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The Northeast Utilities System

MAY 17 2000

Docket No. 50-423
B18119

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555

Millstone Nuclear Power Station, Unit No. 3
Submittal of Second Reactor Vessel Surveillance Capsule Report

The reactor vessel material irradiation surveillance specimens inserted in the Millstone Unit No. 3 reactor vessel prior to initial plant startup are required to be removed and examined, to determine changes in material properties, in accordance with the schedule in the Unit No. 3 Technical Specifications Table 4.4-5. The second specimen, Capsule X, was removed during the sixth refueling outage, on May 19, 1999, and in accordance with 10 CFR 50 Appendix H a summary report is required to be provided within one year of the date of the capsule withdrawal. Northeast Nuclear Energy Company (NNECO) hereby submits four (4) copies of the report on the analysis of the reactor vessel surveillance Capsule X from the Unit No. 3 reactor vessel. This report on Capsule X summarizes testing and the post-irradiation data obtained from Capsule X and also discusses the analysis of the data.

NNECO letter dated November 7, 1988,(1) submitted a report on the first specimen, Capsule U, that was removed during the first refueling outage after 1.3 Effective Full Power Years (EFPY) of Unit No. 3 operation. Technical Specifications 3.4.9.1 states that the second capsule, Capsule Y, shall be removed at approximately 9 EFPY. However, since 9 EFPY is reached in the middle of the seventh fuel cycle, NNECO determined that removal of the standby Capsule X during the sixth refueling outage would provide the closest approximation to the 9 EFPY requirement and also provide additional vessel embrittlement data which can be used to develop new heatup and cooldown limits. Capsule X is identical to Capsule Y with the exception of the lead factor that was slightly greater, resulting in greater capsule fluence.

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(1) NNECO letter from E. J. Mroczka, "Millstone Nuclear Power Station, Unit No. 3, Submittal of First Millstone Unit No. 3, Reactor Vessel Surveillance Capsule Report," dated November 7, 1988, (B13069).

A008 1/4

A summary of the results from the analysis of the reactor vessel materials that were contained in surveillance Capsule X have been included in the report. NNECO will be using these results to develop revised heatup and cooldown limits to support a Technical Specification change and Bases change. The current heatup and cooldown limits are valid through 10 EFPY which is expected to be reached during the second half of 2001.

There are no regulatory commitments contained within this letter.

Should you have any questions regarding this submittal, please contact Mr. Ravi Joshi at (860) 440-2080.

Very truly yours,

NORTHEAST NUCLEAR ENERGY COMPANY

Stephen E. Scace
Director - Nuclear Oversight and
Regulatory Affairs

Enclosure: WCAP-15405, Analysis of Capsule X from the Northeast Nuclear Energy Company Millstone Unit 3 Reactor Vessel Radiation Surveillance Program (4 copies)

cc: w/o enclosure

H. J. Miller, Region I Administrator
V. Nerses, NRC Senior Project Manager, Millstone Unit No. 3
A. C. Cerne, Senior Resident Inspector, Millstone Unit No. 3

Docket No. 50-423
B18119

Enclosure

WCAP-15405, Analysis of Capsule X from the Northeast Nuclear Energy Company
Millstone Unit 3 Reactor Vessel Radiation Surveillance Program

May 2000

Westinghouse Non-Proprietary Class 3

WCAP - 15405
Revision 0

Analysis of Capsule X from the Northeast Nuclear Energy Company Millstone Unit 3 Reactor Vessel Radiation Surveillance Program

Westinghouse Energy Systems

WCAP-15405

Analysis of Capsule X from the Northeast Nuclear Energy Company Millstone Unit 3 Reactor Vessel Radiation Surveillance Program

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PREFACE

This report has been technically reviewed and verified by:

Reviewer:

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

Section 6 — S. L. Anderson

EXECUTIVE SUMMARY

The purpose of this report is to document the results of the testing of surveillance capsule X from the Millstone Unit 3 reactor vessel. Capsule X was removed at 8.0 EFPY and post irradiation mechanical tests of the Charpy V-notch and tensile specimens was performed, along with a fluence evaluation. The peak clad base/metal vessel fluence after 8.0 EFPY of plant operation was 5.06 x 10^{18} n/cm^2. A brief summary of the Charpy V-notch testing results can be found in Section 1 and the updated capsule removal schedule can be found in Section 7. A supplement to this report is a credibility evaluation, which can be found in Appendix D, that shows the Millstone Unit 3 surveillance plate data is credible.

1 SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance capsule X, the second capsule to be removed from the Millstone Unit 3 reactor pressure vessel, led to the following conclusions:

- The Charpy V-notch data presented in WCAP-10732[1] and WCAP-11878[2] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1. which is a hyperbolic tangent curve-fitting program. Appendix B presents a comparison of the Charpy V-Notch test results for each capsule based on hand fit vs. hyperbolic tangent fit. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

- Fluence projections for future operation were based on the assumption that the exposure rates averaged over Cycles 4 through 6 (low-leakage loading pattern) would continue to be applicable throughout plant life.

- The capsule received an average fast neutron fluence (E> 1.0 MeV) of 2.21 x 10^{19} n/cm^2 after 8.0 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel Intermediate Shell Plate B9805-1 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major rolling direction (Longitudinal orientation), to 2.21 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 25.82°F and a 50 ft-lb transition temperature increase of 28.69°F. This results in an irradiated 30 ft-lb transition temperature of 28.27°F and an irradiated 50 ft-lb transition temperature of 59.02°F for the longitudinal oriented specimens.

- Irradiation of the reactor vessel Intermediate Shell Plate B9805-1 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major rolling direction of the plate (Transverse orientation), to 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 25.77°F and a 50 ft-lb transition temperature increase of 26.24°F. This results in an irradiated 30 ft-lb transition temperature of 43.22°F and an irradiated 50 ft-lb transition temperature of 81.04°F for transverse oriented specimens.

- Irradiation of the weld metal Charpy specimens to 2.21 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature decrease of –6.78°F and a 50 ft-lb transition temperature decrease of –4.49°F. This physically should not occur. Hence, these results will be reported as no change.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 43.96°F and a 50 ft-lb transition temperature increase of 31.76°F. This results in an irradiated 30 ft-lb transition temperature of –127.89°F and an irradiated 50 ft-lb transition temperature of –95.95°F.

- The average upper shelf energy of the Intermediate Shell Plate B9805-1 (Longitudinal orientation) resulted in an average energy decrease of 1 ft-lb after irradiation to 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV). This results in an irradiated average upper shelf energy of 132 ft-lb for the longitudinal oriented specimens.

- The average upper shelf energy of the Intermediate Shell Plate B9805-1 (Transverse orientation) resulted in an average energy decrease of 1 ft-lb after irradiation to 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 110 ft-lb for the transverse oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted an average energy decrease of 1 ft-lb after irradiation to 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 142 ft-lb for the weld metal specimens.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in no average energy increase after irradiation to 2.21 x 10^{19} n/cm^2 (E> 1.0MeV). This results in an irradiated average upper shelf energy of 142 ft-lb for the weld HAZ metal.

- A comparison of the Millstone Unit 3 reactor vessel beltline material test results with the Regulatory Guide 1.99, Revision 2[3] predictions led to the following conclusions:

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

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

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

  Calculated: Vessel inner radius* = 1.97×10^{19} n/cm^2

  Vessel 1/4 thickness = 1.17×10^{19} n/cm^2

  Vessel 3/4 thickness = 4.17×10^{19} n/cm^2

  Best Estimate: Vessel inner radius* = 1.84×10^{19} n/cm^2

  Vessel 1/4 thickness = 1.10×10^{19} n/cm^2

  Vessel 3/4 thickness = 3.90×10^{18} n/cm^2

  *Clad/base metal interface

- The credibility evaluation of the Millstone Unit 3 surveillance program presented in Appendix D of this report indicates that the surveillance results for Intermediate Shell Plate B9805-1 are credible.

- All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are expected to maintain an upper shelf energy greater than 50 ft-lb throughout the life of the vessel (32 EFPY) as requred by 10CFR50, Appendix G[4].

2 INTRODUCTION

This report presents the results of the examination of Capsule X, the second capsule removed from the reactor in the continuing surveillance program which monitors the effects of neutron irradiation on the Northeast Utilities Service Company Millstone Unit 3 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the Millstone Unit 3 reactor pressure vessel materials was designed and recommended by the Westinghouse Electric Company. A description of the surveillance program and the preirradiation mechanical properties of the reactor vessel materials is presented in WCAP-10732, "Northeast Utilities Service Company Millstone Unit No. 3 Reactor Vessel Radiation Surveillance Program[1]. The surveillance program was planned to cover the 40-year design life of the reactor pressure vessel and was based on ASTM E185-82, "Standard Recommended Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels"[5]. Capsule X was removed from the reactor after 8.0 EFPY of exposure and shipped to the Westinghouse Science and Technology Center Hot Cell Facility, where the postirradiation mechanical testing of the Charpy V-notch impact and tensile surveillance specimens was performed.

The Charpy V-notch data presented in WCAP-10732[1] and WCAP-11878[2] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1, which is a hyperbolic tangent curve-fitting program. Appendix B presents a comparison of the Charpy V-Notch test results for each capsule based on hand fit vs. hyperbolic tangent fit. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

This report summarizes the testing of and the post-irradiation data obtained from surveillance capsule X removed from the Northeast Utilities Service Company Millstone Unit 3 reactor vessel and discusses the analysis of the data.

3 BACKGROUND

The ability of the large steel pressure vessel containing the reactor core and its primary coolant to resist fracture constitutes an important factor in ensuring safety in the nuclear industry. The beltline region of the reactor pressure vessel is the most critical region of the vessel because it is subjected to significant fast neutron bombardment. The overall effects of fast neutron irradiation on the mechanical properties of low alloy, ferritic pressure vessel steels such as SA533 Grade B Class 1 plate (base material of the Millstone Unit 3 reactor pressure vessel beltline) are well documented in the literature. Generally, low alloy ferritic materials show an increase in hardness and tensile properties and a decrease in ductility and toughness during high-energy irradiation.

A method for ensuring the integrity of reactor pressure vessels has been presented in "Fracture Toughness Criteria for Protection Against Failure," Appendix G to Section XI of the ASME Boiler and Pressure Vessel Code[6]. The method uses fracture mechanics concepts and is based on the reference nil-ductility transition temperature (RT_{NDT}).

RT_{NDT} is defined as the greater of either the drop weight nil-ductility transition temperature (NDTT per ASTM E-208[7]) or the temperature 60°F less than the 50 ft-lb (and 35-mil lateral expansion) temperature as determined from Charpy specimens oriented perpendicular (transverse) to the major rolling direction of the plate. The RT_{NDT} of a given material is used to index that material to a reference stress intensity factor curve (K_{Ic} curve) which appears in Appendix G to the ASME Code[6]. The K_{Ic} curve is a lower bound of static fracture toughness results obtained from several heats of pressure vessel steel. When a given material is indexed to the K_{Ic} curve, allowable stress intensity factors can be obtained for this material as a function of temperature. Allowable operating limits can then be determined using these allowable stress intensity factors.

RT_{NDT} and, in turn, the operating limits of nuclear power plants can be adjusted to account for the effects of radiation on the reactor vessel material properties. The changes in mechanical properties of a given reactor pressure vessel steel, due to irradiation, can be monitored by a reactor surveillance program, such as the Millstone Unit 3 reactor vessel radiation surveillance program[1], in which a surveillance capsule is periodically removed from the operating nuclear reactor and the encapsulated specimens tested. The increase in the average Charpy V-notch 30 ft-lb temperature (ΔRT_{NDT}) due to irradiation is added to the initial RT_{NDT}, along with a margin (M) to cover uncertainties, to adjust the RT_{NDT} (ART) for radiation embrittlement. This ART (RT_{NDT} initial + M + ΔRT_{NDT}) is used to index the material to the K_{Ic} curve and, in turn, to set operating limits for the nuclear power plant that take into account the effects of irradiation on the reactor vessel materials.

4 DESCRIPTION OF PROGRAM

Six surveillance capsules for monitoring the effects of neutron exposure on the Millstone Unit 3 reactor pressure vessel core region (beltline) materials were inserted in the reactor vessel prior to initial plant start-up. The six capsules were positioned in the reactor vessel between the neutron pads and the vessel wall as shown in Figure 4-1. The vertical center of the capsules is opposite the vertical center of the core. The capsules contain specimens made from Intermediate Shell Plate B9805-1 (Heat No. C4039-2), weld metal fabricated with 3/16-inch Mil B-4 weld filler wire heat number 4P6052 Linde 0091 flux lot number 0145, which is identical to that used in the actual fabrication of the beltline welds. Specifically, the closing girth seam between the intermediate and lower shell plates, and all longitudinal weld seams of both the intermediate and lower shell plates.

Capsule X was removed after 8.0 effective full power years (EFPY) of plant operation. This capsule contained Charpy V-notch, tensile, and ½T-CT fracture mechanics specimens made from Intermediate Shell Plate B9805-1 and submerged arc weld metal identical to the vessel beltline welds. In addition, this capsule contained Charpy V-notch specimens from the weld Heat-Affected-Zone (HAZ) of Intermediate Shell Plate B9805-1.

Test material obtained from Intermediate Shell Plate B9805-1 (after the thermal heat treatment and forming of the plate) was taken at least one plate thickness from the quenched ends of the plate. All test specimens were machined from the ¼ and ¾ thickness locations of the plate after performing a simulated post-weld stress-relieving treatment on the test material. Specimens from weld metal and Heat-Affected-Zone (HAZ) metal were machined from a stress-relieved weldment joining Intermediate Shell Plate B9805-1 and Lower Shell Plate B9820-2. All heat-affected-zone specimens were obtained from the weld heat-affected-zone of Intermediate Shell Plate B9805-1.

Charpy V-notch impact specimens from Intermediate Shell Plate B9805-1 were machined both in the longitudinal orientation (longitudinal axis of the specimen parallel to the major rolling direction) and transverse orientation (longitudinal axis of the specimen perpendicular to the major rolling direction). The core region weld Charpy impact specimens were machined from the weldment such that the long dimension of each Charpy specimen was perpendicular to the weld direction. The notch of the weld metal Charpy specimens were machined such that the direction of crack propagation in the specimen was in the welding direction.

Tensile specimens from Intermediate Shell Plate B9805-1 were machined in both the longitudinal and transverse orientation. Tensile specimens from the weld metal were oriented with the long dimension of the specimen perpendicular to the weld direction.

Compact tension test specimens from plate B9805-1 were machined in both the longitudinal and transverse orientations. Compact tension test specimens from the weld metal were machined perpendicular to the weld direction with the notch oriented in the direction of the weld. All specimens were fatigue precracked according to ASTM E399.

The chemical composition and heat treatment of the surveillance program materials is presented in Table 4-1. The chemical analysis and heat treatment reported in Tables 4-1 and 4-2 were obtained from WCAP 10732[1].

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

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

2.5% Ag, 97.5% Pb	Melting Point: 579°F (304°C)
1.5% Ag, 1.0% Sn, 97.5% Pb	Melting Point: 590°F (310°C)

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

Table 4-1 Chemical Analysis of the Surveillance Program Materials used in the Millstone Unit 3 Reactor Pressure Vessel Surveillance Program				
	Chemical Composition (Weight %)			
Element	**Plate B9805-1[(a)]**	**Plate B9805-1[(b)]**	**Actual Production Weld (Intermediate Shell Long. Seam 101-124A)[(c)]**	**Westinghouse Surveillance Program Test Weldment D[(a)]**
C	0.23	0.22	0.14	0.14
Mn	1.32	1.29	1.24	1.33
P	0.010	0.018	0.010	0.018
S	0.010	0.014	0.009	0.012
Si	0.21	0.23	0.15	0.13
Ni	0.61	0.62	0.15	0.060
Mo	0.57	0.58	0.54	0.52
Cr	0.03	0.10	0.01	0.067
Cu	0.05	0.045	0.02	0.038
Al	0.024	0.024	0.004	0.003
Co	0.012	0.017	0.006	0.006
Pb	Not detected	0.001	- -	0.001
W	<0.01	<0.01	0.01	<0.01
Ti	<0.01	0.006	0.01	0.006
Zr	<0.001	<0.002	0.001	<0.002
V	0.006	0.004	0.005	0.003
Sn	0.003	0.005	0.004	0.005
As	0.005	0.007	0.006	0.006
Cb	<0.01	0.002	0.01	<0.002
N_2	0.007	0.006	0.012	0.010
B	<0.001	<0.001	0.001	<0.01

Notes:

a. Chemical Analysis by Westinghouse.
b. Chemical Analysis by Combustion Engineering, Inc.
c. Chemical Analysis of Wire-Flux Weld Sample, Test Number H32255 and Chemistry Data Sheet 101-124A by Combustion Engineering, Inc.

Table 4-2 Heat Treatment History of the Millstone Unit No. 3 Reactor Pressure Vessel Core Region Shell Plates and Weld Seams

Material	Temperature (°F)	Time (hrs.)	Coolant
Intermediate Shell Plates Plate B9805-1	Austenitizing: 1600 ± 25	4	Water-quenched
Plate B9805-2	Tempered: 1225 ± 25	4	Air Cooled
Plate B9805-3	Stress Relief: 1150 ± 50	22[a]	Furnace Cooled
Lower Shell Plates Plate B9820-1	Austenitizing: 1600 ± 25	4	Water-quenched
Plate B9820-2	Tempered: 1225 ± 25	4	Air Cooled
Plate B9820-3	Stress Relief: 1150 ± 50	11[a]	Furnace Cooled
Intermediate Shell Longitudinal Seam Welds	Stress Relief: 1150 ± 50	22[a]	Furnace Cooled
Lower Shell Longitudinal Seam Welds	Stress Relief: 1150 ± 50	11[a]	Furnace Cooled
Intermediate to Lower Shell Girth Seam Weld	Local Stress Relief: 1150 ± 50	6.5	Furnace Cooled
Surveillance Program Test Material			
Surveillance Program Weldment Test Plate "D" (Representative of closing Girth Seam)	Post Weld Stress Relief: 1150 ± 50	8[b]	Furnace Cooled

a. Stress relief includes the intermediate to lower shell closing girth seam post weld heat treatment.

b. The stress relief heat treatment received by the surveillance test weldment has been simulated.

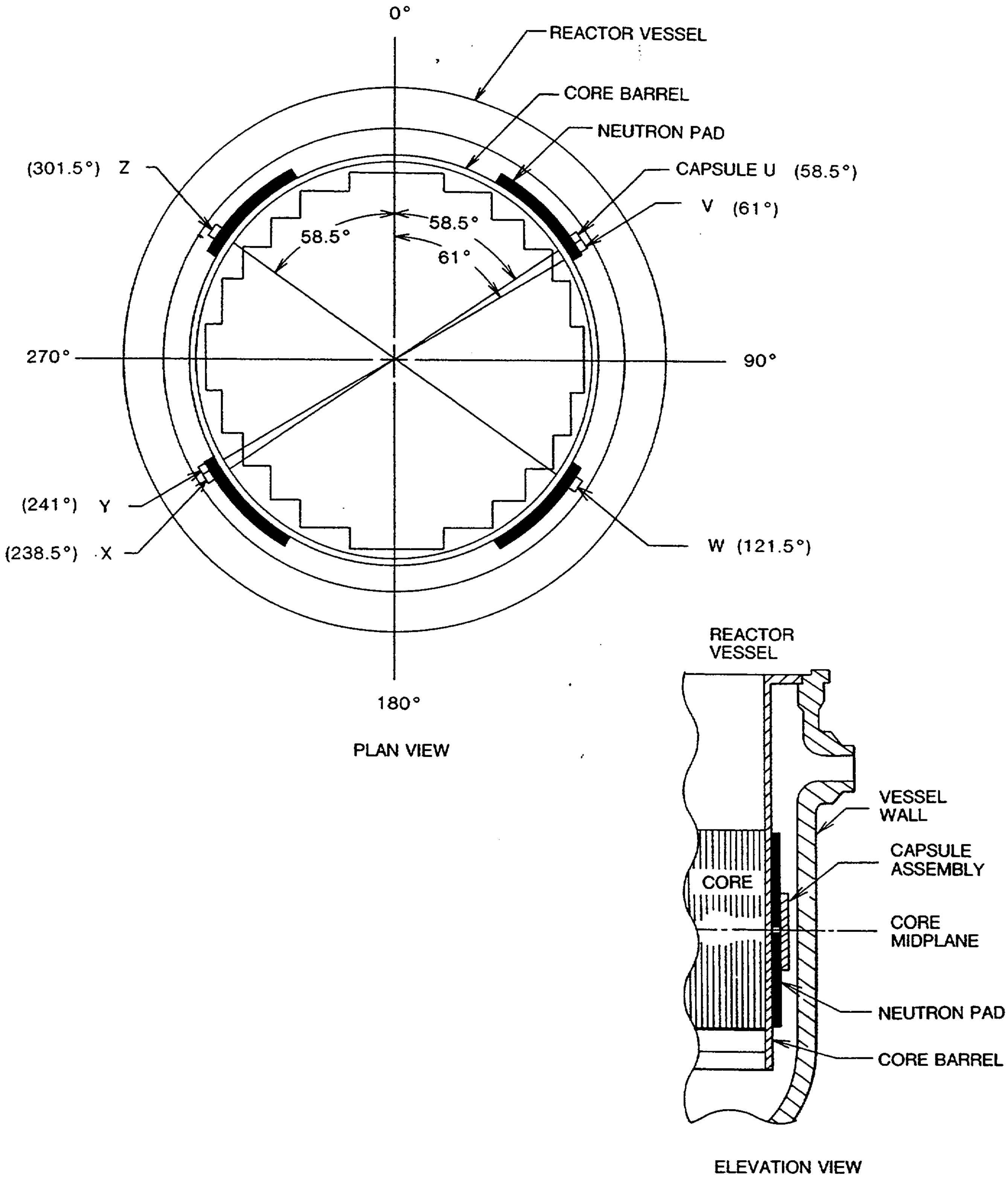


Figure 4-1 Arrangement of Surveillance Capsules in the Millstone Unit 3 Reactor Vessel

LEGEND: EL - INTERMEDIATE SHELL PLATE B9805-1 (LONGITUDINAL)
ET - INTERMEDIATE SHELL PLATE B9805-1 (TRANSVERSE)
EW - WELD METAL
EH - HEAT-AFFECTED-ZONE MATERIAL

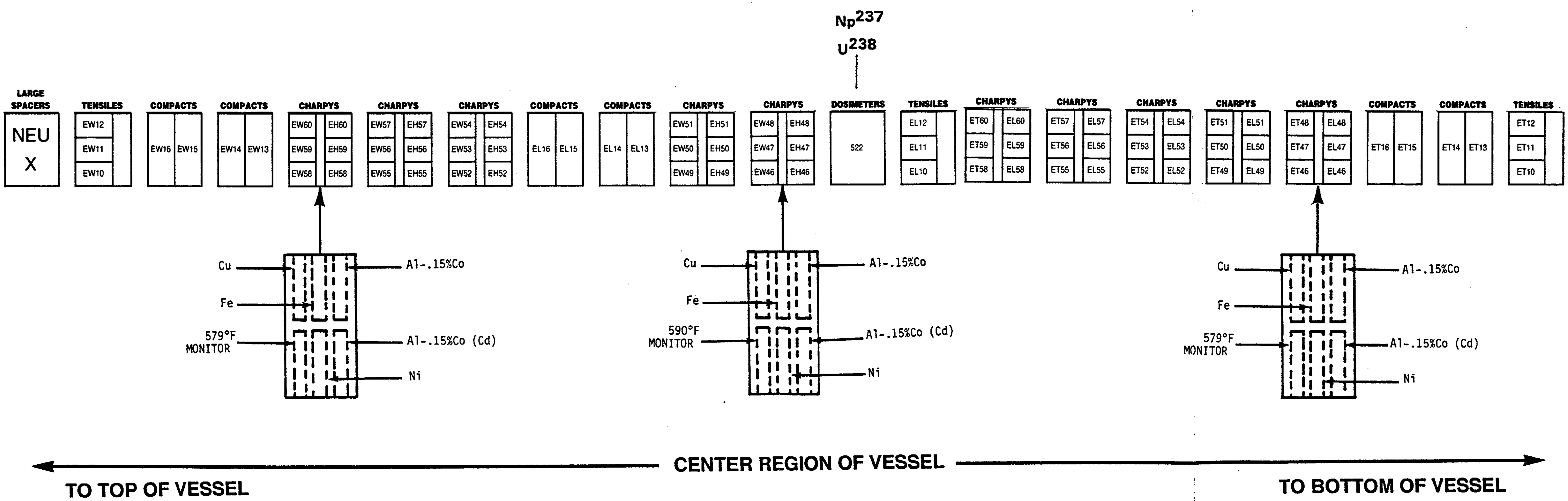


Figure 4-2 Capsule X Diagram Showing the Location of Specimens, Thermal Monitors, and Dosimeters

5 TESTING OF SPECIMENS FROM CAPSULE X

5.1 OVERVIEW

The post-irradiation mechanical testing of the Charpy V-notch impact specimens and tensile specimens was performed in the Remote Metallographic Facility (RMF) at the Westinghouse Science and Technology Center. Testing was performed in accordance with 10CFR50, Appendix H[8], ASTM Specification E185-82[5], 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-10732[1]. No discrepancies were found.

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

The Charpy impact tests were performed per ASTM Specification E23-98[9] and RMF Procedure 8103, Revision 1, on a Tinius-Olsen Model 74, 358J machine. The tup (striker) of the Charpy impact test machine is instrumented with a GRC 930-I instrumentation system, feeding information into an IBM compatible computer. With this system, load-time and energy-time signals can be recorded in addition to the standard measurement of Charpy energy (E_D). From the load-time curve (Appendix A), the load of general yielding (P_{GY}), the time to general yielding (t_{GY}), the maximum load (P_M), and the time to maximum load (t_M) can be determined. Under some test conditions, a sharp drop in load indicative of fast fracture was observed. The load at which fast fracture was initiated is identified as the fast fracture load (P_F), and the load at which fast fracture terminated is identified as the arrest load (P_A). The energy at maximum load (E_M) was determined by comparing the energy-time record and the load-time record. The energy at maximum load is approximately equivalent to the energy required to initiate a crack in the specimen. Therefore, the propagation energy for the crack (E_p) is the difference between the total energy to fracture (E_D) and the energy at maximum load (E_M).

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

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

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

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

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

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

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

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

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

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

Percent shear was determined from post-fracture photographs using the ratio-of-areas methods in compliance with ASTM Specification A370-97[10]. The lateral expansion was measured using a dial gage rig similar to that shown in the same specification.

Tensile tests were performed on a 20,000-pound Instron, split-console test machine (Model 1115) per ASTM Specification E8-99[11] and E21-92[12], and RMF Procedure 8102, Revision 1. All pull rods, grips, and pins were made of Inconel 718. The upper pull rod was connected through a universal joint to improve axiality of loading. The tests were conducted at a constant crosshead speed of 0.05 inches per minute throughout the test.

Extension measurements were made with a linear variable displacement transducer extensometer. The extensometer knife edges were spring-loaded to the specimen and operated through specimen failure. The extensometer gage length was 1.00 inch. The extensometer is rated as Class B-2 per ASTM E83-96[13].

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

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

5.2 CHARPY V-NOTCH IMPACT TEST RESULTS

The results of the Charpy V-notch impact tests performed on the various materials contained in capsule X, which received a fluence of 2.21 x 10^{19} n/cm^2(E> 1.0 MeV) in 8.0 EFPY of operation, are presented in Tables 5-1 through 5-8 and are compared with unirradiated results[1] as shown in Figures 5-1 through 5-12.

The transition temperature increases and upper shelf energy decreases for the capsule X materials are summarized in Table 5-9. A comparison of the surveillance material 30 ft-lb transition temperature shifts and the upper shelf energy decreases with the Regulatory Guide 1.99, Revision 2, predictions is given in Table 5-10. These results led to the following conclusions:

- Irradiation of the reactor vessel Intermediate Shell Plate B9805-1 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major rolling direction (Longitudinal orientation), to 2.21 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 25.82°F and a 50 ft-lb transition temperature increase of 28.69°F. This results in an irradiated 30 ft-lb transition temperature of 28.27°F and an irradiated 50 ft-lb transition temperature of 59.02°F for the longitudinal oriented specimens.

- Irradiation of the reactor vessel Intermediate Shell Plate B9805-1 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major rolling direction of the plate (Transverse orientation), to 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 25.77°F and a 50 ft-lb transition temperature increase of 26.24°F. This results in an irradiated 30 ft-lb transition temperature of 43.22°F and an irradiated 50 ft-lb transition temperature of 81.04°F for transverse oriented specimens.

- Irradiation of the weld metal Charpy specimens to 2.21 x 10^{19} n/cm^2 (E> 1.0MeV) resulted in a 30 ft-lb transition temperature decrease of 6.78°F and a 50 ft-lb transition temperature decrease of 4.49°F. This results in an irradiated 30 ft-lb transition temperature of –43.74°F and an irradiated 50 ft-lb transition temperature of -21.79°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 43.96°F and a 50 ft-lb transition temperature increase of 31.76°F. This results in an irradiated 30 ft-lb transition temperature of –127.89°F and an irradiated 50 ft-lb transition temperature of –95.95°F.

- The average upper shelf energy of the Intermediate Shell Plate B9805-1 (Longitudinal orientation) resulted in an average energy decrease of 1 ft-lb after irradiation to 2.21 x 10^{19} n/cm^2 (E > 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 132 ft-lb for the longitudinal oriented specimens.

- The average upper shelf energy of the Intermediate Shell Plate B9805-1 (Transverse orientation) resulted in an average energy decrease of 1 ft-lb after irradiation to 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 110 ft-lb for the transverse oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted an average energy decrease of 1 ft-lb after irradiation to 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 142 ft-lb for the weld metal specimens.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in an average energy increase of 2 ft-lb after irradiation to 2.21 x 10^{19} n/cm^2 (E> 1.0MeV). This results in an irradiated average upper shelf energy of 144 ft-lb for the weld HAZ metal.

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

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

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

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

All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are expected to maintain an upper shelf energy of no less than 50 ft-lb throughout the life of the vessel (32 EFPY) as required by 10CFR50, Appendix G[4].

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

The Charpy V-notch data presented in WCAP-10732[1] and WCAP-11878[2] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1, which is a hyperbolic tangent curve-fitting program. Appendix B presents a comparison of the Charpy V-Notch test results for each capsule based on hand fit vs. hyperbolic tangent fit. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

Appendix D of this report contains a credibility evaluation of the surveillance data from the Millstone Unit 3 reactor vessel surveillance program. This evaluation indicates that the surveillance results for Intermediate Shell Plate B9805-1 are not credible.

5.3 TENSILE TEST RESULTS

The results of the tensile tests performed on the various materials contained in capsule X irradiated to 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV) are presented in Table 5-11 and are compared with unirradiated results[1] as shown in Figures 5-17 through 5-19.

The results of the tensile tests performed on the Intermediate Shell Plate B9805-1 (longitudinal orientation) indicated that irradiation to 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 2 to 7 ksi increase in the 0.2 percent offset yield strength and approximately a 6 to 10 ksi increase in the ultimate tensile strength when compared to unirradiated data[1] (Figure 5-17).

