT AFF'D ZONE		
4	PI1	R	HEAT AFF'D ZONE		
5	PI1	S	HEAT AFF'D ZONE		

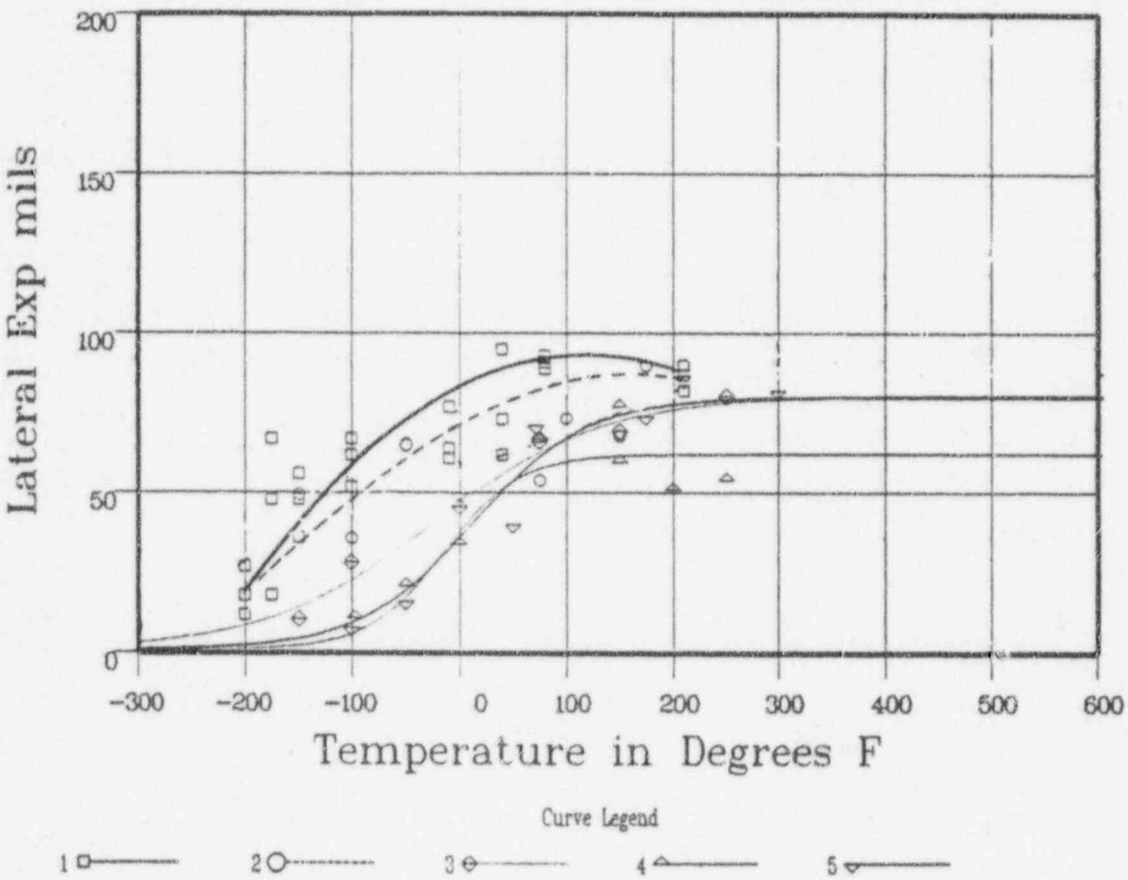
* Upper shelf impact energy not obtainable due to excessive toughness.

Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for Prairie Island Unit 1 Reactor Vessel Heat-Affected-Zone (HAZ) Metal

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:19:30 on 11-06-1996

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	92	0	-152	0
2	0	87	-5	-128	24
3	0	80.69	-11.31	-51.24	100.76
4	0	62.21	-29.79	-11.77	140.23
5	0	80.07	-11.93	-7.49	144.51



Data Set(s) Plotted

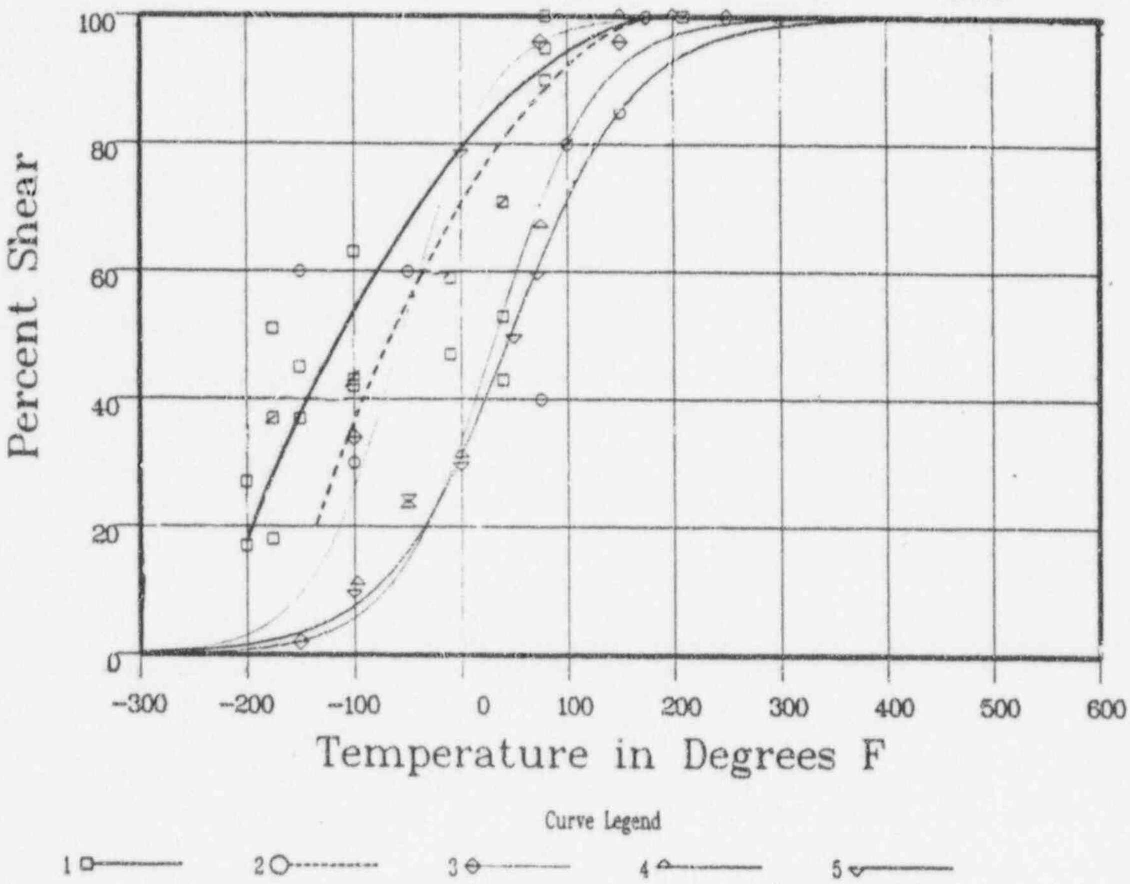
Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	HEAT AFF'D ZONE		
2	PI1	V	HEAT AFF'D ZONE		
3	PI1	P	HEAT AFF'D ZONE		
4	PI1	R	HEAT AFF'D ZONE		
5	PI1	S	HEAT AFF'D ZONE		

Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for Prairie Island Unit 1 Reactor Vessel Heat-Affected-Zone (HAZ) Metal

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:22:20 on 11-06-1996

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	-110	0
2	0	-60	50
3	0	-60.93	49.07
4	0	28.12	138.12
5	0	41.85	151.85



Data Set(s) Plotted

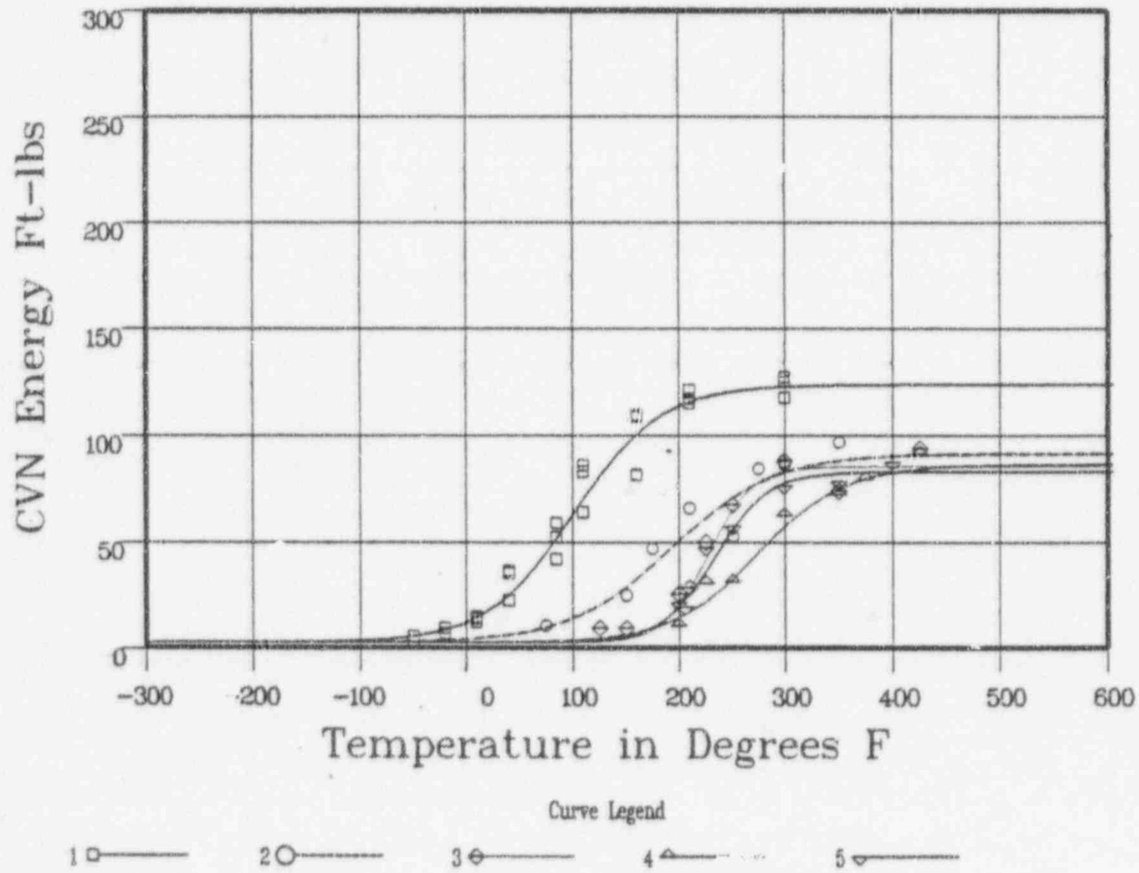
Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	HEAT AFFD ZONE		
2	PI1	V	HEAT AFFD ZONE		
3	PI1	P	HEAT AFFD ZONE		
4	PI1	R	HEAT AFFD ZONE		
5	PI1	S	HEAT AFFD ZONE		

Figure 5-12 Charpy V-Notch Percent Shear vs. Temperature for Prairie Island Unit 1 Reactor Vessel Heat-Affected-Zone (HAZ) Metal

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:25:55 on 11-06-1996

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	123.5	0	46.2	0	78.39	0
2	0	2.19	0	91	-32.5	149.05	102.84	194.65	116.25
3	0	2.19	0	85	-38.5	207.61	161.4	228.16	149.76
4	0	2.19	0	86	-37.5	239.93	193.72	280.48	202.08
5	0	2.19	0	82.5	-41	212.29	166.08	237.98	159.58



Data Set(s) Plotted

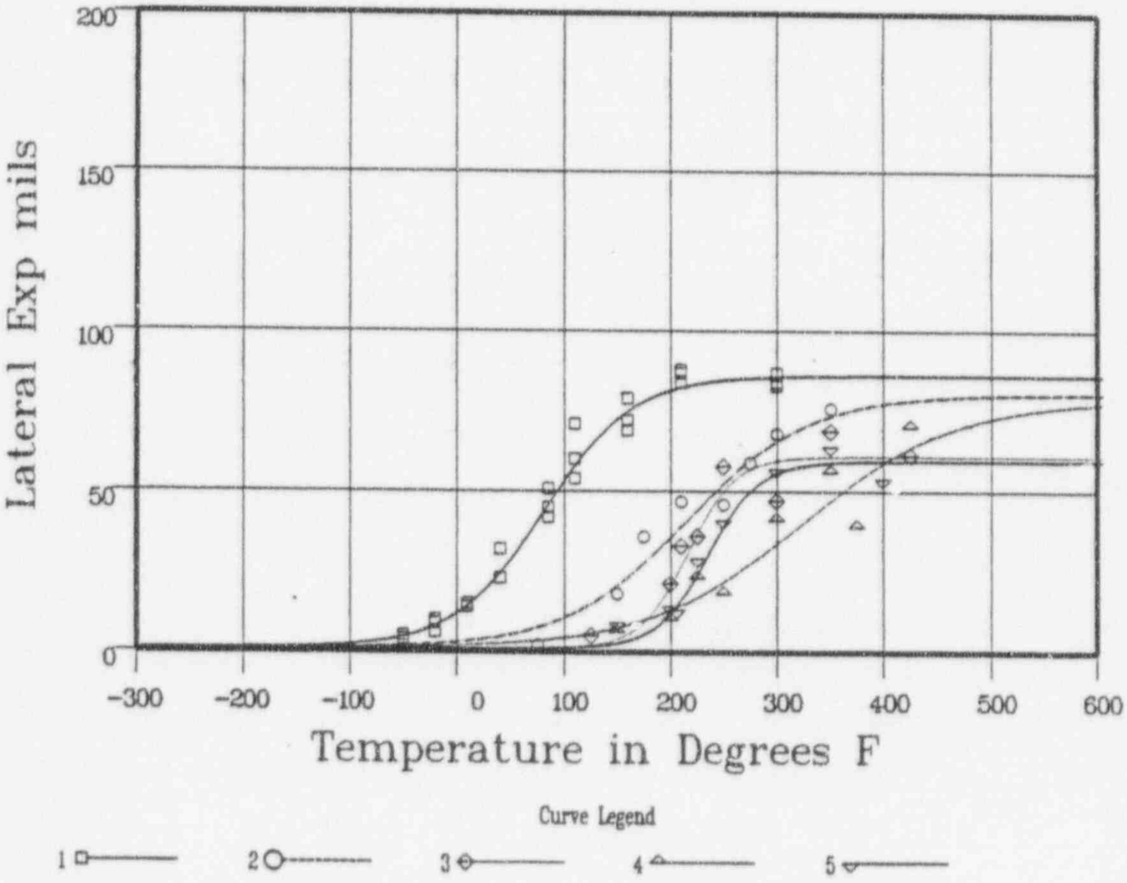
Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	SRM HSST02	LT	SA533B1
2	PI1	V	SRM HSST02	LT	SA533B1
3	PI1	P	SRM HSST02	LT	SA533B1
4	PI1	R	SRM HSST02	LT	SA533B1
5	PI1	S	SRM HSST02	LT	SA533B1

Figure 5-13 Charpy V-Notch Impact Energy vs. Temperature for Prairie Island Unit 1 Reactor Vessel Correlation Monitor Material

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:29:28 on 11-06-1996

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	86.26	0	58.63	0
2	0	80.64	-5.62	192.96	134.33
3	0	60.92	-25.33	217.38	158.74
4	0	79.07	-7.19	299.54	240.9
5	0	59.52	-26.74	238.47	179.83



Data Set(s) Plotted

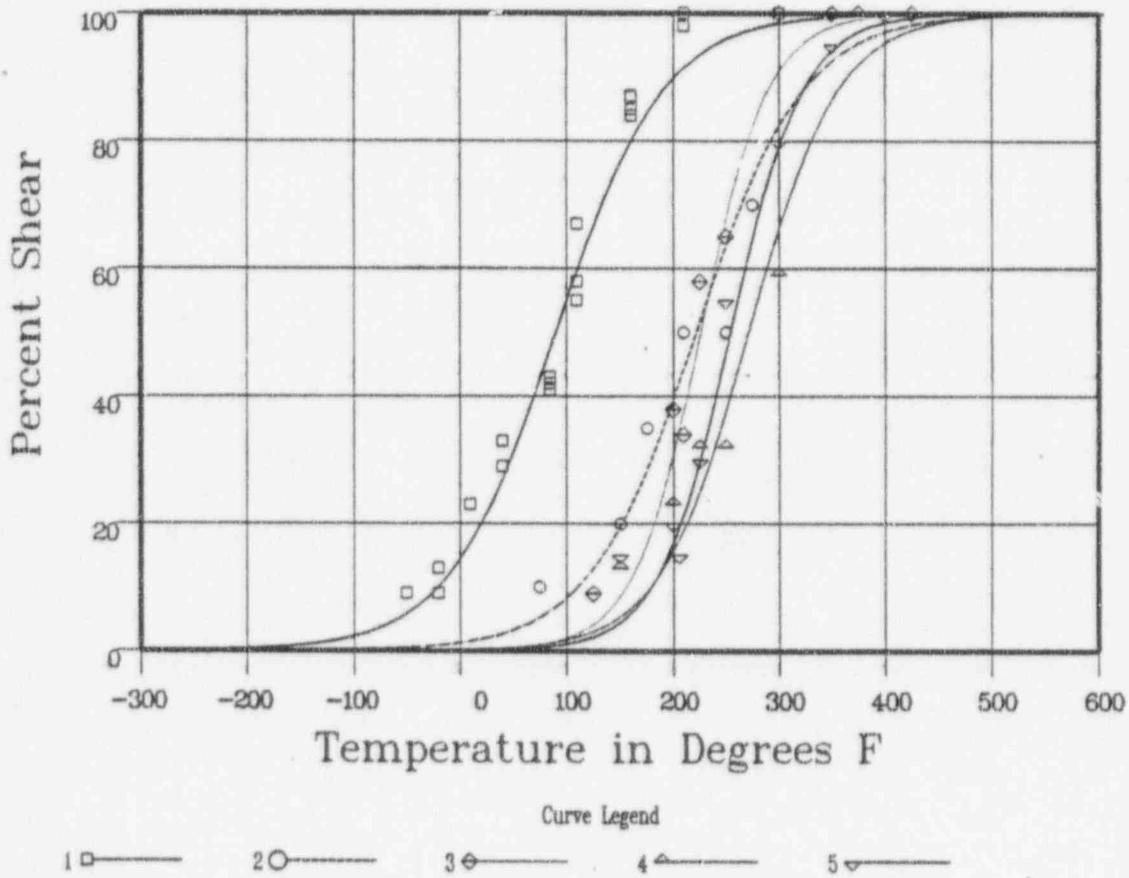
Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	SRM HSST02	LT	SA533B1
2	PI1	V	SRM HSST02	LT	SA533B1
3	PI1	P	SRM HSST02	LT	SA533B1
4	PI1	R	SRM HSST02	LT	SA533B1
5	PI1	S	SRM HSST02	LT	SA533B1

Figure 5-14 Charpy V-Notch Lateral Expansion vs. Temperature for Prairie Island Unit 1 Reactor Vessel Correlation Monitor Material

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:34:04 on 11-06-1996

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	85.55	0
2	0	217.02	131.47
3	0	221.25	135.69
4	0	266.72	181.16
5	0	249.83	164.28



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	PI1	UNIRR	SRM HSST02	LT	SA533B1
2	PI1	V	SRM HSST02	LT	SA533B1
3	PI1	P	SRM HSST02	LT	SA533B1
4	PI1	R	SRM HSST02	LT	SA533B1
5	PI1	S	SRM HSST02	LT	SA533B1

Figure 5-15 Charpy V-Notch Percent Shear vs. Temperature for Prairie Island Unit 1 Reactor Vessel Correlation Monitor Material

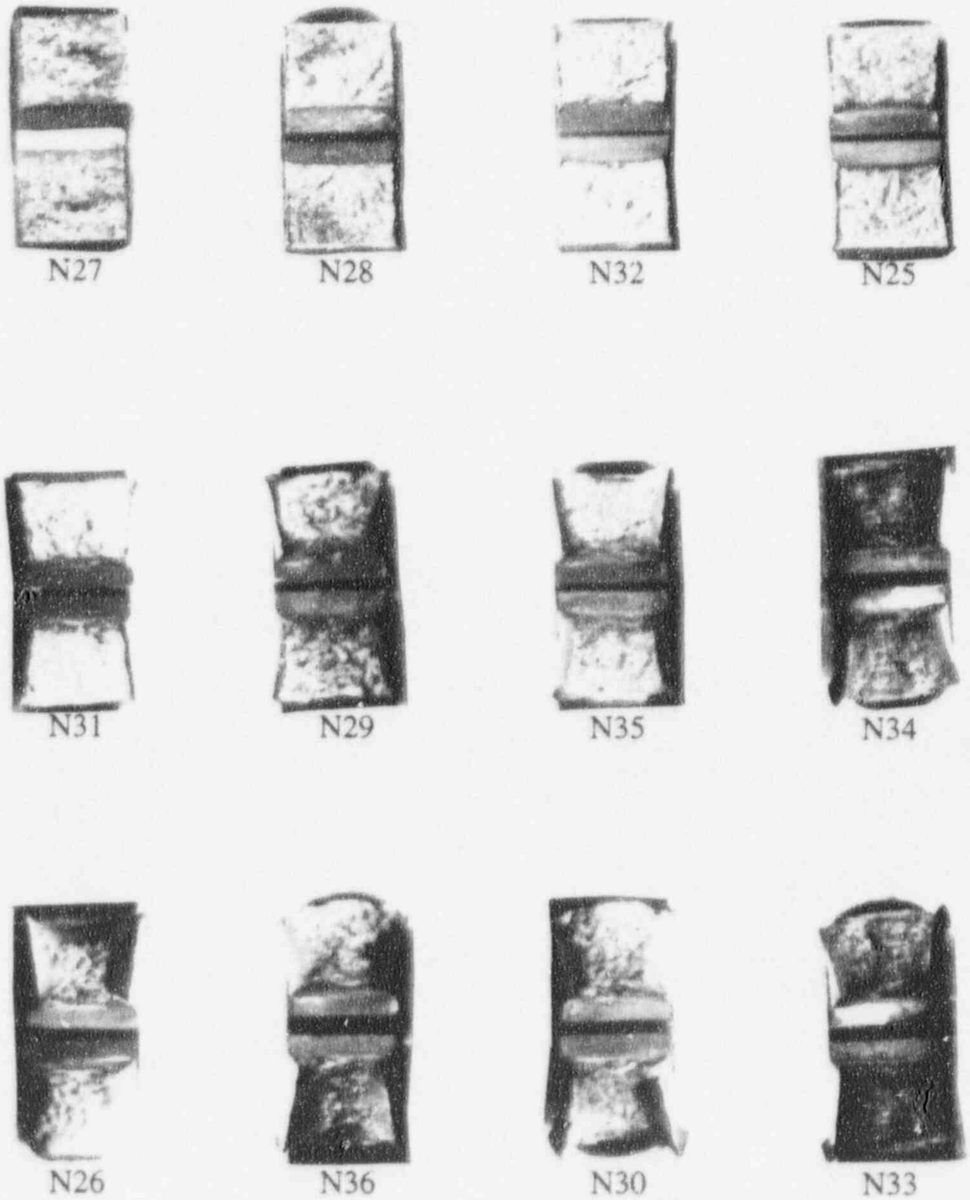


Figure 5-16 Charpy Impact Specimen Fracture Surfaces of the Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C (Tangential Orientation)

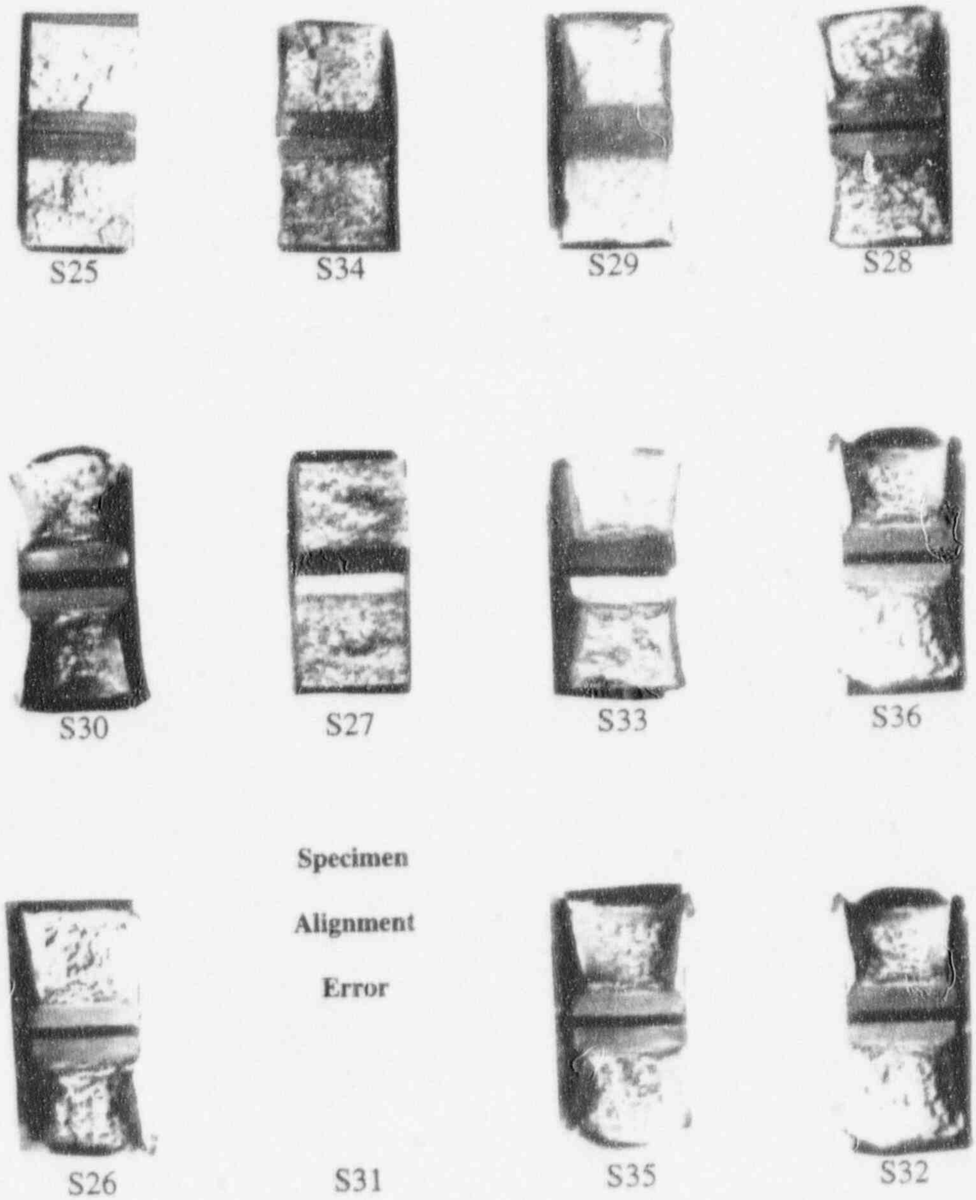


Figure 5-17 Charpy Impact Specimen Fracture Surfaces of the Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C (Axial Orientation)

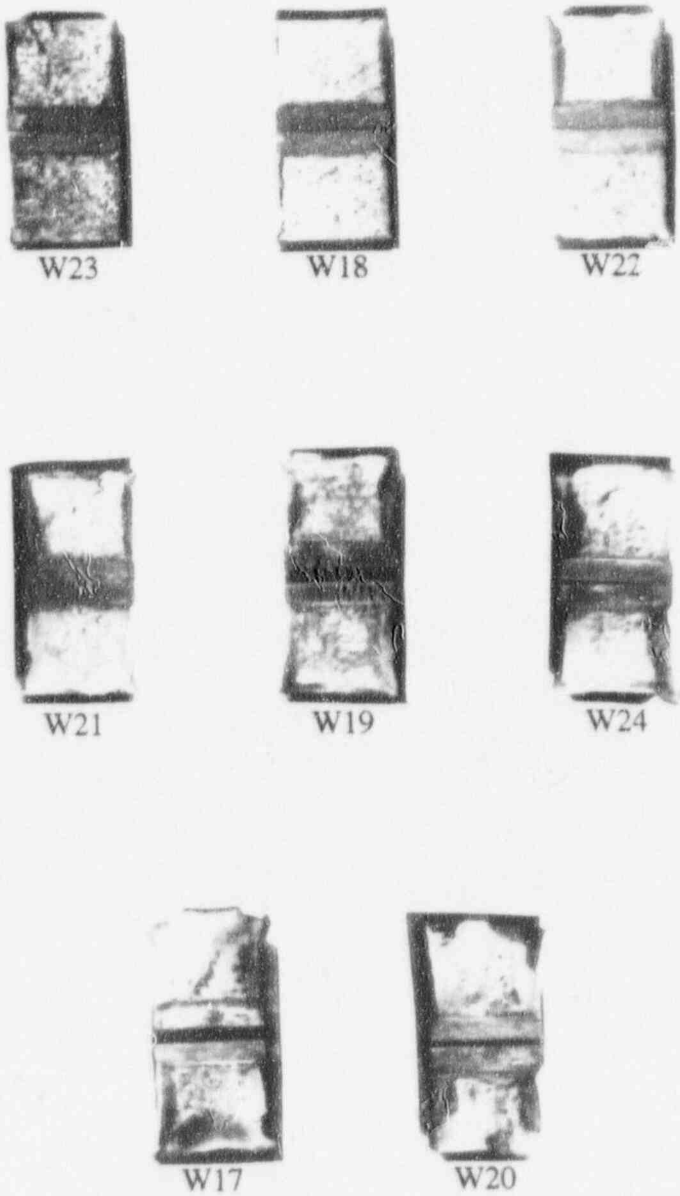


Figure 5-18 Charpy Impact Specimen Fracture Surfaces of the Prairie Island Unit 1 Reactor Vessel Weld Metal

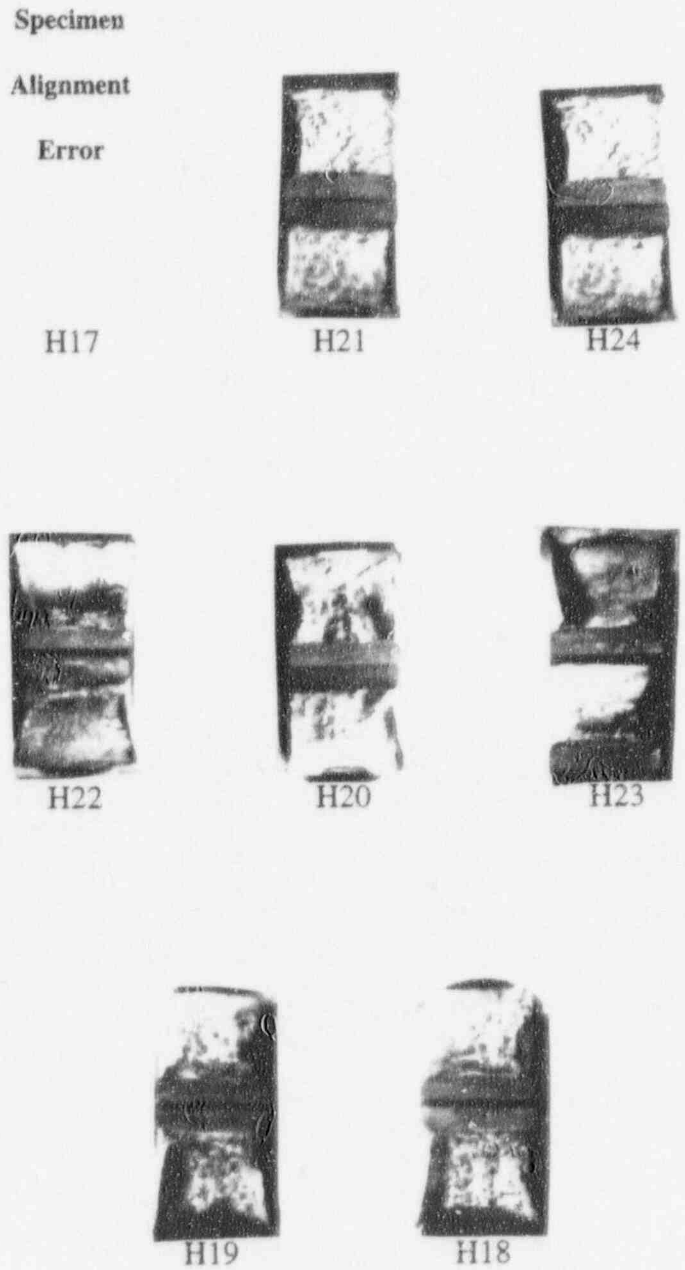


Figure 5-19 Charpy Impact Specimen Fracture Surfaces of the Prairie Island Unit 1 Reactor Vessel Weld Heat-Affected-Zone (HAZ) Metal

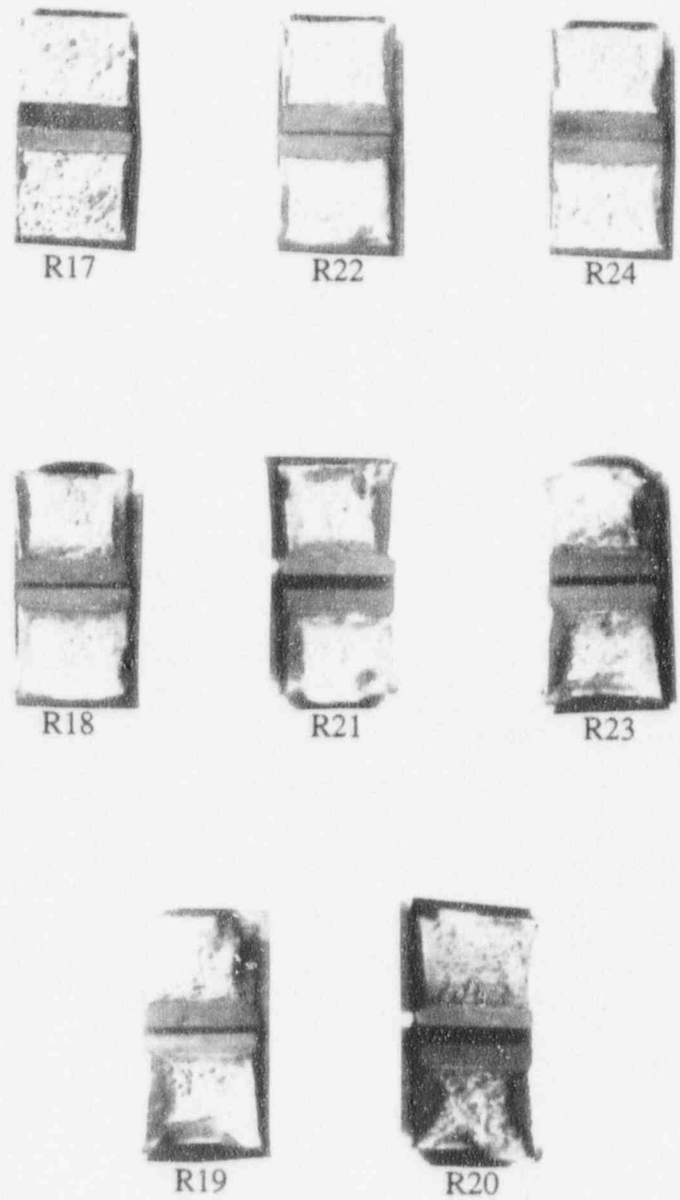


Figure 5-20 Charpy Impact Specimen Fracture Surfaces of the Prairie Island Unit 1 Reactor Vessel Correlation Monitor Material

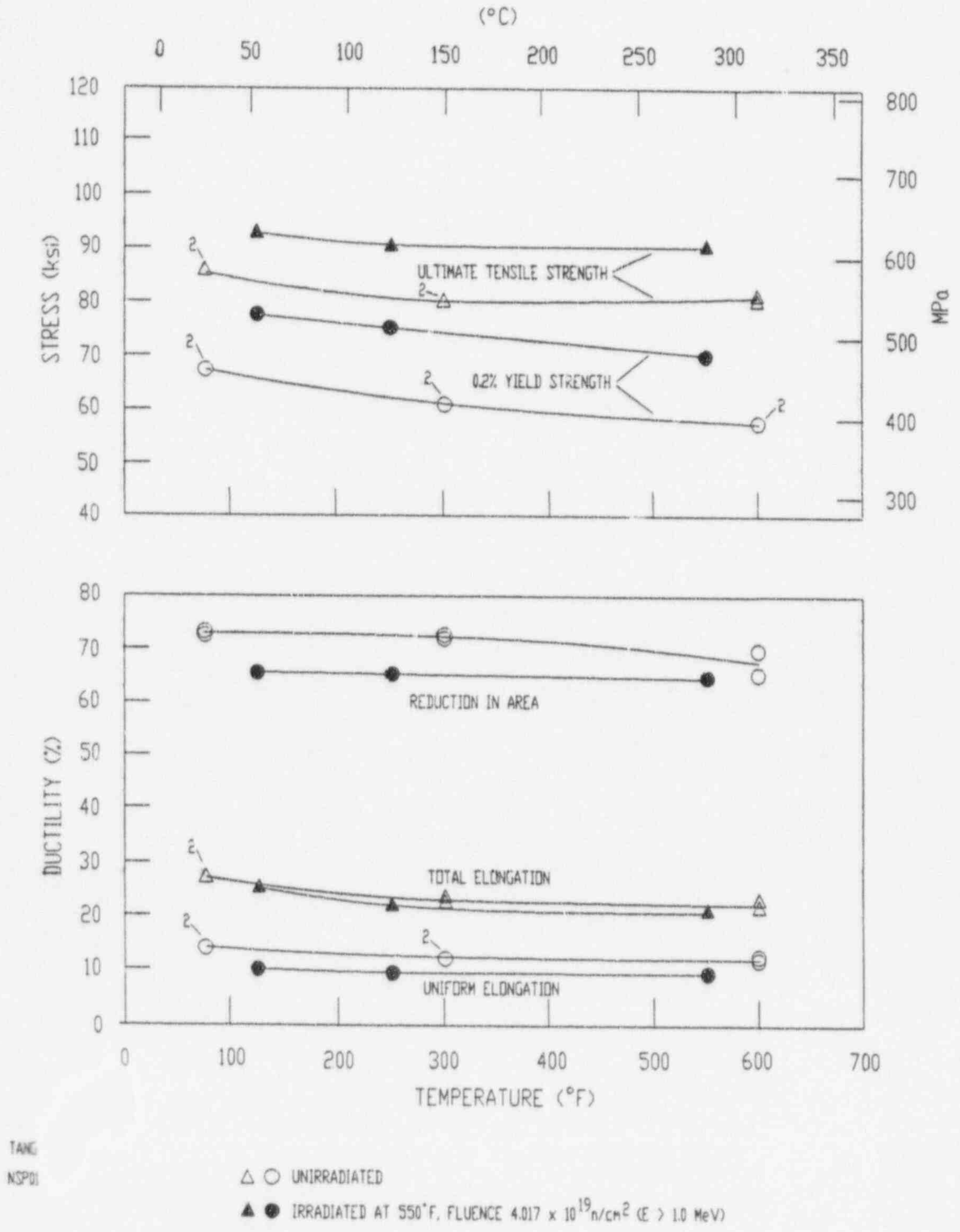


Figure 5-21 Tensile Properties for the Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C (Tangential Orientation)

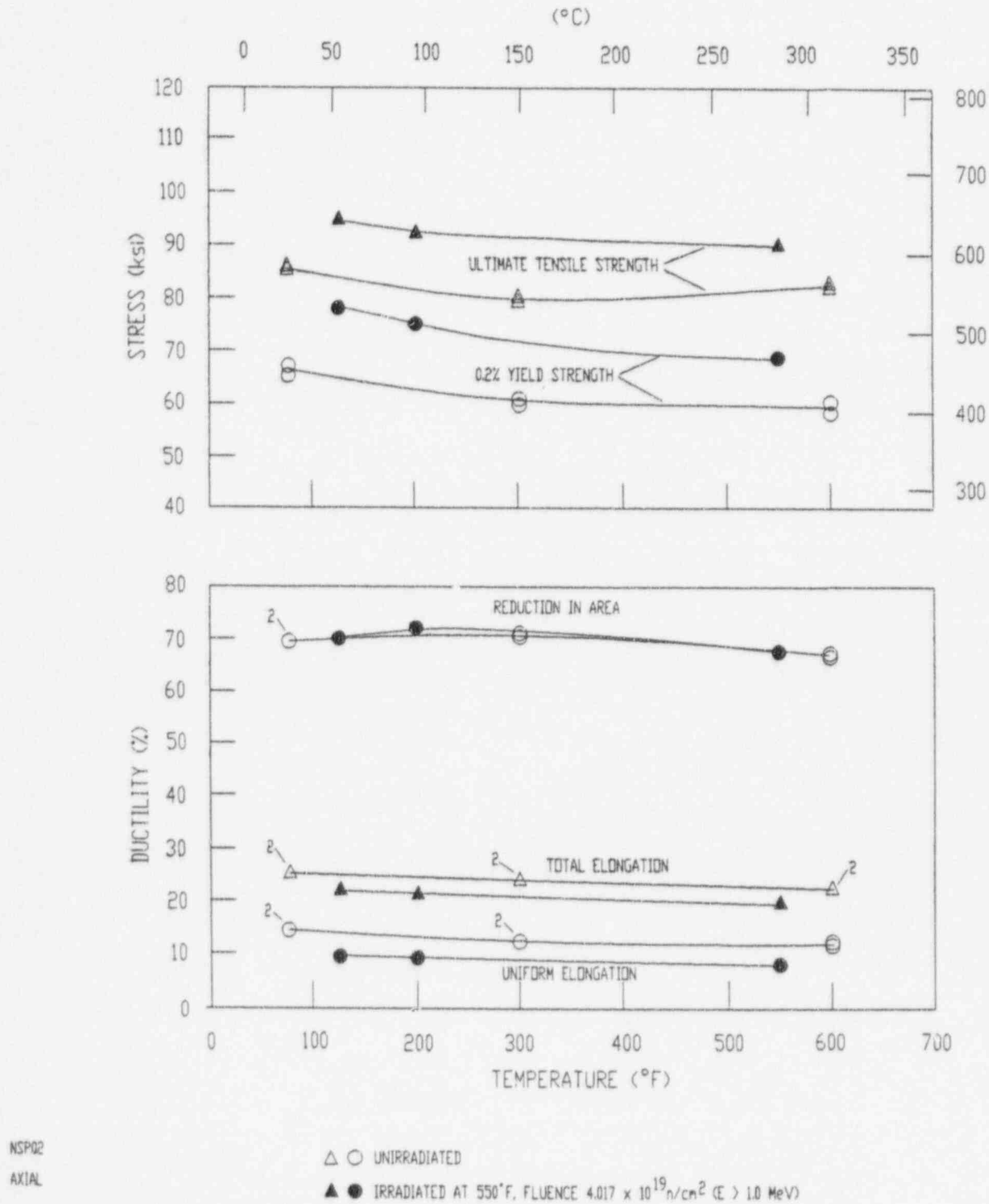


Figure 5-22 Tensile Properties for the Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C (Axial Orientation)

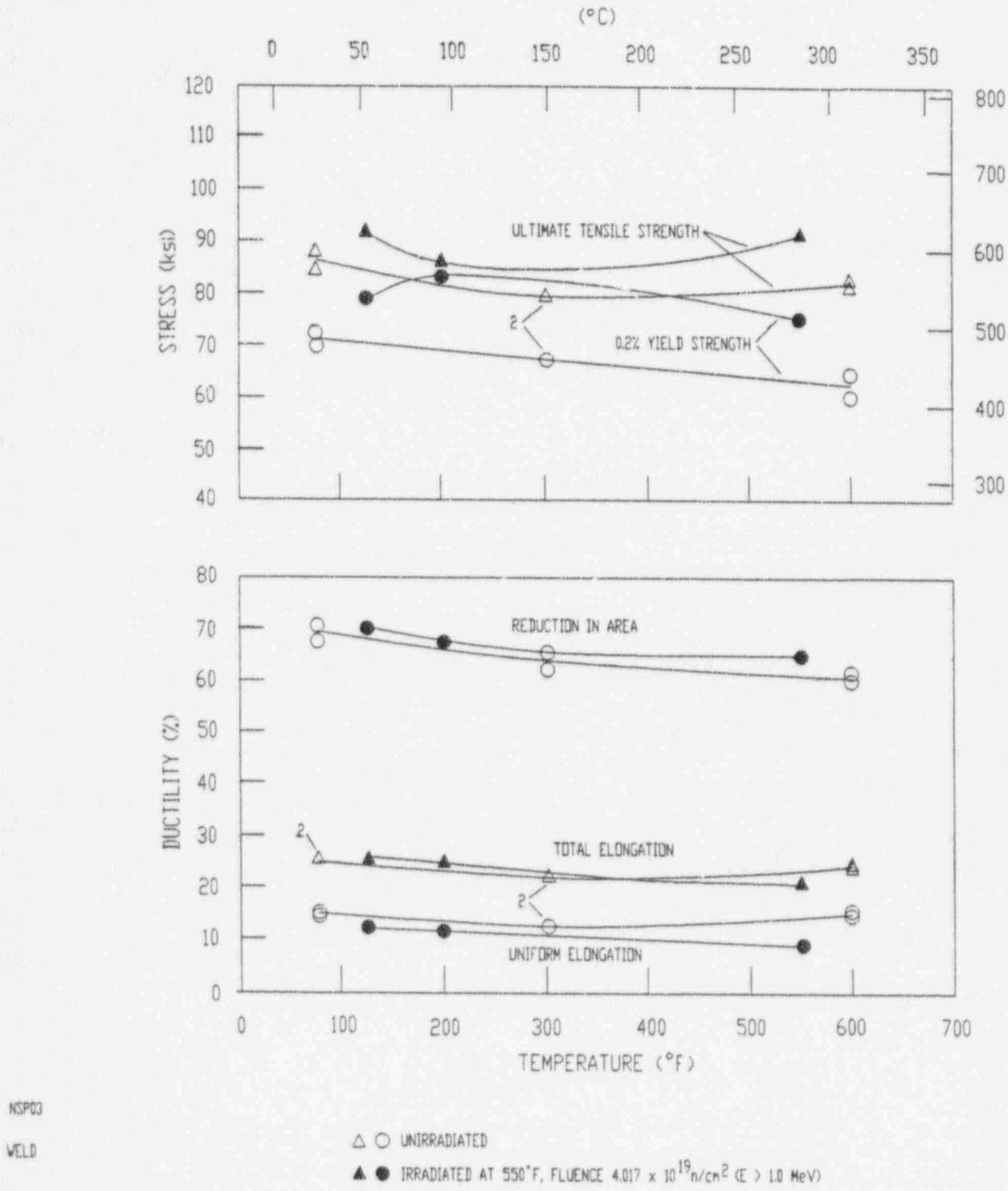
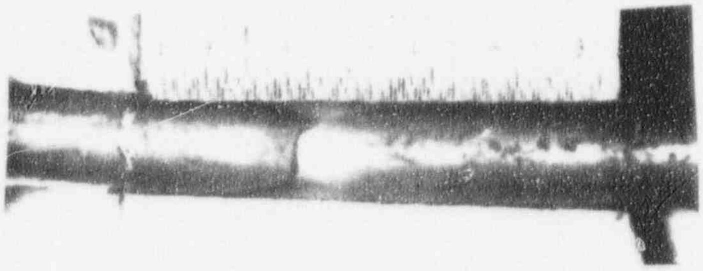
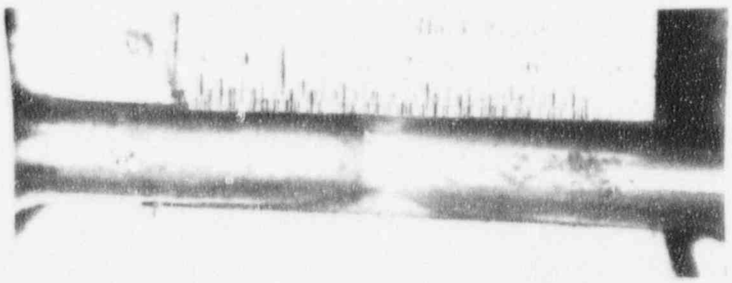


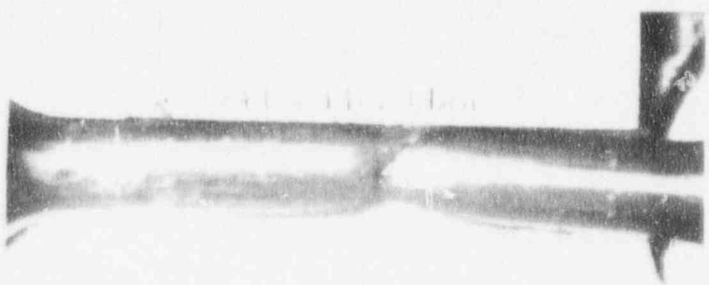
Figure 5-23 Tensile Properties for the Prairie Island Unit 1 Reactor Vessel Weld Metal



Specimen N7 Tested at 125°F

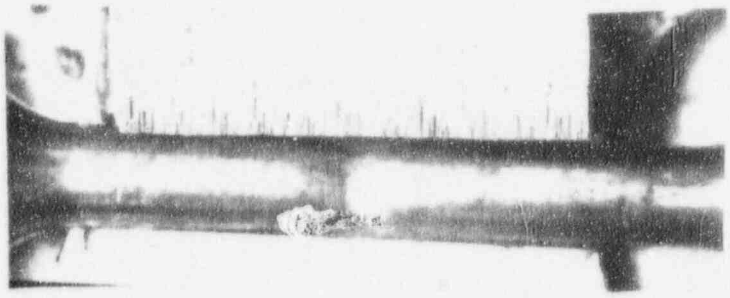


Specimen N8 Tested at 250°F



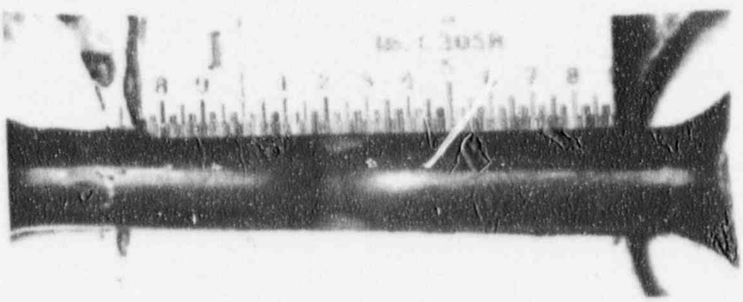
Specimen N9 Tested at 550°F

Figure 5-24 Fractured Tensile Specimens from the Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C (Tangential Orientation)



Specimen S7 Tested at 125°F

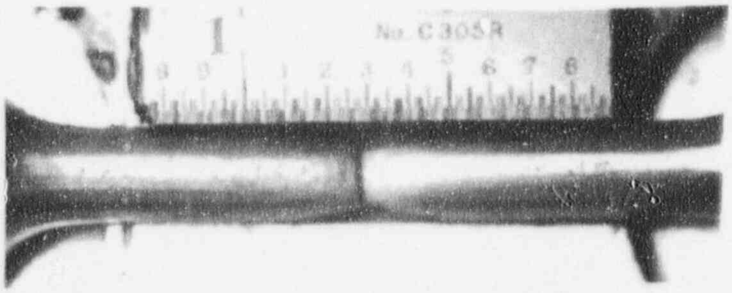
Specimen S8 Tested at 200°F



Specimen S9 Tested at 550°F

Figure 5-25 Fractured Tensile Specimens from the Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C (Axial Orientation)

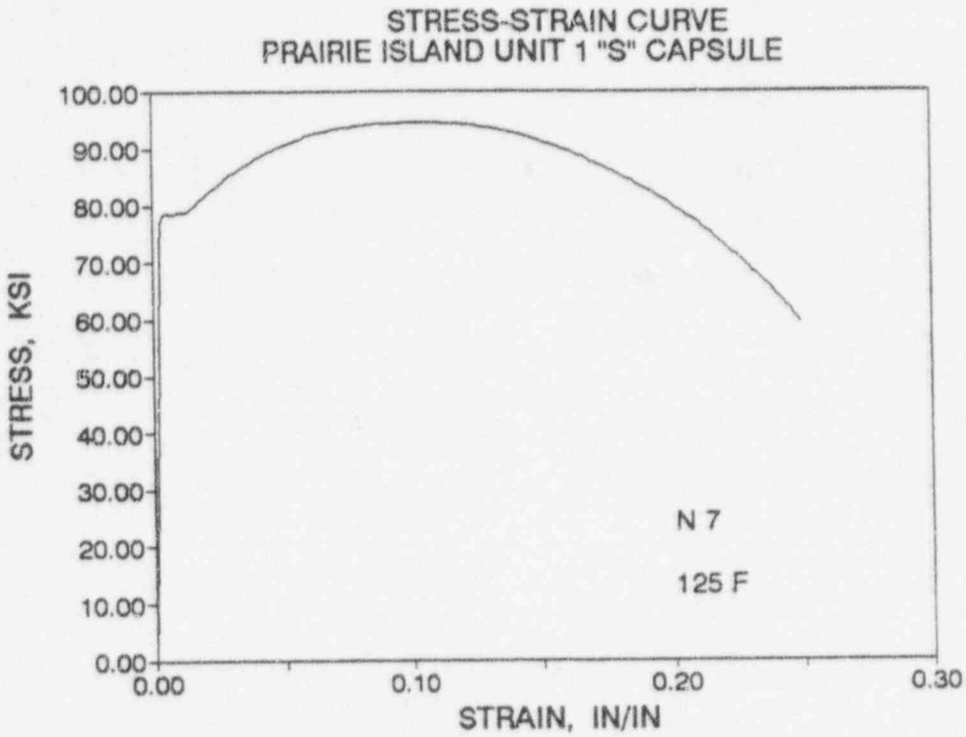
Specimen W7 Tested at 125°F



Specimen W8 Tested at 200°F

Specimen W9 Tested at 550°F

Figure 5-26 Fractured Tensile Specimens from the Prairie Island Unit 1 Reactor Vessel Weld Metal



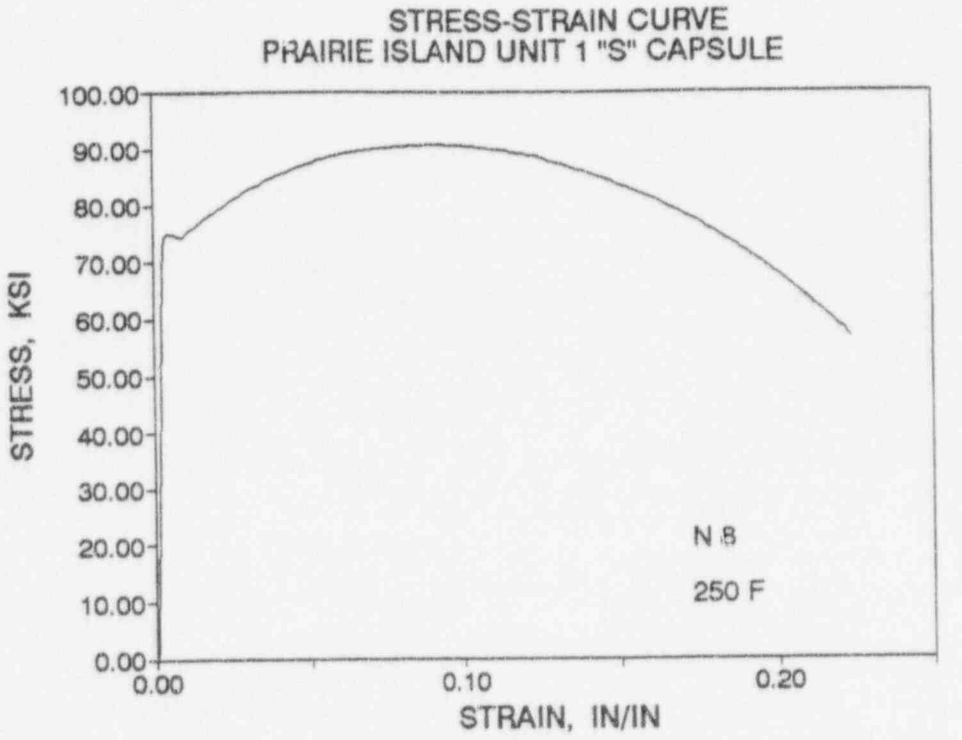


Figure 5-27 Engineering Stress-Strain Curves for Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C Tensile Specimens N7 and N8 (Tangential Orientation)

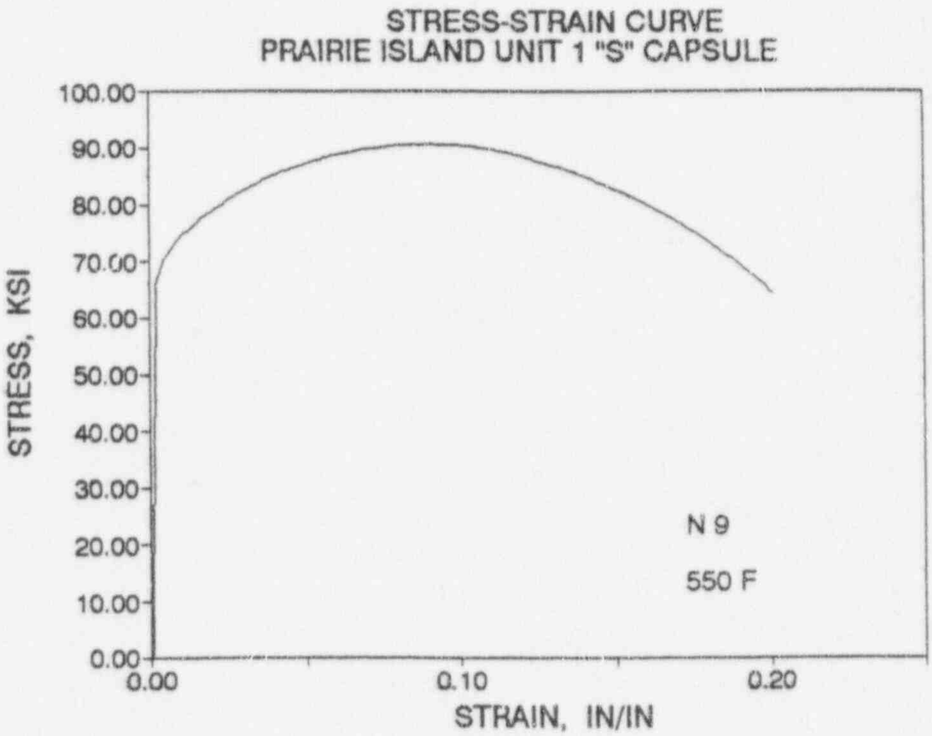
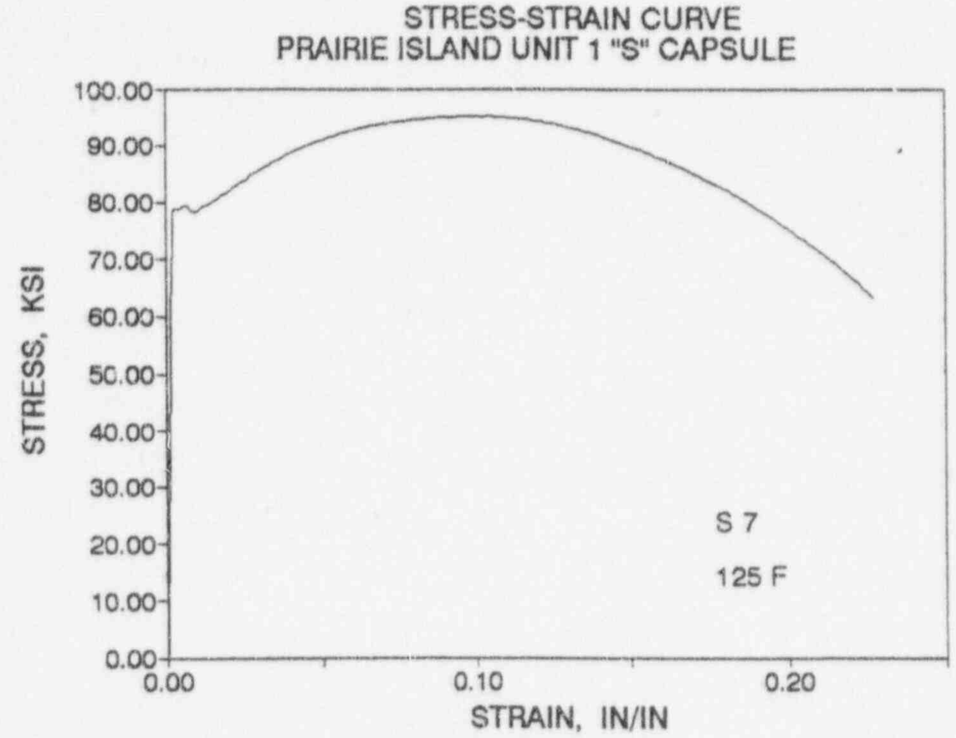


Figure 5-28 Engineering Stress-Strain Curve for Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C Tensile Specimen N9 (Tangential Orientation)



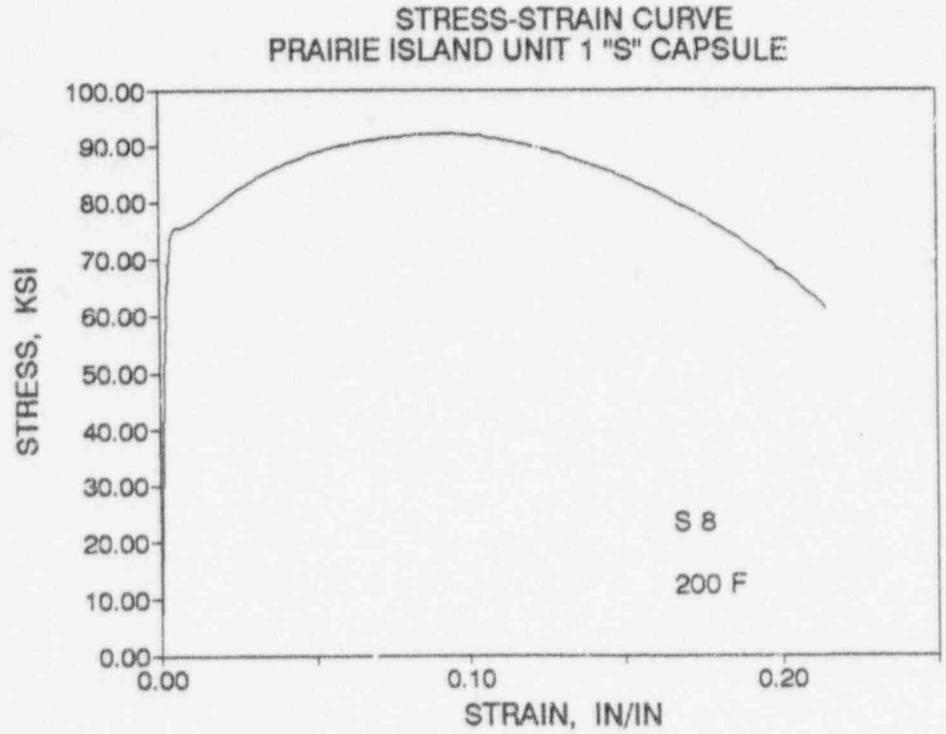


Figure 5-29 Engineering Stress-Strain Curves for Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C Tensile Specimens S7 and S8 (Axial Orientation)

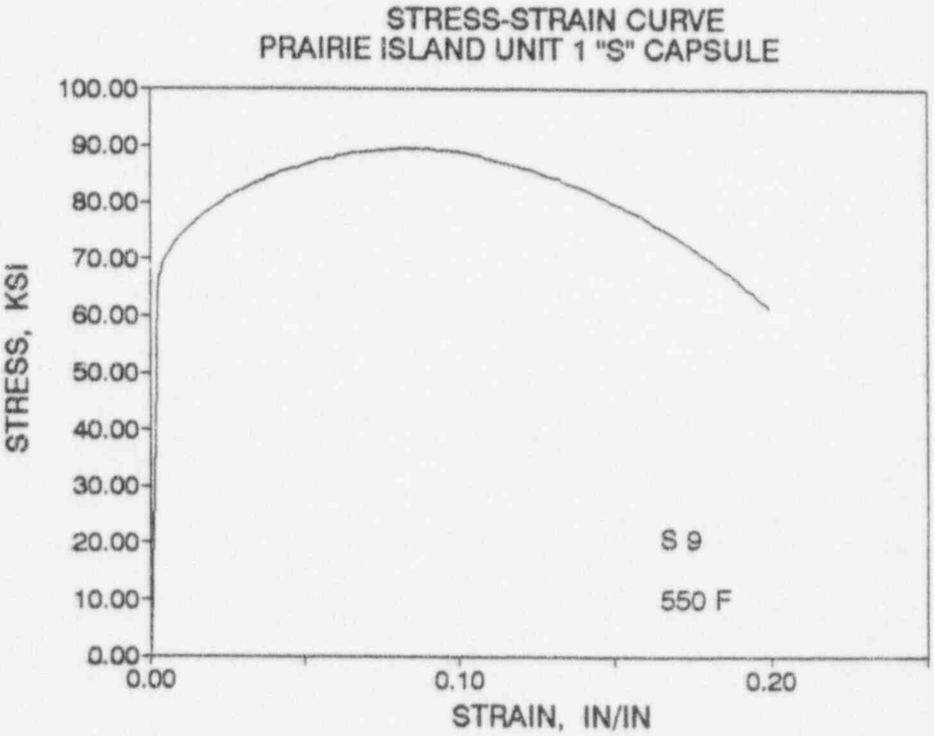


Figure 5-30 Engineering Stress-Strain Curve for Prairie Island Unit 1 Reactor Vessel Intermediate Shell Forging C Tensile Specimen S9 (Axial Orientation)

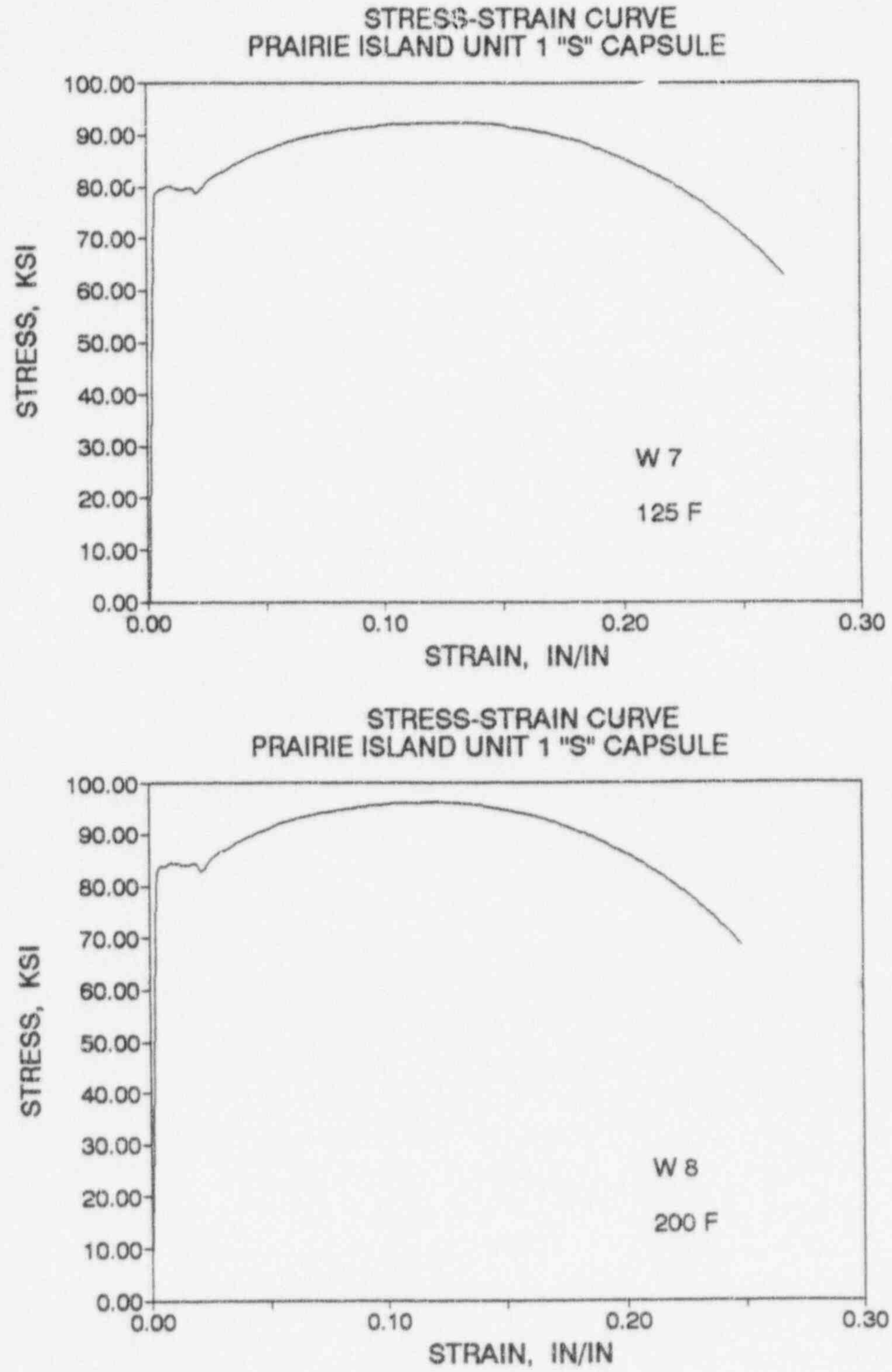


Figure 5-31 Engineering Stress-Strain Curves for Prairie Island Unit 1 Reactor Vessel Weld Metal Tensile Specimens W7 and W8

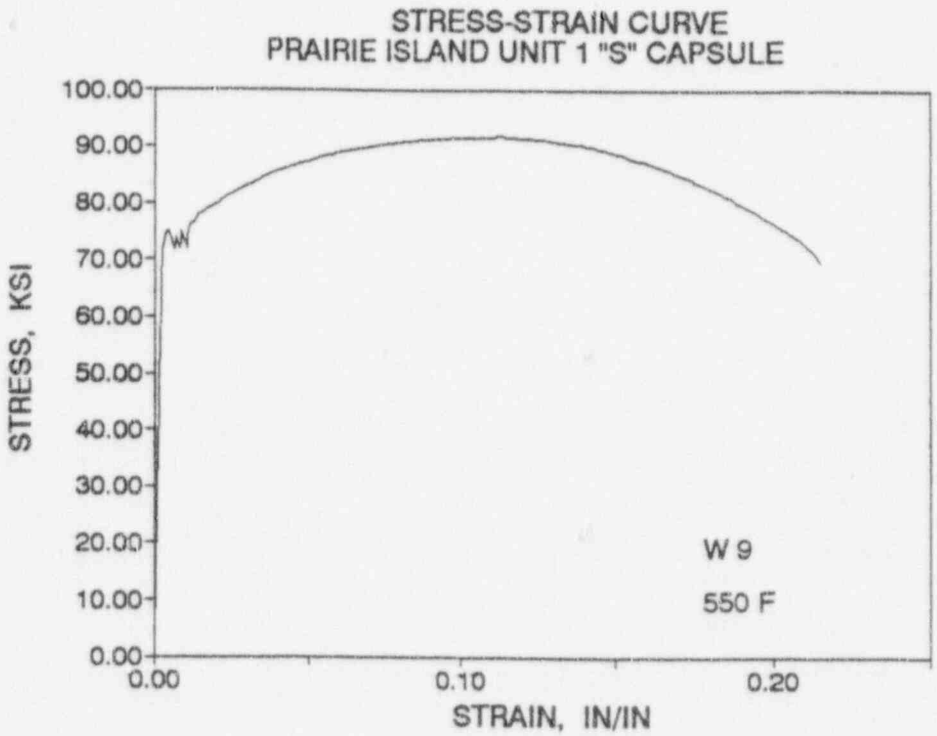


Figure 5-32 Engineering Stress-Strain Curve for Prairie Island Unit 1 Reactor Vessel Weld Metal Tensile Specimen W9

6.0 RADIATION ANALYSIS AND NEUTRON DOSIMETRY

6.1 Introduction

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

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

Because of this potential shift away from a threshold fluence toward an energy dependent damage function for data correlation, ASTM Standard Practice E853[17], "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[18], "Characterizing Neutron Exposures in Ferritic 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 Capsule S, withdrawn at the end of the seventeenth fuel cycle. Also included is an update of the dosimetry evaluation for Capsules R, P, and V withdrawn at the end of the ninth, fifth, and first fuel cycles, respectively. This update is based on current state-of-the-art methodology and nuclear data including recently released neutron transport and dosimetry cross-section libraries derived from the ENDF/B-VI data base. This report provides a consistent up-to-date neutron exposure data base for use in evaluating the material properties of the Prairie Island Unit 1 reactor vessel.