The results of the tensile tests performed on the Intermediate Shell Plate B9805-1 (transverse orientation) indicated that irradiation to 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV) caused an approximate increase of 5 to 12 ksi in the 0.2 percent offset yield strength and approximately a 4 to 6 ksi increase in the ultimate tensile strength when compared to unirradiated data[1] (Figure 5-18).

The results of the tensile tests performed on the surveillance weld metal indicated that irradiation to 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 2 to 4 ksi increase in the 0.2 percent offset yield strength and no increase in the ultimate tensile strength when compared to unirradiated data[1] (Figure 5-19).

The fractured tensile specimens for the Intermediate Shell Plate B9805-1 material are shown in Figures 5-20 and 5-21, while the fractured tensile specimens for the surveillance weld metal are shown in Figure 5-22. The engineering stress-strain curves for the tensile tests are shown in Figures 5-23 through 5-28.

5.4 1/2T COMPACT TENSION SPECIMEN TESTS

Per the surveillance capsule testing contract, the ½T Compact Tension Specimens were not tested and are being stored at the Westinghouse Science and Technology Center Hot Cell facility.

Table 5-1 Charpy V-notch Data for the Millstone Unit 3 Intermediate Shell Plate B9805-1 Irradiated to a Fluence of 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV) (Longitudinal Orientation)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	Ft-lbs	Joules	mils	Mm	%
EL59	-150	-101	2	3	0	0.00	2
EL52	-25	-32	6	8	0	0.00	5
EL47	0	-18	14	19	2	0.05	10
EL50	25	-4	28	38	12	0.30	15
EL55	30	-1	30	41	15	0.38	15
EL60	40	4	31	42	19	0.48	20
EL58	45	7	50	68	30	0.76	25
EL57	50	10	53	72	31	0.79	25
EL51	60	16	35	47	22	0.56	20
EL48	72	22	64	87	34	0.86	45
EL49	100	38	91	123	54	1.37	55
EL54	150	66	99	134	62	1.57	65
EL46	200	93	128	174	73	1.85	95
EL56	250	121	130	176	78	1.98	100
EL53	300	149	138	187	85	2.16	100

Table 5-2 Charpy V-notch Data for the Millstone Unit 3 Intermediate Shell Plate B9805-1 Irradiated to a Fluence of 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV) (Transverse Orientation)							
Sample Number	**Temperature**		**Impact Energy**		**Lateral Expansion**		**Shear**
	F	**C**	**ft-lbs**	**Joules**	**mils**	**mm**	**%**
ET58	-25	-32	8	11	0	0.00	5
ET48	0	-18	7	9	6	0.15	10
ET47	25	-4	24	33	12	0.30	15
ET50	40	4	27	37	16	0.41	15
ET56	50	10	33	45	20	0.51	20
ET53	60	16	43	58	29	0.74	25
ET51	72	22	53	72	31	0.79	30
ET59	80	27	52	71	34	0.86	30
ET57	100	38	60	81	40	1.02	40
ET52	125	52	63	85	40	1.02	45
ET46	160	71	84	114	52	1.32	65
ET49	200	93	102	138	72	1.83	95
ET54	200	93	111	151	71	1.80	100
ET55	250	121	118	160	71	1.80	100
ET60	300	149	108	146	69	1.75	100

Table 5-3 Charpy V-notch Data for the Millstone Unit 3 Surveillance Weld Metal Irradiated to a Fluence of 2.21×10^{19} n/cm^2 (E> 1.0 MeV)							
Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	F	C	Ft-lbs	Joules	mils	mm	%
EW55	-100	-73	3	4	0	0.00	5
EW59	-75	-59	7	9	2	0.05	15
EW46	-50	-46	31	42	19	0.48	25
EW57	-50	-46	11	15	3	0.08	20
EW53	-45	-43	32	43	17	0.43	25
EW49	-40	-40	38	52	23	0.58	40
EW60	-25	-32	45	61	27	0.69	45
EW52	-20	-29	63	85	37	0.94	50
EW58	0	-18	68	92	44	1.12	60
EW51	25	-4	103	140	60	1.52	80
EW54	70	21	134	182	76	1.93	95
EW50	110	43	126	171	78	1.98	95
EW47	150	66	143	194	85	2.16	100
EW56	200	93	141	191	78	1.98	100
EW48	250	121	141	191	81	2.06	100

Table 5-4 Charpy V-notch Data for the Millstone Unit 3 Heat Affected Zone Material Irradiated to a Fluence of 2.21 x 10^{19} n/cm^2 (E> 1.0 MeV)

Sample Number	Temperature		Impact Energy		Lateral Expansion		Shear
	F	C	Ft-lbs	Joules	mils	mm	%
EH53	-200	-129	14	19	1	0.03	2
EH47	-175	-115	16	22	6	0.15	5
EH52	-135	-93	26	35	9	0.23	10
EH50	-125	-87	23	31	8	0.20	10
EH49	-110	-79	27	37	9	0.23	15
EH51	-100	-73	70	95	36	0.91	45
EH59	-100	-73	61	83	29	0.74	60
EH56	-80	-62	40	54	18	0.46	25
EH60	-65	-54	86	117	40	1.02	60
EH54	-50	-46	78	106	42	1.07	45
EH46	0	-18	113	153	56	1.42	90
EH48	50	10	146	198	65	1.65	85
EH58	100	38	161	218	72	1.83	100
EH55	150	66	134	182	73	1.85	100
EH57	200	93	136	184	66	1.68	100

Table 5-5 Instrumented Charpy Impact Test Results for the Millstone Unit 3 Intermediate Shell Plate B9805-1 Irradiated to a Fluence of 2.21 x 10^{19} n/cm^2 (E>1.0 MeV)(Longitudinal Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2) Charpy E_D/A	Max. E_M/A	Prop. E_p/A	Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. T_m (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
EL59	-150	2	16	7	9	920	0.1	922	0.10	920	0	31	31
EL52	-25	6	48	23	26	2548	0.15	2548	0.15	2548	0	85	85
EL47	0	14	113	53	60	3465	0.17	3761	0.21	3761	0	115	120
EL50	25	28	226	146	80	3500	0.17	3968	0.39	3918	0	117	124
EL55	30	30	242	152	90	3523	0.17	4021	0.40	3853	0	117	126
EL60	40	31	250	154	96	3349	0.17	3928	0.42	3902	0	112	121
EL58	45	50	403	298	105	3470	0.17	4247	0.68	4195	0	116	128
EL57	50	53	427	303	124	3360	0.17	4253	0.70	4070	0	112	127
EL51	60	35	282	166	116	3442	0.17	3995	0.43	3926	530	115	124
EL48	72	64	516	307	208	3385	0.17	4290	0.70	4248	724	113	128
EL49	100	91	733	298	435	3288	0.17	4229	0.70	3899	1212	109	125
EL54	150	99	798	286	512	3113	0.17	4032	0.70	3617	2244	104	119
EL46	200	128	1031	323	708	2949	0.18	4009	0.80	3276	2914	98	116
EL56	250	130	1047	326	722	2718	0.17	3908	0.82	N/A	N/A	91	110
EL53	300	138	1112	331	781	2881	0.17	3825	0.83	N/A	N/A	96	112

Table 5-6 Instrumented Charpy Impact Test Results for the Millstone Unit 3 Intermediate Shell Plate B9805-1 Irradiated to a Fluence of 2.21 x 10^{19} n/cm^2 (E>1.0 MeV) (Transverse Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2) Charpy E_D/A	Max. E_M/A	Prop. E_p/A	Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
ET58	-25	8	64	34	30	3336	0.17	3345	0.17	3336	0	111	111
ET48	0	7	56	27	29	2867	0.16	2869	0.16	2867	0	95	96
ET47	25	24	193	118	76	3370	0.17	3800	0.34	3759	0	112	119
ET50	40	27	218	130	88	3055	0.17	3831	0.38	3805	127	102	115
ET56	50	33	266	166	100	3372	0.17	4009	0.44	3973	230	112	123
ET53	60	43	346	216	131	3412	0.17	4122	0.54	4033	401	114	125
ET51	72	53	427	234	193	3097	0.17	4164	0.58	4098	910	103	121
ET59	80	52	419	281	138	3407	0.17	4153	0.66	4059	739	113	126
ET57	100	60	483	285	198	3324	0.17	4144	0.67	4029	1137	111	124
ET52	125	63	508	290	217	3231	0.17	4118	0.69	4096	1700	108	122
ET46	160	84	677	287	390	3201	0.17	4077	0.69	3877	1954	107	121
ET49	200	102	822	277	545	2741	0.17	3877	0.72	2983	2330	91	110
ET54	200	111	894	285	609	3042	0.17	3979	0.71	N/A	N/A	101	117
ET55	250	118	951	273	678	2756	0.17	3894	0.7	N/A	N/A	92	111
ET60	300	108	870	263	607	2977	0.17	3864	0.68	N/A	N/A	99	114

Table 5-7 Instrumented Charpy Impact Test Results for the Millstone Unit 3 Surveillance Weld Metal Irradiated to a Fluence of 2.21 x 10^{19} n/cm^2 (E>1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2)			Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_p/A								
EW55	-100	3	24	8	16	1129	0.11	1138	0.1	1129	0	38	38
EW59	-75	7	56	28	29	3131	0.15	3137	0.15	3131	0	104	104
EW46	-50	31	250	68	181	4114	0.17	4484	0.22	4460	507.65	137	143
EW57	-50	11	89	46	43	4066	0.18	4066	0.18	4066	0	135	135
EW53	-45	32	258	164	94	4097	0.17	4495	0.39	4410	34	136	143
EW49	-40	38	306	198	108	4144	0.17	4639	0.44	4602	477	138	146
EW60	-25	45	363	224	139	3740	0.18	4657	0.51	4501	1273	125	140
EW52	-20	63	508	332	176	3905	0.17	4587	0.69	4464	979	130	141
EW58	0	68	548	246	302	3988	0.17	4645	0.53	4504	2056	133	144
EW51	25	103	830	326	504	3821	0.17	4517	0.69	3783	1683	127	139
EW54	70	134	1080	321	759	3825	0.17	4500	0.68	3456	2450	127	139
EW50	110	126	1015	310	705	3583	0.17	4303	0.7	2660	2177	119	131
EW47	150	143	1152	310	842	3510	0.17	4333	0.69	N/A	N/A	117	131
EW56	200	141	1136	298	838	3340	0.17	4231	0.69	N/A	N/A	111	126
EW48	250	141	1136	296	840	3309	0.17	4178	0.69	N/A	N/A	110	125

Table 5-8 Instrumented Charpy Impact Test Results for the Millstone Unit 3 Heat-Affected-Zone (HAZ) Metal Irradiated to a Fluence of 2.21 x 10^{19} n/cm^2 (E>1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2) Charpy E_D/A	Max. E_M/A	Prop. E_p/A	Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress S_Y (ksi)	Flow Stress (ksi)
EH53	-200	14	113	63	50	4256	0.17	4973	0.21	4963	0	142	154
EH47	-175	16	129	74	55	4491	0.17	5230	0.22	5226	0	150	162
EH52	-135	26	209	83	126	4688	0.18	5119	0.24	4888	0	156	163
EH50	-125	23	185	85	100	4509	0.18	5062	0.25	4953	0	150	159
EH49	-110	27	218	84	134	4529	0.18	4929	0.24	4675	0	151	157
EH51	-100	70	564	260	304	4088	0.17	4900	0.54	4536	0	136	150
EH59	-100	61	491	255	237	4278	0.17	4949	0.52	4874	398	142	154
EH56	-80	40	322	239	84	3850	0.18	4890	0.52	4884	0	128	146
EH60	-65	86	693	352	341	4276	0.18	4889	0.69	4636	1852	142	153
EH54	-50	78	628	254	374	3874	0.18	4715	0.55	3864	0	129	143
EH46	0	113	910	250	661	3998	0.18	4612	0.55	3788	3471	133	143
EH48	50	146	1176	332	844	3858	0.17	4659	0.69	2731	1148	128	142
EH58	100	161	1297	327	970	3513	0.17	4614	0.7	N/A	N/A	117	135
EH55	150	134	1080	307	773	3301	0.21	4326	0.72	N/A	N/A	110	127
EH57	200	136	1096	307	789	3163	0.16	4398	0.69	N/A	N/A	105	126

Table 5-9 Effect of Irradiation to 2.21 x 10^{19} n/cm^2 (E>1.0 MeV) on the Notch Toughness Properties of the Millstone Unit 3 Reactor Vessel Surveillance Materials

Material	Average 30 (ft-lb)[a] Transition Temperature (°F)			Average 35 mil Lateral[b] Expansion Temperature (°F)			Average 50 ft-lb[a] Transition Temperature (°F)			Average Energy Absorption[a] at Full Shear (ft-lb)		
	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔT	Unirradiated	Irradiated	ΔE
Inter. Shell Plate B9805-1 (Long.)	2.45	28.27	25.82	23.24	72.34	49.1	30.33	59.02	28.69	133	132	-1
Inter. Shell Plate B9805-1 (Trans.)	17.44	43.22	25.77	48.9	91.49	42.59	54.8	81.04	26.24	111	110	-1
Weld Metal	-36.96	-43.74	-6.78	-15.34	-14.68	0.66	-17.29	-21.79	-4.49	143	142	-1
HAZ Metal	-171.86	-127.89	43.96	-120.34	-66.16	54.18	-127.71	-95.95	31.76	142	144	2

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

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

Table 5-10 Comparison of the Millstone Unit 3 Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper Shelf Energy Decreases with Regulatory Guide 1.99, Revision 2, Predictions

Material	Capsule	Fluence (x 10^{19} n/cm^2)	30 ft-lb Transition Temperature Shift		Upper Shelf Energy Decrease	
			Predicted (°F) [(a)]	Measured (°F) [(b)]	Predicted (%) [(a)]	Measured (%)[(c)]
Intermediate Shell Plate B9805-1 (Longitudinal)	U	0.449	24.09	25.79	16	0
	X	2.21	37.67	25.82	23	1
Intermediate Shell Plate B9805-1 (Transverse)	U	0.449	24.09	21.85	16	3
	X	2.21	37.67	31.31	23	1
Weld Metal	U	0.449	23.31	30.37	16	6
	X	2.21	36.45	0.0[(d)]	23	1
HAZ Metal	U	0.449	- -	56.46	- -	1
	X	2.21	- -	43.96	- -	0

Notes:

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

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

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

(d) The actual measured capsule X ΔRT_{NDT} value is –4.49°F. This physically should not occur, therefore for conservatism a value of zero will be reported.

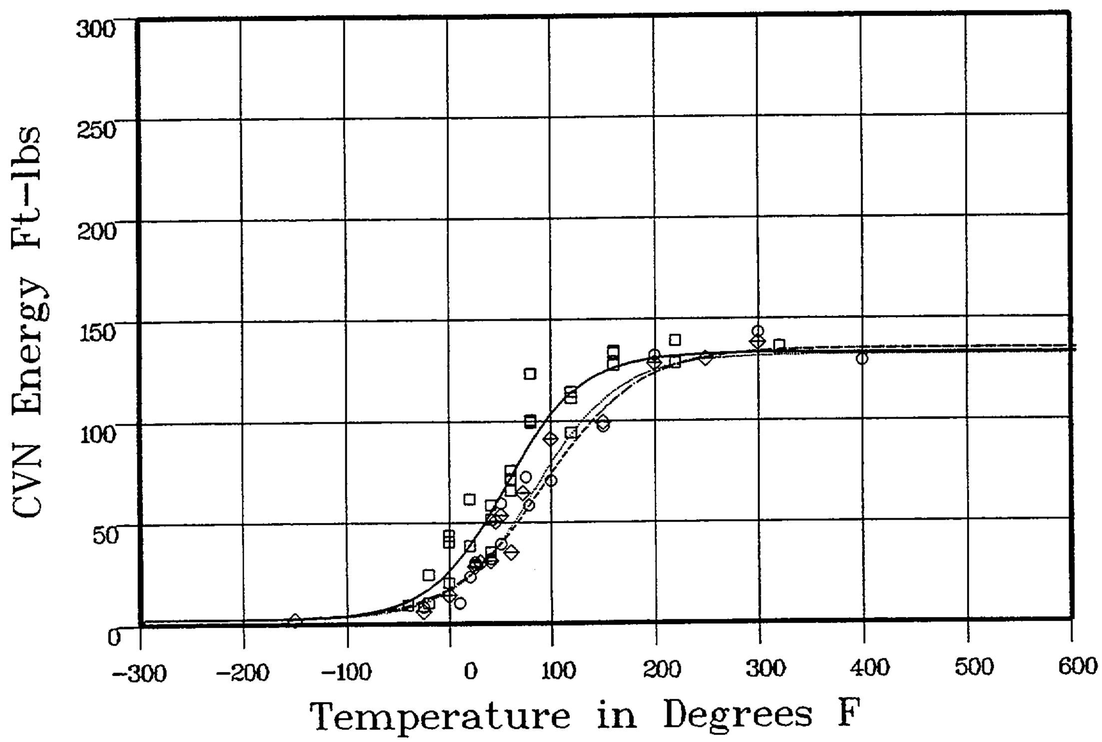
Table 5-11 Tensile Properties of the Millstone Unit 3 Reactor Vessel Surveillance Materials Irradiated to 2.21 x 10^{19} n/cm^2 (E > 1.0 MeV)										
Material	**Sample Number**	**Test Temp. (°F)**	**0.2% Yield Strength (ksi)**	**Ultimate Strength (ksi)**	**Fracture Load (kip)**	**Fracture Stress (ksi)**	**Fracture Strength (ksi)**	**Uniform Elongation (%)**	**Total Elongation (%)**	**Reduction in Area (%)**
Intermediate Shell B9805-1 (Longitudinal)	EL 10	73	68.0	91.6	2.80	189.7	57.0	12.1	27.4	70
	EL 11	175	67.7	87.2	2.77	174.8	56.4	11.6	25.2	68
	EL 12	550	60.1	88.4	3.04	147.7	62.0	11.7	23.5	58
Intermediate Shell B9805-1 (Transverse)	ET 10	100	69.3	90.1	3.76	212.8	76.6	12.2	25.7	64
	ET 11	185	67.2	86.2	2.93	175.1	59.7	11.7	25.8	66
	ET 12	550	62.6	87.3	3.11	158.5	63.3	11.3	21.8	60
Weld	EW 10	0	84.0	100.2	3.12	242.5	63.6	9.8	24.0	74
	EW 11	100	80.5	94.5	2.91	203.2	59.2	9.4	23.3	71
	EW 12	550	74.9	93.5	3.29	169.8	67.0	9.7	21.2	61

INTERMEDIATE SHELL PLATE B9805-1 (LONG.)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:06:24 on 04-04-2000

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	133	0	2.45	0	30.33	0
2	4.49E+18	2.19	0	135	2	28.25	25.79	62.55	32.22
3	2.21E+19	2.19	0	132	-1	28.27	25.82	59.02	28.69



Curve Legend

1 □———— 2 ○---------- 3 ◇————

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	ML3	UNIRR	PLATE SA533B1	LT	C4039-2
2	ML3	U	PLATE SA533B1	LT	C4039-2
3	ML3	X	PLATE SA533B1	LT	C4039-2

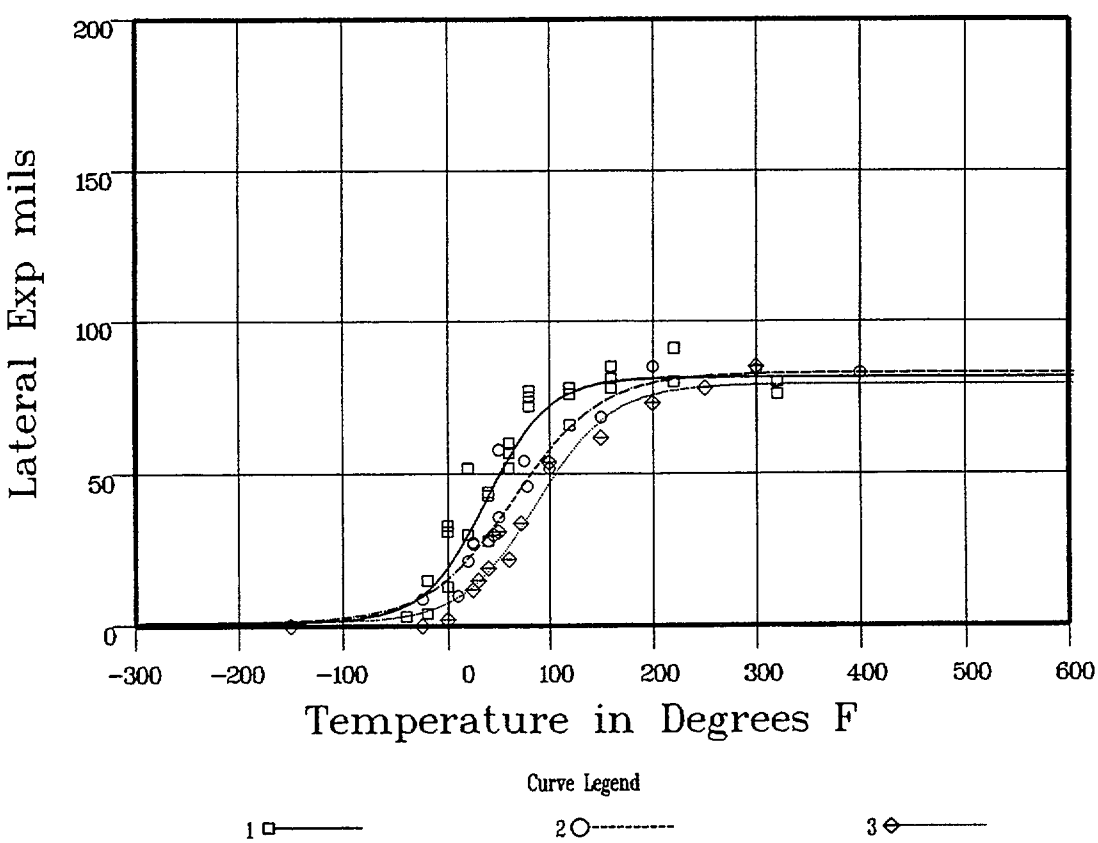
Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Millstone Unit 3 Reactor Vessel Intermediate Shell Plate B9805-1 (Longitudinal Orientation)

INTERMEDIATE SHELL PLATE B9805-1 (LONG.)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:11:14 on 04-04-2000

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	81.47	0	23.24	0
2	4.49E+18	82.87	1.39	45.47	22.23
3	2.21E+19	79.2	-2.27	72.34	49.1



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	ML3	UNIRR	PLATE SA533B1	LT	C4039-2
2	ML3	U	PLATE SA533B1	LT	C4039-2
3	ML3	X	PLATE SA533B1	LT	C4039-2

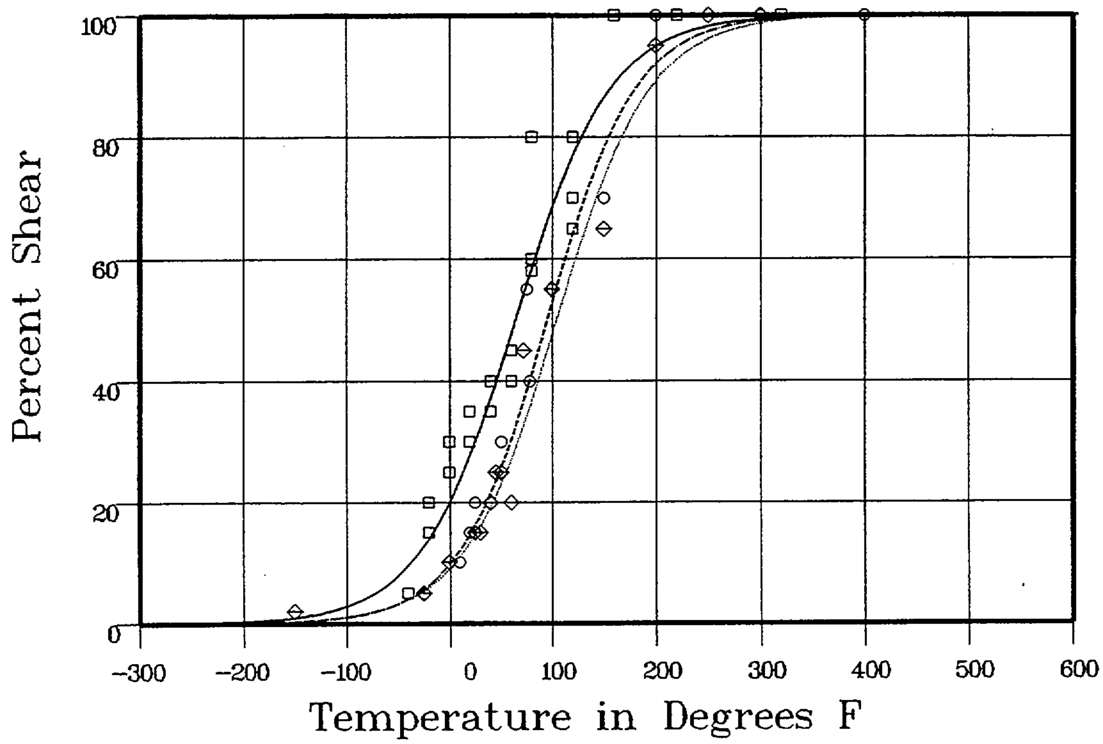
Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Millstone Unit 3 Reactor Vessel Intermediate Shell Plate B9805-1 (Longitudinal Orientation)

INTERMEDIATE SHELL PLATE B9805-1 (LONG.)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:15:02 on 04-04-2000

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	59.53	0
2	4.49E+18	90.58	31.05
3	2.21E+19	99.9	40.37



Curve Legend

1 □———— 2 ○---------- 3 ◇————

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	ML3	UNIRR	PLATE SA533B1	LT	C4039-2
2	ML3	U	PLATE SA533B1	LT	C4039-2
3	ML3	X	PLATE SA533B1	LT	C4039-2

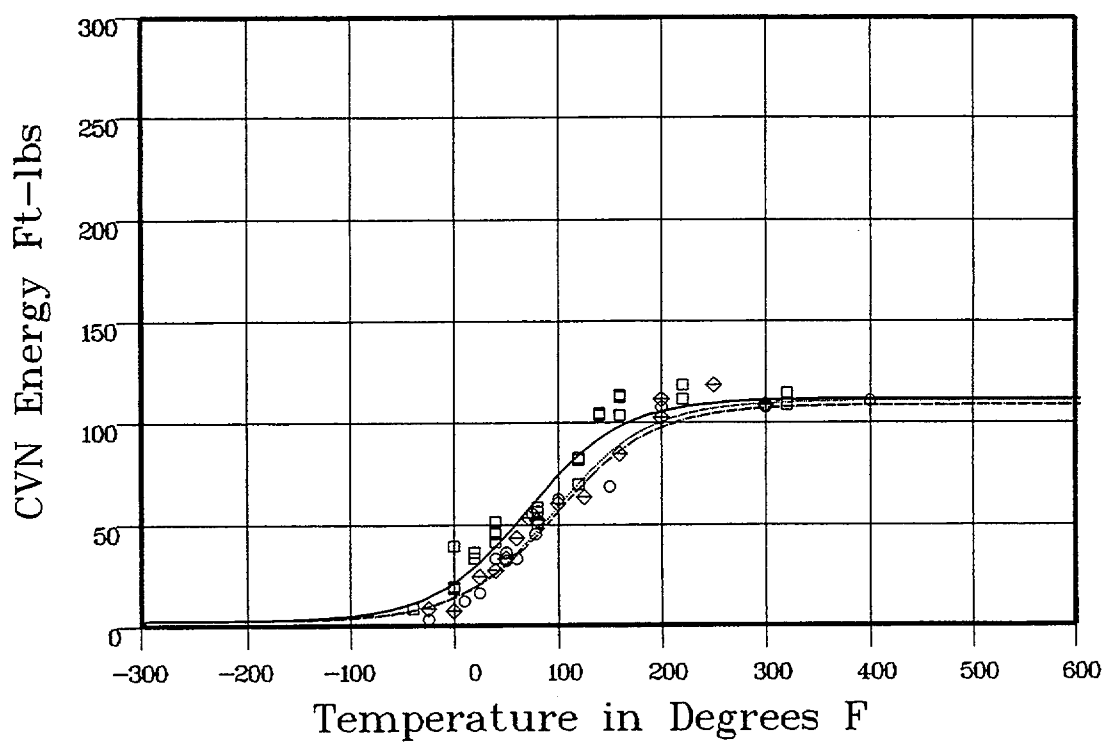
Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Millstone Unit 3 Reactor Vessel Intermediate Shell Plate B9805-1 (Longitudinal Orientation)

INTERMEDIATE SHELL PLATE B9805–1 (TRANS.)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:19:17 on 04-04-2000

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	111	0	17.44	0	54.8	0
2	4.49E+18	2.19	0	108	-3	45.57	28.12	84.65	29.85
3	2.21E+19	2.19	0	110	-1	43.22	25.77	81.04	26.24



Curve Legend

1 □——— 2 O---------- 3 ◇———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	ML3	UNIRR	PLATE SA533B1	TL	C4039-2
2	ML3	U	PLATE SA533B1	TL	C4039-2
3	ML3	X	PLATE SA533B1	TL	C4039-2

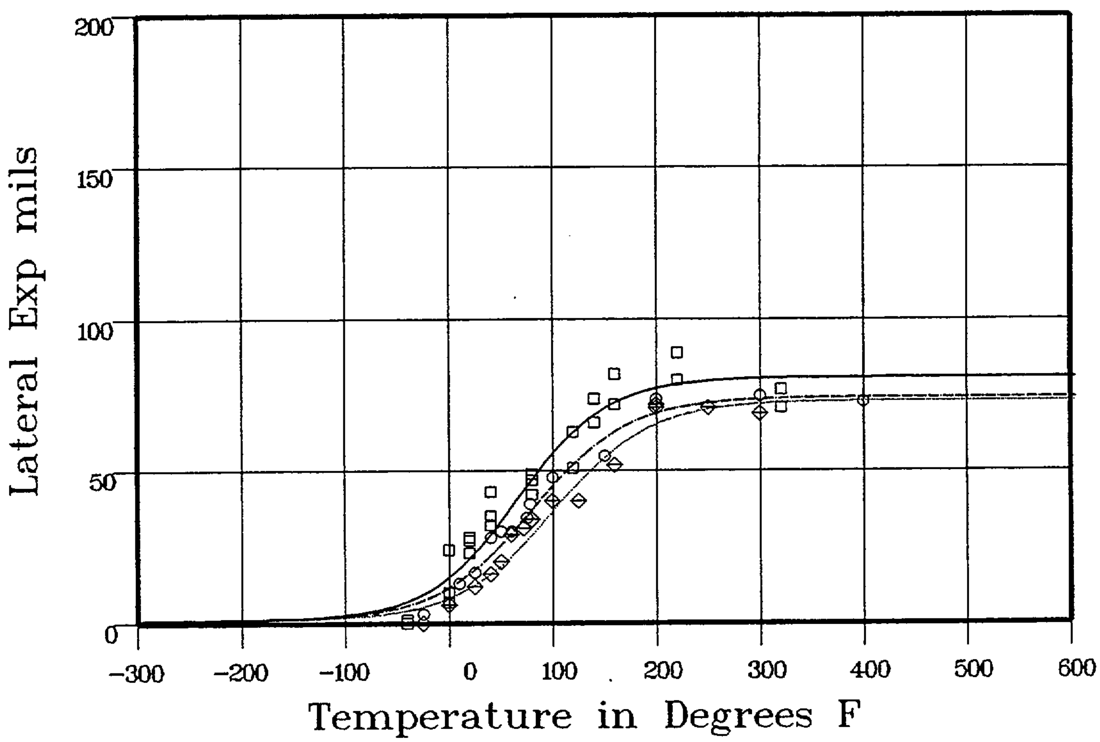
Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Millstone Unit 3 Reactor Vessel Intermediate Shell Plate B9805-1 (Transverse Orientation)