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

6.2 Discrete Ordinates Analysis

A plan view of the reactor geometry at the core midplane is shown in Figure 4-1. Six irradiation capsules attached to the thermal shield are included in the reactor design to constitute the reactor vessel surveillance program. The capsules are located at azimuthal angles of 57°, 67°, 77°, 237°, 247°, and 257° 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 approximately 1-inch square and approximately 63 inches in height. The containers are positioned axially such that the test specimens are centered on the core midplane, thus spanning the central 5.25 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 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 capsules 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, ½T, 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 forward calculation provided the means to:

1 - Evaluate neutron dosimetry obtained from surveillance capsules,
2 - Relate dosimetry results to key locations at the inner radius and through the thickness of the reactor vessel wall,
3 - Enable a direct comparison of analytical prediction with measurement, and
4 - Establish a mechanism for projection of reactor vessel exposure as the design of each new fuel cycle evolves.

The forward transport calculation for the reactor model summarized in Figures 4-1 and 6-1 was carried out in R,θ geometry using the DORT two-dimensional discrete ordinates code Version 2.7.3[19] and the BUGLE-93 cross-section library[20]. The BUGLE-93 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 2-loop plants. Inherent in the development of this reference core power distribution is the use of an out-in fuel management strategy; i.e., fresh fuel on the core periphery. Furthermore, for the peripheral fuel assemblies, the neutron source was increased by a 2σ margin derived from the statistical evaluation of plant-to-plant and cycle-to-cycle variations in peripheral power. Since it is unlikely that any single reactor would exhibit power levels on the core periphery at the nominal + 2σ value for a large number of fuel cycles, the use of this reference distribution is expected to yield somewhat conservative results.

All adjoint calculations were also carried out using an S_8 order of angular quadrature and the P_3 cross-section approximation from the BUGLE-93 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 φ(E > 1.0 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,θ)	=	φ(E > 1.0 MeV) at radius r and azimuthal angle θ.
	I(r,θ,E)	=	Adjoint source importance function at radius r, azimuthal angle θ, and neutron source energy E.
	S(r,θ,E)	=	Neutron source strength at core location r,θ and energy E.

Although the adjoint importance functions used in this analysis were based on a response function defined by the threshold neutron flux φ(E > 1.0 MeV), prior calculations[21] have shown that, while the implementation of low leakage loading patterns significantly impacts both the magnitude and spatial distribution of the neutron field, changes in the relative neutron energy spectrum are of second order. Thus, for a given location, the ratio of [dpa/sec]/[φ(E > 1.0 MeV)] is insensitive to changing core source distributions. In the application of these adjoint importance functions to the Prairie Island Unit 1 reactor, therefore, the iron atom displacement rates (dpa/sec) and the neutron flux φ(E > 0.1 MeV) were computed on a cycle-specific basis by using [dpa/sec]/[φ(E > 1.0 MeV)] and [φ(E > 0.1 MeV)]/[φ(E > 1.0 MeV)] ratios from the forward analysis in conjunction with the cycle specific φ(E > 1.0 MeV) solutions from the individual adjoint evaluations.

The reactor core power distributions used in the plant specific adjoint calculations were taken from the fuel cycle design reports for the first seventeen operating cycles of Prairie Island Unit 1 [22 thru 38].

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 capsule irradiation periods and provide the means to correlate dosimetry results with the corresponding exposure of the reactor vessel wall.

In Table 6-1, the calculated exposure parameters [φ(E > 1.0 MeV), φ(E > 0.1 MeV), and dpa/sec] are given at the geometric center of the three azimuthally symmetric surveillance capsule positions (13°, 23°, and 33°) 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 through 17 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:

$$\phi_{1/4T}(0^\circ) = \phi(168.04,\ 0^\circ)\ F(172.25,\ 0^\circ)$$

where:

	$\phi_{1/4T}(0^\circ)$	=	Projected neutron flux at the ¼T position on the 0° azimuth.
	$\phi(168.04, 0^\circ)$	=	Projected or calculated neutron flux at the vessel inner radius on the 0° azimuth.
	$F(172.25, 0^\circ)$	=	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 Prairie Island Unit 1 surveillance program are listed in Table 6-6. Also given in Table 6-6 are the primary nuclear reactions and associated nuclear constants that were used in the evaluation of the neutron energy spectrum within the surveillance capsules and in the subsequent determination of the various exposure parameters of interest [ϕ(E > 1.0 MeV), ϕ(E > 0.1 MeV), dpa/sec]. The relative locations of the neutron sensors within the capsules are shown in Figure 4-2. The iron, nickel, copper, 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[39 through 50, 55, 56]. 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 Prairie Island Unit 1 reactor was obtained from NUREG-0020, "Licensed Operating Reactors Status Summary Report," for the Cycles 1 through 17 operating period. (For the last two months of Cycle 17, this data was obtained directly from Northern States Power Company personnel, i.e., J. E. Schaefer.) The irradiation history applicable to the exposure of Capsules S, R, P, and V 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 . .adiation 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 Capsules S, R, P, and V, the flux level term in the reaction rate calculations was developed from the plant-specific analysis provided in Table 6-1. Measured and saturated reaction product specific activities as well as the derived full power reaction rates are listed in Table 6-8. The specific activities and 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 specific activities and reaction rates for the ^{237}Np sensors as well.

Values of key fast neutron exposure parameters were derived from the measured reaction rates using the FERRET least squares adjustment code[51]. 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) to the measured reaction rate data. The "measured" exposure parameters along with the associated uncertainties were then obtained from the adjusted 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[52]. 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[53], 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[54]. 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 evaluations of the Capsules S, R, P, and V dosimetry are given in Table 6-9. The data summarized in this table include fast neutron exposure evaluations in terms of $\Phi(E > 1.0 \text{ MeV})$, $\Phi(E > 0.1 \text{ MeV})$, and dpa. In general, excellent results were achieved in the fits of the adjusted spectra to the individual measured reaction rates. The measured and FERRET adjusted 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 adjusted spectra match the measured reaction rates to better than 9%. The adjusted 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 measured and calculated fluence at the center of each capsule are presented. The results for the Capsules S, R, P, and V dosimetry evaluations (M/C ratios of 0.99 for $\Phi(E > 1.0\ MeV)$) are consistent with results obtained from similar evaluations of dosimetry from other reactors using methodologies based on ENDF/B-VI cross-sections.

6.4 Projections of Reactor Vessel Exposure

The best estimate exposure of the Prairie Island Unit 1 reactor vessel was developed using a combination of absolute plant specific transport calculations and all available plant specific measurement data. In the case of Prairie Island Unit 1, the measurement data base consists of 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 measurement/calculation (M/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 Prairie Island Unit 1, the derived plant specific bias factors were 0.99, 1.07, and 1.03 for $\Phi(E > 1.0\ MeV)$, $\Phi(E > 0.1\ MeV)$, and dpa, respectively. Bias factors of this magnitude are fully consistent with experience using the BUGLE-93 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 M/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 Prairie Island Unit 1, the derived uncertainties in the bias factor, K, and the additional uncertainty from the analytical sensitivity studies combine to yield a net uncertainty of ±12%.

Based on this best estimate approach, neutron exposure projections at key locations on the reactor vessel inner radius are given in Table 6-13. Along with the current (18.12 EFPY) exposure, projections are also provided for exposure periods of 24 EFPY and 35 EFPY. Projections for future operation were based on the assumption that the average exposure rates averaged over the Cycles 13 through 17 irradiation period would continue to be applicable throughout plant life.

In the calculation of exposure gradients within the reactor vessel wall for the Prairie Island Unit 1 reactor vessel, exposure projections to 24, and 35 EFPY were also employed. Data based on both a $\Phi(E > 1.0\ \text{MeV})$ slope and a plant-specific dpa slope through the vessel wall are provided in Table 6-14.

In order to access RT_{NDT} versus fluence curves, dpa equivalent fast neutron fluence levels for the ¼T, ½T and ¾T positions were defined by the relations:

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

$$\phi(\tfrac{1}{2}T) = \phi(0T)\ \frac{dpa(\tfrac{1}{2}T)}{dpa(0T)}$$

and

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

Using this approach results in the dpa equivalent fluence values listed in Table 6-14. In Table 6-15 updated lead factors are listed for each of the Prairie Island Unit 1 surveillance capsules. Lead factor data based on the accumulated fluence through Cycle 17 are provided for each remaining capsule.

FIGURE 6-1

PLAN VIEW OF A REACTOR VESSEL SURVEILLANCE CAPSULE

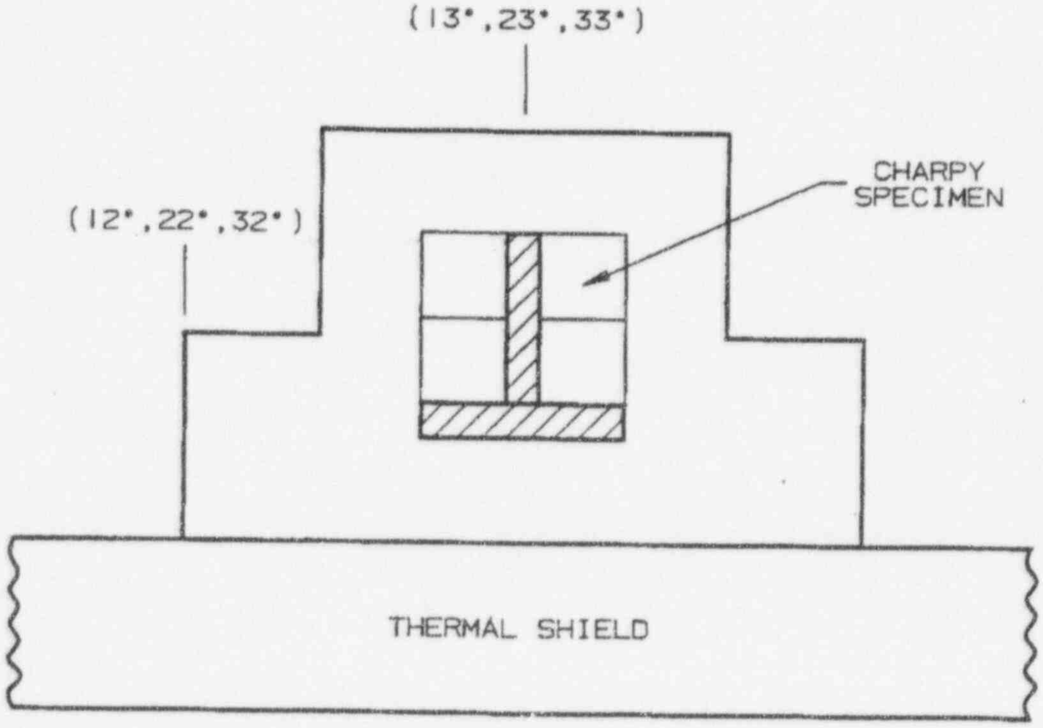


TABLE 6-1

CALCULATED FAST NEUTRON EXPOSURE RATES AND IRON ATOM DISPLACEMENT RATES AT THE SURVEILLANCE CAPSULE CENTER

	ϕ(E > 1.0 MeV) (n/cm^2-sec)		
Cycle No.	13°	23°	33°
Reference	1.59e+11	9.35e+10	8.83e+10
1	1.421e+11	8.131e+10	7.656e+10
2	1.279e+11	7.730e+10	7.285e+10
3	1.568e+11	8.703e+10	7.931e+10
4	1.507e+11	8.943e+10	8.431e+10
5	1.586e+11	8.936e+10	8.304e+10
6	1.593e+11	9.117e+10	8.515e+10
7	1.318e+11	8.149e+10	8.422e+10
8	1.729e+11	9.813e+10	9.248e+10
9	1.256e+11	8.338e+10	8.098e+10
10	1.827e+11	9.315e+10	8.195e+10
11	1.825e+11	1.054e+11	9.506e+10
12	1.349e+11	9.243e+10	8.773e+10
13	1.004e+11	7.256e+10	6.842e+10
14	8.159e+10	5.947e+10	5.809e+10
15	8.218e+10	5.828e+10	5.672e+10
16	9.478e+10	7.061e+10	6.403e+10
17	9.668e+10	7.086e+10	6.241e+10
	ϕ(E > 0.1 MeV) (n/cm^2-sec)		
Cycle No.	13°	23°	33°
Reference	6.02e+11	3.22e+11	3.11e+11
1	5.384e+11	2.797e+11	2.695e+11
2	4.848e+11	2.659e+11	2.564e+11
3	5.942e+11	2.994e+11	2.792e+11
4	5.712e+11	3.077e+11	2.968e+11
5	6.012e+11	3.074e+11	2.923e+11
6	6.036e+11	3.136e+11	2.997e+11
7	4.996e+11	2.803e+11	2.964e+11
8	6.554e+11	3.376e+11	3.255e+11
9	4.761e+11	2.868e+11	2.850e+11
10	6.926e+11	3.205e+11	2.885e+11
11	6.917e+11	3.626e+11	3.346e+11
12	5.111e+11	3.180e+11	3.088e+11
13	3.804e+11	2.496e+11	2.409e+11
14	3.092e+11	2.046e+11	2.045e+11
15	3.115e+11	2.005e+11	1.997e+11
16	3.592e+11	2.429e+11	2.254e+11
17	3.664e+11	2.438e+11	2.197e+11

TABLE 6-1 cont'd

CALCULATED FAST NEUTRON EXPOSURE RATES AND IRON ATOM DISPLACEMENT RATES AT THE SURVEILLANCE CAPSULE CENTER

	Displacement Rate (dpa/sec)		
Cycle No.	13°	23°	33°
Reference	2.83e-10	1.59e-10	1.52e-10
1	2.529e-10	1.382e-10	1.317e-10
2	2.277e-10	1.314e-10	1.253e-10
3	2.791e-10	1.479e-10	1.364e-10
4	2.682e-10	1.520e-10	1.450e-10
5	2.824e-10	1.519e-10	1.428e-10
6	2.835e-10	1.550e-10	1.465e-10
7	2.346e-10	1.385e-10	1.449e-10
8	3.078e-10	1.668e-10	1.591e-10
9	2.236e-10	1.418e-10	1.393e-10
10	3.253e-10	1.584e-10	1.410e-10
11	3.249e-10	1.792e-10	1.635e-10
12	2.401e-10	1.571e-10	1.509e-10
13	1.787e-10	1.234e-10	1.177e-10
14	1.452e-10	1.011e-10	9.992e-11
15	1.463e-10	9.907e-11	9.756e-11
16	1.687e-10	1.200e-10	1.101e-10
17	1.721e-10	1.205e-10	1.073e-10

TABLE 6-2

CALCULATED AZIMUTHAL VARIATION OF FAST NEUTRON EXPOSURE RATES AND IRON ATOM DISPLACEMENT RATES AT THE REACTOR VESSEL CLAD/BASE METAL INTERFACE

	$\phi(E > 1.0$ MeV) (n/cm^2-sec)			
Cycle No.	0°	15°	30°	45°
Reference	5.32e+10	3.25e+10	2.22e+10	1.87e+10
1	4.827e+10	2.902e+10	1.925e+10	1.676e+10
2	4.236e+10	2.645e+10	1.838e+10	1.581e+10
3	5.266e+10	3.192e+10	2.016e+10	1.794e+10
4	4.994e+10	3.096e+10	2.123e+10	1.810e+10
5	5.322e+10	3.233e+10	2.096e+10	1.866e+10
6	5.327e+10	3.248e+10	2.146e+10	1.833e+10
7	4.103e+10	2.717e+10	2.056e+10	1.895e+10
8	5.870e+10	3.510e+10	2.325e+10	1.908e+10
9	4.436e+10	2.654e+10	2.036e+10	1.676e+10
10	6.215e+10	3.667e+10	2.096e+10	1.951e+10
11	6.159e+10	3.720e+10	2.439e+10	1.795e+10
12	4.658e+10	2.878e+10	2.235e+10	1.741e+10
13	3.148e+10	2.196e+10	1.749e+10	1.549e+10
14	2.549e+10	1.791e+10	1.468e+10	1.366e+10
15	2.532e+10	1.794e+10	1.433e+10	1.357e+10
16	2.941e+10	2.098e+10	1.666e+10	1.384e+10
17	2.931e+10	2.135e+10	1.642e+10	1.329e+10
	$\phi(E > 0.1$ MeV) (n/cm^2-sec)			
Cycle No.	0°	15°	30°	45°
Reference	1.46e+11	9.45e+10	6.05e+10	4.91e+10
1	1.323e+11	8.444e+10	5.256e+10	4.407e+10
2	1.161e+11	7.696e+10	5.017e+10	4.158e+10
3	1.443e+11	9.289e+10	5.503e+10	4.719e+10
4	1.368e+11	9.009e+10	5.797e+10	4.761e+10
5	1.458e+11	9.408e+10	5.722e+10	4.907e+10
6	1.460e+11	9.451e+10	5.859e+10	4.821e+10
7	1.124e+11	7.907e+10	5.612e+10	4.984e+10
8	1.608e+11	1.021e+11	6.348e+10	5.019e+10
9	1.216e+11	7.723e+10	5.559e+10	4.409e+10
10	1.703e+11	1.067e+11	5.722e+10	5.131e+10
11	1.688e+11	1.082e+11	6.658e+10	4.721e+10
12	1.276e+11	8.374e+10	6.101e+10	4.579e+10
13	8.626e+10	6.390e+10	4.774e+10	4.073e+10
14	6.984e+10	5.213e+10	4.008e+10	3.593e+10
15	6.937e+10	5.220e+10	3.912e+10	3.569e+10
16	8.058e+10	6.104e+10	4.549e+10	3.640e+10
17	8.031e+10	6.212e+10	4.482e+10	3.494e+10

TABLE 6-2 cont'd

CALCULATED AZIMUTHAL VARIATION OF FAST NEUTRON EXPOSURE RATES AND IRON ATOM DISPLACEMENT RATES AT THE REACTOR VESSEL CLAD/BASE METAL INTERFACE

	Displacement Rate (dpa/sec)			
Cycle No.	0°	15°	30°	45°
Reference	8.68e-11	5.46e-11	3.65e-11	3.03e-11
1	7.869e-11	4.875e-11	3.158e-11	2.715e-11
2	6.904e-11	4.443e-11	3.014e-11	2.561e-11
3	8.584e-11	5.363e-11	3.306e-11	2.907e-11
4	8.141e-11	5.201e-11	3.482e-11	2.932e-11
5	8.675e-11	5.431e-11	3.437e-11	3.023e-11
6	8.683e-11	5.456e-11	3.520e-11	2.970e-11
7	6.688e-11	4.565e-11	3.371e-11	3.070e-11
8	9.568e-11	5.896e-11	3.814e-11	3.092e-11
9	7.231e-11	4.459e-11	3.339e-11	2.716e-11
10	1.013e-10	6.160e-11	3.438e-11	3.161e-11
11	1.004e-10	6.249e-11	4.000e-11	2.908e-11
12	7.592e-11	4.834e-11	3.665e-11	2.821e-11
13	5.132e-11	3.689e-11	2.868e-11	2.509e-11
14	4.154e-11	3.010e-11	2.408e-11	2.213e-11
15	4.127e-11	3.014e-11	2.350e-11	2.198e-11
16	4.794e-11	3.524e-11	2.733e-11	2.242e-11
17	4.778e-11	3.586e-11	2.692e-11	2.152e-11

TABLE 6-3

RELATIVE RADIAL DISTRIBUTION OF $\phi(E > 1.0\ MeV)$
WITHIN THE REACTOR VESSEL WALL

RADIUS (cm)	AZIMUTHAL ANGLE 0°	15°	30°	45°
168.04	1.000	1.000	1.000	1.000
168.27	0.987	0.987	0.985	0.987
168.88	0.940	0.942	0.937	0.942
169.75	0.862	0.865	0.857	0.866
170.93	0.754	0.757	0.749	0.760
172.25	0.639	0.644	0.636	0.647
173.53	0.540	0.546	0.539	0.550
174.98	0.444	0.451	0.444	0.454
176.46	0.362	0.370	0.363	0.372
177.58	0.308	0.317	0.311	0.318
179.03	0.250	0.259	0.253	0.260
180.66	0.196	0.206	0.201	0.206
181.63	0.169	0.179	0.175	0.178
182.60	0.144	0.154	0.151	0.154
184.06	0.110	0.122	0.120	0.122
184.87	0.101	0.113	0.112	0.113

Note: Base Metal Inner Radius = 168.04 cm
Base Metal ¼T = 172.25 cm
Base Metal ½T = 176.46 cm
Base Metal ¾T = 180.66 cm
Base Metal Outer Radius = 184.87 cm

TABLE 6-4

RELATIVE RADIAL DISTRIBUTION OF $\phi(E > 0.1\ MeV)$
WITHIN THE REACTOR VESSEL WALL

RADIUS		AZIMUTHAL ANGLE		
(cm)	0°	15°	30°	45°
168.04	1.000	1.000	1.000	1.000
168.27	1.005	1.007	1.005	1.007
168.88	1.002	1.007	1.004	1.008
169.75	0.980	0.990	0.985	0.992
170.93	0.934	0.948	0.945	0.953
172.25	0.873	0.891	0.889	0.899
173.53	0.809	0.831	0.831	0.841
174.98	0.736	0.763	0.763	0.773
176.46	0.662	0.693	0.694	0.703
177.58	0.606	0.640	0.642	0.650
179.03	0.536	0.573	0.577	0.582
180.66	0.461	0.502	0.507	0.509
181.63	0.416	0.458	0.466	0.465
182.60	0.369	0.415	0.423	0.421
184.06	0.298	0.348	0.361	0.357
184.87	0.276	0.327	0.343	0.339

Note: Base Metal Inner Radius = 168.04 cm
Base Metal ¼T = 172.25 cm
Base Metal ½T = 176.46 cm
Base Metal ¾T = 180.66 cm
Base Metal Outer Radius = 184.87 cm

TABLE 6-5

RELATIVE RADIAL DISTRIBUTION OF dpa/sec
WITHIN THE REACTOR VESSEL WALL

RADIUS (cm)	AZIMUTHAL ANGLE 0°	15°	30°	45°
168.04	1.000	1.000	1.000	1.000
168.27	0.988	0.990	0.988	0.989
168.88	0.951	0.955	0.950	0.954
169.75	0.889	0.896	0.889	0.857
170.93	0.804	0.814	0.805	0.812
172.25	0.712	0.726	0.716	0.723
173.53	0.630	0.648	0.638	0.644
174.98	0.547	0.568	0.558	0.563
176.46	0.472	0.495	0.486	0.490
177.58	0.420	0.445	0.436	0.439
179.03	0.360	0.386	0.379	0.380
180.66	0.301	0.328	0.322	0.322
181.63	0.267	0.296	0.291	0.289
182.60	0.234	0.264	0.261	0.258
184.06	0.187	0.219	0.220	0.216
184.87	0.173	0.206	0.208	0.205

Note: Base Metal Inner Radius = 168.04 cm
Base Metal ¼T = 172.25 cm
Base Metal ½T = 176.46 cm
Base Metal ¾T = 180.66 cm
Base Metal Outer Radius = 184.87 cm

TABLE 6-6

NUCLEAR PARAMETERS USED IN THE EVALUATION OF NEUTRON SENSORS

Monitor Material	Reaction of Interest	Target Atom Fraction	Response Range	Product Half-life	Fission Yield (%)
Copper	$^{63}Cu\ (n,\alpha)$	0.6917	E > 4.7 MeV	5.271 y	
Iron	$^{54}Fe\ (n,p)$	0.0580	E > 1.0 MeV	312.5 d	
Nickel	$^{58}Ni\ (n,p)$	0.6827	E > 1.0 MeV	70.78 d	
Uranium-238	$^{238}U\ (n,f)$	0.9996	E > 0.4 MeV	30.17 y	6.00
Neptunium-237	$^{237}Np\ (n,f)$	1.0000	E > 0.08 MeV	30.17 y	6.27
Cobalt-Al	$^{59}Co\ (n,\gamma)$	0.0015	E > 0.015 MeV	5.271 y	

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

TABLE 6-7

MONTHLY THERMAL GENERATION DURING THE FIRST SEVENTEEN FUEL CYCLES
OF THE PRAIRIE ISLAND UNIT 1 REACTOR

Cycle 1		Cycle 2		Cycle 3		Cycle 4	
Month	Thermal Gen. MWt-hr	Month	Thermal Gen. MWt-hr	Month	Thermal Gen. MWt-hr	Month	Thermal Gen. MWt-hr
Dec-73	128000	Apr-76	0	Apr-77	0	Apr-78	375189
Jan-74	0	May-76	730614	May-77	1027843	May-78	1216949
Feb-74	385824	Jun-76	1107963	Jun-77	1093671	Jun-78	1128613
Mar-74	104496	Jul-76	1112551	Jul-77	1202230	Jul-78	904285
Apr-74	379161	Aug-76	1167605	Aug-77	1208004	Aug-78	1065847
May-74	0	Sep-76	763875	Sep-77	1139867	Sep-78	1032140
Jun-74	0	Oct-76	1219726	Oct-77	1159500	Oct-78	1218111
Jul-74	779680	Nov-76	1151899	Nov-77	1176823	Nov-78	1100717
Aug-74	933538	Dec-76	1219726	Dec-77	1204540	Dec-78	1198352
Sep-74	145829	Jan-77	1192135	Jan-78	1192991	Jan-79	1208813
Oct-74	192888	Feb-77	1020845	Feb-78	1042857	Feb-79	1098392
Nov-74	1113715	Mar-77	583997	Mar-78	950466	Mar-79	1146048
Dec-74	1184901					Apr-79	184809
Jan-75	988566						
Feb-75	886380						
Mar-75	1195237						
Apr-75	917380						
May-75	694637						
Jun-75	966751						
Jul-75	966751						
Aug-75	819786						
Sep-75	1135530						
Oct-75	1055159						
Nov-75	1133234						
Dec-75	1184901						
Jan-76	1191790						
Feb-76	831268						
Mar-76	907705						

TABLE 6-7 cont'd

MONTHLY THERMAL GENERATION DURING THE FIRST SEVENTEEN FUEL CYCLES OF THE PRAIRIE ISLAND UNIT 1 REACTOR

Cycle 5		Cycle 6		Cycle 7		Cycle 8	
Month	Thermal Gen. MWt-hr	Month	Thermal Gen. MWt-hr	Month	Thermal Gen. MWt-hr	Month	Thermal Gen. MWt-hr
May-79	778462	Sep-80	0	Oct-81	68509	Dec-82	455376
Jun-79	1014740	Oct-80	133518	Nov-81	1122238	Jan-83	1080444
Jul-79	118710	Nov-80	1154538	Dec-81	1194009	Feb-83	629364
Aug-79	1055832	Dec-80	1212882	Jan-82	1208146	Mar-83	1214694
Sep-79	1116328	Jan-81	1209516	Feb-82	1088527	Apr-83	1180326
Oct-79	372109	Feb-81	1089462	Mar-82	1221195	May-83	1198584
Nov-79	533052	Mar-81	1226346	Apr-82	1151592	Jun-83	1131996
Dec-79	1171117	Apr-81	1168002	May-82	1170085	Jul-83	1194288
Jan-80	1214492	May-81	1216248	Jun-82	1183135	Aug-83	1198584
Feb-80	905162	Jun-81	1155660	Jul-82	1204884	Sep-83	1109442
Mar-80	1208785	Jul-81	1216248	Aug-82	1220108	Oct-83	1218990
Apr-80	1175683	Aug-81	1203906	Sep-82	1128763	Nov-83	1172808
May-80	1201936	Sep-81	627198	Oct-82	1199446	Dec-83	38664
Jun-80	1128884			Nov-82	493698		
Jul-80	401787						
Aug-80	904020						

Cycle 9		Cycle 10		Cycle 11		Cycle 12	
Month	Thermal Gen. MWt-hr	Month	Thermal Gen. MWt-hr	Month	Thermal Gen. MWt-hr	Month	Thermal Gen. MWt-hr
Jan-84	1053719	Feb-85	0	Apr-86	760857	May-87	107076
Feb-84	1104603	Mar-85	764836	May-86	1222014	Jun-87	1115895
Mar-84	1212731	Apr-85	1180670	Jun-86	1181914	Jul-87	1136890
Apr-84	1175628	May-85	1171123	Jul-86	1222014	Aug-87	1219821
May-84	1224392	Jun-85	1179610	Aug-86	1218848	Sep-87	1178880
Jun-84	1177748	Jul-85	1199765	Sep-86	1168195	Oct-87	1215622
Jul-84	1212731	Aug-85	1185974	Oct-86	1224125	Nov-87	1173632
Aug-84	1148065	Sep-85	1154150	Nov-86	1179803	Dec-87	1217722
Sep-84	1139585	Oct-85	1210373	Dec-86	1182969	Jan-88	1217722
Oct-84	813081	Nov-85	1179610	Jan-87	1213572	Feb-88	1138990
Nov-84	890467	Dec-85	1217798	Feb-87	781962	Mar-88	1027715
Dec-84	1135345	Jan-86	1084138	Mar-87	899099	Apr-88	1177831
Jan-85	323324	Feb-86	710736	Apr-87	186785	May-88	1216672
		Mar-86	82742			Jun-88	1176781
						Jul-88	1050810
						Aug-88	628806

TABLE 6-7 cont'd

MONTHLY THERMAL GENERATION DURING THE FIRST SEVENTEEN FUEL CYCLES OF THE PRAIRIE ISLAND UNIT 1 REACTOR

Cycle 13		Cycle 14		Cycle 15		Cycle 16	
Month	Thermal Gen. MWt-hr	Month	Thermal Gen. MWt-hr	Month	Thermal Gen. MWt-hr	Month	Thermal Gen. MWt-hr
Sep-88	52944	Feb-90	32301	Jun-91	2079	Nov-92	0
Oct-88	1212012	Mar-90	1204506	Jul-91	1180804	Dec-92	0
Nov-88	1171334	Apr-90	1185750	Aug-91	1048795	Jan-93	736230
Dec-88	1225572	May-90	1221177	Sep-91	1183922	Feb-93	1073237
Jan-89	1226615	Jun-90	1177415	Oct-91	1222381	Mar-93	1226705
Feb-89	1106665	Jul-90	1209716	Nov-91	1164173	Apr-93	1181079
Mar-89	1222443	Aug-90	1200338	Dec-91	1222381	May-93	1224631
Apr-89	1179678	Sep-90	1185750	Jan-92	1221342	Jun-93	1184190
May-89	1128834	Oct-90	1224303	Feb-92	1138187	Jul-93	1224631
Jun-89	1184893	Nov-90	1132611	Mar-92	1221342	Aug-93	1161377
Jul-89	1181764	Dec-90	1177415	Apr-92	1182883	Sep-93	1184190
Aug-89	1224529	Jan-91	1224303	May-92	1180804	Oct-93	1223594
Sep-89	1182807	Feb-91	1102394	Jun-92	1181843	Nov-93	1171747
Oct-89	1199496	Mar-91	1182625	Jul-92	1221342	Dec-93	1223693
Nov-89	1177592	Apr-91	1175331	Aug-92	1222381	Jan-94	1223693
Dec-89	949166	May-91	934638	Sep-92	958364	Feb-94	1097176
Jan-90	349418			Oct-92	563376	Mar-94	1223693
						Apr-94	1115842
						May-94	211554

TABLE 6-7 cont'd

MONTHLY THERMAL GENERATION DURING THE FIRST SEVENTEEN FUEL CYCLES OF THE PRAIRIE ISLAND UNIT 1 REACTOR

Cycle 17	
Month	Thermal Gen. MWt-hr
Jun-94	0
Jul-94	1085468
Aug-94	920848
Sep-94	1187328
Oct-94	1226425
Nov-94	1178068
Dec-94	1225396
Jan-95	1225396
Feb-95	1081353
Mar-95	1225396
Apr-95	1183212
May-95	1225396
Jun-95	1186299
Jul-95	1204818
Aug-95	1225396
Sep-95	1185270
Oct-95	1182183
Nov-95	1185270
Dec-95	1134855
Jan-96	151245

TABLE 6-8

MEASURED SENSOR ACTIVITIES AND REACTION RATES
SURVEILLANCE CAPSULE S
SATURATED ACTIVITIES AND REACTION RATES

Reaction	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co			
Top Middle	1.70e+05	2.49e+05	4.33e-17
Bottom Middle	1.83e+05	2.68e+05	4.66e-17
^{54}Fe (n,p) ^{54}Mn			
Top	1.30e+06	3.03e+06	4.60e-15
Top Middle	1.13e+06	2.63e+06	4.00e-15
Middle	1.17e+06	2.73e+06	4.14e-15
Bottom Middle	1.20e+06	2.80e+06	4.25e-15
Bottom	1.28e+06	2.98e+06	4.53e-15
^{58}Ni (n,p) ^{58}Co			
Middle	2.28e+06	3.58e+07	5.92e-15
^{59}Co (n,γ) ^{60}Co			
Top	3.87e+07	5.66e+07	3.55e-12
Bottom	3.86e+07	5.65e+07	3.54e-12
^{59}Co (n,γ) ^{60}Co (Cd)			
Top	1.41e+07	2.06e+07	1.33e-12
Bottom	1.43e+07	2.09e+07	1.35e-12
^{238}U (n,f) ^{137}Cs			
Middle	1.67e+06	5.21e+06	3.43e-14
^{237}Np (n,f) ^{137}Cs			
Middle	1.13e+07	3.52e+07	2.21e-13

TABLE 6-8 cont'd

MEASURED SENSOR ACTIVITIES AND REACTION RATES
SURVEILLANCE CAPSULE R
SATURATED ACTIVITIES AND REACTION RATES

Reaction	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co			
Top Middle	2.42e+05	4.29e+05	7.46e-17
Bottom Middle	2.50e+05	4.43e+05	7.70e-17
^{54}Fe (n,p) ^{54}Mn			
Top	2.74e+06	6.09e+06	9.25e-15
Top Middle	2.47e+06	5.49e+06	8.34e-15
Middle	2.56e+06	5.69e+06	8.64e-15
Bottom Middle	2.59e+06	5.76e+06	8.74e-15
Bottom	2.67e+06	5.93e+06	9.01e-15
^{58}Ni (n,p) ^{58}Co			
Middle	3.84e+06	7.58e+07	1.26e-14
^{59}Co (n,γ) ^{60}Co			
Top	7.41e+07	1.31e+08	8.31e-12
Bottom	8.13e+07	1.44e+08	9.12e-12
Bottom	8.16e+07	1.45e+08	9.15e-12
^{59}Co (n,γ) ^{60}Co (Cd)			
Top	2.96e+07	5.24e+07	3.46e-12
Bottom	3.01e+07	5.33e+07	3.51e-12
^{238}U (n,f) ^{137}Cs			
Middle	2.09e+06	1.20e+07	7.93e-14
^{237}Np (n,f) ^{137}Cs			
Middle	1.41e+07	8.12e+07	5.10e-1[illegible]

TABLE 6-8 cont'd

MEASURED SENSOR ACTIVITIES AND REACTION RATES
SURVEILLANCE CAPSULE P
SATURATED ACTIVITIES AND REACTION RATES

Reaction	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$			
Top Middle	1.27e+05	3.37e+05	5.86e-17
Bottom Middle	1.18e+05	3.13e+05	5.44e-17
$^{54}Fe\ (n,p)\ ^{54}Mn$			
Top	1.08e+06	3.78e+06	5.74e-15
Top Middle	8.41e+05	2.94e+06	4.47e-15
Bottom Middle	1.00e+06	3.50e+06	5.32e-15
Bottom	1.12e+06	3.92e+06	5.96e-15
$^{58}Ni\ (n,p)\ ^{58}Co$			
Middle	3.77e+05	4.75e+07	7.86e-15
$^{59}Co\ (n,\gamma)\ ^{60}Co$			
Top	2.64e+07	7.00e+07	4.34e-12
Bottom	3.15e+07	8.36e+07	5.18e-12
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)			
Top	9.34e+06	2.48e+07	1.57e-12
Bottom	9.92e+06	2.63e+07	1.67e-12
$^{238}U\ (n,f)\ ^{137}Cs$			
Middle	5.55e+05	5.42e+06	3.57e-14
$^{237}Np\ (n,f)\ ^{137}Cs$			
Middle	4.28e+06	4.18e+07	2.62e-13

TABLE 6-8 cont'd

MEASURED SENSOR ACTIVITIES AND REACTION RATES
SURVEILLANCE CAPSULE V
SATURATED ACTIVITIES AND REACTION RATES

Reaction	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$			
Top Middle	5.61e+04	3.60e+05	6.26e-17
Bottom Middle	6.35e+04	4.07e+05	7.08e-17
$^{54}Fe\ (n,p)\ ^{54}Mn$			
Top	2.23e+06	5.03e+06	7.65e-15
Top Middle	2.05e+06	4.63e+06	7.03e-15
Middle	2.09e+06	4.72e+06	7.17e-15
Bottom Middle	2.17e+06	4.90e+06	7.44e-15
Bottom	2.32e+06	5.24e+06	7.96e-15
$^{58}Ni\ (n,p)\ ^{58}Co$			
Middle	1.00e+07	5.16e+07	8.54e-15
$^{59}Co\ (n,\gamma)\ ^{60}Co$			
Top	1.90e+07	1.22e+08	7.71e-12
Bottom	2.23e+07	1.43e+08	9.05e-12
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)			
Top	8.25e+06	5.29e+07	3.49e-12
Bottom	7.68e+06	4.92e+07	3.25e-12
$^{238}U\ (n,f)\ ^{137}Cs$			
Middle	2.44e+05	7.82e+06	5.15e-14
$^{237}Np\ (n,f)\ ^{137}Cs$			
Middle	1.88e+06	6.03e+07	3.78e-13

TABLE 6-9

SUMMARY OF NEUTRON DOSIMETRY RESULTS
SURVEILLANCE CAPSULES S, R, P AND V

Measured Flux and Fluence for Capsule S				
Quantity	Flux	Quantity	Fluence	Uncertainty
	[n/cm^2-sec]		[n/cm^2]	
ϕ (E > 1.0 MeV)	7.024e+10	Φ (E > 1.0 MeV)	4.017e+19	8%
ϕ (E > 0.1 MeV)	2.769e+11	Φ (E > 0.1 MeV)	1.584e+20	15%
ϕ (E < 0.414 eV)	9.268e+10	Φ (E < 0.414 eV)	5.300e+19	19%
dpa/sec	1.278e-10	dpa	7.309e-02	11%

Measured Flux and Fluence for Capsule R				
Quantity	Flux	Quantity	Fluence	Uncertainty
	[n/cm^2-sec]		[n/cm^2]	
ϕ (E > 1.0 MeV)	1.645e+11	Φ (E > 1.0 MeV)	4.478e+19	8%
ϕ (E > 0.1 MeV)	6.675e+11	Φ (E > 0.1 MeV)	1.817e+20	15%
ϕ (E < 0.414 eV)	2.285e+11	Φ (E < 0.414 eV)	6.221e+19	19%
dpa/sec	3.011e-10	dpa	8.197e-02	11%

Measured Flux and Fluence for Capsule P				
Quantity	Flux	Quantity	Fluence	Uncertainty
	[n/cm^2-sec]		[n/cm^2]	
ϕ (E > 1.0 MeV)	8.501e+10	Φ (E > 1.0 MeV)	1.318e+19	8%
ϕ (E > 0.1 MeV)	3.221e+11	Φ (E > 0.1 MeV)	4.995e+19	15%
ϕ (E < 0.414 eV)	1.294e+11	Φ (E < 0.414 eV)	2.007e+19	18%
dpa/sec	1.518e-10	dpa	2.354e-02	10%

Measured Flux and Fluence for Capsule V				
Quantity	Flux	Quantity	Fluence	Uncertainty
	[n/cm^2-sec]		[n/cm^2]	
ϕ (E > 1.0 MeV)	1.276e+11	Φ (E > 1.0 MeV)	5.630e+18	8%
ϕ (E > 0.1 MeV)	5.102e+11	Φ (E > 0.1 MeV)	2.251e+19	15%
ϕ (E < 0.414 eV)	2.122e+11	Φ (E < 0.414 eV)	9.363e+18	19%
dpa/sec	2.337e-10	dpa	1.031e-02	11%

TABLE 6-10

COMPARISON OF MEASURED AND FERRET CALCULATED REACTION RATES AT THE SURVEILLANCE CAPSULE CENTER

Surveillance Capsule S			
	Reaction Rate (rps/nucleus)		
	Measured	Adjusted Calc.	M/C Adjusted
^{63}Cu (n,α)	4.49e-17	4.38e-17	1.03
^{54}Fe (n,p)	4.31e-15	4.42e-15	0.98
^{58}Ni (n,p)	5.92e-15	6.05e-15	0.98
^{238}U (n,f) (Cd)	2.40e-14	2.28e-14	1.05
^{237}Np (n,f) (Cd)	2.18e-13	2.07e-13	1.05
^{59}Co (n,γ)	3.54e-12	3.55e-12	1.00
^{59}Co (n,γ) (Cd)	1.34e-12	1.35e-12	0.99

Surveillance Capsule R			
	Reaction Rate (rps/nucleus)		
	Measured	Adjusted Calc.	M/C Adjusted
^{63}Cu (n,α)	7.58e-17	7.48e-17	1.01
^{54}Fe (n,p)	8.80e-15	9.04e-15	0.97
^{58}Ni (n,p)	1.26e-14	1.27e-14	0.99
^{238}U (n,f) (Cd)	5.61e-14	5.16e-14	1.09
^{237}Np (n,f) (Cd)	5.02e-13	4.88e-13	1.03
^{59}Co (n,γ)	8.86e-12	8.87e-12	1.00
^{59}Co (n,γ) (Cd)	3.49e-12	3.49e-12	1.00

TABLE 6-10 cont'd

COMPARISON OF MEASURED AND FERRET CALCULATED REACTION RATES AT THE SURVEILLANCE CAPSULE CENTER

Surveillance Capsule T			
	Reaction Rate (rps/nucleus)		
	Measured	Adjusted Calc.	M/C Adjusted
^{63}Cu (n,α)	5.65e-17	5.54e-17	1.02
^{54}Fe (n,p)	5.37e-15	5.57e-15	0.96
^{58}Ni (n,p)	7.87e-15	7.85e-15	1.00
^{238}U (n,f) (Cd)	2.85e-14	2.79e-14	1.02
^{237}Np (n,f) (Cd)	2.58e-13	2.46e-13	1.05
^{59}Co (n,γ)	4.76e-12	4.76e-12	1.00
^{59}Co (n,γ) (Cd)	1.62e-12	1.62e-12	1.00

Surveillance Capsule V			
	Reaction Rate (rps/nucleus)		
	Measured	Adjusted Calc.	M/C Adjusted
^{63}Cu (n,α)	6.67e-17	6.60e-17	1.01
^{54}Fe (n,p)	7.45e-15	7.62e-15	0.98
^{238}U (n,f) (Cd)	4.22e-14	4.08e-14	1.03
^{237}Np (n,f) (Cd)	3.72e-13	3.68e-13	1.01
^{59}Co (n,γ)	8.38e-12	8.39e-12	1.00
^{59}Co (n,γ) (Cd)	3.37e-12	3.37e-12	1.00

TABLE 6-11

ADJUSTED NEUTRON ENERGY SPECTRUM AT THE CENTER OF SURVEILLANCE CAPSULE

Capsule S					
Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73e+01	5.78e+06	28	9.12e-03	1.32e+10
2	1.49e+01	1.23e+07	29	5.53e-03	1.39e+10
3	1.35e+01	4.48e+07	30	3.35e-03	4.32e+09
4	1.16e+01	1.21e+08	31	2.84e-03	4.11e+09
5	1.00e+01	2.73e+08	32	2.40e-03	4.00e+09
6	8.61e+00	4.72e+08	33	2.03e-03	1.17e+10
7	7.41e+00	1.14e+09	34	1.23e-03	1.14e+10
8	6.07e+00	1.73e+09	35	7.49e-04	1.08e+10
9	4.97e+00	3.58e+09	36	4.54e-04	9.59e+09
10	3.68e+00	4.21e+09	37	2.75e-04	1.00e+10
11	2.87e+00	8.16e+09	38	1.67e-04	9.17e+09
12	2.23e+00	1.08e+10	39	1.01e-04	1.02e+10
13	1.74e+00	1.47e+10	40	6.14e-05	1.03e+10
14	1.35e+00	1.57e+10	41	3.73e-05	1.05e+10
15	1.11e+00	2.70e+10	42	2.26e-05	1.04e+10
16	8.21e-01	3.01e+10	43	1.37e-05	1.02e+10
17	6.39e-01	3.21e+10	44	8.31e-06	1.02e+10
18	4.98e-01	2.18e+10	45	5.04e-06	1.03e+10
19	3.88e-01	3.00e+10	46	3.06e-06	1.04e+10
20	3.02e-01	3.66e+10	47	1.86e-06	1.04e+10
21	1.83e-01	3.31e+10	48	1.13e-06	9.22e+09
22	1.11e-01	2.50e+10	49	6.83e-07	8.06e+09
23	6.74e-02	2.04e+10	50	4.14e-07	1.39e+10
24	4.09e-02	1.23e+10	51	2.51e-07	1.51e+10
25	2.[illegible]e-02	1.15e+10	52	1.52e-07	1.65e+10
26	1.99e-02	7.60e+09	53	9.24e-08	4.71e+10
27	1.50e-02	1.24e+10			

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

TABLE 6-11 cont'd

ADJUSTED NEUTRON ENERGY SPECTRUM AT THE CENTER OF SURVEILLANCE CAPSULE

Capsule R					
Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73e+01	8.52e+06	28	9.12e-03	3.08e+10
2	1.49e+01	1.83e+07	29	5.53e-03	3.26e+10
3	1.35e+01	6.93e+07	30	3.35e-03	1.02e+10
4	1.16e+01	1.93e+08	31	2.84e-03	9.75e+09
5	1.00e+01	4.49e+08	32	2.40e-03	9.58e+09
6	8.61e+00	8.17e+08	33	2.03e-03	2.84e+10
7	7.41e+00	2.05e+09	34	1.23e-03	2.79e+10
8	6.07e+00	3.32e+09	35	7.49e-04	2.66e+10
9	4.97e+00	7.41e+09	36	4.54e-04	2.40e+10
10	3.68e+00	9.30e+09	37	2.75e-04	2.53e+10
11	2.87e+00	1.86e+10	38	1.67e-04	2.42e+10
12	2.23e+00	2.55e+10	39	1.01e-04	2.60e+10
13	1.74e+00	3.55e+10	40	6.14e-05	2.61e+10
14	1.35e+00	3.84e+10	41	3.73e-05	2.62e+10
15	1.11e+00	6.68e+10	42	2.26e-05	2.60e+10
16	8.21e-01	7.46e+10	43	1.37e-05	2.55e+10
17	6.39e-01	7.97e+10	44	8.31e-06	2.53e+10
18	4.98e-01	5.34e+10	45	5.04e-06	2.53e+10
19	3.88e-01	7.30e+10	46	3.06e-06	2.53e+10
20	3.02e-01	8.74e+10	47	1.86e-06	2.53e+10
21	1.83e-01	7.86e+10	48	1.13e-06	2.25e+10
22	1.11e-01	5.91e+10	49	6.83e-07	2.00e+10
23	6.74e-02	4.78e+10	50	4.14e-07	3.60e+10
24	4.09e-02	2.90e+10	51	2.51e-07	3.82e+10
25	2.55e-02	2.70e+10	52	1.52e-07	4.08e+10
26	1.99e-02	1.77e+10	53	9.24e-08	1.14e+11
27	1.50e-02	2.88e+10			

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

TABLE 6-11 cont'd

ADJUSTED NEUTRON ENERGY SPECTRUM AT THE
CENTER OF SURVEILLANCE CAPSULE

Capsule P					
Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73e+01	7.22e+06	28	9.12e-03	1.50e+10
2	1.49e+01	1.54e+07	29	5.53e-03	1.58e+10
3	1.35e+01	5.65e+07	30	3.35e-03	4.87e+09
4	1.16e+01	1.54e+08	31	2.84e-03	4.66e+09
5	1.00e+01	3.47e+08	32	2.40e-03	4.57e+09
6	8.61e+00	6.03e+08	33	2.03e-03	1.35e+10
7	7.41e+00	1.47e+09	34	1.23e-03	1.32e+10
8	6.07e+00	2.23e+09	35	7.49e-04	1.26e+10
9	4.97e+00	4.54e+09	36	4.54e-04	1.13e+10
10	3.68e+00	5.24e+09	37	2.75e-04	1.18e+10
11	2.87e+00	1.01e+10	38	1.67e-04	1.11e+10
12	2.23e+00	1.32e+10	39	1.01e-04	1.21e+10
13	1.74e+00	1.76e+10	40	6.14e-05	1.22e+10
14	1.35e+00	1.87e+10	41	3.73e-05	1.23e+10
15	1.11e+00	3.18e+10	42	2.26e-05	1.22e+10
16	8.21e-01	3.49e+10	43	1.37e-05	1.19e+10
17	6.39e-01	3.70e+10	44	8.31e-06	1.19e+10
18	4.98e-01	2.51e+10	45	5.04e-06	1.20e+10
19	3.88e-01	3.42e+10	46	3.06e-06	1.20e+10
20	3.02e-01	4.16e+10	47	1.86e-06	1.20e+10
21	1.83e-01	3.74e+10	48	1.13e-06	1.09e+10
22	1.11e-01	2.83e+10	49	6.83e-07	9.74e+09
23	6.74e-02	2.30e+10	50	4.14e-07	1.72e+10
24	4.09e-02	1.39e+10	51	2.51e-07	1.96e+10
25	2.55e-02	1.30e+10	52	1.52e-07	2.24e+10
26	1.99e-02	8.58e+09	53	9.24e-08	7.01e+10
27	1.50e-02	1.40e+10			

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

TABLE 6-11 cont'd

ADJUSTED NEUTRON ENERGY SPECTRUM AT THE CENTER OF SURVEILLANCE CAPSULE

Capsule V					
Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73e+01	7.72e+06	28	9.12e-03	2.67e+10
2	1.49e+01	1.66e+07	29	5.53e-03	2.86e+10
3	1.35e+01	6.30e+07	30	3.35e-03	8.97e+09
4	1.16e+01	1.75e+08	31	2.84e-03	8.65e+09
5	1.00e+01	4.04e+08	32	2.40e-03	8.56e+09
6	8.61e+00	7.28e+08	33	2.03e-03	2.56e+10
7	7.41e+00	1.80e+09	34	1.23e-03	2.54e+10
8	6.07e+00	2.88e+09	35	7.49e-04	2.45e+10
9	4.97e+00	6.29e+09	36	4.54e-04	2.23e+10
10	3.68e+00	7.68e+09	37	2.75e-04	2.38e+10
11	2.87e+00	1.49e+10	38	1.67e-04	2.37e+10
12	2.23e+00	1.98e+10	39	1.01e-04	2.45e+10
13	1.74e+00	2.69e+10	40	6.14e-05	2.44e+10
14	1.35e+00	2.89e+10	41	3.73e-05	2.44e+10
15	1.11e+00	4.98e+10	42	2.26e-05	2.40e+10
16	8.21e-01	5.54e+10	43	1.37e-05	2.34e+10
17	6.39e-01	5.94e+10	44	8.31e-06	2.31e+10
18	4.98e-01	4.01e+10	45	5.04e-06	2.30e+10
19	3.88e-01	5.55e+10	46	3.06e-06	2.30e+10
20	3.02e-01	6.76e+10	47	1.86e-06	2.29e+10
21	1.83e-01	6.18e+10	48	1.13e-06	2.03e+10
22	1.11e-01	4.74e+10	49	6.83e-07	1.83e+10
23	6.74e-02	3.90e+10	50	4.14e-07	3.30e+10
24	4.09e-02	2.40e+10	51	2.51e-07	3.52e+10
25	2.55e-02	2.27e+10	52	1.52e-07	3.76e+10
26	1.99e-02	1.51e+10	53	9.24e-08	1.06e+11
27	1.50e-02	2.48e+10			

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

TABLE 6-12

COMPARISON OF CALCULATED AND MEASURED INTEGRATED NEUTRON EXPOSURE OF PRAIRIE ISLAND UNIT 1 SURVEILLANCE CAPSULES S, R, P, AND V

CAPSULE S			
	Calculated	Measured	M/C
Φ(E > 1.0 MeV) [n/cm2]	4.338e+19	4.017e+19	0.93
Φ(E > 0.1 MeV) [n/cm2]	1.527e+20	1.584e+20	1.04
dpa	7.461e-02	7.309e-02	0.98

CAPSULE R			
	Calculated	Measured	M/C
Φ(E > 1.0 MeV) [n/cm2]	4.000e+19	4.478e+19	1.12
Φ(E > 0.1 MeV) [n/cm2]	1.516e+20	1.817e+20	1.20
dpa	7.121e-02	8.197e-02	1.15

CAPSULE P			
	Calculated	Measured	M/C
Φ(E > 1.0 MeV) [n/cm2]	1.314e+19	1.318e+19	1.00
Φ(E > 0.1 MeV) [n/cm2]	4.521e+19	4.994e+19	1.10
dpa	2.234e-02	2.354e-02	1.05

CAPSULE V			
	Calculated	Measured	M/C
Φ(E > 1.0 MeV) [n/cm2]	6.267e+18	5.630e+18	0.90
Φ(E > 0.1 MeV) [n/cm2]	2.375e+19	2.251e+19	0.95
dpa	1.116e-02	1.031e-02	0.92

TABLE 6-13

NEUTRON EXPOSURE PROJECTIONS AT KEY LOCATIONS ON THE REACTOR VESSEL CLAD/BASE METAL INTERFACE

Best Estimate Exposure (18.12 EFPY) at the Reactor Vessel Inner Radius				
	0°	15°	30°	45°
Φ (E > 1.0 MeV) Φ (E > 0.1 MeV) dpa	1.59e+19 4.74e+19 2.70e-02	1.13e+19 3.57e+19 1.98e-02	8.98e+18 2.66e+19 1.53e-02	7.88e+18 2.25e+19 1.33e-02

Best Estimate Exposure (24 EFPY) at the Reactor Vessel Inner Radius				
	0°	15°	30°	45°
Φ (E > 1.0 MeV) Φ (E > 0.1 MeV) dpa	2.11e+19 6.27e+19 3.58e-02	1.50e+19 4.73e+19 2.62e-02	1.19e+19 3.53e+19 2.03e-02	1.04e+19 2.98e+19 1.76e-02

Best Estimate Exposure (35 EFPY) at the Reactor Vessel Inner Radius				
	0°	15°	30°	45°
Φ (E > 1.0 MeV) Φ (E > 0.1 MeV) dpa	3.07e+19 9.15e+19 5.22e-02	2.18e+19 6.90e+19 3.82e-02	1.73e+19 5.15e+19 2.96e-02	1.52e+19 4.35e+19 2.57e-02

TABLE 6-14

NEUTRON EXPOSURE VALUES WITHIN THE PRAIRIE ISLAND UNIT 1 REACTOR VESSEL

FLUENCE BASED ON E > 1.0 MeV SLOPE

24 EFPY Φ (E > 1.0 MeV) [n/cm²]				
	0°	15°	30°	45°
Surface	2.11e+19	1.50e+19	1.19e+19	1.04e+19
¼ T	1.35e+19	9.64e+18	7.56e+18	6.75e+18
½ T	7.63e+18	5.54e+18	4.32e+18	3.88e+18
¾ T	4.13e+18	3.08e+18	2.39e+18	2.15e+18

35 EFPY Φ (E > 1.0 MeV) [n/cm²]				
	0°	15°	30°	45°
Surface	3.07e+19	2.18e+19	1.73e+19	1.52e+19
¼ T	1.96e+19	1.41e+19	1.10e+19	9.85e+18
½ T	1.11e+19	8.08e+18	6.30e+18	5.66e+18
¾ T	6.02e+18	4.50e+18	3.49e+18	3.14e+18

FLUENCE BASED ON dpa SLOPE

24 EFPY Φ (E > 1.0 MeV) [n/cm²]				
	0°	15°	30°	45°
Surface	2.11e+19	1.50e+19	1.19e+19	1.04e+19
¼ T	1.50e+19	1.09e+19	8.52e+18	7.55e+18
½ T	9.95e+18	7.41e+18	5.78e+18	5.12e+18
¾ T	6.34e+18	4.91e+18	3.83e+18	3.36e+18

35 EFPY Φ (E > 1.0 MeV) [n/cm²]				
	0°	15°	30°	45°
Surface	3.07e+19	2.18e+19	1.73e+19	1.52e+19
¼ T	2.19e+19	1.58e+19	1.24e+19	1.10e+19
½ T	1.45e+19	1.08e+19	8.43e+18	7.46e+18
¾ T	9.25e+18	7.16e+18	5.59e+18	4.90e+18

TABLE 6-15

UPDATED LEAD FACTORS FOR PRAIRIE ISLAND UNIT 1
SURVEILLANCE CAPSULES

Capsule	Lead Factor
V[a]	2.94
P[b]	1.72
R[c]	2.99
S[d]	1.77
N[e]	1.77
T[e]	1.89

[a] - Withdrawn at the enu of Cycle 1.
[b] - Withdrawn at the end of Cycle 5.
[c] - Withdrawn at the end of Cycle 9.
[d] - Withdrawn at the end of Cycle 17.
[e] - Capsules remaining in the reactor.

7.0 RECOMMENDED 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 Prairie Island Unit 1 reactor vessel. This recommended removal schedule is applicable to 35 EFPY.

TABLE 7-1

Recommended Surveillance Capsule Removal Schedule for the Prairie Island Unit 1 Reactor Vessel

Capsule	Capsule Location (degree)	Lead Factor[a]	Withdrawal EFPY[b]	Fluence[a] (n/cm^2, E > 1.0 MeV)
V	77	2.94	1.34	5.630×10^{18} [c]
P	247	1.72	4.60	1.318×10^{19} [c]
R	257	2.99	8.56	4.478×10^{19} [c]
S	57	1.77	18.12	4.017×10^{19} [c]
T	67	1.89	Standby	- - - [d]
N	237	1.77	Standby	- - - [d]

NOTES:

(a) Updated in Capsule S dosimetry analysis; see Section 6.0 of this report.

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

(c) Plant-specific evaluation.

(d) Capsule T will reach the projected peak vessel fluence (at 52.5 EFPY) at approximately 27.7 EFPY. Capsule N will reach the projected peak fleunce (at 52.5 EFPY) at approximately 29.6 EFPY.

8.0 REFERENCES

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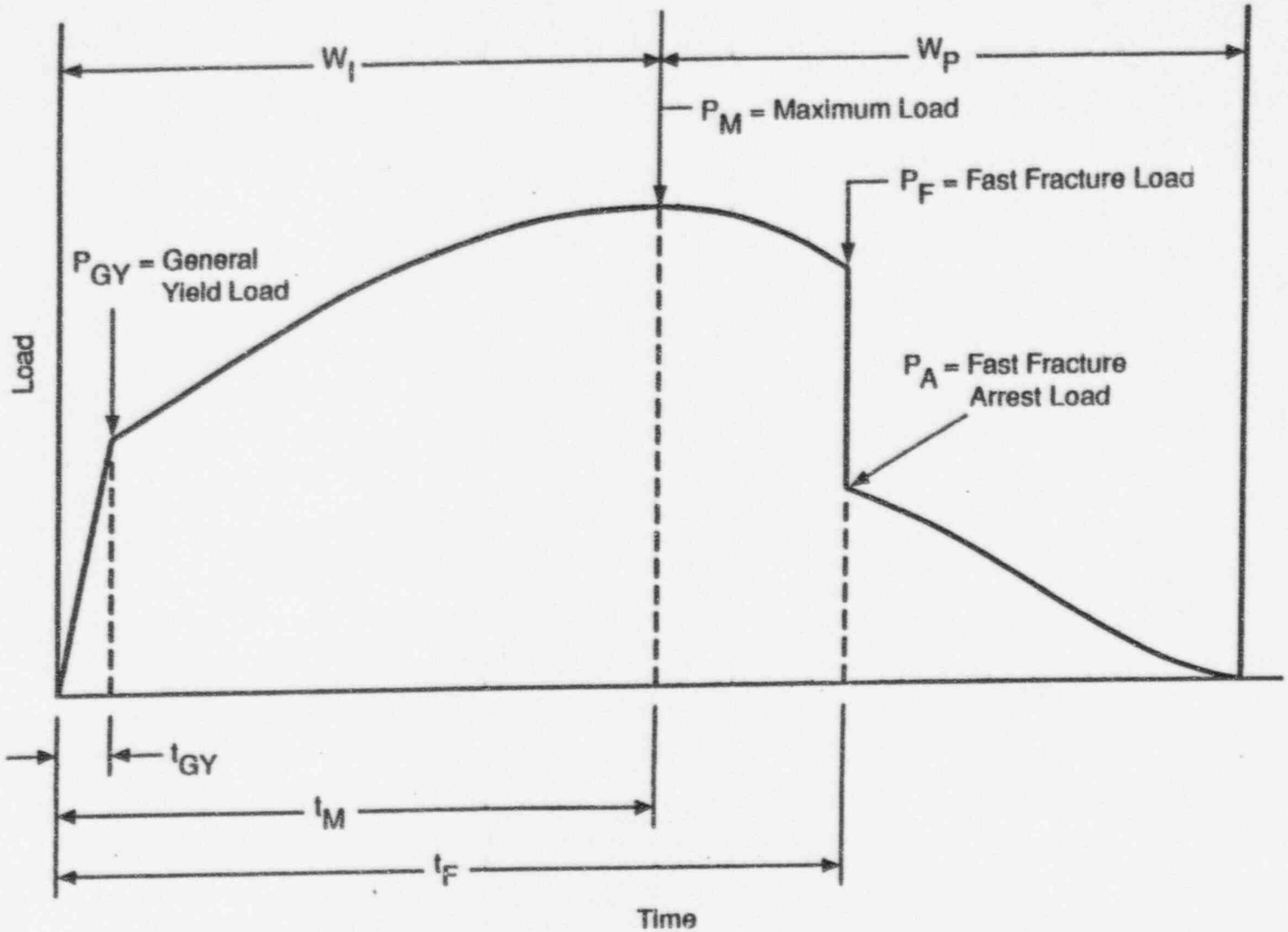
APPENDIX A

LOAD-TIME RECORDS FOR CAPSULE S CHARPY IMPACT TESTS

Curve 784472-AF13



W_I = Fracture Initiation Region

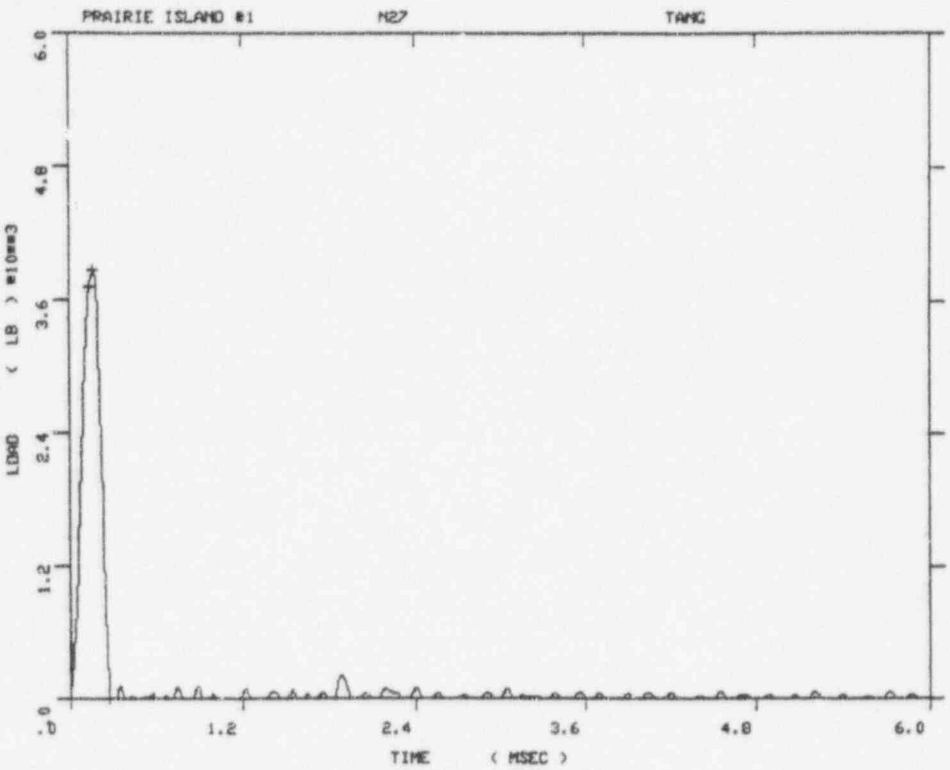
W_P = Fracture Propagation Region

t_{GY} = Time to General Yielding

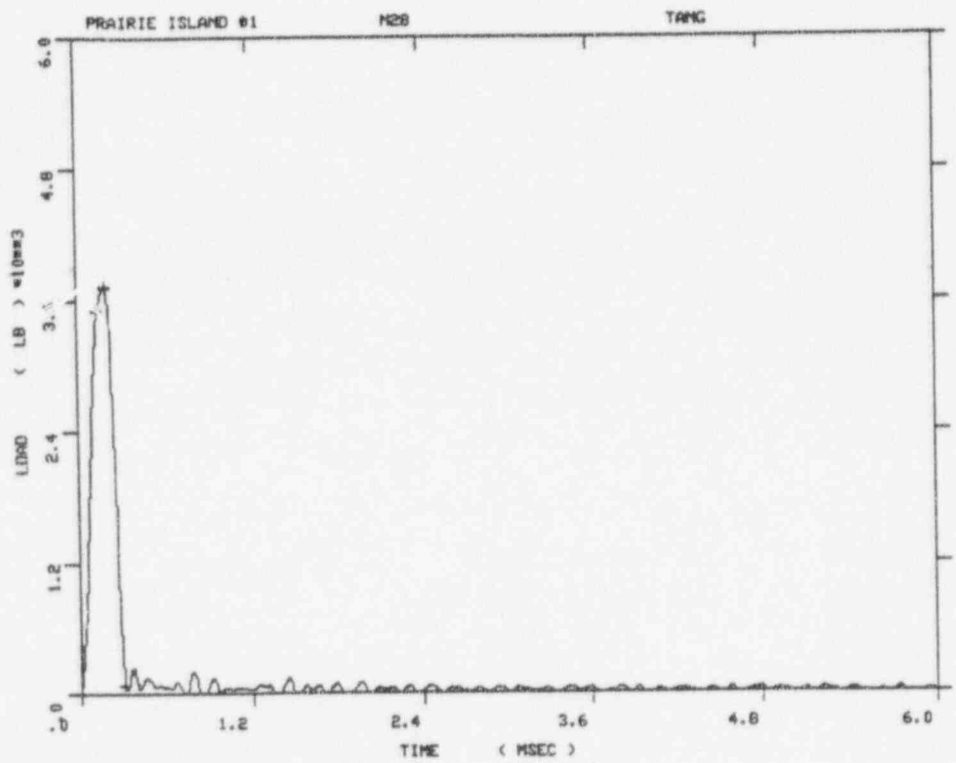
t_M = Time to Maximum Load

t_F = Time to Fast (Brittle) Fracture Start

Fig. A-1-Idealized load-time record

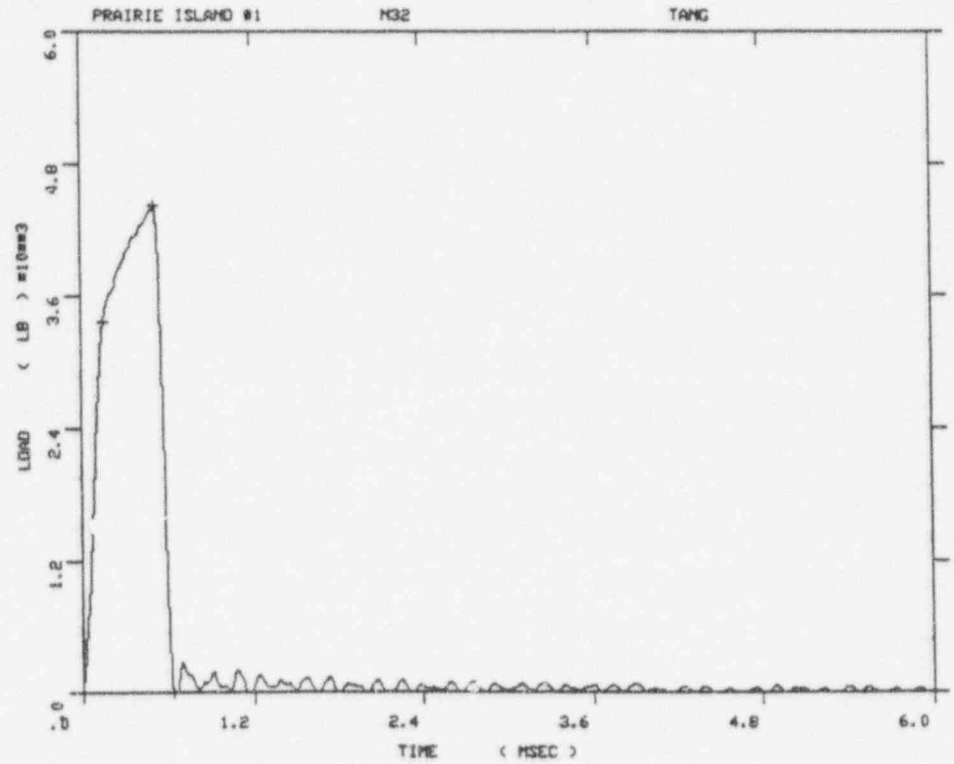


PRAIRIE ISLAND #1
SPECIMEN NUMBER :N27
MATERIAL :TANG
CAPSULE :PRAIRIE ISLAND

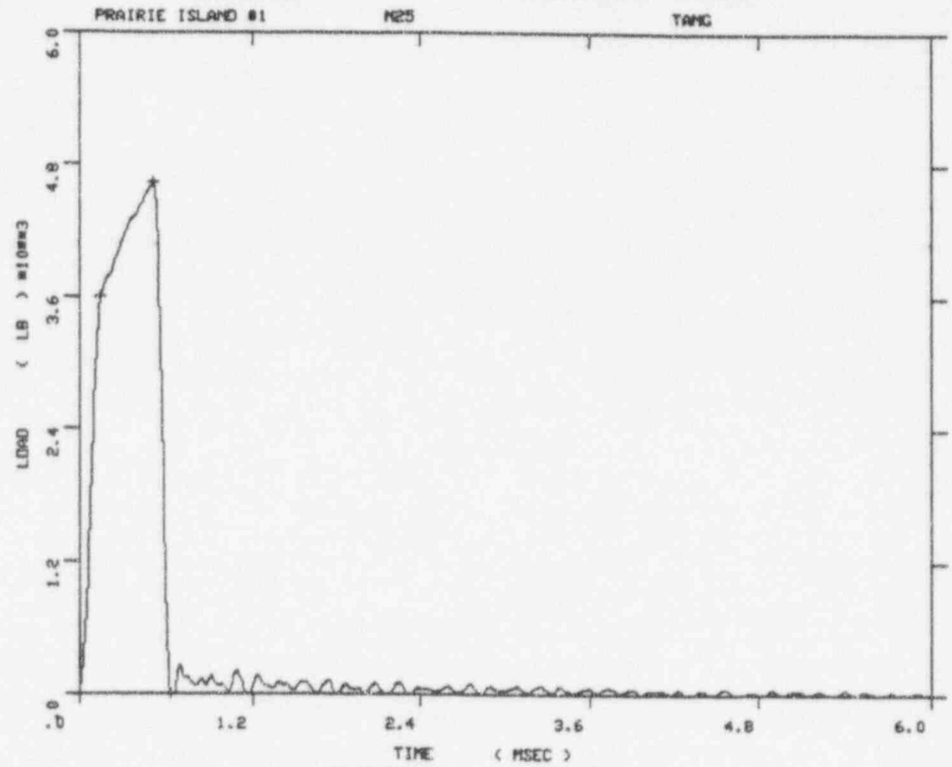


PRAIRIE ISLAND #1
SPECIMEN NUMBER :N28
MATERIAL :TANG
CAPSULE :PRAIRIE ISLAND

Figure A-2. Load-time records for Specimens N27 and N28.

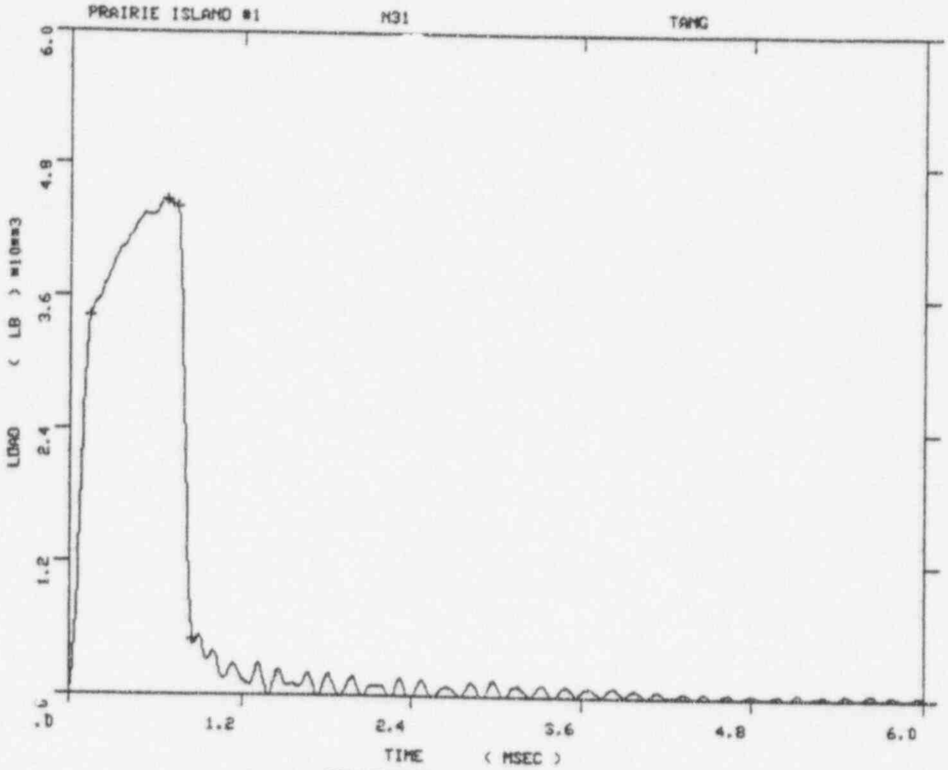


PRAIRIE ISLAND #1
SPECIMEN NUMBER :N32
MATERIAL :TANG
CAPSULE :PRAIRIE ISLAND

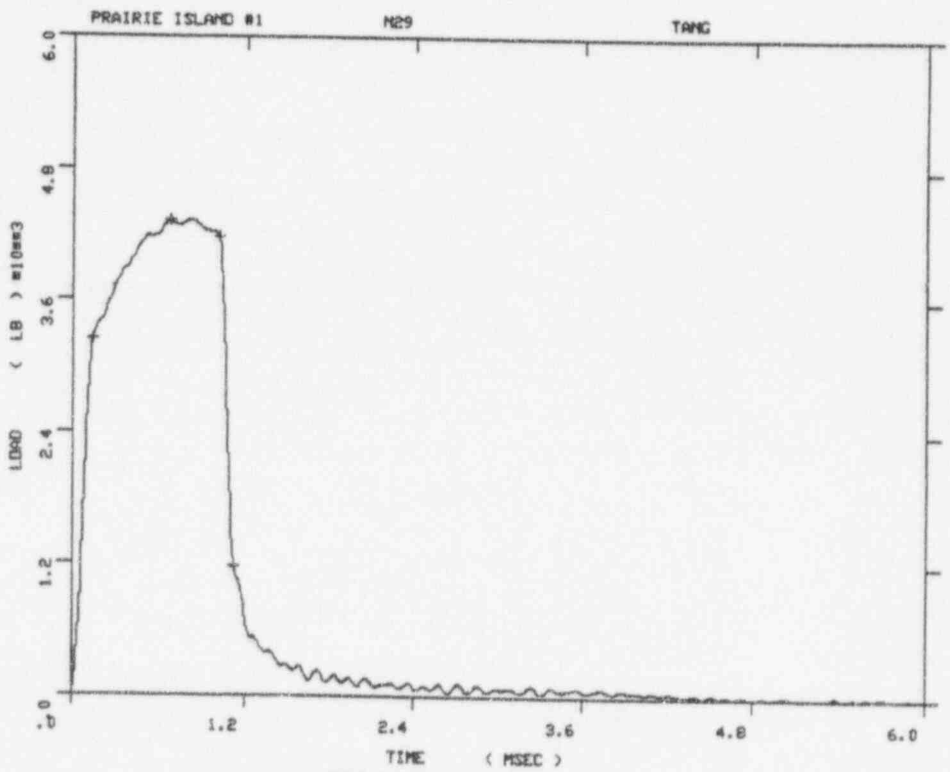


PRAIRIE ISLAND #1
SPECIMEN NUMBER :N25
MATERIAL :TANG
CAPSULE :PRAIRIE ISLAND

Figure A-3. Load-time records for Specimens N32 and N25.

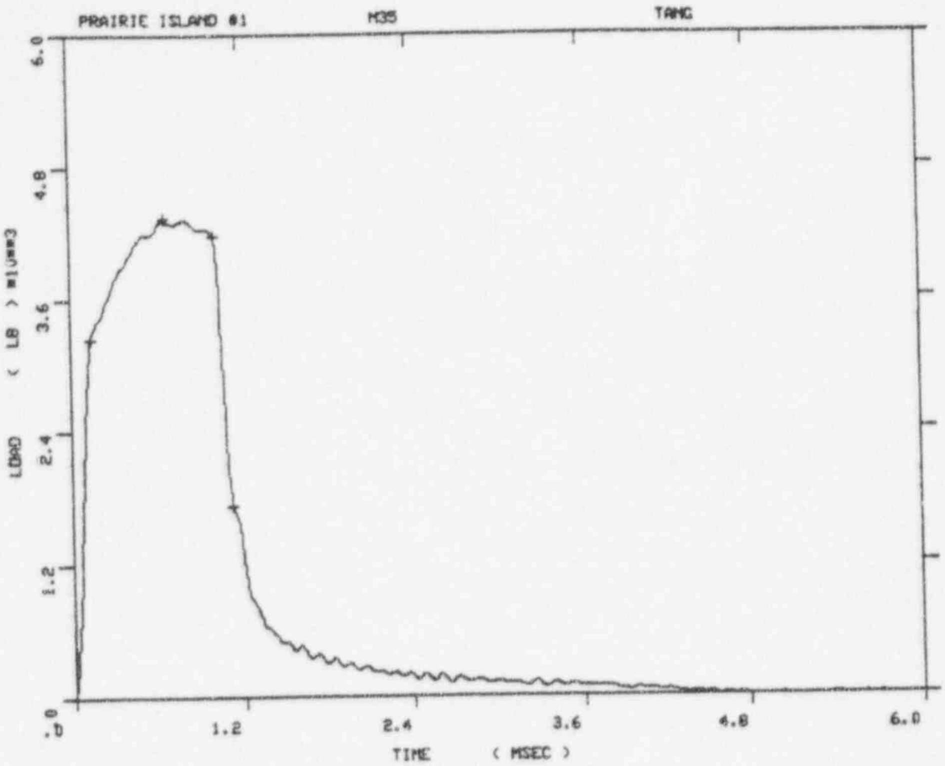


PRAIRIE ISLAND #1
SPECIMEN NUMBER :N31
MATERIAL :TANG
CAPSULE :PRAIRIE ISLAND



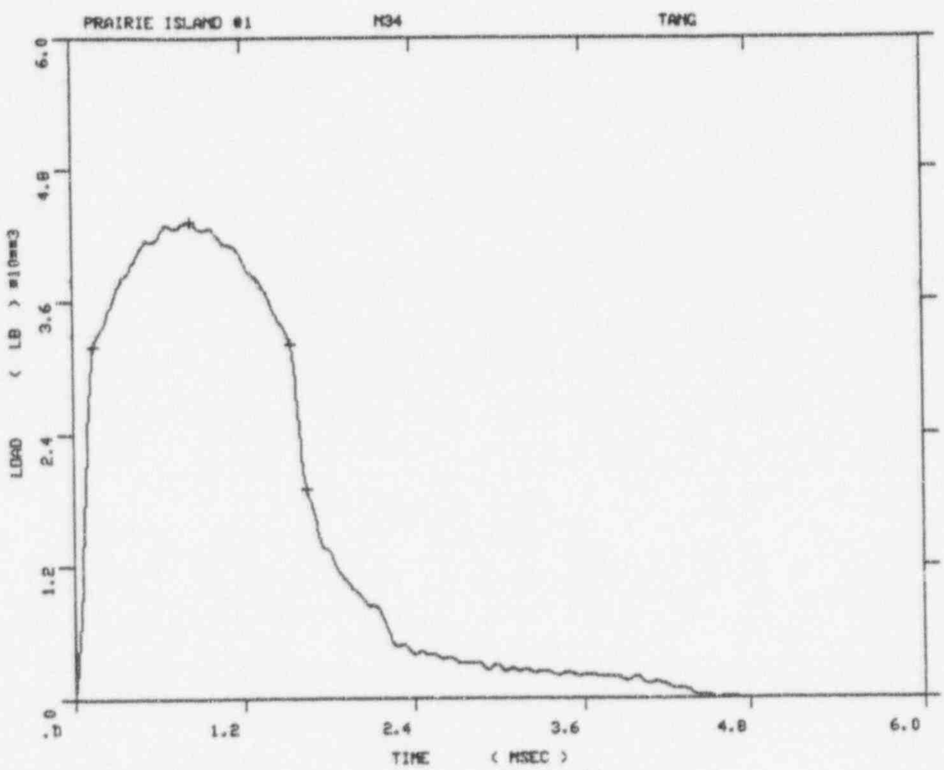
PRAIRIE ISLAND #1
SPECIMEN :N29
MATERIAL :TANG
CAPSULE :PRAIRIE ISLAND

Figure A-4. Load-time records for Specimens N31 and N29.



PRAIRIE ISLAND #1

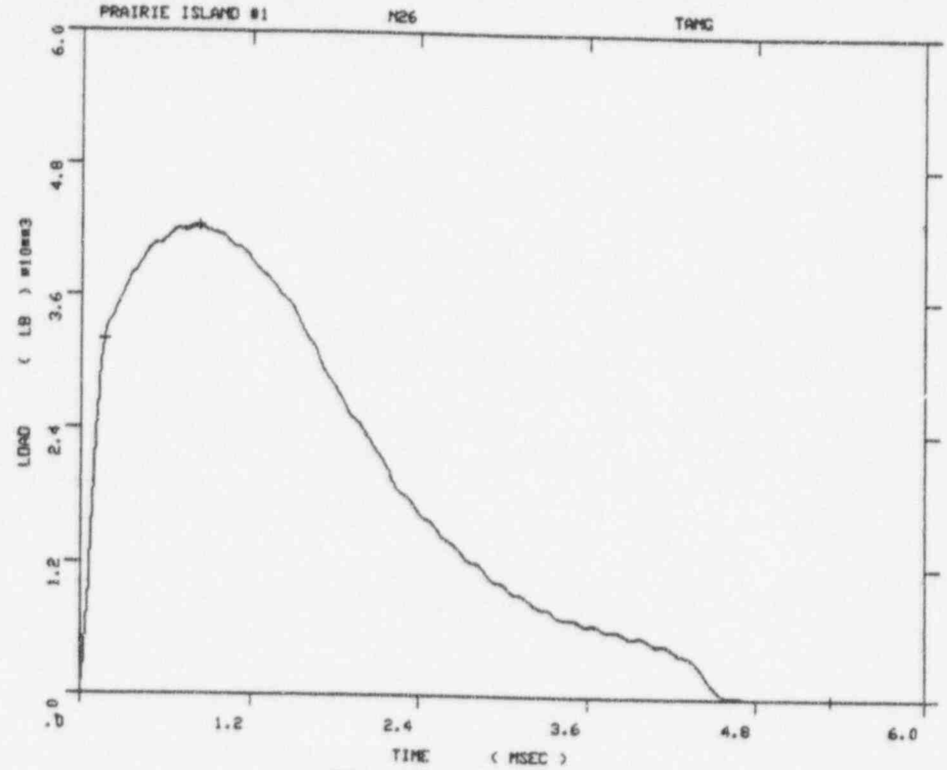
SPECIMEN :N35
MATERIAL :TANG
CAPSULE :PRAIRIE ISLAND



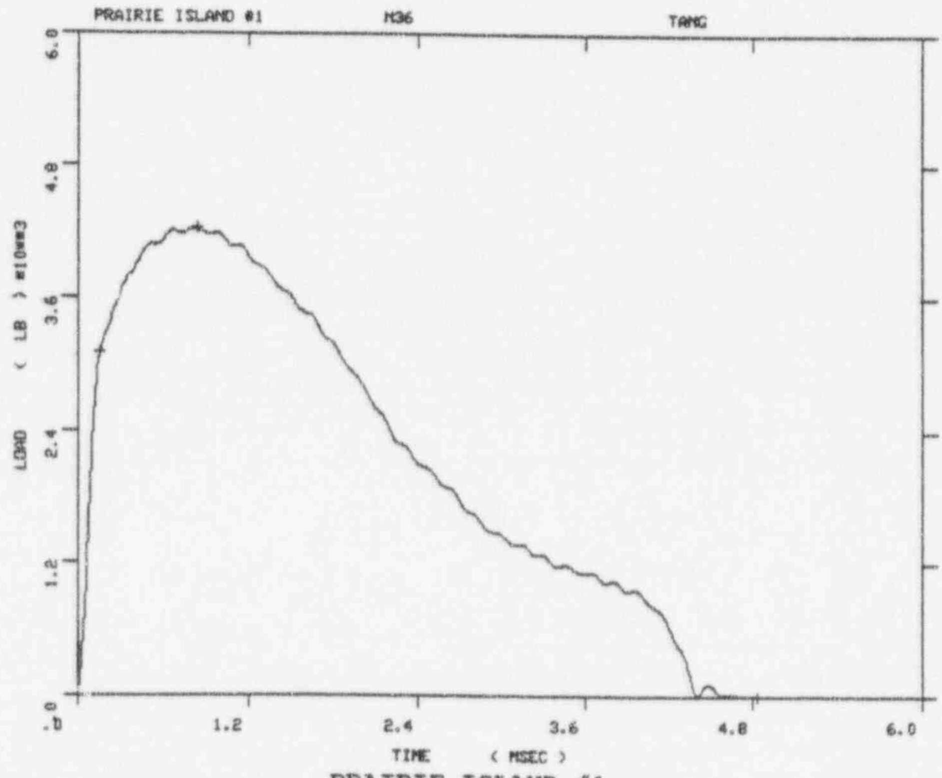
PRAIRIE ISLAND #1

SPECIMEN NUMBER :N34
MATERIAL :TANG
CAPSULE :PRAIRIE ISLAND

Figure A-5. Load-time records for Specimens N35 and N34.

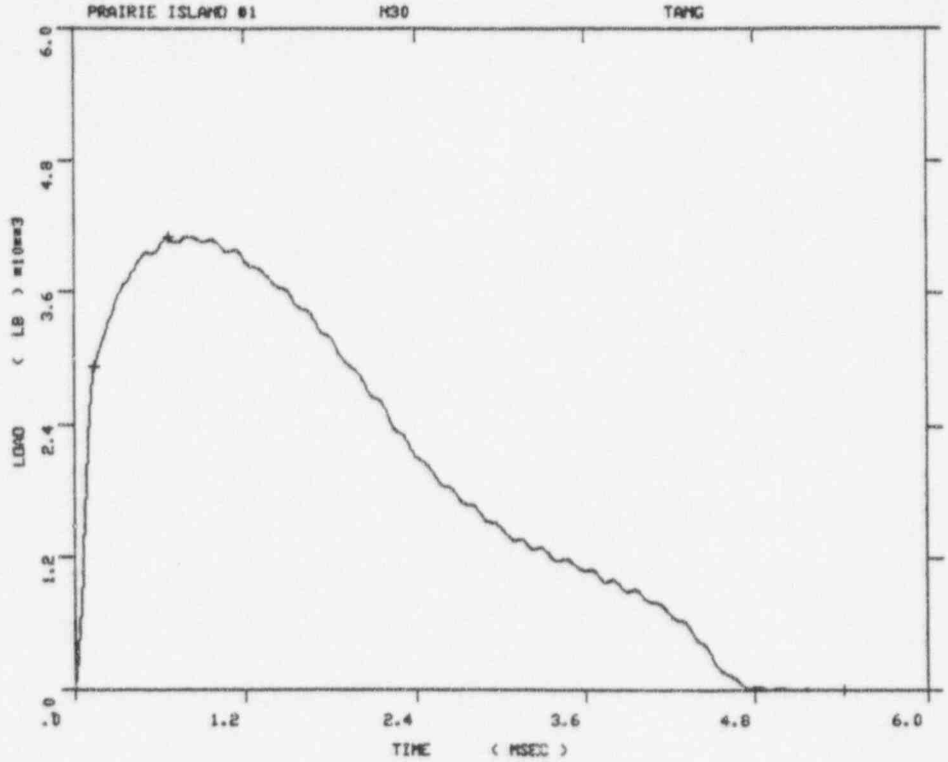


PRAIRIE ISLAND #1
SPECIMEN NUMBER :N26
MATERIAL :TANG
CAPSULE :PRAIRIE ISLAND
:UNIT #1 "S"

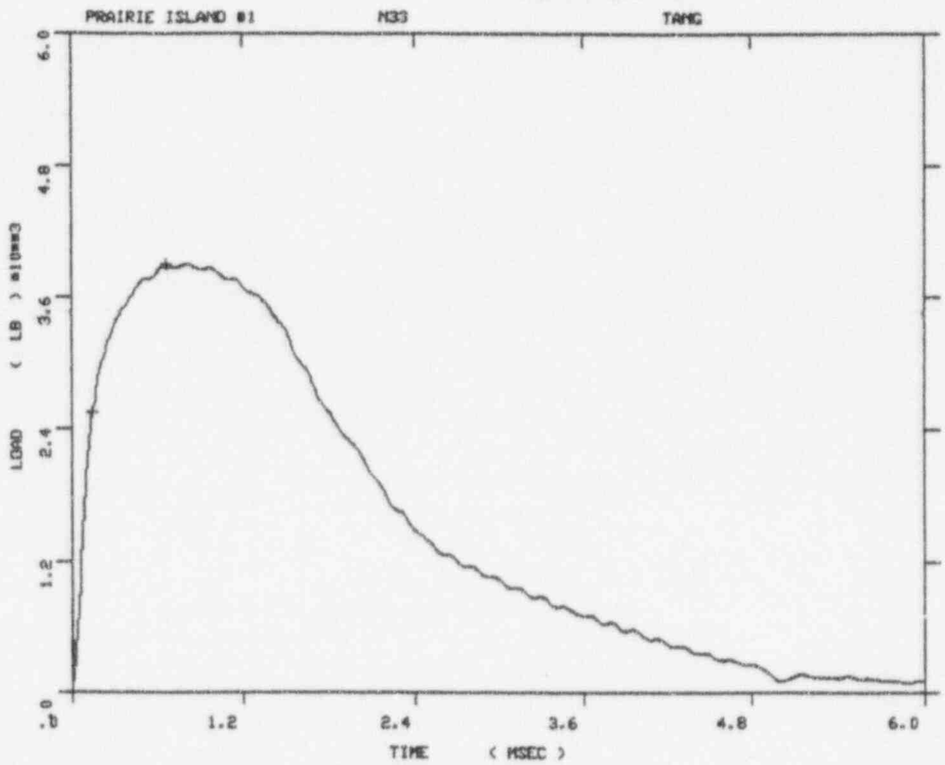


PRAIRIE ISLAND #1
SPECIMEN NUMBER :N36
MATERIAL :TANG
CAPSULE :PRAIRIE ISLAND
:UNIT #1 "S"

Figure A-6. Load-time records for Specimens N26 and N36.



PRAIRIE ISLAND #1
SPECIMEN :N30
MATERIAL :TANG
CAPSULE :PRAIRIE ISLAND
:UNIT #1 "S"



PRAIRIE ISLAND #1
SPECIMEN NUMBER :N33
MATERIAL :TANG
CAPSULE :PRAIRIE ISLAND
:UNIT #1 "S"

Figure A-7. Load-time records for Specimens N30 and N33.

SPECIMEN NUMBERING CODE:

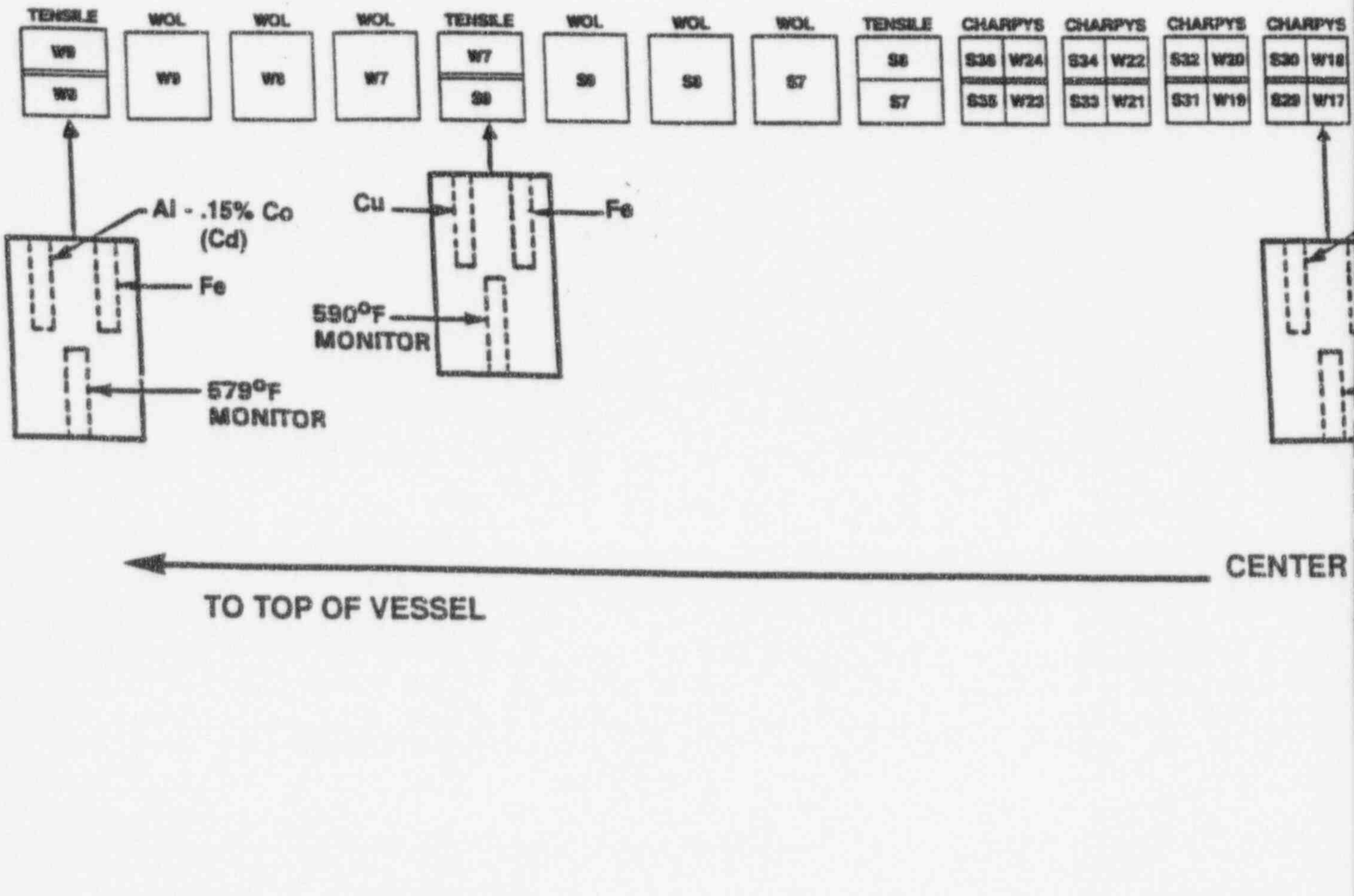
N - FORGING C (TANGENTIAL)

S - FORGING C (AXIAL)

R - ASTM CORRELATION MONITOR

W - WELD METAL

H - HEAT AFFECTED ZONE MATERIAL



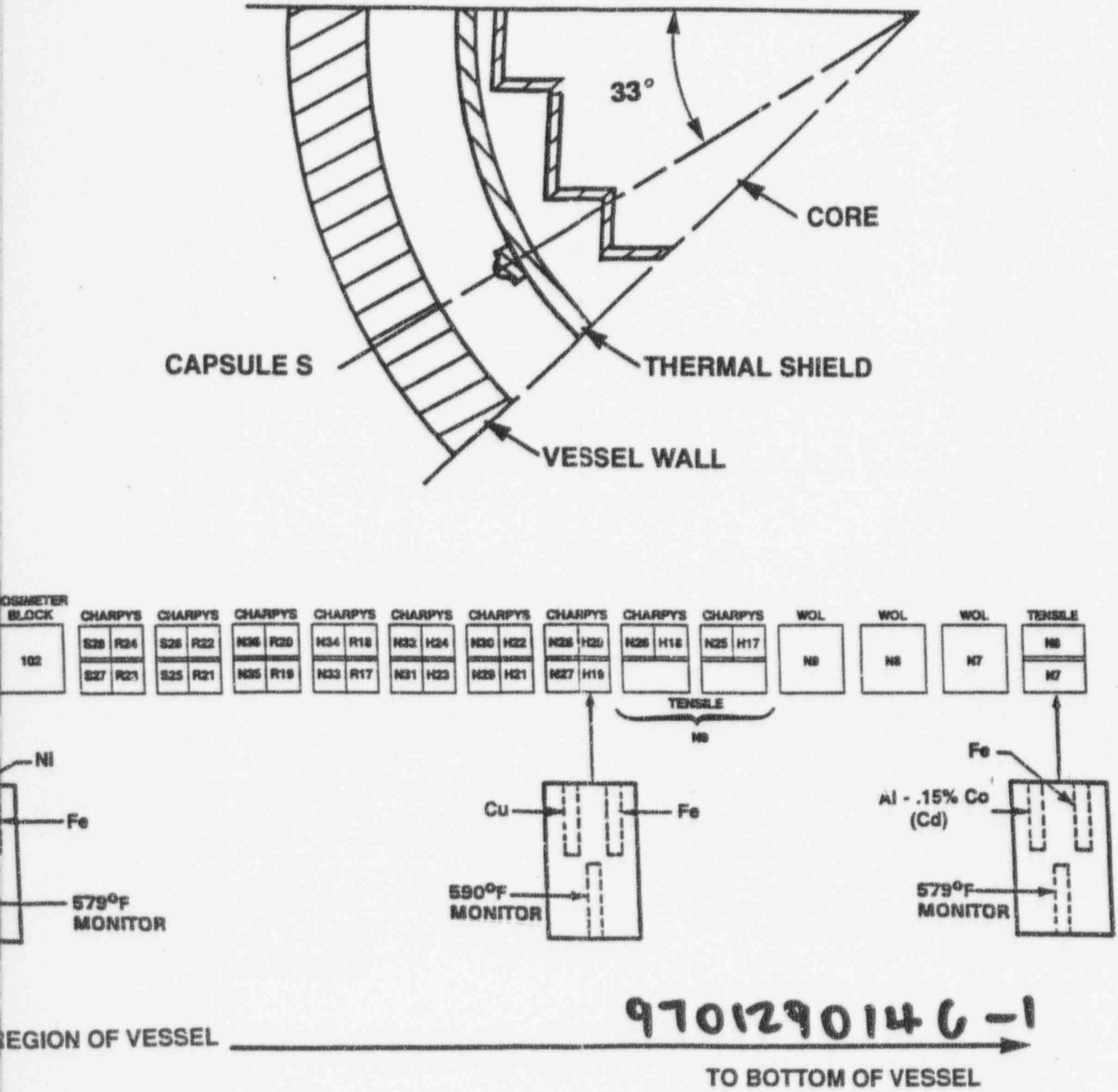
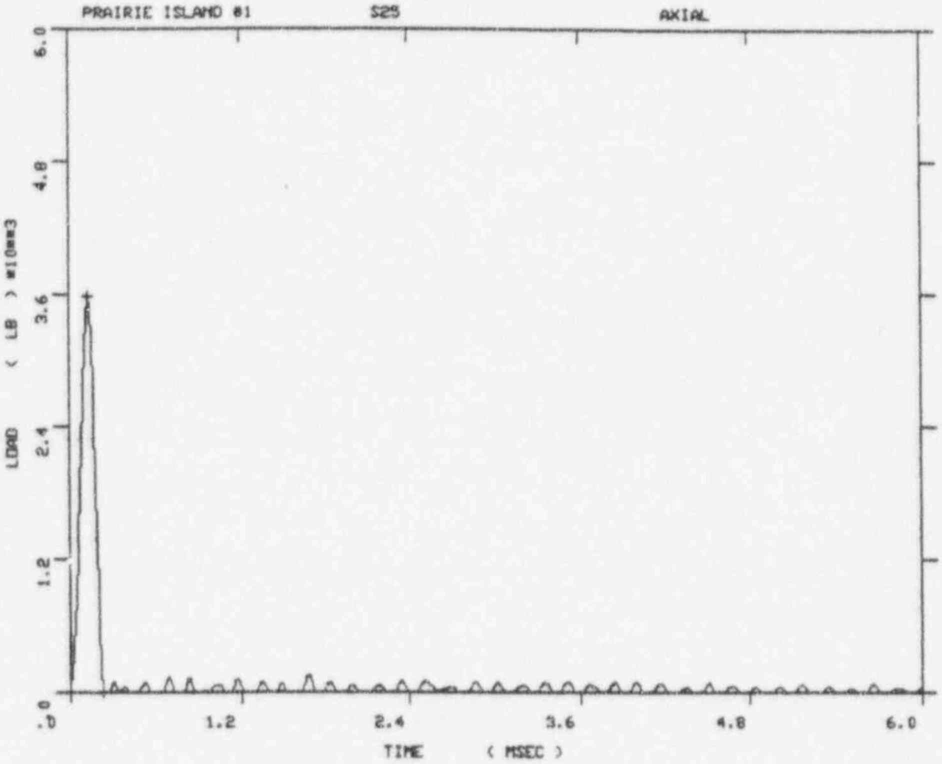
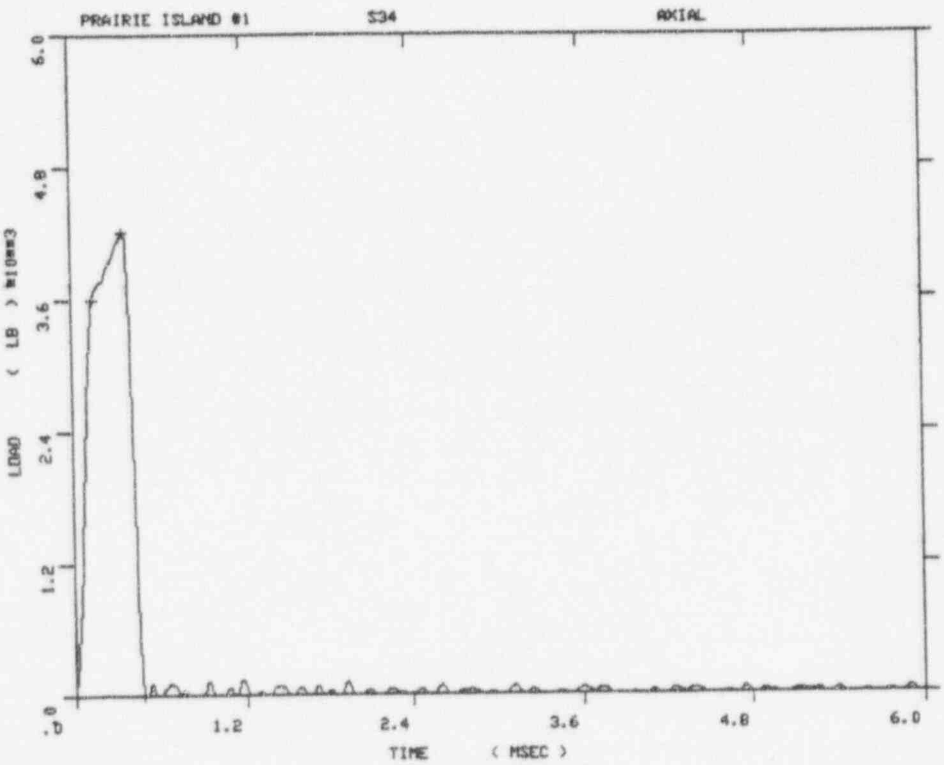


Figure 4-2 Capsule S Diagram Showing the Location of Specimens, Thermal Monitors and Dosimeters

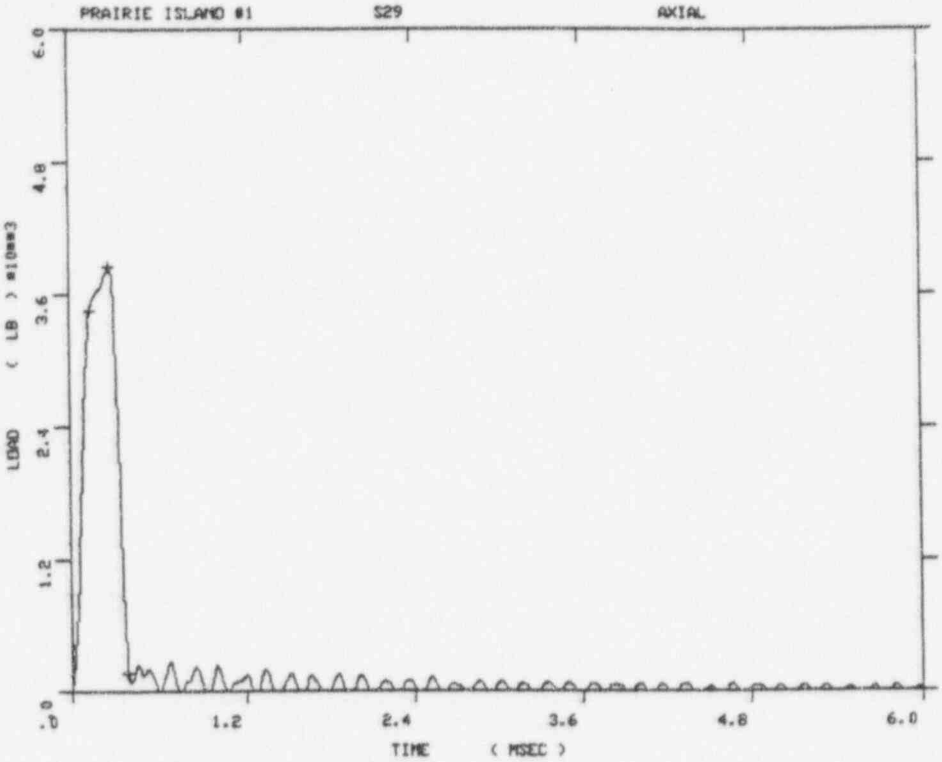


PRAIRIE ISLAND #1
SPECIMEN NUMBER :S25
MATERIAL :AXIAL
CAPSULE :PRAIRIE ISLAND

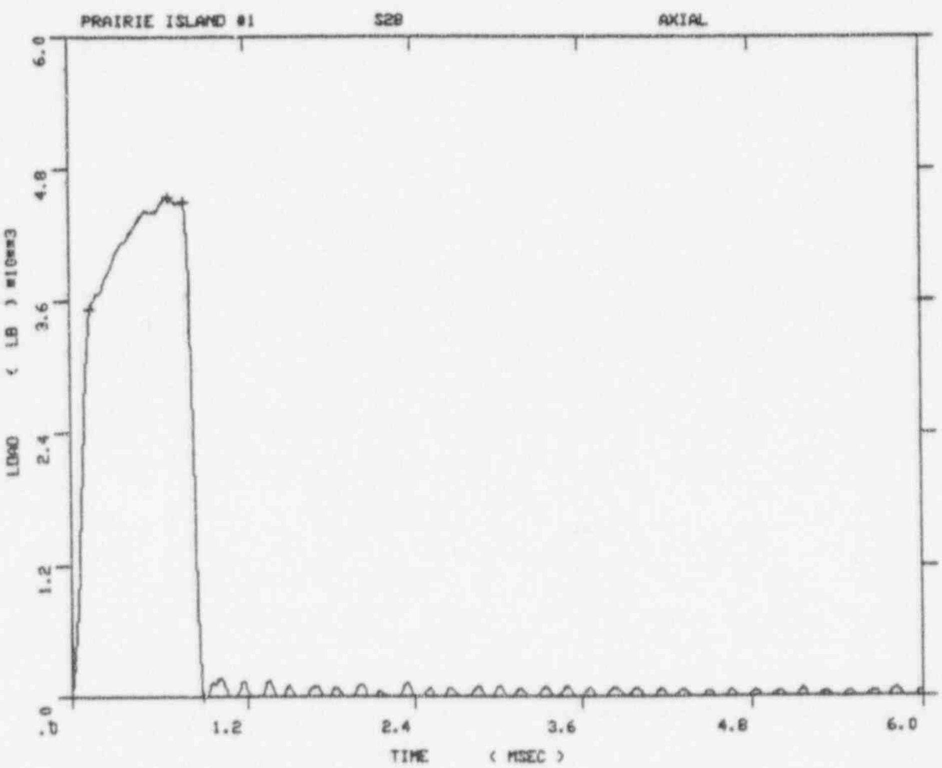


PRAIRIE ISLAND #1
SPECIMEN NUMBER :S34
MATERIAL :AXIAL
CAPSULE :PRAIRIE ISLAND

Figure A-8. Load-time records for Specimens S25 and S34.

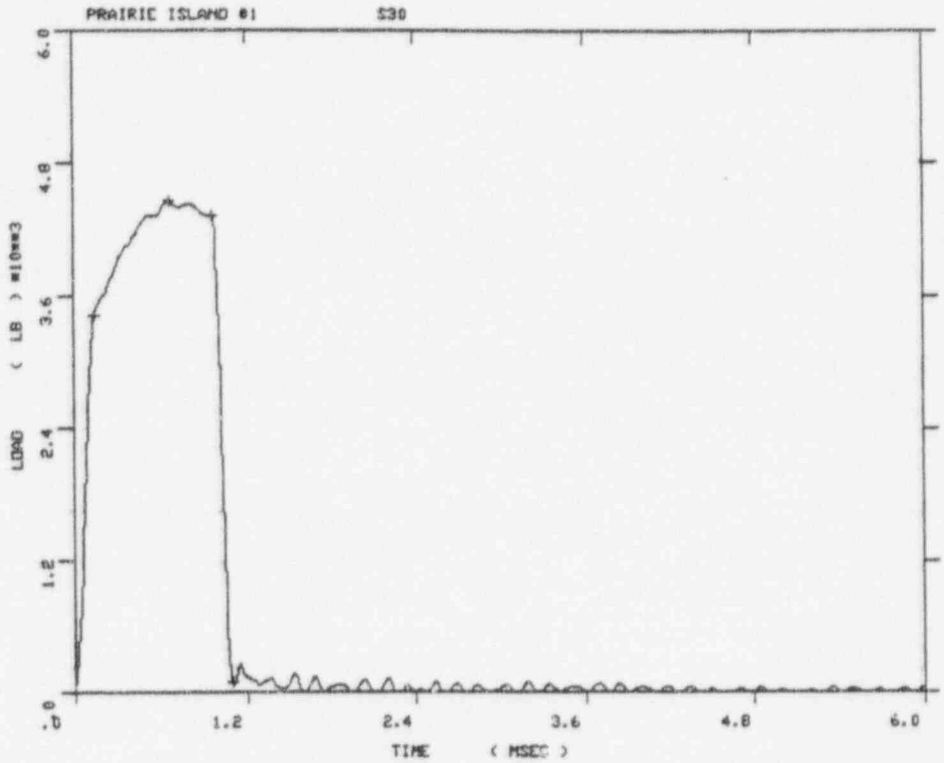


PRAIRIE ISLAND #1
SPECIMEN NUMBER :S29
MATERIAL :AXIAL
CAPSULE :PRAIRIE ISLAND

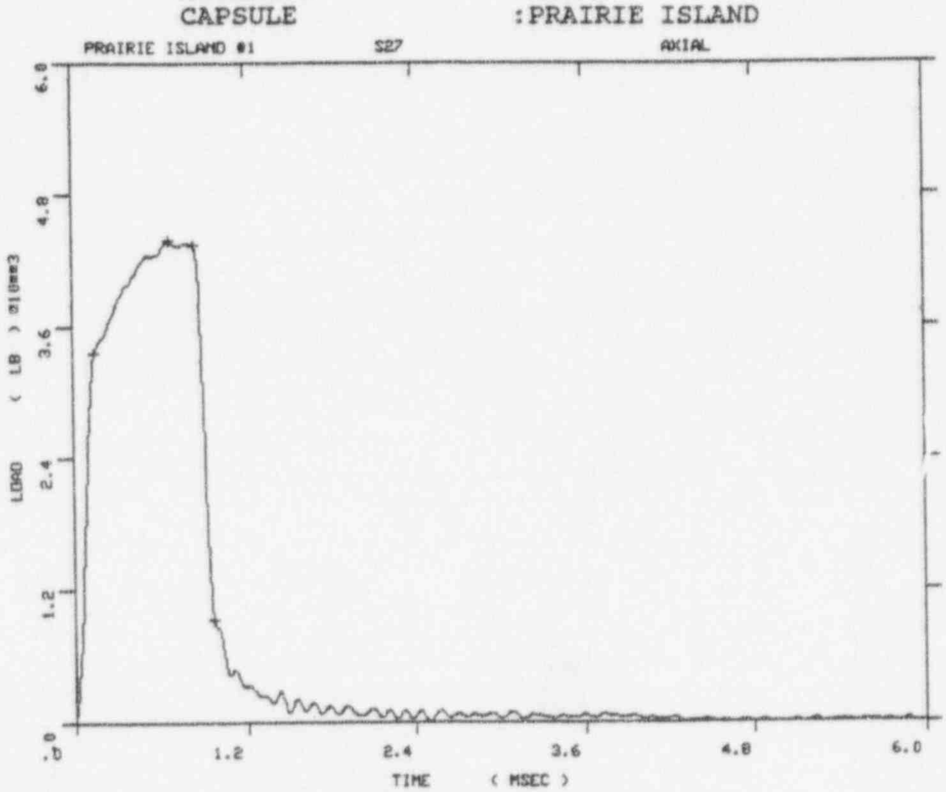


PRAIRIE ISLAND #1
SPECIMEN NUMBER :S28
MATERIAL :AXIAL
CAPSULE :PRAIRIE ISLAND

Figure A-9. Load-time records for Specimens S29 and S28.

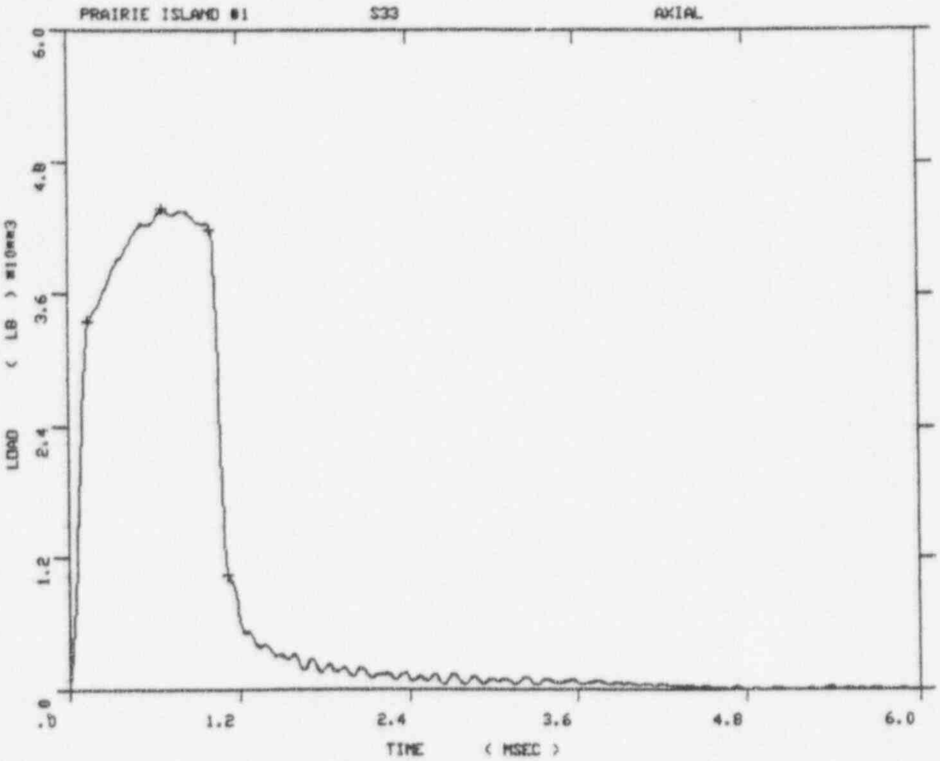


PRAIRIE ISLAND #1
SPECIMEN NUMBER :S30
MATERIAL :AXIAL
CAPSULE :PRAIRIE ISLAND

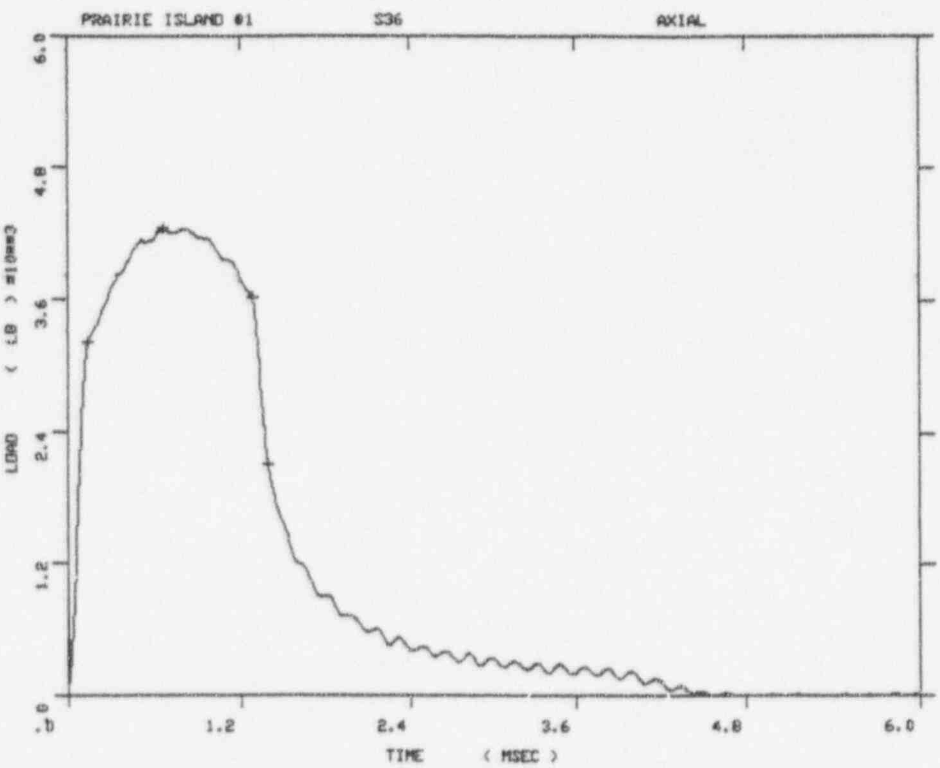


PRAIRIE ISLAND #1
SPECIMEN NUMBER :S27
MATERIAL :AXIAL
CAPSULE :PRAIRIE ISLAND

Figure A-10. Load-time records for Specimens S30 and S27.

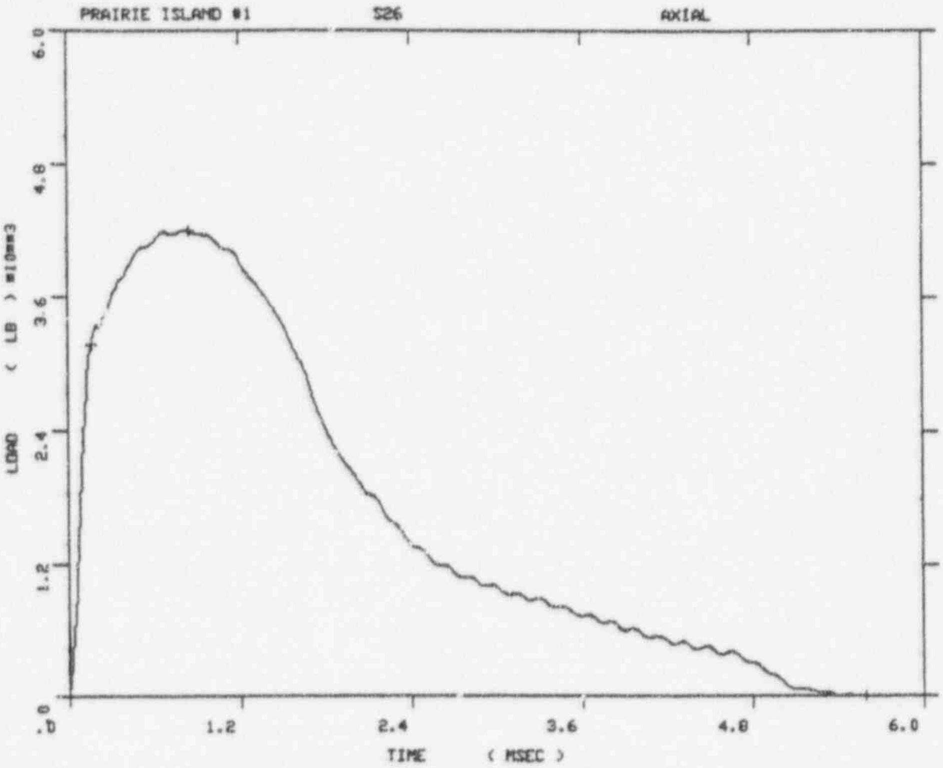


PRAIRIE ISLAND #1
SPECIMEN :S33
MATERIAL :AXIAL
CAPSULE :PRAIRIE ISLAND



PRAIRIE ISLAND #1
SPECIMEN NUMBER :S36
MATERIAL :AXIAL
CAPSULE :PRAIRIE ISLAND

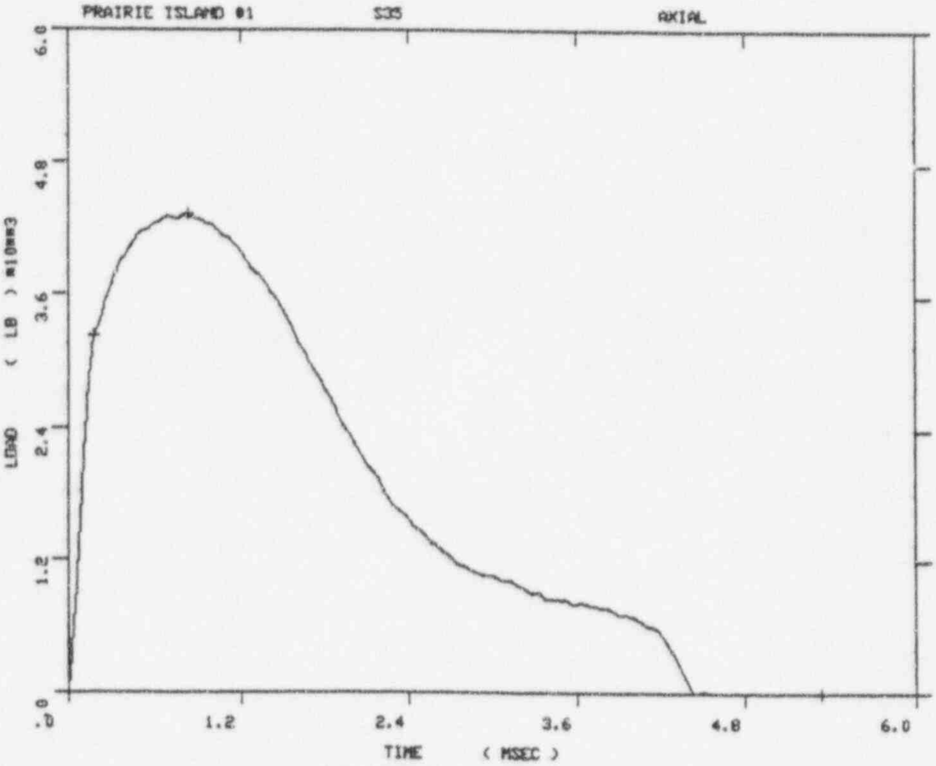
Figure A-11. Load-time records for Specimens S33 and S36.



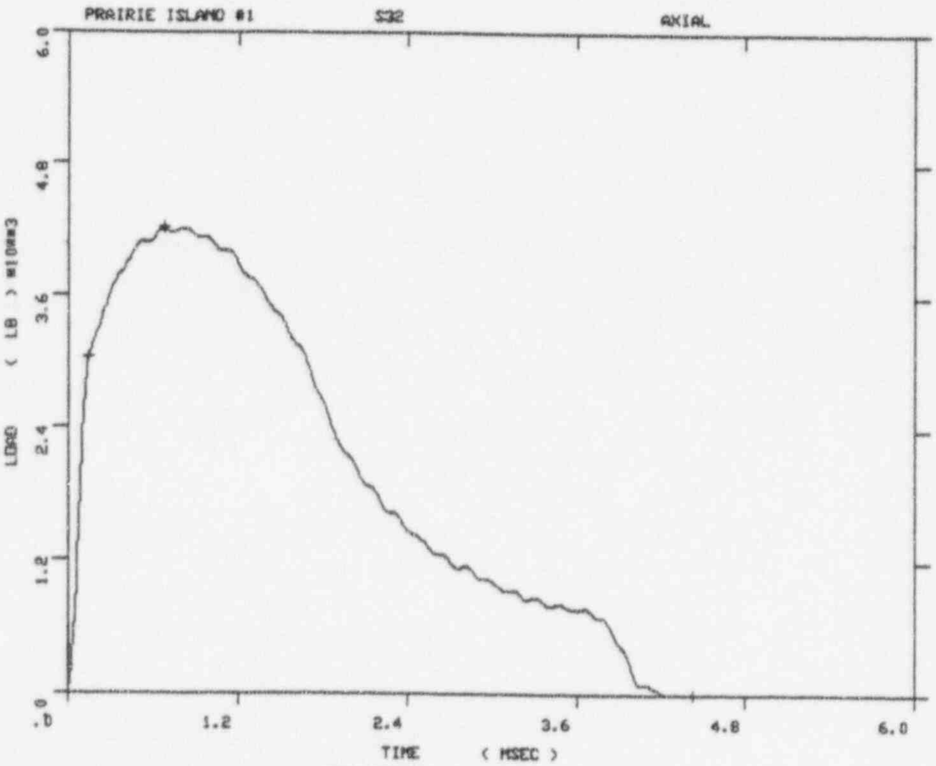
PRAIRIE ISLAND #1
SPECIMEN NUMBER :S26
MATERIAL :AXIAL
CAPSULE :PRAIRIE ISLAND

Specimen Alignment Error - Data not valid.

Figure A-12. Load-time records for Specimens S26 and S31.

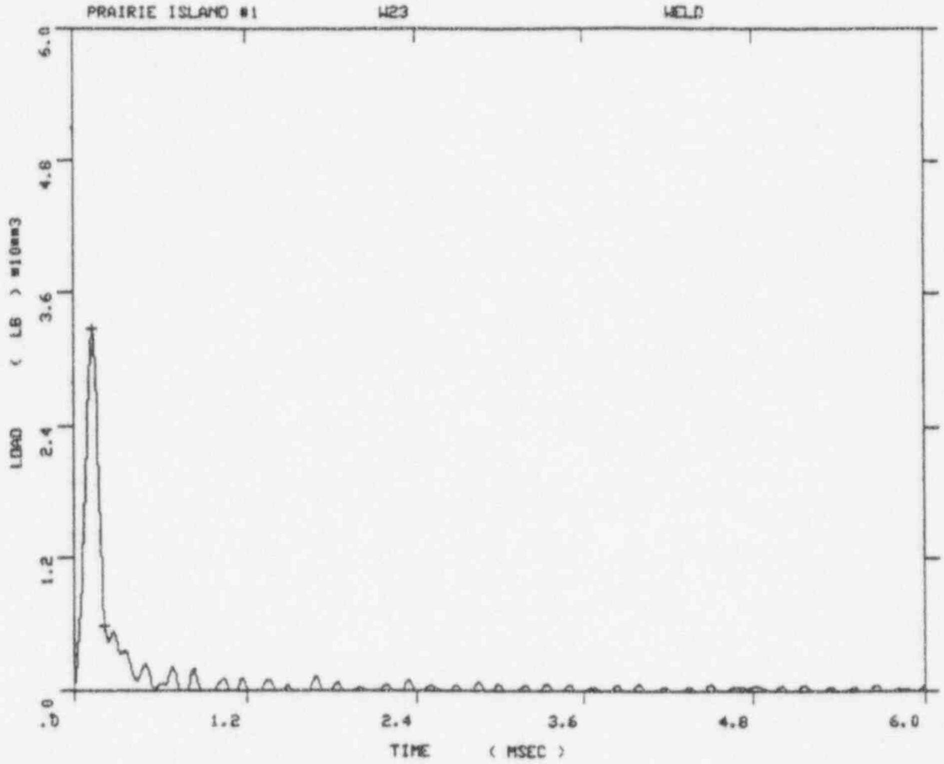


PRAIRIE ISLAND #1
SPECIMEN :S35
MATERIAL :AXIAL
CAPSULE :PRAIRIE ISLAND



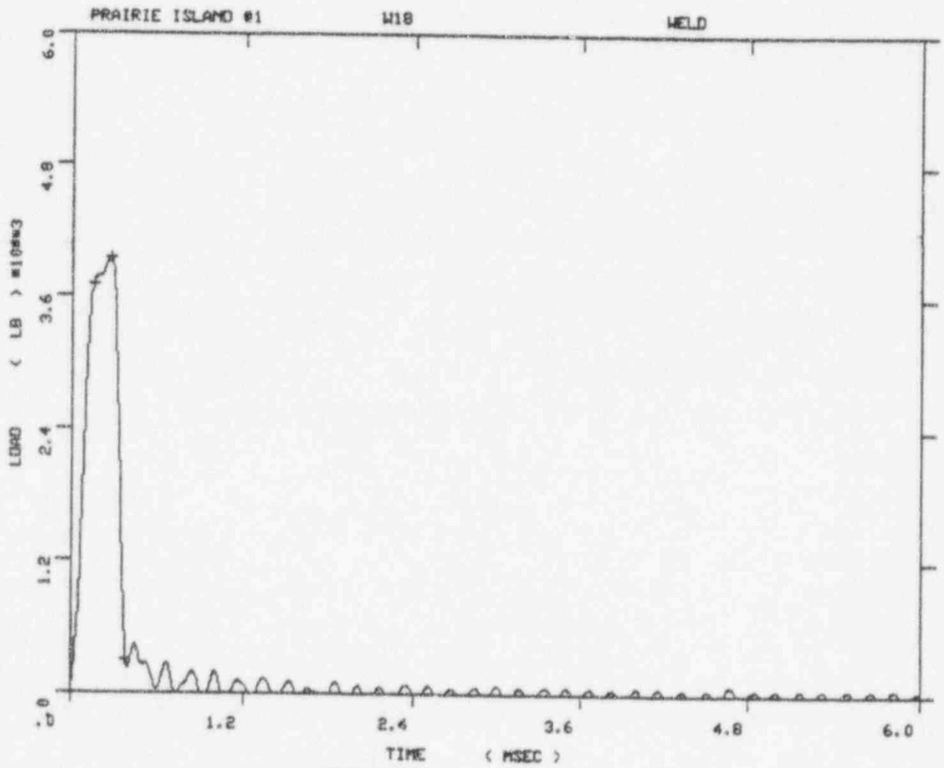
PRAIRIE ISLAND #1
SPECIMEN NUMBER :S32
MATERIAL :AXIAL
CAPSULE :PRAIRIE ISLAND

Figure A-13. Load-time records for Specimens S35 and S32.



PRAIRIE ISLAND #1

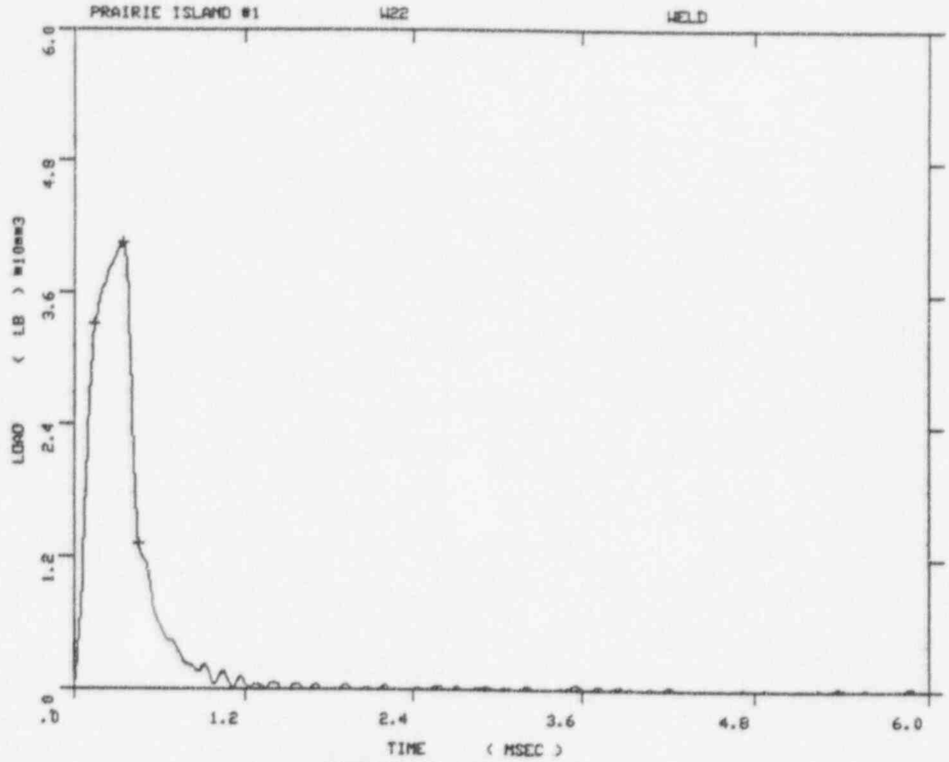
SPECIMEN :W23
MATERIAL :WELD
CAPSULE :PRAIRIE ISLAND



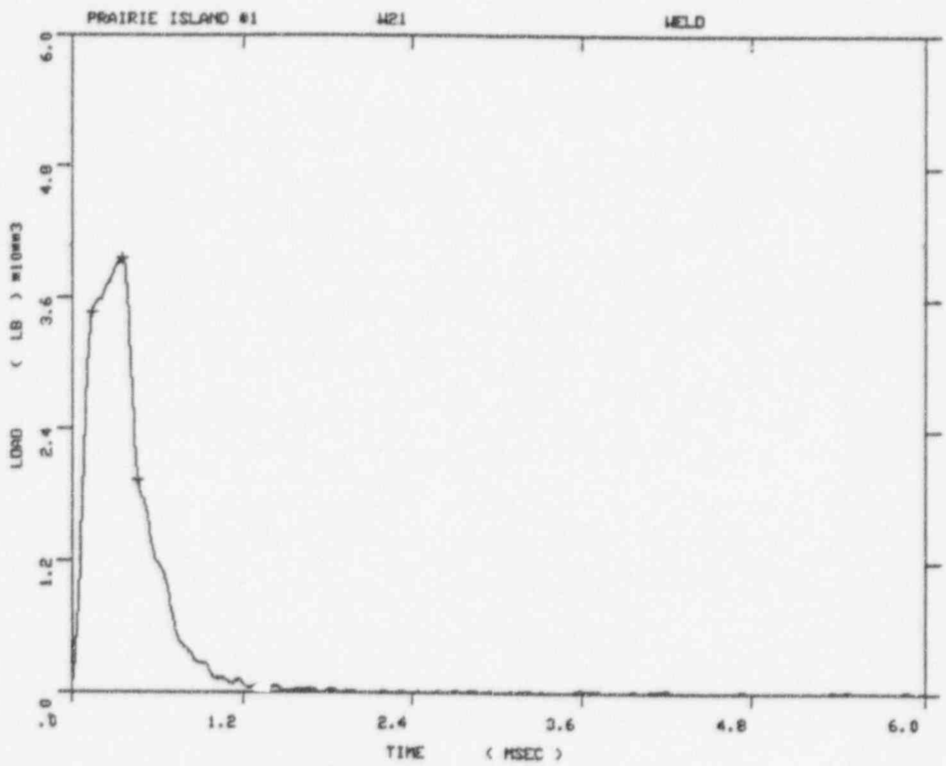
PRAIRIE ISLAND #1

SPECIMEN NUMBER :W18
MATERIAL :WELD
CAPSULE :PRAIRIE ISLAND

Figure A-14. Load-time records for Specimens W23 and W18.

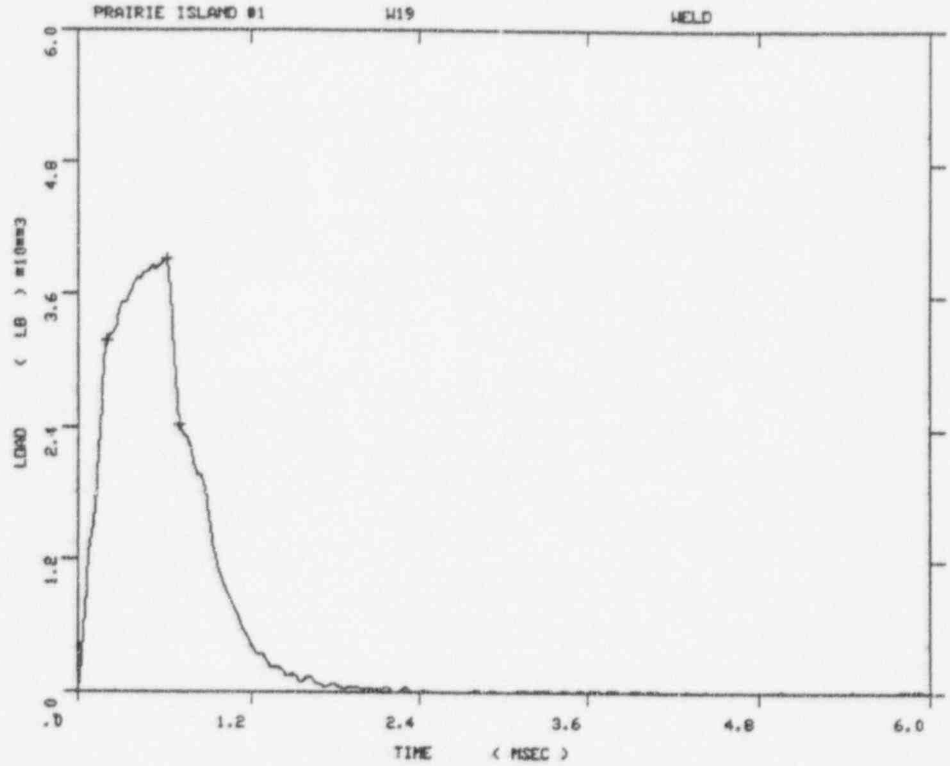


PRAIRIE ISLAND #1
SPECIMEN NUMBER :W22
MATERIAL :WELD
CAPSULE :PRAIRIE ISLAND



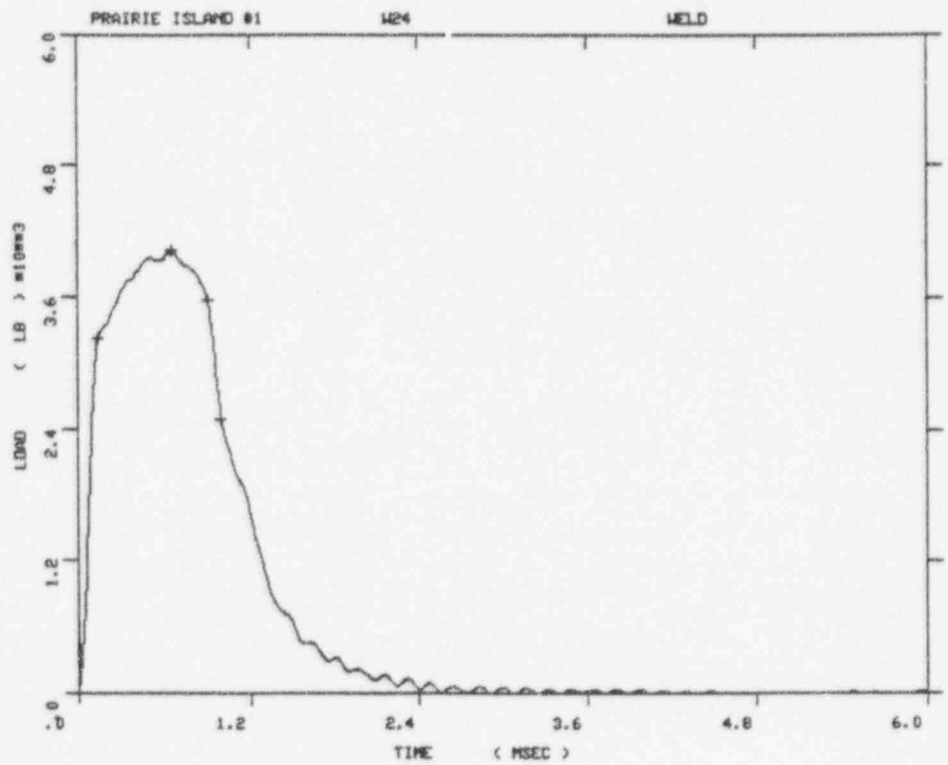
PRAIRIE ISLAND #1
SPECIMEN NUMBER :W21
MATERIAL :WELD
CAPSULE :PRAIRIE ISLAND

Figure A-15. Load-time records for Specimens W22 and W21.



PRAIRIE ISLAND #1

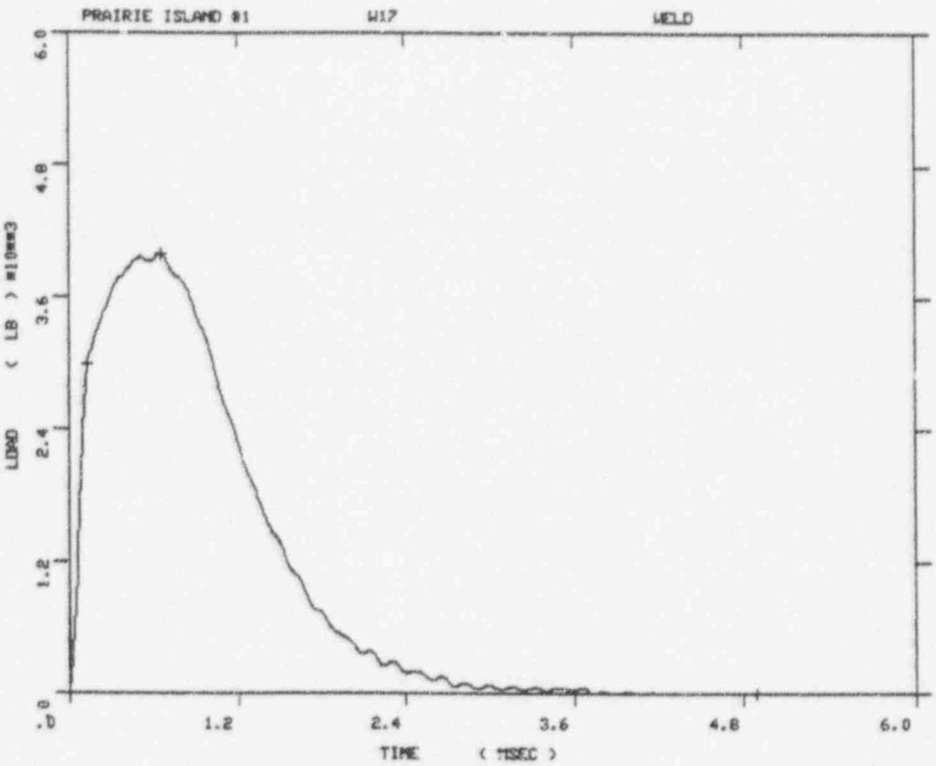
SPECIMEN :W19
MATERIAL :WELD
CAPSULE :PRAIRIE ISLAND



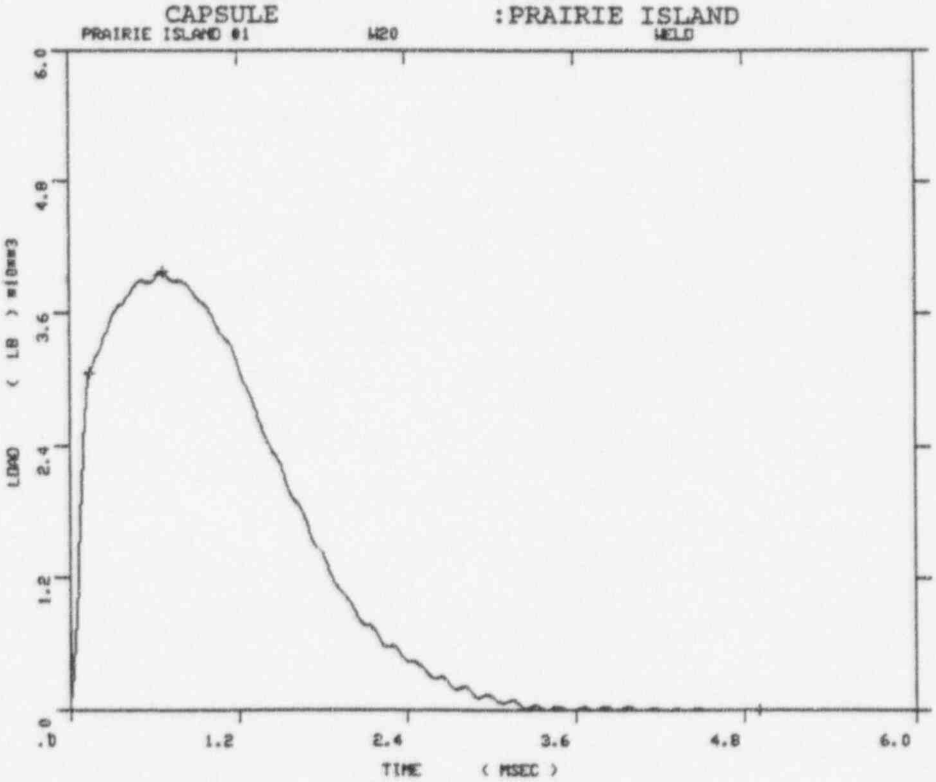
PRAIRIE ISLAND #1

SPECIMEN NUMBER :W24
MATERIAL :WELD
CAPSULE :PRAIRIE ISLAND

Figure A-16. Load-time records for Specimens W19 and W24.