INTERMEDIATE SHELL PLATE B9805–1 (TRANS.)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:22:18 on 04-04-2000

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	80.95	0	48.9	0
2	4.49E+18	74.45	-6.5	70.01	21.11
3	2.21E+19	73.31	-7.64	91.49	42.59



Curve Legend

1 □——— 2 ○------- 3 ◇———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	ML3	UNIRR	PLATE SA533B1	TL	C4039-2
2	ML3	U	PLATE SA533B1	TL	C4039-2
3	ML3	X	PLATE SA533B1	TL	C4039-2

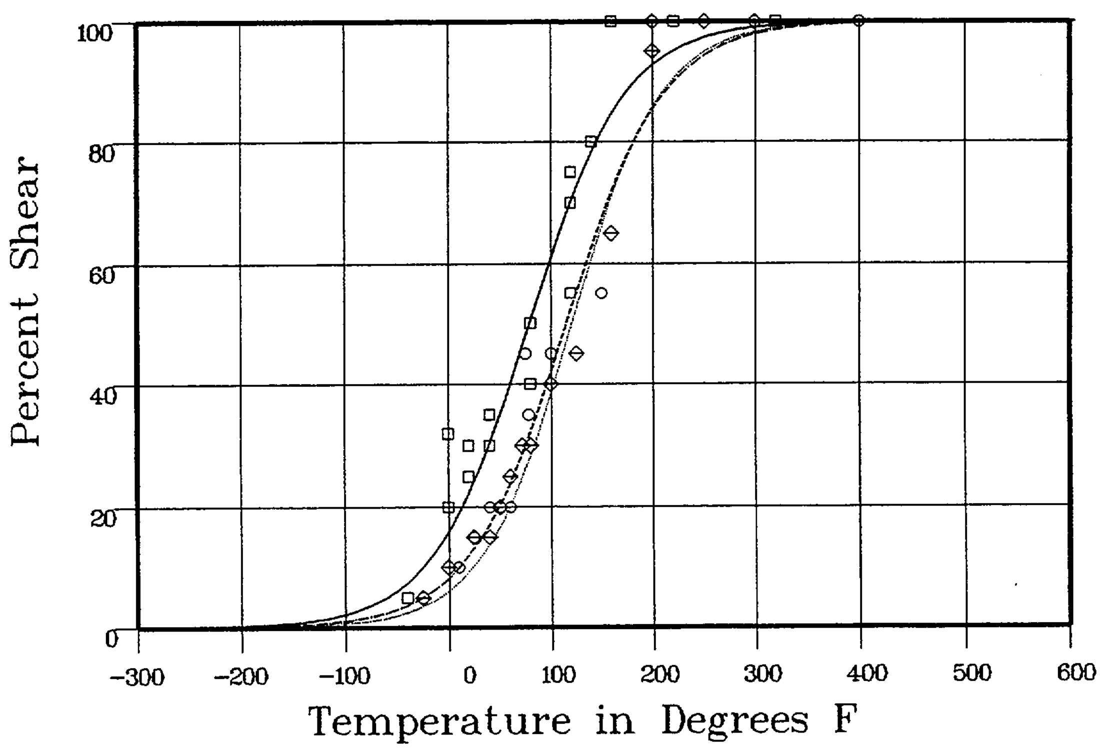
Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Millstone Unit 3 Reactor Vessel Intermediate Shell Plate B9805-1 (Transverse Orientation)

INTERMEDIATE SHELL PLATE B9805-1 (TRANS.)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:24:54 on 04-04-2000

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	74.35	0
2	4.49E+18	110.58	36.23
3	2.21E+19	116.01	41.66



Curve Legend

1 □——— 2 ○--------- 3 ◇———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	ML3	UNIRR	PLATE SA533B1	TL	C4039-2
2	ML3	U	PLATE SA533B1	TL	C4039-2
3	ML3	X	PLATE SA533B1	TL	C4039-2

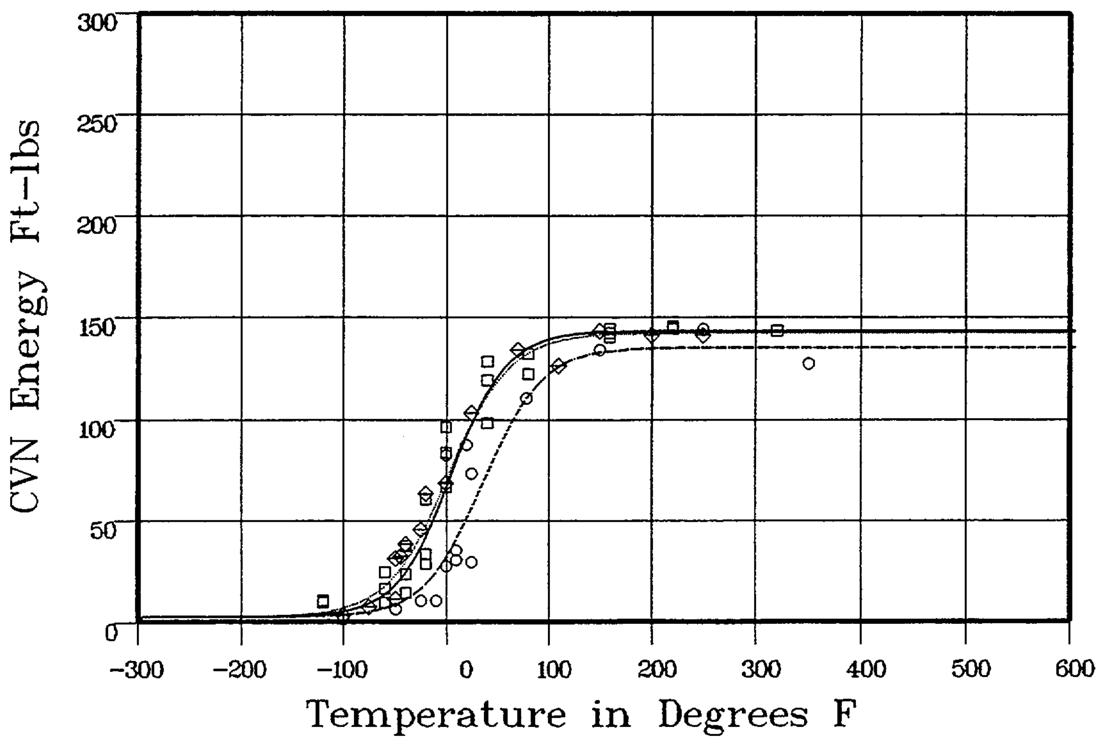
Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Millstone Unit 3 Reactor Vessel Intermediate Shell Plate B9805-1 (Transverse Orientation)

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:33:25 on 04-04-2000

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	143	0	-36.96	0	-17.29	0
2	4.49E+18	2.19	0	135	-8	-6.58	30.37	14.94	32.24
3	2.21E+19	2.19	0	142	-1	-43.74	-6.78	-21.79	-4.49



Curve Legend

1 □———— 2 ○---------- 3 ◇————

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	ML3	UNIRR	WELD		4P6052
2	ML3	U	WELD		4P6052
3	ML3	X	WELD		4P6052

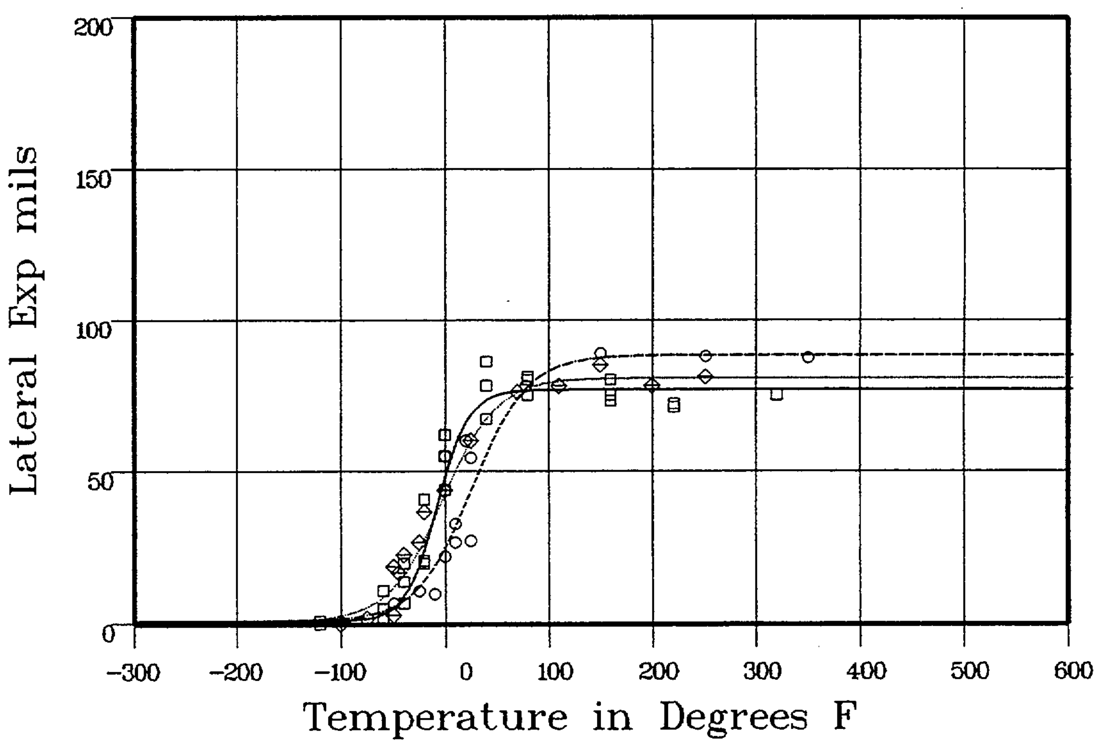
Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for Millstone Unit 3 Reactor Vessel Weld Metal

SURVEILANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:35:57 on 04-04-2000

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	76.73	0	-15.34	0
2	4.49E+18	88.3	11.57	9.24	24.58
3	2.21E+19	80.51	3.77	-14.68	.66



Curve Legend

1 □———— 2 ○--------- 3 ◇————

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	ML3	UNIRR	WELD		4P6052
2	ML3	U	WELD		4P6052
3	ML3	X	WELD		4P6052

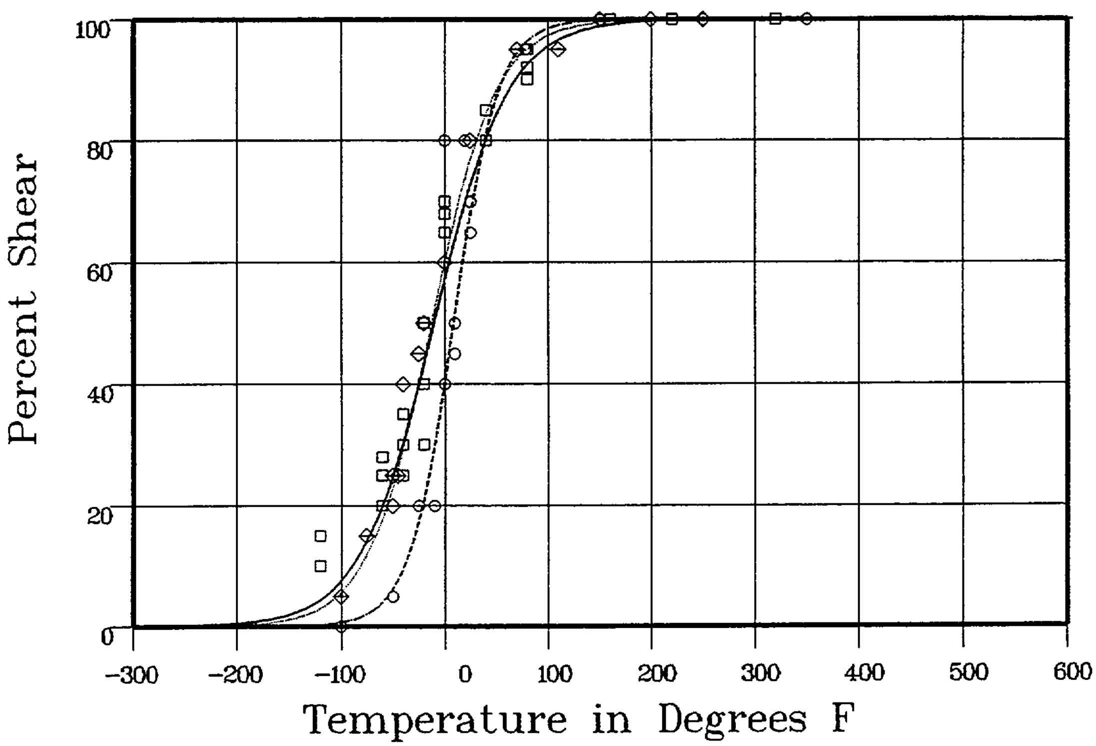
Figure 5-8 Charpy V-Notch Lateral Expansion vs. Temperature for Millstone Unit 3 Reactor Vessel Weld Metal

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:38:56 on 04-04-2000

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	-15	0
2	4.49E+18	3.95	18.95
3	2.21E+19	-17.13	-2.13



Curve Legend

1 □——— 2 ○--------- 3 ◇———

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	ML3	UNIRR	WELD		4P6052
2	ML3	U	WELD		4P6052
3	ML3	X	WELD		4P6052

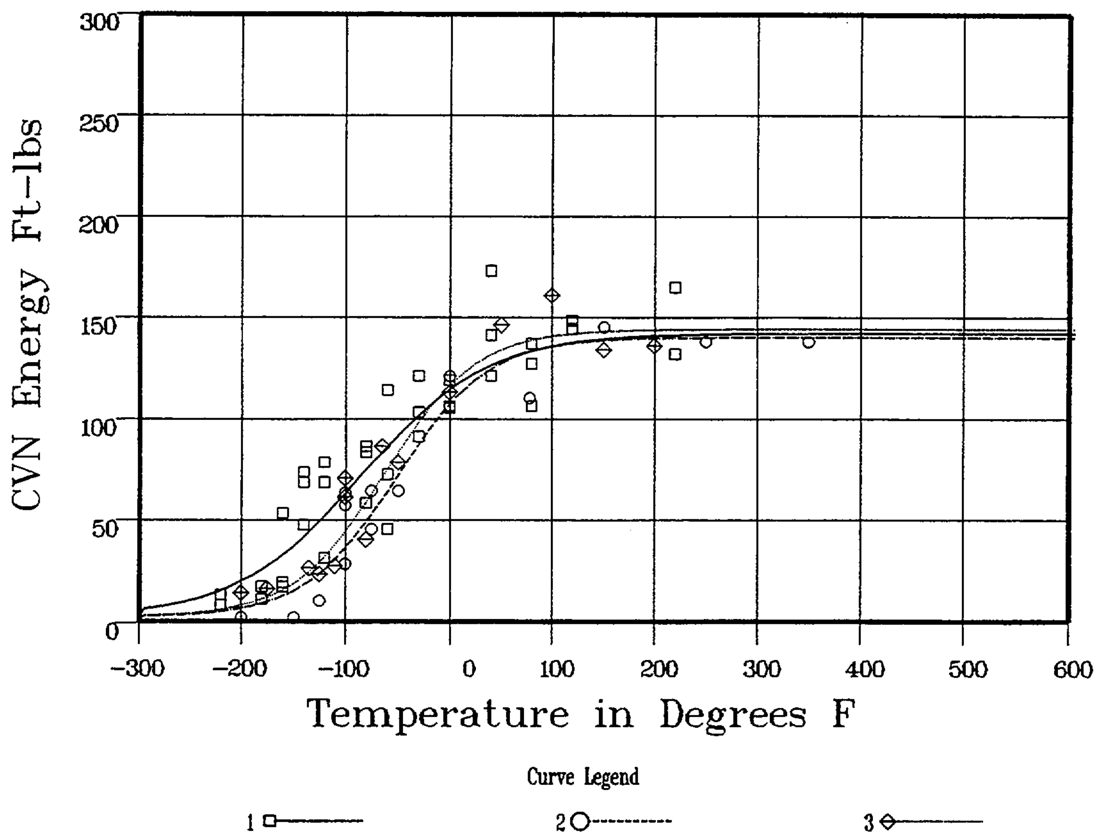
Figure 5-9 Charpy V-Notch Percent Shear vs Temperature for Millstone Unit 3 Reactor Vessel Weld Metal

HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:16:11 on 04-05-2000

Results

Curve	Fluence	LSE	d-LSE	USE	d-USE	T @ 30	d-T @ 30	T @ 50	d-T @ 50
1	0	2.19	0	142	0	-171.86	0	-127.71	0
2	4.49E+18	2.19	0	140	-2	-115.39	56.46	-82.95	44.76
3	2.21E+19	2.19	0	144	2	-127.89	43.96	-95.95	31.76



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	ML3	UNIRR	HEAT AFFD ZONE		C4039-2
2	ML3	U	HEAT AFFD ZONE		C4039-2
3	ML3	X	HEAT AFFD ZONE		C4039-2

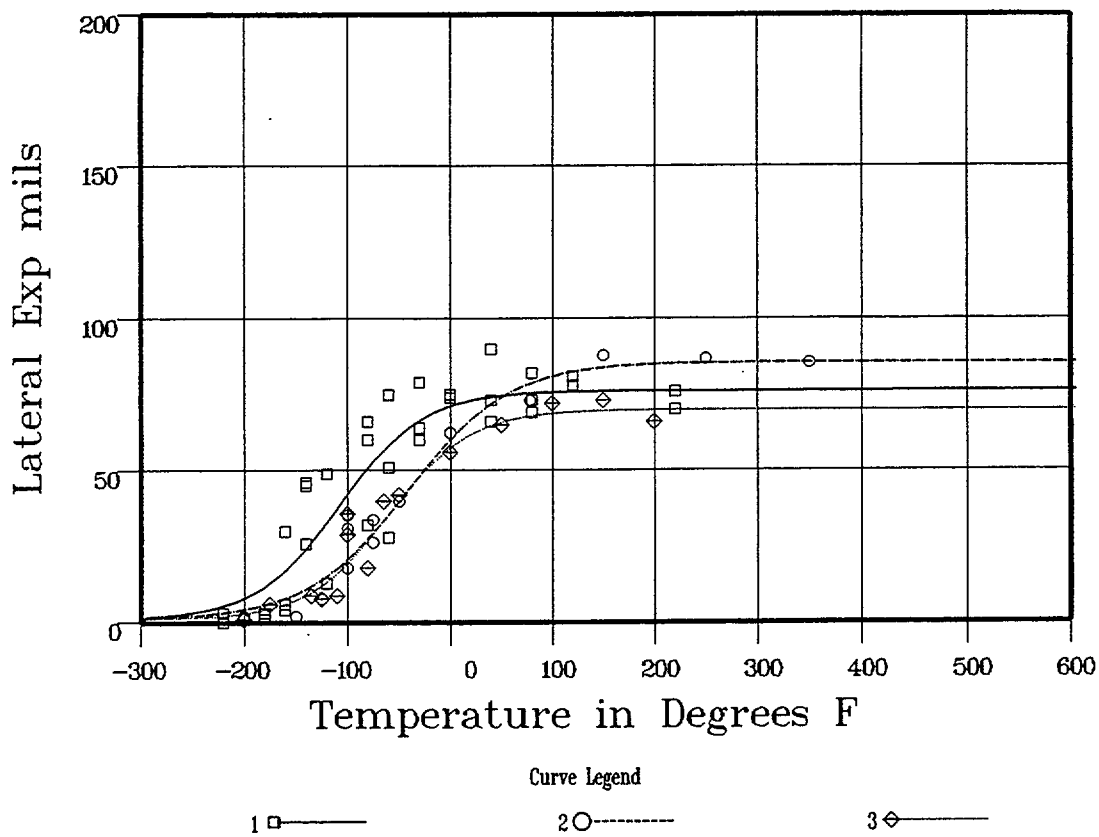
Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for Millstone Unit 3 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:59:43 on 04-04-2000

Results

Curve	Fluence	USE	d-USE	T @ LE35	d-T @ LE35
1	0	76.2	0	-120.34	0
2	4.49E+18	85.59	9.38	-66.18	54.16
3	2.21E+19	69.91	-6.28	-66.16	54.18



Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	ML3	UNIRR	HEAT AFFD ZONE		C4039-2
2	ML3	U	HEAT AFFD ZONE		C4039-2
3	ML3	X	HEAT AFFD ZONE		C4039-2

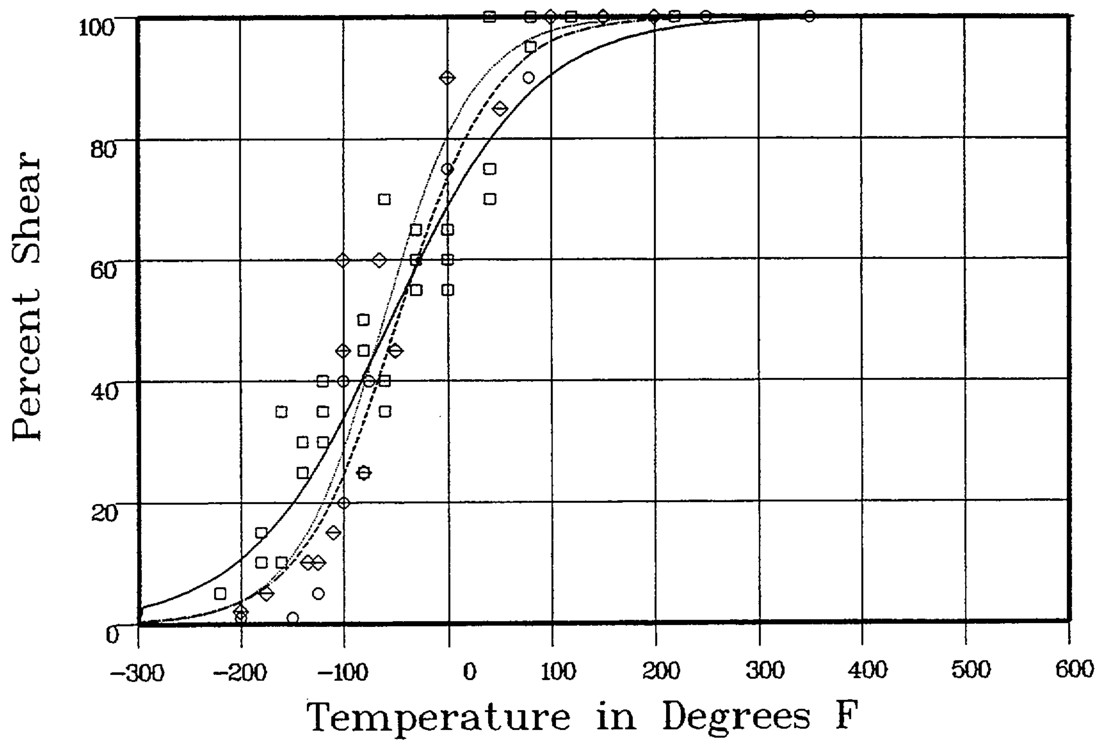
Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for Millstone Unit 3 Reactor Vessel Heat-Affected-Zone Material

HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:23:17 on 04-05-2000

Results

Curve	Fluence	T @ 50% Shear	d-T @ 50% Shear
1	0	-59.06	0
2	4.49E+18	-52.5	6.56
3	2.21E+19	-65.62	-6.56



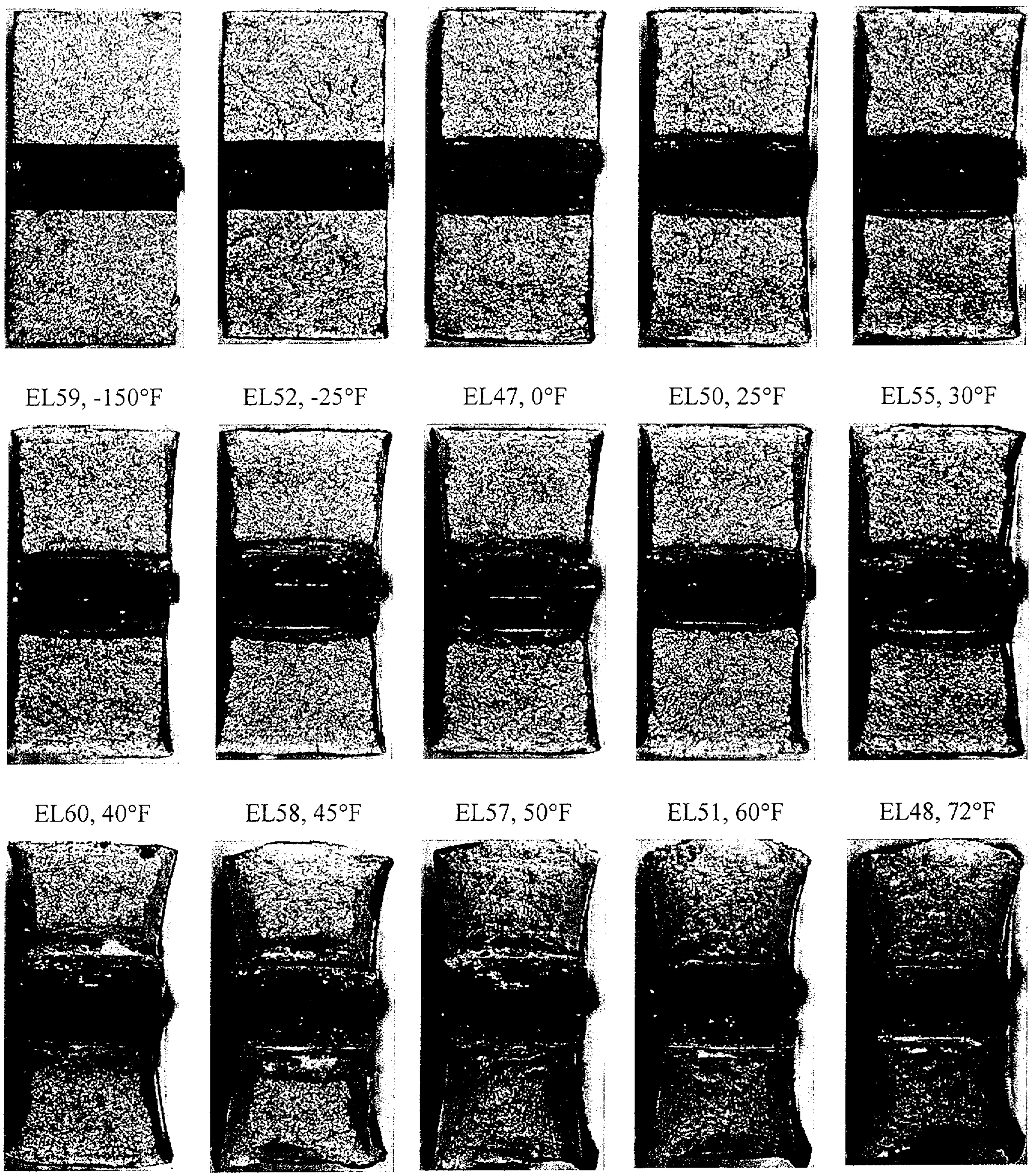
Curve Legend

1 □———— 2 ○---------- 3 ◇————

Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat#
1	ML3	UNIRR	HEAT AFFD ZONE		C4039-2
2	ML3	U	HEAT AFFD ZONE		C4039-2
3	ML3	X	HEAT AFFD ZONE		C4039-2

Figure 5-12 Charpy V-Notch Percent Shear vs. Temperature for Millstone Unit 3 Reactor Vessel Heat-Affected-Zone Material



EL49, 100°F EL54, 150°F EL46, 200°F EL56, 250°F EL53, 300°F

Figure 5-13 **Charpy Impact Specimen Fracture Surfaces for Millstone Unit 3 Reactor Vessel Intermediate Shell Plate B9805-1 (Longitudinal Orientation)**

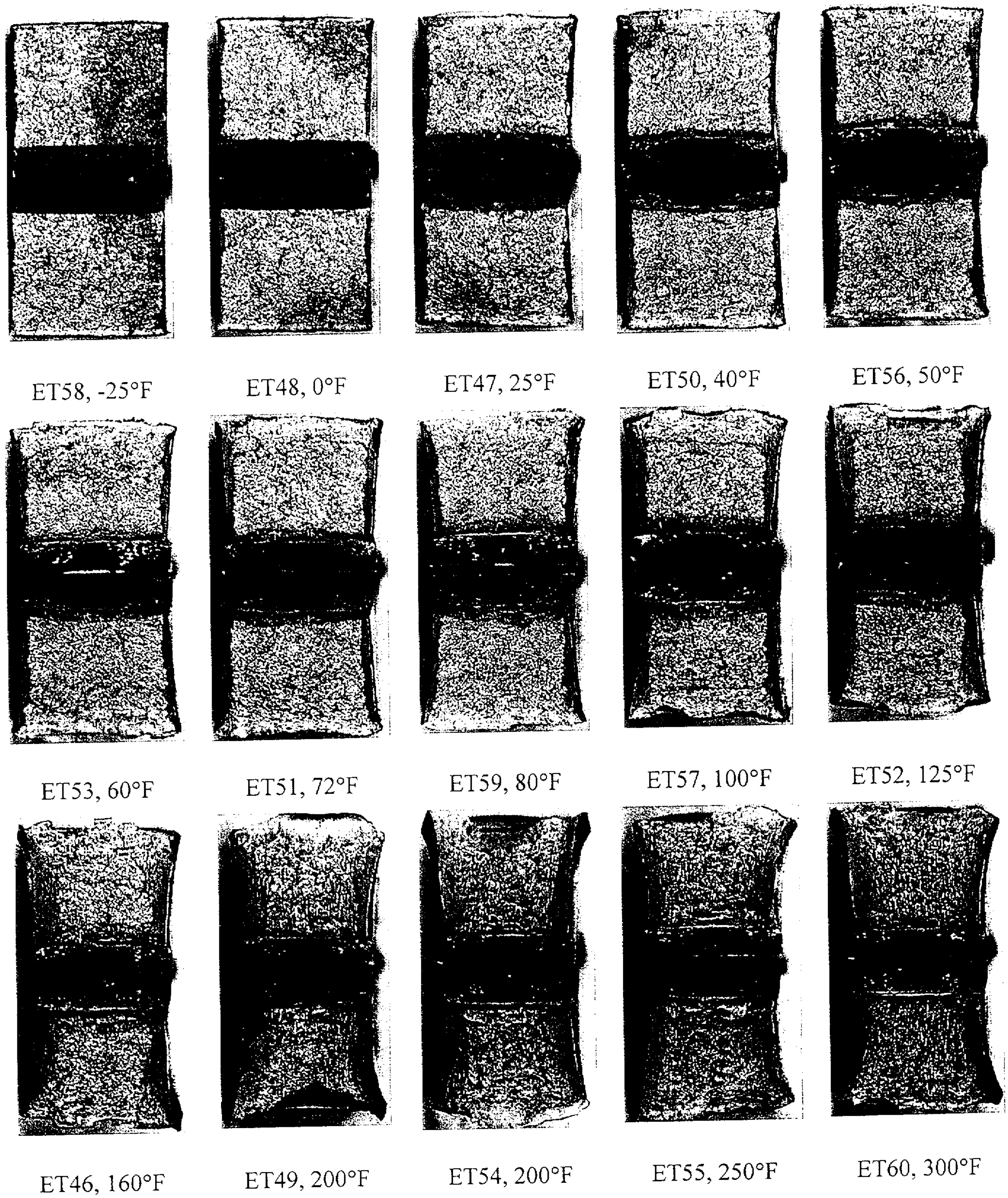


Figure 5-14 Charpy Impact Specimen Fracture Surfaces for Millstone Unit 3 Reactor Vessel Intermediate Shell Plate B9805-1 (Transverse Orientation)