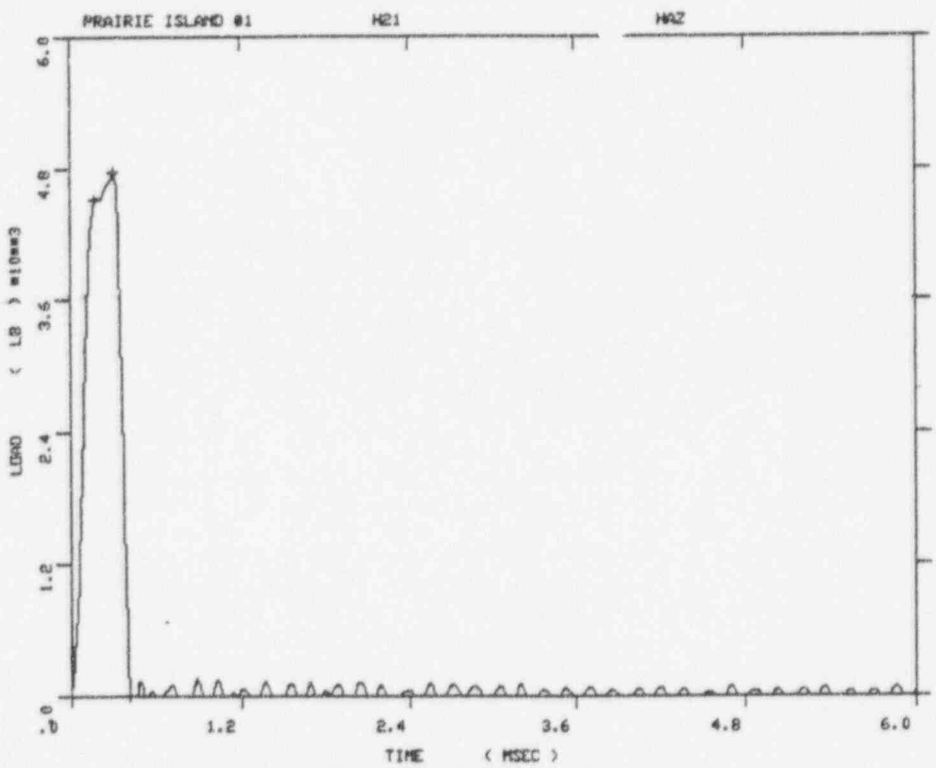
PRAIRIE ISLAND #1
SPECIMEN NUMBER :W17
MATERIAL :WELD
CAPSULE :PRAIRIE ISLAND



PRAIRIE ISLAND #1
SPECIMEN NUMBER :W20
MATERIAL :WELD
CAPSULE :PRAIRIE ISLAND

Figure A-17. Load-time records for Specimens W17 and W20.

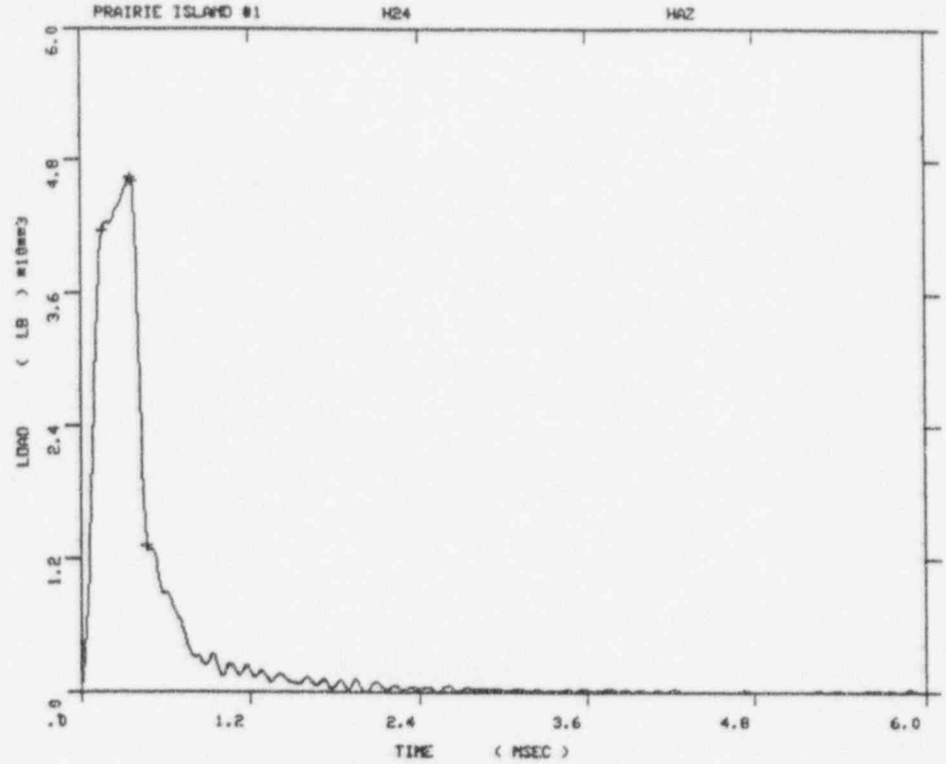
Specimen Alignment Error - Data not valid.



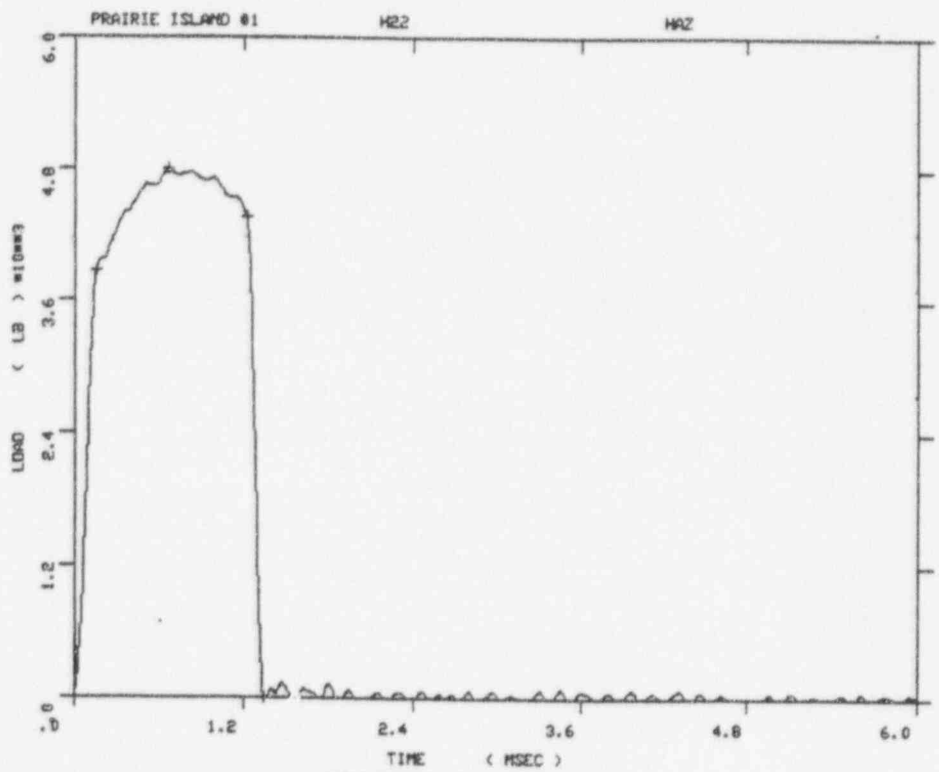
PRAIRIE ISLAND #1

SPECIMEN	:H21
MATERIAL	:HAZ
CAPSULE	:PRAIRIE ISLAND

Figure A-18. Load-time records for Specimens H17 and H21.

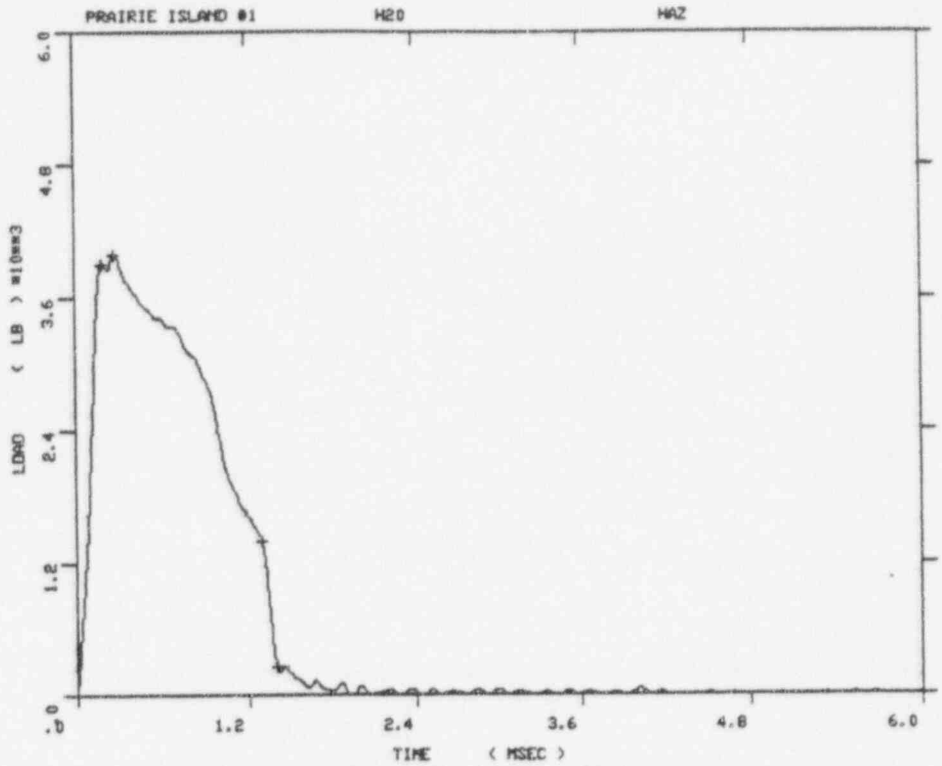


PRAIRIE ISLAND #1
SPECIMEN NUMBER :H24
MATERIAL :HAZ
CAPSULE :PRAIRIE ISLAND

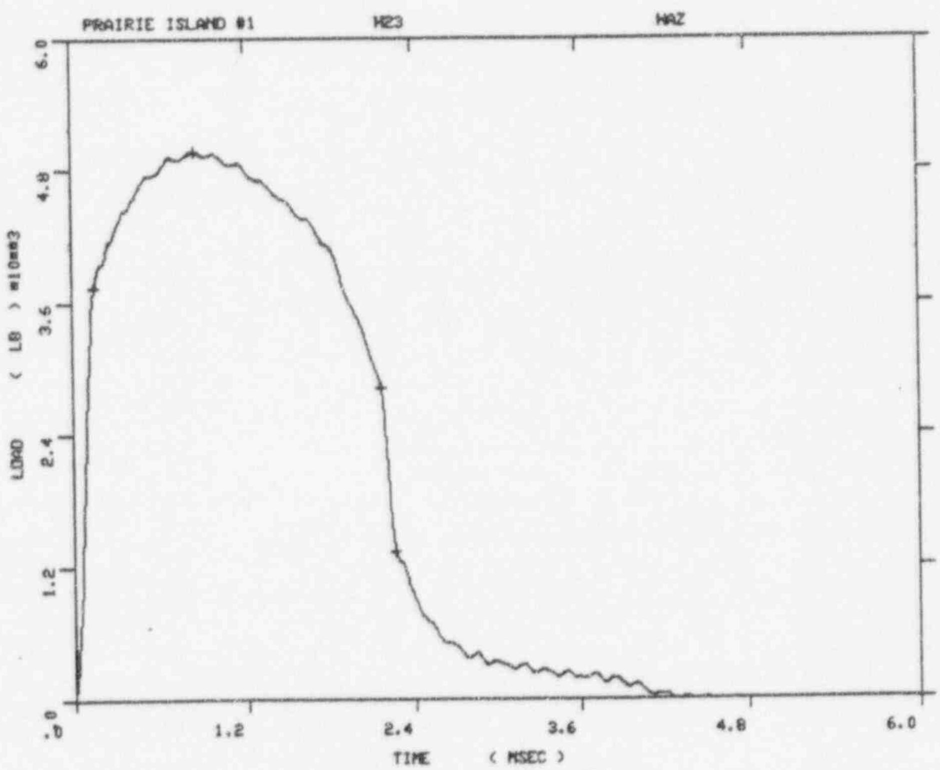


PRAIRIE ISLAND #1
SPECIMEN NUMBER :H22
MATERIAL :HAZ
CAPSULE :PRAIRIE ISLAND

Figure A-19. Load-time records for Specimens H24 and H22.

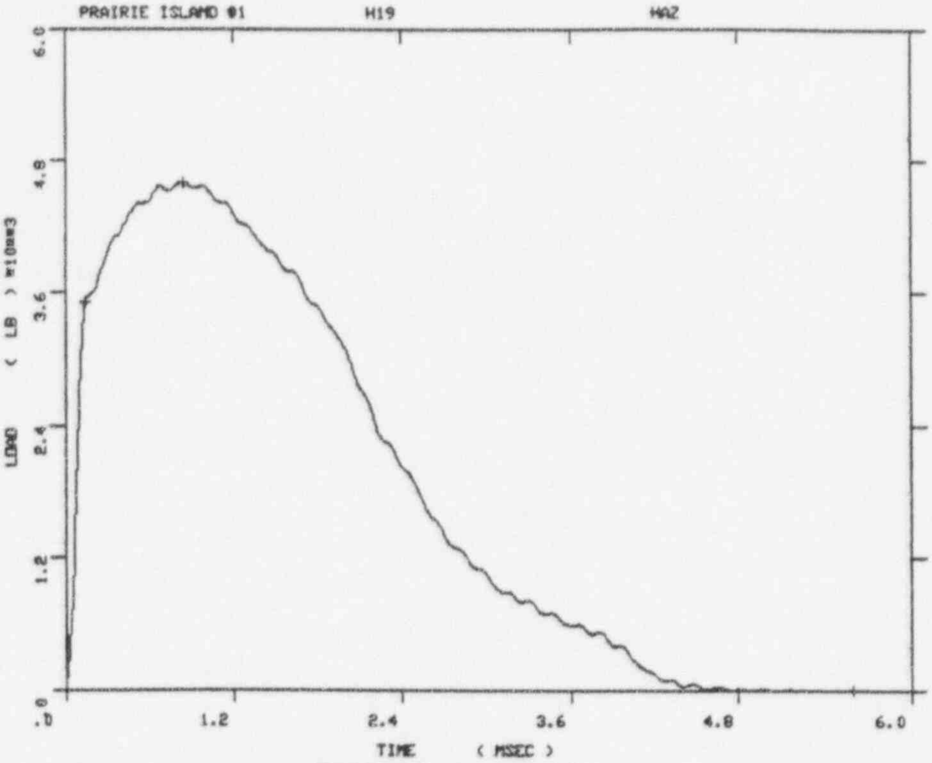


PRAIRIE ISLAND #1
SPECIMEN NUMBER :H20
MATERIAL :HAZ
CAPSULE :PRAIRIE ISLAND

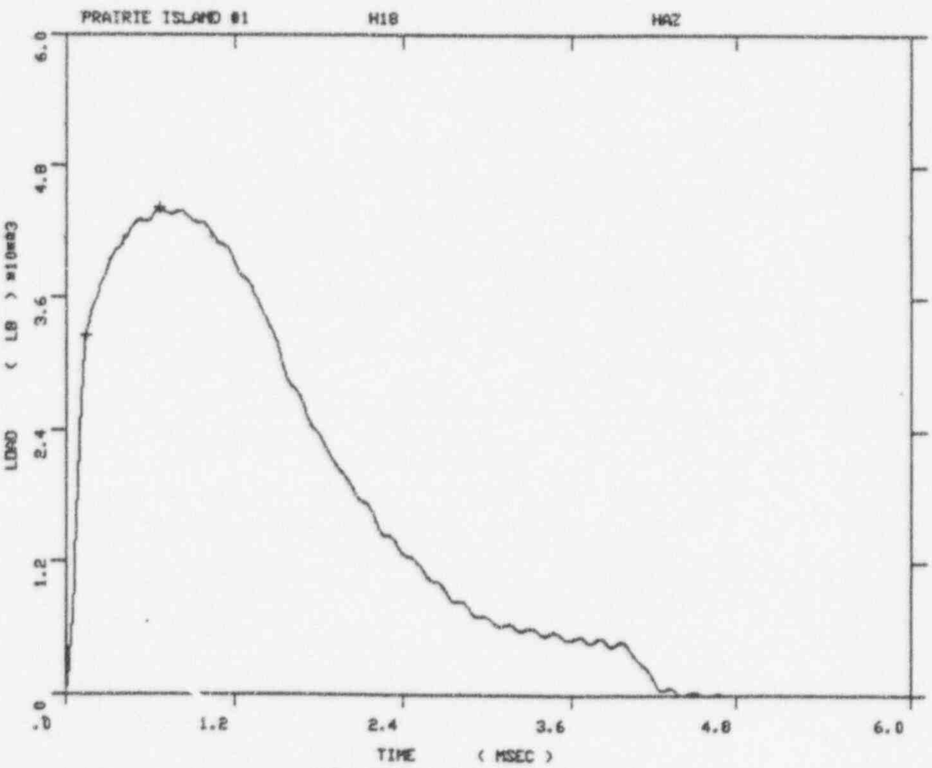


PRAIRIE ISLAND #1
SPECIMEN NUMBER :H23
MATERIAL :HAZ
CAPSULE :PRAIRIE ISLAND

Figure A-20. Load-time records for Specimens H20 and H23.

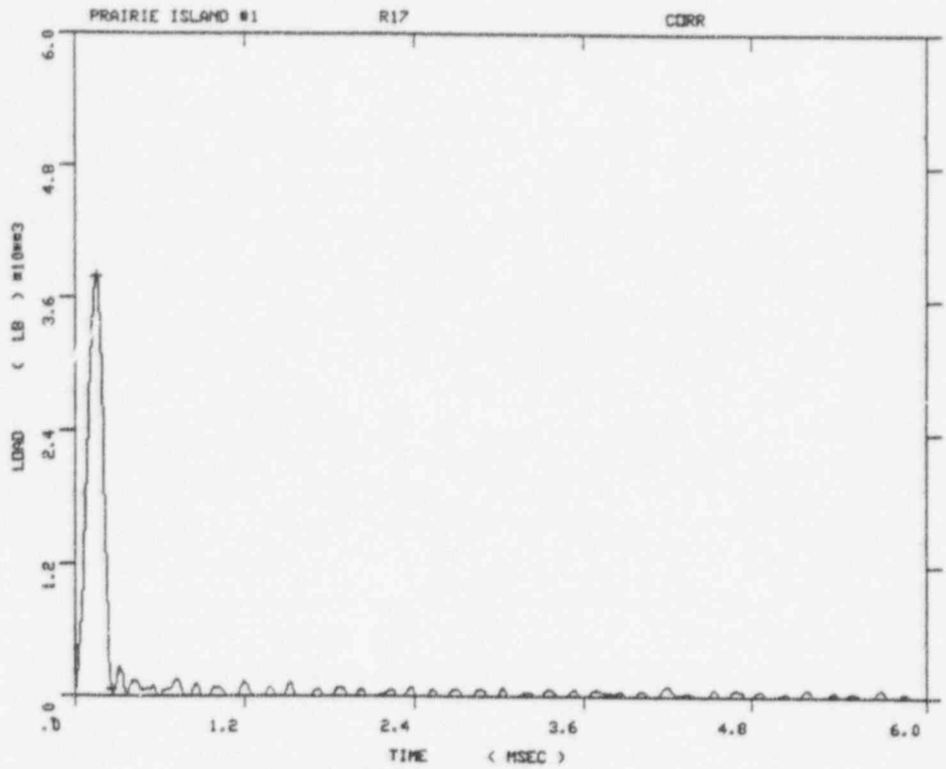


PRAIRIE ISLAND #1
SPECIMEN NUMBER :H19
MATERIAL :HAZ
CAPSULE :PRAIRIE ISLAND

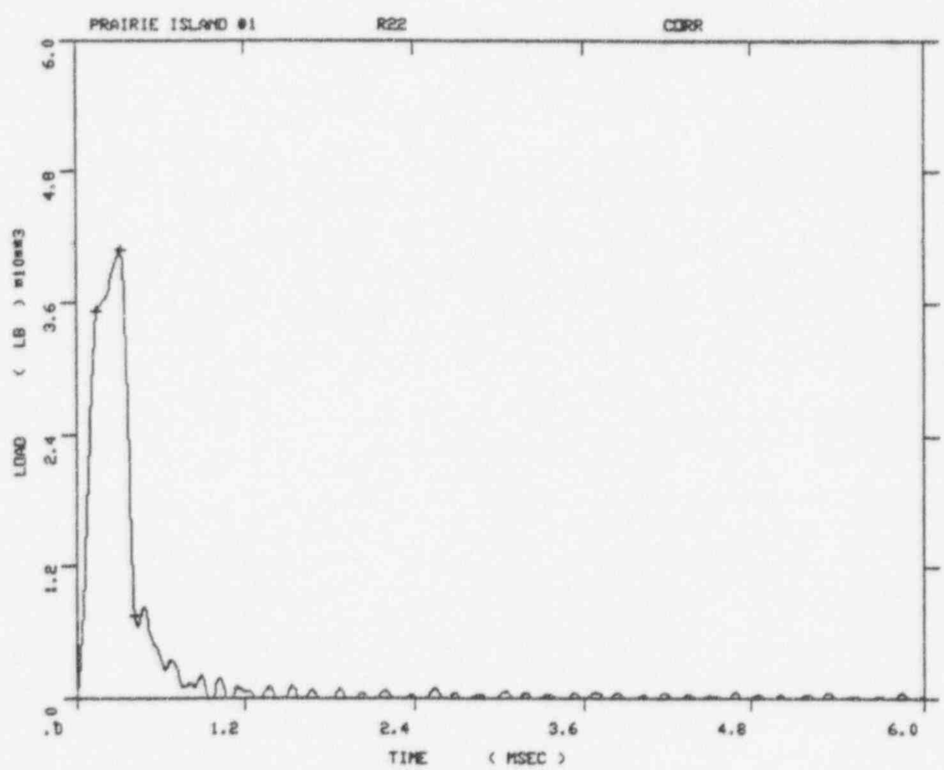


PRAIRIE ISLAND #1
SPECIMEN NUMBER :H18
MATERIAL :HAZ
CAPSULE :PRAIRIE ISLAND

Figure A-21. Load-time records for Specimens H19 and H18.

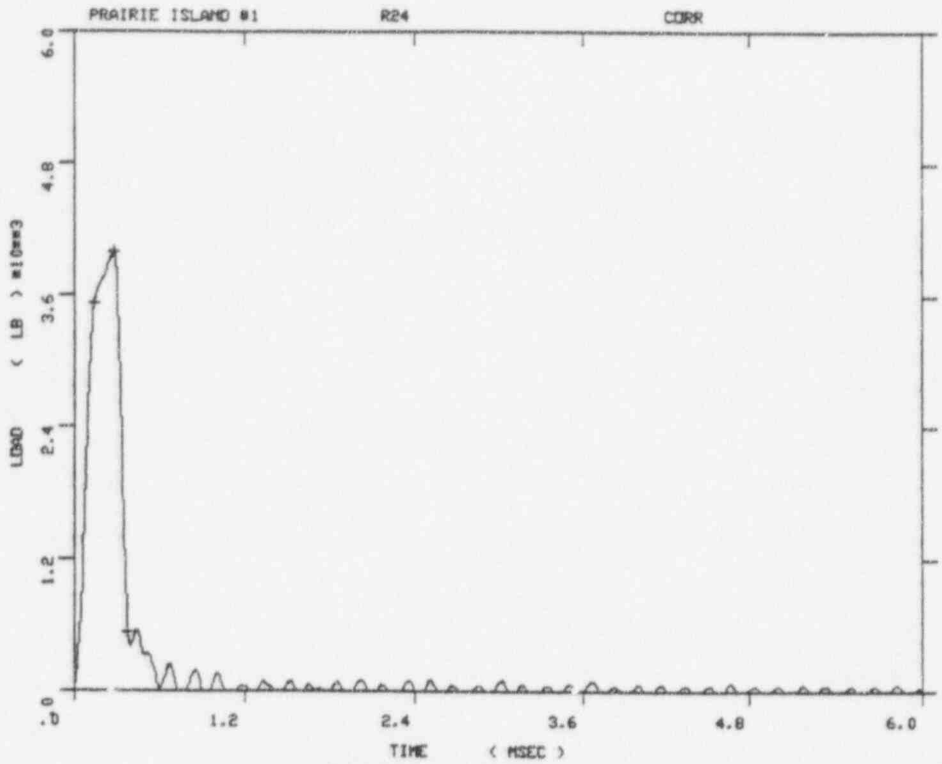


PRAIRIE ISLAND #1
SPECIMEN NUMBER :R17
MATERIAL :CORR
CAPSULE :PRAIRIE ISLAND

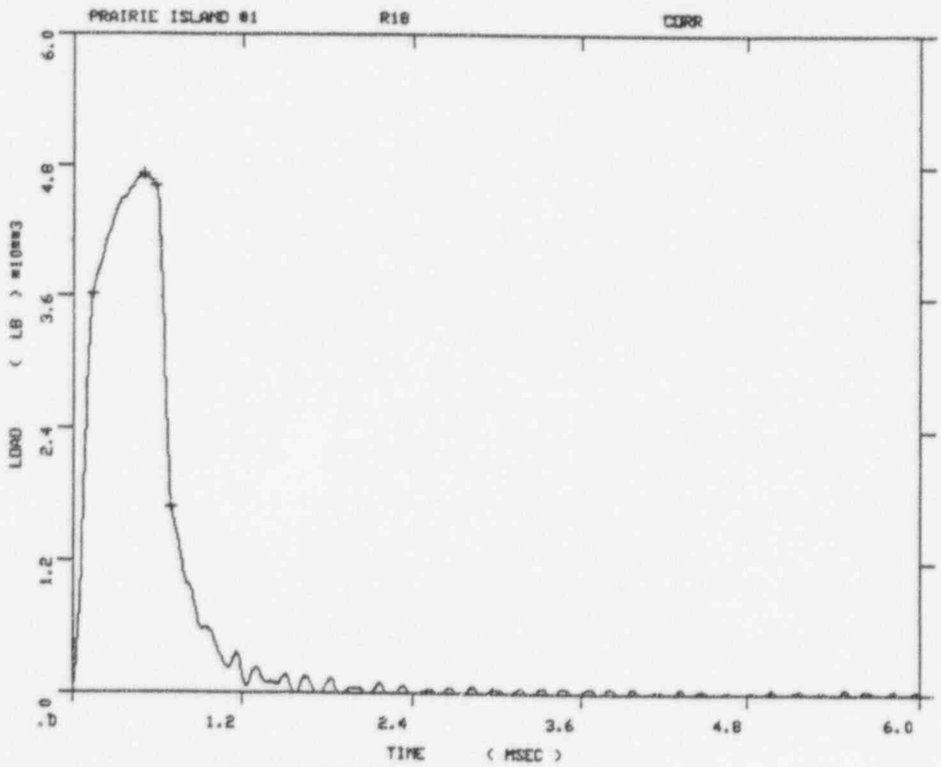


PRAIRIE ISLAND #1
SPECIMEN NUMBER :R22
MATERIAL :CORR
CAPSULE :PRAIRIE ISLAND

Figure A-22. Load-time records for Specimens R17 and R22.

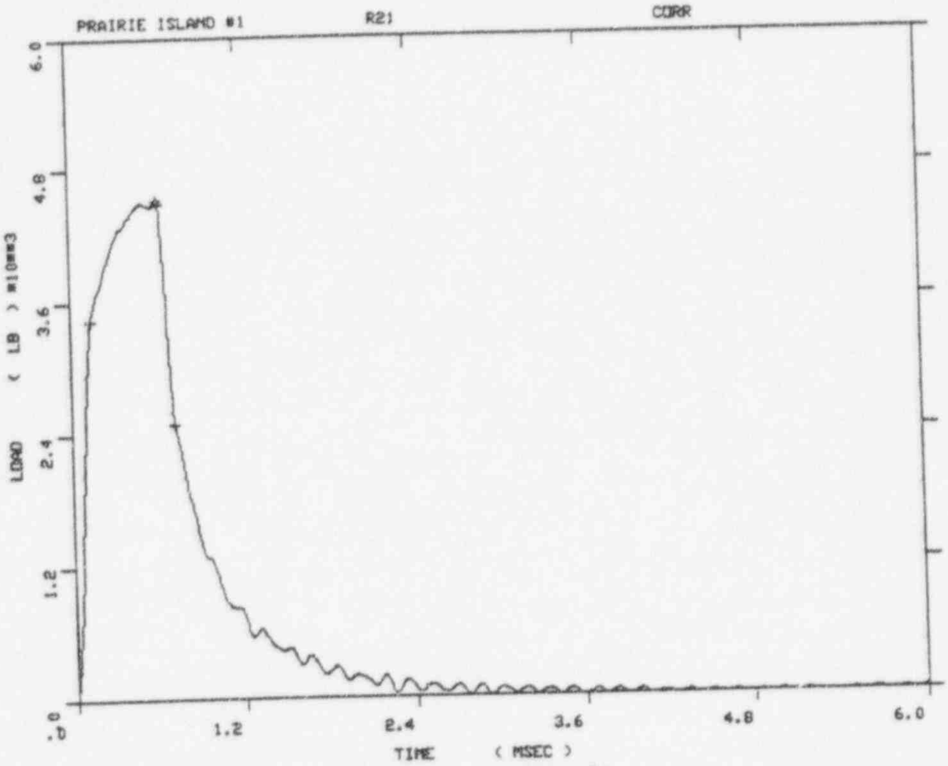


PRAIRIE ISLAND #1
SPECIMEN NUMBER :R24
MATERIAL :CORR
CAPSULE :PRAIRIE ISLAND

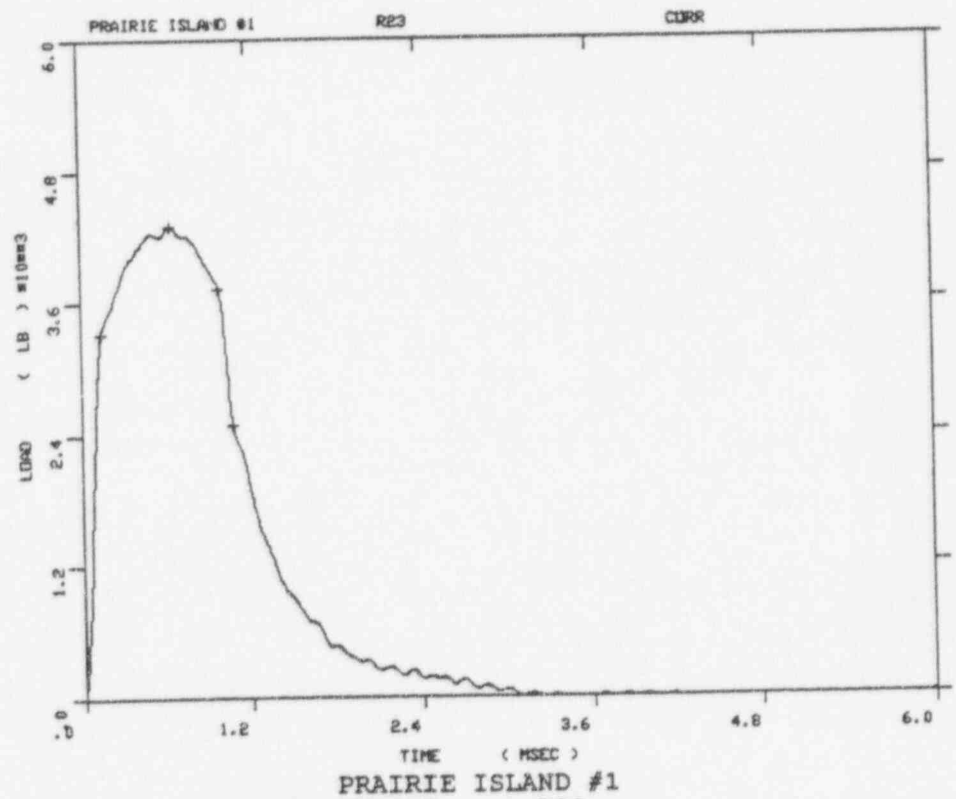


PRAIRIE ISLAND #1
SPECIMEN :R18
MATERIAL :CORR
CAPSULE :PRAIRIE ISLAND

Figure A-23. Load-time records for Specimens R24 and R18.

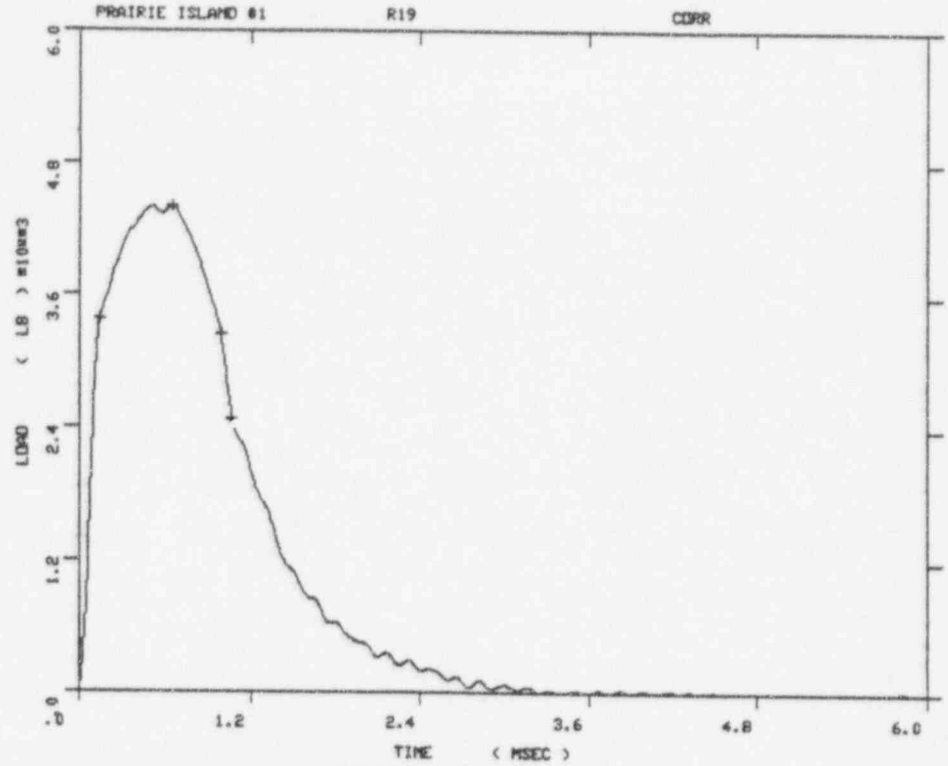


PRAIRIE ISLAND #1
SPECIMEN NUMBER :R21
MATERIAL :CORR
CAPSULE :PRAIRIE ISLAND

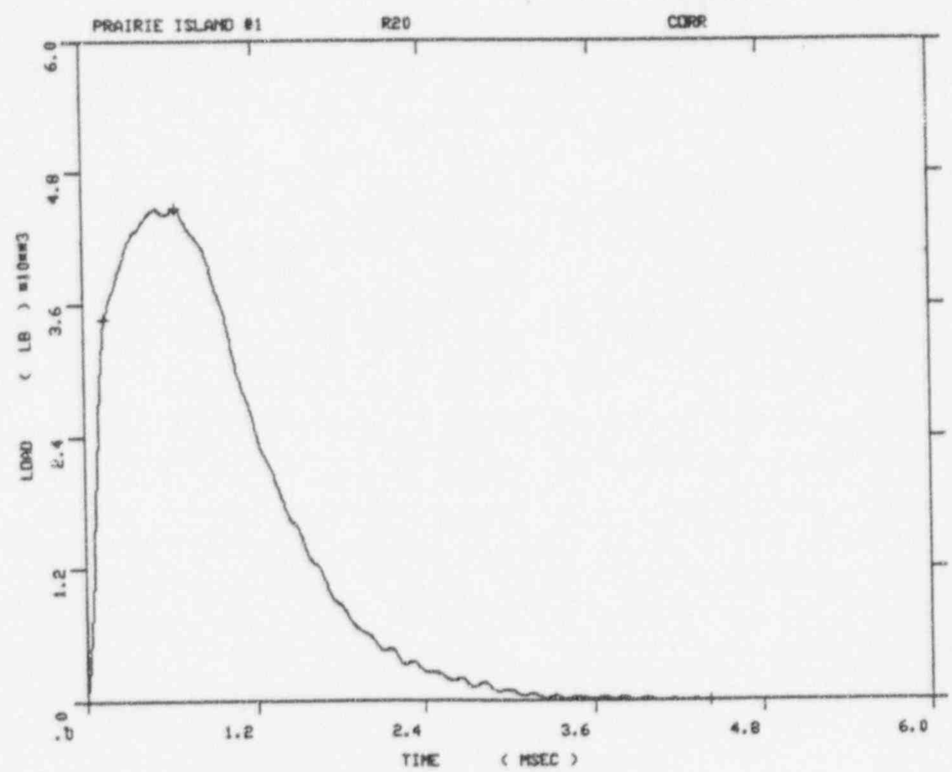


PRAIRIE ISLAND #1
SPECIMEN NUMBER :R23
MATERIAL :CORR
CAPSULE :PRAIRIE ISLAND

Figure A-24. Load-time records for Specimens R21 and R23.



PRAIRIE ISLAND #1
SPECIMEN NUMBER :R19
MATERIAL :CORR
CAPSULE :PRAIRIE ISLAND



PRAIRIE ISLAND #1
SPECIMEN NUMBER :R20
MATERIAL :CORR
CAPSULE :PRAIRIE ISLAND

Figure A-25. Load-time records for Specimens R19 and R20.

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 30 ft-lb Transition Temperature Shifts (°F) for Intermediate Shell Forging C (Tangential)						
Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔT_{30}	Unirradiated	Irradiated	ΔT_{30}
V	-25	13	38	-38.91	17.44	56.36
P	-25	-5	20	-38.91	-15.8	23.11
R	-25	55	80	-38.91	56.93	95.85
S	--	--	--	-38.91	62.55	101.46

Table B-2 50 ft-lb Transition Temperature Shifts (°F) for Intermediate Shell Forging C (Tangential)						
Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔT_{50}	Unirradiated	Irradiated	ΔT_{50}
V	-5	34	39	-6.35	44.34	50.69
P	-5	20	25	-6.35	16.92	23.27
R	-5	90	95	-6.35	94.84	101.19
S	--	--	--	-6.35	98.8	105.15

Table B-3 35-mil Lateral Expansion Temperature Shifts (°F) for Intermediate Shell Forging C (Tangential)						
Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔT_{35}	Unirradiated	Irradiated	ΔT_{35}
V	-25	38*	63	-24.28	47.82	72.11
P	-25	7	32	-24.28	9.34	33.63
R	-25	70	95	-24.28	80.86	105.15
S	--	--	--	-24.28	88.08	112.37

* Extracted from plot in WCAP-8916.

Table B-4 Upper Shelf Energy Shifts (ft-lb) for Intermediate Shell Forging C (Tangential)						
Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔE	Unirradiated	Irradiated	ΔE
V	158	143	-15	158	143	-15
P	158	142	-16	158	142	-16
R	158	145	-13	158	145	-13
S	--	--	--	158	142.5	-15.5

Table B-5 30 ft-lb Transition Temperature Shifts (°F) for Intermediate Shell Forging C (Axial)						
Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔT_{30}	Unirradiated	Irradiated	ΔT_{30}
V	-27	-3	24	-31.31	-7.24	24.07
P	-27	10	37	-31.31	2.66	33.98
R	-27	60	87	-31.31	52.87	84.18
S	--	--	--	-31.31	42.95	74.27

Table B-6 50 ft-lb Transition Temperature Shifts (°F) for Intermediate Shell Forging C (Axial)						
Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔT_{50}	Unirradiated	Irradiated	ΔT_{50}
V	4	19	15	3.95	20.11	16.15
P	4	55	51	3.95	54.27	50.32
R	4	100	96	3.95	99.55	95.6
S	--	--	--	3.95	80.63	76.68

Table B-7 35-mil Lateral Expansion Temperature Shifts (°F) for Intermediate Shell Forging C (Axial)						
Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔT_{35}	Unirradiated	Irradiated	ΔT_{35}
V	-12.5	17	29.5	-13.05	18.92	31.97
P	-12	28	40	-13.05	18.14	31.2
R	-12	85	97	-13.05	85.16	98.21
S	--	--	--	-13.05	75.02	88.07

Table B-8 Upper Shelf Energy Shifts (ft-lb) for Intermediate Shell Forging C (Axial)						
Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔE	Unirradiated	Irradiated	ΔE
V	143	155	12	143	155	12
P	143	136	-7	143	136	-7
R	143	129	-14	143	129	-14
S	--	--	--	143	135	-8

Table B-9 30 ft-lb Transition Temperature Shifts (°F) for the Surveillance Weld Material						
Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔT_{30}	Unirradiated	Irradiated	ΔT_{30}
V	-57	-32	25	-64.44	-30.05	34.38
P	-57	-15	42	-64.44	-19.28	45.15
R	-57	60	117	-64.44	58.02	122.47
S	--	--	--	-64.44	95.98	160.43

Table B-10 50 ft-lb Transition Temperature Shifts (°F) for the Surveillance Weld Material

Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔT_{50}	Unirradiated	Irradiated	ΔT_{50}
V	-14	18	32	-26.93	20.42	47.35
P	-14	46	60	-26.93	45.01	71.94
R	-14	115	129	-26.93	134.95	161.88
S	--	--	--	-26.93	143.91	170.84

Table B-11 35-mil Lateral Expansion Temperature Shifts (°F) for the Surveillance Weld Material

Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔT_{35}	Unirradiated	Irradiated	ΔT_{35}
V	-45	14	59	-50.79	22.58	73.38
P	-45	25	70	-50.79	25.55	76.34
R	-45	90	135	-50.79	117.04	167.83
S	--	--	--	-50.79	132.74	183.53

Table B-12 Upper Shelf Energy Shifts (ft-lb) for the Surveillance Weld Material

Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔE	Unirradiated	Irradiated	ΔE
V	78.5	91	12.5	78.5	91	12.5
P	78.5	83	4.5	78.5	83	4.5
R	78.5	75	-3.5	78.5	75	-3.5
S	--	--	--	78.5	84.5	6

Table B-13 30 ft-lb Transition Temperature Shifts (°F) for the Weld Heat-Affected-Zone (HAZ) Material

Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔT_{30}	Unirradiated*	Irradiated	ΔT_{30}
V	-200	-200	0	-260.00	-200.00*	0
P	-200	-130	70	-200.00	-125.35	74.65
R	-200	-60	140	-200.00	-50.31	149.69
S	--	--	--	-200.00	-62.89	137.11

Table B-14 50 ft-lb Transition Temperature Shifts (°F) for the Weld Heat-Affected-Zone (HAZ) Material

Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔT_{50}	Unirradiated*	Irradiated	ΔT_{50}
V	-125	-125	0	-125.00	-125.00*	0
P	-170	-105	65	-125.00	-88.8	36.20
R	-170	-5	165	-125.00	-21.13	103.87
S	--	--	--	-125.00	-26.8	98.20

Table B-15 35-mil Lateral Expansion Temperature Shifts (°F) for the Weld Heat-Affected-Zone (HAZ) Material

Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔT_{35}	Unirradiated*	Irradiated	ΔT_{35}
V	-152	-128	24	-152.00	-128.00	24.00
P	-175	-65	110	-152.00	-51.24	100.76
R	-175	0	175	-152.00	-11.77	140.23
S	--	--	--	-152.00	-7.49	144.51

* Because the hyperbolic tangent curve fitting process did not provide a smooth S-shaped curve for the unirradiated and Capsule V data, these values have been retained from the original Charpy V-notch hand fit curves documented in WCAP-8086 and WCAP-8916.

Table B-16 Upper Shelf Energy Shifts (ft-lb) for the Weld Heat-Affected-Zone (HAZ) Material						
	Hand-Fit Plots			CVGRAPH Plots		
Capsule	Unirradiated	Irradiated	ΔE	Unirradiated	Irradiated	ΔE
V	211	*	*	211	*	*
P	211	143	-68	211	143	-68
R	211	97	-114	211	97	-114
S	--	--	--	211	136	-75

* Upper shelf impact energy not obtainable due to excessive toughness.

Table B-17 30 ft-lb Transition Temperature Shifts (°F) for the Correlation Monitor HSST Plate 02						
	Hand-Fit Plots			CVGRAPH Plots		
Capsule	Unirradiated	Irradiated	ΔT_{30}	Unirradiated	Irradiated	ΔT_{30}
V	49	159	110	46.2	149.05	102.84
P	49	205	156	46.2	207.61	161.4
R	49	235	186	46.2	239.93	193.72
S	--	--	--	46.2	212.29	166.08

Table B-18 50 ft-lb Transition Temperature Shifts (°F) for the Correlation Monitor HSST Plate 02						
	Hand-Fit Plots			CVGRAPH Plots		
Capsule	Unirradiated	Irradiated	ΔT_{50}	Unirradiated	Irradiated	ΔT_{50}
V	81	194	113	78.39	194.65	116.25
P	81	232	151	78.39	228.16	149.76
R	81	285	204	78.39	280.48	202.08
S	--	--	--	78.39	237.98	159.58

Table B-19 35-mil Lateral Expansion Temperature Shifts (°F) for the Correlation Monitor HSST Plate 02						
Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔT_{35}	Unirradiated	Irradiated	ΔT_{35}
V	53	88	35	58.63	192.96	134.33
P	53	218	165	58.63	217.38	158.74
R	53	280	227	58.63	299.54	240.9
[illegible]	--	--	--	58.63	238.47	179.82

Table B-20 Upper Shelf Energy Shifts (ft-lb) for the Correlation Monitor HSST Plate 02						
Capsule	Hand-Fit Plots			CVGRAPH Plots		
	Unirradiated	Irradiated	ΔE	Unirradiated	Irradiated	ΔE
V	123.5	91	-32.5	123.5	91	-32.5
P	123.5	85	-38.5	123.5	85	-38.5
R	123.5	86	-37.5	123.5	86	-37.5
S	--	--	--	123.5	82.5	-41

APPENDIX C

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

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:47:03 on 10-28-1996
Page 1
Coefficients of Curve 1

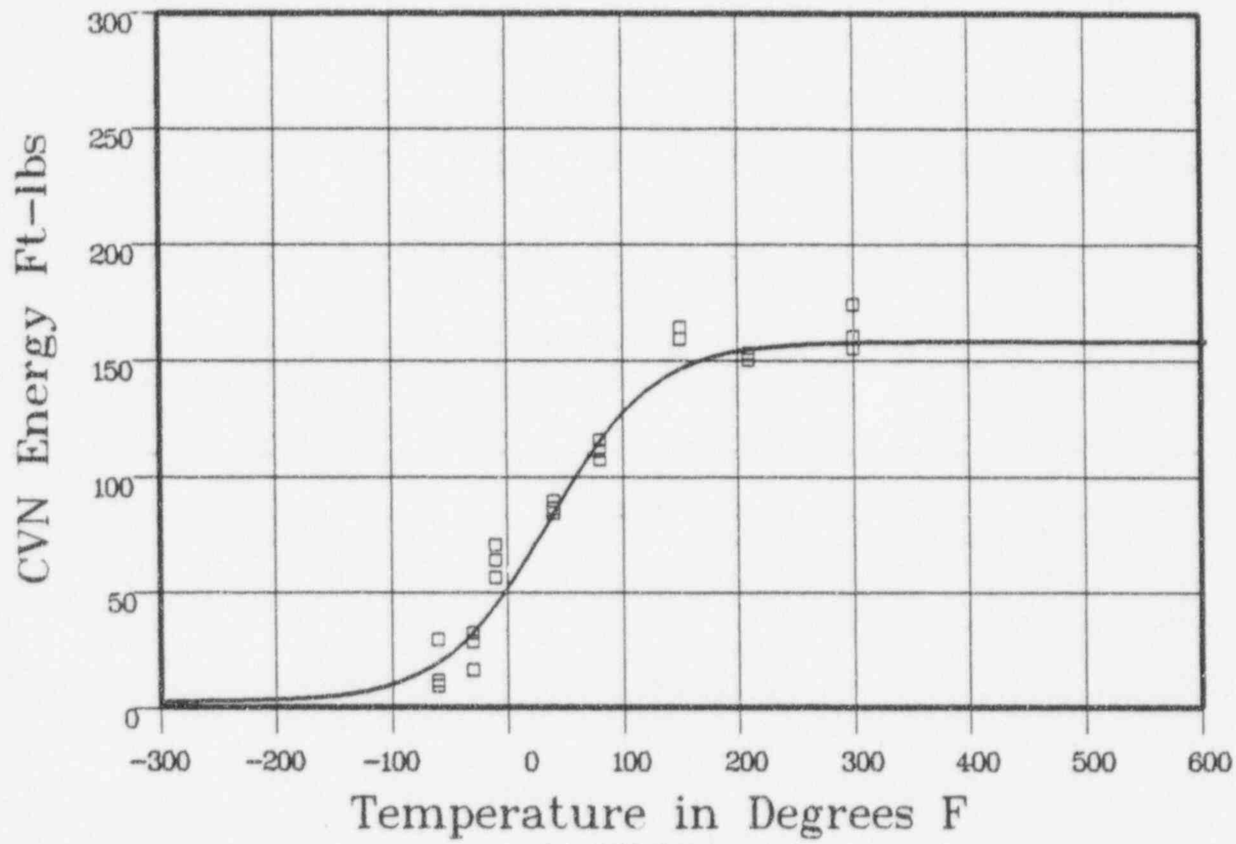
A = 80.09	B = 77.9	C = 91.49	T0 = 30.93

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

Upper Shelf Energy: 158 Fixed Temp. at 30 ft-lbs: -38.9 Temp. at 50 ft-lbs: -6.3 Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted
Plant: PI1 Cap.: UNIRR Material: FORGING SA5083 Ori.: LT Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-60	9	20.97	-11.97
-60	29	20.97	8.02
-60	11.5	20.97	-9.47
-30	32	34.73	-2.73
-30	16	34.73	-18.73
-30	28	34.73	-6.73
-10	63.5	47.39	16.1
-10	56	47.39	8.6
-10	70	47.39	22.6

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

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
40	89	87.79	1.2
40	84	87.79	-3.79
40	86	87.79	-1.79
80	107	118.28	-11.28
80	115.5	118.28	-2.78
80	111	118.28	-7.28
150	159	147.25	11.74
150	164	147.25	16.74
210	150	154.95	-4.95
210	153	154.95	-1.95
210	153	154.95	-1.95
300	160	157.56	2.43
300	155	157.56	-2.56
300	174	157.56	16.43

SUM of RESIDUALS = 15.9

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:54:12 on 10-28-1996
Page 1
Coefficients of Curve 1

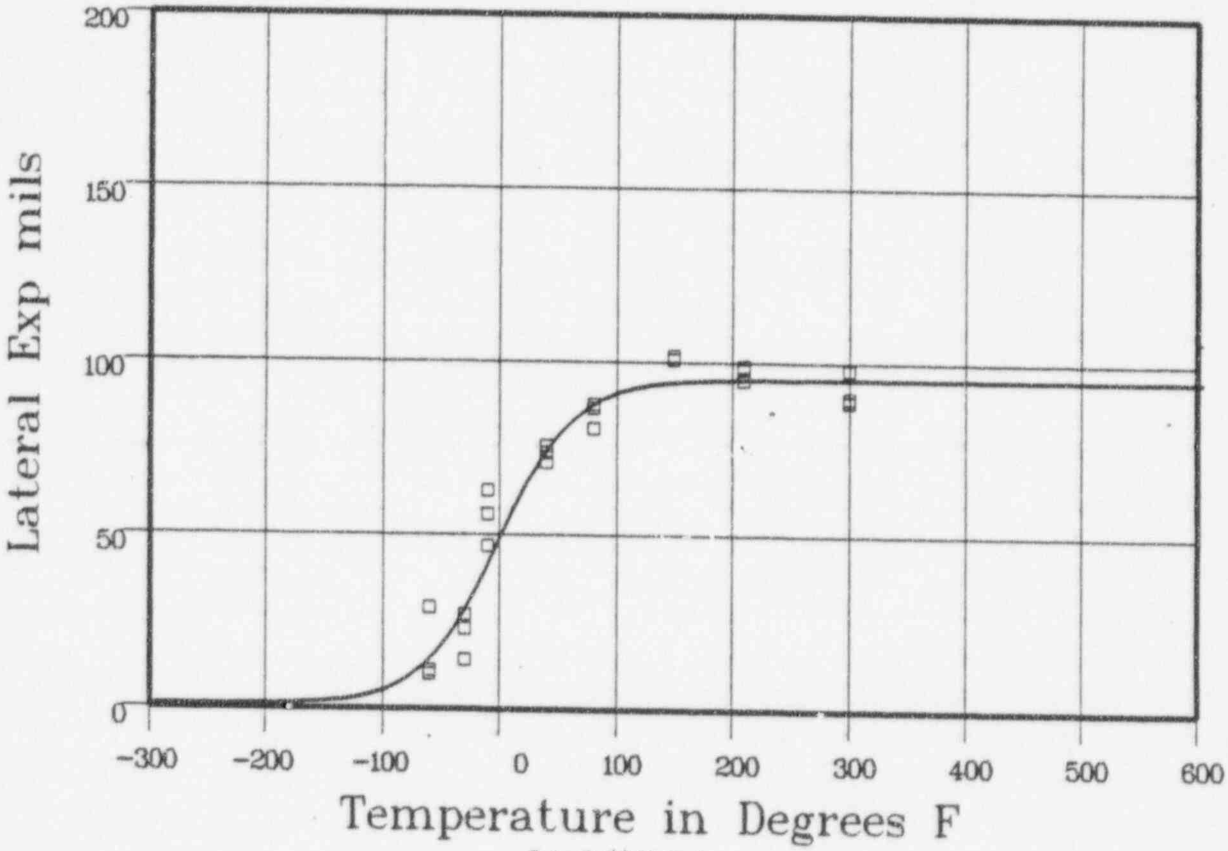
A = 48.15	B = 47.15	C = 65.31	T0 = -5.62

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

Upper Shelf L.E.: 95.3 Temperature at L.E. 35: -24.3 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: UNIRR Material: FORGING SA5083 Ori.: LT Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-60	11	16	-5
-60	29	16	12.99
-60	10	16	-6
-30	27	31.33	-4.33
-30	14	31.33	-17.33
-30	23	31.33	-8.33
-10	56	44.99	11
-10	47	44.99	2
-10	63	44.99	18

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

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
40	76	76.6	-.6
40	71	76.6	-5.6
40	74	76.6	-2.6
80	81	88.91	-7.91
80	88	88.91	-.91
80	87	88.91	-1.91
150	102	94.51	7.48
150	101	94.51	6.48
210	99	95.17	3.82
210	98	95.17	2.82
210	95	95.17	-.17
300	98	95.29	2.7
300	90	95.29	-5.29
300	89	95.29	-6.29

SUM of RESIDUALS = -5.02

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:55:05 on 10-28-1996
Page 1
Coefficients of Curve 1

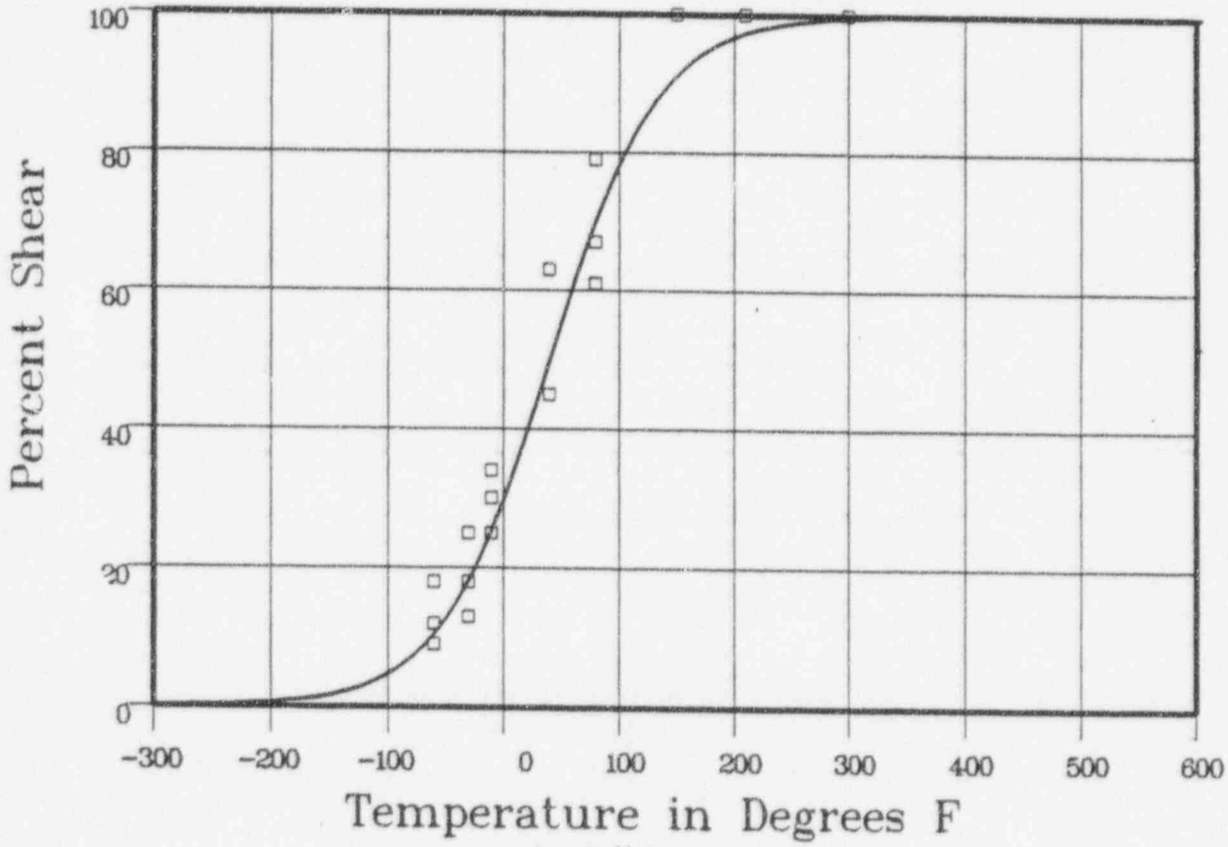
A = 50	B = 50	C = 93.78	T0 = 35.9

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

Temperature at 50% Shear: 35.9

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted
Plant: PI1 Cap.: UNIRR Material: FORGING SA5083 Ori.: LT Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-60	9	11.45	-2.45
-60	18	11.45	6.54
-60	12	11.45	.54
-30	25	19.69	5.3
-30	13	19.69	-6.69
-30	18	19.69	-1.69
-10	34	27.31	6.68
-10	25	27.31	-2.31
-10	30	27.31	2.68

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

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
40	63	52.18	10.81
40	45	52.18	-7.18
40	45	52.18	-7.18
80	79	71.91	7.08
80	67	71.91	-4.91
80	61	71.91	-10.91
150	100	91.93	8.06
150	100	91.93	8.06
210	100	97.61	2.38
210	100	97.61	2.38
210	100	97.61	2.38
300	100	99.64	.35
300	100	99.64	.35
300	100	99.64	.35

SUM of RESIDUALS = 20.66

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:18:07 on 10-23-1996

Page 1

Coefficients of Curve 1

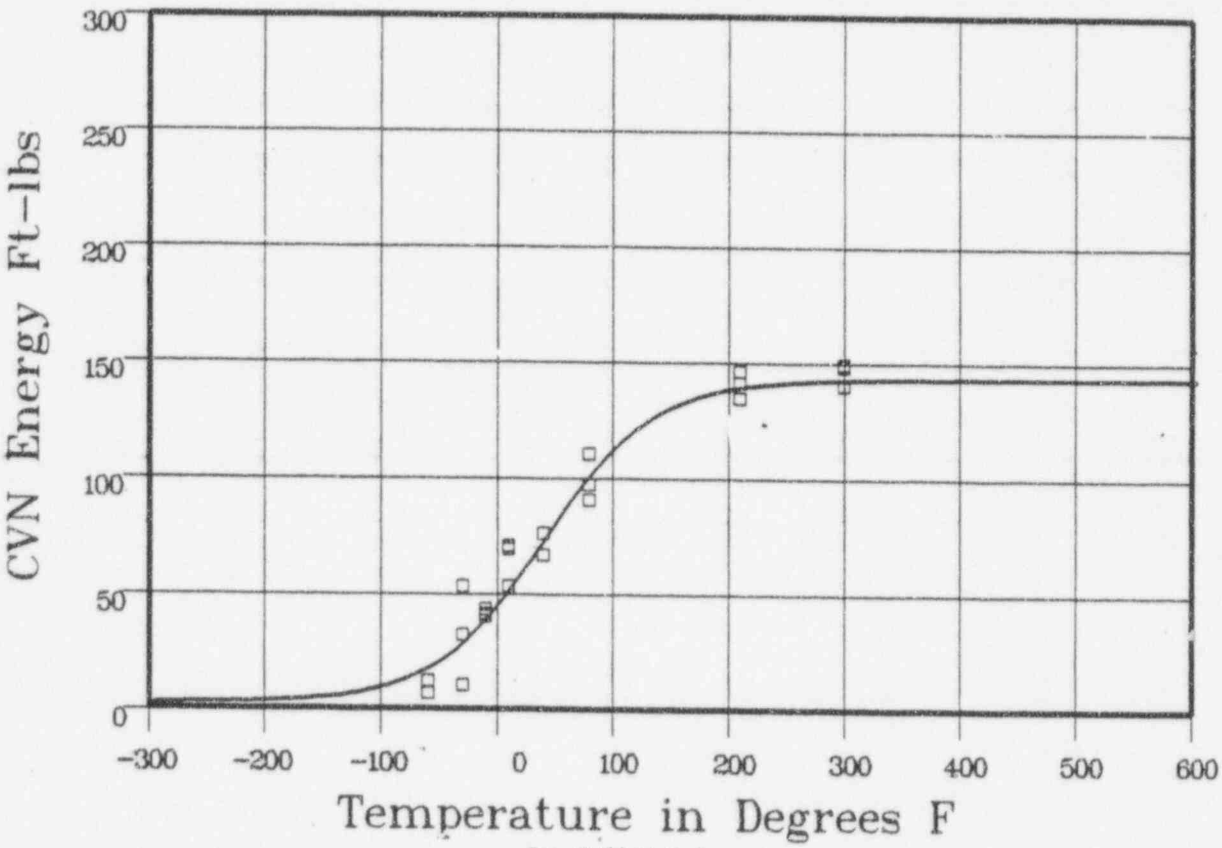
A = 72.59	B = 70.4	C = 95.73	T0 = 35.81

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

Upper Shelf Energy: 143 Fixed Temp. at 30 ft-lbs: -31.3 Temp. at 50 ft-lbs: 3.9 Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: UNIRR Material: FORGING SA5083 Ori.: TL Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-60	6.5	18.96	-12.46
-60	12	18.96	-6.96
-60	6.5	18.96	-12.46
-30	32	30.61	1.38
-30	53	30.61	22.38
-30	10	30.61	-20.61
-10	41	41.26	-.26
-10	43	41.26	1.73
-10	40	41.26	-1.26

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

UNIRRADIATED

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
10	69	54.06	14.93
10	53	54.06	-1.06
10	70.5	54.06	16.43
40	76	75.67	.32
40	66.5	75.67	-9.17
80	110	102.96	7.03
80	90.5	102.96	-12.46
30	97	102.96	-5.96
210	141	139.39	1.6
210	134.5	139.39	-4.89
210	146	139.39	6.6
300	149	142.43	6.56
300	148	142.43	5.56
300	140	142.43	-2.43

SUM of RESIDUALS = -5.49

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:19:33 on 10-23-1996

Page 1

Coefficients of Curve 1

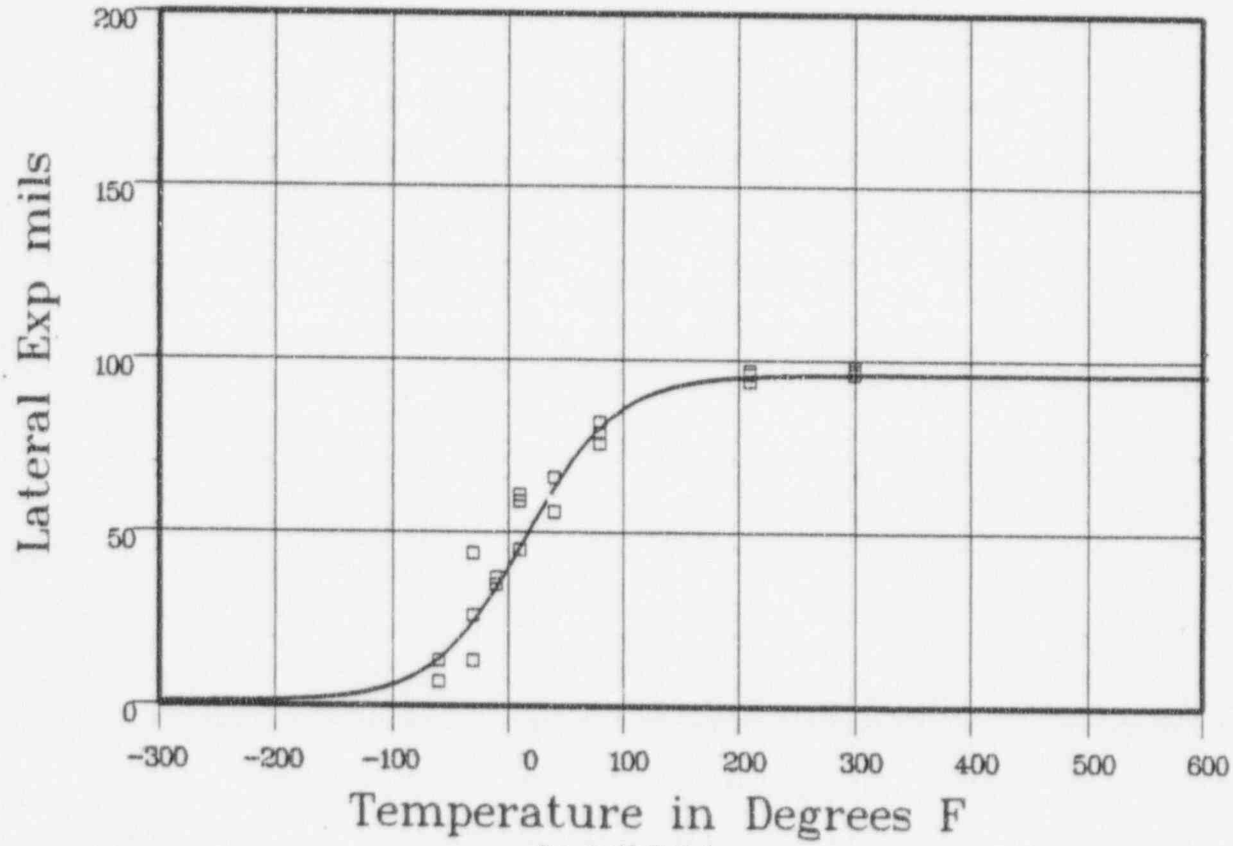
A = 48.5	B = 47.5	C = 79.91	T0 = 10.31

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

Upper Shelf L.E.: 96.01 Temperature at L.E. 35: -13 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: UNIRR Material: FORGING SA5083 Ori.: TL Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-60	7	14.95	-7.95
-60	13	14.95	-1.95
-60	7	14.95	-7.95
-30	26	26.38	-.38
-30	44	26.38	17.61
-30	13	26.38	-13.38
-10	35	36.68	-1.68
-10	37	36.68	.31
-10	35	36.68	-1.68

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

UNIRRADIATED

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed LE.	Differential
10	61	48.32	12.67
10	45	48.32	-3.32
10	59	48.32	10.67
40	66	65.38	.61
40	56	65.38	-9.38
80	82	81.87	.12
80	76	81.87	-5.87
80	79	81.87	-2.87
210	97	95.38	1.61
210	94	95.38	-1.38
210	96	95.38	.61
300	96	95.95	.04
300	97	95.95	1.04
300	98	95.95	2.04

SUM of RESIDUALS = -10.45

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:20:46 on 10-23-1996

Page 1

Coefficients of Curve 1

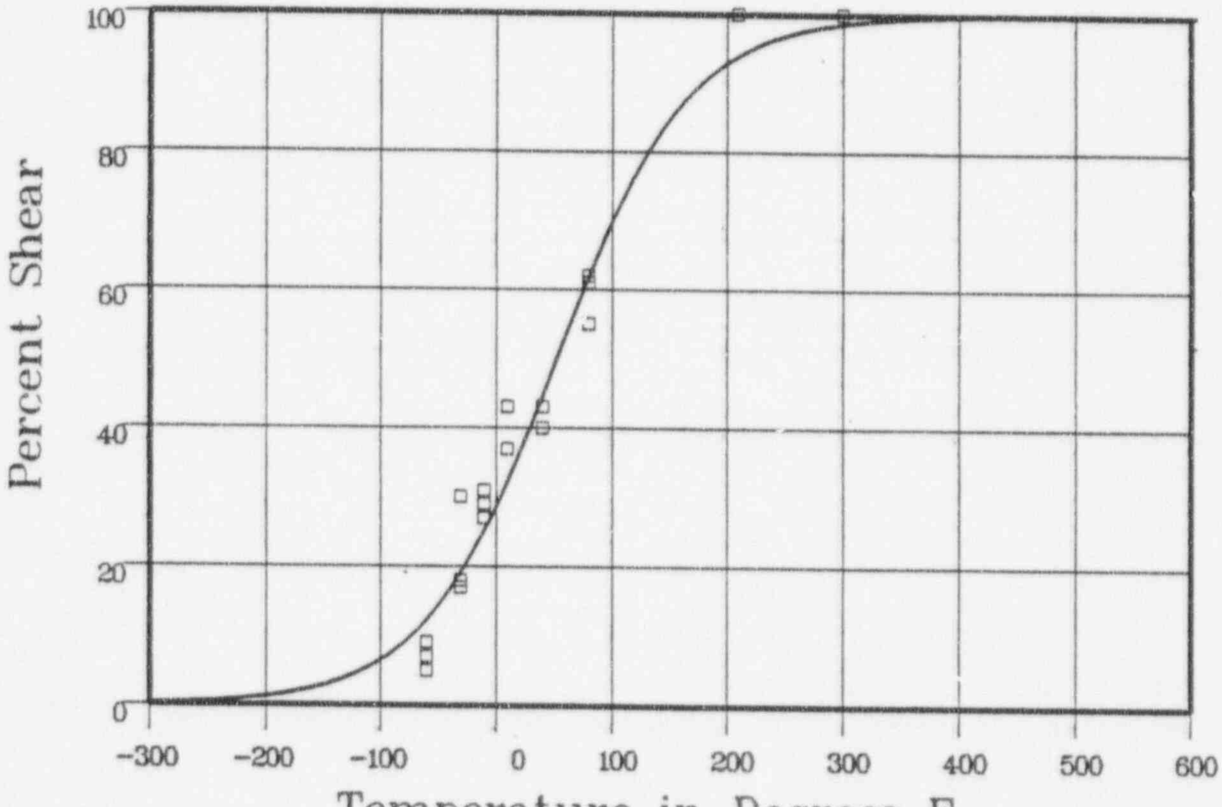
A = 50	B = 50	C = 114.53	T0 = 47.81

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

Temperature at 50% Shear: 47.8

Material: FORGING SA508-3 Heat Number: 21918/38566 Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: UNIRR Material: FORGING SA508-3 Ori.: TL Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-60	5	13.2	-8.2
-60	9	13.2	-4.2
-60	7	13.2	-6.2
-30	18	20.44	-2.44
-30	30	20.44	9.55
-30	17	20.44	-3.44
-10	31	26.7	4.29
-10	27	26.7	.29
-10	29	26.7	2.29

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

UNIRRADIATED

Page 2

Material: FORGING SA508 Heat Number: 21918/38566 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
10	43	34.06	8.93
10	37	34.06	2.93
10	43	34.06	8.93
40	43	46.59	-3.59
40	40	46.59	-6.59
80	62	63.69	-1.69
80	55	63.69	-8.69
80	61	63.69	-2.69
210	100	94.43	5.56
210	100	94.43	5.56
210	100	94.43	5.56
300	100	98.79	1.2
300	100	98.79	1.2
300	100	98.79	1.2

SUM of RESIDUALS = 9.75

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:22:20 on 10-23-1996

Page 1

Coefficients of Curve 1

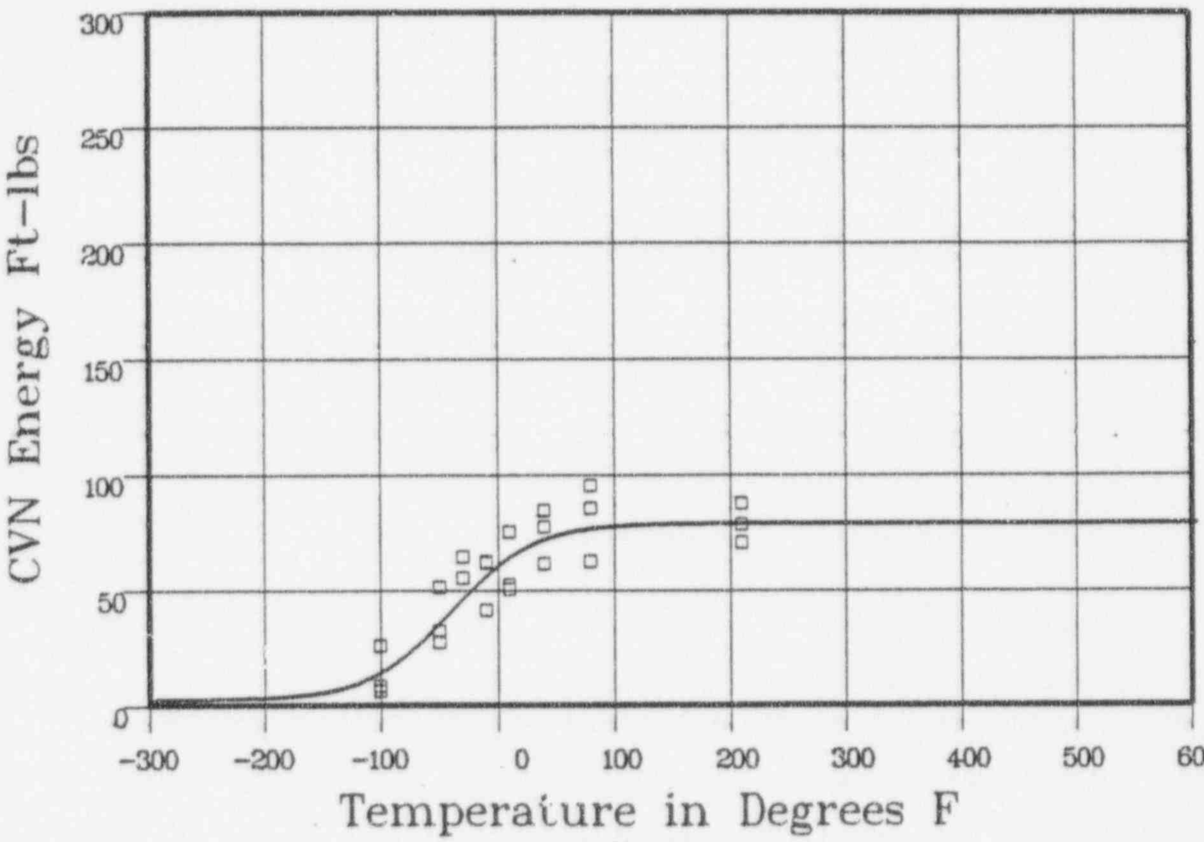
A = 40.34	B = 38.15	C = 69.88	T0 = -45

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

Upper Shelf Energy: 78.5 Fixed   Temp. at 30 ft-lbs: -64.4   Temp. at 50 ft-lbs: -26.9   Lower Shelf Energy: 2.19 Fixed

Material: WELD   Heat Number: 1752   Orientation:

Capsule: UNIRR   Total Fluence:



Data Set(s) Plotted

Plant: PI1   Cap.: UNIRR   Material: WELD   Ori.:   Heat #: 1752

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	8	15.29	-7.29
-100	6	15.29	-9.29
-100	25.5	15.29	10.2
-50	51	37.62	13.37
-50	27	37.62	-10.62
-50	32	37.62	-5.62
-30	55	48.41	6.58
-30	64	48.41	15.58
-10	41	58	-17

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

UNIRRADIATED

Page 2

Material: WELD   Heat Number: 1752   Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-10	62	58	3.99
-10	61.5	58	3.49
10	52	65.4	-13.4
10	75	65.4	9.59
10	50	65.4	-15.4
40	77	72.34	4.65
40	84	72.34	11.65
40	61	72.34	-11.34
80	85	76.42	8.57
80	95	76.42	18.57
80	62	76.42	-14.42
210	70	78.44	-8.44
210	87	78.44	8.55
210	78	78.44	-.44

SUM of RESIDUALS = 1.53

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:23:51 on 10-23-1996

Page 1

Coefficients of Curve 1

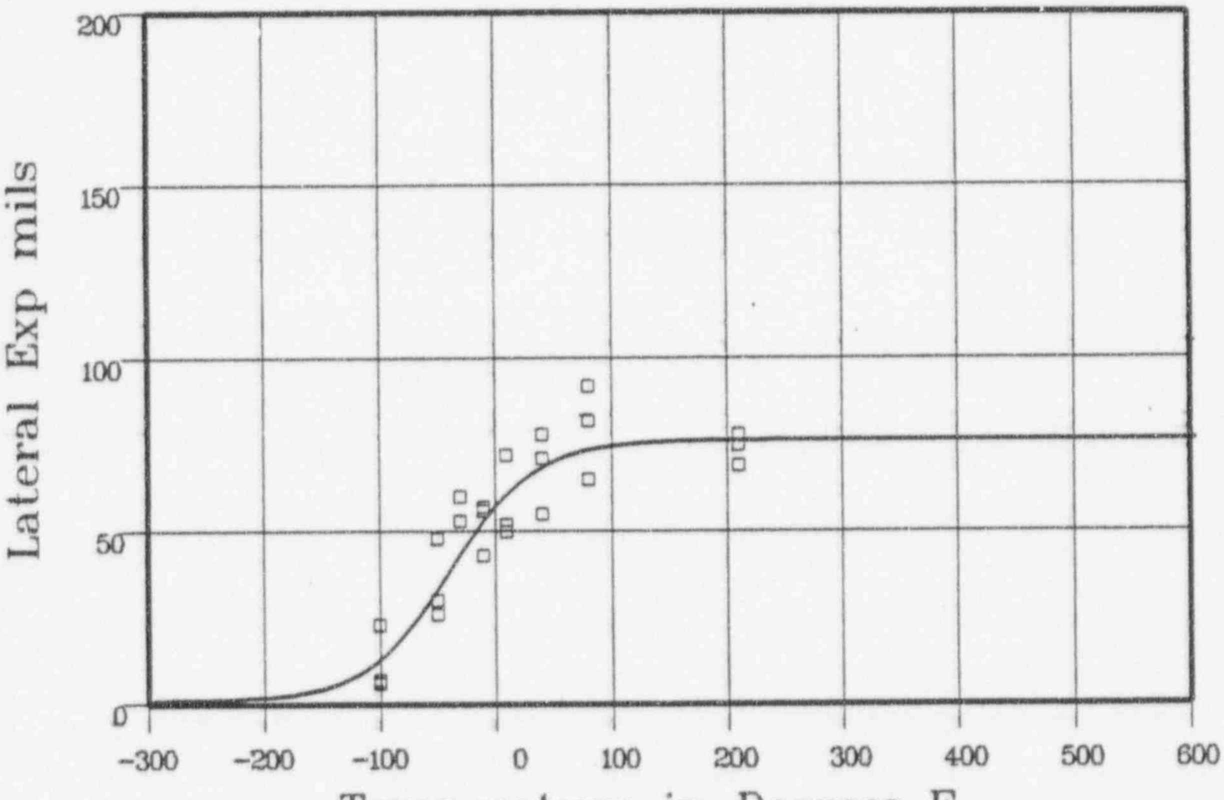
A = 38.7	B = 37.7	C = 73.18	T0 = -43.71

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

Upper Shelf L.E.: 76.41 Temperature at L.E. 35: -50.9 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 1752 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: UNIRR Material: WELD Ori.: Heat #: 1752

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	7	14.33	-7.33
-100	6	14.33	-8.33
-100	23	14.33	8.66
-50	48	35.47	12.52
-50	26	35.47	-9.47
-50	30	35.47	-5.47
-30	53	45.69	7.3
-30	60	45.69	14.3
-10	43	54.94	-11.94

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

UNIRRADIATED

Page 2

Material: WELD Heat Number: 1752 Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-10	56	54.94	1.05
-10	57	54.94	2.05
10	50	62.29	-12.29
10	72	62.29	9.7
10	52	62.29	-10.29
40	71	69.46	1.53
40	78	69.46	8.53
40	55	69.46	-14.46
80	82	73.93	8.06
80	92	73.93	18.06
80	65	73.93	-8.93
210	69	76.34	-7.34
210	78	76.34	1.65
210	75	76.34	-1.34

SUM of RESIDUALS = -3.8

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:25:11 on 10-23-1996

Page 1

Coefficients of Curve 1

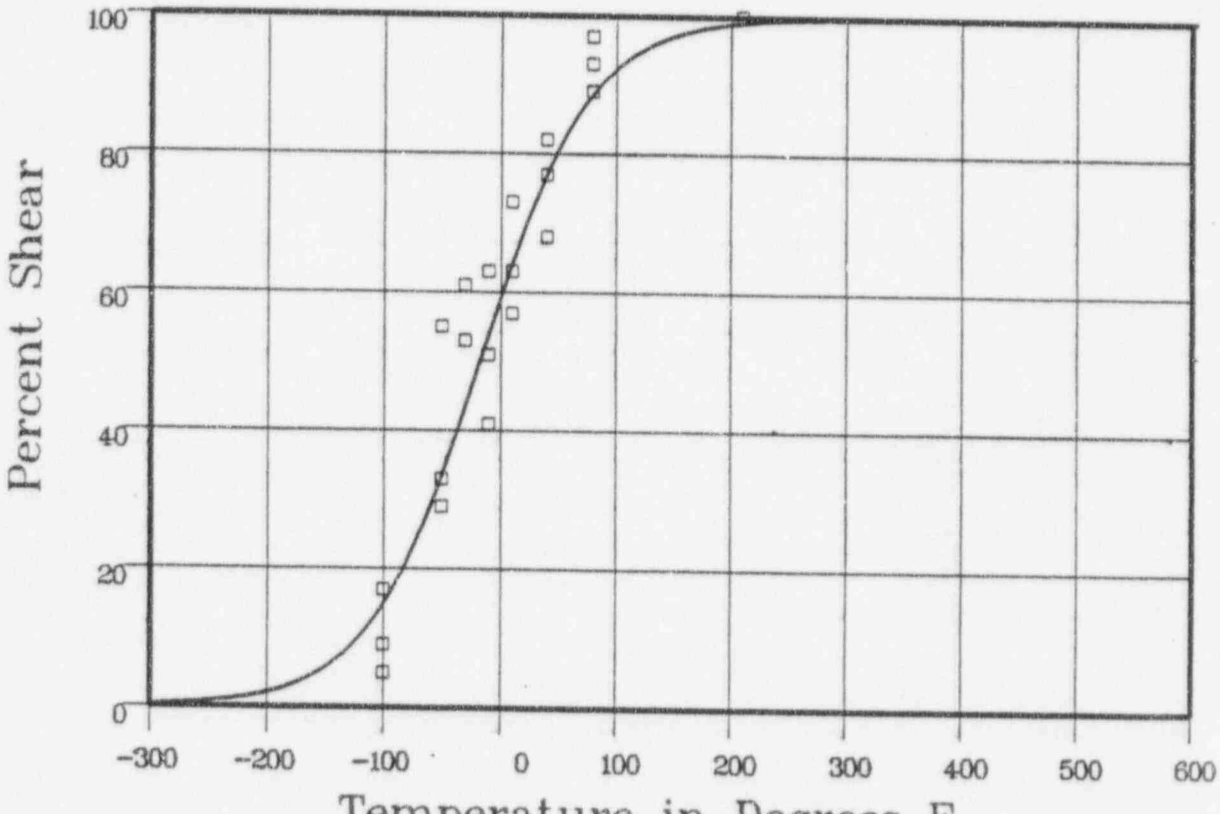
A = 50	B = 50	C = 94.9	T0 = -22.03

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

Temperature at 50% Shear: -22

Material: WELD Heat Number: 1752 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: UNIRR Material: WELD Ori: Heat #: 1752

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	9	16.2	-7.2
-100	5	16.2	-11.2
-100	17	16.2	.79
-50	55	35.67	19.32
-50	33	35.67	-2.67
-50	29	35.67	-6.67
-30	53	45.81	7.18
-30	61	45.81	15.18
-10	41	56.3	-15.3

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

UNIRRADIATED

Page 2

Material: WELD   Heat Number: 1752   Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-10	63	56.3	6.69
-10	51	56.3	-5.3
10	57	66.26	-9.26
10	73	66.26	6.73
10	63	66.26	-3.26
40	77	78.7	-1.7
40	82	78.7	3.29
40	68	78.7	-10.7
80	93	89.56	3.43
80	97	89.56	7.43
80	89	89.56	-.56
210	100	99.25	.74
210	100	99.25	.74
210	100	99.25	.74

SUM of RESIDUALS = -1.55

UNIRRADIATED

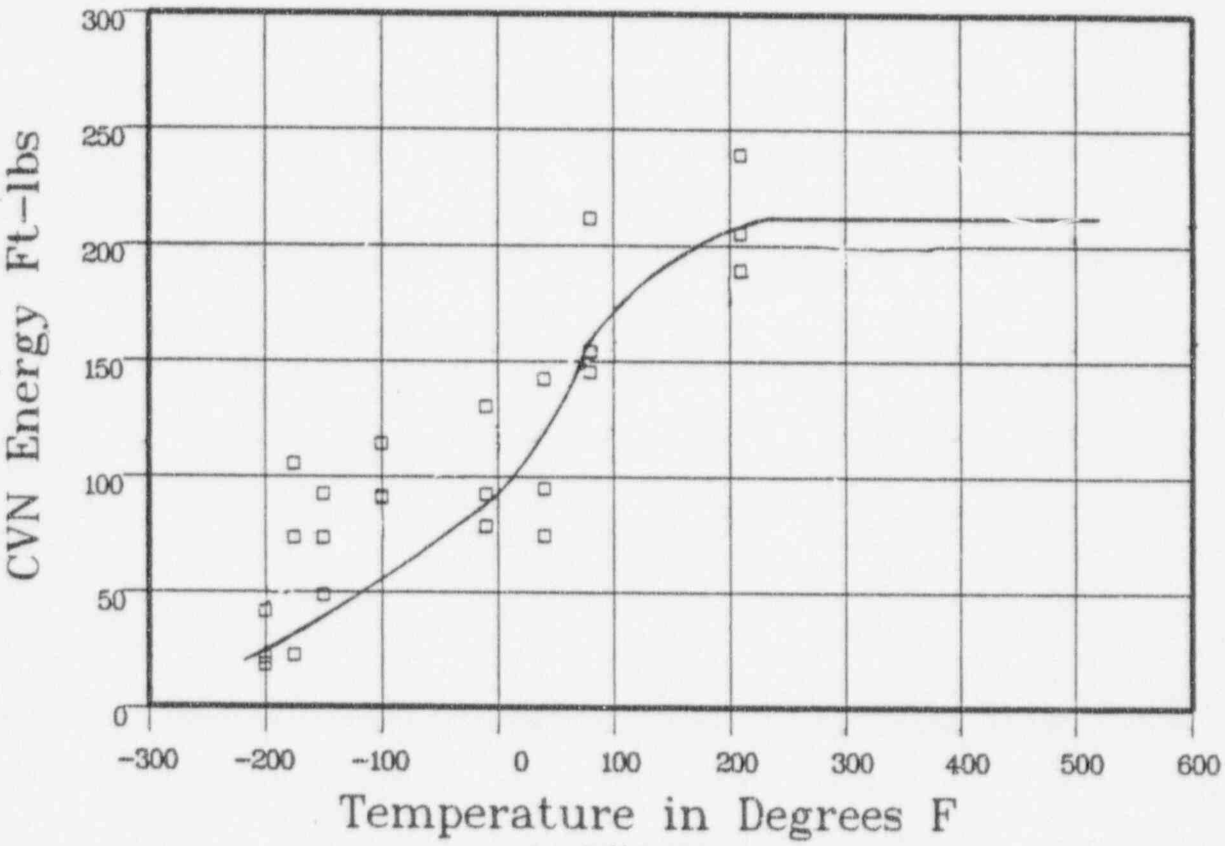
Best-Fit Curve as documented in WCAP-8916

(not fit with hyperbolic-tangent function)

Upper Shelf Energy: 211 Fixed Temp. at 30 ft-lbs: -200 Temp. at 50 ft-lbs: -125 Lower Shelf Energy:

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

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: UNIRR Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-200	21	45.52	-24.52
-200	18	45.52	-27.52
-200	41	45.52	-4.52
-175	73	52.91	20.08
-175	22	52.91	-30.91
-175	105	52.91	52.08
-150	48	61.11	-13.11
-150	92	61.11	30.88
-150	73	61.11	11.88

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

UNIRRADIATED

Page 2

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

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	91	79.7	11.29
-100	114	79.7	34.29
-100	90	79.7	10.29
-10	78	117.23	-39.23
-10	92	117.23	-25.23
-10	130	117.23	12.76
40	94.5	137.53	-43.03
40	142	137.53	4.46
40	74	137.53	-63.53
80	154	152.18	1.81
80	145	152.18	-7.18
80	211.5	152.18	59.31
210	239	185.95	53.04
210	189	185.95	3.04
210	205	185.95	19.04

SUM of RESIDUALS = 45.45

UNIRRADIATED

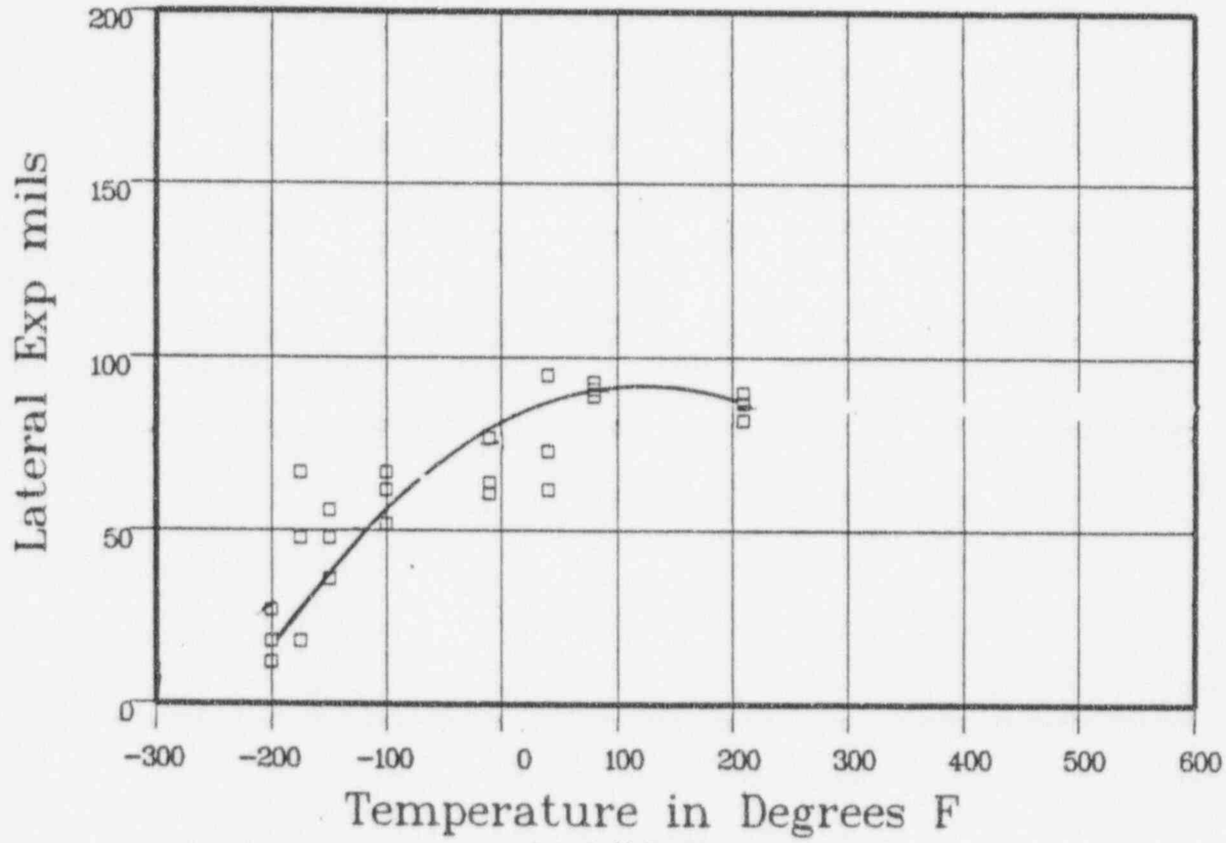
Best-Fit Curve as documented in WCAP-8916

(not fit with hyperbolic-tangent function)

Upper Shelf L.E: 92 Temperature at L.E 35: -152 Lower Shelf L.E:

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: UNIRR Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-200	12	29.97	-17.97
-200	18	29.97	-11.97
-200	27	29.97	-2.97
-175	48	36.65	11.34
-175	18	36.65	-18.65
[illegible]	67	36.65	30.34
[illegible]	36	43.71	-7.71
-150	56	43.71	12.28
-150	48	43.71	4.28

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

UNIRRADIATED

Page 2

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

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed LE	Differential
-100	62	57.49	4.5
-100	67	57.49	9.5
-100	52	57.49	-5.49
-10	61	75.23	-14.23
-10	64	75.23	-11.23
-10	77	75.23	1.76
40	73	80.49	-7.49
40	95	80.49	14.5
40	62	80.49	-18.49
80	89	83.03	5.96
80	93	83.03	9.96
80	91	83.03	7.96
210	90	86.23	3.76
210	87	86.23	.76
210	82	86.23	-4.23

SUM of RESIDUALS = -3.53

UNIRRADIATED

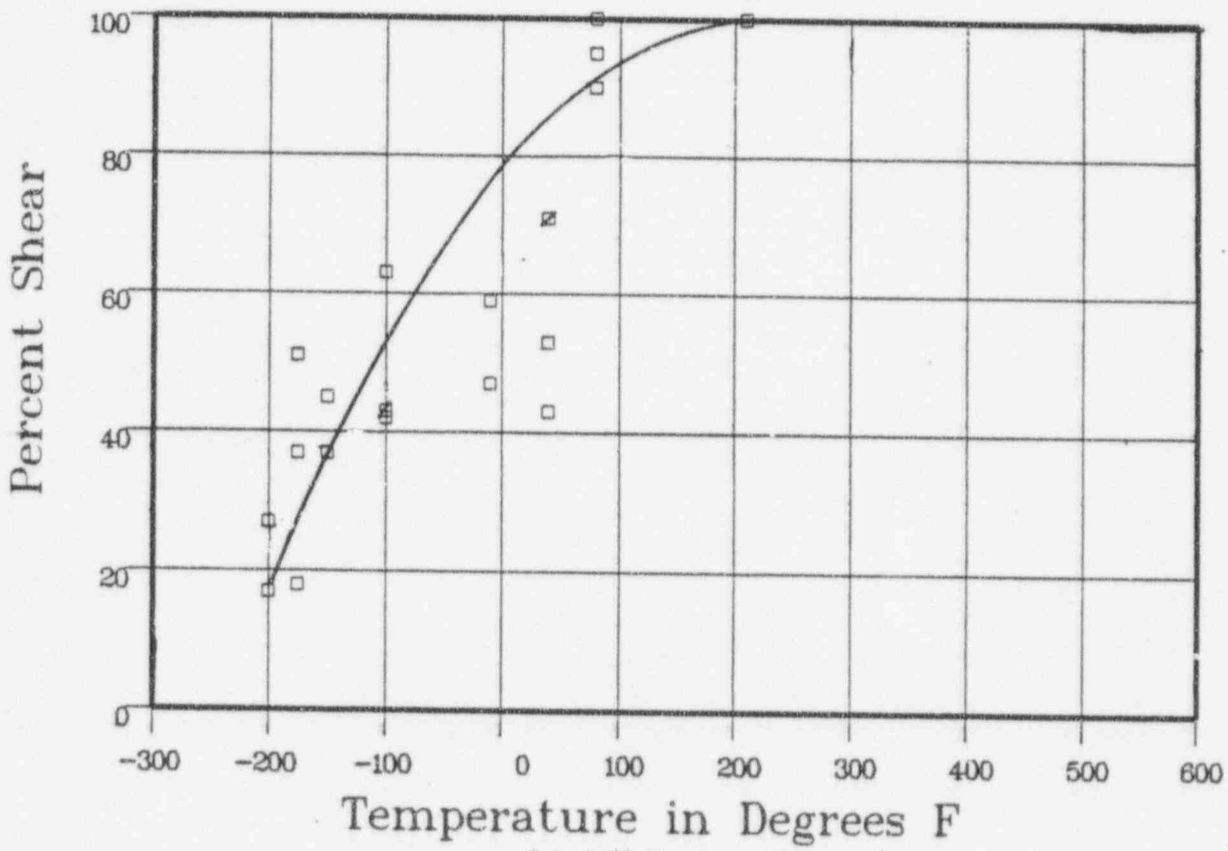
Best-Fit Curve as documented in WCAP-8916

(not fit with hyperbolic-tangent function)

Temperature at 50% Shear: -110

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: UNIRR Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-200	17	25.82	-8.82
-200	17	25.82	-8.82
-200	27	25.82	1.17
-175	37	29.99	7
-175	18	29.99	-11.99
-175	51	29.99	21
-150	37	34.51	2.48
-150	45	34.51	10.48
-150	37	34.51	2.48

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

UNIRRADIATED

Page 2

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

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	42	44.38	-2.38
-100	63	44.38	18.61
-100	43	44.38	-1.38
-10	47	62.74	-15.74
-10	47	62.74	-15.74
-10	59	62.74	-3.74
40	53	71.83	-18.83
40	71	71.83	-.83
40	43	71.83	-28.83
80	90	78.04	11.95
80	95	78.04	16.95
80	100	78.04	21.95
210	100	91.26	8.73
210	100	91.26	8.73
210	100	91.26	8.73

SUM of RESIDUALS = 23.13

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:51:24 on 10-23-1996

Page 1

Coefficients of Curve 1

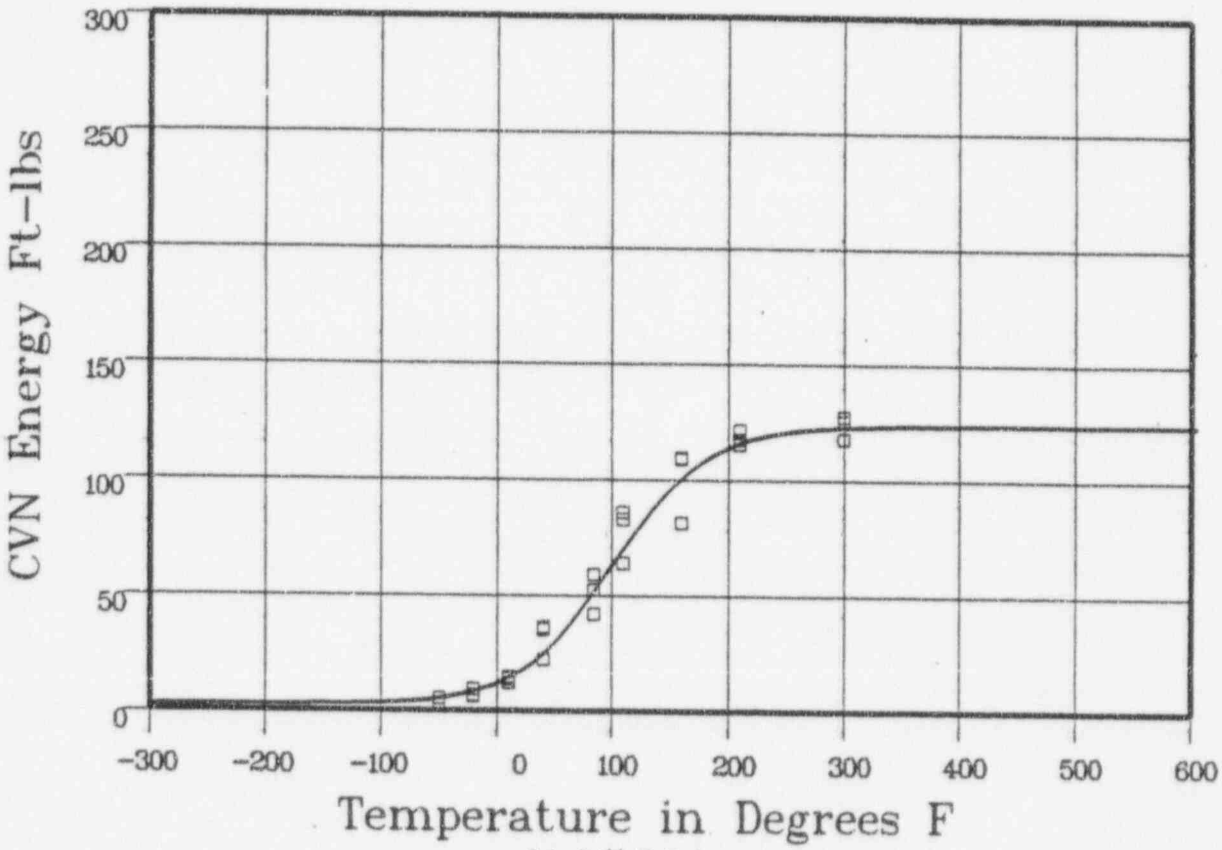
A = 62.84	B = 60.65	C = 82.25	T0 = 96.09

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

Upper Shelf Energy: 123.5 Fixed   Temp. at 30 ft-lbs: 46.2   Temp. at 50 ft-lbs: 78.3   Lower Shelf Energy: 2.19 Fixed

Material: SRM HSST02   Heat Number: SA533B1   Orientation: LT

Capsule: UNIRR   Total Fluence:



Data Set(s) Plotted

Plant: PI1   Cap.: UNIRR   Material: SRM HSST02   Ori.: LT   Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	3	5.58	-2.58
-50	5	5.58	-.58
-50	5	5.58	-.58
-20	6	9	-3
-20	6.5	9	-2.5
-20	9	9	0
10	13.5	15.51	-2.01
10	12	15.51	-3.51
10	14.5	15.51	-1.01

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

UNIRRADIATED

Page 2

Material: SRM HSST02 Heat Number: SA533B1 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
40	35	26.89	8.1
40	22	26.89	-4.89
40	36	26.89	9.1
85	52	54.71	-2.71
85	58.5	54.71	3.78
85	41.5	54.71	-13.21
110	63.5	73	-9.5
110	82.5	73	9.49
110	85.5	73	12.49
160	109	102.32	6.67
160	108.5	102.32	6.17
160	81	102.32	-21.32
210	121	116.34	4.65
210	117	116.34	.65
210	115	116.34	-1.34
300	127	122.65	4.34
300	125	122.65	2.34
300	117.5	122.65	-5.15

SUM of RESIDUALS = -6.15

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:52:52 on 10-23-1996
Page 1
Coefficients of Curve 1

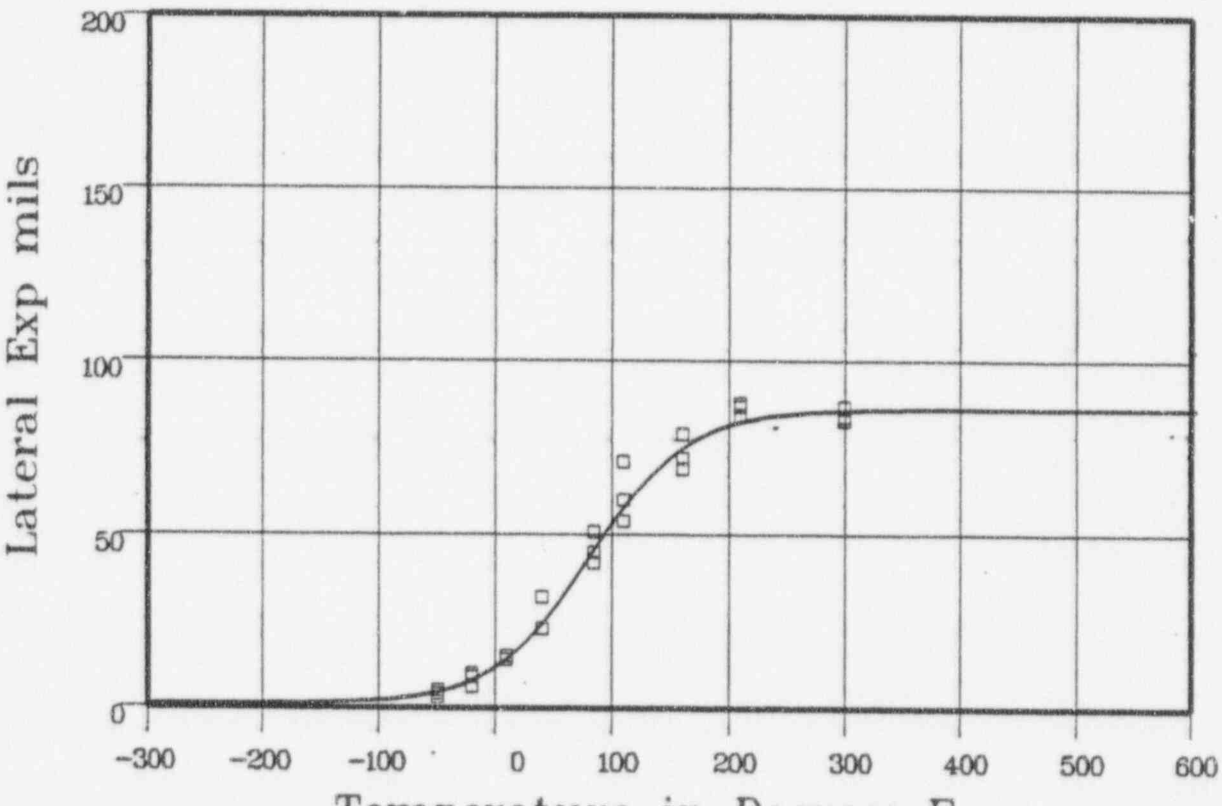
A = 43.65	B = 42.65	C = 84.08	T0 = 76.27

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

Upper Shelf L.E.: 86.31 Temperature at L.E. 35: 58.9 Lower Shelf L.E.: 1 Fixed

Material: SRM HSST02 Heat Number: SA533B1 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted
Plant: PI1 Cap.: UNIRR Material: SRM HSST02 Ori.: LT Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	4	5.03	-1.03
-50	3	5.03	-2.03
-50	5	5.03	-.03
-20	9	8.84	.15
-20	6	8.84	-2.84
-20	10	8.84	1.15
10	14	15.61	-1.61
10	15	15.61	-.61
10	14	15.61	-1.61

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

UNIRRADIATED

Page 2

Material: SRM HSST02 Heat Number: SA533B1 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
40	32	26.31	5.68
40	23	26.31	-3.31
40	32	26.31	5.68
85	45	48.06	-3.06
85	51	48.06	2.93
85	42	48.06	-6.06
110	54	59.9	-5.9
110	60	59.9	.09
110	71	59.9	11.09
160	79	76.07	2.92
160	72	76.07	-4.07
160	69	76.07	-7.07
210	87	82.91	4.08
210	84	82.91	1.08
210	88	82.91	5.08
300	84	85.9	-1.9
300	87	85.9	1.09
300	83	85.9	-2.9

SUM of RESIDUALS = -3.03

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:54:03 on 10-23-1996

Page 1

Coefficients of Curve 1

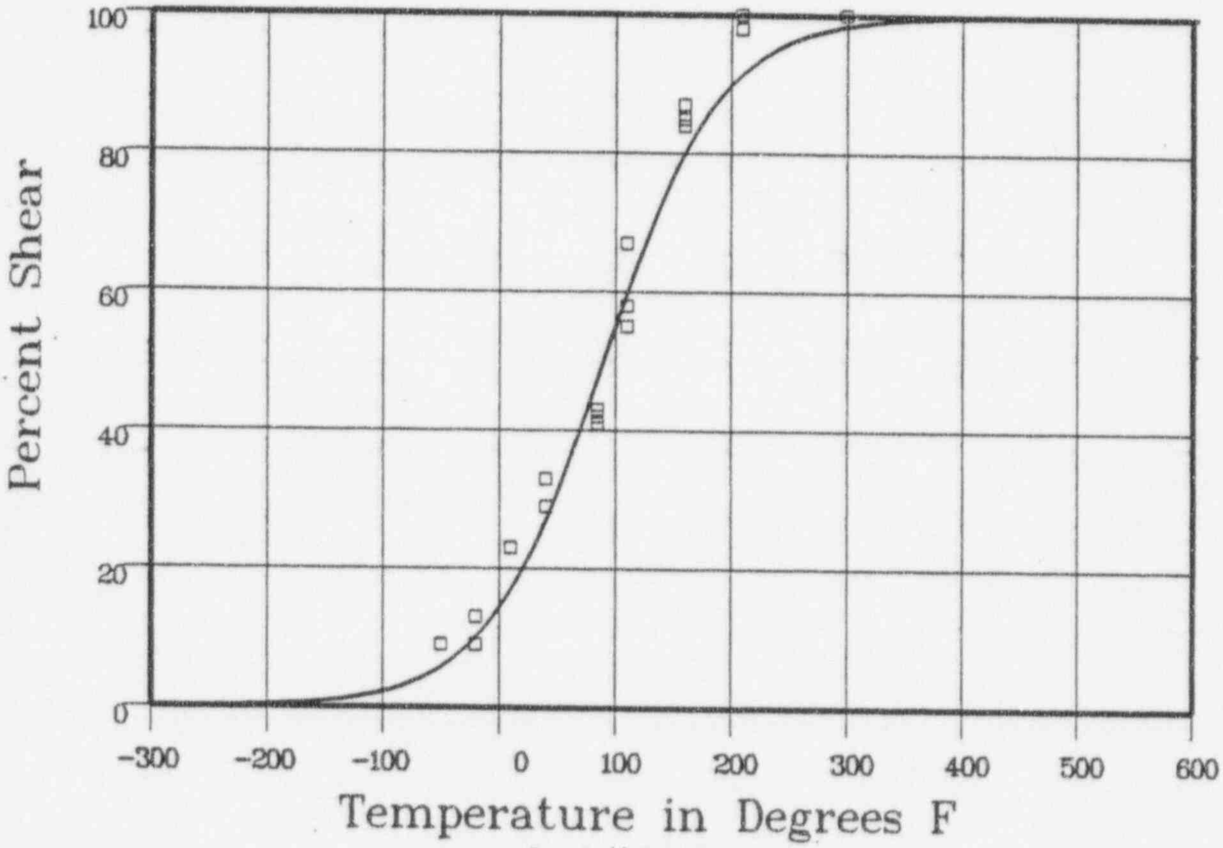
A = 50	B = 50	C = 100.89	T0 = 85.54

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

Temperature at 50% Shear: 85.5

Material: SRM HSST02 Heat Number: SA533B1 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: UNIRR Material: SRM HSST02 Ori.: LT Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	9	6.37	2.62
-50	9	6.37	2.62
-50	9	6.37	2.62
-20	13	10.98	2.01
-20	9	10.98	-1.98
-20	13	10.98	2.01
10	23	18.27	4.72
10	23	18.27	4.72
10	23	18.27	4.72

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

UNIRRADIATED

Page 2

Material: SRM HSST02 Heat Number: SA533B1 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
40	29	28.84	.15
40	33	28.84	4.15
40	29	28.84	.15
85	42	49.72	-7.72
85	43	49.72	-6.72
85	41	49.72	-8.72
110	55	61.88	-6.88
110	58	61.88	-3.88
110	67	61.88	5.11
160	87	81.39	5.6
160	84	81.39	2.6
160	85	81.39	3.6
210	100	92.17	7.82
210	98	92.17	5.82
210	98	92.17	5.82
300	100	98.59	1.4
300	100	98.59	1.4
300	100	98.59	1.4

SUM of RESIDUALS = 35.18

CAPSULE V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:03:52 on 10-23-1996

Page 1

Coefficients of Curve 1

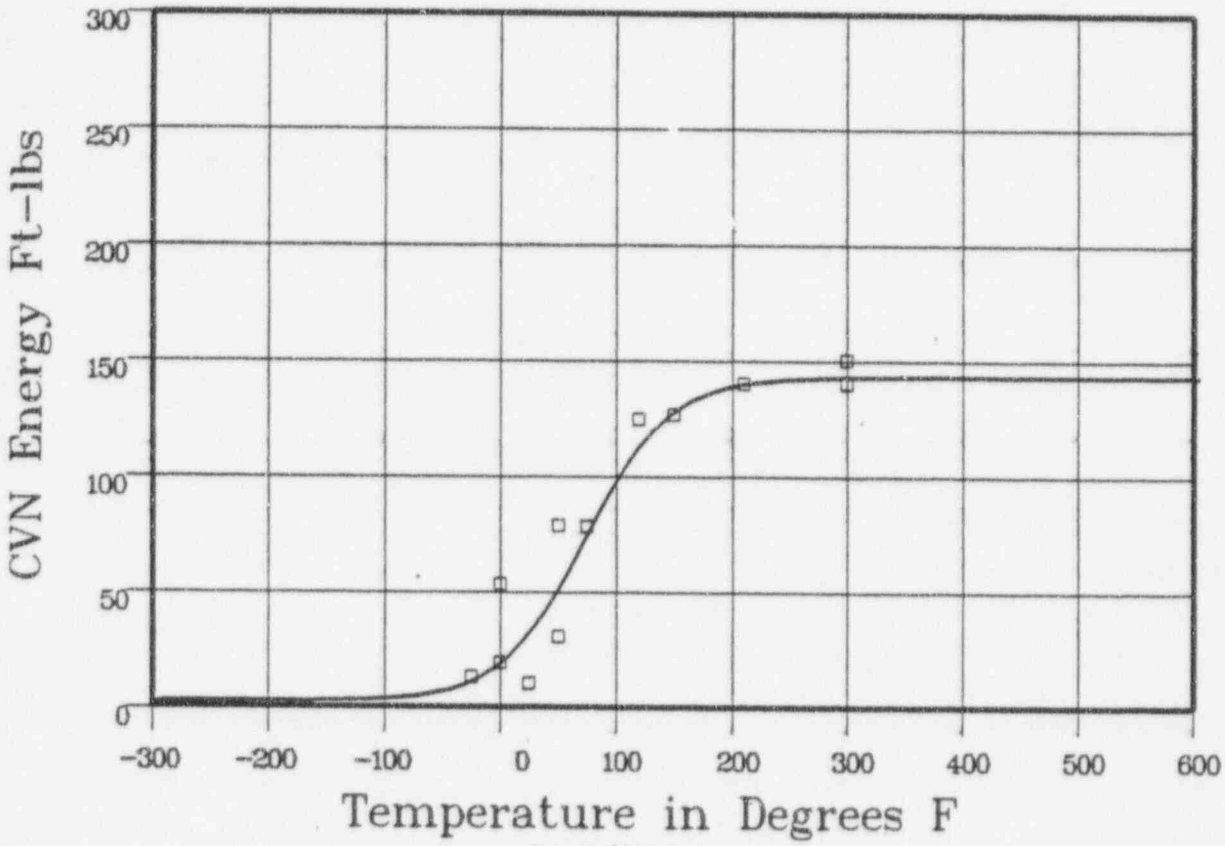
A = 72.59	B = 70.4	C = 73	T0 = 68.63

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

Upper Shelf Energy: 143 Fixed   Temp. at 30 ft-lbs: 17.4   Temp. at 50 ft-lbs: 44.3   Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA5083   Heat Number: 21918/38566   Orientation: LT

Capsule: V   Total Fluence:



Data Set(s) Plotted

Plant: PI1   Cap.: V   Material: FORGING SA5083   Ori.: LT   Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	13	12.25	.74
0	53	20.83	32.16
0	19	20.83	-1.83
25	10	34.9	-24.9
50	30.5	55	-24.5
50	78.5	55	23.49
75	78	78.72	-.72
120	124.5	115.3	9.19
150	126.5	129.31	-2.81

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

CAPSULE V

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
210	140	140.13	-.13
300	150	142.75	7.24
300	140	142.75	-2.75

SUM of RESIDUALS = 15.17

CAPSULE V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:05:05 on 10-23-1996

Page 1

Coefficients of Curve 1

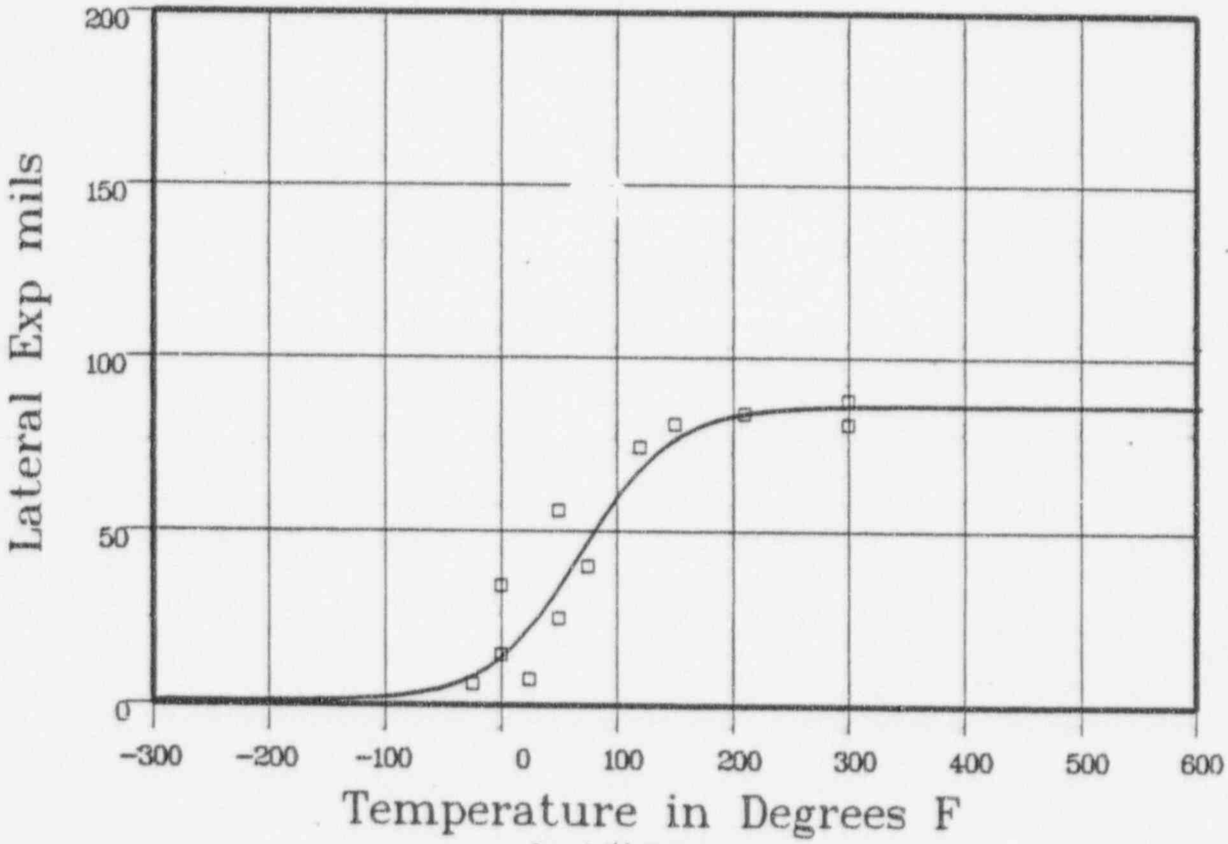
A = 43.71	B = 42.71	C = 79.59	T0 = 64.21

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

Upper Shelf L.E.: 86.43 Temperature at L.E. 35: 47.7 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA508B Heat Number: 21918/38566 Orientation: LT

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: V Material: FORGING SA508B Ori.: LT Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	6	9.2	-3.2
0	34.5	15.18	19.31
0	14.5	15.18	-.68
25	7.5	24.22	-16.72
50	25	36.16	-11.16
50	56	36.16	19.83
75	40	49.46	-9.46
120	74.5	69.55	4.94
150	81	77.56	3.43

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

CAPSULE V

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
210	84	84.29	-.29
300	81	86.2	-5.2
300	88	86.2	1.79

SUM of RESIDUALS = 2.54

CAPSULE V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:06:06 on 10-23-1996

Page 1

Coefficients of Curve 1

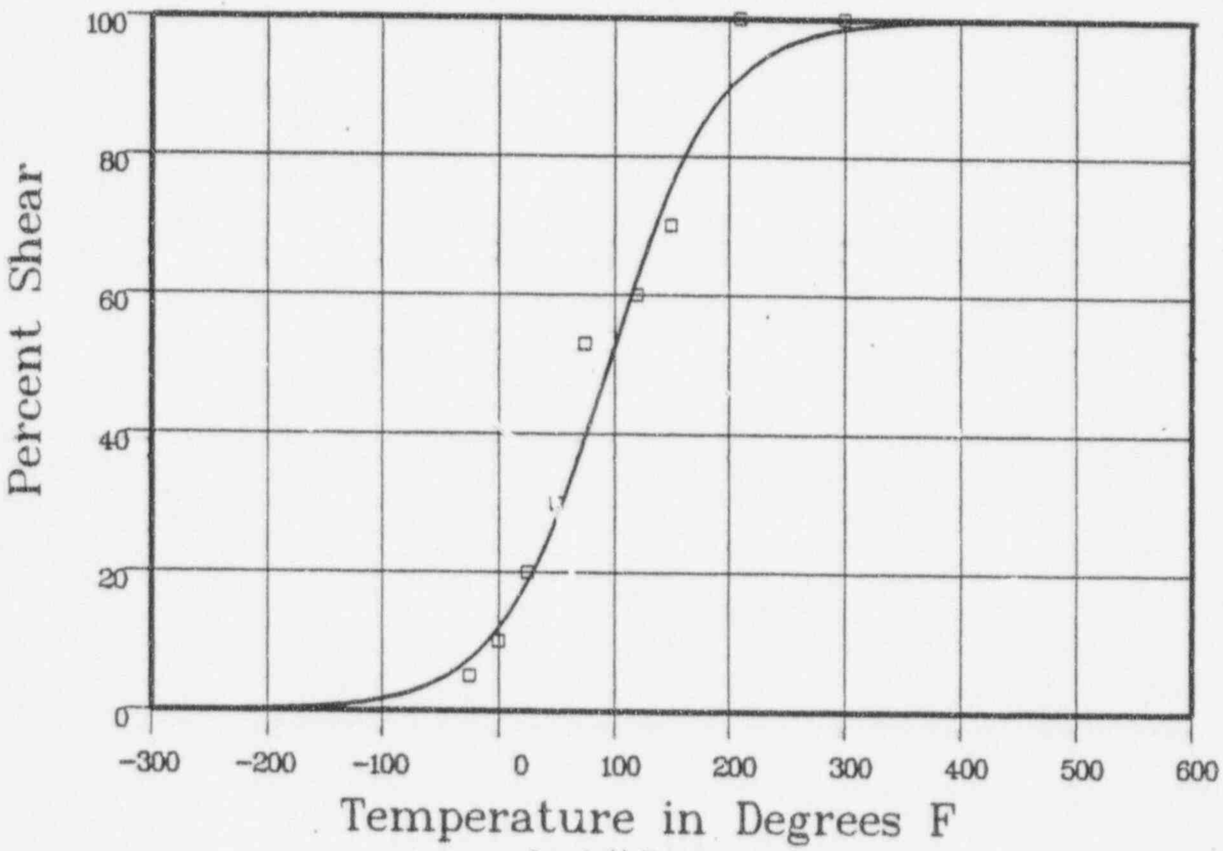
A = 50	B = 50	C = 95.71	T0 = 90.82

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

Temperature at 50% Shear: 90.8

Material: FORGING SA508-3 Heat Number: 21918/38566 Orientation: LT

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: V Material: FORGING SA508-3 Ori: LT Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	5	8.16	-3.16
0	10	13.03	-3.03
0	10	13.03	-3.03
25	20	20.17	-.17
50	30	29.88	.11
50	30	29.88	.11
75	53	41.81	11.18
120	60	64.78	-4.78
150	70	77.49	-7.49

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

CAPSULE V

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
210	100	92.34	7.65
300	100	98.75	1.24
300	100	98.75	1.24

SUM of RESIDUALS = -.12

CAPSULE V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:07:20 on 10-23-1996

Page 1

Coefficients of Curve 1

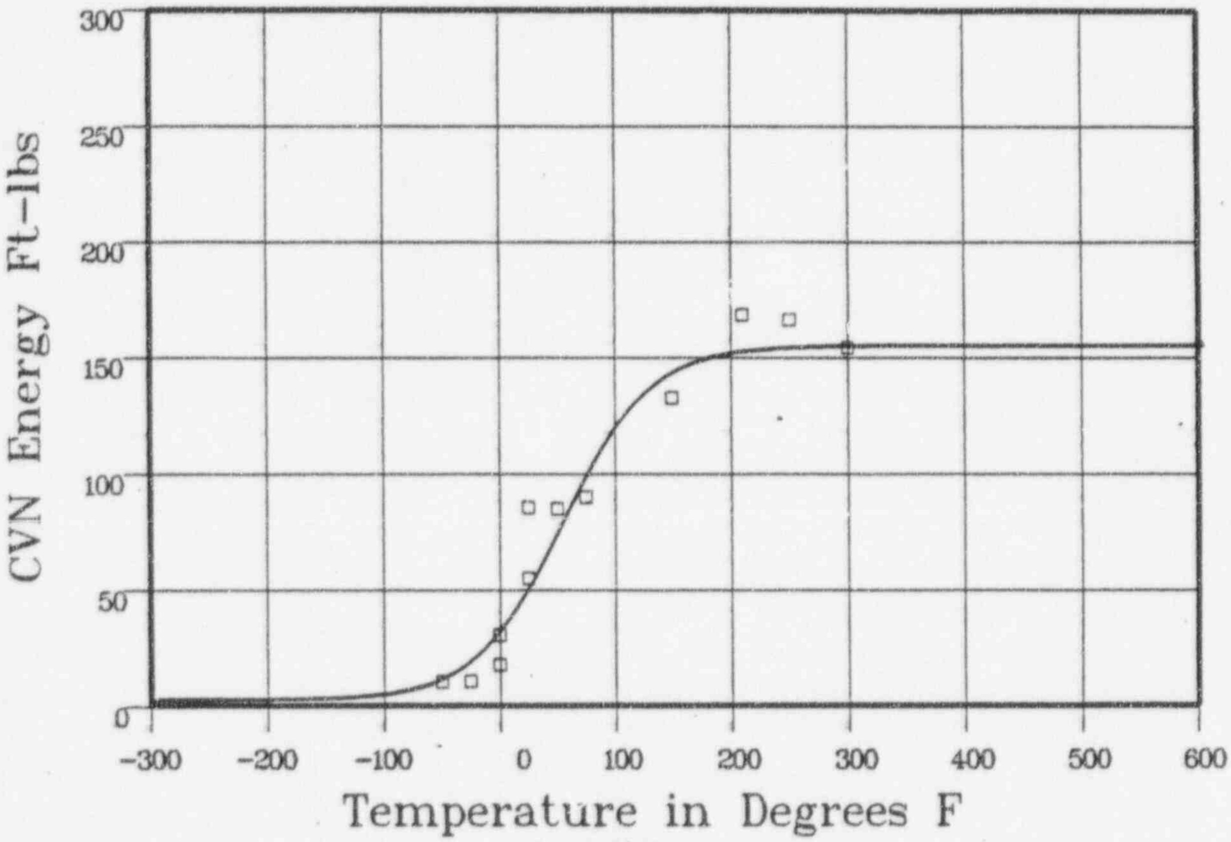
A = 78.59	B = 76.4	C = 76.36	T0 = 50.15

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

Upper Shelf Energy: 155 Fixed Temp. at 30 ft-lbs: -7.2 Temp. at 50 ft-lbs: 20.1 Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA508.3 Heat Number: 21918/38566 Orientation: TL

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: V Material: FORGING SA508.3 Ori: TL Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	10	12.53	-2.53
-25	10.5	20.92	-10.42
0	17.5	34.57	-17.07
0	30	34.57	-4.57
25	54.5	54.3	.19
25	85	54.3	30.69
50	84.5	78.44	6.05
75	89.5	102.61	-13.11
150	132.5	144.58	-12.08

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

CAPSULE V

Page 2

Material: FORGING SA508З Heat Number: 21918/38566 Orientation: TL

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
210	168	152.71	15.28
250	166	154.18	11.81
300	154	154.78	-.78

SUM of RESIDUALS = 3.45

CAPSULE V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:08:34 on 10-23-1996
Page 1

Coefficients of Curve 1

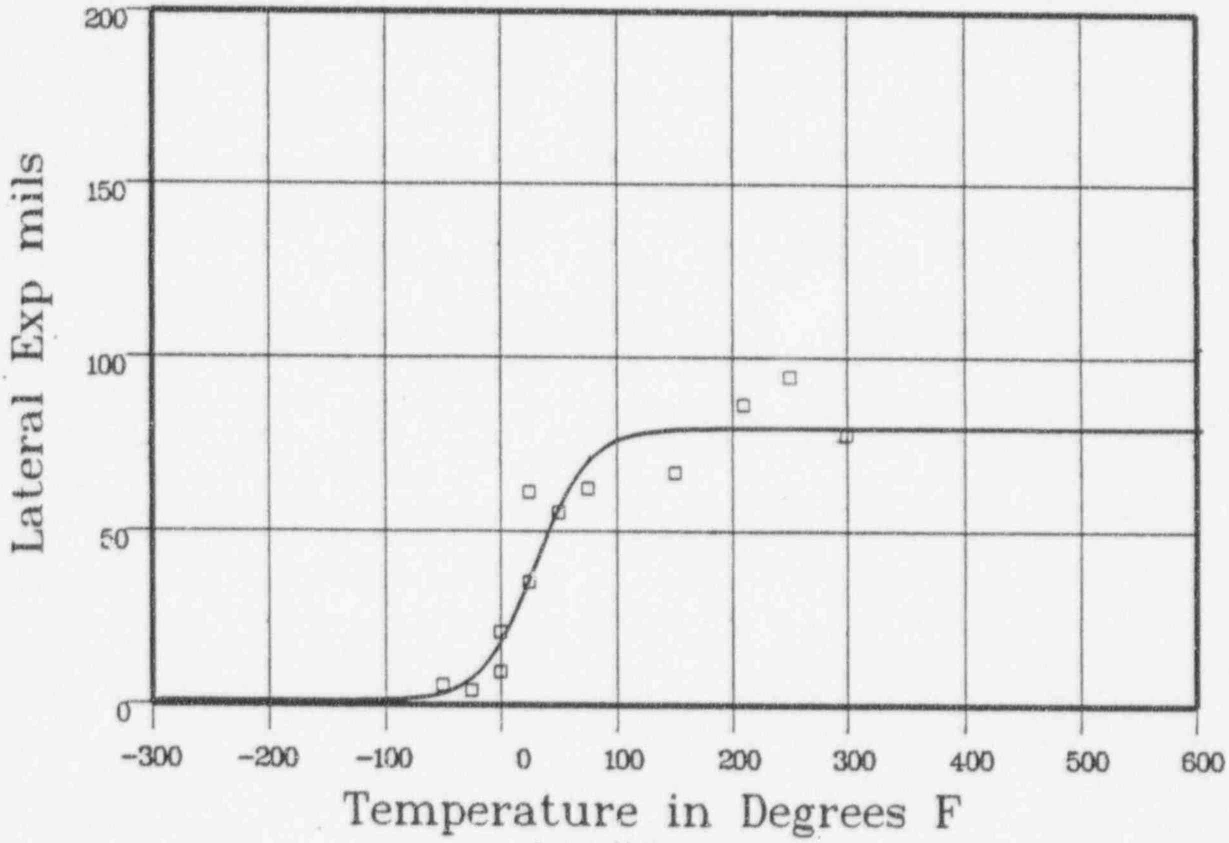
A = 40.43	B = 39.43	C = 46.1	T0 = 25.31

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

Upper Shelf L.E.: 79.86 Temperature at L.E. 35: 18.9 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: V Material: FORGING SA5083 Ori.: TL Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	5.5	3.89	1.6
-25	4	8.99	-4.99
0	9.5	20.72	-11.22
0	21	20.72	.27
25	35.5	40.16	-4.66
25	61.5	40.16	21.33
50	55.5	59.73	-4.23
75	62.5	71.67	-9.17
150	67	79.51	-12.51

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

CAPSULE V

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
210	86.5	79.83	6.66
250	94.5	79.86	14.63
300	78	79.86	-1.86

SUM of RESIDUALS = -4.15

CAPSULE V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:09:47 on 10-23-1996

Page 1

Coefficients of Curve 1

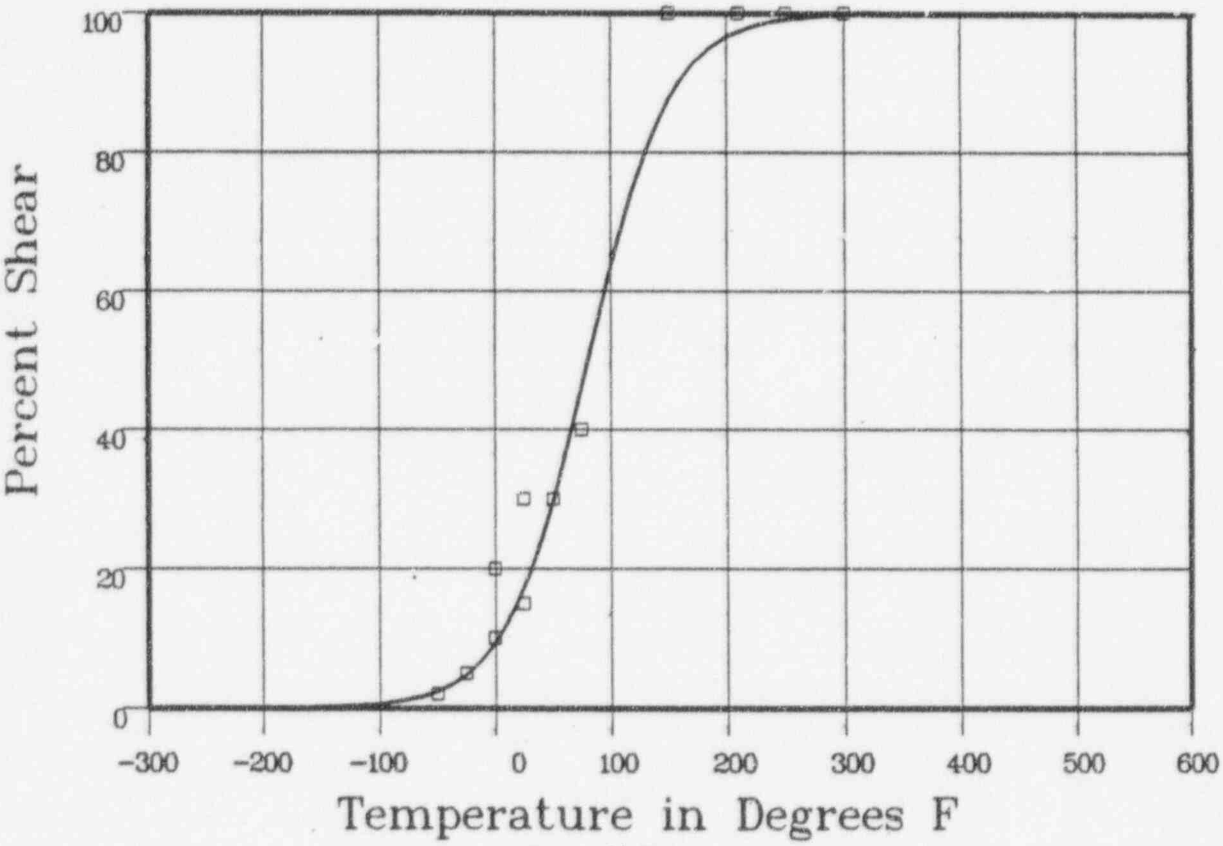
A = 50	B = 50	C = 71.11	T0 = 75.87

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

Temperature at 50% Shear: 75.8

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: V Material: FORGING SA5083 Ori.: TL Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	2	2.81	-.81
-25	5	5.53	-.53
0	20	10.58	9.41
0	10	10.58	-.58
25	15	19.29	-4.29
25	30	19.29	10.7
50	30	32.56	-2.56
75	40	49.38	-9.38
150	100	88.94	11.05

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

CAPSULE V

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: V Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
210	100	97.75	2.24
250	100	99.25	.74
300	100	99.81	.18

SUM of RESIDUALS = 16.17

CAPSULE V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:11:20 on 10-23-1996

Page 1

Coefficients of Curve 1

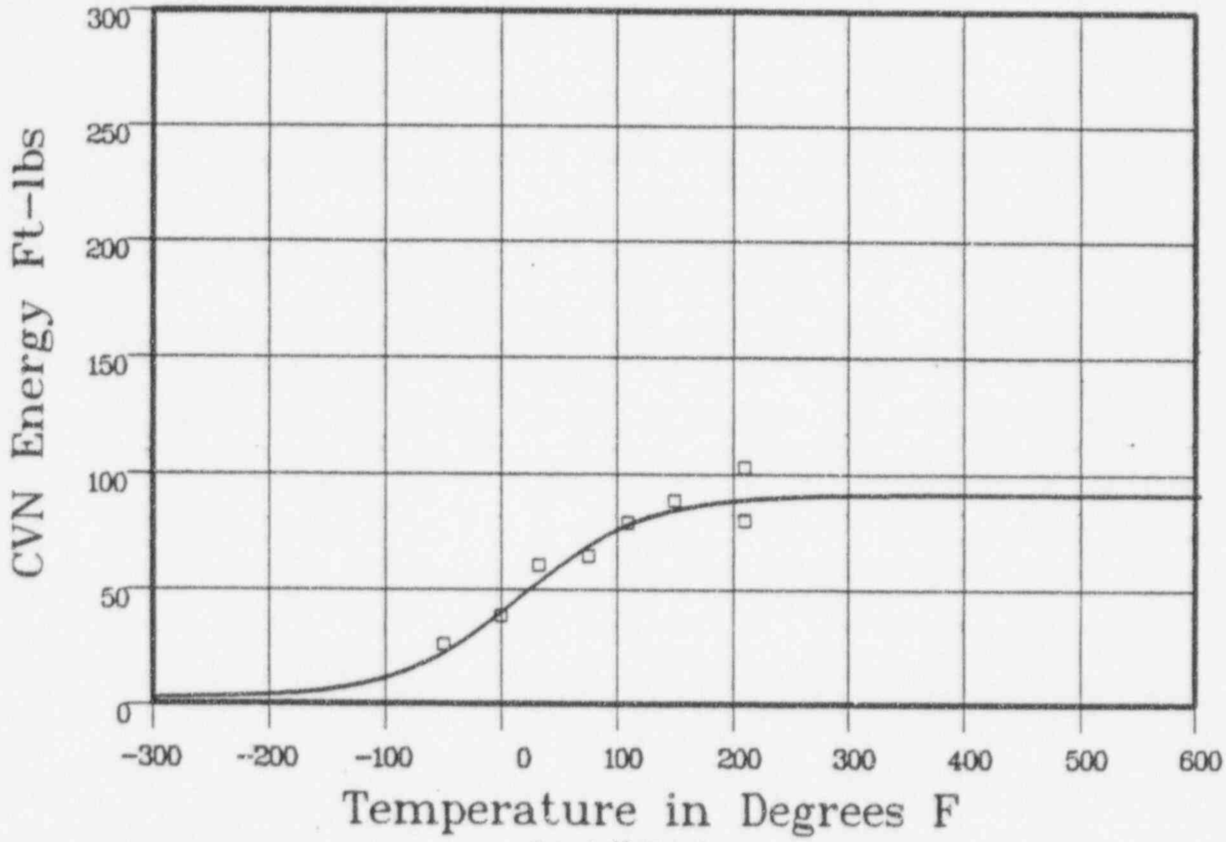
A = 46.59	B = 44.4	C = 107.48	T0 = 12.17

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

Upper Shelf Energy: 91 Fixed Temp. at 30 ft-lbs: -30 Temp. at 50 ft-lbs: 20.4 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 1752 Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: V Material: WELD Ori.: Heat #: 1752

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	25.5	23.44	2.05
0	38	41.59	-3.59
32	60	54.69	5.3
75	64	69.95	-5.95
110	78.5	78.62	-.12
150	88	84.65	3.34
210	79.5	88.81	-9.31
210	102.5	88.81	13.68

SUM of RESIDUALS = 5.4

CAPSULE V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:12:21 on 10-23-1996
Page 1

Coefficients of Curve 1

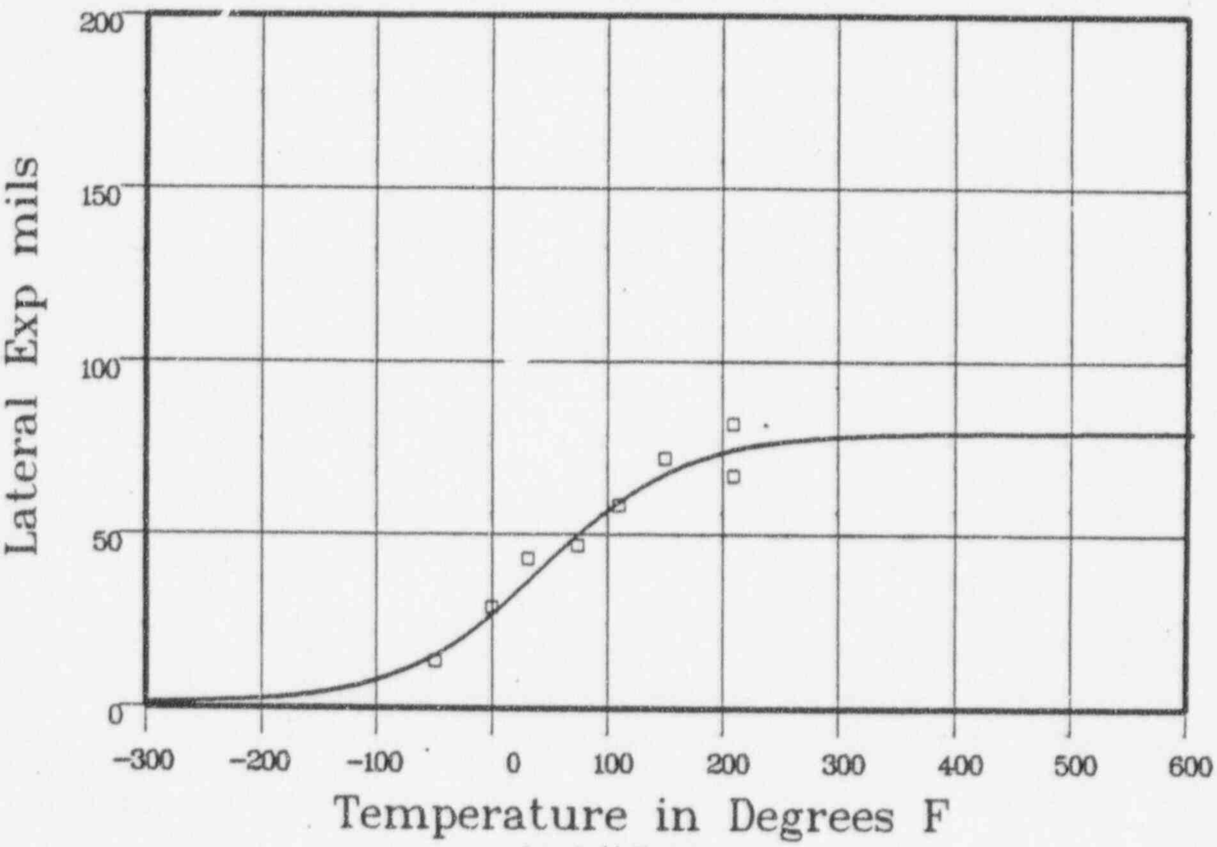
A = 40.31	B = 39.31	C = 124.25	T0 = 38.9

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

Upper Shelf L.E.: 79.62 Temperature at L.E. 35: 22 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 1752 Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: V Material: WELD Ori.: Heat #: 1752

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	13.5	16.16	-2.66
0	29	28.38	.61
32	43	38.12	4.87
75	47	51.41	-4.41
110	58.5	60.63	-2.13
150	72	68.35	3.64
210	67	74.91	-7.91
210	82	74.91	7.08

SUM of RESIDUALS = -.92

CAPSULE V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:13:23 on 10-23-1996

Page 1

Coefficients of Curve 1

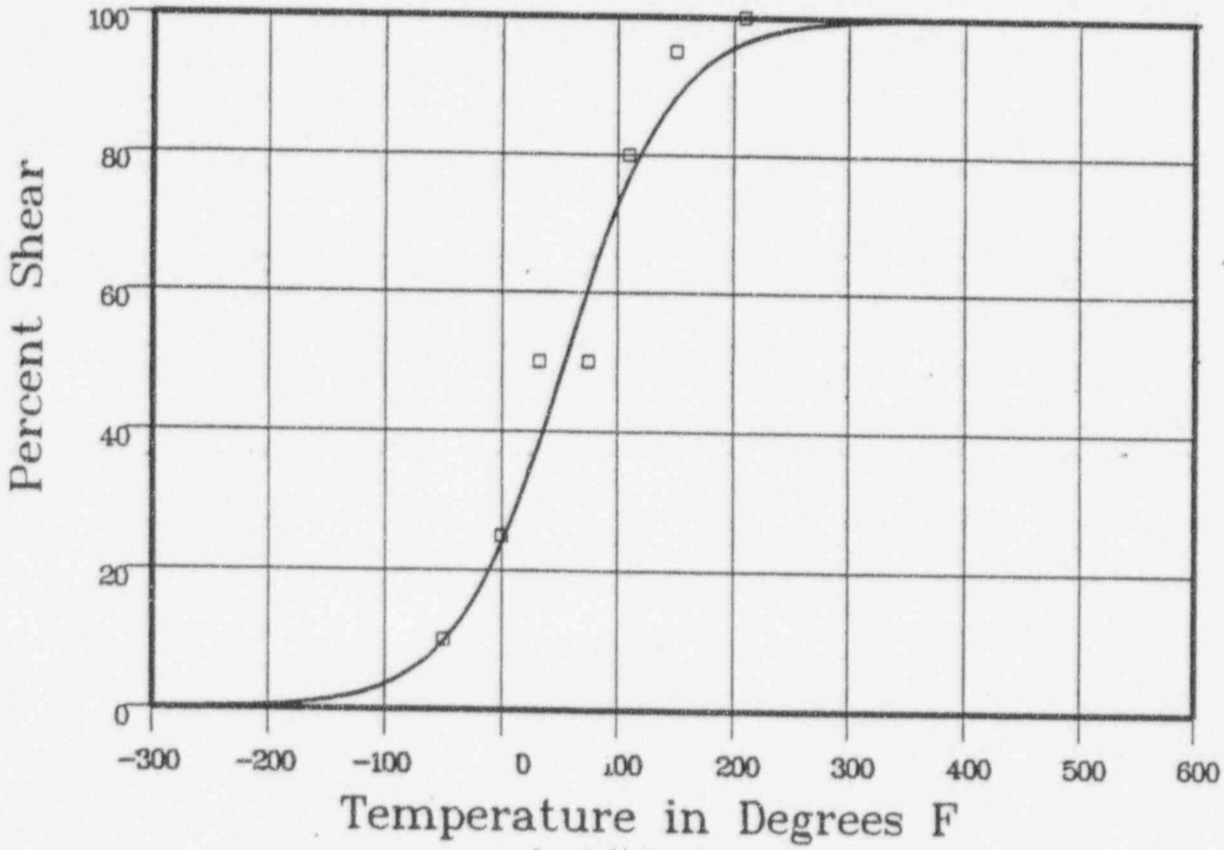
A = 50	B = 50	C = 94.09	T0 = 49.68

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

Temperature at 50% Shear: 49.6

Material: WELD Heat Number: 1752 Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: V Material: WELD Ori: Heat #: 1752

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	10	10.72	-.72
0	25	25.8	-.8
32	50	40.71	9.28
75	50	63.13	-13.13
110	80	78.27	1.72
150	95	89.39	5.6
210	100	96.79	3.2
210	100	96.79	3.2

SUM of RESIDUALS = 8.35

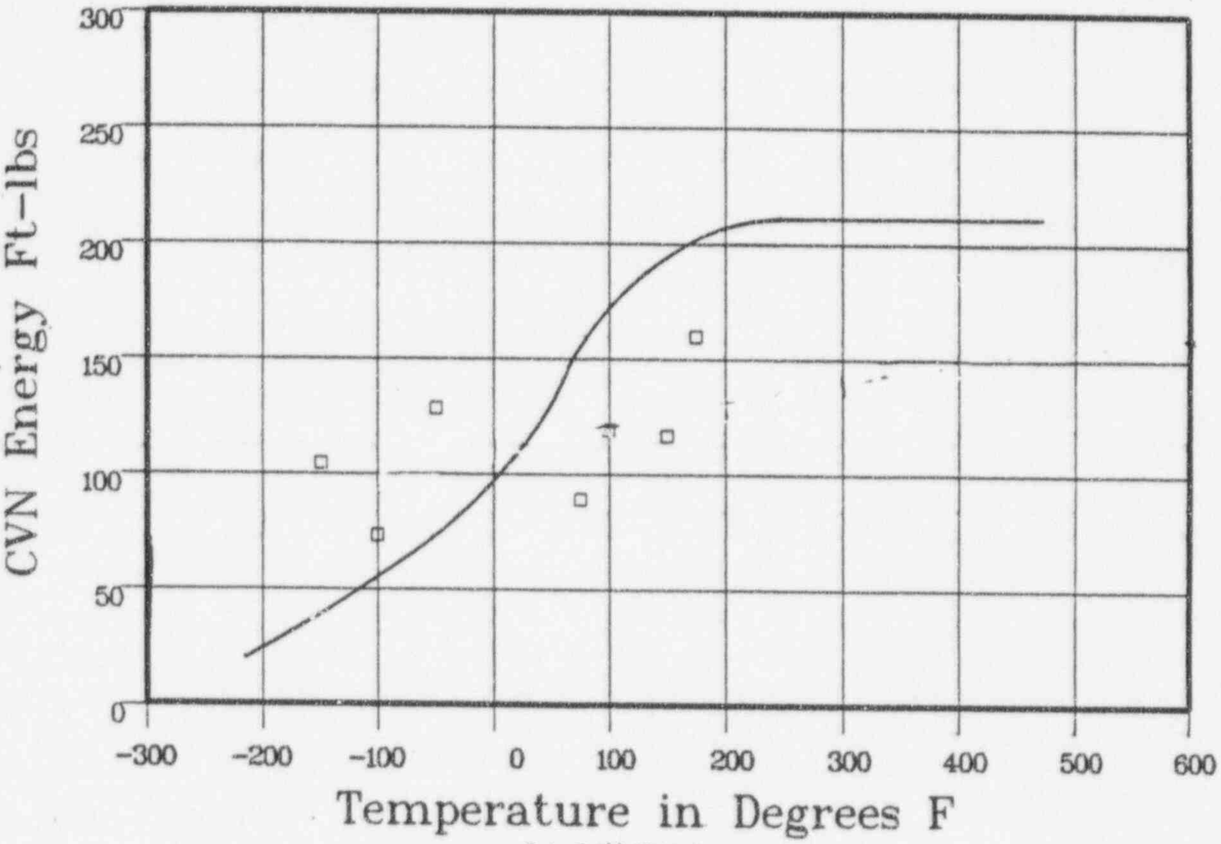
Best-Fit Curve as documented in WCAP-8916

(not fit with hyperbolic-tangent function)

Upper Shelf Energy: <211* Temp. at 30 ft-lbs: <-200 Temp. at 50 ft-lbs: <-125 Lower Shelf Energy:

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: V Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-150	104	90.8	13.19
-100	73	97.2	-24.2
-50	128	103.52	24.47
75	88.5	118.47	-29.97
100	119	121.27	-2.27
150	116.5	126.62	-10.12
175	159.5	129.18	30.31

SUM of RESIDUALS = 1.4

* Upper shelf impact energy not obtainable due to excessive toughness.