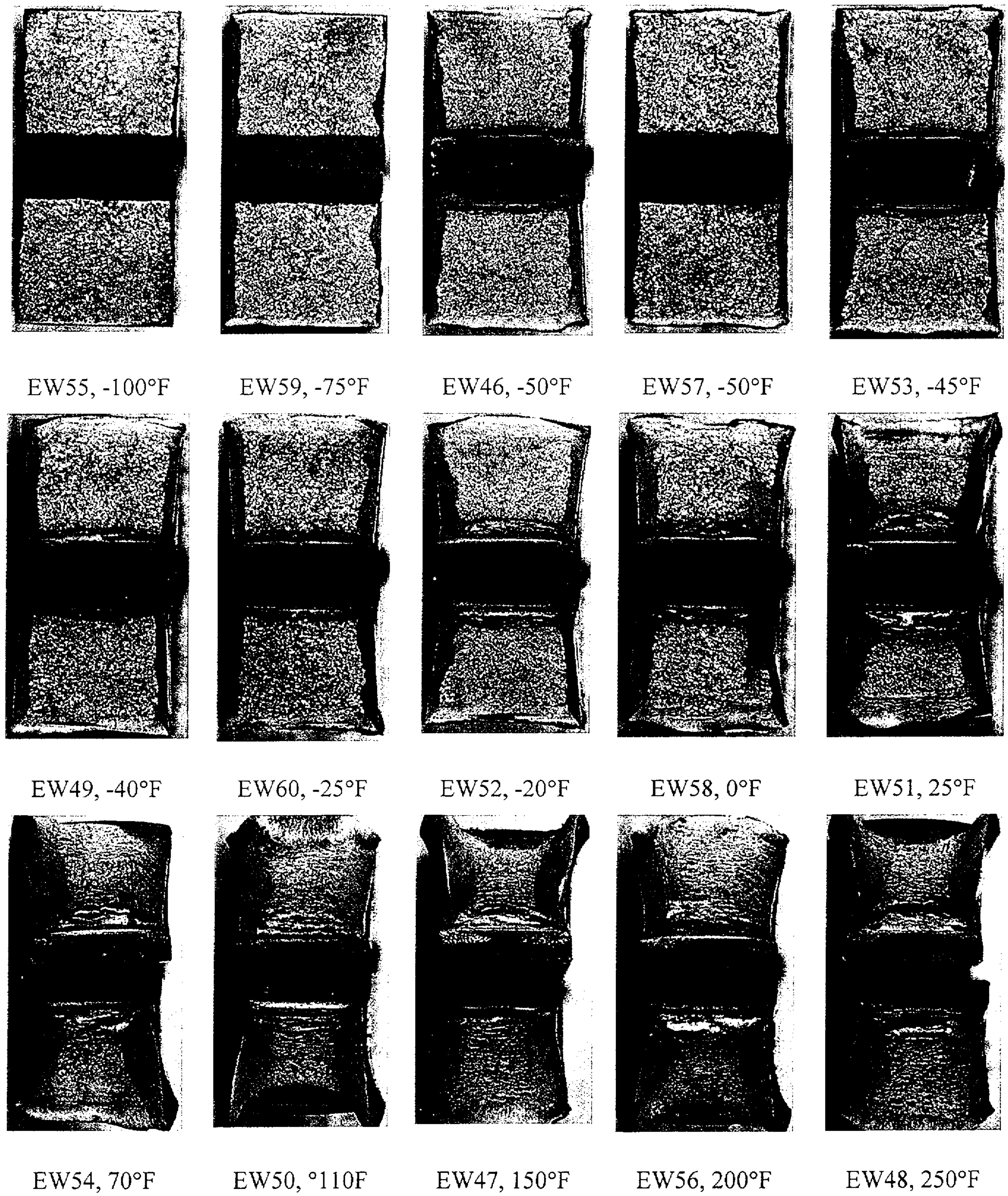


Figure 5-15 Charpy Impact Specimen Fracture Surfaces for Millstone Unit 3 Reactor Vessel Weld Metal

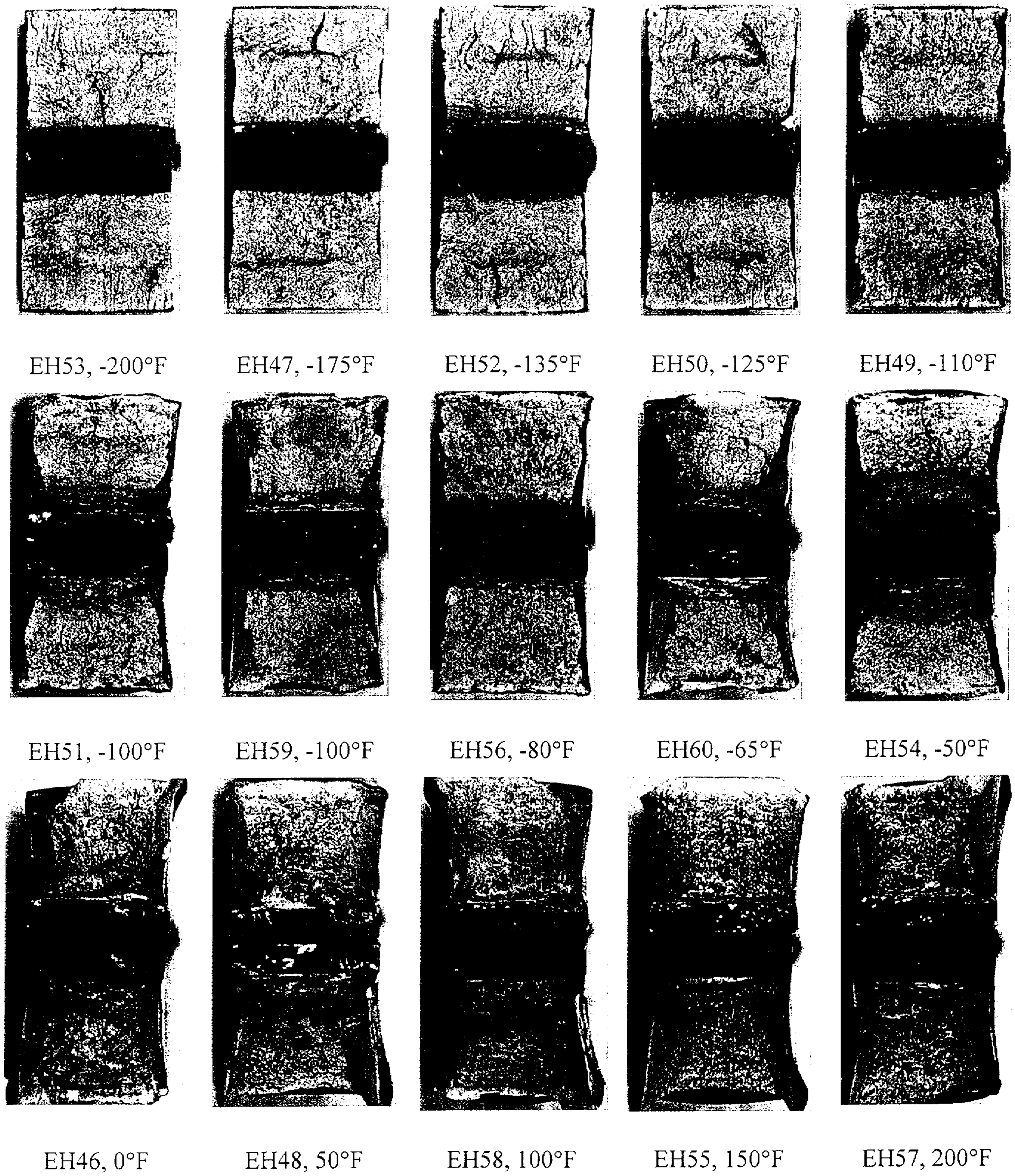


Figure 5-16 **Charpy Impact Specimen Fracture Surfaces for Millstone Unit 3 Reactor Vessel Heat-Affected-Zone Metal**

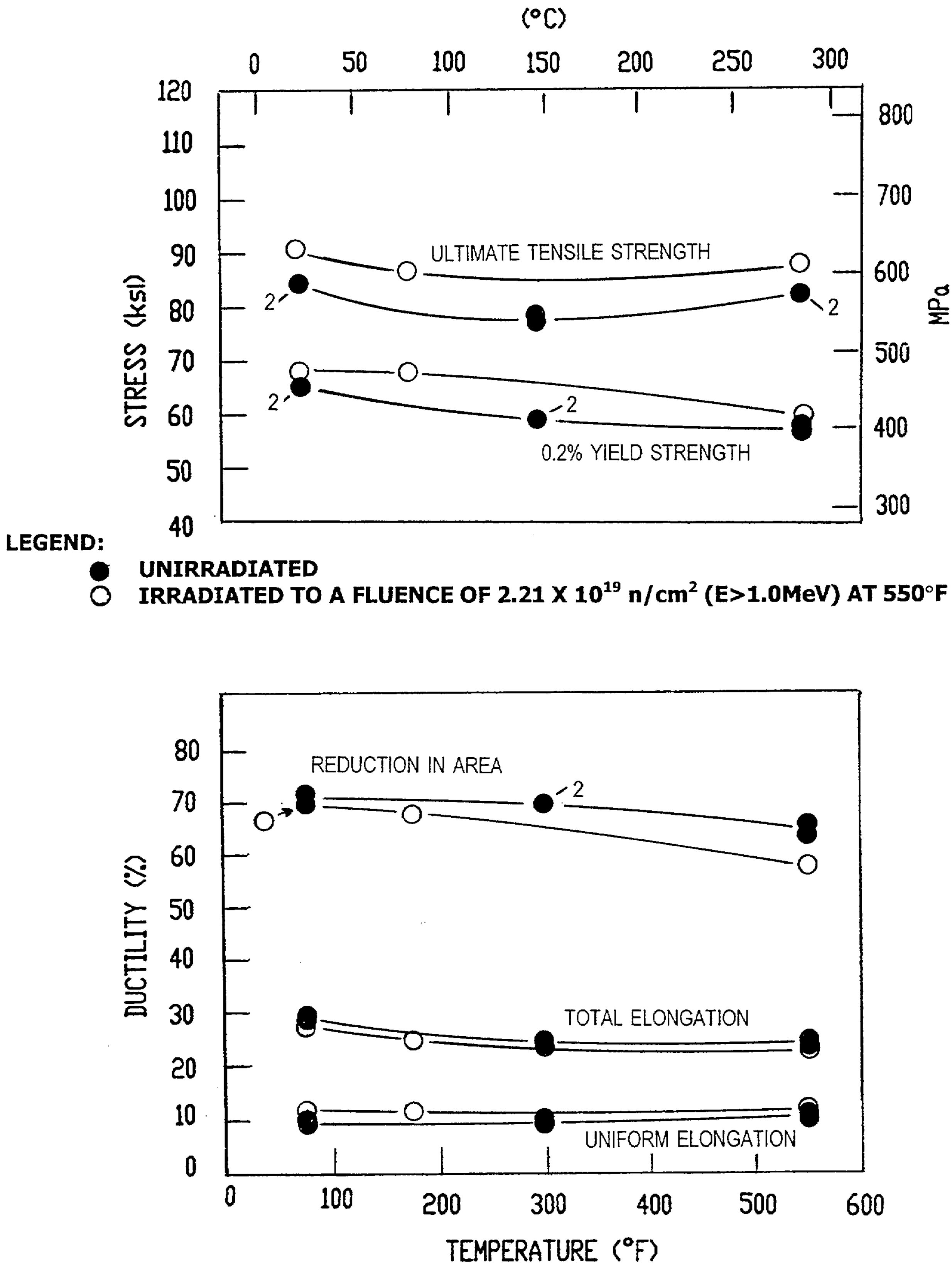


Figure 5-17 Tensile Properties for Millstone Unit 3 Reactor Vessel Intermediate Shell Plate B9805-1 (Longitudinal Orientation)

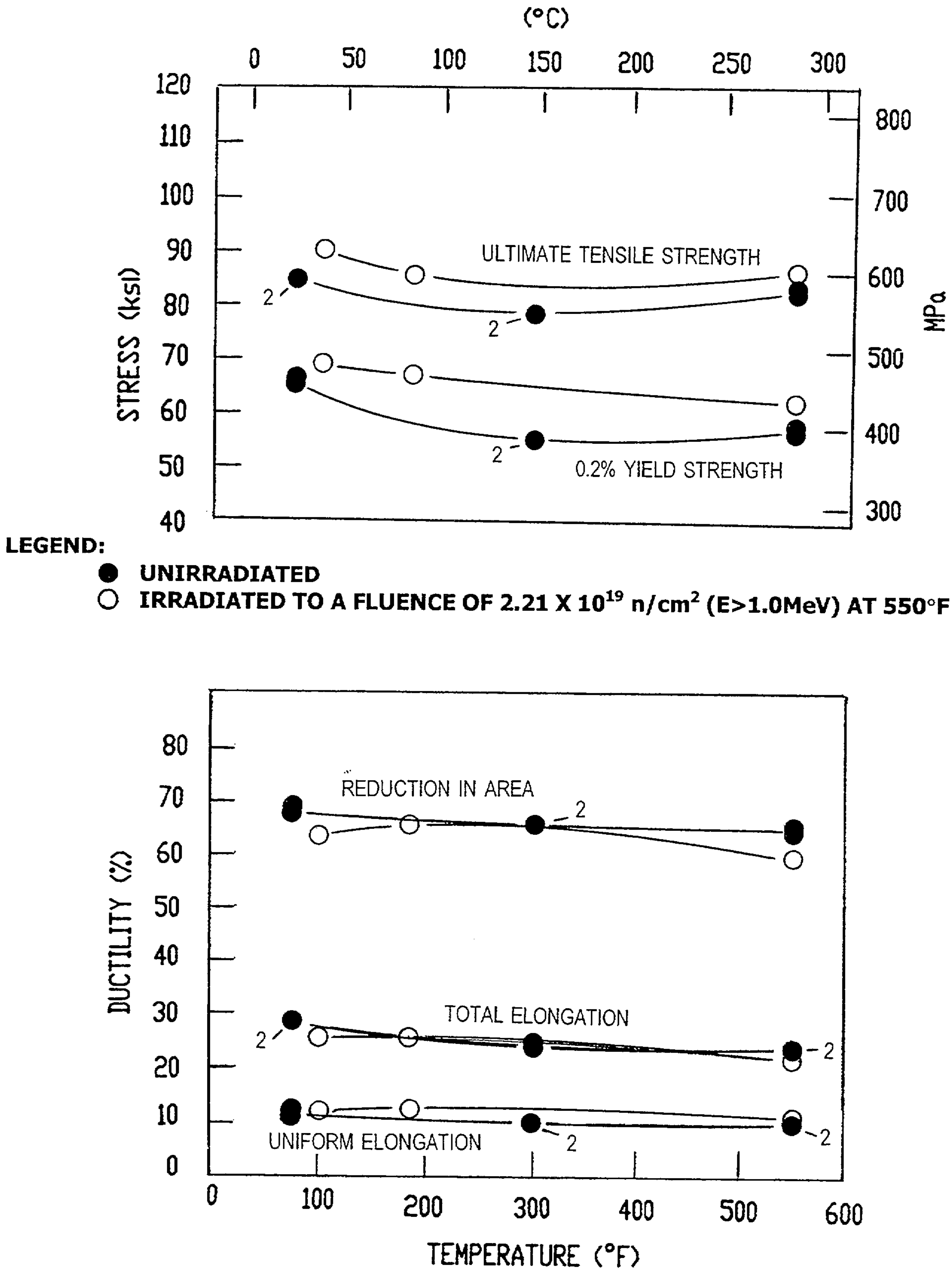


Figure 5-18 **Tensile Properties for Millstone Unit 3 Reactor Vessel Intermediate Shell Plate B9805-1 (Transverse Orientation)**

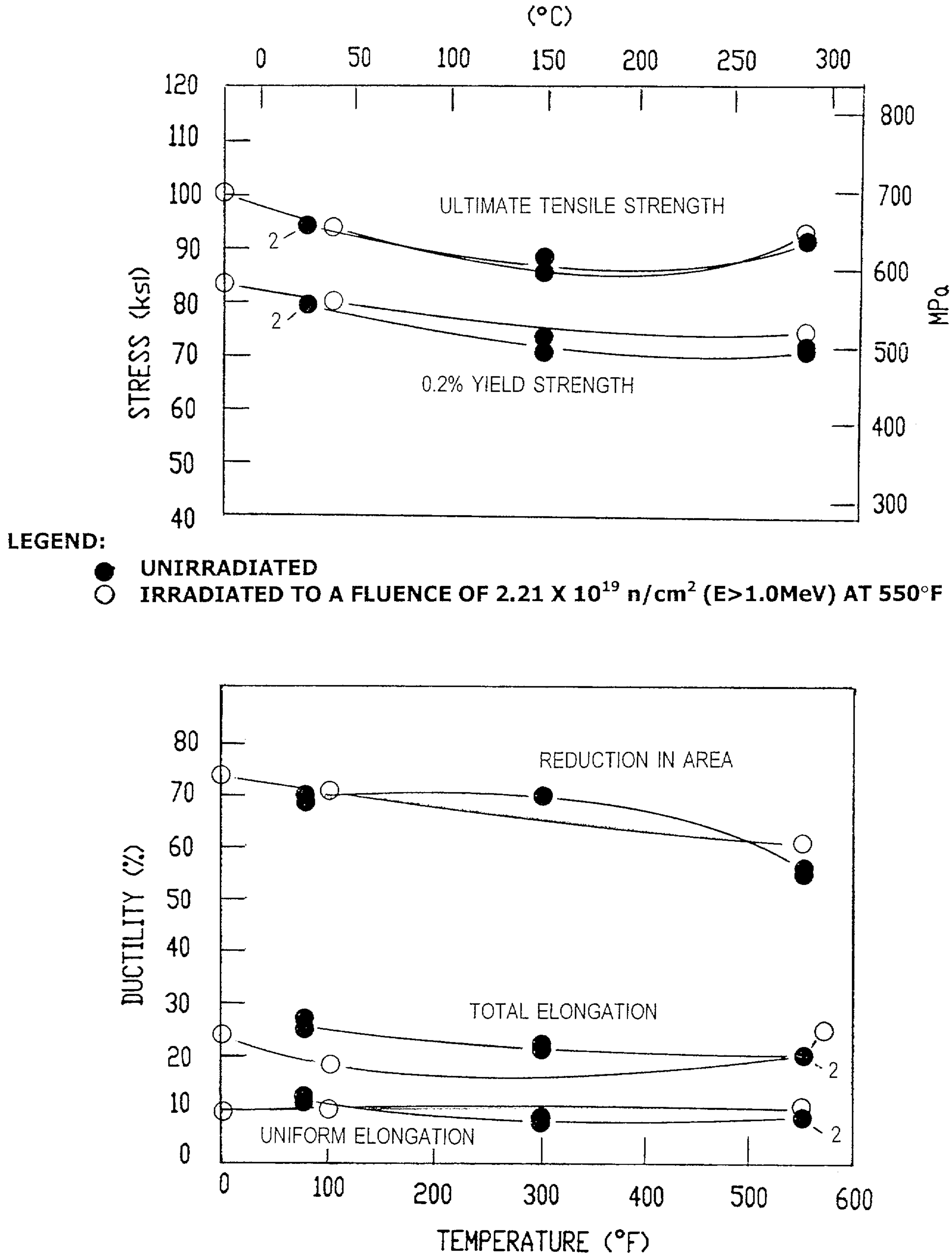
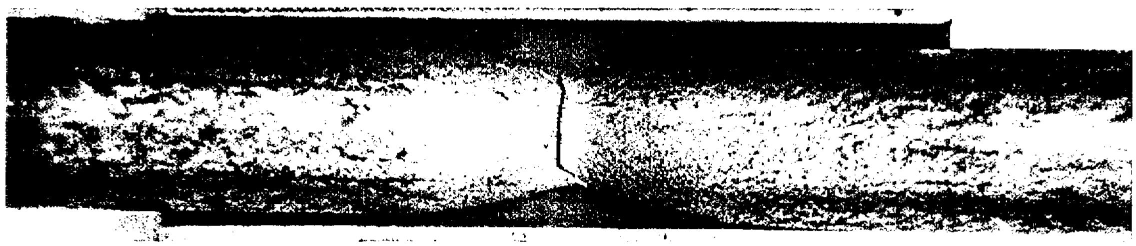


Figure 5-19 Tensile Properties for Millstone Unit 3 Reactor Vessel Weld Metal



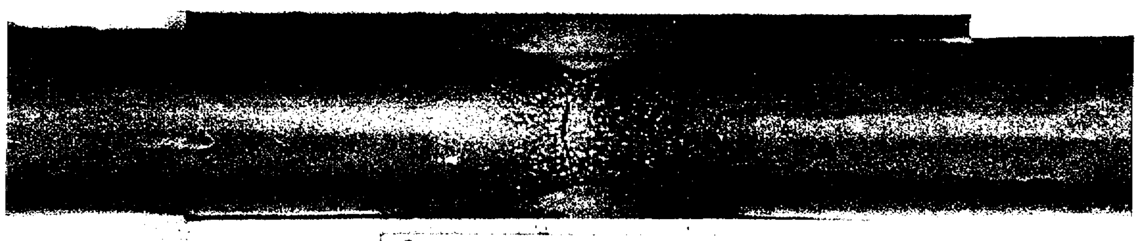
Specimen EL10 Tested at 73°F

Specimen EL11 Tested at 175°F

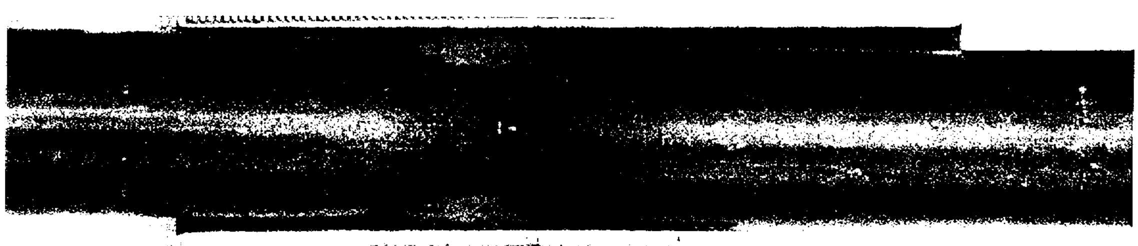
Specimen EL12 Tested at 550°F

Figure 5-20 Fractured Tensile Specimens from Millstone Unit 3 Reactor Vessel Intermediate Shell Plate B9805-1 (Longitudinal Orientation)

Specimen ET10 Tested at 100°F



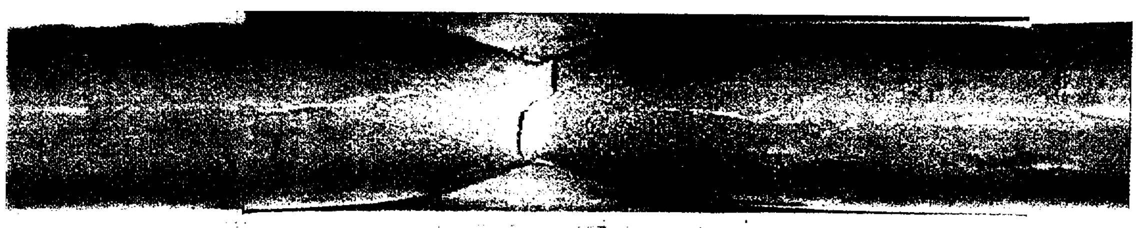
Specimen ET11 Tested at 185°F



Specimen ET12 Tested at 550°F

Figure 5-21 **Fractured Tensile Specimens from Millstone Unit 3 Reactor Vessel Intermediate Shell Plate B9805-1** (Transverse Orientation)

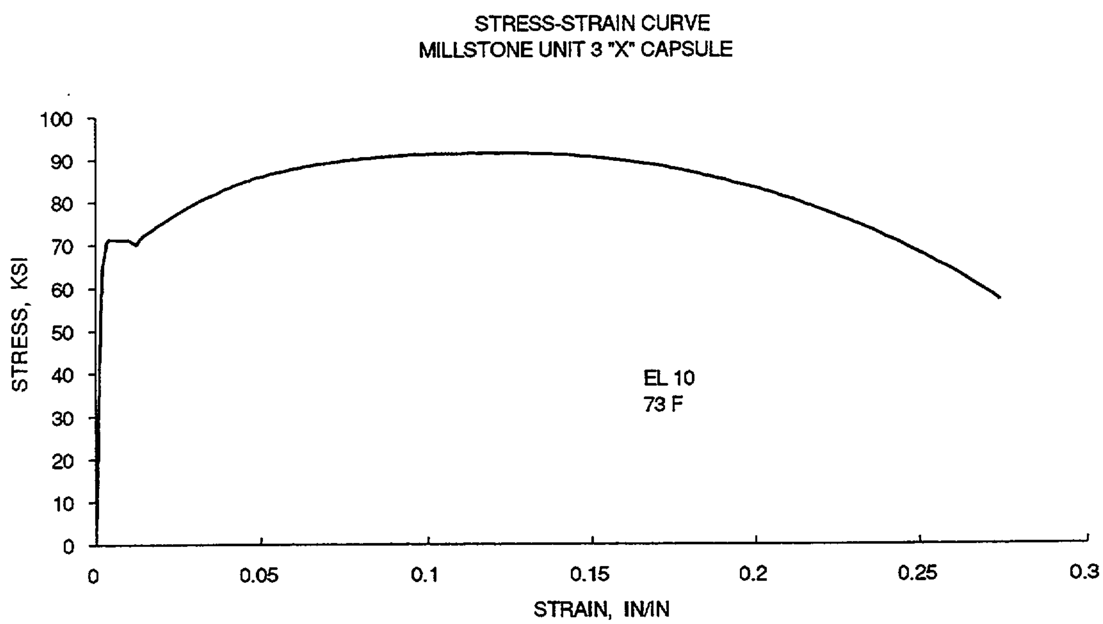
Specimen EW10 Tested at 0°F



Specimen EW11 Tested at 100°F

Specimen EW12 Tested at 550°F

Figure 5-22 Fractured Tensile Specimens from Millstone Unit 3 Reactor Vessel Weld Metal



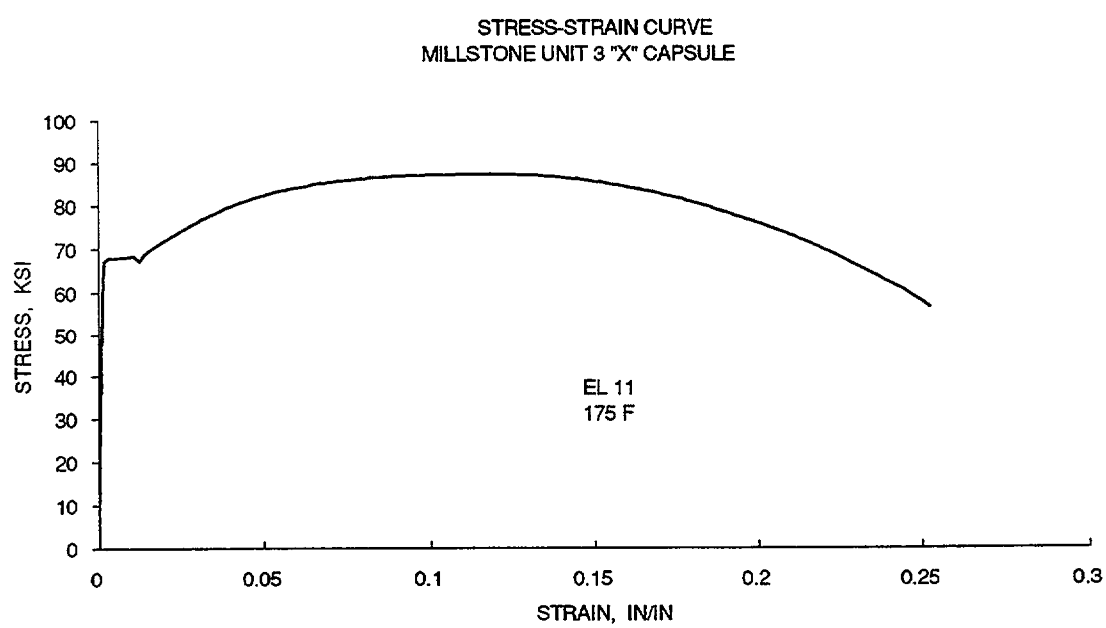


Figure 5-23 Engineering Stress-Strain Curves for Intermediate Shell Plate B9805-1Tensile Specimens EL10 and EL11 (Longitudinal Orientation)