CAPSULE V

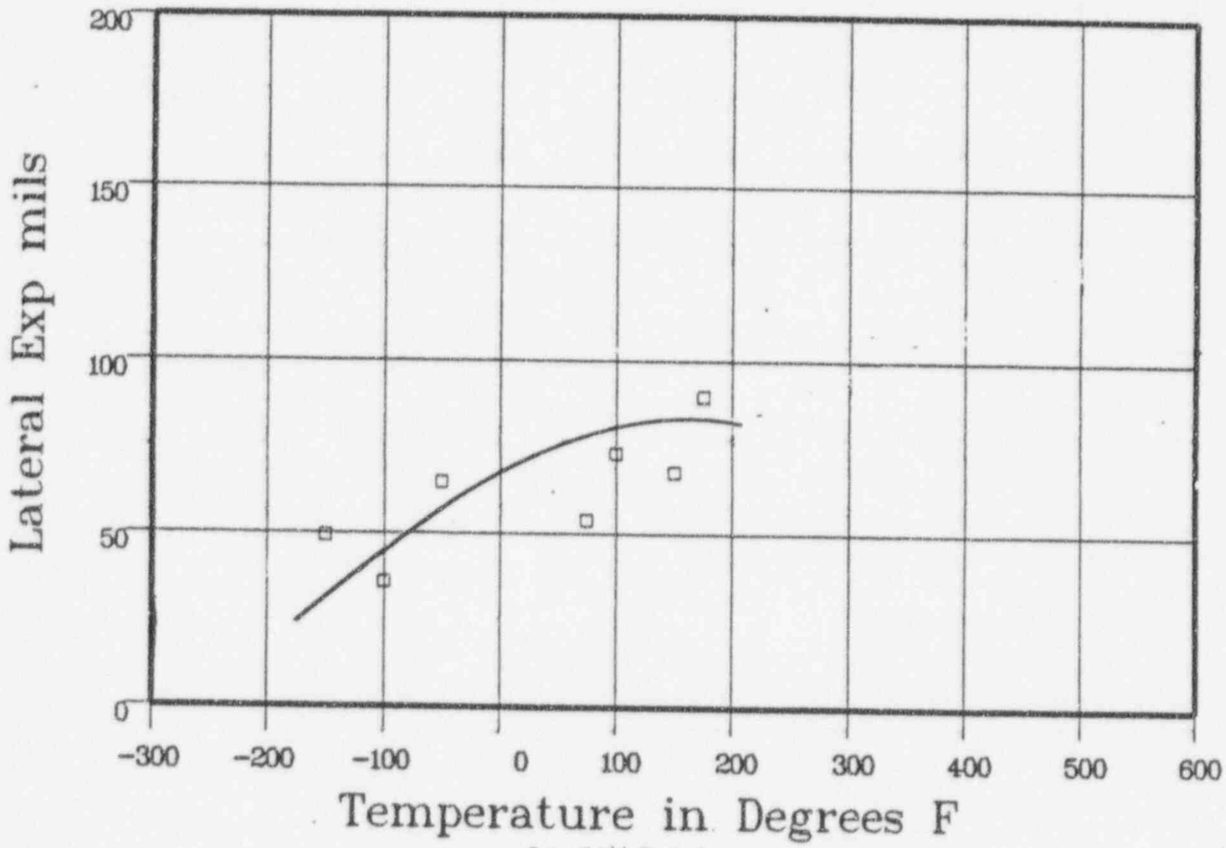
Best-Fit Curve as documented in WCAP-8916

(not fit with hyperbolic-tangent function)

Upper Shelf L.E.: 87 Temperature at L.E. 35: -128 Lower Shelf L.E.:

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

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: V Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-150	49.5	43.58	5.91
-100	36	48.03	-12.03
-50	65	52.85	12.14
75	54	66.54	-12.54
100	73.5	69.57	3.92
150	68	75.9	-7.9
175	90	79.2	10.79

SUM of RESIDUALS = .29

CAPSULE V

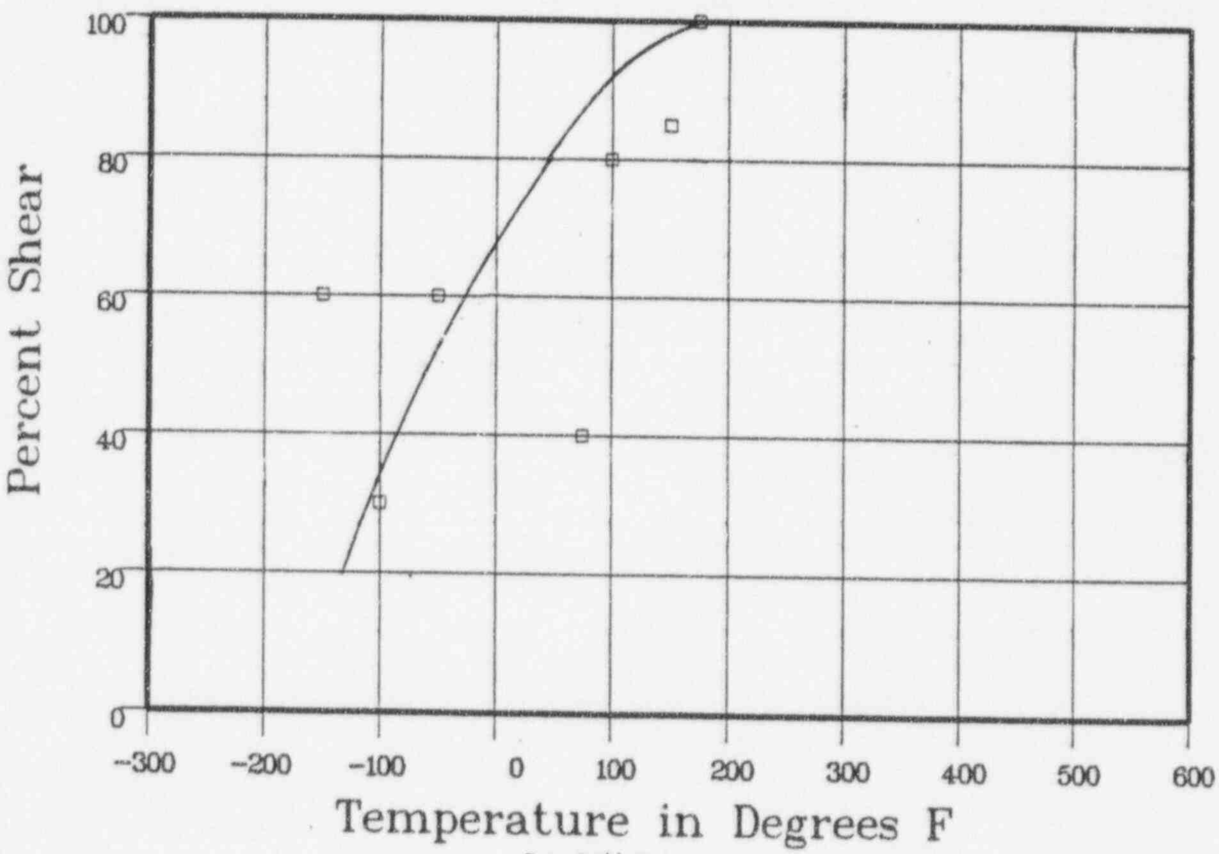
Best-Fit Curve as documented in WCAP-8916

(not fit with hyperbolic-tangent function)

Temperature at 50% Shear: -60

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: V   Total Fluence:



Data Set(s) Plotted

Plant: PI1   Cap: V   Material: HEAT AFFD ZONE   Ori: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-150	60	41.01	18.98
-100	30	47.93	-17.93
-50	60	54.94	5.05
75	40	71.09	-31.09
100	80	73.89	6.1
150	85	78.93	6.06
175	100	81.17	18.82

SUM of RESIDUALS = 5.99

CAPSULE V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:19:59 on 10-23-1996

Page 1

Coefficients of Curve 1

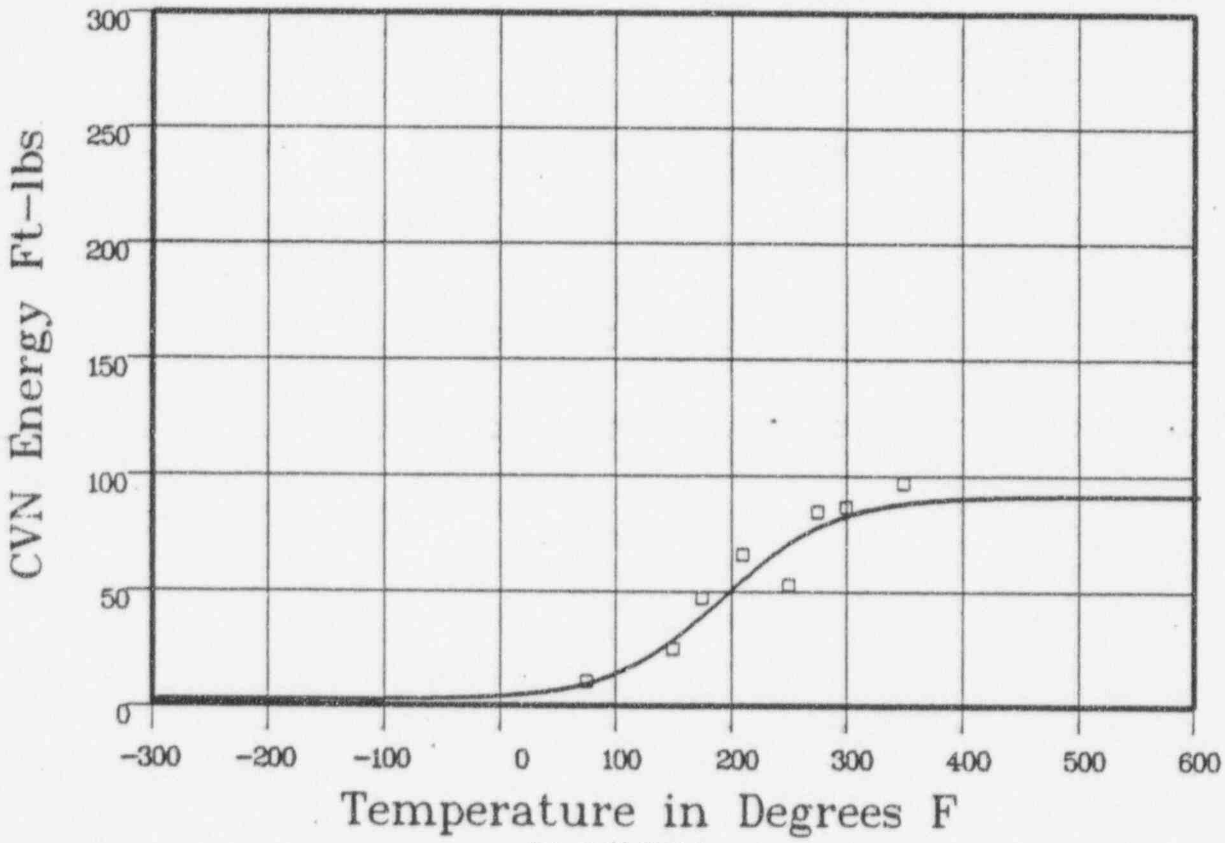
A = 46.59	B = 44.4	C = 97.09	T0 = 187.2

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

Upper Shelf Energy: 91 Fixed Temp. at 30 ft-lbs: 149 Temp. at 50 ft-lbs: 194.6 Lower Shelf Energy: 2.19 Fixed

Material: SRM HSST02 Heat Number: SA533B1 Orientation: LT

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: V Material: SRM HSST02 Ori: LT Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
75	10.5	10.2	.29
150	24.5	30.37	-5.87
175	46.5	41.04	5.45
210	65.5	56.83	8.66
250	52.5	71.88	-19.38
275	84	78.49	5.5
300	86	83.07	2.92
350	96.5	87.99	8.5

SUM of RESIDUALS = 6.08

CAPSULE V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:21:02 on 10-23-1996

Page 1

Coefficients of Curve 1

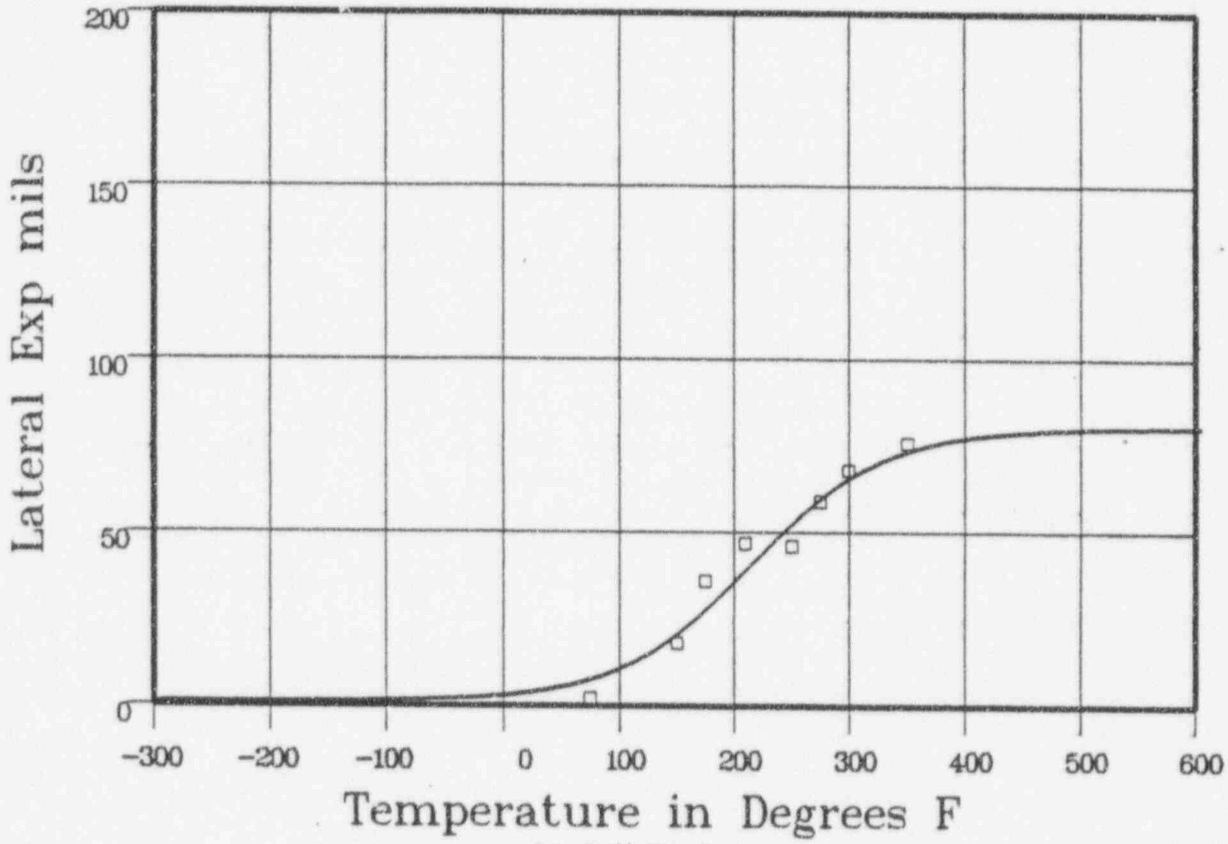
A = 40.82	B = 39.82	C = 116.11	T0 = 210.05

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

Upper Shelf L.E.: 80.64 Temperature at L.E. 35: 192.9 Lower Shelf L.E.: 1 Fixed

Material: SRM HSST02 Heat Number: SA533B1 Orientation: LT

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: V Material: SRM HSST02 Ori.: LT Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
75	2	8.08	-6.08
150	18	21.88	-3.88
175	36	29.14	6.85
210	47	40.8	6.19
250	46	54	-8
275	59	61.02	-2.02
300	68	66.68	1.31
350	76	74.08	1.91

SUM of RESIDUALS = -3.71

CAPSULE V

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:21:54 on 10-23-1996

Page 1

Coefficients of Curve 1

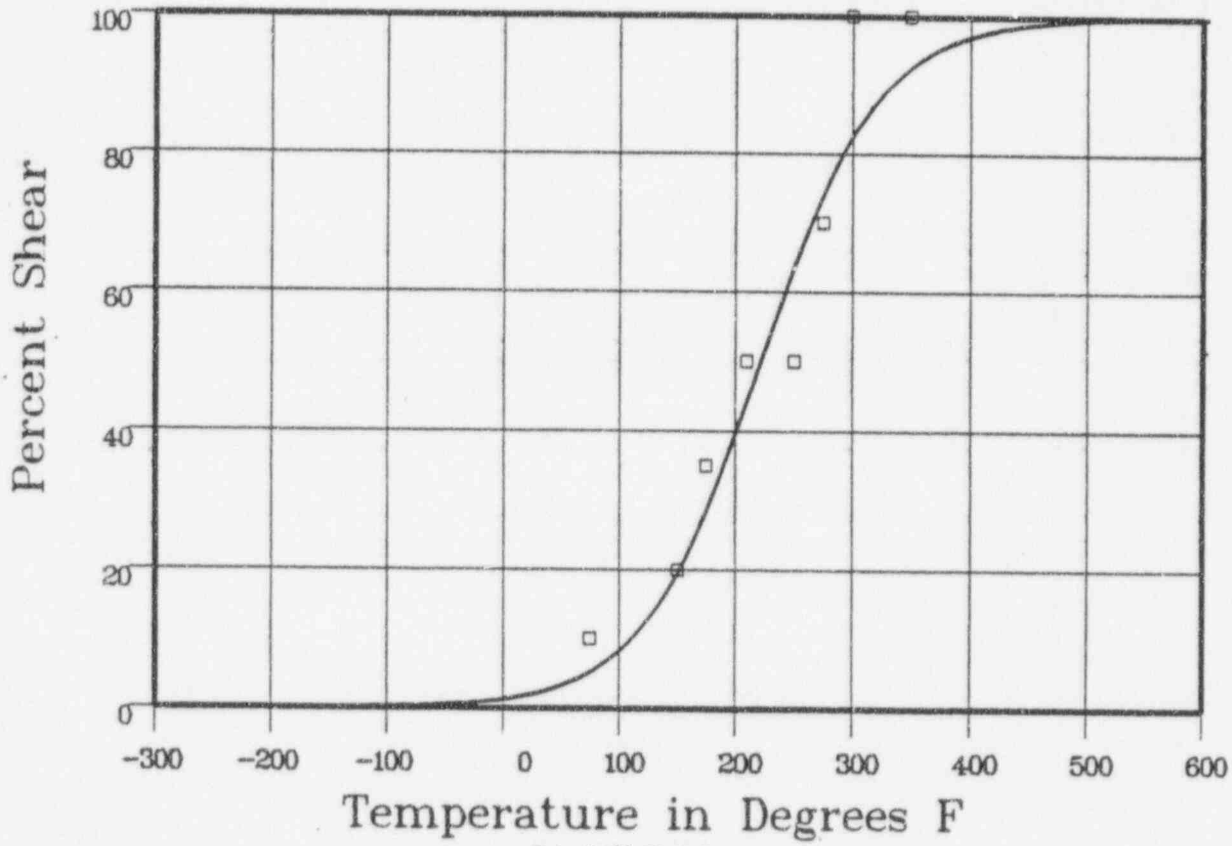
A = 50	B = 50	C = 101.52	T0 = 217.03

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

Temperature at 50% Shear: 217

Material: SRM HSST02 Heat Number: SA533B1 Orientation: LT

Capsule: V Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: V Material: SRM HSST02 Ori: LT Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
75	10	5.74	4.25
150	20	21.07	-1.07
175	35	30.4	4.59
210	50	46.54	3.45
250	50	65.68	-15.68
275	70	75.8	-5.8
300	100	83.67	16.32
350	100	93.2	6.79

SUM of RESIDUALS = 12.85

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:45:49 on 09-20-1996

Page 1

Coefficients of Curve 1

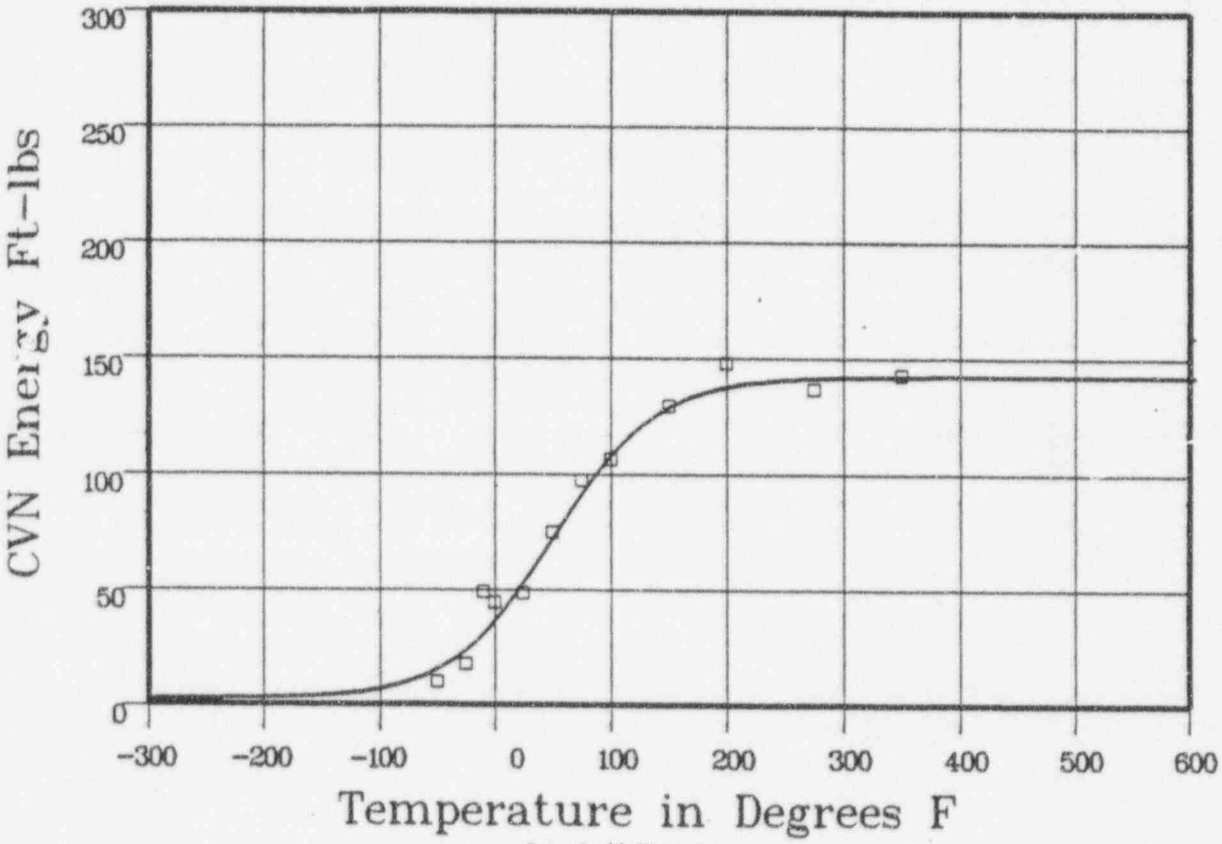
A = 72.09	B = 69.9	C = 88.61	T0 = 45.93

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

Upper Shelf Energy: 142 Fixed Temp. at 30 ft-lbs: -15.8 Temp. at 50 ft-lbs: 16.9 Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: P Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: P Material: FORGING SA5083 Ori.: LT Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	9.5	16.58	-7.08
-25	17.5	25.66	-8.16
-10	48.5	33.03	15.46
0	44	38.79	5.2
25	48	55.88	-7.88
50	74.5	75.3	-.8
75	97	94.23	2.76
100	106	110.13	-4.13
150	129	129.81	-.81

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

CAPSULE P

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: P Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
200	147.5	137.8	9.69
275	136.5	141.2	-4.7
350	142.5	141.85	.64

SUM of RESIDUALS = .17

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:54:12 on 09-20-1996

Page 1

Coefficients of Curve 1

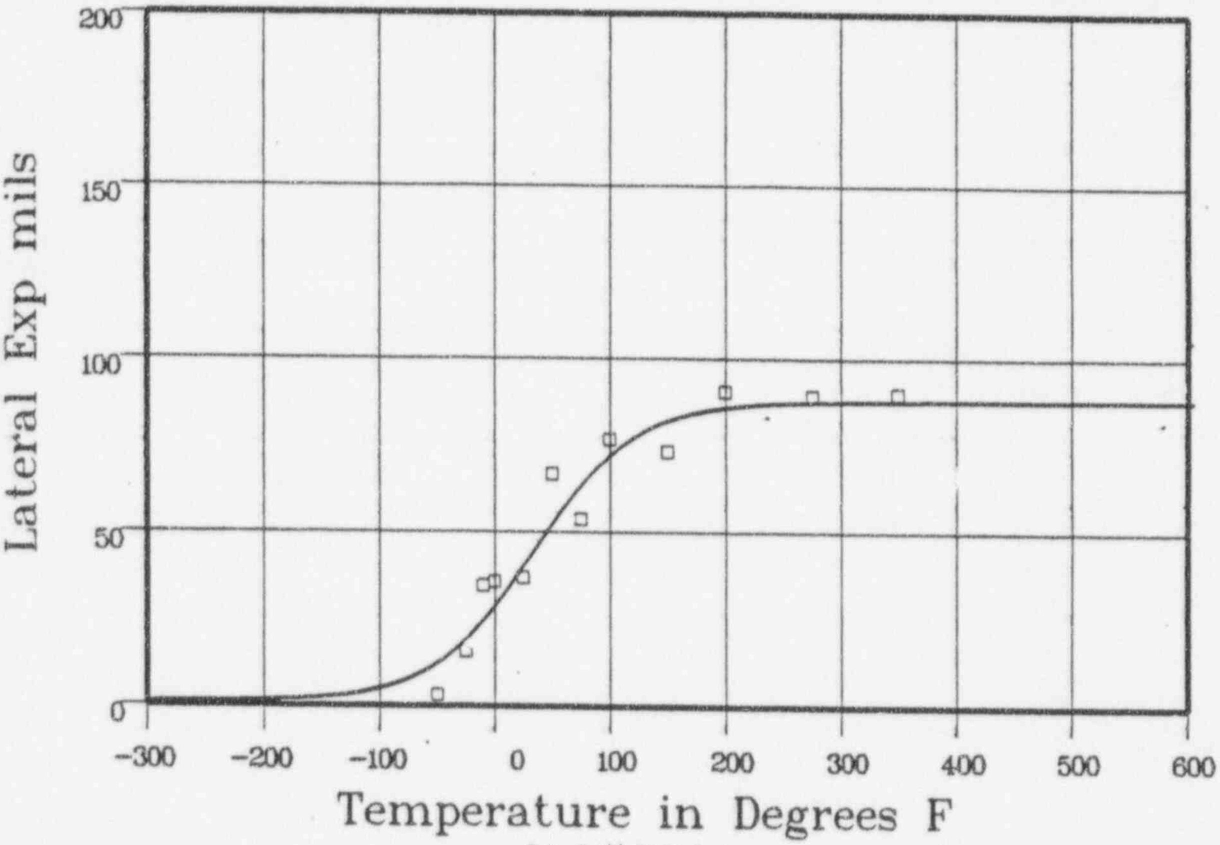
A = 44.53	B = 43.53	C = 88.6	T0 = 29.06

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

Upper Shelf L.E.: 88.06 Temperature at L.E. 35: 9.3 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: P Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: P Material: FORGING SA5083 Ori: LT Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	3.09	13.51	-10.41
-25	15.69	20.84	-5.14
-10	34.59	26.49	8.1
0	35.79	30.74	5.05
25	37	42.53	-5.53
50	66.9	54.62	12.27
75	53.9	65.27	-11.37
100	76.8	73.45	3.34
150	73.19	82.73	-9.53

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

CAPSULE P

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: P Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed LE	Differential
200	90.59	86.26	4.33
275	89.4	87.72	1.67
350	90.19	88	2.19

SUM of RESIDUALS = -5

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:56:14 on 09-20-1996
Page 1
Coefficients of Curve 1

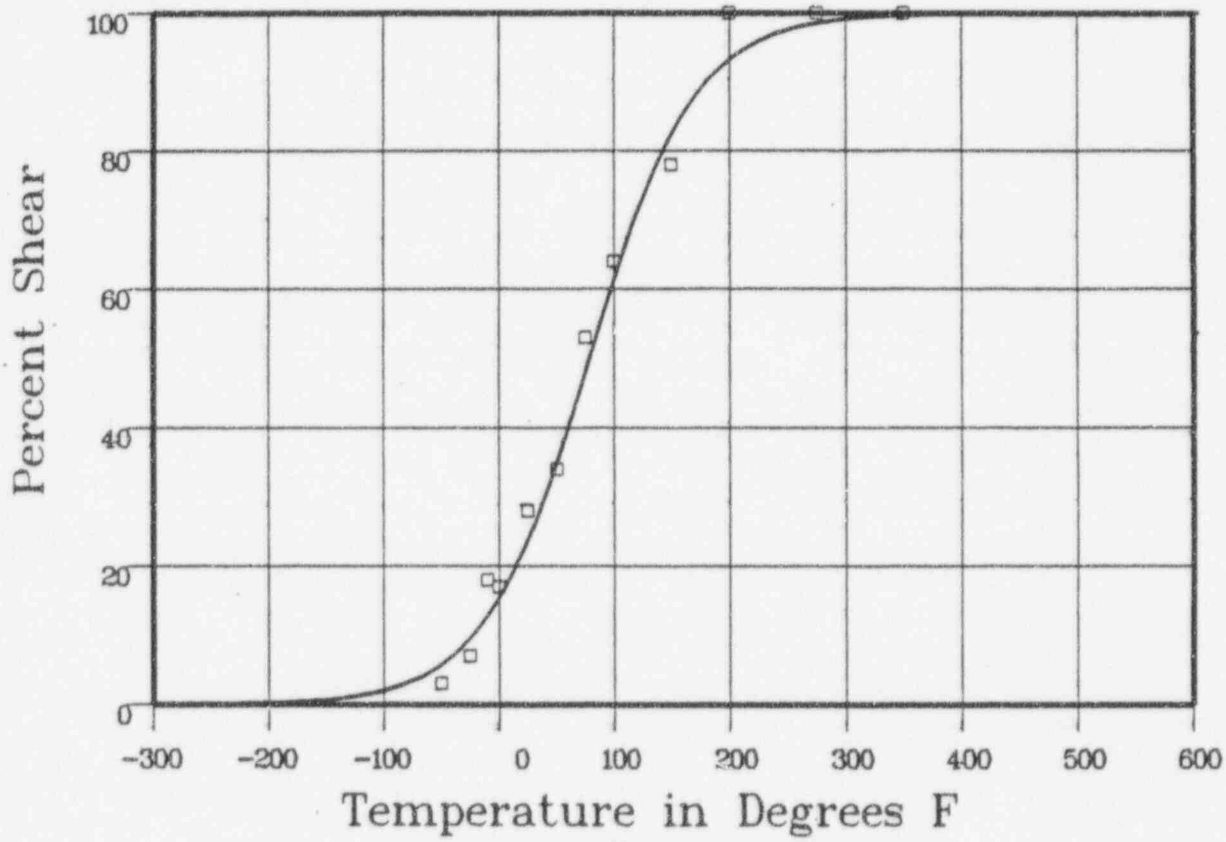
A = 50	B = 50	C = 92.45	T0 = 74.12

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

Temperature at 50% Shear: 74.1

Material: FORGING SA508B Heat Number: 21918/38566 Orientation: LT

Capsule: P Total Fluence:



Data Set(s) Plotted
Plant: PI1 Cap.: P Material: FORGING SA508B Ori.: LT Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	3	6.38	-3.38
-25	7	10.48	-3.48
-10	18	13.94	4.05
0	17	16.74	.25
25	28	25.67	2.32
50	34	37.24	-3.24
75	53	50.47	2.52
100	64	63.64	.35
150	78	83.77	-5.77

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

CAPSULE P

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: P Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
200	100	93.83	6.16
275	100	98.72	1.27
350	100	99.74	.25

SUM of RESIDUALS = 1.32

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:51:05 on 09-20-1996

Page 1

Coefficients of Curve 1

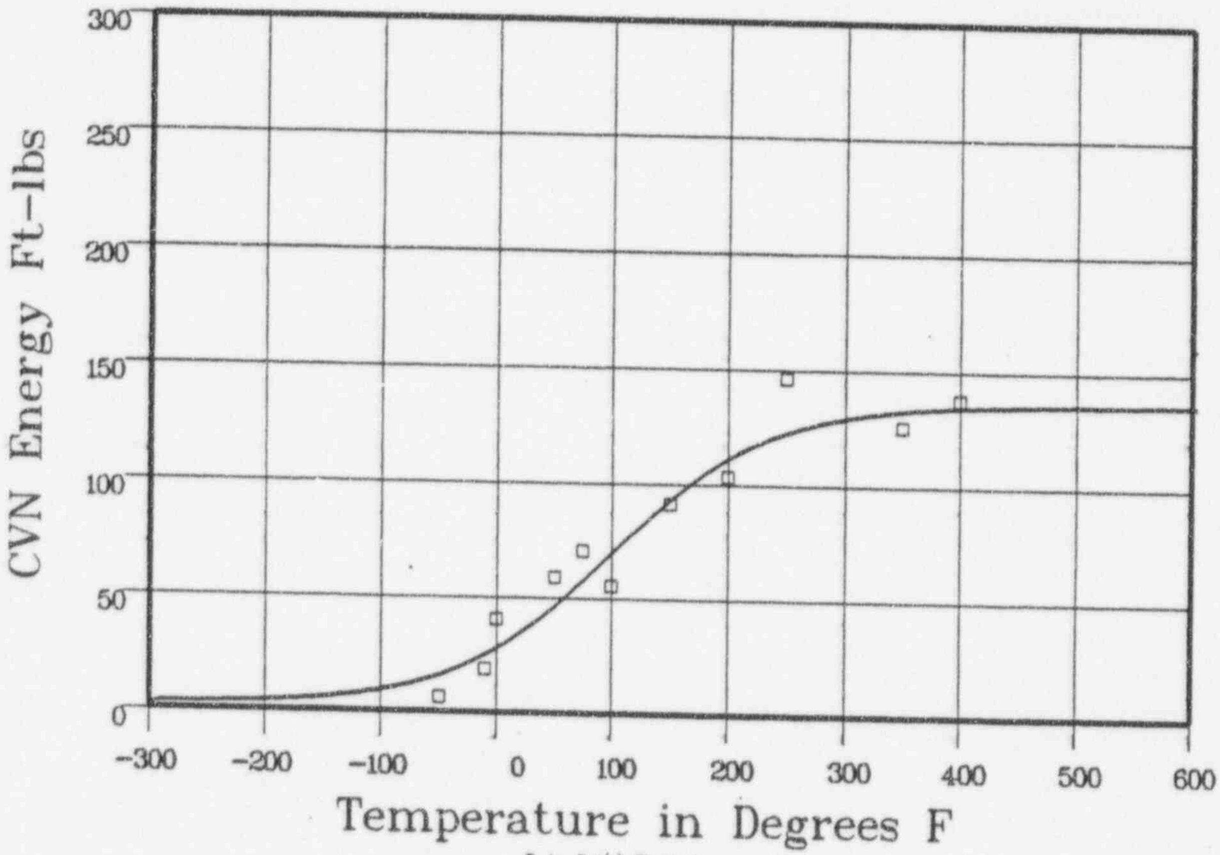
A = 69.09	B = 66.9	C = 137.41	T0 = 94.62

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

Upper Shelf Energy: 136 Fixed   Temp. at 30 ft-lbs: 2.6   Temp. at 50 ft-lbs: 54.2   Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA5083   Heat Number: 21918/38566   Orientation: TL

Capsule: P   Total Fluence:



Data Set(s) Plotted

Plant: PI1   Cap.: P   Material: FORGING SA5083   Ori.: TL   Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	6	16.73	-10.73
-10	18.5	26.15	-7.65
0	40	29.15	10.84
50	58.5	48.1	10.39
75	70	59.6	10.39
100	55	71.71	-16.71
150	91	94.68	-3.68
200	103	112.25	-9.25
250	146	123.37	22.62

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

CAPSULE P

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: P Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
350	125.5	132.82	-7.32
400	137.5	134.44	3.05

SUM of RESIDUALS = 1.94

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:58:38 on 09-20-1996

Page 1

Coefficients of Curve 1

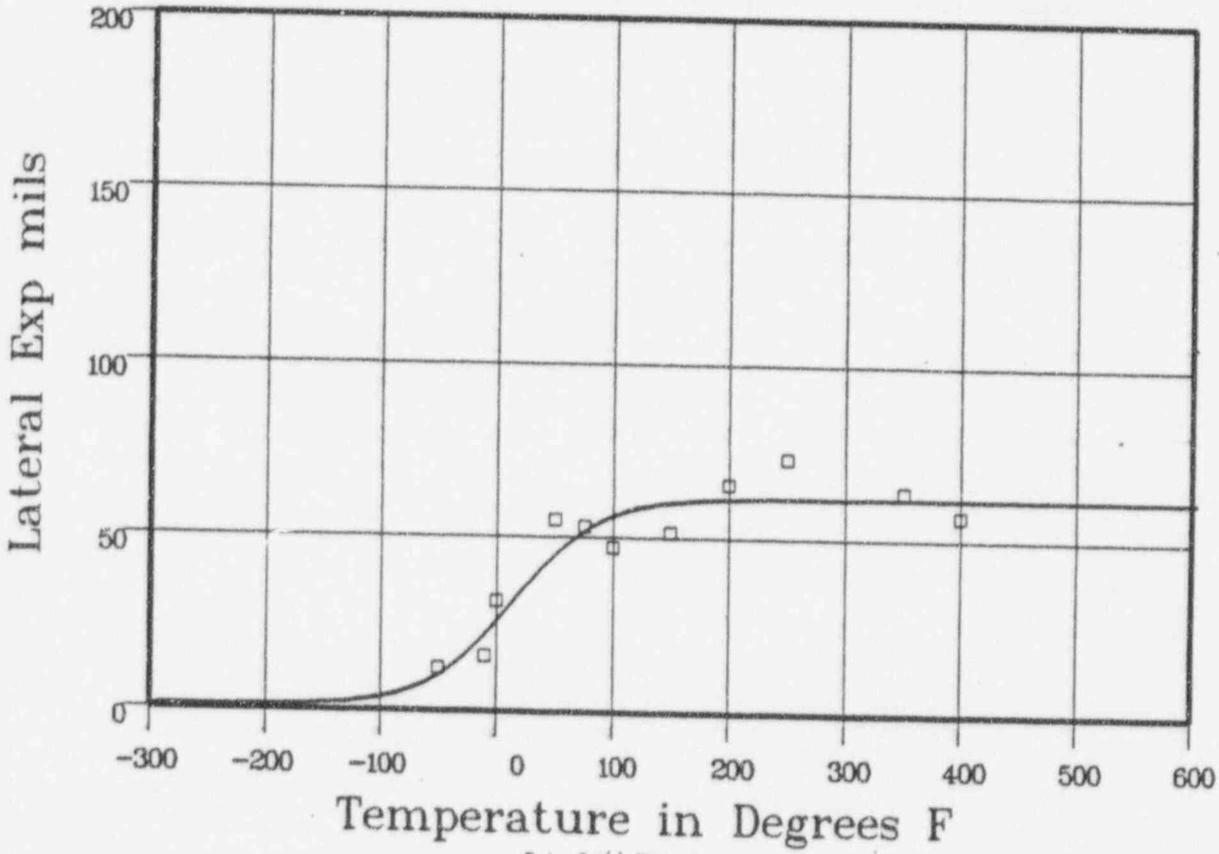
A = 31.43	B = 30.43	C = 74.61	T0 = 9.37

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

Upper Shelf L.E.: 61.87 Temperature at L.E. 35: 18.1 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: P Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: P Material: FORGING SA5083 Ori.: TL Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	12.19	11.29	.9
-10	15.69	23.7	-8
0	31.5	27.63	3.86
50	55.09	46.54	8.55
75	53.09	52.93	.16
100	47.2	56.94	-9.74
150	51.59	60.5	-8.9
200	65.69	61.51	4.18
250	73.19	61.77	11.42

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

CAPSULE P

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: P Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
350	63.79	61.86	1.93
400	57.09	61.87	-4.77

SUM of RESIDUALS = -.4

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:00:45 on 09-20-1996

Page 1

Coefficients of Curve 1

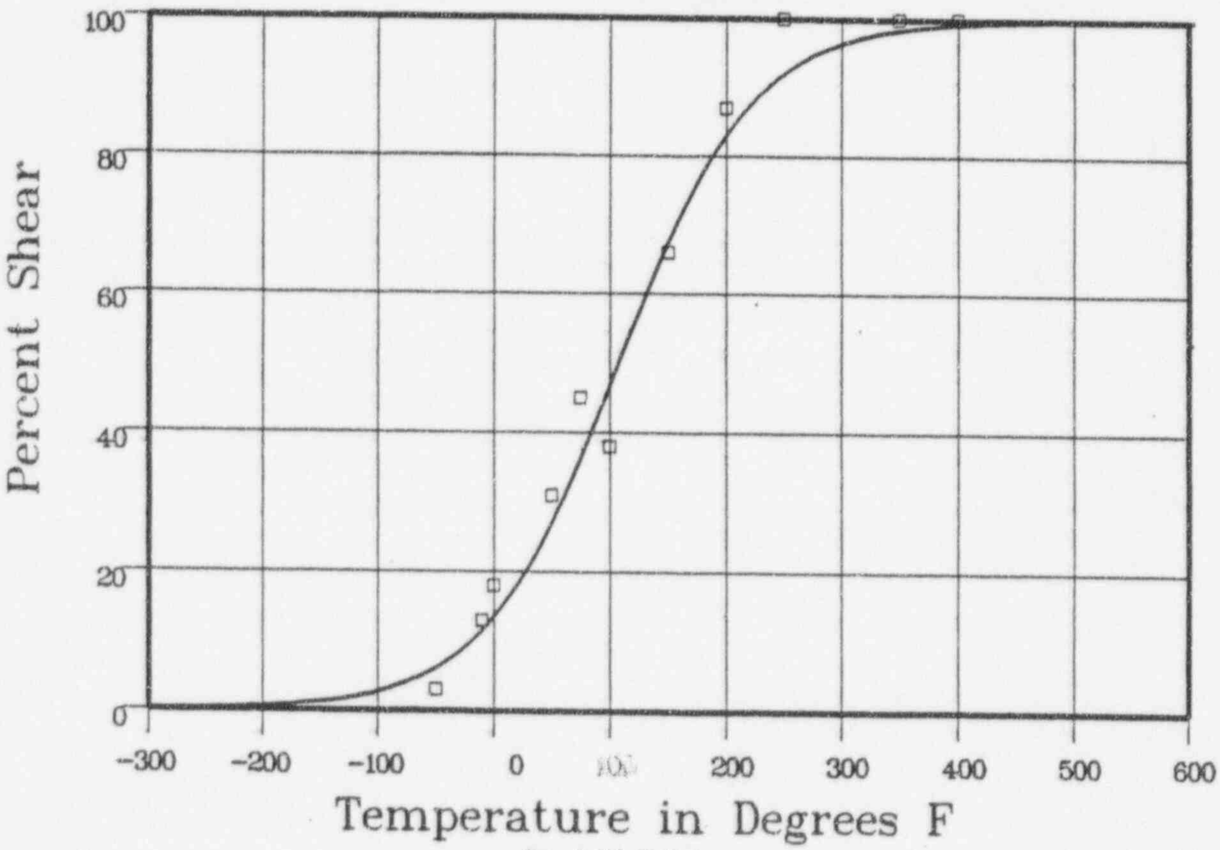
A = 50	B = 50	C = 116.11	T0 = 103.12

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

Temperature at 50% Shear: 103.1

Material: FORGING SA508J Heat Number: 21918/38566 Orientation: TL

Capsule: P Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: P Material: FORGING SA508J Ori.: TL Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	3	6.67	-3.67
-10	13	12.47	.52
0	18	14.47	3.52
50	31	28.59	2.4
75	45	38.12	6.87
100	38	48.65	-10.65
150	66	69.15	-3.15
200	87	84.13	2.86
250	100	92.62	7.37

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

CAPSULE P

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: P Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
350	100	98.59	1.4
400	100	99.4	.59

SUM of RESIDUALS = 8.09

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:07:26 on 09-20-1996

Page 1

Coefficients of Curve 1

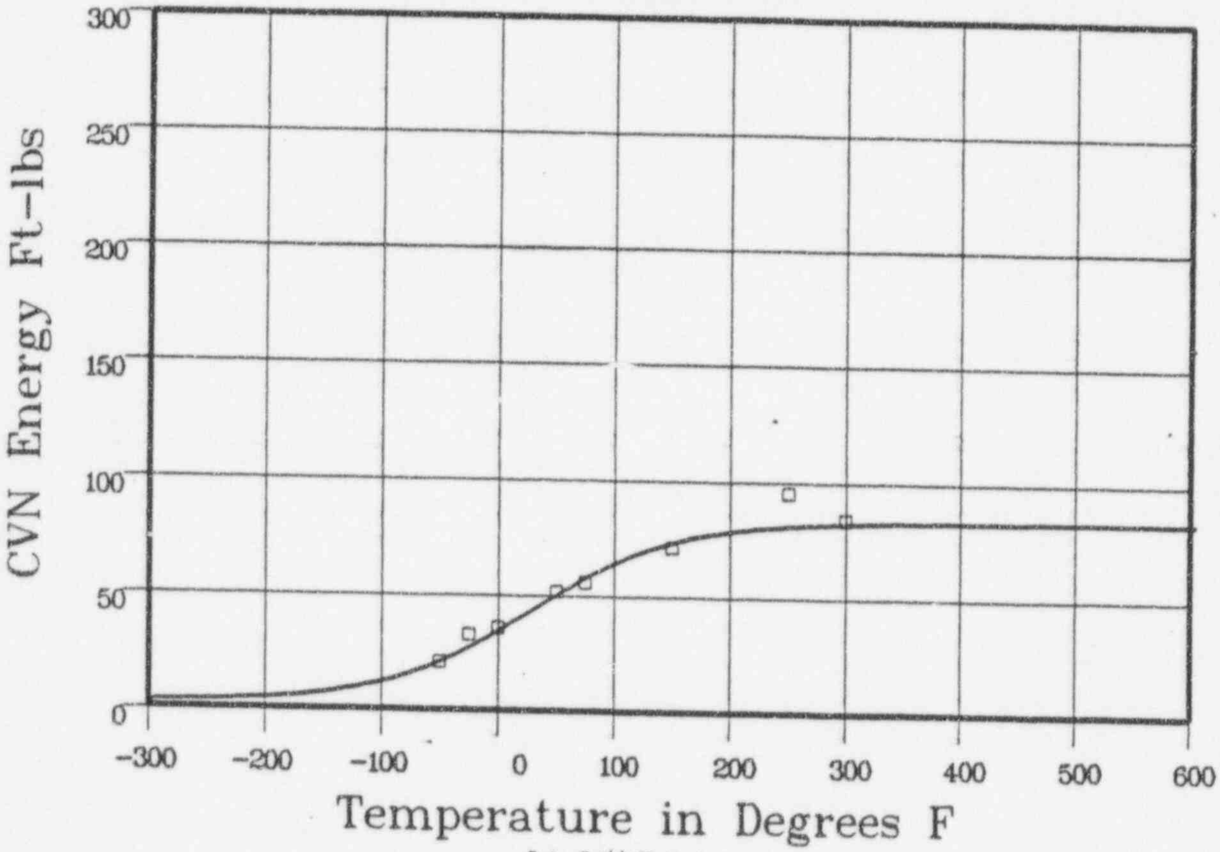
A = 42.59	B = 40.4	C = 126.6	T0 = 21.55

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

Upper Shelf Energy: 83 Fixed Temp. at 30 ft-lbs: -19.2 Temp. at 50 ft-lbs: 45 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 1752 Orientation:

Capsule: P Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: P Material: WELD Ori.: Heat #: 1752

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	20.5	21.92	-1.42
-25	32.5	28.37	4.12
0	35.5	35.78	-.28
50	51.5	51.52	-.02
75	55.5	58.7	-3.2
150	71	73.61	-2.61
250	95	80.86	14.13
300	83.5	82.01	1.48

SUM of RESIDUALS = 12.17

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:10:56 on 09-20-1996

Page 1

Coefficients of Curve 1

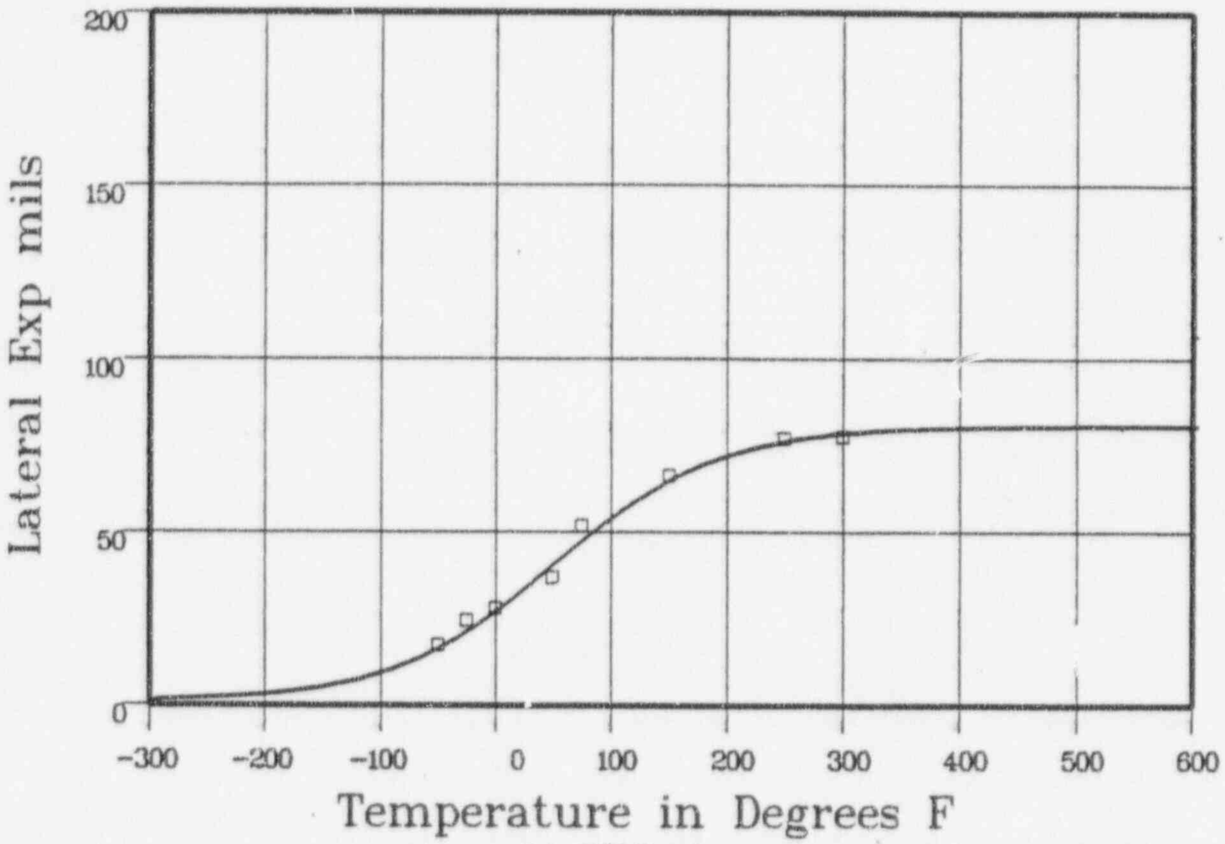
A = 40.96	B = 39.96	C = 141.84	T0 = 46.87

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

Upper Shelf L.E.: 80.92 Temperature at L.E. 35: 25.5 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 1752 Orientation:

Capsule: P Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: P Material: WELD Ori: Heat #: 1752

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	17.29	17.24	.05
-25	24.39	22.28	2.11
0	28	28.21	-.21
50	37	41.84	-4.84
75	52	48.78	3.21
150	66.5	65.78	.71
250	77.19	76.61	.58
300	77.59	78.73	-1.13

SUM of RESIDUALS = .49

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:12:30 on 09-20-1996

Page 1

Coefficients of Curve 1

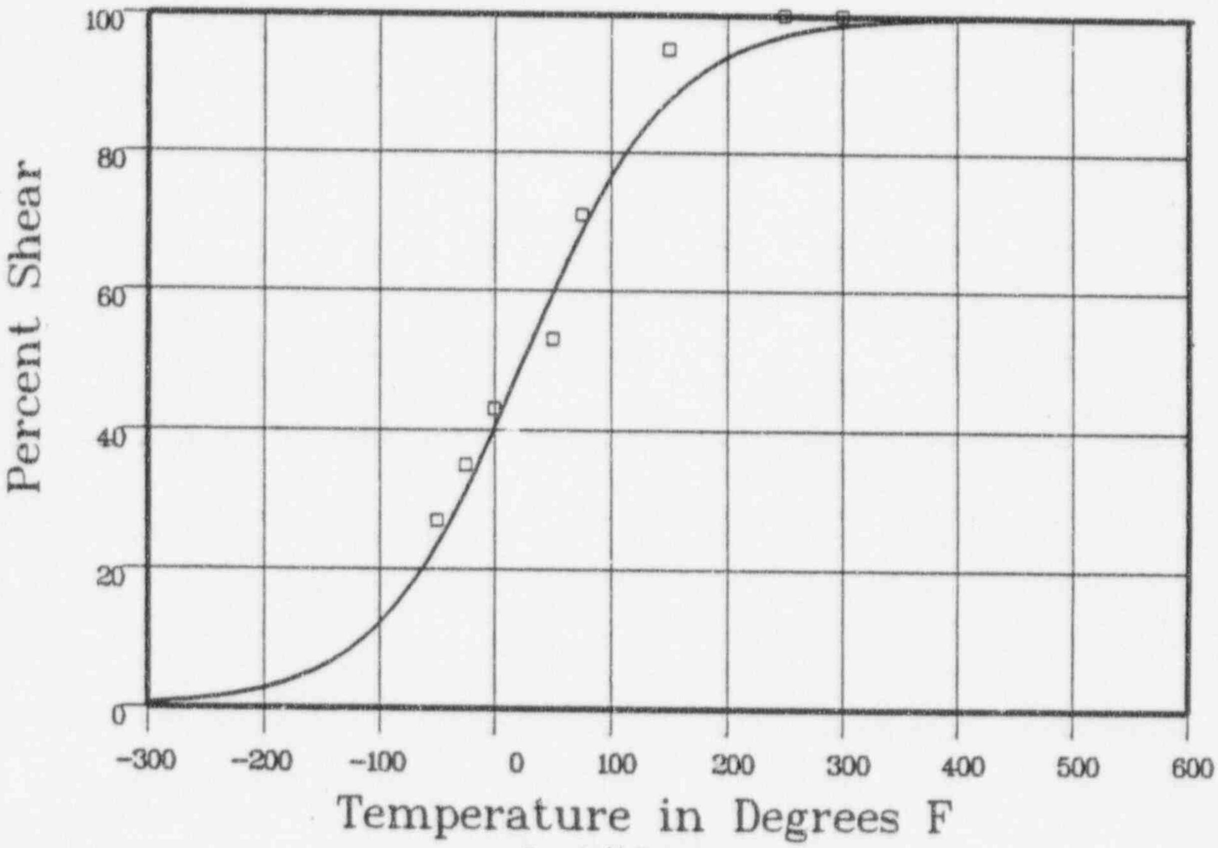
A = 50	B = 50	C = 127.45	T0 = 20.47

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

Temperature at 50% Shear: 20.4

Material: WELD Heat Number: 1752 Orientation:

Capsule: P Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: P Material: WELD Ori: Heat #: 1752

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	27	24.86	2.13
-25	35	32.88	2.11
0	43	42.03	.96
50	53	61.38	-8.38
75	71	70.17	.82
150	95	88.41	6.58
250	100	97.34	2.65
300	100	98.77	1.22

SUM of RESIDUALS = 8.12

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:15:26 on 09-20-1996
Page 1
Coefficients of Curve 1

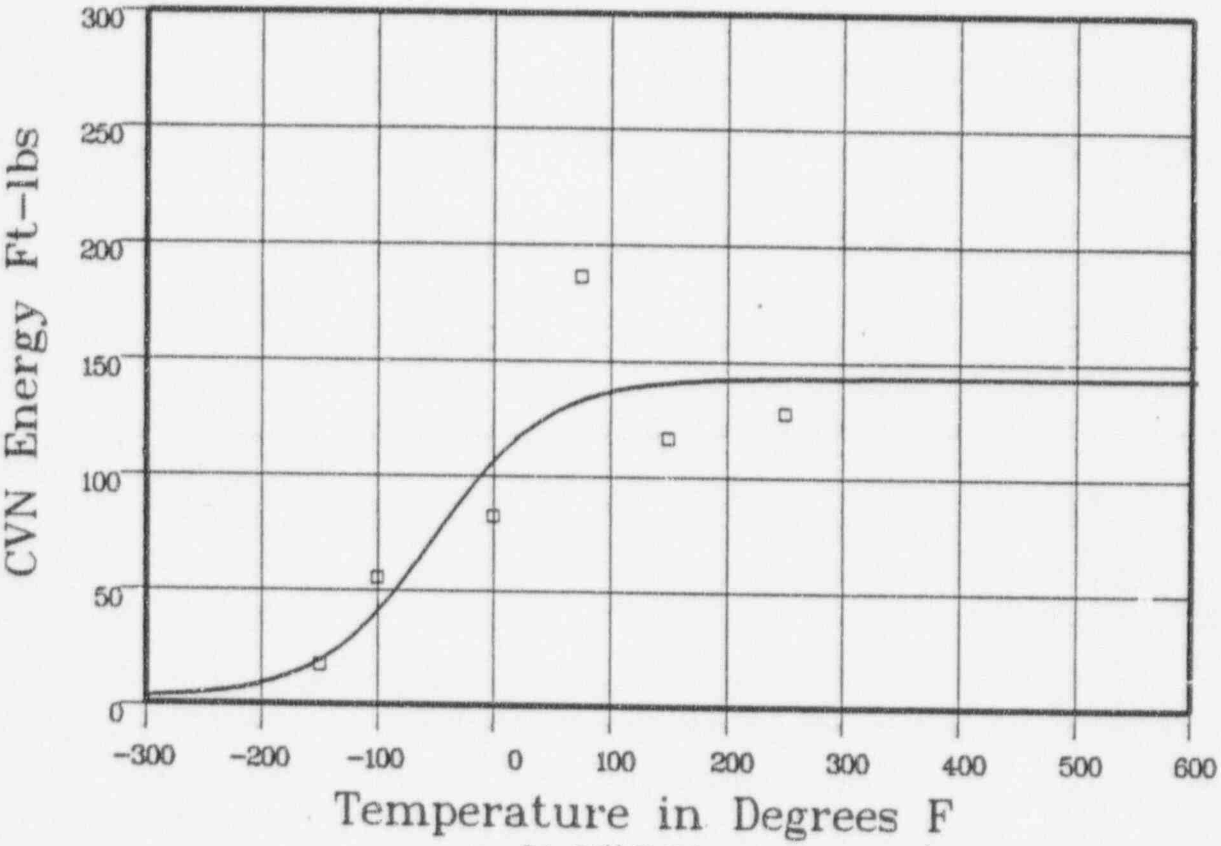
A = 72.59	B = 70.4	C = 99.22	T0 = -55.78

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

Upper Shelf Energy: 143 Fixed Temp. at 30 ft-lbs: -125.3 Temp. at 50 ft-lbs: -88.8 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: P Total Fluence:



Data Set(s) Plotted
Plant: PI1 Cap: P Material: HEAT AFFD ZONE Ori: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-150	17	20.53	-3.53
-100	55	43.15	11.84
0	82	108.47	-26.47
75	186	133.58	52.41
150	116.5	140.81	-24.31
250	127.5	142.7	-15.2

SUM of RESIDUALS = -5.26

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:36:33 on 09-20-1996

Page 1

Coefficients of Curve 1

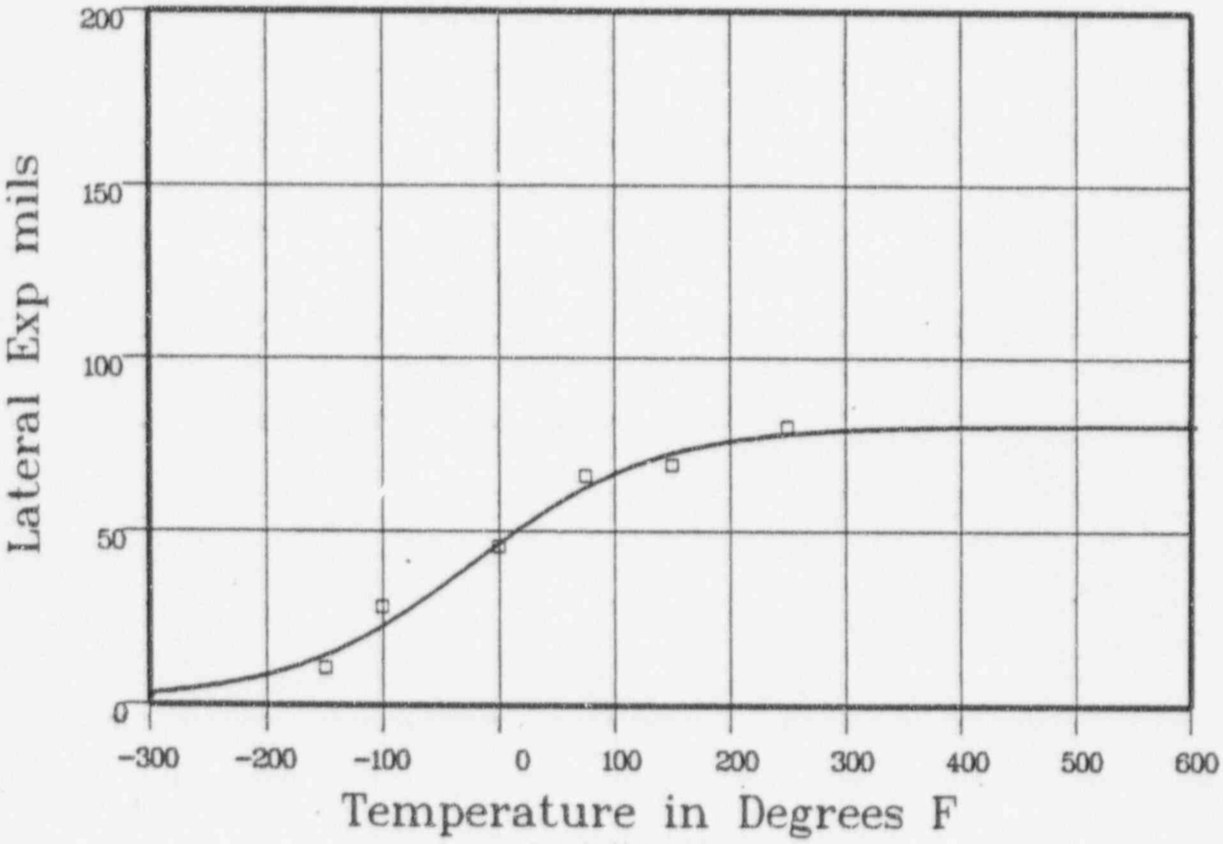
A = 40.84	B = 39.84	C = 158	T0 = -27.89

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

Upper Shelf L.E.: 80.69 Temperature at L.E. 35: -51.2 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: P Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: P Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-150	10.6	15	-4.4
-100	28.29	23.82	4.47
0	45.7	47.8	-2.1
75	66.09	63.65	2.44
150	69.3	73.1	-3.8
250	80.3	78.39	1.9

SUM of RESIDUALS = -1.49

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:40:14 on 09-20-1996

Page 1

Coefficients of Curve 1

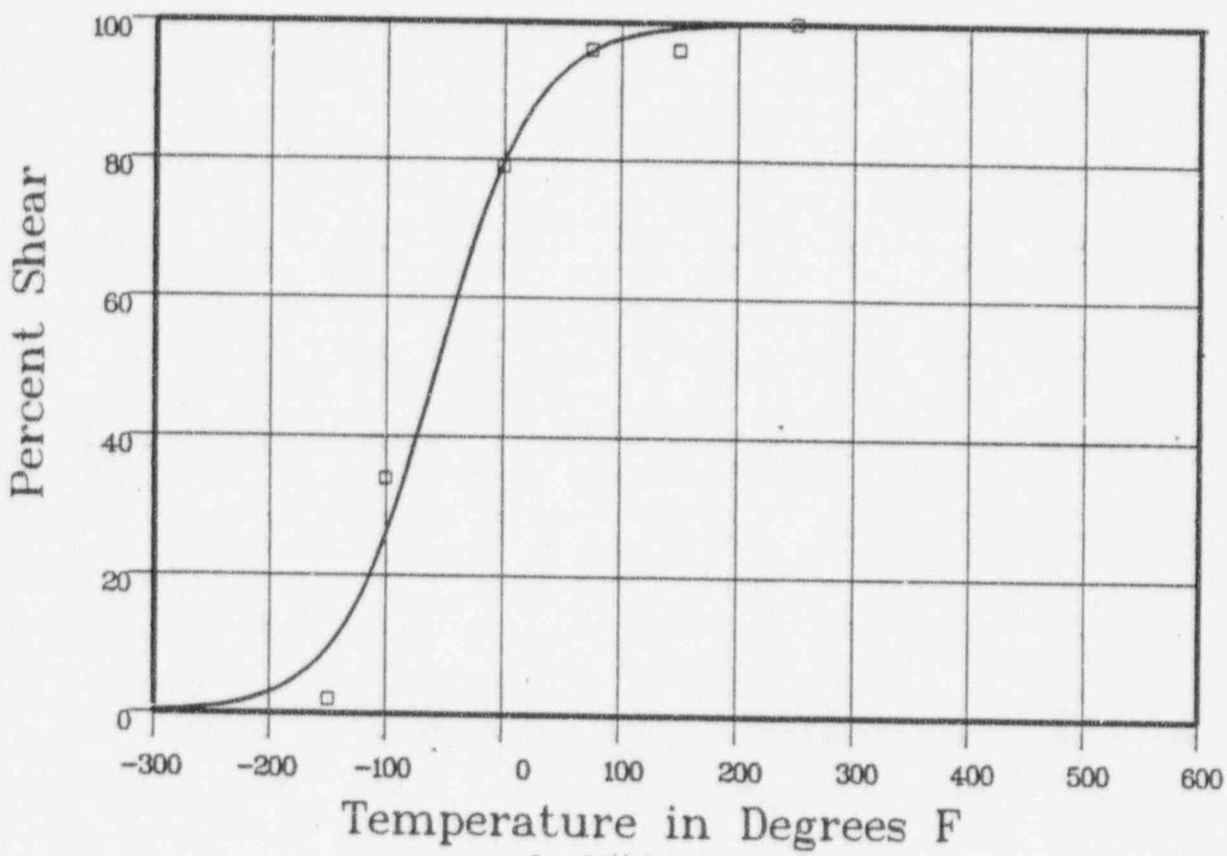
A = 50	B = 50	C = 83.22	T0 = -60.93

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

Temperature at 50% Shear: -60.9

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: P Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: P Material: HEAT AFFD ZONE Ori: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-150	2	10.52	-8.52
-100	34	28.11	5.88
0	79	81.22	-2.22
75	96	96.32	-.32
150	96	99.37	-3.37
250	100	99.94	.05