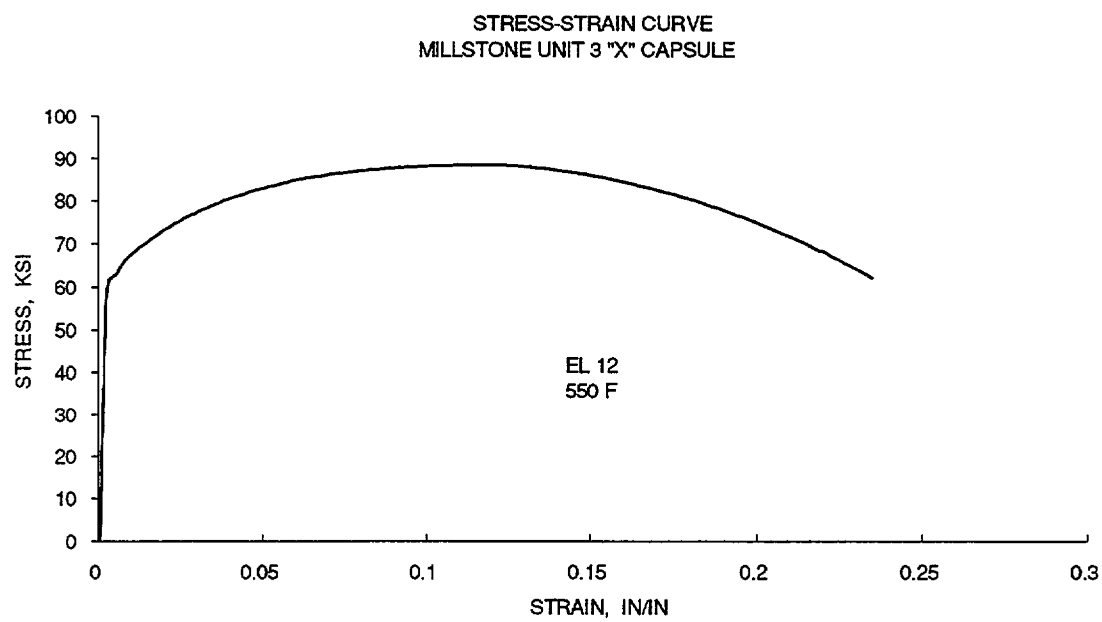


Figure 5-24 Engineering Stress-Strain Curves for Intermediate Shell Plate B9805-1Tensile Specimen EL12 (Longitudinal Orientation)

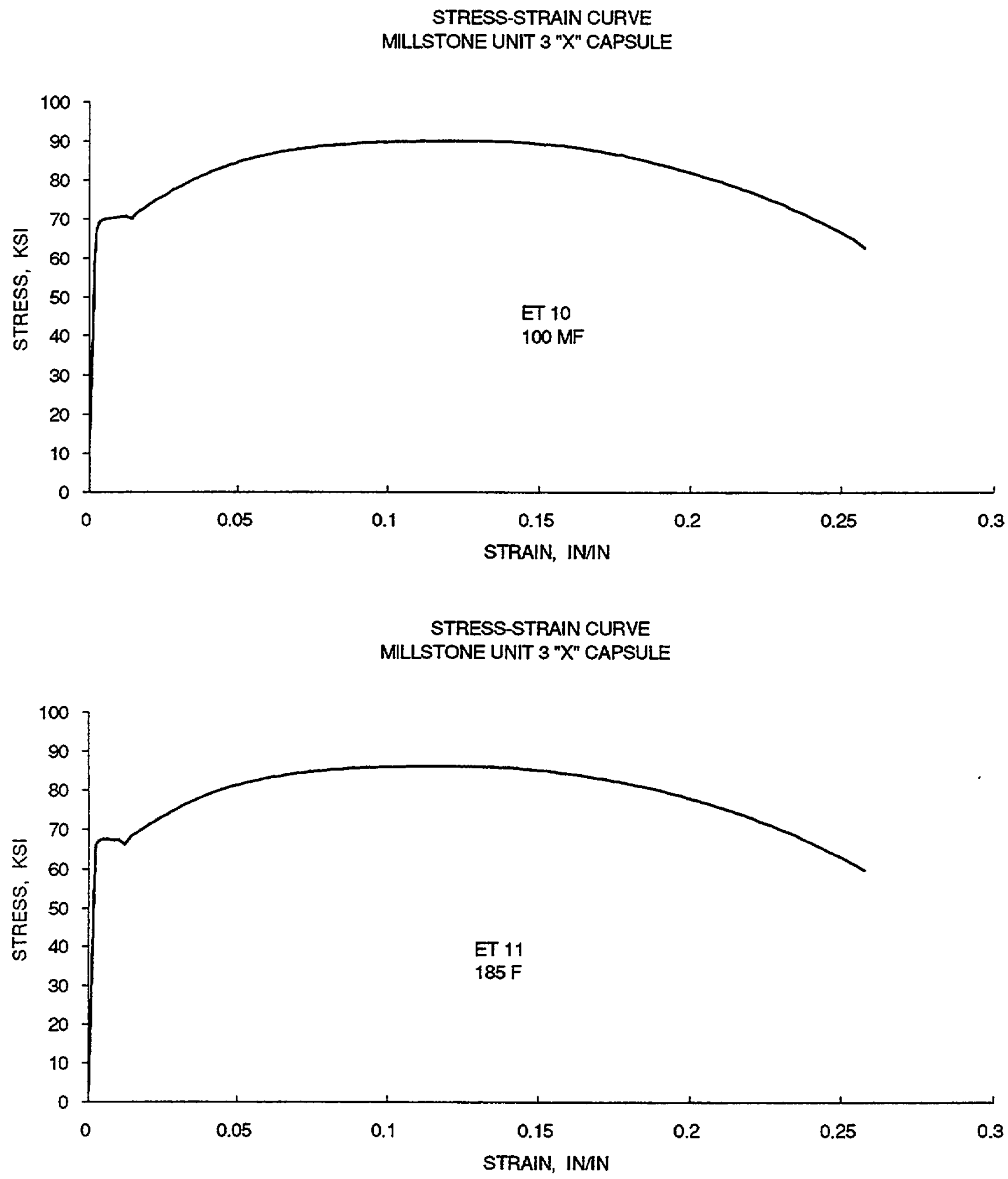


Figure 5-25 Engineering Stress-Strain Curves for Intermediate Shell Plate B9805-1 Tensile Specimens ET10 and ET11 (Transverse Orientation)

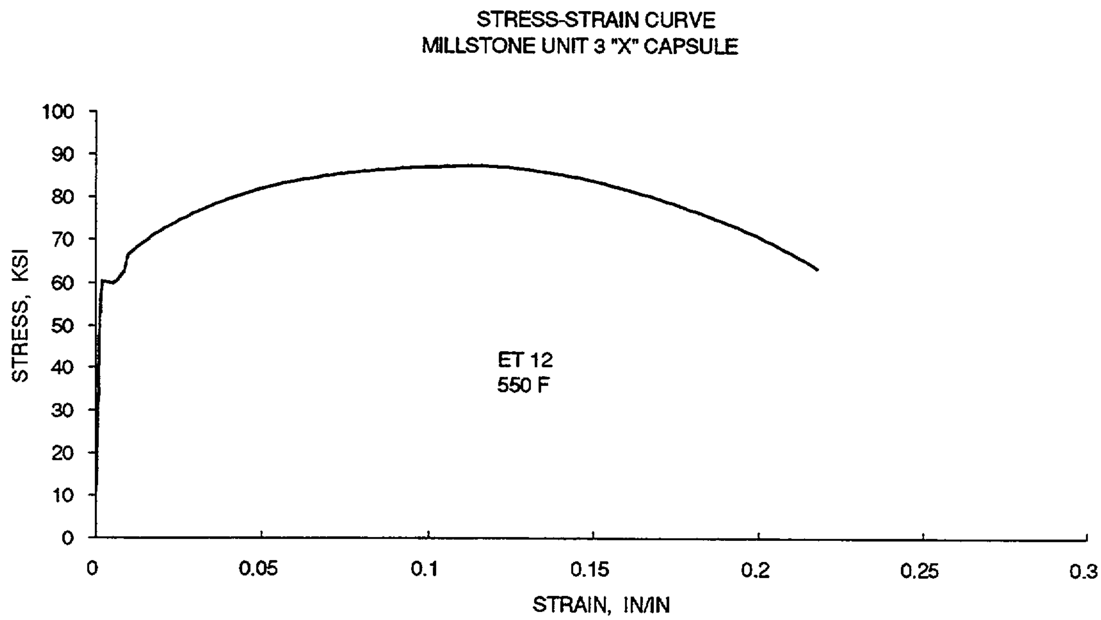


Figure 5-26 Engineering Stress-Strain Curves for Intermediate Shell Plate B9805-1 Tensile Specimen ET12 (Transverse Orientation)

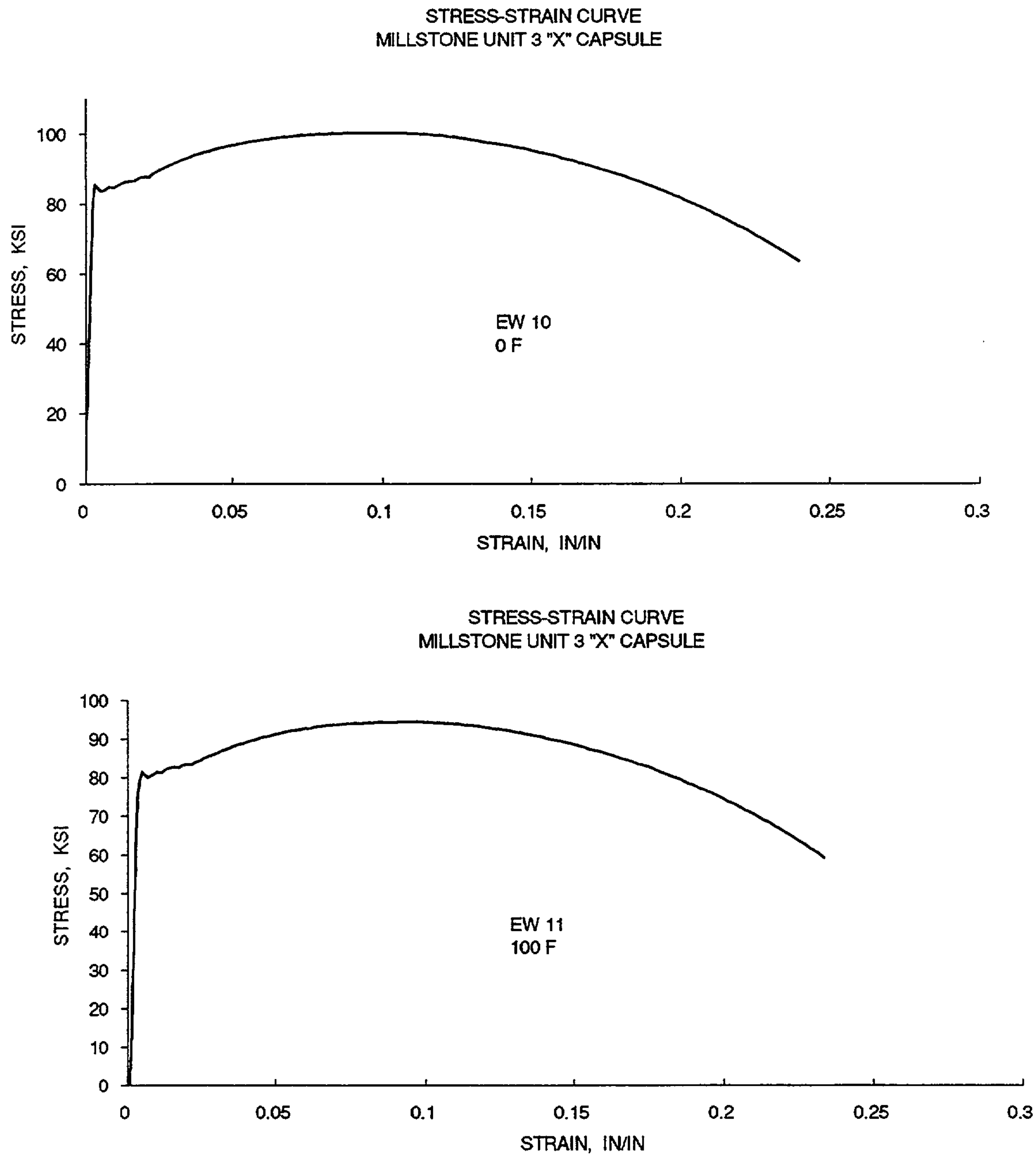


Figure 5-27 Engineering Stress-Strain Curves for Weld Metal Tensile Specimens EW10 and EW11

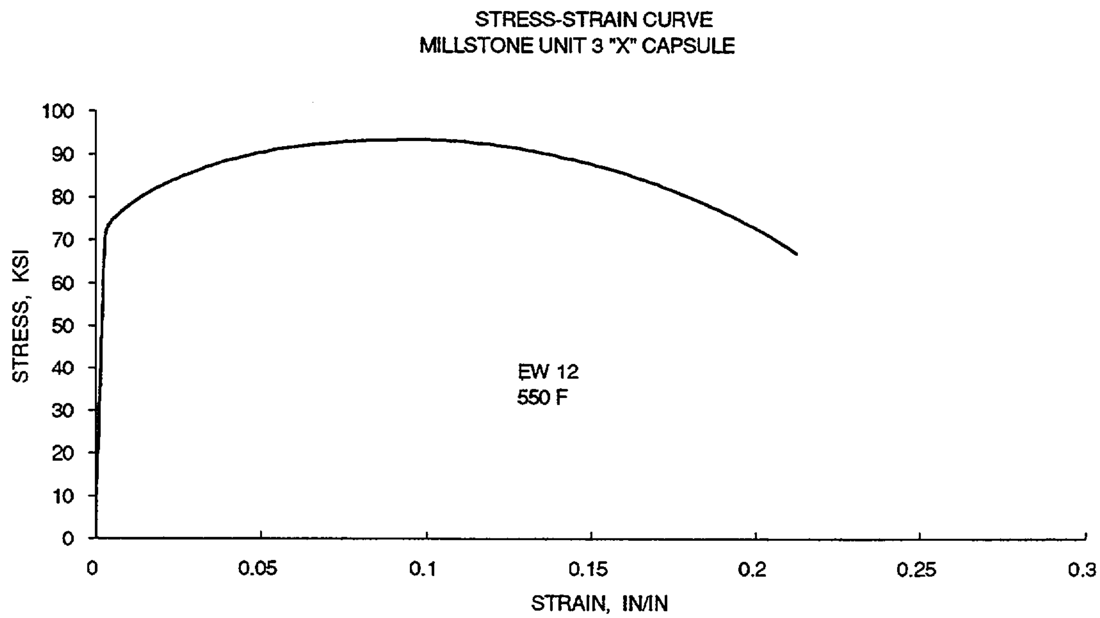


Figure 5-28 Engineering Stress-Strain Curves for Weld Metal Tensile Specimen EW12

6.0 RADIATION ANALYSIS AND NEUTRON DOSIMETRY

6.1 INTRODUCTION

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

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

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

This section provides the results of the neutron dosimetry evaluations performed in conjunction with the analysis of test specimens contained in surveillance Capsules U and X which were withdrawn at various intervals during the first six fuel cycles. This evaluation is based on current state-of-the-art methodology and nuclear data including neutron transport and dosimetry cross-section libraries derived from the ENDF/B-VI data base. This report provides a consistent up-to-date neutron exposure data base for use in evaluating the material properties of the Millstone Unit 3 reactor vessel.

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

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

6.2 DISCRETE ORDINATES ANALYSIS

A plan view of the reactor geometry at the core midplane is shown in Figure 4-1. Six irradiation capsules attached to the neutron pads were included in the reactor design to constitute the reactor vessel surveillance program. The capsules are located at azimuthal angles of 58.5°, 61°, 121.5°, 238.5°, 241°, and 301.5° relative to the core cardinal axis as shown in Figure 4-1.

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

From a neutronic standpoint, the surveillance capsules and associated support structures are significant. The presence of these materials has a marked effect on both the spatial distribution of neutron flux and the neutron energy spectrum in the water annulus between the neutron pad 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 capsule as well as for the determination of exposure parameter ratios, i.e., [dpa/sec]/[$\phi(E > 1.0$ MeV)], within the reactor vessel geometry. The relative radial gradient information was required to permit the projection of measured exposure parameters to locations interior to the reactor vessel wall, i.e., the ¼T and ¾T locations.

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

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

1. Evaluate neutron dosimetry obtained from surveillance capsules,

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

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

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

The 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 3.1[14] and the BUGLE-96 cross-section library[15]. The BUGLE-96 library is a 47 energy group ENDF/B-VI based data set produced specifically for light water reactor applications. In these analyses, anisotropic scattering was treated with a P_3 expansion of the scattering cross-sections and the angular discretization was modeled with an S_8 order of angular quadrature.

The core power distribution utilized in the reference forward transport calculation was derived from statistical studies of long-term operation of Westinghouse 4-loop plants. Inherent in the development of this reference core power distribution is the use of an out-in fuel management strategy, i.e., fresh fuel on the core periphery. Furthermore, for the peripheral fuel assemblies, the neutron source was increased by a 2σ margin derived from the statistical evaluation of plant-to-plant and cycle-to-cycle variations in peripheral power. Since it is unlikely that any single reactor would exhibit power levels on the core periphery at the nominal +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-96 library. Adjoint source locations were chosen at several azimuthal locations along the reactor vessel inner radius as well as at the geometric center of each surveillance capsule. Again, these calculations were run in r,θ geometry to provide neutron source distribution importance functions for the exposure parameter of interest, in this case $\phi(E > 1.0 \text{ MeV})$.

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

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

where:

$\phi(r_o,\theta_o)$	=	Neutron flux (E > 1.0 MeV) at the location of the adjoint source point having radius r_o and azimuthal angle θ_o.
$I(r,\theta,E)$	=	Adjoint source importance function at radius r, azimuthal angle θ, and neutron source energy E.
$S(r,\theta,E)$	=	Neutron source strength at core location r,θ and energy E.

Although the adjoint importance functions used in this analysis were based on a response function defined by the threshold neutron flux $\phi(E > 1.0$ MeV), prior calculations[16] have shown that, while the implementation of low leakage loading patterns significantly impacts both the magnitude and spatial distribution of the neutron field, changes in the relative neutron energy spectrum are of second order. Thus, for a given location, the ratio of [dpa/sec]/[$\phi(E > 1.0$ MeV)] is insensitive to changing core source distributions. In the application of these adjoint importance functions to the Millstone Unit 3 reactor, therefore, the iron atom displacement rates (dpa/sec) and the neutron flux $\phi(E > 0.1$ MeV) were computed on a cycle-specific basis by using [dpa/sec]/[$\phi(E > 1.0$ MeV)] and [$\phi(E > 0.1$ MeV)]/[$\phi(E > 1.0$ MeV)] ratios from the forward analysis in conjunction with the cycle specific $\phi(E > 1.0$ 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 data for Millstone Unit 3[17 through 23].

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

In Table 6-1, the calculated exposure parameters [$\phi(E > 1.0$ MeV), $\phi(E > 0.1$ MeV), and dpa/sec] are given at the geometric center of the two azimuthally symmetric surveillance capsule positions (29° and 31.5°) for the dual capsule position and the one azimuthally symmetric surveillance capsule position (31.5°) for the single capsule position 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 plant specific power distributions for each cycle.

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

Radial gradient information applicable to $\phi(E > 1.0$ MeV), $\phi(E > 0.1$ MeV), and dpa/sec is given in Tables 6-3, 6-4, and 6-5, respectively. The data, obtained from the reference forward neutron transport calculation, are presented on a relative basis for each exposure parameter at several azimuthal locations.

Exposure distributions through the vessel wall may be obtained by normalizing the calculated or projected exposure at the vessel inner radius to the gradient data listed in Tables 6-3 through 6-5.

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

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

where:

$\phi_{1/4T}(0^\circ)$	=	Projected neutron flux at the ¼T position on the 0° azimuth.
$\phi(220.35,0^\circ)$	=	Projected or calculated neutron flux at the vessel inner radius on the 0° azimuth.
$F(225.87,0^\circ)$	=	Ratio of the neutron flux at the ¼T position to the flux at the vessel inner radius for the 0° azimuth. This data is obtained from Table 6-3.

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

6.3 NEUTRON DOSIMETRY

The passive neutron sensors included in the Millstone Unit 3 surveillance program are listed in Table 6-6. Also given in Table 6-6 are the primary nuclear reactions and associated nuclear constants that were used in the evaluation of the neutron energy spectrum within the surveillance capsules and in the subsequent determination of the various exposure parameters of interest [$\phi(E > 1.0 \text{ MeV})$, $\phi(E > 0.1 \text{ MeV})$, dpa/sec]. The relative locations of the neutron sensors within the capsules are shown in Figure 4-2. The iron, nickel, copper, and cobalt-aluminum monitors, in wire form, were placed in holes drilled in spacers at several axial levels within the capsules. The cadmium shielded uranium and neptunium fission monitors were accommodated within the dosimeter block located near the center of the capsule.

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

- The measured specific activity of each monitor,
- The physical characteristics of each monitor,
- The operating history of the reactor,
- The energy response of each monitor, and

- The neutron energy spectrum at the monitor location.

The specific activity of each of the neutron monitors was determined using established ASTM procedures[24 through 37]. Following sample preparation and weighing, the activity of each monitor was determined by means of a high resolution gamma spectrometer. The irradiation history of the Millstone Unit 3 reactor was obtained from utility personnel[38] and data reported in NUREG-0020, "Licensed Operating Reactors Status Summary Report," for the first six cycles of operation. The irradiation history applicable to the exposure of Capsules U and X is given in Table 6-7.

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

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

where:

R = Reaction rate averaged over the irradiation period and referenced to operation at a core power level of P_{ref} (rps/nucleus).

A = Measured specific activity (dps/gm).

N_0 = Number of target element atoms per gram of sensor.

F = Weight fraction of the target isotope in the sensor material.

Y = Number of product atoms produced per reaction.

P_j = Average core power level during irradiation period j (MW).

P_{ref} = Maximum or reference power level of the reactor (MW).

C_j = Calculated ratio of $\phi(E > 1.0$ MeV) during irradiation period j to the time weighted average $\phi(E > 1.0$ MeV) over the entire irradiation period.

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

t_j = Length of irradiation period j (sec).

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

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

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

For the irradiation history of Capsules U and X, the flux level term in the reaction rate calculations was set to 1.0 for Capsule U only. Measured and saturated reaction product specific activities as well as the derived full power reaction rates are listed in Table 6-8. The reaction rates of the ^{238}U sensors provided in Table 6-8 include corrections for ^{235}U impurities, plutonium build-in, and gamma ray induced fissions. Corrections for gamma ray induced fissions were also included in the reaction rates for the ^{237}Np sensors as well.

Values of key fast neutron exposure parameters were derived from the measured reaction rates using the FERRET least squares adjustment code [39]. The FERRET approach used the measured reaction rate data, sensor reaction cross-sections, and a calculated trial spectrum as input and proceeded to adjust the group fluxes from the trial spectrum to produce a best fit (in a least squares sense) within the constraints of the parameter uncertainties. The best estimate exposure parameters, along with the associated uncertainties, were then obtained from the best estimate spectrum.

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

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

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

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

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

In the least squares adjustment, the continuous quantities (i.e., neutron spectra and cross-sections) were approximated in a multi-group format consisting of 53 energy groups. The trial input spectrum was converted to the FERRET 53 group structure using the SAND-II code[40]. 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[41], 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[42]. The uncertainties associated with the measured reaction rates included both statistical (counting) and systematic components. The systematic component of the overall uncertainty accounts for counter efficiency, counter calibrations, irradiation history corrections, and corrections for competing reactions in the individual sensors.

Results of the FERRET evaluation of the Capsule U and X dosimetry are given in Table 6-9. The data summarized in this table include fast neutron exposure evaluations in terms of $\Phi(E > 1.0\ \text{MeV})$, $\Phi(E > 0.1\ \text{MeV})$, and dpa. In general, excellent results were achieved in the fits of the best estimate spectra to the individual measured reaction rates. The measured, calculated and best estimate reaction rates for each reaction are given in Table 6-10. An examination of Table 6-10 shows that, in all cases, reaction rates calculated with the best estimate spectra match the measured reaction rates to better than 5%. The best estimate spectra from the least squares evaluation is given in Table 6-11 in the FERRET 53 energy group structure.

In Table 6-12, absolute comparisons of the best estimate and calculated fluence at the center of Capsules U and X are presented. The results for the Capsules U and X dosimetry evaluation [BE/C ratio of 0.93 for $\Phi(E > 1.0\ \text{MeV})$] 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 Millstone Unit 3 reactor vessel was developed using a combination of absolute plant specific transport calculations and all available plant specific measurement data. In the case of Millstone Unit 3, the measurement data base contains measurements from the two surveillance capsules discussed in this report.

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

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

where:

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

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

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

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

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

For Millstone Unit 3, the derived plant specific bias factors were 0.93, 0.94, and 0.94 for $\Phi(E > 1.0\ \text{MeV})$, $\Phi(E > 0.1\ \text{MeV})$, and dpa, respectively. Bias factors of this magnitude developed with BUGLE-96 are fully consistent with experience using the ENDF/B-VI based cross-section library.

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

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

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

The net uncertainty in the bias factor, K, is combined with the uncertainty from the analytical sensitivity study to define the overall fluence uncertainty at the reactor vessel wall. In the case of Millstone Unit 3, the derived uncertainties in the bias factor, K, and the additional uncertainty from the analytical sensitivity studies combine to yield a net uncertainty of $\pm$ 8.5%

Based on this best-estimate approach, neutron exposure projections at key locations on the reactor vessel inner radius are given in Table 6-13; furthermore, calculated neutron exposure projections are also provided for comparison purposes. Along with the current 8.0 EFPY exposure, projections are also provided for exposure periods of 12, 16, 32, and 54 EFPY. Projections for future operation were based on the assumption that the Cycles 4 through 6 exposure rates based on low leakage fuel management would continue to be applicable throughout plant life.

In the derivation of best estimate and calculated exposure gradients within the reactor vessel wall for the Millstone Unit 3 reactor vessel, exposure projections to 12, 16, 32, and 54 EFPY were also employed. Data based on both a $\Phi(E > 1.0\ MeV)$ slope and a plant-specific dpa slope through the vessel wall are provided in Table 6-14.

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

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

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

In Table 6-15, updated lead factors are listed for each of the Millstone Unit 3 surveillance capsules.

Figure 6-1

Plan View of a Dual Reactor Vessel Surveillance Capsule

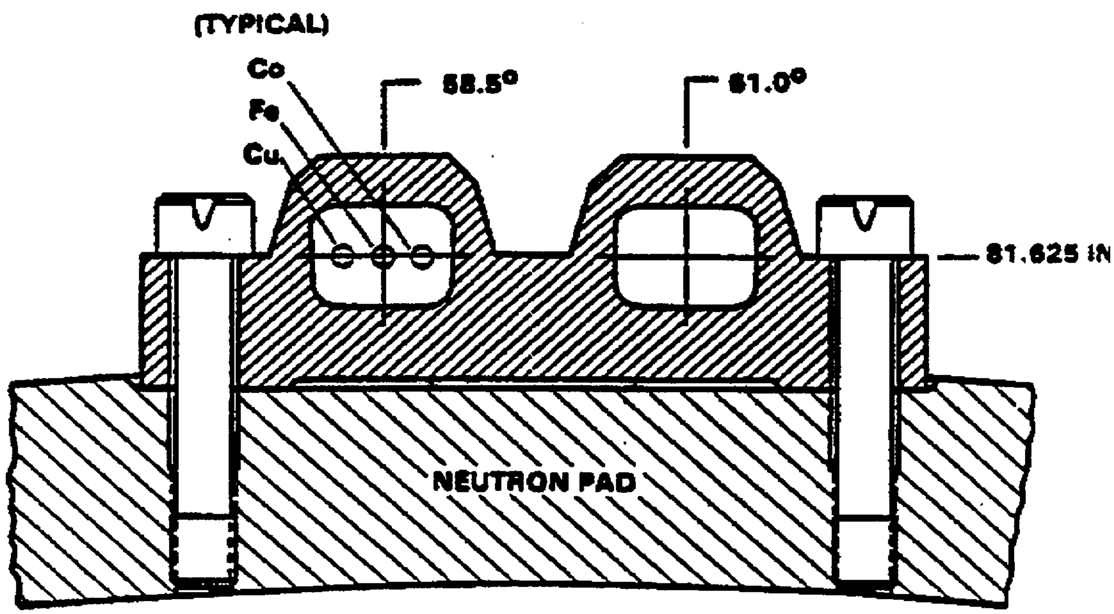


Table 6-1

Calculated Fast Neutron Exposure Rates and Iron Atom Displacement Rates at the Surveillance Capsule Center

	ϕ(E > 1.0 MeV) (n/cm^2-sec)		
	Dual Capsule Positions		Single Capsule
Cycle No.	29°	31.5°	31.5°
Reference	1.40E+11	1.49E+11	1.48E+11
1	9.92E+10	1.06E+11	1.05E+11
2	7.44E+10	7.68E+10	7.59E+10
3	8.36E+10	8.92E+10	8.83E+10
4	7.99E+10	8.46E+10	8.37E+10
5	8.56E+10	9.04E+10	8.94E+10
6	7.17E+10	7.76E+10	7.68E+10

	ϕ(E > 0.1 MeV) (n/cm^2-sec)		
	Dual Capsule Positions		Single Capsule
Cycle No.	29°	31.5°	31.5°
Reference	6.06E+11	6.48E+11	6.43E+11
1	4.30E+11	4.61E+11	4.57E+11
2	3.23E+11	3.34E+11	3.31E+11
3	3.63E+11	3.88E+11	3.85E+11
4	3.47E+11	3.68E+11	3.65E+11
5	3.71E+11	3.93E+11	3.90E+11
6	3.11E+11	3.37E+11	3.35E+11

	Iron Atom Displacement Rate (dpa/sec)		
	Dual Capsule Positions		Single Capsule
Cycle No.	29°	31.5°	31.5°
Reference	2.66E-10	2.84E-10	2.80E-10
1	1.88E-10	2.02E-10	1.99E-10
2	1.41E-10	1.46E-10	1.44E-10
3	1.59E-10	1.70E-10	1.68E-10
4	1.52E-10	1.61E-10	1.59E-10
5	1.63E-10	1.72E-10	1.70E-10
6	1.36E-10	1.47E-10	1.46E-10

Table 6-2

Calculated Azimuthal Variation of Fast Neutron Exposure Rates and Iron Atom Displacement Rates at the Reactor Vessel Clad/Base Metal Interface

		ϕ(E > 1.0 MeV) (n/cm^2-sec)		
Cycle No.	0°	15°	30°	45°
Reference	1.95E+10	2.93E+10	3.33E+10	3.41E+10
1	1.44E+10	2.12E+10	2.38E+10	2.46E+10
2	1.30E+10	1.82E+10	1.81E+10	1.54E+10
3	1.42E+10	1.97E+10	2.04E+10	2.09E+10
4	1.31E+10	1.86E+10	1.95E+10	1.89E+10
5	1.21E+10	1.95E+10	2.08E+10	1.91E+10
6	1.02E+10	1.40E+10	1.76E+10	1.64E+10

		ϕ(E > 0.1 MeV) (n/cm^2-sec)		
Cycle No.	0°	15°	30°	45°
Reference	4.13E+10	6.25E+10	7.26E+10	8.57E+10
1	3.04E+10	4.53E+10	5.21E+10	6.19E+10
2	2.76E+10	3.88E+10	3.94E+10	3.86E+10
3	3.00E+10	4.21E+10	4.45E+10	5.26E+10
4	2.77E+10	3.98E+10	4.26E+10	4.75E+10
5	2.56E+10	4.15E+10	4.54E+10	4.80E+10
6	2.16E+10	2.98E+10	3.84E+10	4.11E+10

		Iron Atom Displacement Rate (dpa/sec)		
Cycle No.	0°	15°	30°	45°
Reference	3.03E-11	4.50E-11	5.13E-11	5.39E-11
1	2.23E-11	3.27E-11	3.68E-11	3.89E-11
2	2.03E-11	2.79E-11	2.78E-11	2.43E-11
3	2.20E-11	3.03E-11	3.14E-11	3.31E-11
4	2.03E-11	2.87E-11	3.01E-11	2.99E-11
5	1.88E-11	2.99E-11	3.21E-11	3.02E-11
6	1.59E-11	2.15E-11	2.71E-11	2.59E-11

Table 6-3

Relative Radial Distribution of $\phi(E > 1.0\ MeV)$
within the Reactor Vessel Wall

Radius	Azimuthal Angle			
(cm)	0°	15°	30°	45°
220.35	1.000	1.000	1.000	1.000
221.00	0.959	0.959	0.956	0.957
222.30	0.852	0.852	0.845	0.847
223.60	0.740	0.738	0.731	0.732
224.89	0.636	0.632	0.625	0.625
225.87	0.564	0.559	0.552	0.551
227.01	0.489	0.485	0.476	0.476
228.63	0.398	0.393	0.386	0.385
230.09	0.329	0.324	0.318	0.316
231.39	0.277	0.272	0.267	0.264
232.68	0.232	0.228	0.223	0.221
234.14	0.191	0.187	0.182	0.180
235.76	0.153	0.149	0.146	0.144
236.90	0.131	0.127	0.124	0.122
237.88	0.114	0.110	0.108	0.106
239.18	0.095	0.091	0.089	0.087
240.47	0.079	0.075	0.073	0.071
241.77	0.065	0.061	0.059	0.058
242.42	0.062	0.058	0.056	0.055

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

Table 6-4

Relative Radial Distribution of $\phi(E > 0.1\ MeV)$ within the Reactor Vessel Wall

Radius		Azimuthal Angle		
(cm)	0°	15°	30°	45°
220.35	1.000	1.000	1.000	1.000
221.00	1.012	1.010	1.010	1.007
222.30	0.998	0.992	0.989	0.985
223.60	0.962	0.952	0.948	0.942
224.89	0.917	0.902	0.900	0.890
225.87	0.880	0.864	0.860	0.849
227.01	0.835	0.816	0.813	0.801
228.63	0.772	0.750	0.748	0.733
230.09	0.715	0.691	0.690	0.674
231.39	0.665	0.640	0.639	0.622
232.68	0.616	0.590	0.589	0.572
234.14	0.563	0.536	0.535	0.518
235.76	0.506	0.478	0.479	0.461
236.90	0.468	0.438	0.440	0.422
237.88	0.434	0.404	0.406	0.388
239.18	0.391	0.361	0.363	0.345
240.47	0.350	0.318	0.320	0.303
241.77	0.308	0.274	0.276	0.259
242.42	0.300	0.264	0.266	0.249

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

Table 6-5

Relative Radial Distribution of dpa/sec
within the Reactor Vessel Wall

Radius (cm)	Azimuthal Angle 0°	15°	30°	45°
220.35	1.000	1.000	1.000	1.000
221.00	0.965	0.965	0.963	0.965
222.30	0.876	0.875	0.872	0.879
223.60	0.785	0.782	0.779	0.788
224.89	0.699	0.695	0.692	0.704
225.87	0.639	0.634	0.632	0.644
227.01	0.577	0.571	0.568	0.582
228.63	0.498	0.492	0.490	0.504
230.09	0.437	0.429	0.429	0.442
231.39	0.389	0.381	0.381	0.393
232.68	0.346	0.338	0.338	0.350
234.14	0.304	0.295	0.295	0.307
235.76	0.263	0.253	0.255	0.264
236.90	0.237	0.227	0.229	0.237
237.88	0.216	0.206	0.207	0.215
239.18	0.191	0.180	0.182	0.188
240.47	0.167	0.156	0.158	0.163
241.77	0.147	0.133	0.135	0.139
242.42	0.143	0.128	0.130	0.133

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

Table 6-6

Nuclear Parameters Used in the Evaluation of Neutron Sensors

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

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

Table 6-7

Monthly Thermal Generation During the First Six Fuel Cycles
of the Millstone Unit 3 Reactor
(Reactor Power of 3411 MWt)

Year	Month	Thermal Generation (MW-hr)	Year	Month	Thermal Generation (MW-hr)
1986	2	179659	1989	1	2501514
1986	3	920219	1989	2	1253701
1986	4	1209581	1989	3	2463334
1986	5	2136399	1989	4	2057414
1986	6	2447154	1989	5	705110
1986	7	1943450	1989	6	0
1986	8	969533	1989	7	1321694
1986	9	2191009	1989	8	2463752
1986	10	2535717	1989	9	2381981
1986	11	2451178	1989	10	2503052
1986	12	2532654	1989	11	2147662
1987	1	2355814	1989	12	1928054
1987	2	2291058	1990	1	2261784
1987	3	888362	1990	2	2263450
1987	4	1398883	1990	3	2177643
1987	5	2087262	1990	4	403460
1987	6	1847660	1990	5	1567181
1987	7	2537011	1990	6	1991239
1987	8	2532946	1990	7	2536291
1987	9	2314676	1990	8	2529099
1987	10	2365836	1990	9	2326876
1987	11	0	1990	10	2235276
1987	12	0	1990	11	2450749
1988	1	0	1990	12	2417217
1988	2	1349671	1991	1	1384282
1988	3	2425760	1991	2	63729
1988	4	1285473	1991	3	0
1988	5	2524662	1991	4	959797
1988	6	2448484	1991	5	2529524
1988	7	2535537	1991	6	1929096
1988	8	2534907	1991	7	2012906
1988	9	2452649	1991	8	0
1988	10	1437176	1991	9	0
1988	11	1940329	1991	10	0
1988	12	2334061	1991	11	0
			1991	12	0

Table 6-7 cont'd

Monthly Thermal Generation During the First Six Fuel Cycles
of the Millstone Unit 3 Reactor
(Reactor Power of 3411 MWt)

Year	Month	Thermal Generation (MW-hr)	Year	Month	Thermal Generation (MW-hr)
1992	1	0	1995	1	2536730
1992	2	1833846	1995	2	2256119
1992	3	2436486	1995	3	2522685
1992	4	1808770	1995	4	994439
1992	5	1193515	1995	5	0
1992	6	2088145	1995	6	1791455
1992	7	2418929	1995	7	2536641
1992	8	2529546	1995	8	2527767
1992	9	2373464	1995	9	2455456
1992	10	0	1995	10	2530620
1992	11	1577344	1995	11	2415574
1992	12	1985021	1995	12	1277671
1993	1	2359254	1996	1	2529213
1993	2	2289934	1996	2	2346090
1993	3	2365021	1996	3	2441886
1993	4	1685792	1996	4	0
1993	5	2529502	1996	5	0
1993	6	2449102	1996	6	0
1993	7	2382199	1996	7	0
1993	8	0	1996	8	0
1993	9	0	1996	9	0
1993	10	0	1996	10	0
1993	11	1553727	1996	11	0
1993	12	2480277	1996	12	0
1994	1	2418781	1997	1	0
1994	2	2288301	1997	2	0
1994	3	2536180	1997	3	0
1994	4	2451313	1997	4	0
1994	5	2508472	1997	5	0
1994	6	2451945	1997	6	0
1994	7	2516197	1997	7	0
1994	8	2536950	1997	8	0
1994	9	1268064	1997	9	0
1994	10	2529921	1997	10	0
1994	11	2450229	1997	11	0
1994	12	2533923	1997	12	0

Table 6-7 cont'd

Monthly Thermal Generation During the First Six Fuel Cycles
of the Millstone Unit 3 Reactor
(Reactor Power of 3411 MWt)

Year	Month	Thermal Generation (MW-hr)	Year	Month	Thermal Generation (MW-hr)
1998	1	0	1999	1	2445941
1998	2	0	1999	2	2286862
1998	3	0	1999	3	2486085
1998	4	0	1999	4	2361732
1998	5	0	1999	5	2944
1998	6	0			
1998	7	1850147			
1998	8	1653257			
1998	9	2150126			
1998	10	2173356			
1998	11	1791172			
1998	12	857010			

Table 6-8

Measured Sensor Activities and Reaction Rates

Surveillance Capsule U

Reaction	Location	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	Top	6.430E+04	4.035E+05	6.156E-17
	Middle	6.010E+04	3.771E+05	5.753E-17
	Bottom	5.810E+04	3.646E+05	5.562E-17
^{54}Fe (n,p) ^{54}Mn	Top	2.350E+06	3.817E+06	6.051E-15
	Middle	2.710E+06	4.402E+06	6.978E-15
	Bottom	2.160E+06	3.509E+06	5.562E-15
^{58}Ni (n,p) ^{58}Co	Middle	4.820E+07	5.446E+07	7.797E-15
	Bottom	4.870E+07	5.503E+07	7.877E-15
^{59}Co (n,γ) ^{60}Co	Top	1.260E+07	7.907E+07	5.159E-12
	Middle	1.240E+07	7.781E+07	5.077E-12
	Bottom	1.240E+07	7.781E+07	5.077E-12
^{59}Co (n,γ) ^{60}Co (Cd)	Middle	6.450E+06	4.048E+07	2.641E-12
	Bottom	6.420E+06	4.029E+07	2.628E-12
^{238}U (n,f) ^{137}Cs	Middle	1.770E+05	5.826E+06	3.827E-14
	Including ^{235}U, ^{239}Pu, and γ,fission corrections			3.205E-14
^{237}Np (n,f) ^{137}Cs	Middle	1.470E+06	4.838E+07	3.087E-13
	Including γ,fission correction			3.056E-13

Table 6-8 cont'd

Measured Sensor Activities and Reaction Rates

Surveillance Capsule X

Reaction	Location	Measured Activity (dps/gm)	Saturated Activity (dps/gm)	Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	Top	1.220E+05	3.137E+05	4.786E-17
	Middle	1.310E+05	3.369E+05	5.139E-17
	Bottom	1.180E+05	3.034E+05	4.629E-17
$^{54}Fe\ (n,p)\ ^{54}Mn$	Top	6.460E+05	3.008E+06	4.768E-15
	Middle	6.850E+05	3.190E+06	5.056E-15
	Bottom	6.420E+05	2.989E+06	4.739E-15
$^{58}Ni\ (n,p)\ ^{58}Co$	Top	1.820E+06	4.854E+07	6.949E-15
	Middle	1.880E+06	5.014E+07	7.178E-15
	Bottom	1.760E+06	4.694E+07	6.720E-15
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Top	2.250E+07	5.786E+07	3.775E-12
	Middle	2.330E+07	5.992E+07	3.909E-12
	Bottom	2.270E+07	5.837E+07	3.808E-12
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)	Top	1.270E+07	3.266E+07	2.131E-12
	Middle	1.180E+07	3.034E+07	1.980E-12
	Bottom	1.250E+07	3.214E+07	2.097E-12
$^{238}U\ (n,f)\ ^{137}Cs$	Middle	7.780E+05	5.107E+06	3.355E-14
	Including ^{235}U, ^{239}Pu, and γ,fission corrections			2.601E-14
$^{237}Np\ (n,f)\ ^{137}Cs$	Middle	6.080E+06	3.991E+07	2.546E-13
	Including γ,fission correction			2.521E-13

Table 6-9

Summary of Neutron Dosimetry Results
Surveillance Capsules U and X

Best Estimate Flux and Fluence for Capsule U

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	1σ Uncertainty
ϕ (E > 1.0 MeV)	9.908E+10	Φ (E > 1.0 MeV)	4.197E+18	6%
ϕ (E > 0.1 MeV)	4.352E+11	Φ (E > 0.1 MeV)	1.844E+19	10%
ϕ (E < 0.414 eV)	1.032E+11	Φ (E < 0.414 eV)	4.372E+18	14%
dpa/sec	1.906E-10	Dpa	8.074E-03	7%

Best Estimate Flux and Fluence for Capsule X

Quantity	Flux [n/cm^2-sec]	Quantity	Fluence [n/cm^2]	1σ Uncertainty
ϕ (E > 1.0 MeV)	8.198E+10	Φ (E > 1.0 MeV)	2.070E+19	6%
ϕ (E > 0.1 MeV)	3.590E+11	Φ (E > 0.1 MeV)	9.064E+19	10%
ϕ (E < 0.414 eV)	7.467E+10	Φ (E < 0.414 eV)	1.885E+19	15%
dpa/sec	1.573E-10	Dpa	3.972E-02	7%

Table 6-10

Comparison of Measured, Calculated, and Best Estimate Reaction Rates at the Surveillance Capsule Center

Surveillance Capsule U

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,α)	5.82E-17	5.44E-17	5.65E-17	0.97	1.04	1.07
^{54}Fe (n,p)	6.20E-15	6.23E-15	6.09E-15	0.98	0.98	1.00
^{58}Ni (n,p)	7.84E-15	8.73E-15	8.27E-15	1.05	0.95	0.90
^{238}U (n,f) (Cd)	3.20E-14	3.36E-14	3.18E-14	0.99	0.95	0.95
^{237}Np (n,f) (Cd)	3.06E-13	3.25E-13	3.04E-13	0.99	0.94	0.94
^{59}Co (n,γ)	5.10E-12	4.53E-12	5.02E-12	0.98	1.11	1.13
^{59}Co (n,γ) (Cd)	2.63E-12	3.14E-12	2.68E-12	1.02	0.85	0.84

Surveillance Capsule X

Reaction	Measured	Calculated	Best Estimate	BE / Meas	BE/ Calc	Meas/Calc
^{63}Cu (n,α)	4.85E-17	4.50E-17	4.69E-17	0.97	1.04	1.08
^{54}Fe (n,p)	4.85E-15	5.15E-15	4.98E-15	1.03	0.97	0.94
^{58}Ni (n,p)	6.95E-15	7.22E-15	6.99E-15	1.01	0.97	0.96
^{238}U (n,f) (Cd)	2.60E-14	2.78E-14	2.63E-14	1.01	0.95	0.94
^{237}Np (n,f) (Cd)	2.52E-13	2.69E-13	2.51E-13	1.00	0.93	0.94
^{59}Co (n,γ)	3.83E-12	3.75E-12	3.78E-12	0.99	1.01	1.02
^{59}Co (n,γ) (Cd)	2.07E-12	2.60E-12	2.10E-12	1.01	0.81	0.80

Table 6-11

Best Estimate Neutron Energy Spectrum at the Center of Surveillance Capsules

Capsule U

Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	7.11E+06	28	9.12E-03	2.41E+10
2	1.49E+01	1.54E+07	29	5.53E-03	2.46E+10
3	1.35E+01	5.71E+07	30	3.36E-03	7.66E+09
4	1.16E+01	1.58E+08	31	2.84E-03	7.54E+09
5	1.00E+01	3.60E+08	32	2.40E-03	7.48E+09
6	8.61E+00	6.32E+08	33	2.04E-03	2.22E+10
7	7.41E+00	1.53E+09	34	1.23E-03	2.20E+10
8	6.07E+00	2.36E+09	35	7.49E-04	2.16E+10
9	4.97E+00	4.87E+09	36	4.54E-04	1.72E+10
10	3.68E+00	5.69E+09	37	2.75E-04	1.86E+10
11	2.87E+00	1.10E+10	38	1.67E-04	1.89E+10
12	2.23E+00	1.48E+10	39	1.01E-04	2.01E+10
13	1.74E+00	2.03E+10	40	6.14E-05	2.01E+10
14	1.35E+00	2.28E+10	41	3.73E-05	1.99E+10
15	1.11E+00	4.24E+10	42	2.26E-05	1.96E+10
16	8.21E-01	4.56E+10	43	1.37E-05	1.91E+10
17	6.39E-01	5.23E+10	44	8.32E-06	1.81E+10
18	4.98E-01	3.37E+10	45	5.04E-06	1.69E+10
19	3.88E-01	5.23E+10	46	3.06E-06	1.63E+10
20	3.02E-01	5.77E+10	47	1.86E-06	1.54E+10
21	1.83E-01	5.86E+10	48	1.13E-06	9.53E+09
22	1.11E-01	3.81E+10	49	6.83E-07	1.20E+10
23	6.74E-02	3.61E+10	50	4.14E-07	1.87E+10
24	4.09E-02	1.94E+10	51	2.51E-07	1.84E+10
25	2.55E-02	2.24E+10	52	1.52E-07	1.76E+10
26	1.99E-02	1.12E+10	53	9.24E-08	4.85E+10
27	1.50E-02	2.15E+10			

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

Table 6-11 cont'd

Best Estimate Neutron Energy Spectrum at the
Center of Surveillance Capsules

Capsule X

Group #	Energy (MeV)	Flux (n/cm^2-sec)	Group #	Energy (MeV)	Flux (n/cm^2-sec)
1	1.73E+01	5.88E+06	28	9.12E-03	1.97E+10
2	1.49E+01	1.27E+07	29	5.53E-03	2.00E+10
3	1.35E+01	4.73E+07	30	3.36E-03	6.24E+09
4	1.16E+01	1.31E+08	31	2.84E-03	6.13E+09
5	1.00E+01	2.99E+08	32	2.40E-03	6.07E+09
6	8.61E+00	5.24E+08	33	2.04E-03	1.80E+10
7	7.41E+00	1.27E+09	34	1.23E-03	1.77E+10
8	6.07E+00	1.95E+09	35	7.49E-04	1.73E+10
9	4.97E+00	4.03E+09	36	4.54E-04	1.37E+10
10	3.68E+00	4.71E+09	37	2.75E-04	1.48E+10
11	2.87E+00	9.11E+09	38	1.67E-04	1.48E+10
12	2.23E+00	1.23E+10	39	1.01E-04	1.60E+10
13	1.74E+00	1.68E+10	40	6.14E-05	1.60E+10
14	1.35E+00	1.88E+10	41	3.73E-05	1.59E+10
15	1.11E+00	3.51E+10	42	2.26E-05	1.57E+10
16	8.21E-01	3.77E+10	43	1.37E-05	1.53E+10
17	6.39E-01	4.31E+10	44	8.32E-06	1.46E+10
18	4.98E-01	2.78E+10	45	5.04E-06	1.36E+10
19	3.88E-01	4.31E+10	46	3.06E-06	1.31E+10
20	3.02E-01	4.75E+10	47	1.86E-06	1.24E+10
21	1.83E-01	4.82E+10	48	1.13E-06	7.65E+09
22	1.11E-01	3.13E+10	49	6.83E-07	9.40E+09
23	6.74E-02	2.96E+10	50	4.14E-07	1.43E+10
24	4.09E-02	1.59E+10	51	2.51E-07	1.38E+10
25	2.55E-02	1.84E+10	52	1.52E-07	1.29E+10
26	1.99E-02	9.14E+09	53	9.24E-08	3.36E+10
27	1.50E-02	1.76E+10			

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

Table 6-12

Comparison of Calculated and Best Estimate Integrated Neutron Exposure of Millstone Unit 3 Surveillance Capsules U and X

CAPSULE U

	Calculated	Best Estimate	BE/C
$\Phi(E > 1.0\ MeV)$ [n/cm^2]	4.49E+18	4.20E+18	0.93
$\Phi(E > 0.1\ MeV)$ [n/cm^2]	1.95E+19	1.84E+19	0.94
dpa	8.54E-03	8.07E-03	0.95

CAPSULE X

	Calculated	Best Estimate	BE/C
$\Phi(E > 1.0\ MeV)$ [n/cm^2]	2.21E+19	2.07E+19	0.94
$\Phi(E > 0.1\ MeV)$ [n/cm^2]	9.62E+19	9.06E+19	0.94
dpa	4.21E-02	3.97E-02	0.94

AVERAGE BE/C RATIOS

	BE/C
$\Phi(E > 1.0\ MeV)$ [n/cm^2]	0.93
$\Phi(E > 0.1\ MeV)$ [n/cm^2]	0.94
Dpa	0.94

Table 6-13

Azimuthal Variations of the Neutron Exposure Projections
on the Reactor Vessel Clad/Base Metal Interface at the Core Midplane

Best Estimate

	0°	15°	30°[a]	45°
8 EFPY				
E>1.0 MeV	3.02E+18	4.36E+18	4.73E+18	4.55E+18
E>0.1 MeV	6.45E+18	9.39E+18	1.04E+19	1.15E+19
dpa	4.74E-03	6.78E-03	7.37E-03	7.28E-03
12 EFPY				
E>1.0 MeV	4.41E+18	6.41E+18	7.01E+18	6.69E+18
E>0.1 MeV	9.42E+18	1.38E+19	1.54E+19	1.70E+19
dpa	6.93E-03	9.96E-03	1.09E-02	1.07E-02
16 EFPY				
E>1.0 MeV	5.80E+18	8.46E+18	9.28E+18	8.83E+18
E>0.1 MeV	1.24E+19	1.82E+19	2.05E+19	2.24E+19
dpa	9.11E-03	1.31E-02	1.45E-02	1.41E-02
32 EFPY				
E>1.0 MeV	1.14E+19	1.66E+19	1.84E+19	1.74E+19
E>0.1 MeV	2.43E+19	3.58E+19	4.05E+19	4.41E+19
dpa	1.79E-02	2.59E-02	2.86E-02	2.78E-02
54 EFPY				
E>1.0 MeV	1.90E+19	2.79E+19	3.09E+19	2.91E+19
E>0.1 MeV	4.06E+19	6.01E+19	6.81E+19	7.39E+19
dpa	2.99E-02	4.34E-02	4.82E-02	4.66E-02

Note:

a) Maximum neutron exposure projection reported for 30° vessel location representing the octant containing the 12.5° neutron pad span.

Table 6-13 cont'd

Azimuthal Variations of The Neutron Exposure Projections
on the Reactor Vessel Clad/Base Metal Interface at the Core Midplane

	Calculated			
	0°	15°	30°[a]	45°
8 EFPY				
E>1.0 MeV	3.23E+18	4.67E+18	5.06E+18	4.87E+18
E>0.1 MeV	6.84E+18	9.96E+18	1.11E+19	1.22E+19
dpa	5.02E-03	7.18E-03	7.81E-03	7.70E-03
12 EFPY				
E>1.0 MeV	4.72E+18	6.86E+18	7.50E+18	7.16E+18
E>0.1 MeV	9.99E+18	1.46E+19	1.64E+19	1.80E+19
dpa	7.33E-03	1.05E-02	1.16E-02	1.13E-02
16 EFPY				
E>1.0 MeV	6.21E+18	9.05E+18	9.93E+18	9.45E+18
E>0.1 MeV	1.31E+19	1.93E+19	2.17E+19	2.37E+19
dpa	9.65E-03	1.39E-02	1.53E-02	1.49E-02
32 EFPY				
E>1.0 MeV	1.22E+19	1.78E+19	1.97E+19	1.86E+19
E>0.1 MeV	2.58E+19	3.80E+19	4.30E+19	4.67E+19
dpa	1.89E-02	2.74E-02	3.03E-02	2.94E-02
54 EFPY				
E>1.0 MeV	2.04E+19	2.99E+19	3.31E+19	3.12E+19
E>0.1 MeV	4.31E+19	6.37E+19	7.22E+19	7.84E+19
dpa	3.16E-02	4.59E-02	5.10E-02	4.93E-02

Note:

a) Maximum neutron exposure projection reported for 30° vessel location representing the octant containing the 12.5° neutron pad span.

Table 6-14

Neutron Exposure Values within the
Millstone Unit 3 Reactor Vessel

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

	0°	15°	30°[b]	45°
12 EFPY				
Surface	4.41E+18	6.41E+18	7.01E+18	6.69E+18
¼ T	2.49E+18	3.59E+18	3.87E+18	3.69E+18
¾ T	5.76E+17	8.13E+17	8.71E+17	8.15E+17
16 EFPY				
Surface	5.80E+18	8.46E+18	9.28E+18	8.83E+18
¼ T	3.27E+18	4.73E+18	5.13E+18	4.87E+18
¾ T	7.58E+17	1.07E+18	1.15E+18	1.08E+18
32 EFPY				
Surface	1.14E+19	1.66E+19	1.84E+19	1.74E+19
¼ T	6.41E+18	9.31E+18	1.02E+19	9.58E+18
¾ T	1.49E+18	2.11E+18	2.29E+18	2.12E+18
54 EFPY				
Surface	1.90E+19	2.79E+19	3.09E+19	2.91E+19
¼ T	1.07E+19	1.56E+19	1.71E+19	1.61E+19
¾ T	2.49E+18	3.54E+18	3.84E+18	3.55E+18

Note:

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

b) Maximum neutron exposure projection reported for 30° vessel location representing the octant containing the 12.5° neutron pad span.

Table 6-14 cont'd

Neutron Exposure Values within the
Millstone Unit 3 Reactor Vessel

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

	0°	15°	30°[b]	45°
12 EFPY				
Surface	4.41E+18	6.41E+18	7.01E+18	6.69E+18
¼ T	2.82E+18	4.07E+18	4.43E+18	4.31E+18
¾ T	1.04E+18	1.45E+18	1.60E+18	1.59E+18
16 EFPY				
Surface	5.80E+18	8.46E+18	9.28E+18	8.83E+18
¼ T	3.71E+18	5.37E+18	5.87E+18	5.69E+18
¾ T	1.37E+18	1.92E+18	2.12E+18	2.09E+18
32 EFPY				
Surface	1.14E+19	1.66E+19	1.84E+19	1.74E+19
¼ T	7.27E+18	1.06E+19	1.16E+19	1.12E+19
¾ T	2.69E+18	3.77E+18	4.21E+18	4.12E+18
54 EFPY				
Surface	1.90E+19	2.79E+19	3.09E+19	2.91E+19
¼ T	1.22E+19	1.77E+19	1.95E+19	1.88E+19
¾ T	4.50E+18	6.33E+18	7.07E+18	6.90E+18

Note:

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

b) Maximum neutron exposure projection reported for 30° vessel location representing the octant containing the 12.5° neutron pad span.

Table 6-14 cont'd

Neutron Exposure Values within the
Millstone Unit 3 Reactor Vessel

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

	0°	15°	30°[b]	45°
12 EFPY				
Surface	4.72E+18	6.86E+18	7.50E+18	7.16E+18
¼ T	2.66E+18	3.84E+18	4.14E+18	3.95E+18
¾ T	6.17E+17	8.70E+17	9.32E+17	8.72E+17
16 EFPY				
Surface	6.21E+18	9.05E+18	9.93E+18	9.45E+18
¼ T	3.50E+18	5.06E+18	5.48E+18	5.21E+18
¾ T	8.11E+17	1.15E+18	1.24E+18	1.15E+18
32 EFPY				
Surface	1.22E+19	1.78E+19	1.97E+19	1.86E+19
¼ T	6.86E+18	9.96E+18	1.09E+19	1.02E+19
¾ T	1.59E+18	2.26E+18	2.45E+18	2.27E+18
54 EFPY				
Surface	2.04E+19	2.99E+19	3.31E+19	3.12E+19
¼ T	1.15E+19	1.67E+19	1.83E+19	1.72E+19
¾ T	2.66E+18	3.79E+18	4.11E+18	3.80E+18

Note:

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

b) Maximum neutron exposure projection reported for 30° vessel location representing the octant containing the 12.5° neutron pad span.

Table 6-14 cont'd

Neutron Exposure Values within the
Millstone Unit 3 Reactor Vessel

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

	0°	15°	30°[b]	45°
12 EFPY				
Surface	4.72E+18	6.86E+18	7.50E+18	7.16E+18
¼ T	3.02E+18	4.35E+18	4.74E+18	4.61E+18
¾ T	1.12E+18	1.55E+18	1.72E+18	1.70E+18
16 EFPY				
Surface	6.21E+18	9.05E+18	9.93E+18	9.45E+18
¼ T	3.97E+18	5.74E+18	6.27E+18	6.09E+18
¾ T	1.47E+18	2.05E+18	2.27E+18	2.24E+18
32 EFPY				
Surface	1.22E+19	1.78E+19	1.97E+19	1.86E+19
¼ T	7.77E+18	1.13E+19	1.24E+19	1.20E+19
¾ T	2.88E+18	4.04E+18	4.50E+18	4.41E+18
54 EFPY				
Surface	2.04E+19	2.99E+19	3.31E+19	3.12E+19
¼ T	1.30E+19	1.89E+19	2.09E+19	2.01E+19
¾ T	4.82E+18	6.77E+18	7.56E+18	7.39E+18

Note:

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

b) Maximum neutron exposure projection reported for 30° vessel location representing the octant containing the 12.5° neutron pad span.

Table 6-15

Updated Lead Factors for Millstone Unit 3
Surveillance Capsules

Capsule	Lead Factor
U[a]	4.31
X[b]	4.37
W[c]	4.32
V[c]	4.11
Y[c]	4.11
Z[c]	4.32

[a] - Withdrawn at the end of Cycle 1.
[b] - Withdrawn at the end of Cycle 6.
[c] - Not withdrawn; standby.

The surveillance capsule lead factor is defined by:

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

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

7 SURVEILLANCE CAPSULE REMOVAL SCHEDULE

The following surveillance capsule removal schedule meets the requirements of ASTM E185-82 and is recommended for future capsules to be removed from the Millstone Unit 3 reactor vessel. This recommended removal schedule is applicable to 32 EFPY of operation.

Table 7-1 Millstone Unit 3 Reactor Vessel Surveillance Capsule Withdrawal Schedule

Capsule	Location	Lead Factor[a]	Removal Time (EFPY)[b]	Fluence (n/cm^2, E>1.0 MeV)[a]
U	58.5°	4.31	1.3	6.44×10^{18} (c)
X	238.5°	4.37	8.0	1.85×10^{19} (c)
W	121.5°	4.32	12.3	3.19×10^{19} (c,d)
Y[e]	241°	4.11	Standby	---
V[e]	61°	4.11	Standby	---
Z[e]	301.5°	4.32	Standby	---

Notes:

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

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

(c) Plant specific evaluation.

(d) This fluence is not less than once or greater than twice the peak end of license EOL fluence, and is approximately equal to the peak vessel fluence at 54 EFPY.

(e) These capsules will be at the approximate 54 EFPY peak surface (i.e. clad/base metal interface) fluence when capsule W is withdrawn and should be removed and placed in storage at the first outage passed 12.3 EFPY of operation.