SUM of RESIDUALS = -8.5

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:42:32 on 09-20-1996

Page 1

Coefficients of Curve 1

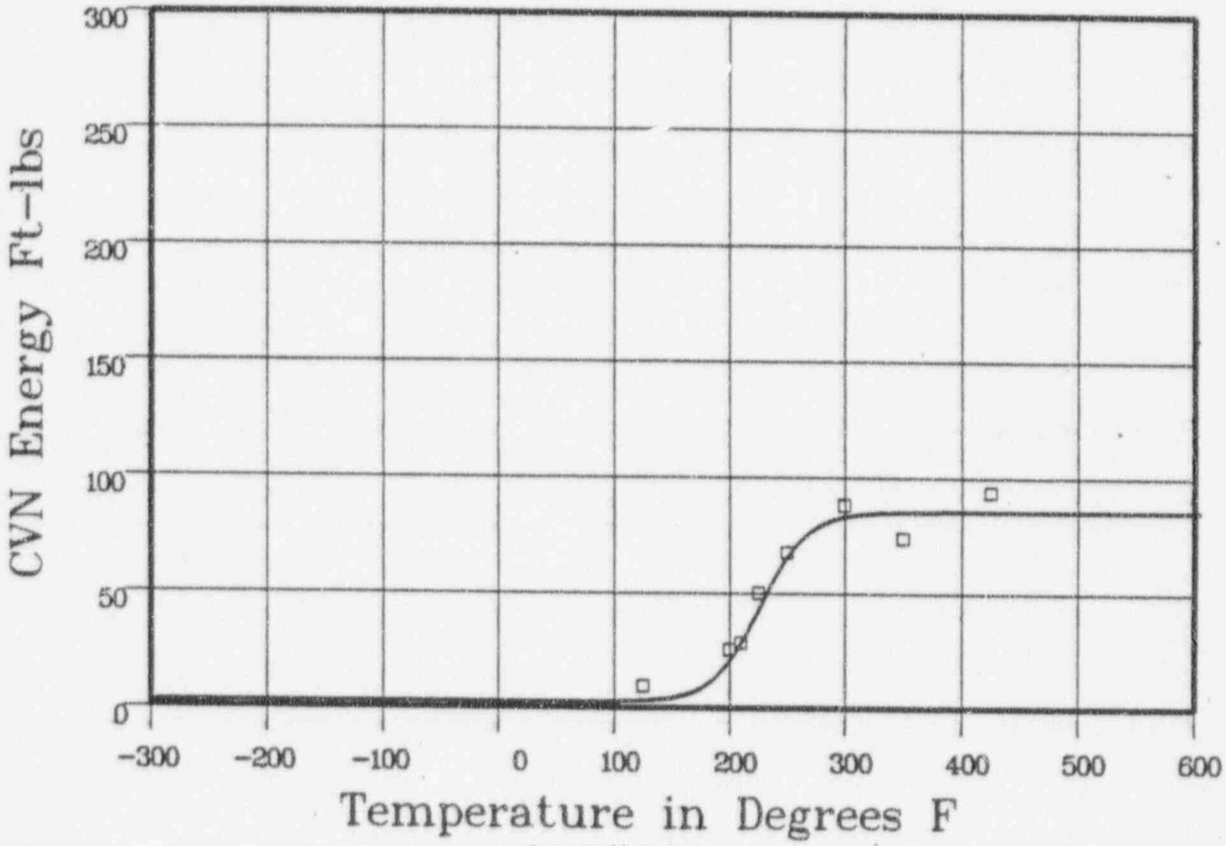
A = 43.59	B = 41.4	C = 41.34	T0 = 221.71

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

Upper Shelf Energy: 85 Fixed   Temp. at 30 ft-lbs: 207.6   Temp. at 50 ft-lbs: 228.1   Lower Shelf Energy: 2.19 Fixed

Material: SRM HSST02   Heat Number: SA533B1   Orientation: LT

Capsule: P   Total Fluence:



Data Set(s) Plotted

Plant: PI1   Cap: P   Material: SRM HSST02   Ori: LT   Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
125	9	2.96	6.03
200	25	23.65	1.34
210	28	32.17	-4.17
225	49.5	46.87	2.62
250	67	68.19	-1.19
300	87.5	83.16	4.33
350	73.5	84.83	-11.33
425	93.5	84.99	8.5

SUM of RESIDUALS = 6.14

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:44:46 on 09-20-1996

Page 1

Coefficients of Curve 1

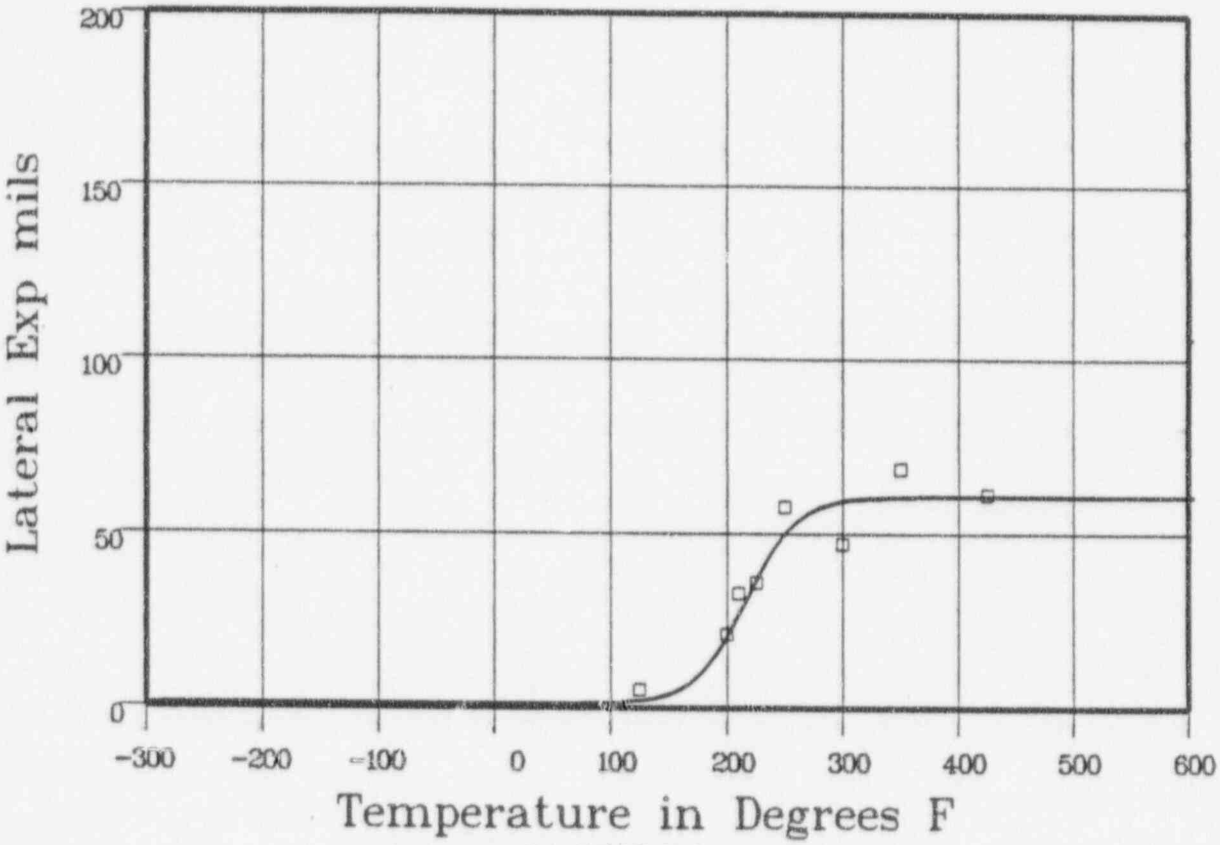
A = 30.96	B = 29.96	C = 44.51	T0 = 211.34

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

Upper Shelf L.E.: 60.92 Temperature at L.E. 35: 217.3 Lower Shelf L.E.: 1 Fixed

Material: SRM HSST02 Heat Number: SA533B1 Orientation: LT

Capsule: P Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: P Material: SRM HSST02 Ori: LT Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
125	5.09	2.21	2.88
200	21.29	23.48	-2.18
210	33.09	30.05	3.04
225	36.2	39.87	-3.67
250	57.9	51.95	5.94
300	47.2	59.83	-12.63
350	68.9	60.8	8.09
425	61.4	60.92	.47

SUM of RESIDUALS = 1.95

CAPSULE P

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:46:41 on 09-20-1996

Page 1

Coefficients of Curve 1

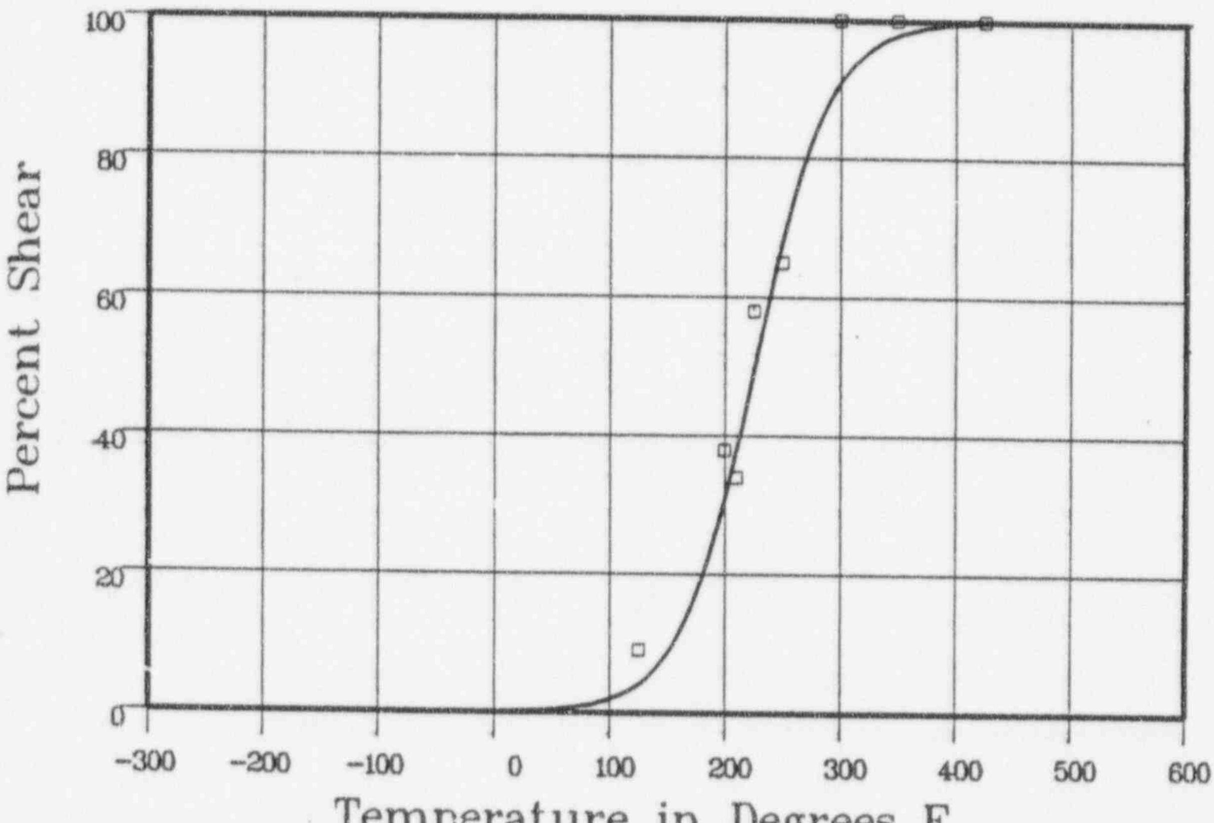
A = 50	B = 50	C = 64.26	T0 = 221.25

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

Temperature at 50% Shear: 221.2

Material: SRM HSST02 Heat Number: SA533B1 Orientation: LT

Capsule: P Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: P Material: SRM HSST02 Ori: LT Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
125	9	4.76	4.23
200	38	34.04	3.95
210	34	41.33	-7.33
225	58	52.91	5.08
250	65	70.98	-5.98
300	100	92.06	7.93
350	100	98.21	1.78
425	100	99.82	.17

SUM of RESIDUALS = 9.85

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:56:14 on 09-20-1996
Page 1
Coefficients of Curve 1

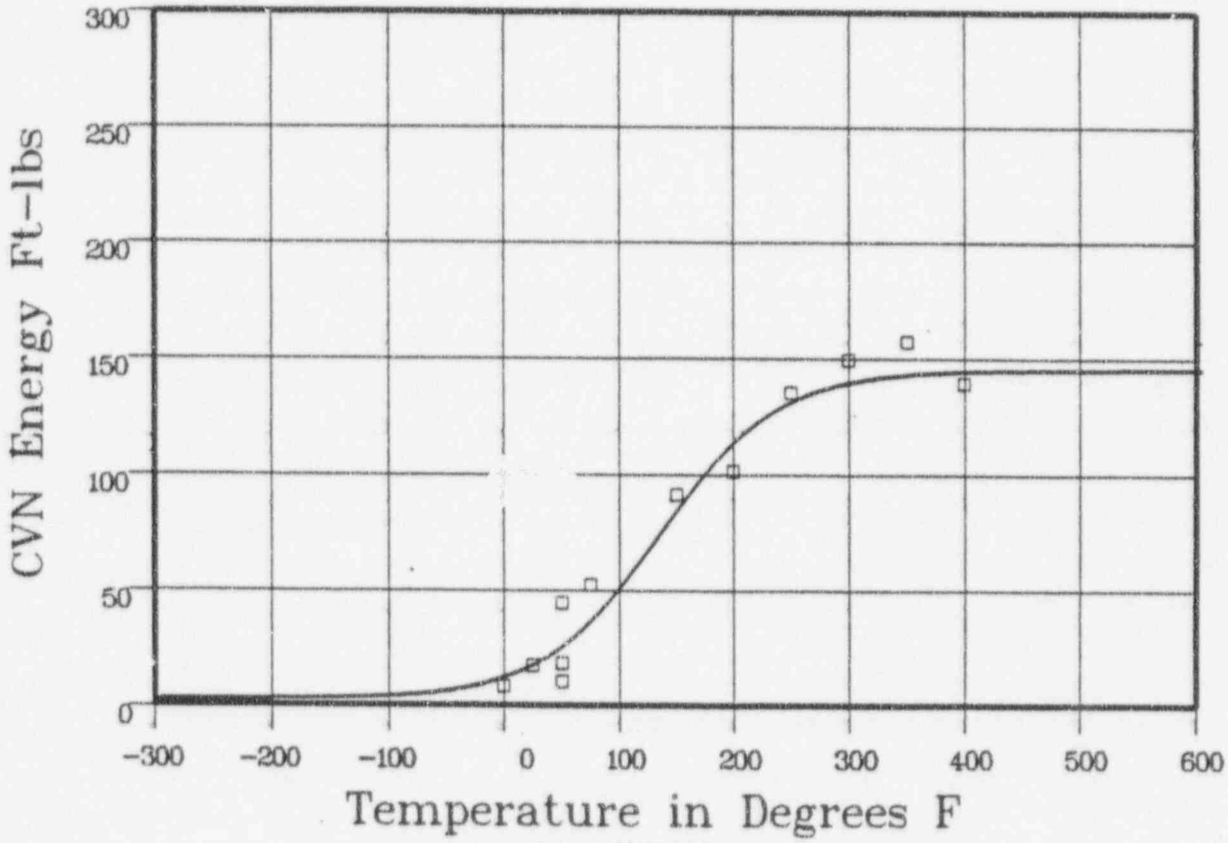
A = 73.59	B = 71.4	C = 103.43	T0 = 130.37

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

Upper Shelf Energy: 145 Fixed   Temp. at 30 ft-lbs: 56.9   Temp. at 50 ft-lbs: 94.8   Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA5083   Heat Number: 21918/38566   Orientation: LT

Capsule: R   Total Fluence:



Data Set(s) Plotted
Plant: PI1   Cap: R   Material: FORGING SA5083   Ori: LT   Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	8	12.82	-4.82
25	17	18.66	-1.66
50	10	27.11	-17.11
50	18	27.11	-9.11
50	44	27.11	16.88
75	52	38.65	13.34
150	91	86.98	4.01
200	101	115.51	-14.51
250	135	132.14	2.85

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

CAPSULE R

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: R Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
300	149	139.82	9.17
350	157	142.98	14.01
400	139	144.22	-5.22

SUM of RESIDUALS = 7.81

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:58:21 on 09-20-1996

Page 1

Coefficients of Curve 1

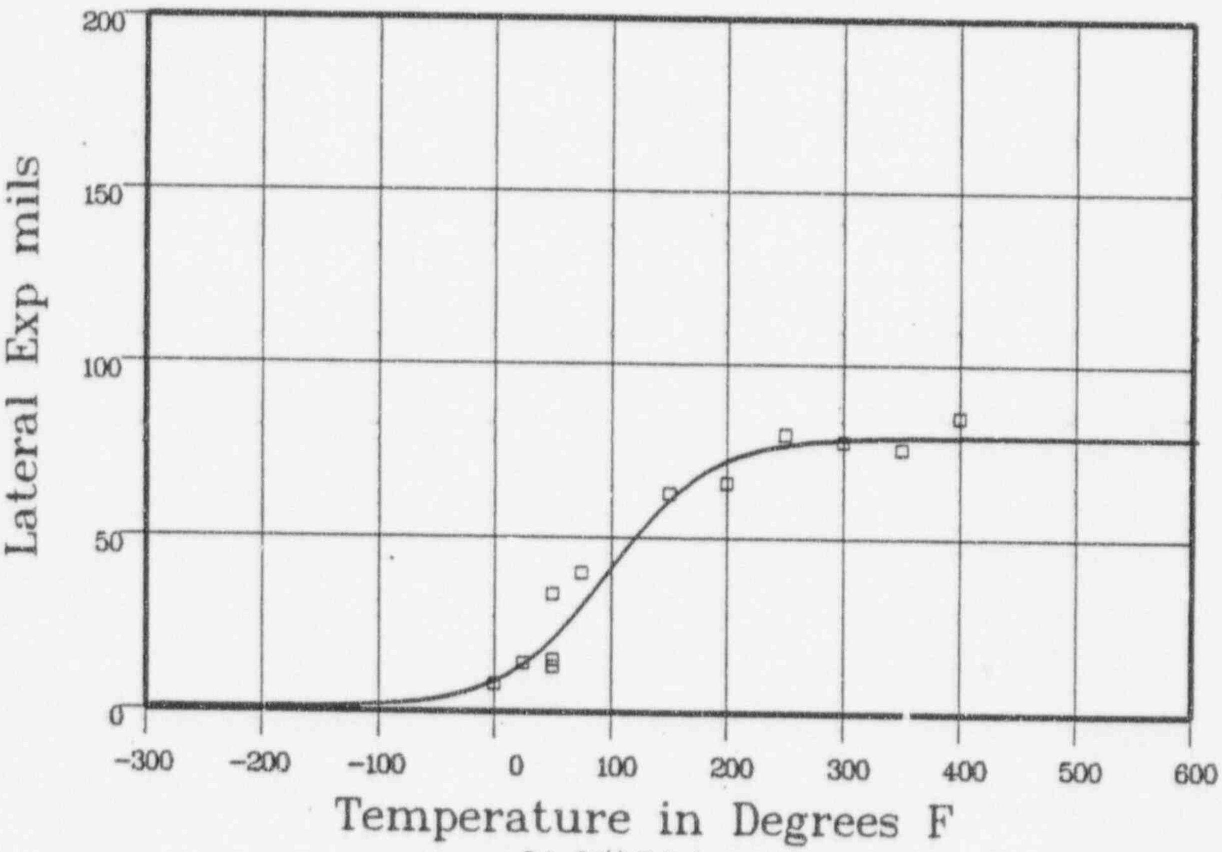
A = 40.25	B = 39.25	C = 88.75	T0 = 92.81

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

Upper Shelf L.E.: 79.5 Temperature at L.E. 35: 80.8 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: R Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: R Material: FORGING SA5083 Ori.: LT Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	8	9.62	-1.62
25	14	14.99	-.99
50	13	22.66	-9.66
50	15	22.66	-7.66
50	34	22.66	11.33
75	40	32.47	7.52
150	63	62.54	.45
200	66	7[illegible]6	-7.06
250	80	77.29	2.7

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

CAPSULE R

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: R Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed LE	Differential
300	78	78.77	-.77
350	76	79.26	-3.26
400	85	79.42	5.57

SUM of RESIDUALS = -3.45

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:00:13 on 09-20-1996

Page 1

Coefficients of Curve 1

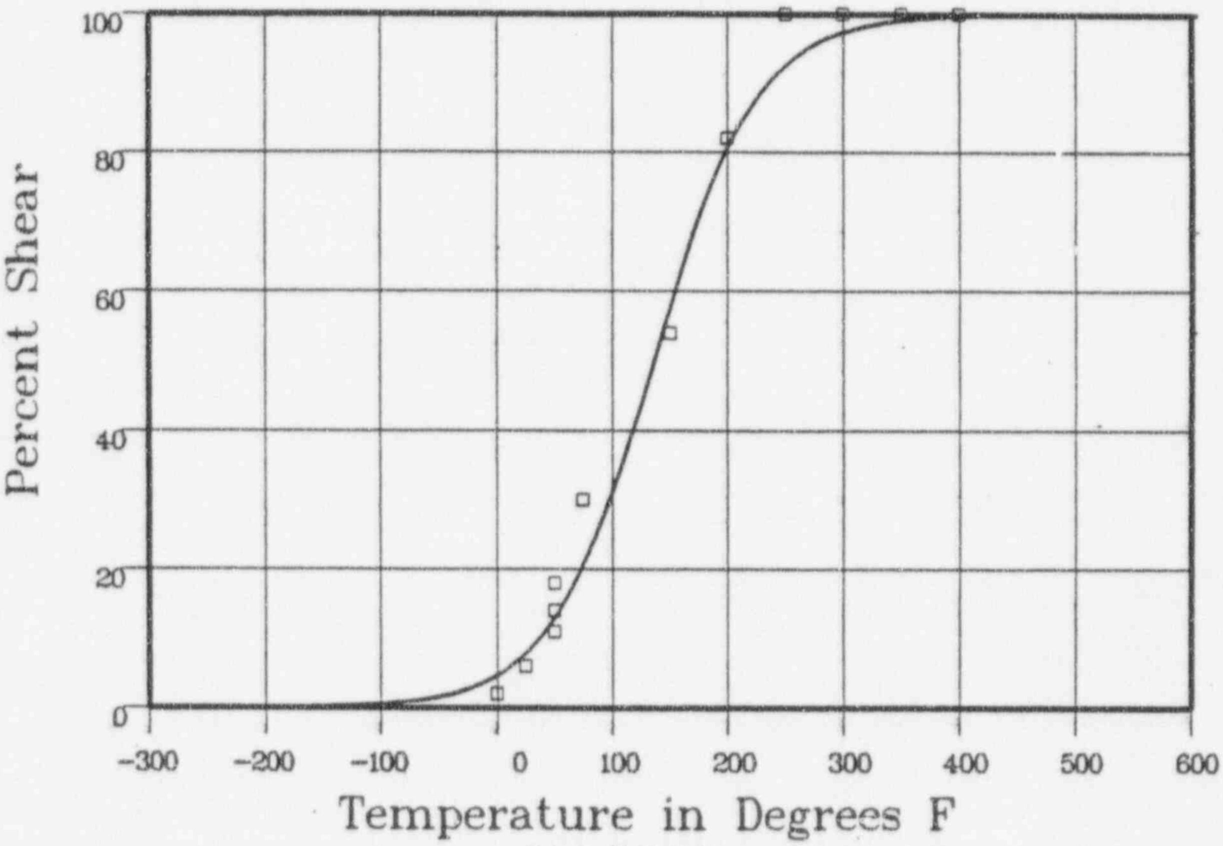
A = 50	B = 50	C = 90.25	T0 = 131.25

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

Temperature at 50% Shear: 131.2

Material: FORGING SA508-3 Heat Number: 21918/38566 Orientation: LT

Capsule: R Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: R Material: FORGING SA508-3 Ori.: LT Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	2	5.17	-3.17
25	6	8.67	-2.67
50	11	14.17	-3.17
50	14	14.17	-.17
50	18	14.17	3.82
75	30	22.33	7.66
150	54	60.24	-6.24
200	82	82.1	-.1
250	100	93.28	6.71

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

CAPSULE R

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: R Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
300	100	97.67	2.32
350	100	99.22	.77
400	100	99.74	.25

SUM of RESIDUALS = 6.01

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:02:22 on 09-20-1996

Page 1

Coefficients of Curve 1

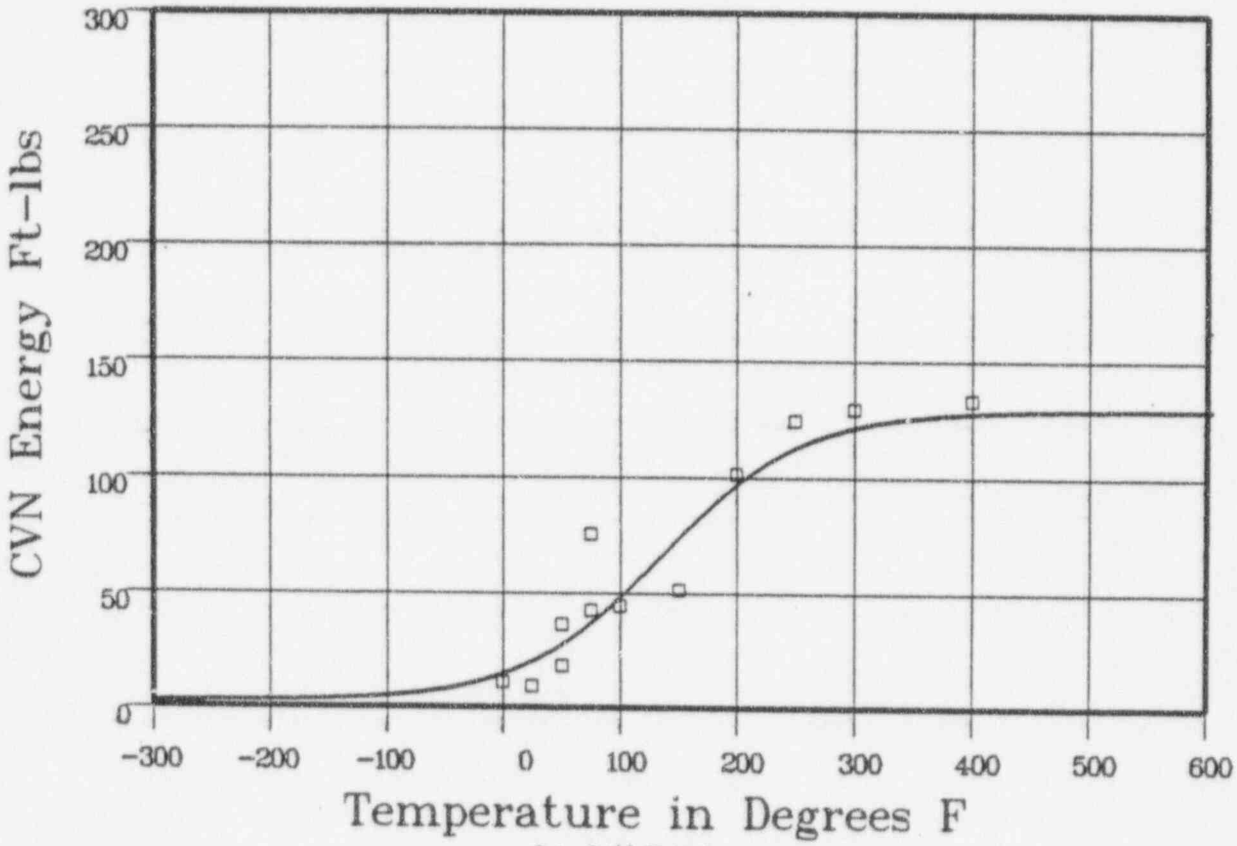
A = 65.59	B = 63.4	C = 121.63	T0 = 130.11

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

Upper Shelf Energy: 129 Fixed Temp. at 30 ft-lbs: 52.8 Temp. at 50 ft-lbs: 99.5 Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: R Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: R Material: FORGING SA5083 Ori: TL Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	11	15.55	-4.55
25	9	21.32	-12.32
50	18	28.98	-10.98
50	36	28.98	7.01
75	42	38.68	3.31
75	75	38.68	36.31
100	44	50.21	-6.21
150	51	75.87	-24.87
200	101	98.48	2.51

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

CAPSULE R

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: R Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
250	124	113.49	10.5
300	129	121.68	7.31
400	133	127.51	5.48

SUM of RESIDUALS = 13.49

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:26:34 on 10-22-1996

Page 1

Coefficients of Curve 1

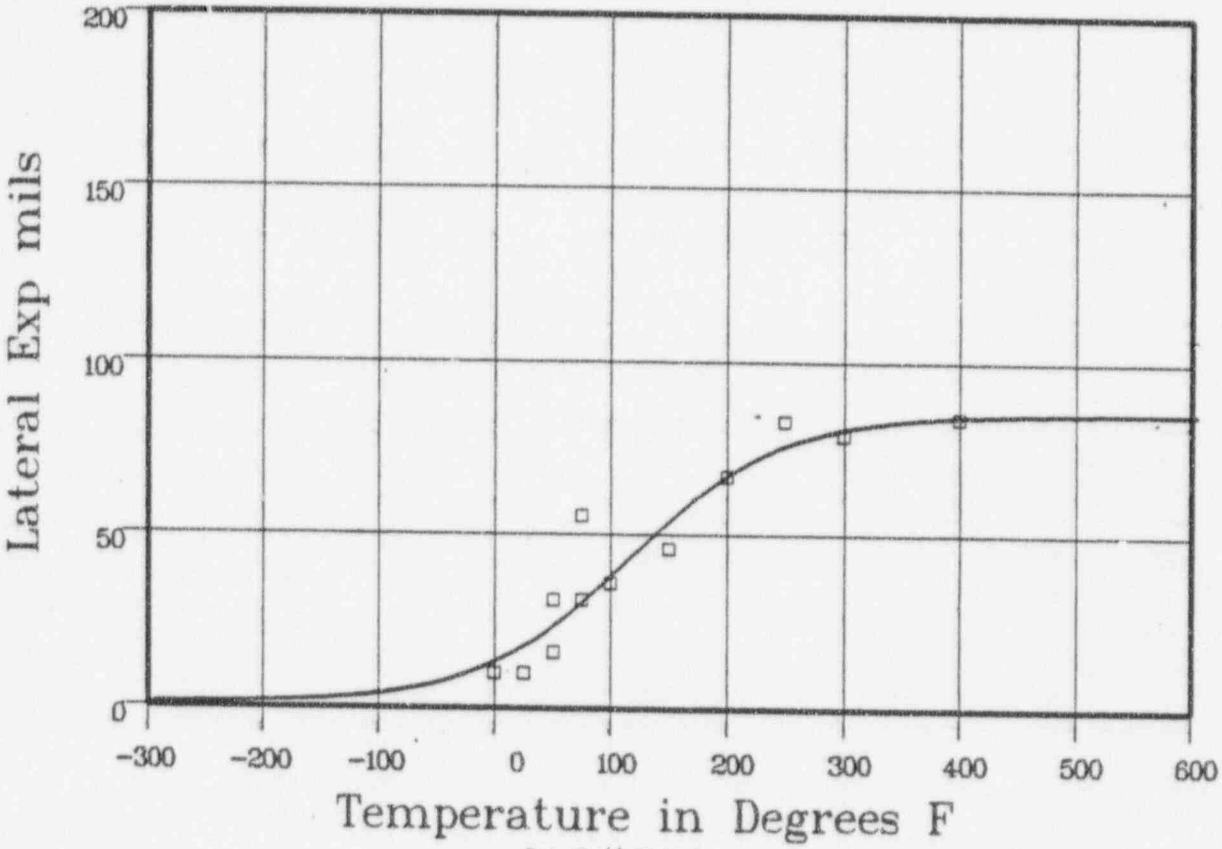
A = 43.34	B = 42.34	C = 131.35	T0 = 111.47

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

Upper Shelf L.E.: 85.68 Temperature at L.E. 35: 85.2 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: R Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: R Material: FORGING SA5083 Ori: TL Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	10	14.11	-4.11
25	10	18.89	-8.89
50	16	24.85	-8.85
50	31	24.85	6.14
75	31	31.87	-.87
75	55.5	31.87	23.62
100	36	39.65	-3.65
150	46	55.41	-9.41
200	67	68.21	-1.21

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

CAPSULE R

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: R Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
250	83	76.51	6.48
300	79	81.13	-2.13
400	84	84.64	-.64

SUM of RESIDUALS = -3.55

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:06:43 on 09-20-1996

Page 1

Coefficients of Curve 1

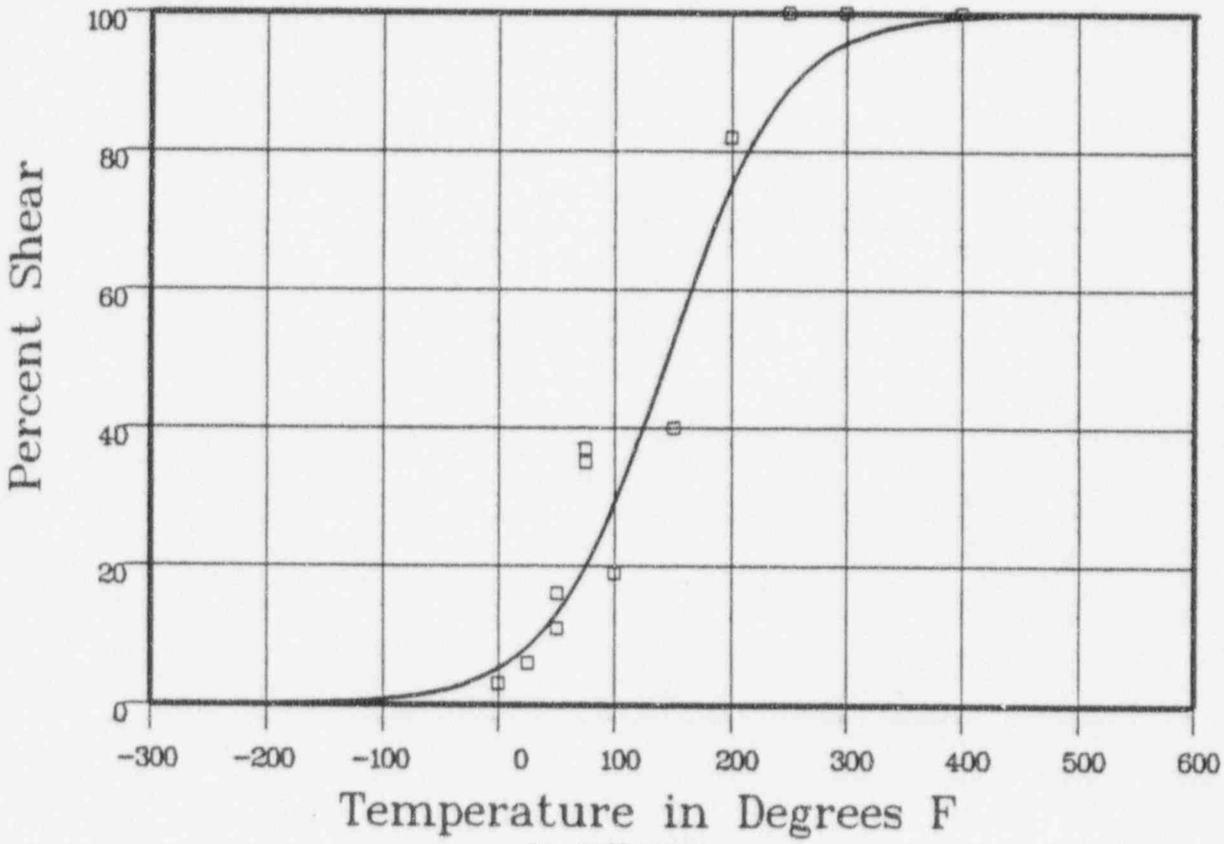
A = 50	B = 50	C = 100.28	T0 = 140.03

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

Temperature at 50% Shear: 140

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: R Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: R Material: FORGING SA5083 Ori.: TL Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	3	5.77	-2.77
25	6	9.15	-3.15
50	11	14.23	-3.23
50	16	14.23	1.76
75	35	21.46	13.53
75	37	21.46	15.53
100	19	31.03	-12.03
150	40	54.95	-14.95
200	82	76.77	5.22

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

CAPSULE R

Page 2

Material: FORGING SA508З Heat Number: 21918/38566 Orientation: TL

Capsule: R Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
250	100	89.96	10.03
300	100	96.04	3.95
400	100	99.44	.55

SUM of RESIDUALS = 14.44

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:29:02 on 10-22-1996

Page 1

Coefficients of Curve 1

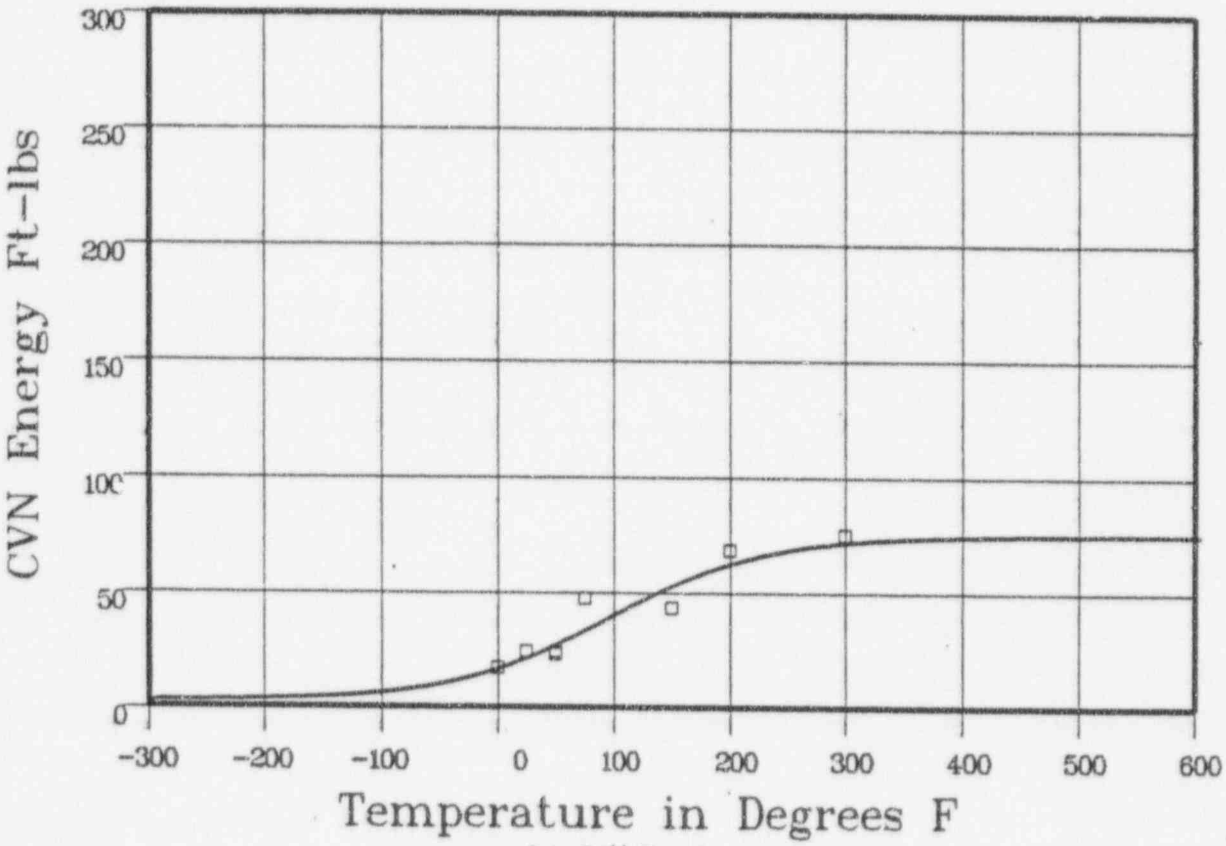
A = 38.59	B = 36.4	C = 136.18	T0 = 90.82

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

Upper Shelf Energy: 75 Fixed Temp. at 30 ft-lbs: 58 Temp. at 50 ft-lbs: 134.9 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 1752 Orientation:

Capsule: R Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: R Material: WELD Ori.: Heat #: 1752

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	17	17.38	-.38
25	24	22.26	1.73
50	24	28	-4
50	23	28	-5
75	47	34.39	12.6
150	43	53.49	-10.49
200	68	62.8	5.19
300	75	71.77	3.22

SUM of RESIDUALS = 2.88

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:33:48 on 10-24-1996

Page 1

Coefficients of Curve 1

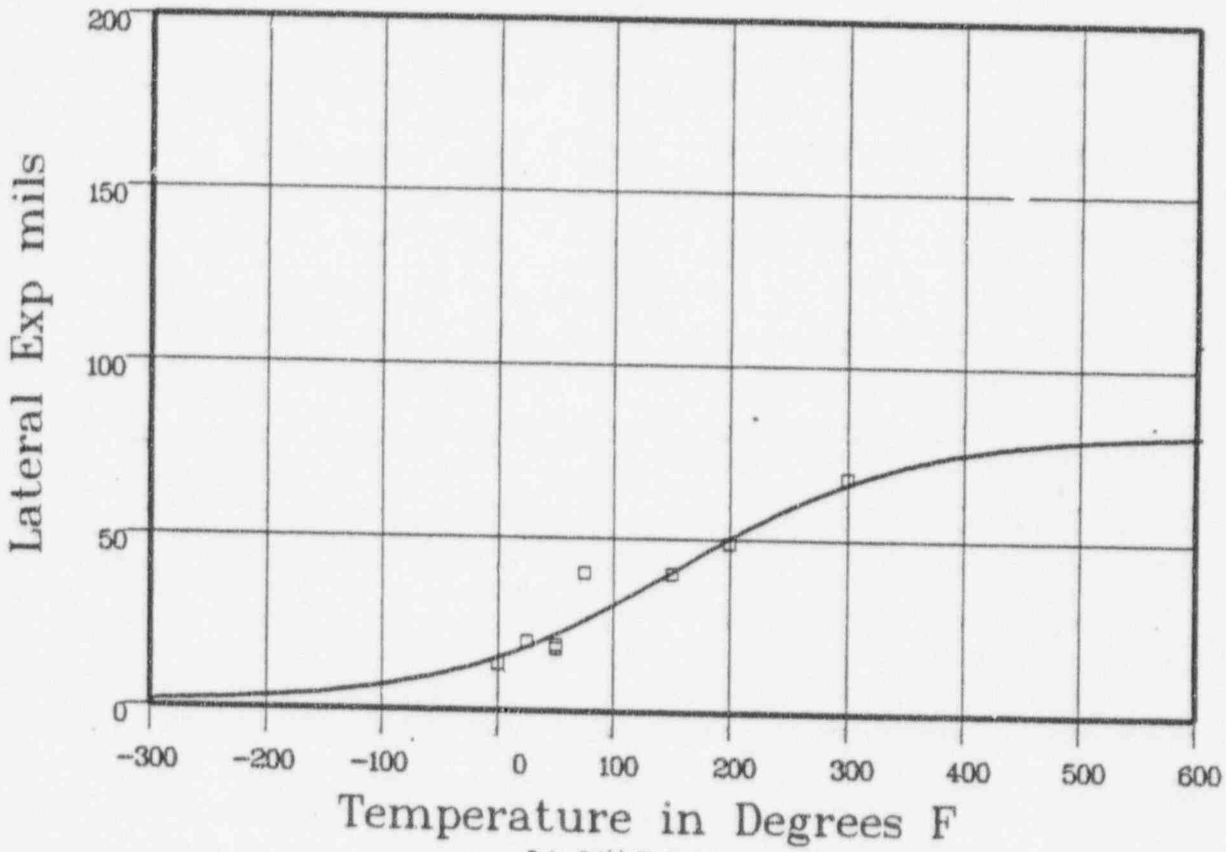
A = 41.55	B = 40.55	C = 202.14	T0 = 150

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

Upper Shelf L.E.: 82.1 Temperature at L.E. 35: 117 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 1752 Orientation:

Capsule: R Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: R Material: WELD Ori.: Heat #: 1752

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	13.5	15.98	-2.48
25	20	19.24	.75
50	19	22.98	-3.98
50	18	22.98	-4.98
75	40	27.16	12.83
150	40	41.55	-1.55
200	49	51.38	-2.38
300	68	67.11	.88

SUM of RESIDUALS = -.92

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:32:03 on 10-22-1996
Page 1
Coefficients of Curve 1

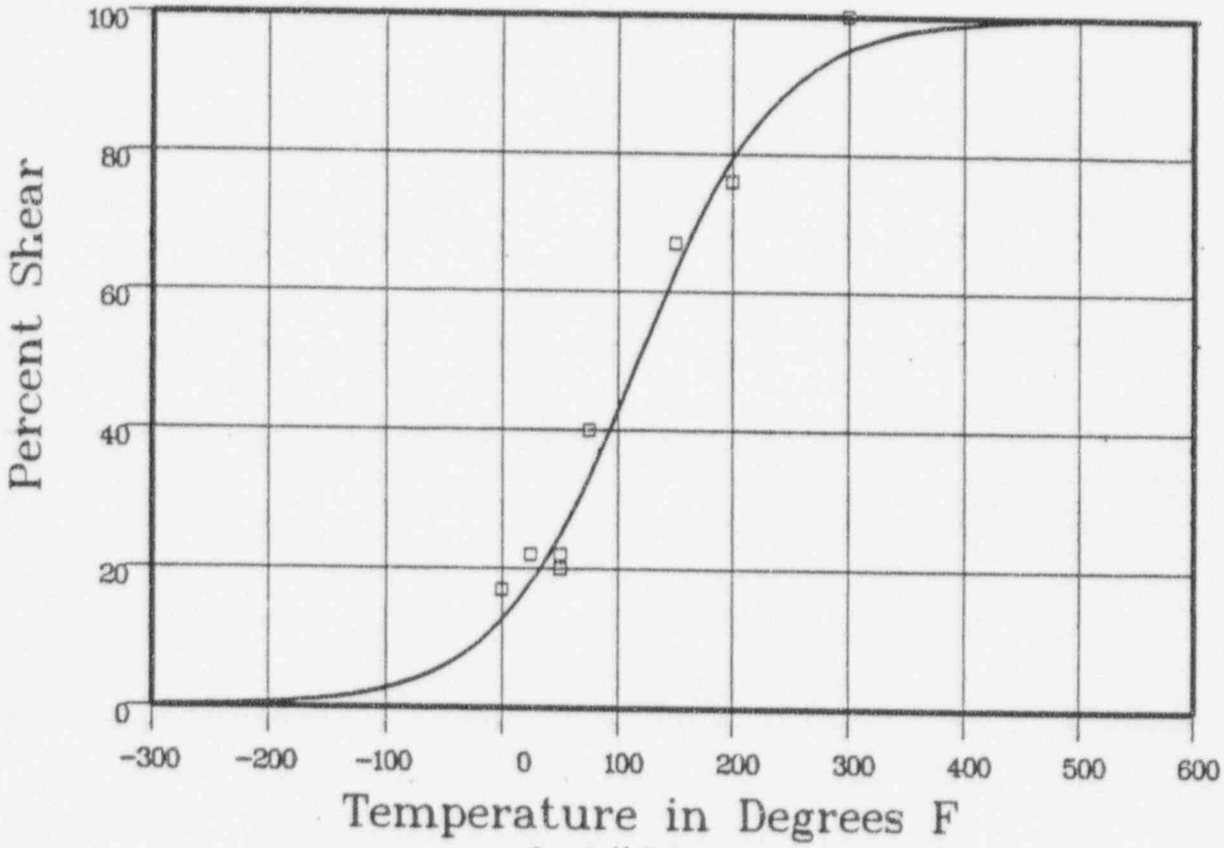
A = 50	B = 50	C = 122.4	T0 = 113.08

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

Temperature at 50% Shear: 113

Material: WELD Heat Number: 1752 Orientation:

Capsule: R Total Fluence:



Data Set(s) Plotted
Plant: PI1 Cap.: R Material: WELD Ori.: Heat #: 1752

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	17	13.61	3.38
25	22	19.16	2.83
50	22	26.29	-4.29
50	20	26.29	-6.29
75	40	34.92	5.07
150	67	64.63	2.36
200	76	80.53	-4.53
300	100	95.49	4.5

SUM of RESIDUALS = 3.03

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:06:08 on 10-23-1996

Page 1

Coefficients of Curve 1

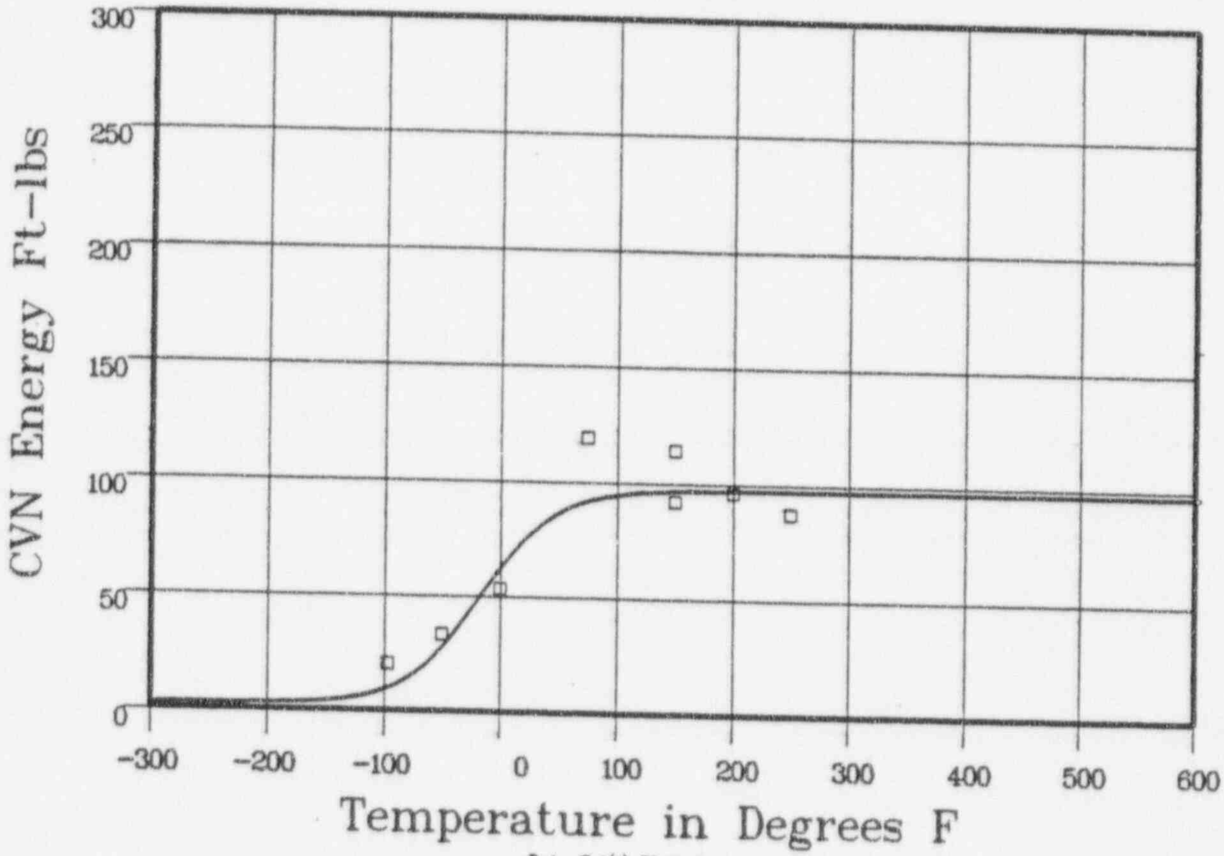
A = 49.59	B = 47.4	C = 65.08	T0 = -21.68

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

Upper Shelf Energy: 97 Fixed Temp. at 30 ft-lbs: -50.3 Temp. at 50 ft-lbs: -21.1 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: R Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: R Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-97	20	10.72	9.27
-50	33	30.18	2.81
0	53	64.83	-11.83
75	119	92.37	26.62
150	114	96.51	17.48
150	92	96.51	-4.51
200	96	96.89	-.89
250	87	96.97	-9.97

SUM of RESIDUALS = 28.96

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:41:58 on 10-22-1996
Page 1
Coefficients of Curve 1

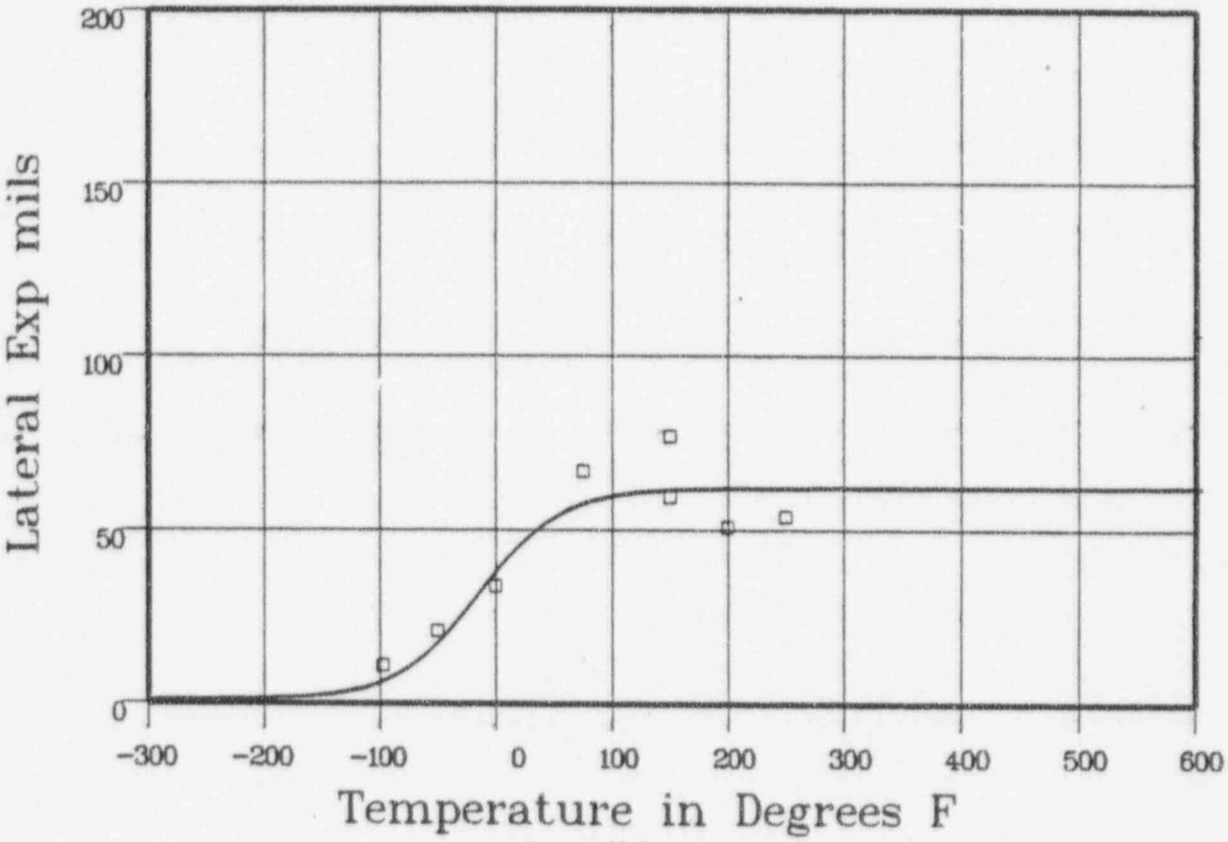
A = 31.6	B = 30.6	C = 71.09	T0 = -19.68

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

Upper Shelf L.E.: 62.21 Temperature at L.E. 35: -11.7 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: R Total Fluence:



Data Set(s) Plotted
Plant: PI1 Cap.: R Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-97	11	7.24	3.75
-50	21	19.29	1.7
0	34	39.87	-5.87
75	67	58.22	8.77
150	77	61.7	15.29
150	59.5	61.7	-2.2
200	51	62.08	-11.08
250	54	62.18	-8.18

SUM of RESIDUALS = 2.18

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:00:24 on 10-22-1996

Page 1

Coefficients of Curve 1

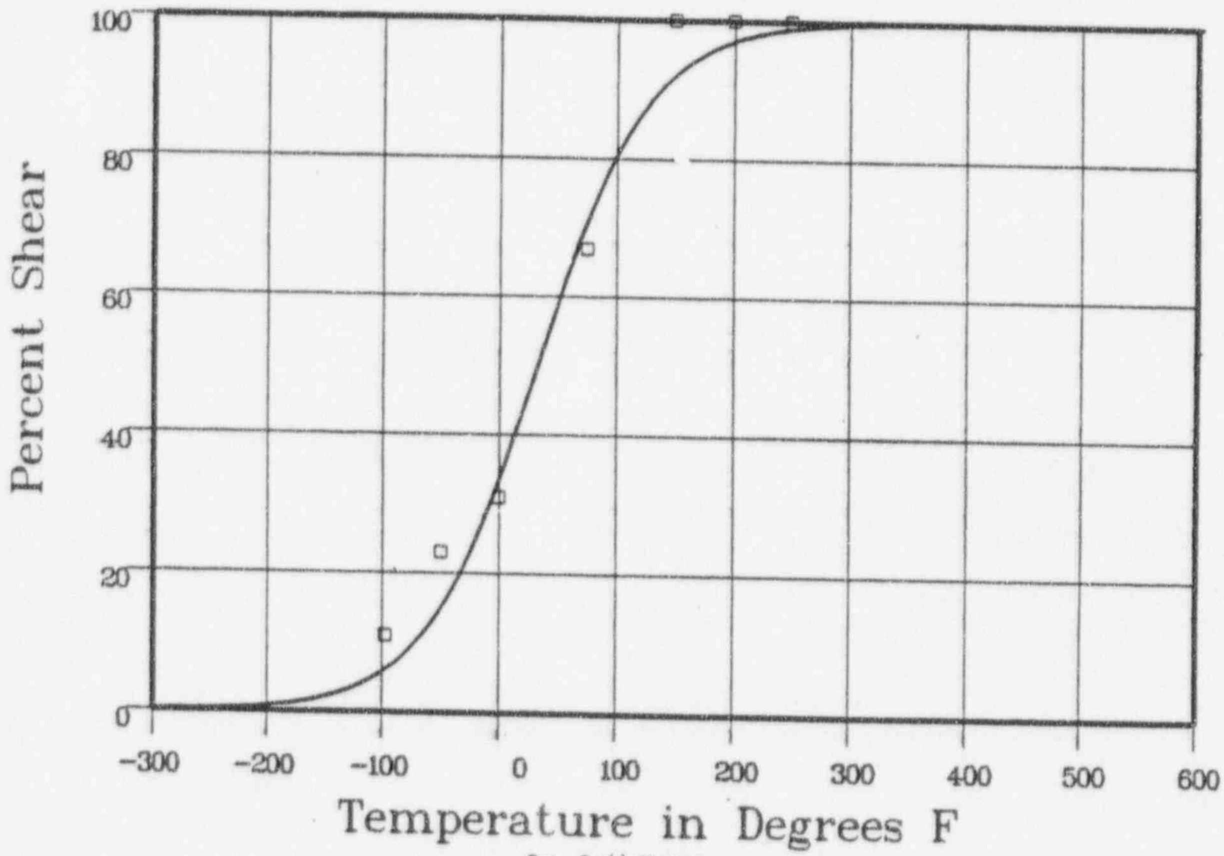
A = 50	B = 50	C = 95.4	T0 = 28.12

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

Temperature at 50% Shear: 28.1

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: R Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: R Material: HEAT AFFD ZONE Ori: Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-97	11	6.76	4.23
-50	23	16.27	6.72
0	31	35.67	-4.67
75	67	72.76	-5.76
150	100	92.78	7.21
150	100	92.78	7.21
200	100	97.34	2.65
250	100	99.05	.94

SUM of RESIDUALS = 18.53

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:07:56 on 10-23-1996

Page 1

Coefficients of Curve 1

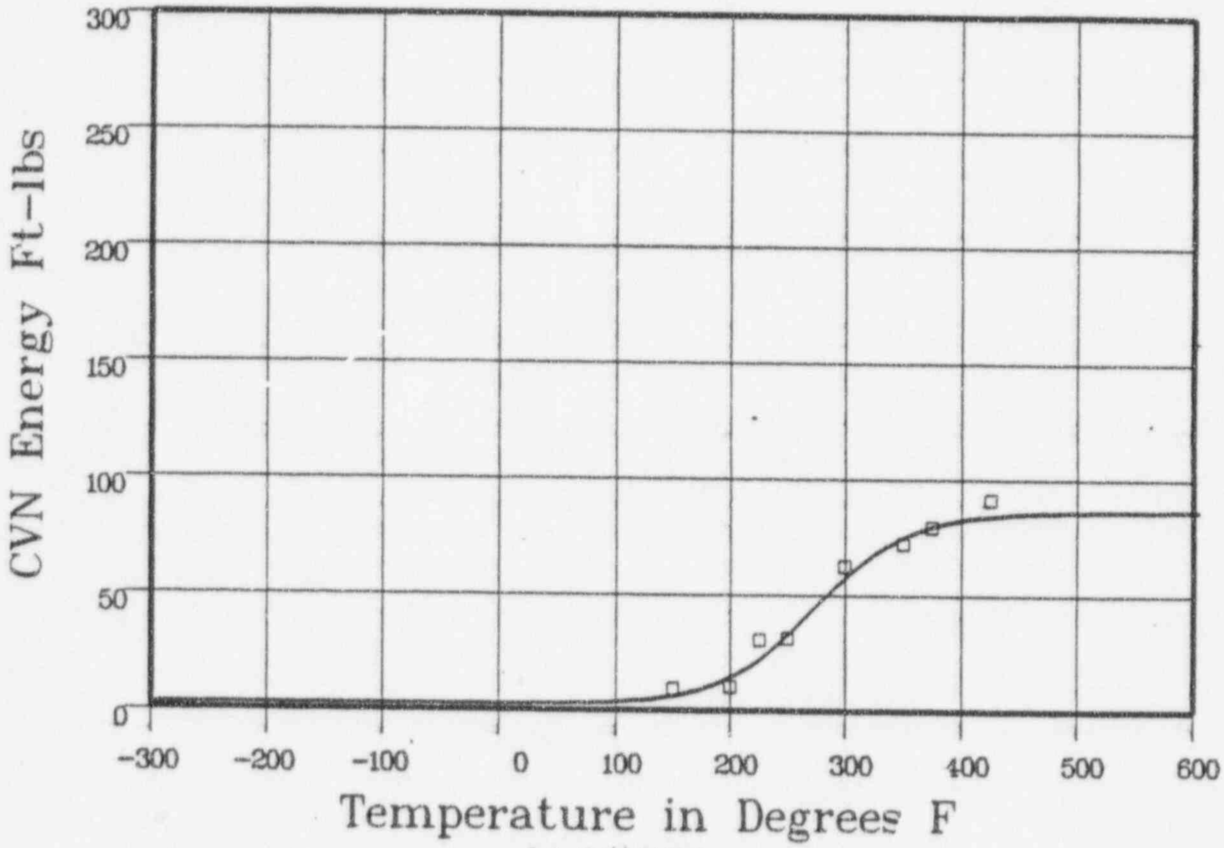
A = 44.09	B = 41.9	C = 82.42	T0 = 268.79

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

Upper Shelf Energy: 86 Fixed   Temp. at 30 ft-lbs: 239.9   Temp. at 50 ft-lbs: 280.4   Lower Shelf Energy: 2.19 Fixed

Material: SRM HSST02   Heat Number: SA533B1   Orientation: LT

Capsule: R   Total Fluence:



Data Set(s) Plotted

Plant: PI1   Cap: R   Material: SRM HSST02   Ori: LT   Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
150	9	6.64	2.35
200	10	15.48	-5.48
225	30	23.71	6.28
250	31	34.7	-3.7
300	62	59.24	2.75
350	72	75.74	-3.74
375	79	80.07	-1.07
425	91	84.14	6.85

SUM of RESIDUALS = 4.23

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:09:32 on 10-23-1996

Page 1

Coefficients of Curve 1

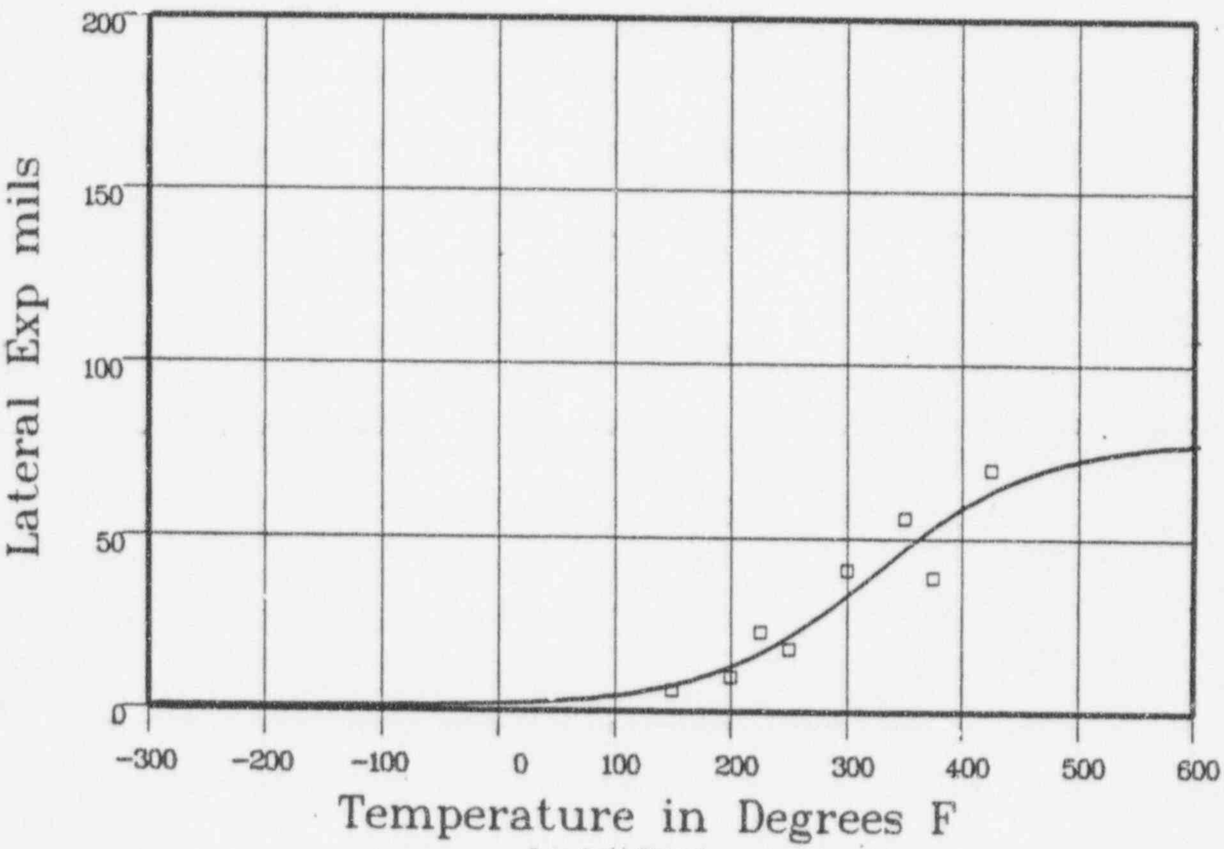
A = 40.03	B = 39.03	C = 144.46	T0 = 318.28

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

Upper Shelf L.E.: 79.07 Temperature at L.E. 35: 299.5 Lower Shelf L.E.: 1 Fixed

Material: SRM HSST02 Heat Number: SA533B1 Orientation: LT

Capsule: R Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: R Material: SRM HSST02 Ori.: LT Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
150	6	7.92	-1.92
200	10	13.7	-3.7
225	23	17.83	5.16
250	18	22.84	-4.84
300	41	35.12	5.87
350	56	48.47	7.52
375	39	54.62	-15.62
425	70	64.56	5.43

SUM of RESIDUALS = -2.09

CAPSULE R

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:11:48 on 10-23-1996
Page 1
Coefficients of Curve 1

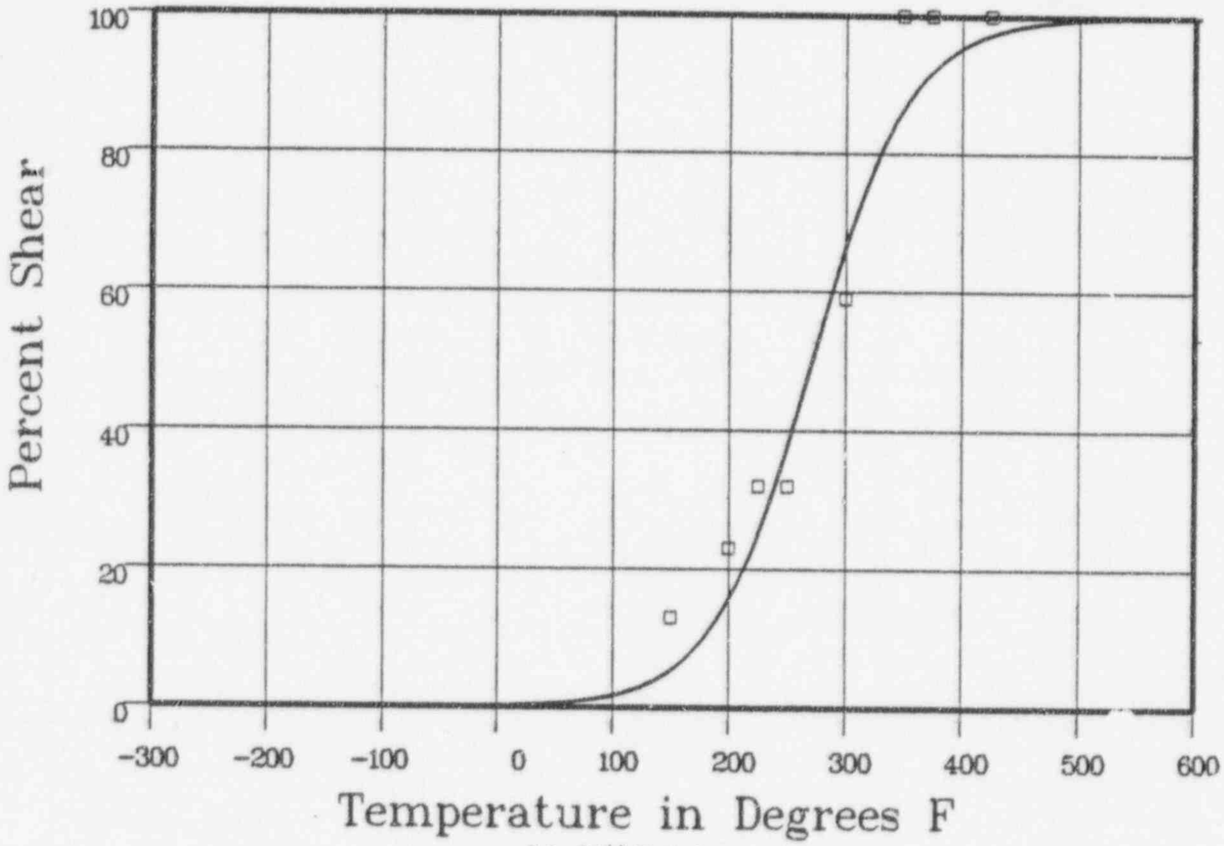
A = 50	B = 50	C = 84.88	T0 = 266.71

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

Temperature at 50% Shear: 266.7

Material: SRM HSST02 Heat Number: SA533B1 Orientation: LT

Capsule: R Total Fluence:



Data Set(s) Plotted
Plant: PI1 Cap: R Material: SRM HSST02 Ori: LT Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
150	13	6	6.99
200	23	17.19	5.8
225	32	27.22	4.77
250	32	40.27	-8.27
300	59	68.65	-9.65
350	100	87.67	12.32
375	100	92.76	7.23
425	100	97.65	2.34

SUM of RESIDUALS = 21.53

CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:16:32 on 10-16-1996

Page 1

Coefficients of Curve 1

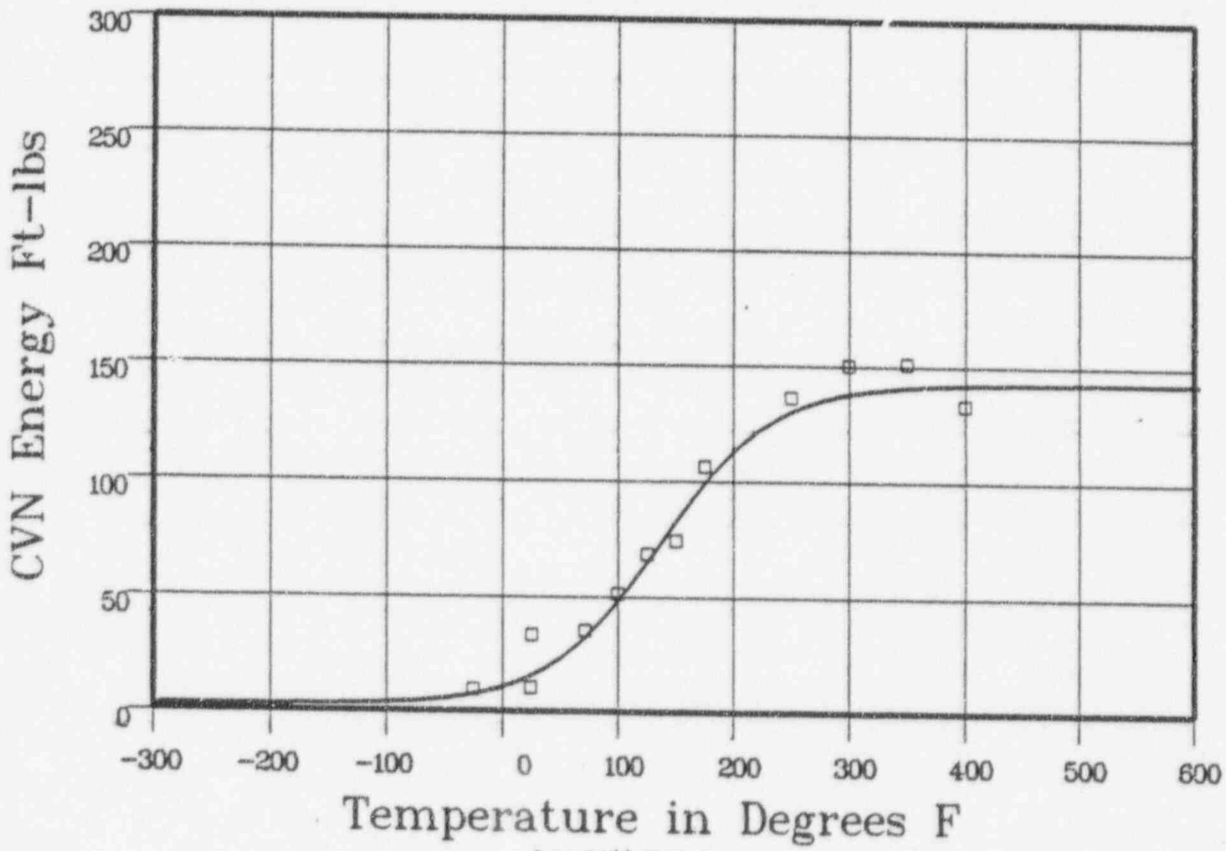
A = 72.34	B = 70.15	C = 98.28	T0 = 131.25

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

Upper Shelf Energy: 142.5 Fixed   Temp. at 30 ft-lbs: 62.5   Temp. at 50 ft-lbs: 98.8   Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA5083   Heat Number: 21918/38566   Orientation: LT

Capsule: S   Total Fluence:



Data Set(s) Plotted

Plant: PI1   Cap.: S   Material: FORGING SA5083   Ori.: LT   Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	9	7.8	1.19
25	10	16.68	-6.68
26	33	16.94	16.05
72	35	34.53	.46
100	51	50.76	.23
125	68	67.89	.1
150	74	85.57	-11.57
175	106	101.66	4.33
250	136	131	4.99

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

CAPSULE S

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: S Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
300	150	138.11	11.88
350	151	140.88	10.11
400	133	141.91	-8.91

SUM of RESIDUALS = 22.21

CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:34:15 on 10-16-1996
Page 1
Coefficients of Curve 1

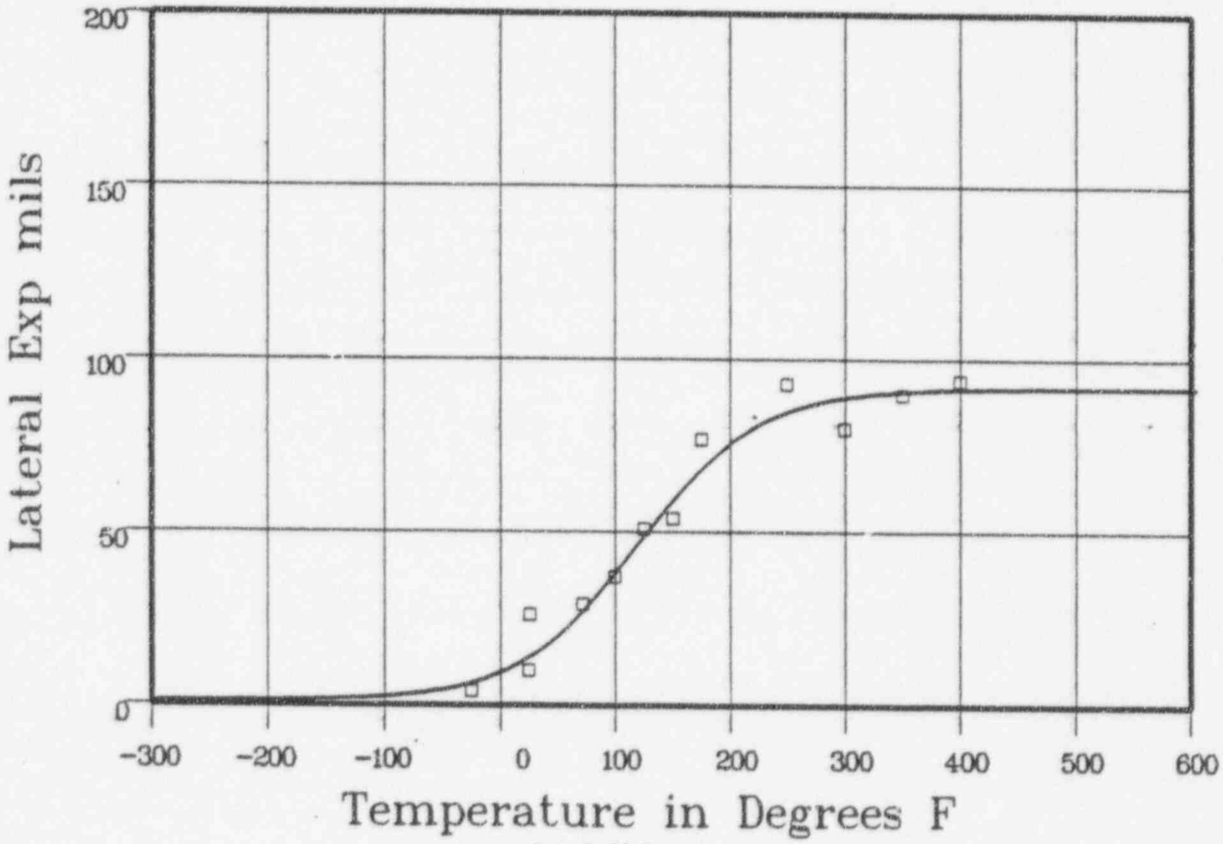
A = 46.52	B = 45.52	C = 105.18	T0 = 115.31

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

Upper Shelf L.E.: 92.05 Temperature at L.E. 35: 88 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: S Total Fluence:



Data Set(s) Plotted
Plant: PI1 Cap.: S Material: FORGING SA5083 Ori.: LT Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	4	6.9	-2.9
25	10	14.86	-4.86
26	26	15.08	10.91
72	29	28.77	.22
100	37	39.94	-2.94
125	51	50.7	.29
150	54	61.02	-7.02
175	77	69.9	7.09
250	93	85.52	7.47

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

CAPSULE S

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: S Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
300	80	89.41	-9.41
350	90	91.01	-1.01
400	94	91.65	2.34

SUM of RESIDUALS = .16

CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:37:04 on 10-16-1996

Page 1

Coefficients of Curve 1

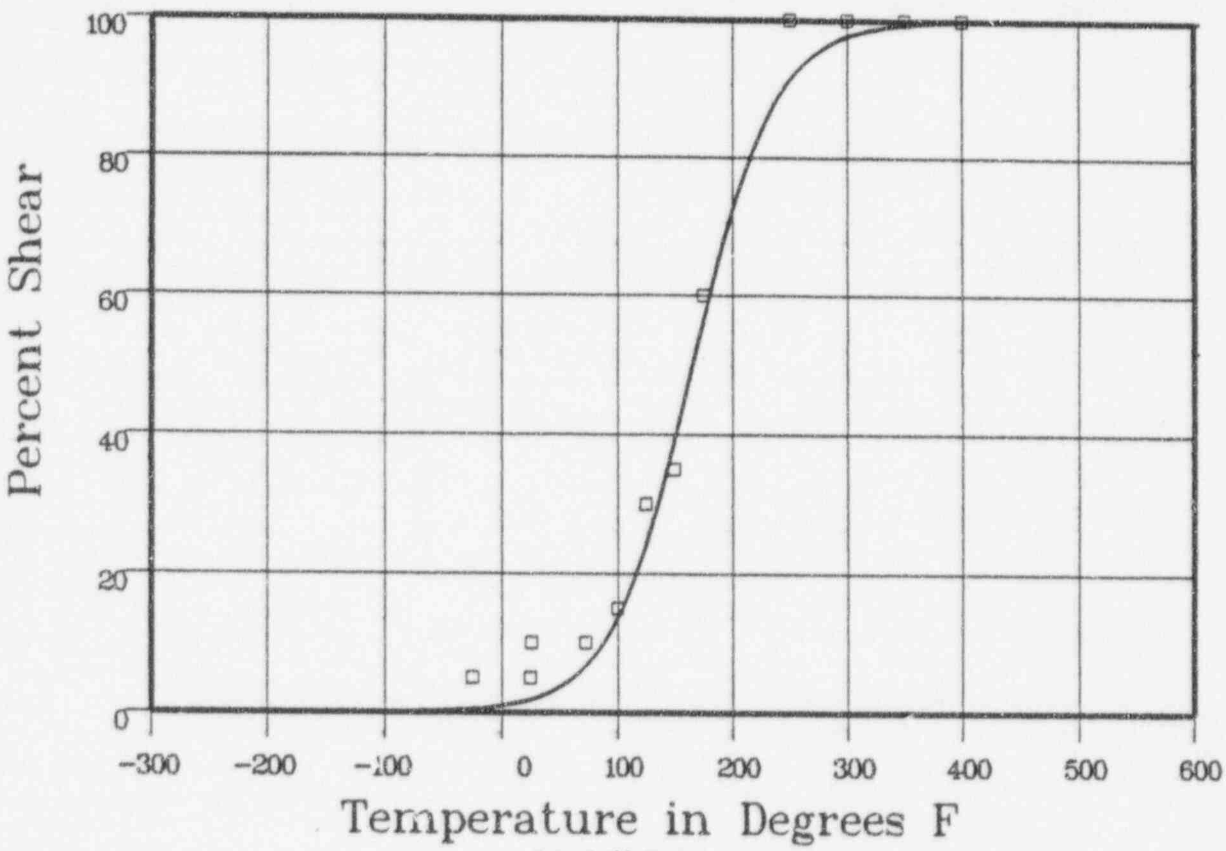
A = 50	B = 50	C = 71.28	T0 = 161.25

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

Temperature at 50% Shear: 161.2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: S Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: S Material: FORGING SA5083 Ori.: LT Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	5	.53	4.46
25	5	2.14	2.85
26	10	2.19	7.8
72	10	7.55	2.44
100	15	15.2	-.2
125	30	26.56	3.43
150	35	42.17	-7.17
175	60	59.52	.47
250	100	92.34	7.65

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

CAPSULE S

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: LT

Capsule: S Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
300	100	98	1.99
350	100	99.5	.49
400	100	99.87	.12

SUM of RESIDUALS = 24.37

CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:07:02 on 10-29-1996

Page 1

Coefficients of Curve 1

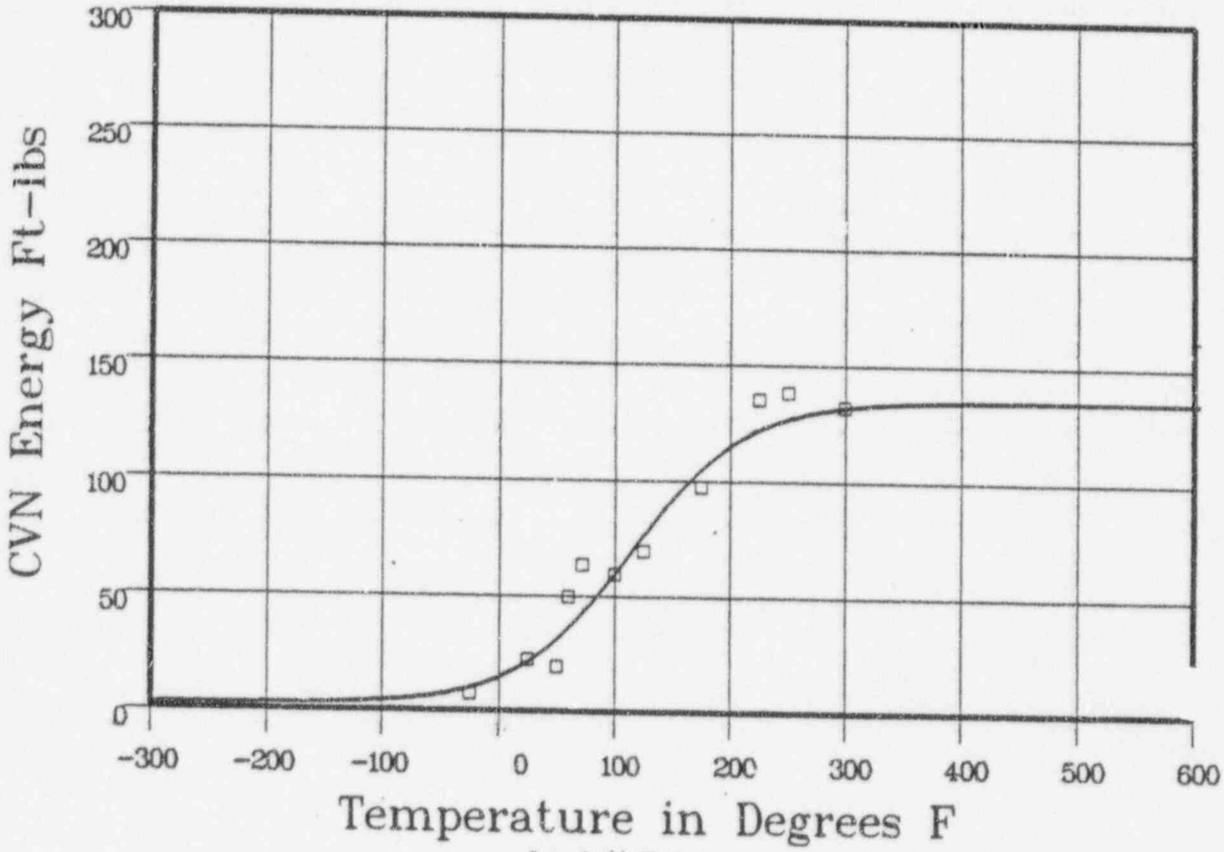
A = 68.59	B = 66.4	C = 100.05	T0 = 109.43

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

Upper Shelf Energy: 135 Fixed Temp. at 30 ft-lbs: 42.9 Temp. at 50 ft-lbs: 80.6 Lower Shelf Energy: 2.19 Fixed

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: S Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: S Material: FORGING SA5083 Ori.: TL Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	7	10.66	-3.66
25	22	22.92	-.92
50	19	33.22	-14.22
60	49	38.22	10.77
72	63	44.85	18.14
100	59	62.35	-3.35
125	69	78.84	-9.84
175	97	106.79	-9.79
225	135	123.01	11.98

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

CAPSULE S

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: S Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
250	138	127.45	10.54
300	132	132.12	-.12

SUM of RESIDUALS = 9.52

CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:08:11 on 10-16-1996

Page 1

Coefficients of Curve 1

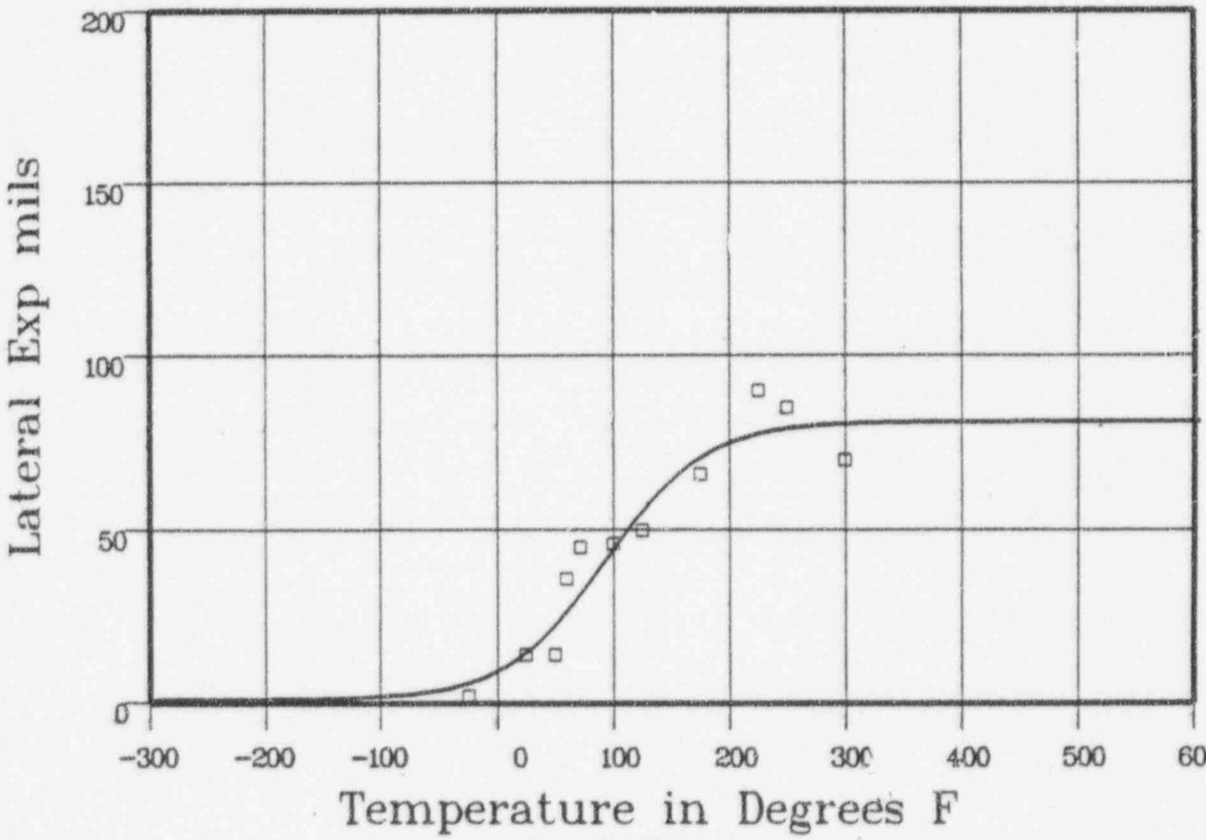
A = 41.05	B = 40.05	C = 65.93	T0 = 88.12

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

Upper Shelf L.E.: 81.11 Temperature at L.E. 35: 75 Lower Shelf L.E.: 1 Fixed

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: S Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: S Material: FORGING SA5083 Ori.: TL Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	2	6.37	-4.37
25	14	15.98	-1.98
50	14	24.36	-10.36
60	36	28.39	7.6
72	45	33.62	11.37
100	46	46.56	-.56
125	50	57.26	-7.26
175	66	71.75	-5.75
225	90	77.93	12.06

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

CAPSULE S

Page 2

Material: FORGING SA508З Heat Number: 21918/38566 Orientation: TL

Capsule: S Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed LE	Differential
250	85	79.3	5.69
300	70	80.54	-10.54

SUM of RESIDUALS = -4.13

CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:34:32 on 10-16-1996

Page 1

Coefficients of Curve 1

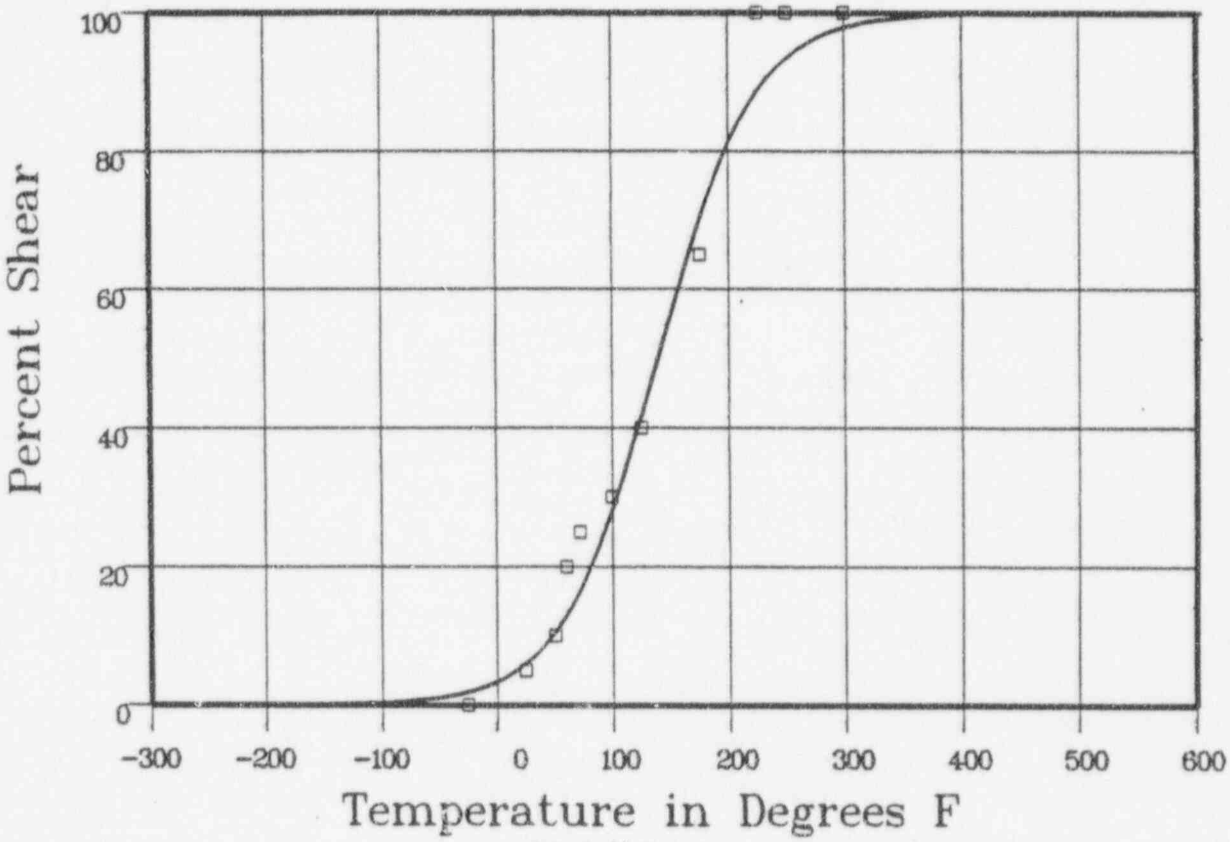
A = 50	B = 50	C = 83.43	T0 = 134.47

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

Temperature at 50% Shear: 134.4

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: S Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap: S Material: FORGING SA5083 Ori: TL Heat #: 21918/38566

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	0	2.14	-2.14
25	5	6.76	-1.76
50	10	11.66	-1.66
60	20	14.36	5.63
72	25	18.27	6.72
100	30	30.44	-.44
125	40	44.34	-4.34
175	65	72.54	-7.54
225	100	89.75	10.24

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

CAPSULE S

Page 2

Material: FORGING SA5083 Heat Number: 21918/38566 Orientation: TL

Capsule: S Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
250	100	94.09	5.9
300	100	98.14	1.85

SUM of RESIDUALS = 12.46

CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:29:21 on 11-06-1996

Page 1

Coefficients of Curve 1

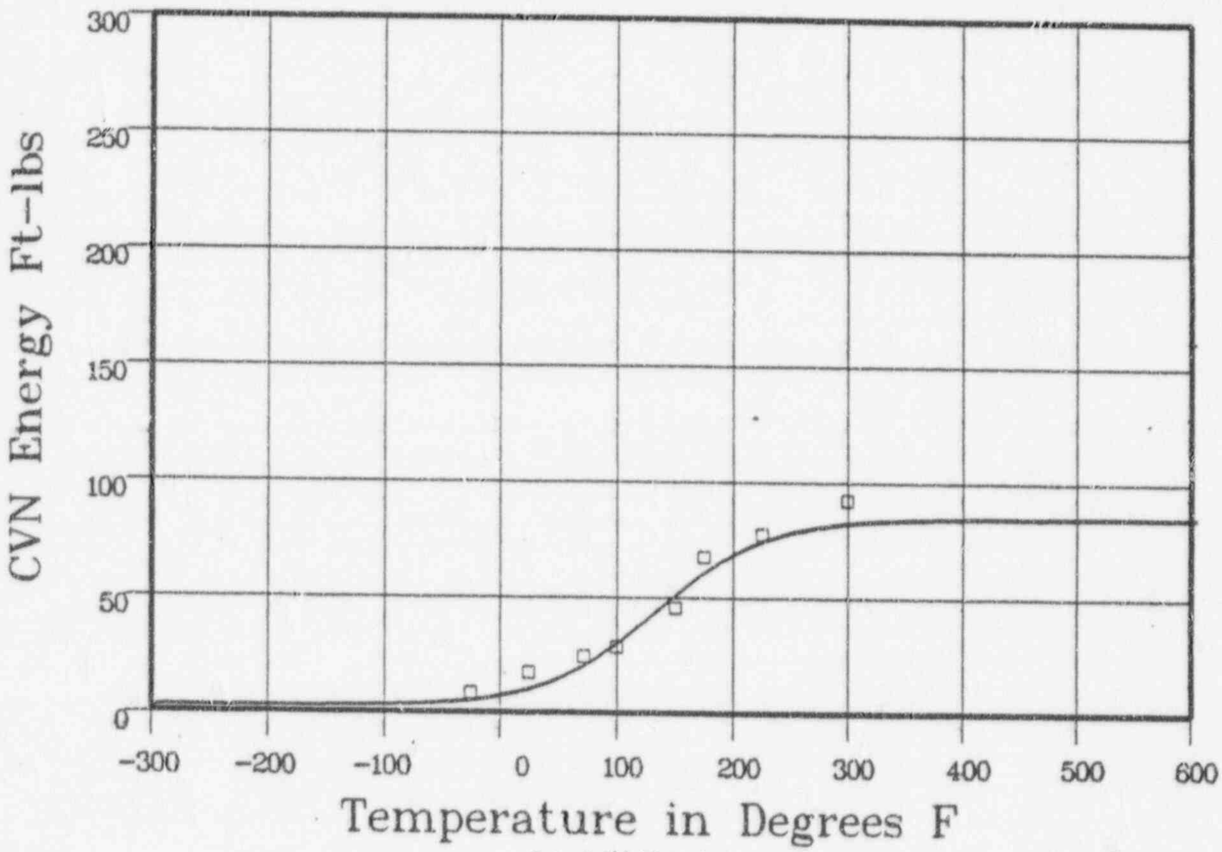
A = 43.34	B = 41.15	C = 95.94	T0 = 128.27

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

Upper Shelf Energy: 84.5 Fixed Temp. at 30 ft-lbs: 95.9 Temp. at 50 ft-lbs: 143.9 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 1752 Orientation:

Capsule: S Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: S Material: WELD Ori.: Heat #: 1752

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	8	5.43	2.56
25	17	10.76	6.23
72	24	21.64	2.35
100	28	31.56	-3.56
150	45	52.51	-7.51
175	67	61.94	5.05
225	77	74.82	2.17
300	92	82.26	9.73

SUM of RESIDUALS = 17.04

CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:47:35 on 11-07-1996

Page 1

Coefficients of Curve 1

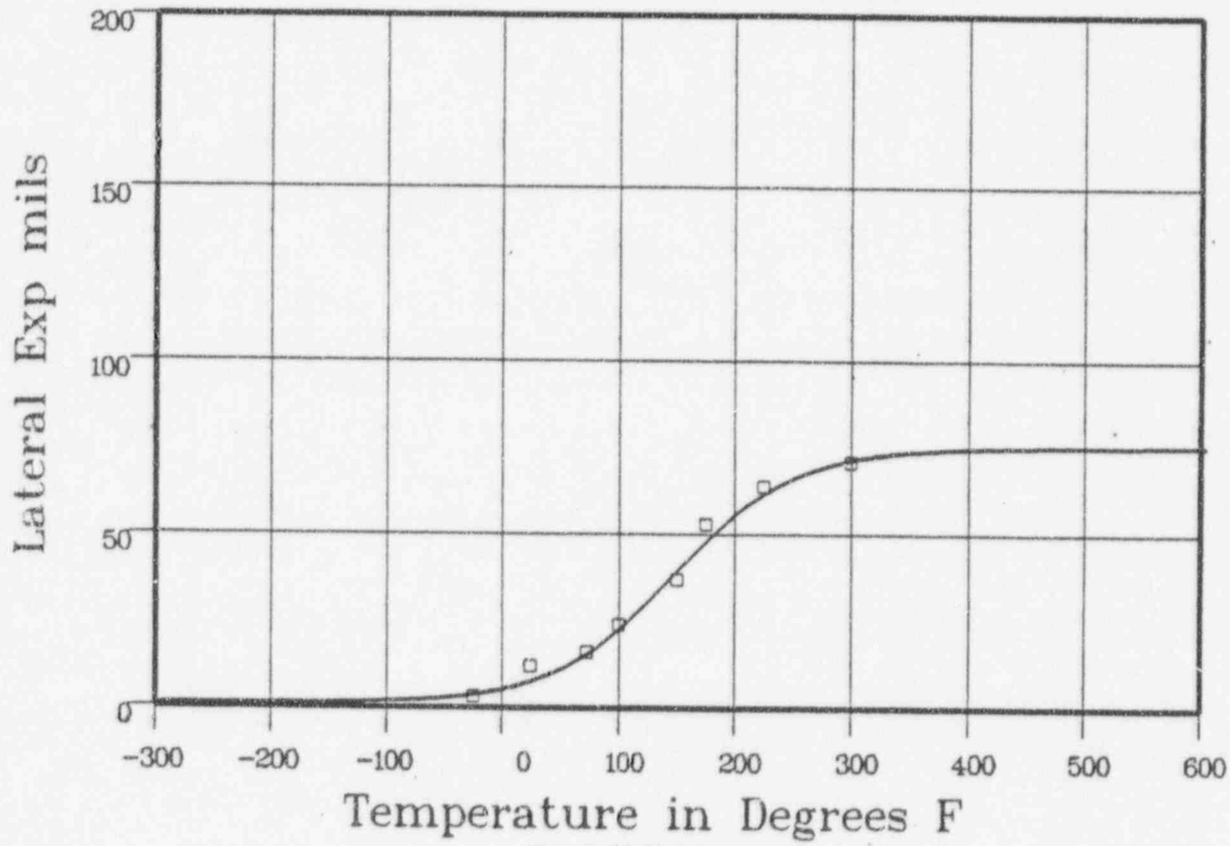
A = 38.28	B = 37.28	C = 105.19	T0 = 142.03

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

Upper Shelf L.E.: 75.56 Temperature at L.E. 35: 132.7 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 1752 Orientation:

Capsule: S Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: S Material: WELD Ori.: Heat #: 1752

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	3	3.98	-.98
25	12	8.27	3.72
72	16	16.57	-.57
100	24	24.13	-.13
150	37	41.09	-4.09
175	53	49.59	3.4
225	64	62.8	1.19
300	71	72.03	-1.03

SUM of RESIDUALS = 1.49

CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:48:34 on 11-07-1996

Page 1

Coefficients of Curve 1

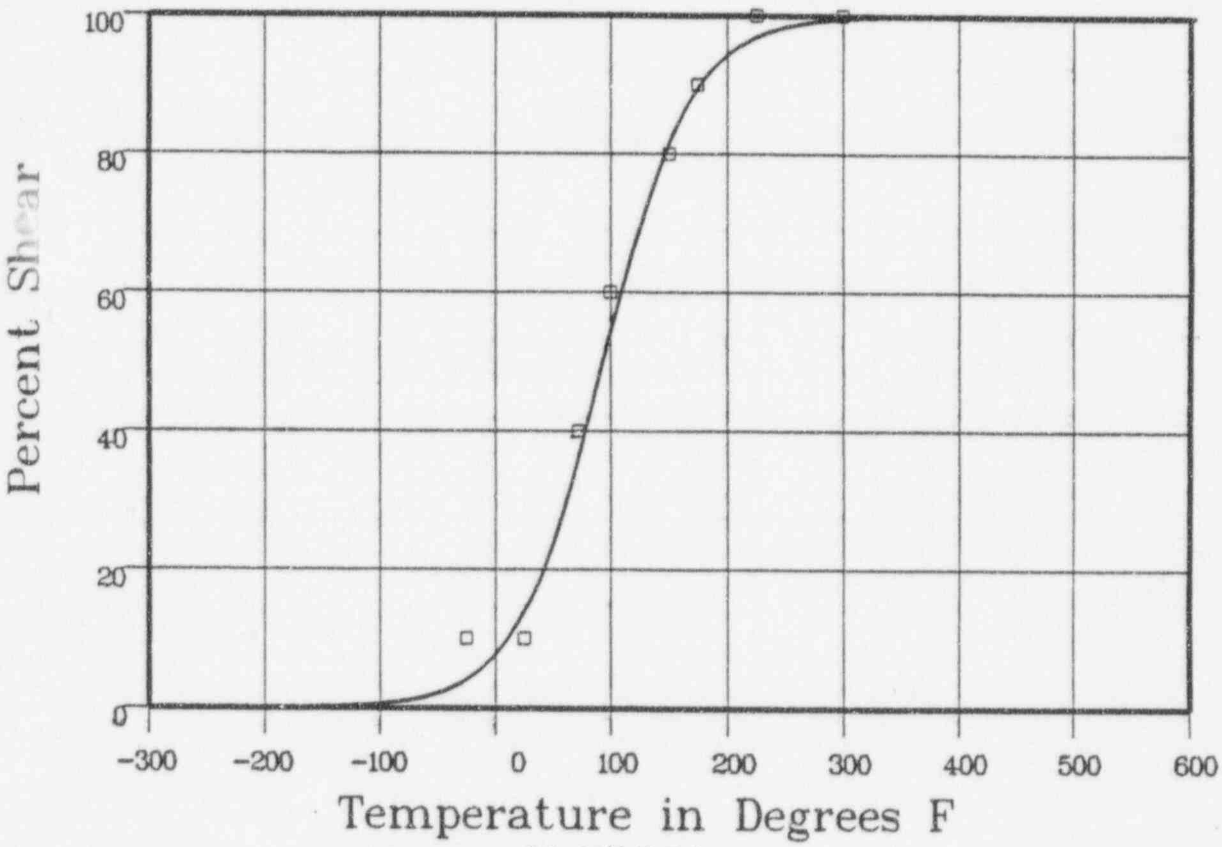
A = 50	B = 50	C = 75.73	T0 = 89.06

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

Temperature at 50% Shear: 89

Material: WELD Heat Number: 1752 Orientation:

Capsule: S Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: S Material: WELD Ori.: Heat #: 1752

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	10	4.68	5.31
25	10	15.55	-5.55
72	40	38.92	1.07
100	60	57.17	2.82
150	80	83.33	-3.33
175	90	90.63	-.63
225	100	97.31	2.68
300	100	99.62	.37

SUM of RESIDUALS = 2.76

CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:36:32 on 10-18-1996

Page 1

Coefficients of Curve 1

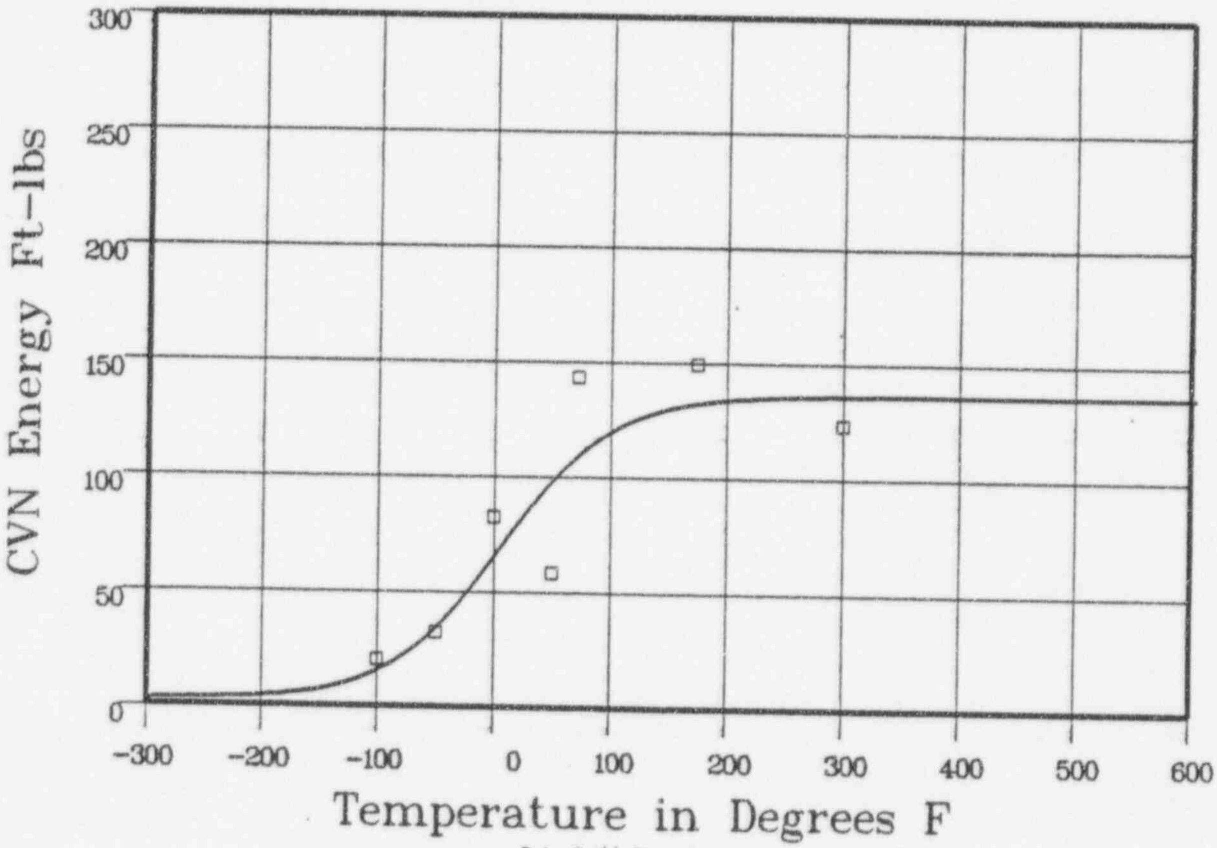
A = 69.09	B = 66.9	C = 96.08	T0 = 1.4

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

Upper Shelf Energy: 136 Fixed Temp. at 30 ft-lbs: -62.8 Temp. at 50 ft-lbs: -26.8 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: Orientation:

Capsule: S Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: S Material: HEAT AFFD ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	20	16.65	3.34
-50	32	36.37	-4.37
0	82	68.12	13.87
50	58	100.31	-42.31
72	143	110.97	32.02
175	149	132.48	16.51
300	123	135.73	-12.73

SUM of RESIDUALS = 6.33

CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:39:38 on 10-18-1996

Page 1

Coefficients of Curve 1

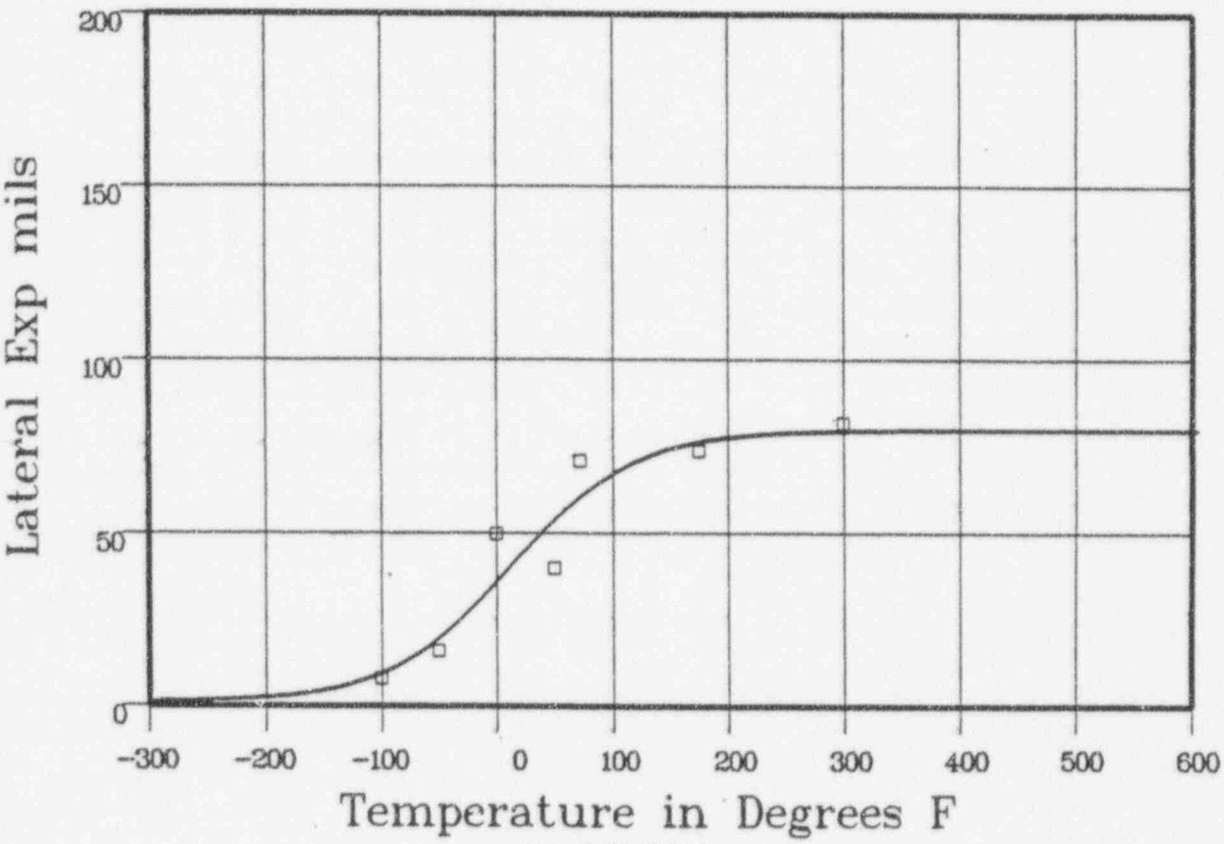
A = 40.53	B = 39.53	C = 106.41	T0 = 7.5

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

Upper Shelf L.E.: 80.07 Temperature at L.E. 35: -7.4 Lower Shelf L.E.: 1 Fixed

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

Capsule: S Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: S Material: HEAT AFF'D ZONE Ori.: Heat #:

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	8	10.25	-2.25
-50	16	21.03	-5.03
0	50	37.75	12.24
50	40	55.53	-15.53
72	71	61.93	9.06
175	74	76.81	-2.81
300	82	79.74	2.25

SUM of RESIDUALS = -2.08

CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:42:07 on 10-18-1996
Page 1
Coefficients of Curve 1

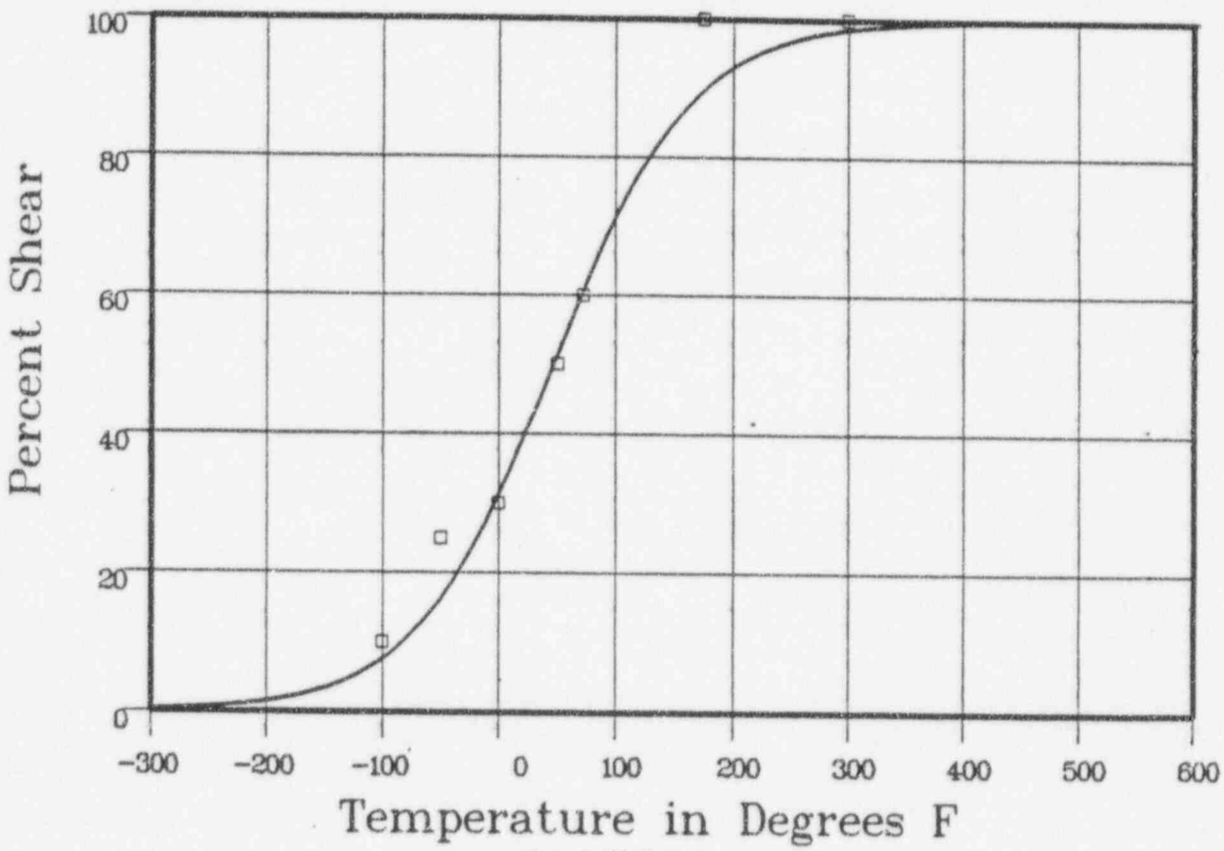
A = 50	B = 50	C = 118.09	T0 = 41.85

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

Temperature at 50% Shear: 41.8

Material: HEAT AFFD ZONE   Heat Number: Orientation:

Capsule: S   Total Fluence:



Data Set(s) Plotted
Plant: PI1   Cap.: S   Material: HEAT AFFD ZONE   Ori.:   Heat #:

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	10	8.29	1.7
-50	25	17.42	7.57
0	30	32.98	-2.98
50	50	53.44	-3.44
72	60	62.49	-2.49
175	100	90.5	9.49
300	100	98.75	1.24

SUM of RESIDUALS = 11.09

CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 08:10:02 on 10-29-1996

Page 1

Coefficients of Curve 1

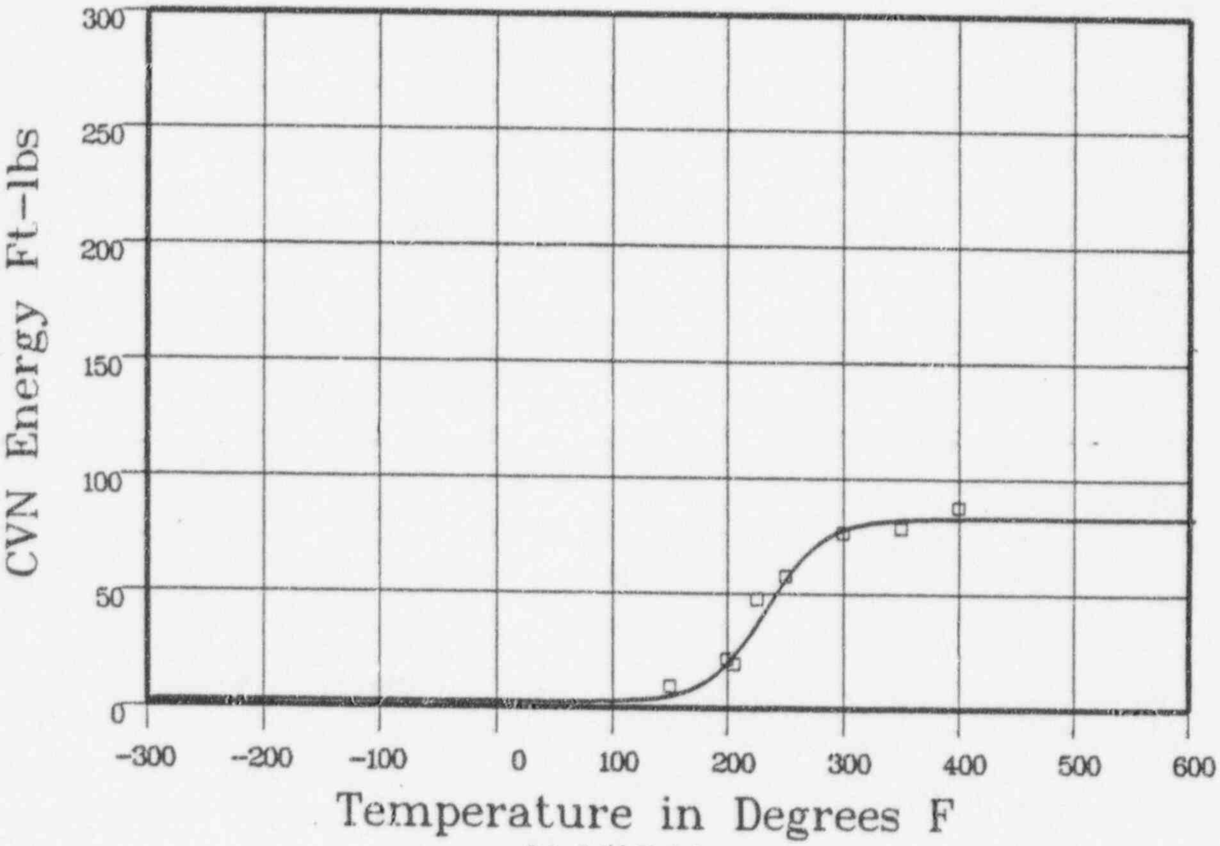
A = 42.34	B = 40.15	C = 50.3	T0 = 228.28

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

Upper Shelf Energy: 82.5 Fixed Temp. at 30 ft-lbs: 212.2 Temp. at 50 ft-lbs: 237.9 Lower Shelf Energy: 2.19 Fixed

Material: SRM HSST02 Heat Number: SA533B1 Orientation:

Capsule: S Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: S Material: SRM HSST02 Ori.: Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
150	9	5.62	3.37
200	21	21.88	-.88
206	19	25.64	-6.64
225	47	39.73	7.26
250	57	58.68	-1.68
300	76	78.11	-2.11
350	78	81.86	-3.86
400	87	82.41	4.58

SUM of RESIDUALS = .03

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CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:29:48 on 10-18-1996

Page 1

Coefficients of Curve 1

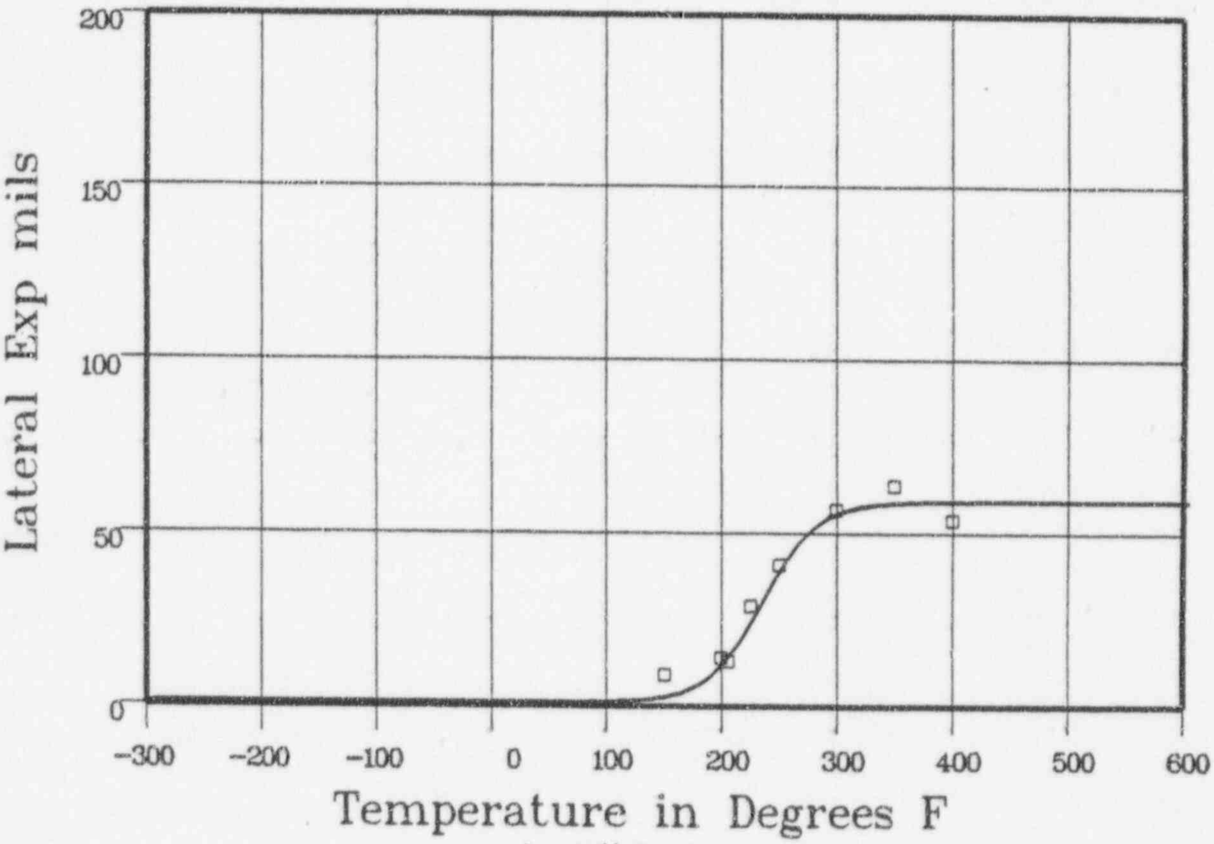
A = 30.26	B = 29.26	C = 48.02	T0 = 230.62

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

Upper Shelf L.E.: 59.52 Temperature at L.E. 35: 238.4 Lower Shelf L.E.: 1 Fixed

Material: SRM HSST02 Heat Number: SA533B1 Orientation:

Capsule: S Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: S Material: SRM HSST02 Ori.: Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
150	9	2.96	6.03
200	14	13.77	.22
206	13	16.44	-3.44
225	29	26.84	2.15
250	41	41.46	-.46
300	57	56.43	.56
350	64	59.11	4.88
400	54	59.46	-5.46

SUM of RESIDUALS = 4.46

CAPSULE S

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:02:12 on 10-18-1996

Page 1

Coefficients of Curve 1

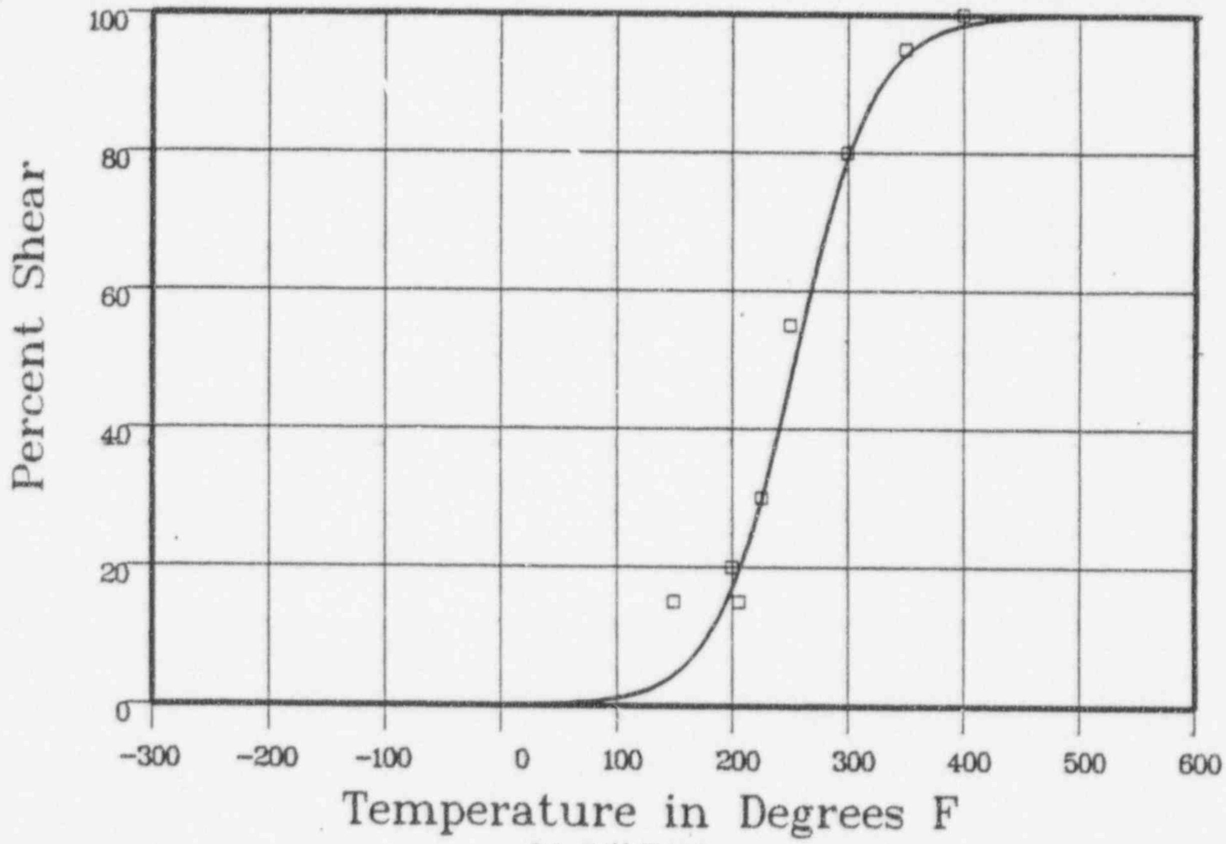
A = 50	B = 50	C = 68.53	T0 = 249.84

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

Temperature at 50% Shear: 249.8

Material: SRM HSST02 Heat Number: SA533B1 Orientation:

Capsule: S Total Fluence:



Data Set(s) Plotted

Plant: PI1 Cap.: S Material: SRM HSST02 Ori.: Heat #: SA533B1

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
150	15	5.14	9.85
200	20	18.93	1.06
206	15	21.76	-6.76
225	30	32.62	-2.62
250	55	50.11	4.88
300	80	81.2	-1.2
350	95	94.89	.1
400	100	98.76	1.23

SUM of RESIDUALS = 6.54

APPENDIX D
SURVEILLANCE DATA CREDIBILITY EVALUATION

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 methodology 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 have been four surveillance capsules removed from the Prairie Island Unit 1 reactor vessel. This capsule data 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 Prairie Island Unit 1 reactor vessel surveillance data and determine if the Prairie Island Unit 1 surveillance data is credible.

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, "Fracture Toughness Requirements", December 19, 1995 to be:

> "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 Prairie Island Unit 1 reactor vessel consists of the following beltline region materials:

a) Intermediate shell forging C, heat number 21918/38566

b) Lower shell forging D, heat number 21887/38530

c) Circumferential weld wire UM 89, heat number 1752, UM 89 flux, batch number 1230

Per WCAP-8086[3], the Prairie Island Unit 1 surveillance program was based on ASTM E185-70, "Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels". Per Section 3.1.2 of ASTM E185-70, *"A minimum test program shall consist of specimens taken from the following locations (1) base metal of one heat, incorporated in the highest flux location of the reactor vessel, that has the highest initial ductile-brittle transition temperature, (2) weld metal, fully representative of fabrication practice used for the welds in the highest flux location of the reactor vessel, (weld wire or rod, and flux must come from one of the heats used in the highest flux region of the reactor vessel) and (3) the heat-affected zone of the weldments noted above."*

Therefore, at the time the Prairie Island Unit 1 surveillance capsule program was developed, intermediate shell forging C was judged to be most limiting based on the above recommendations and was utilized in the surveillance program.

The surveillance program weld for Prairie Island Unit 1 was fabricated using the same heat of weld wire used to fabricate the circumferential weld seam (heat 1752). The results of mechanical property tests performed on the surveillance weld are considered to be representative of the property changes expected in the reactor vessel beltline seams.

Therefore, the materials selected for use in the Prairie Island Unit 1 surveillance program were those judged to be most likely controlling with regard to radiation embrittlement according to the accepted methodology at the time the surveillance program was developed. The Prairie Island Unit 1 surveillance program meets this criteria.

Criterion 2: ***Scatter in the plots of Charpy energy versus temperature for the irradiated and unirradiated conditions should be small enough to permit the determination of the 30 ft-lb temperature and upper shelf energy, unambiguously.***

Plots of Charpy energy versus temperature for the unirradiated condition are presented in WCAP-8086[3], "Northern States Power Company Prairie Island Unit No. 1 Reactor Vessel Radiation Surveillance Program," dated June 1973. Plots of Charpy energy versus temperature for the irradiated conditions are presented in Appendix C of this report for Capsules V, P, R and S.

Based on engineering judgement, the scatter in the data presented in these plots is small enough to determine the 30 ft-lb temperature and the upper shelf energy of the Prairie Island Unit 1 surveillance materials unambiguously. Therefore, the Prairie Island Unit 1 surveillance program meets this criteria.

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 least squares method, as described in Regulatory Position 2.1, will be utilized in determining a best-fit line for this data to determine if this criteria is met.

Table D1 Prairie Island Unit 1 Surveillance Capsule Data Calculation of Best-Fit Line as Described in Position 2.1 of Regulatory Guide 1.99, Revision 2

Material	Capsule	$f^{(a)}$	$FF^{(b)}$ (x)	ΔRT_{NDT} (y)	FF x ΔRT_{NDT} (xy)	FF^2 (x^2)
Intermediate Shell Forging C (Axial)	V	0.563	0.839	24.07	20.19	0.704
	P	1.318	1.077	33.98	36.60	1.160
	R	4.478	1.380	84.18	116.17	1.904
	S	4.017	1.357	74.27	100.78	1.841
Intermediate Shell Forging C (Tangential)	V	0.563	0.839	56.36	47.29	0.704
	P	1.318	1.077	23.11	24.89	1.160
	R	4.478	1.380	95.85	132.27	1.940
	S	4.017	1.357	101.46	137.68	1.841
	$\Sigma^{n}_{i=1}$		9.306	493.28	615.87	11.218
Weld Metal	V	0.563	0.839	34.38	28.84	0.704
	P	1.318	1.077	45.15	48.63	1.160
	R	4.478	1.380	122.47	169.01	1.904
	S	4.017	1.357	160.43	217.70	1.841
	$\Sigma^{n}_{i=1}$		4.653	362.43	464.18	5.609

NOTES:
(a) f = Fluence (10^{19} n/cm^2, E > 1.0 MeV)
(b) FF = Fluence Factor = $f^{(0.28 - 0.1 * \log f)}$

Per the 27[th] Edition of the CRC Standard Mathematical Tables (page 497), for a straight line fit by the method of least squares, the values b_o and b_l are obtained by solving the normal equations

$$n\, b_o + b_1\, \Sigma x_i = \Sigma y_i$$

and

$$b_o\, \Sigma x_i + b_1\, \Sigma x_i^2 = \Sigma x_i y_i$$

These equations can be re-written as follows:

$$\sum_{i=1}^{n} y_i = an + b\sum_{i=1}^{n} x_i$$

and

$$\sum_{i=1}^{n} x_i y_i = a\sum_{i=1}^{n} x_i + b\sum_{i=1}^{n} x_i^2$$

<u>Intermediate Shell Forging C:</u>
Based on the data provided in Table D1, these equations become:

1.) 493.28 = 8a + 9.306b or a = 61.66 - 1.16b

and

2.) 615.87 = 9.306a + 11.218b

Thus, by substituting Eq. 1 into Eq. 2, b = 107.1. Now, enter b (= 107.1) into Eq. 1 and a = -62.9. Therefore, the equation of the straight line which provides the best fit in the sense of least squares is:

Y' = 107.1 (X) - 62.9

The error in predicting a value Y corresponding to a given X value is: e = Y - Y'.

Table D2: Be_ Fit Evaluation for Intermediate Forging

Base Material (Orientation)	FF	ΔRT_{NDT} (30 ft-lb) (°F)	Best Fit ΔRT_{NDT} (°F)	Scatter of ΔRT_{NDT} (°F)
Intermediate Shell Forging C (Axial)	0.839	24.07	27.0	-2.9
	1.077	33.98	52.4	-18.4
	1.340	44.18	84.9	-0.7
	1.357	74.27	82.4	-8.1
Intermediate Shell Forging C (Tangential)	0.839	56.36	27.0	29.4
	1.077	23.11	52.4	-29.3
	1.380	95.85	84.9	11.0
	1.357	101.46	82.4	19.1

The scatter of ΔRT_{NDT} values about a best-fit line drawn, as described in Regulatory Position 2.1, should be less than 17°F for base metal. However, even if the fluence range is large, the scatter should not exceed twice this value (34°F). As shown above, the error is within 34°F of the best-fit line. Therefore, this criteria is met for the Prairie Island Unit 1 surveillance forging material.

Weld Metal:

Based on the data provided in Table D1 the equations become:

1.) $362.43 = 4a + 4.653b$ or $a = 90.61 - 1.163b$

and

2.) $464.18 = 4.653a + 5.609b$

Thus, by substituting Eq. 1 into Eq. 2, b = 216.7. Now, enter b (= 216.7) into Eq. 1 and a = -161.5. Therefore, the equation of the straight line which provides the best fit in the sense of least squares is:

$$Y' = 216.7 (X) - 161.5$$

The error in predicting a value Y corresponding to a given X value is: $e = Y - Y'$

Table D3: Best Fit Evaluation for Weld Metal

Base Material	FF	ΔRT_{NDT} (30 ft-lb) (°F)	Best Fit ΔRT_{NDT} (°F)	Scatter of ΔRT_{NDT} (°F)
Weld Metal	0.839	34.38	20.3	14.1
	1.077	45.15	71.9	-26.8
	1.380	122.47	137.5	-15.0
	1.357	160.43	132.6	27.8

The scatter of ΔRT_{NDT} values about a best-fit line drawn, as described in Regulatory Position 2.1, should be less than 28°F. However, even if the fluence range is large, the scatter should not exceed twice this value (56°F). As shown above, the error is within 56°F of the best-fit line. Therefore, this criteria is met for the Prairie Island Unit 1 surveillance weld material.

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

The Prairie Island Unit 1 capsule specimens are located in the reactor between the thermal shield and the vessel wall and are positioned opposite the center of the core. The test capsules are in baskets attached to the thermal shield. The location of the specimens with respect to the reactor vessel beltline provides assurance that the reactor vessel wall and the specimens experience equivalent operating conditions and will not differ by more than 25°F.

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

Correlation monitor material was supplied by the Oak Ridge National Laboratory from plate material used in the AEC-sponsored Heavy Section Steel Technology (HSST) Program. This material, which was obtained from a 12-inch thick A533 Grade B Class 1 plate (HSST Plate 02), was provided to Subcommittee II (of ASTM Committee E 10 on Radioisotopes and Radiation Effects) to serve as correlation monitor material in reactor vessel surveillance programs. The plate was produced by the Lukens Steel Company and heat treated by Combustion Engineering, Inc.

Figure D1 contains a plot of the residual (measured shift minus Regulatory Guide 1.99, Revision 2 shift) versus capsule fluence data. The plot shows the Prairie Island Unit 1 data as solid points. The data has been shifted such that the mean value is at zero and the two-sigma bound at 45°F. All of the Prairie Island Unit 1 correlation monitor material data falls within the two-sigma scatter band of the A533 Grade B Class 1 data per this criterion.

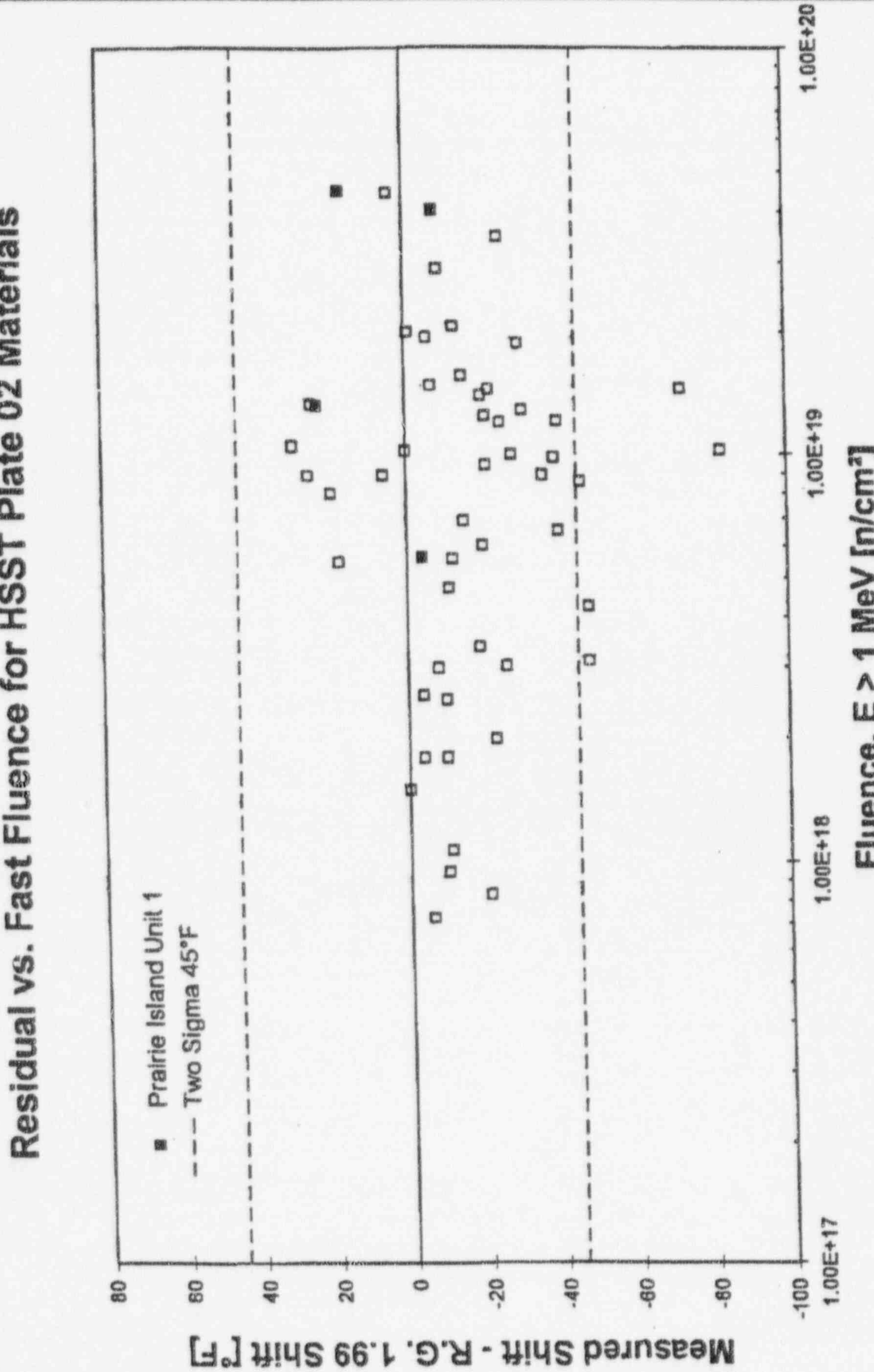


FIGURE D1: **Residual vs. Fast Fluence for HSST Plate 02 Materials**

Conclusion:

Based on the preceding responses to the criteria of Regulatory Guide 1.99, Revision 2, Section B, and the application of engineering judgement, the Prairie Island Unit 1 surveillance weld metal data is credible.