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APPENDIX A

LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS

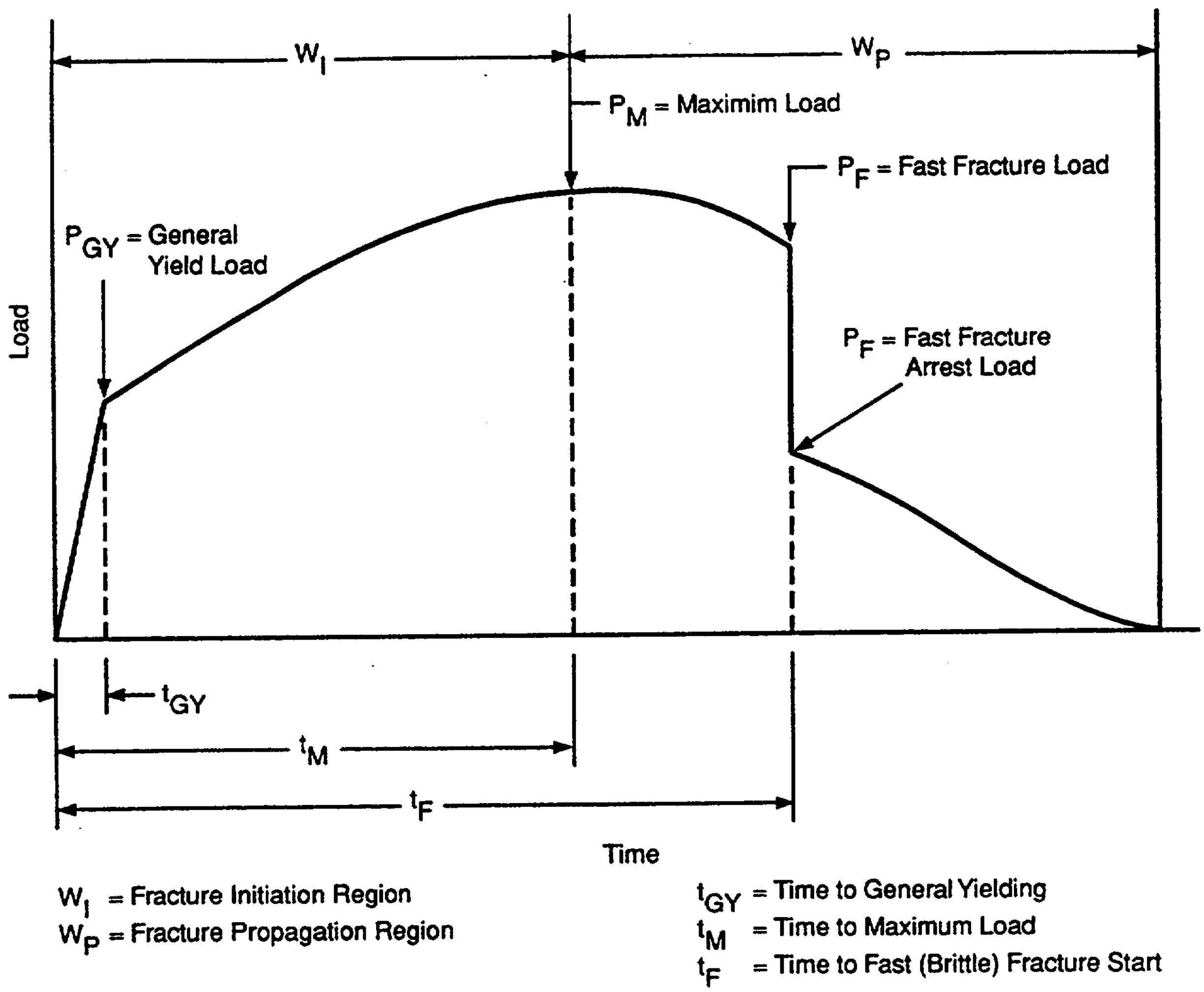
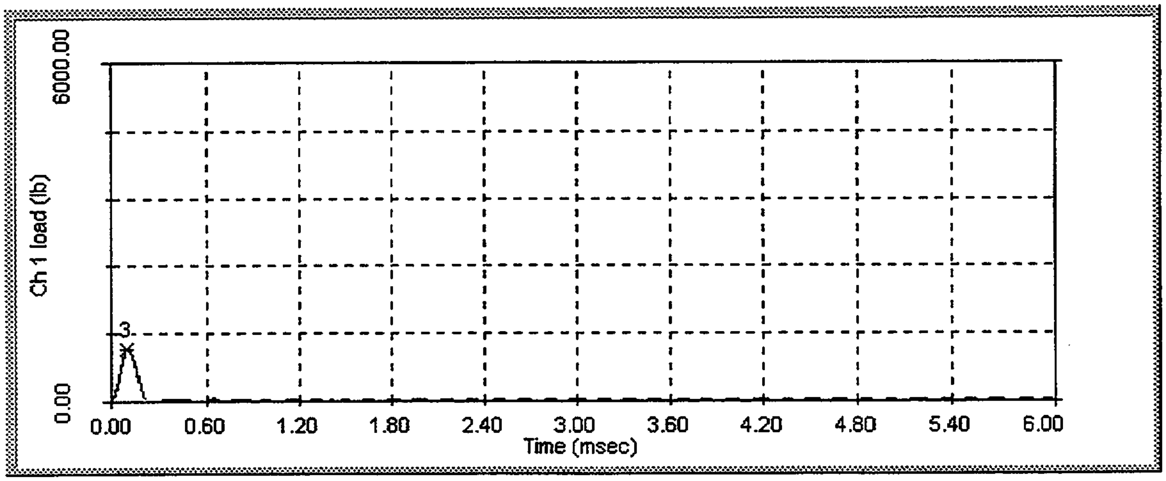
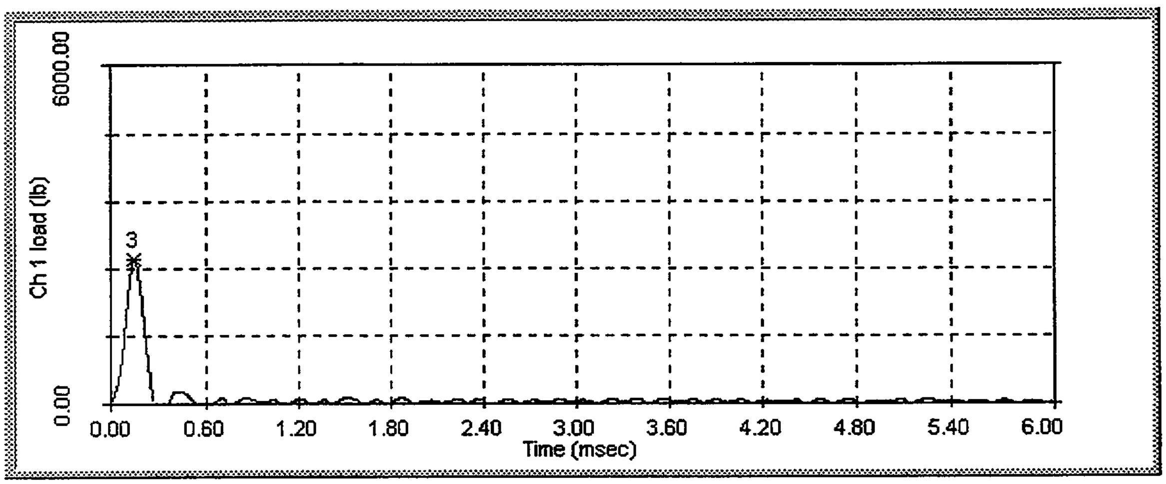


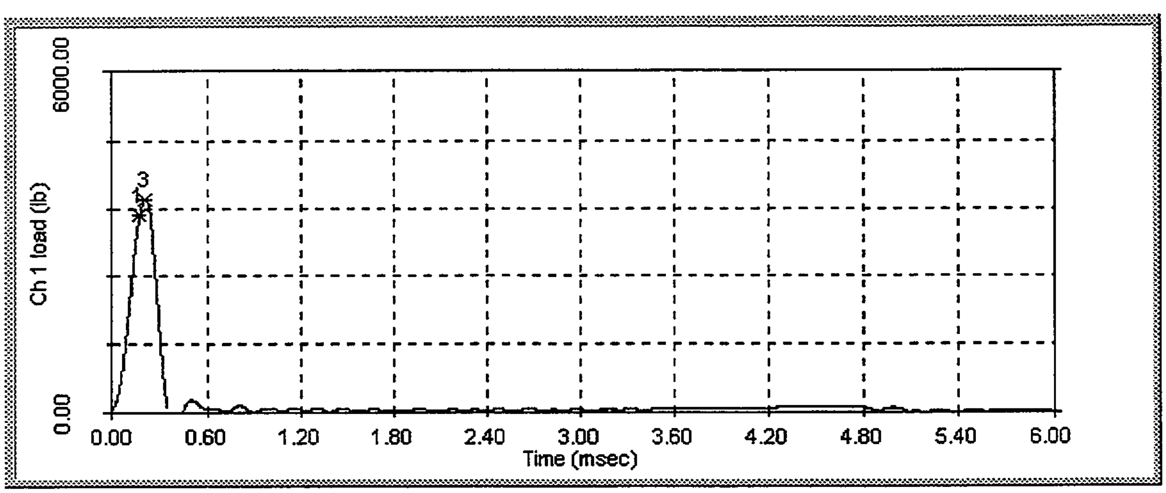
Fig. A-1-Idealized load-time record



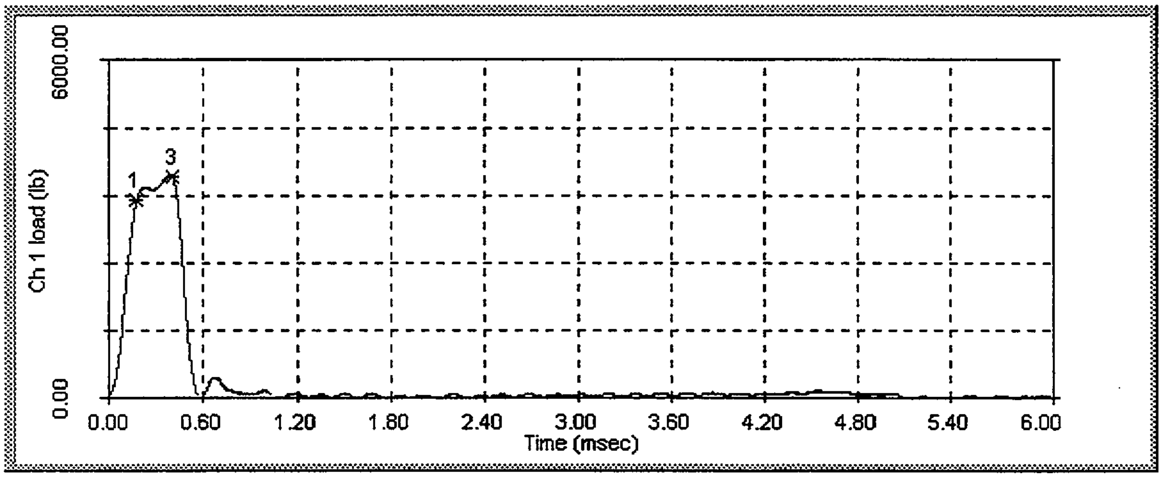
EL59, -150°F



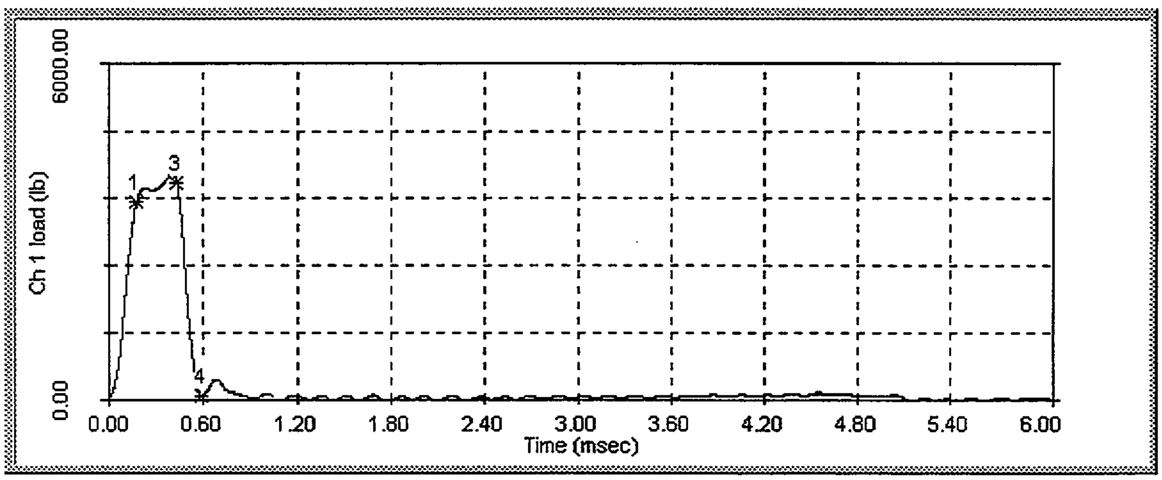
EL52, -25°F



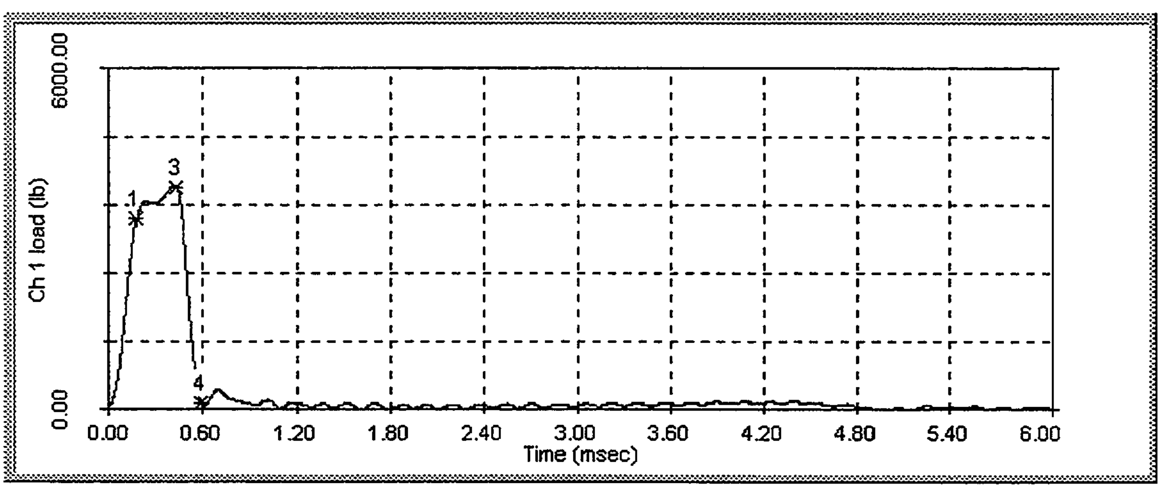
EL47, 0°F



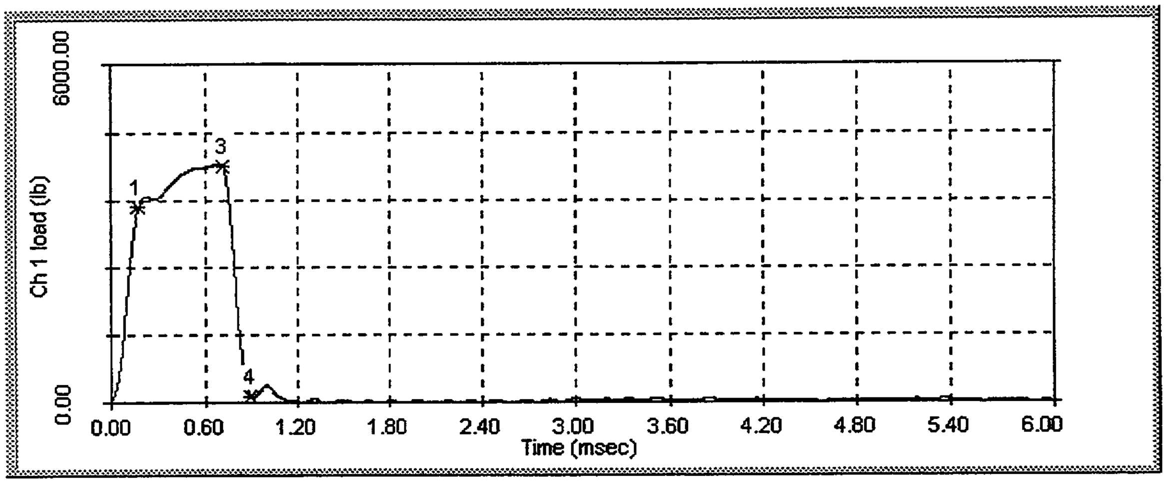
EL50, 25°F



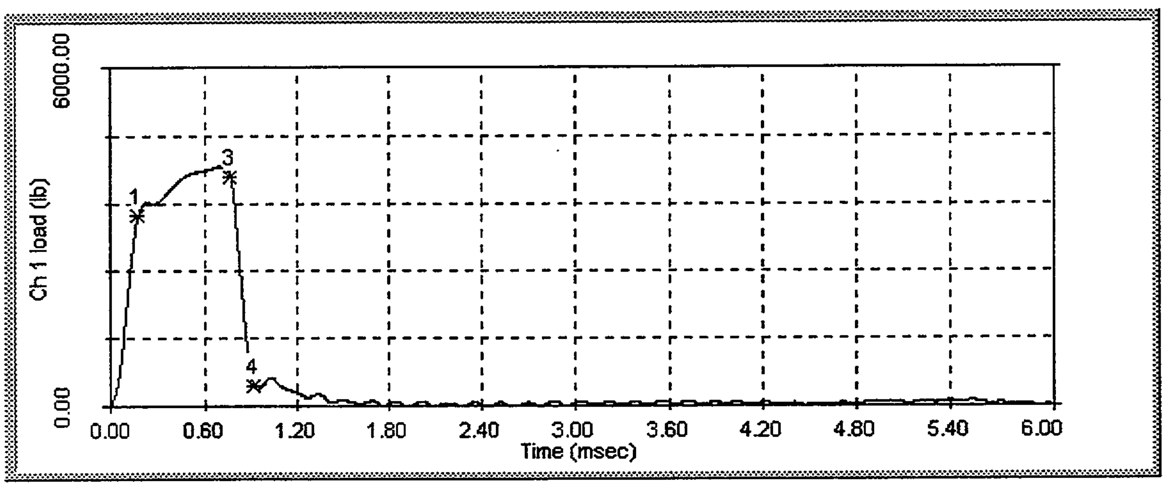
EL55, 30°F



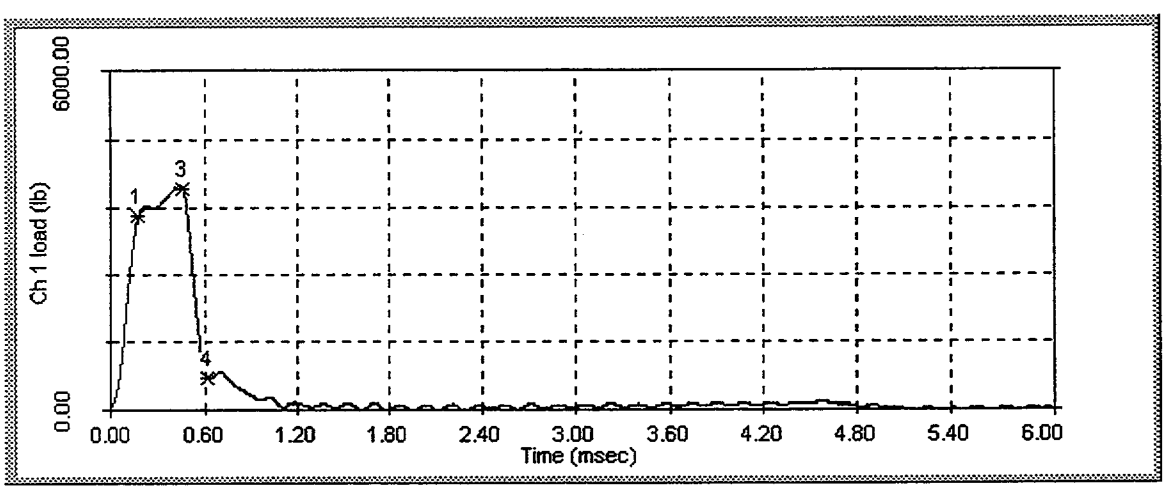
EL60, 40°F



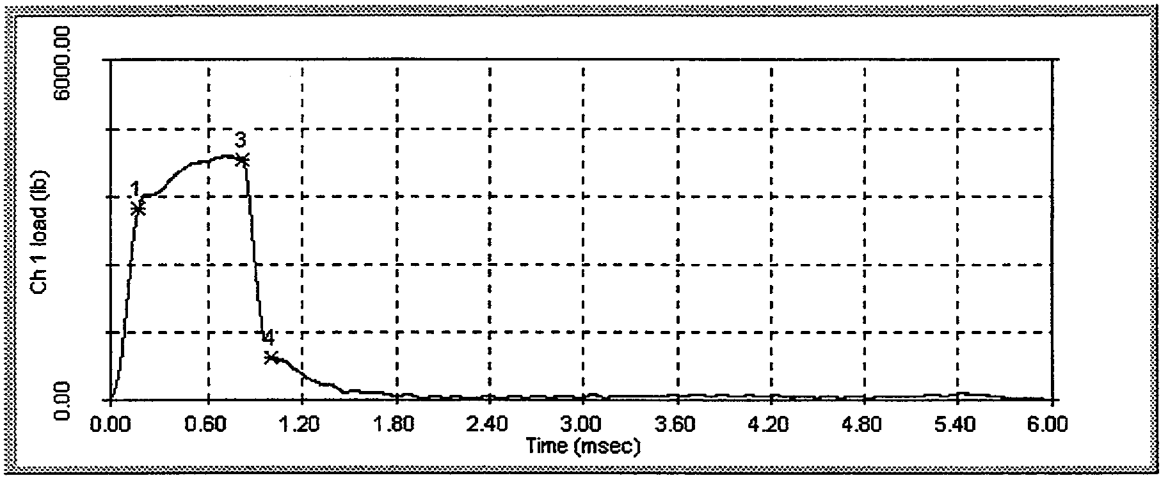
EL58, 45°F



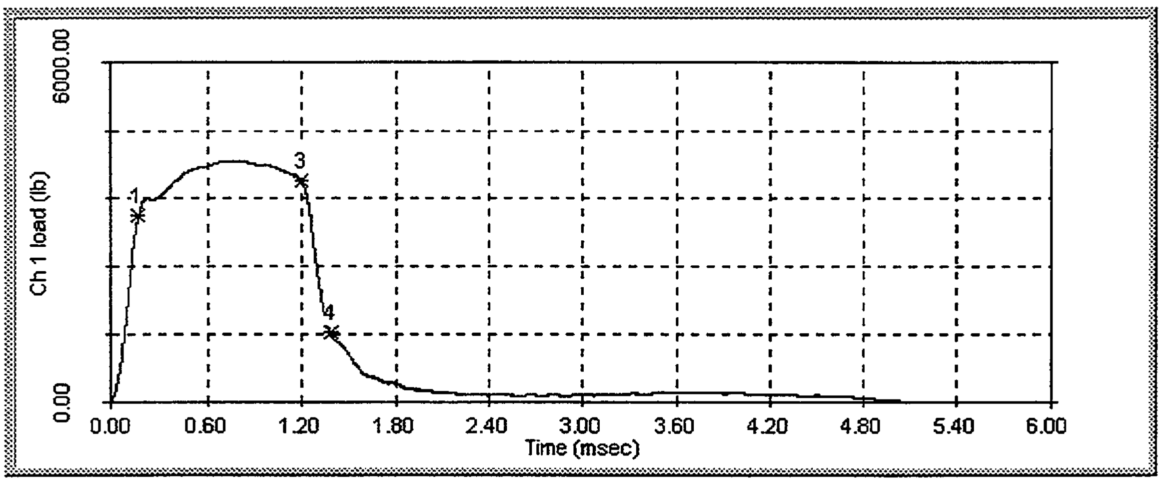
EL57, 50°F



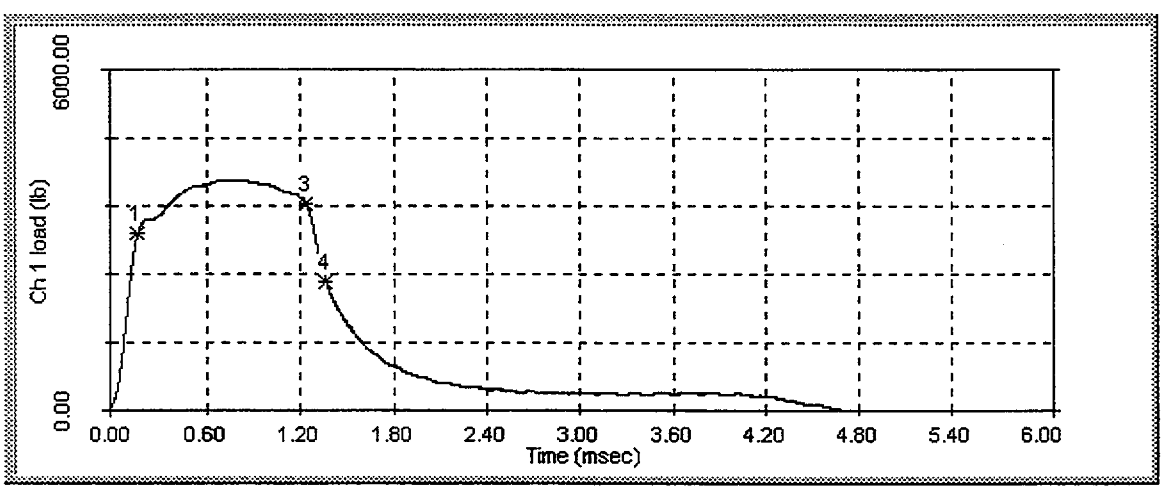
EL51, 60°F



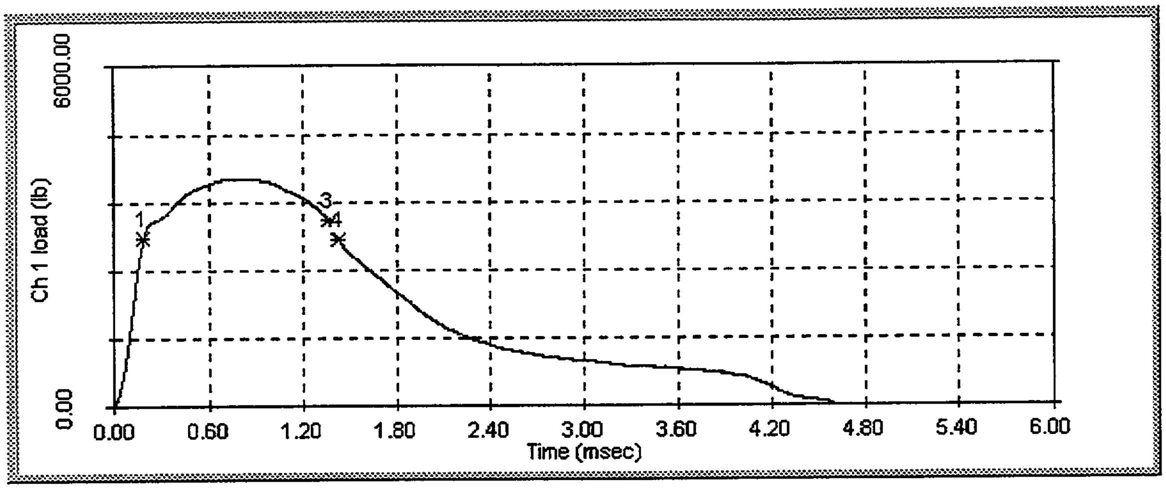
EL48, 72°F



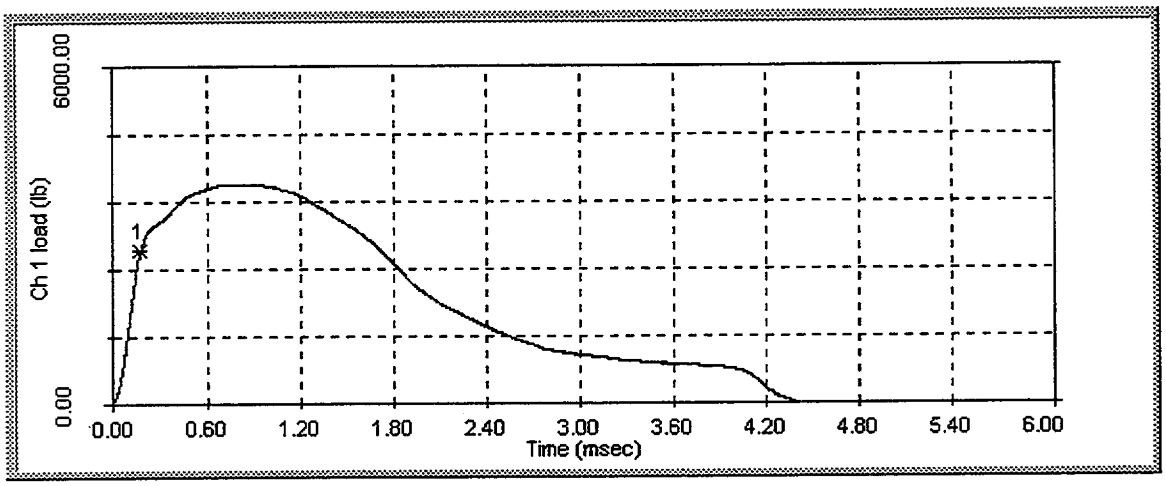
EL49, 100°F



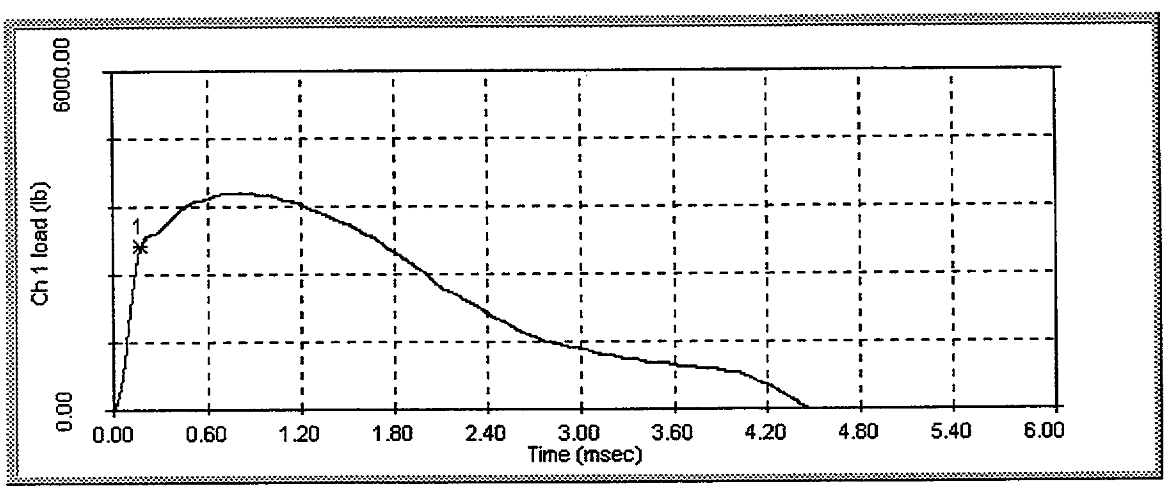
EL54, 150°F



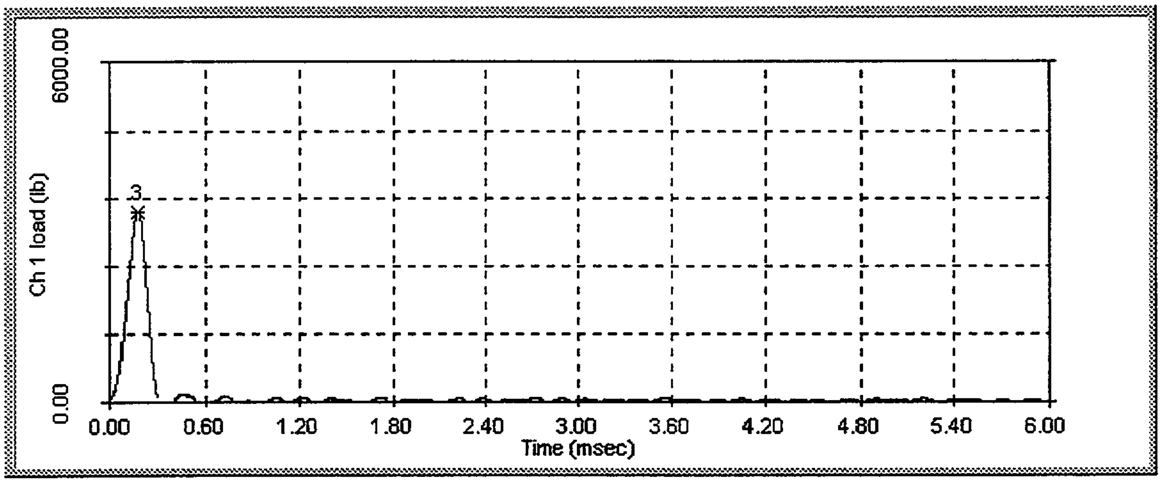
EL46, 200°F



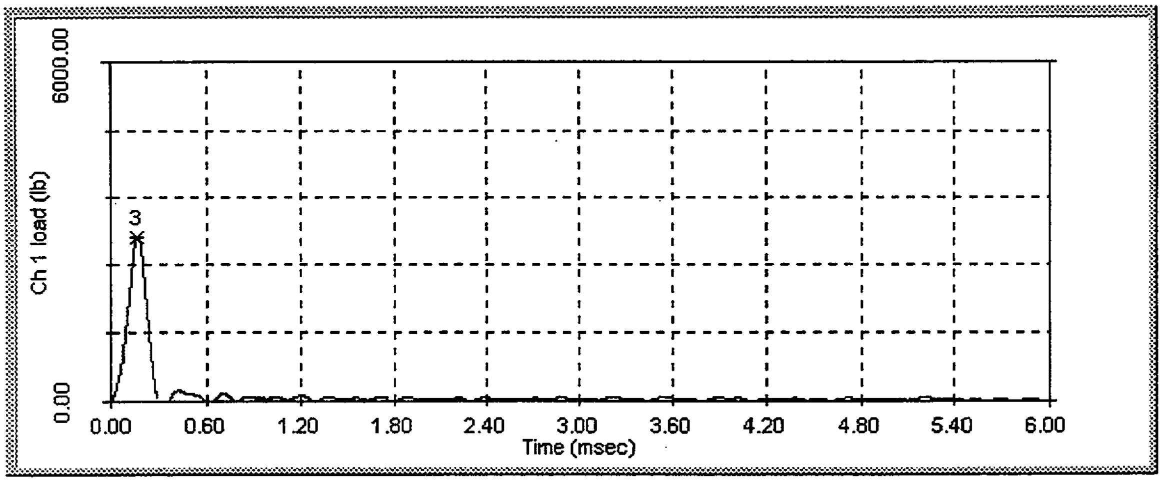
EL56, 250°F



EL53, 300°F



ET58, -25°F



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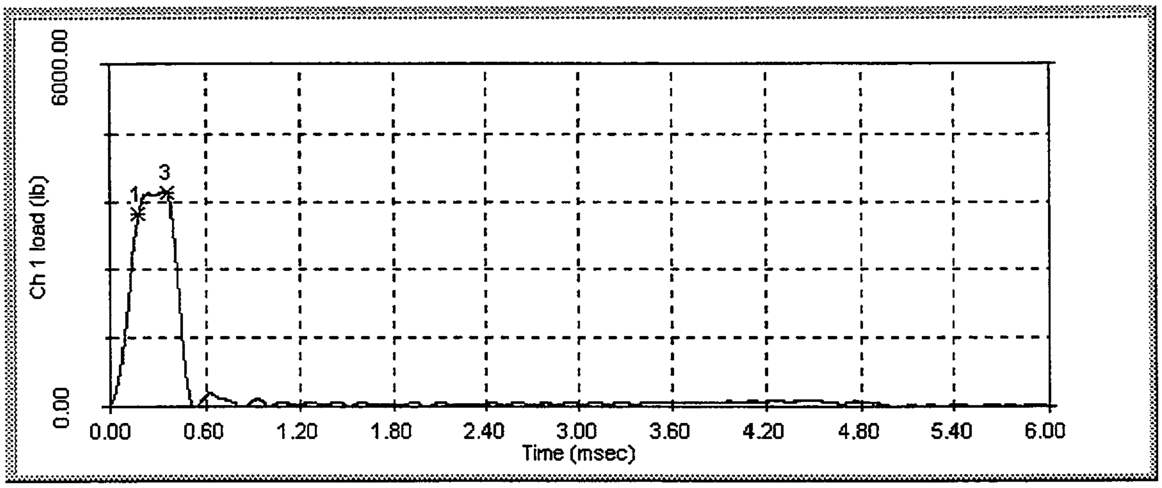

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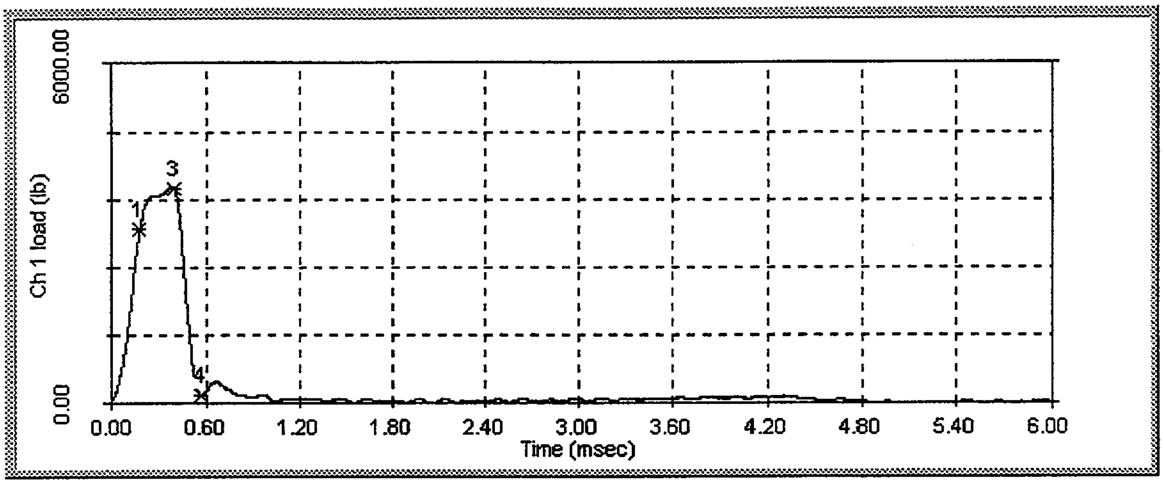
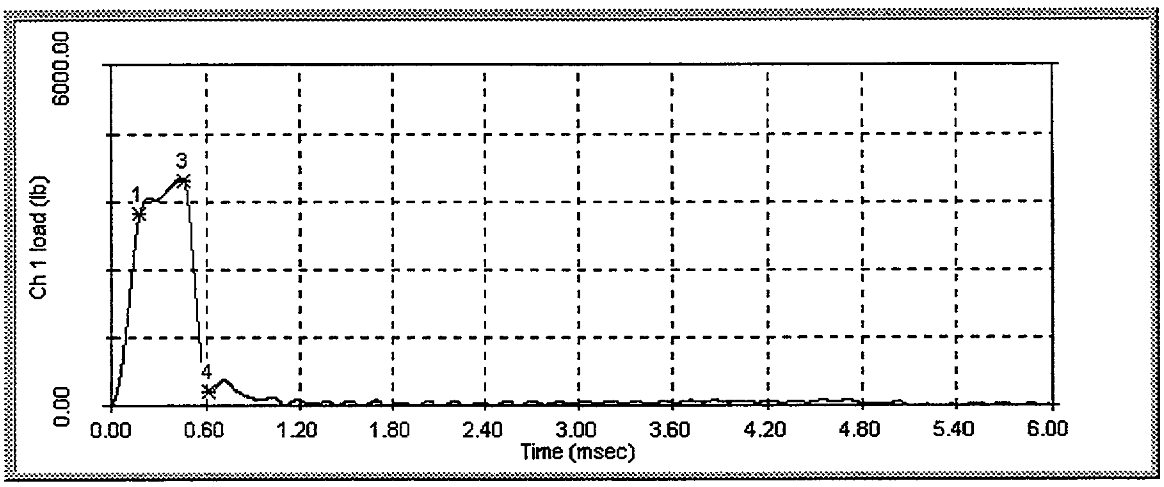
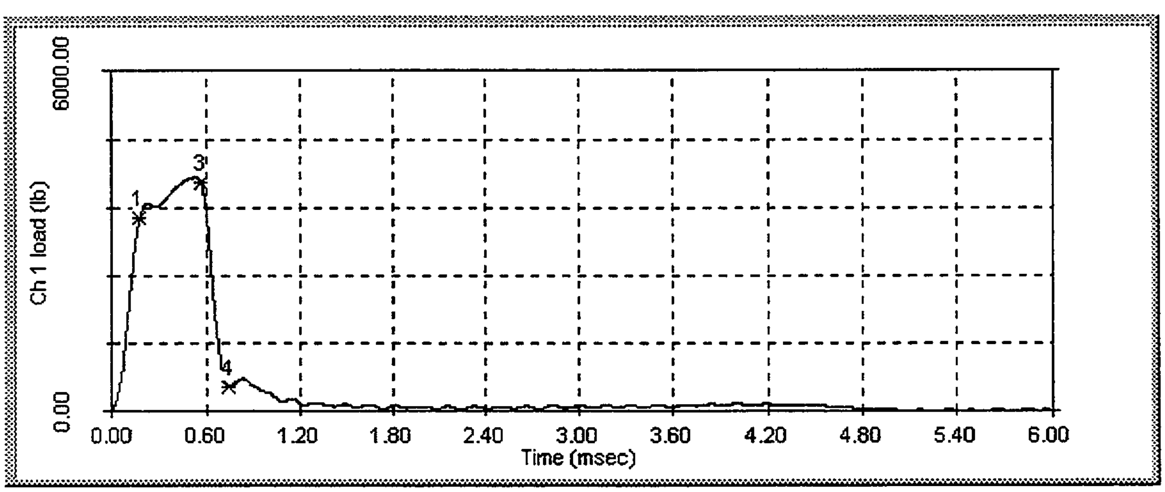


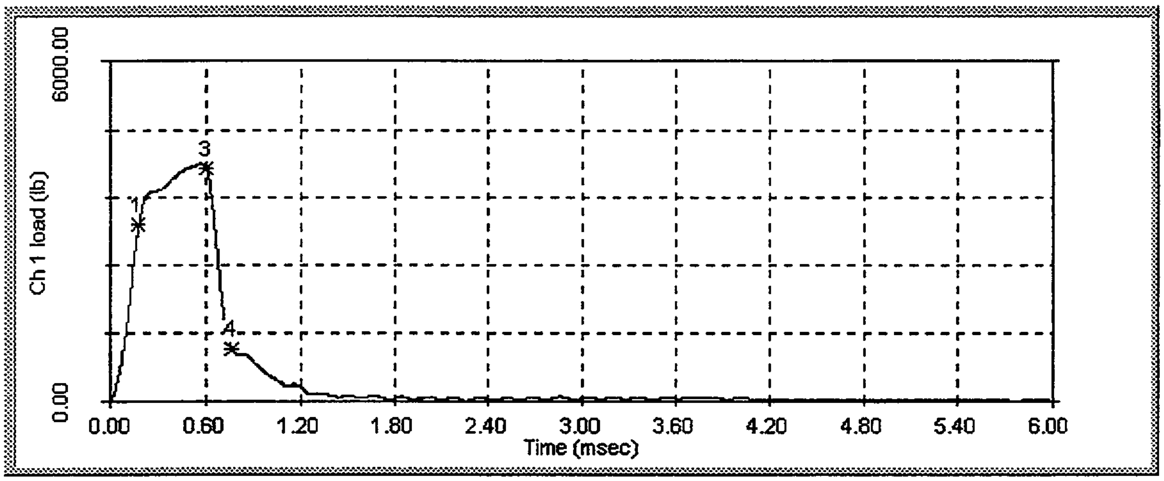
ET50, 40°F



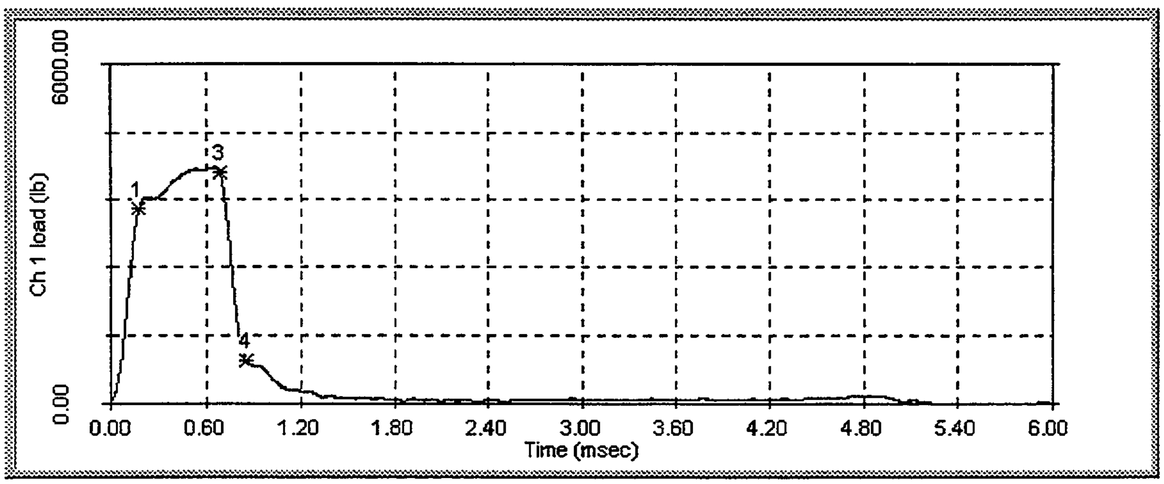
ET56, 50°F



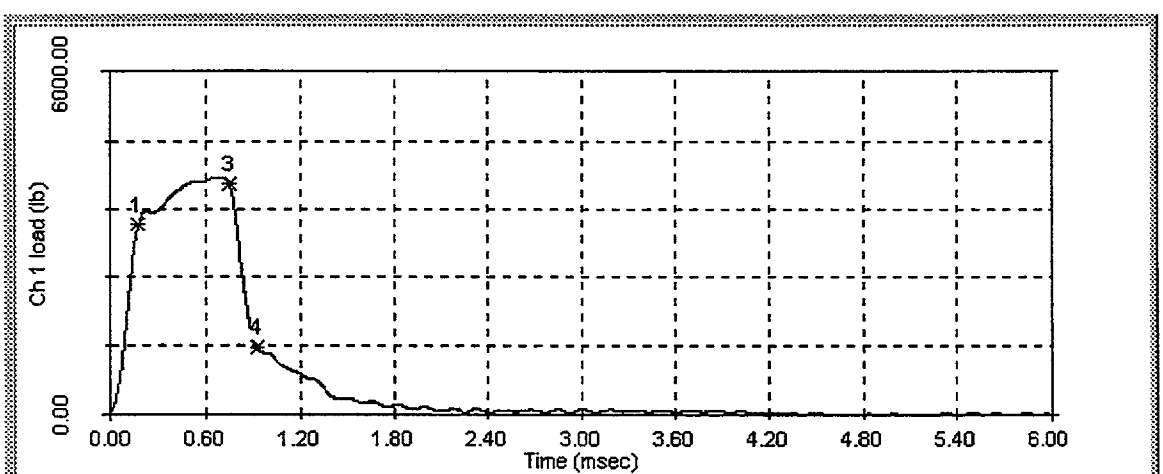
ET53, 60°F



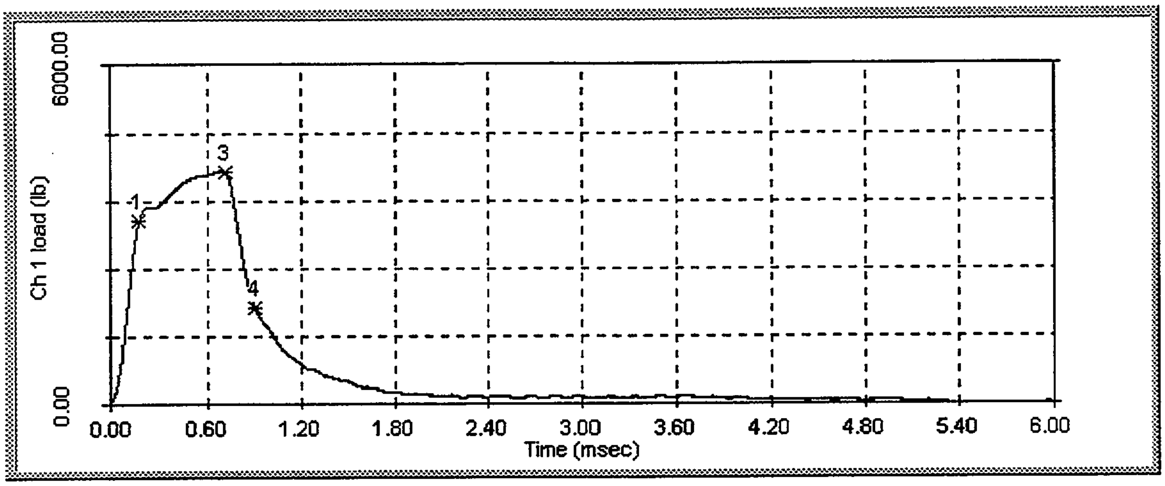
ET51, 72°F



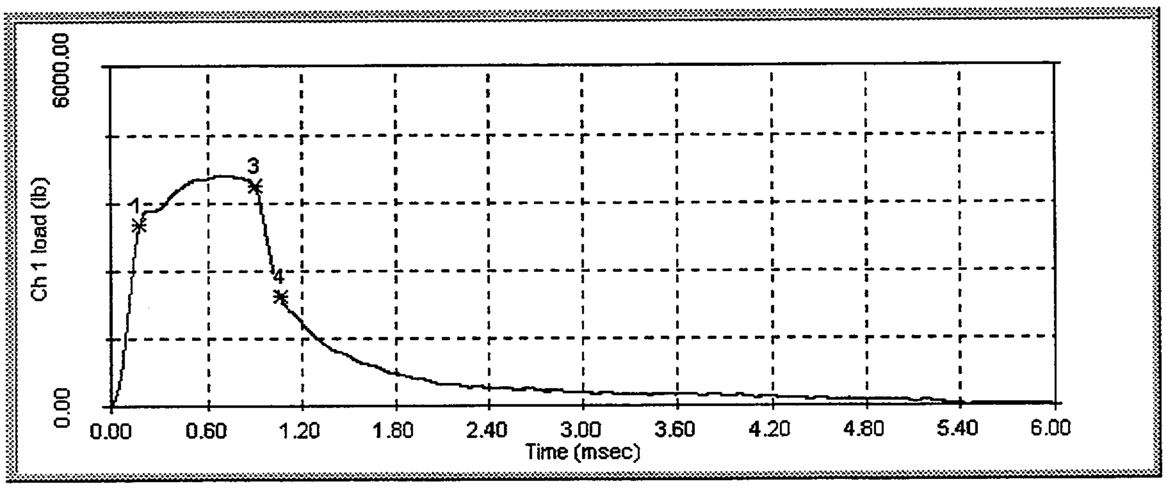
ET59, 80°F



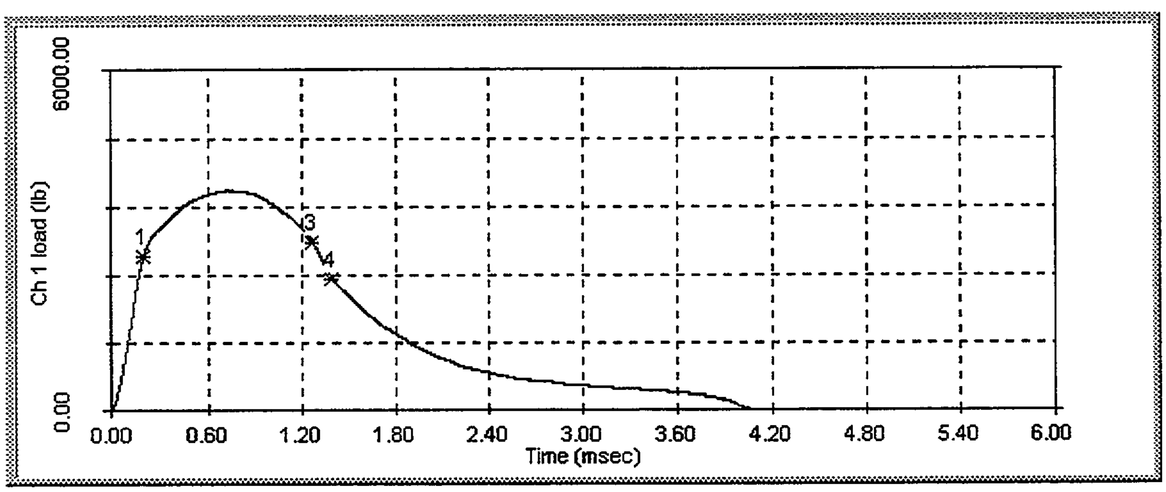
ET57, 100°F



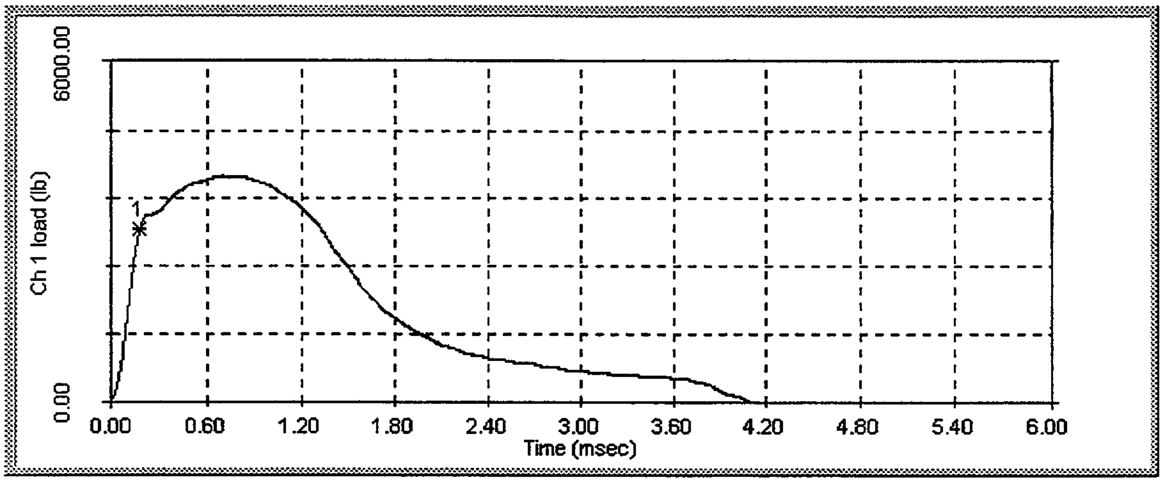
ET52, 125°F



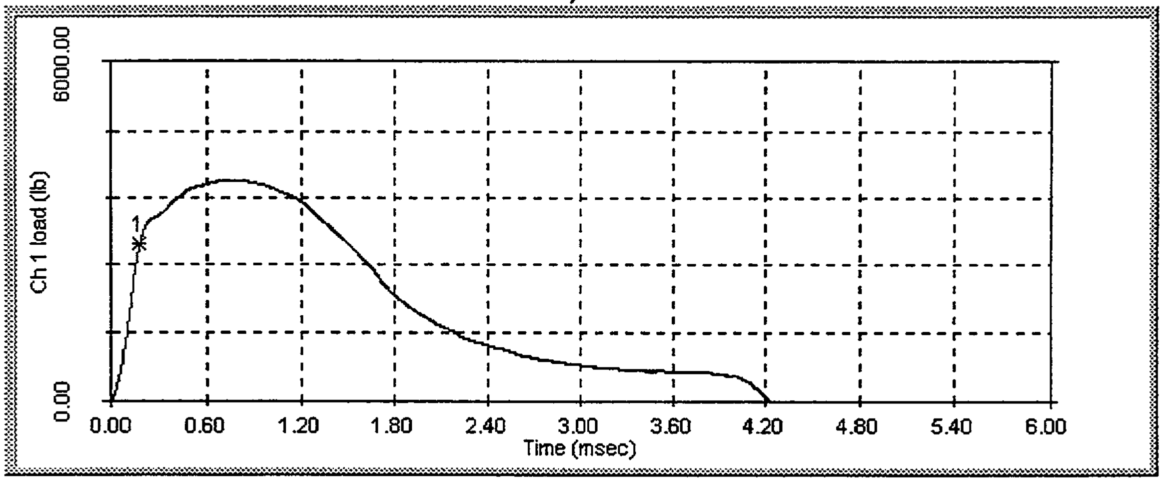
ET46, 160°F



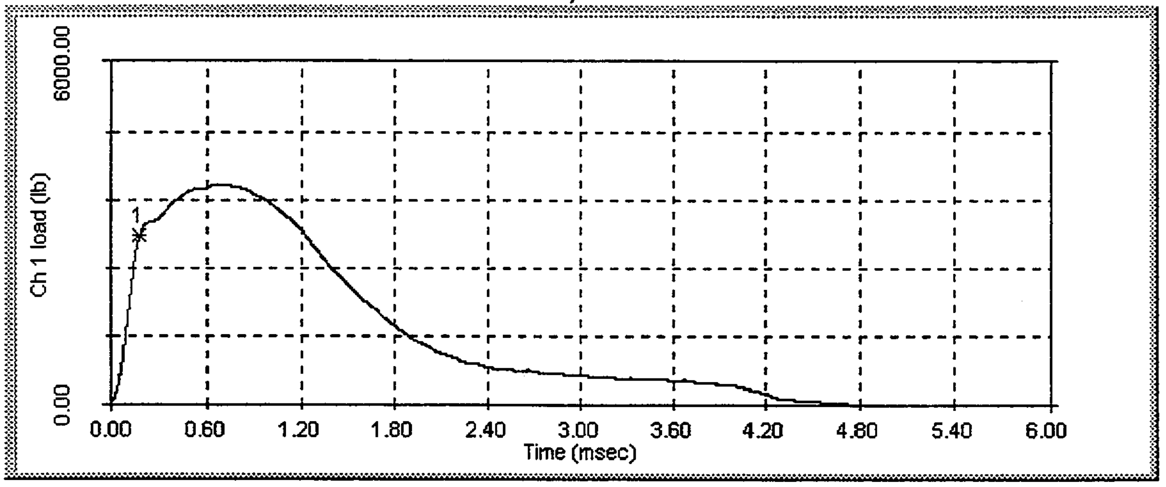
ET49, 200°F



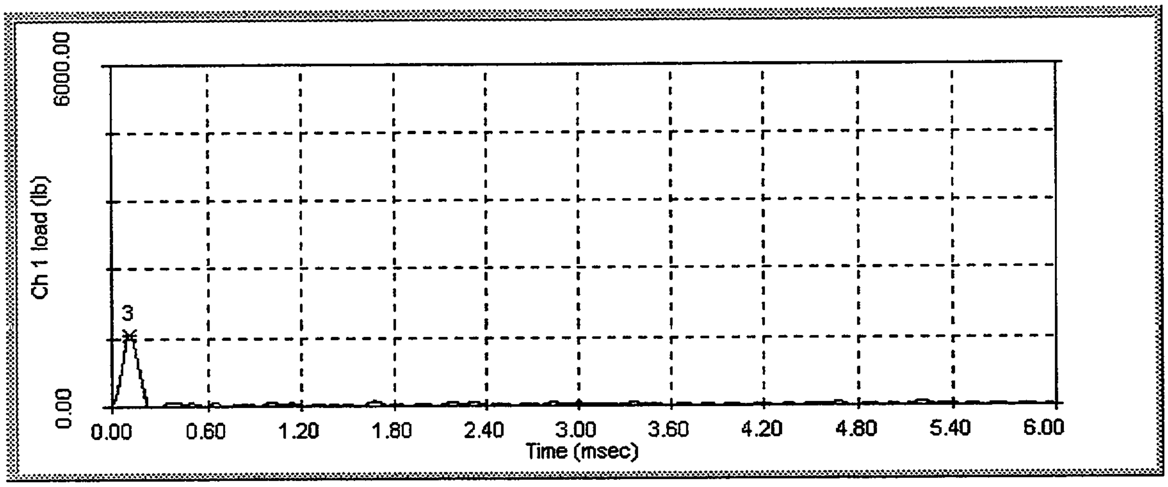
ET54, 200°F



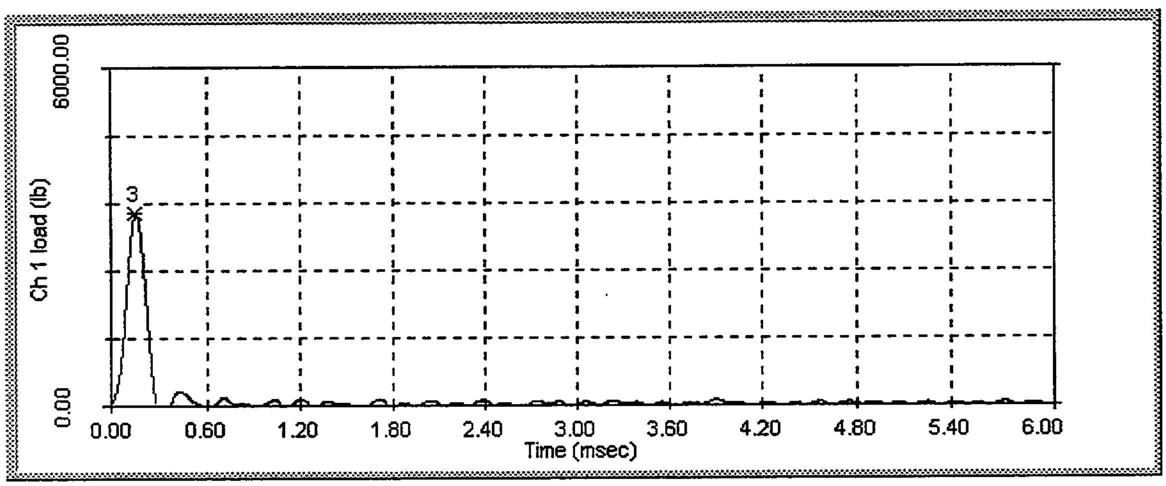
ET55, 250°F



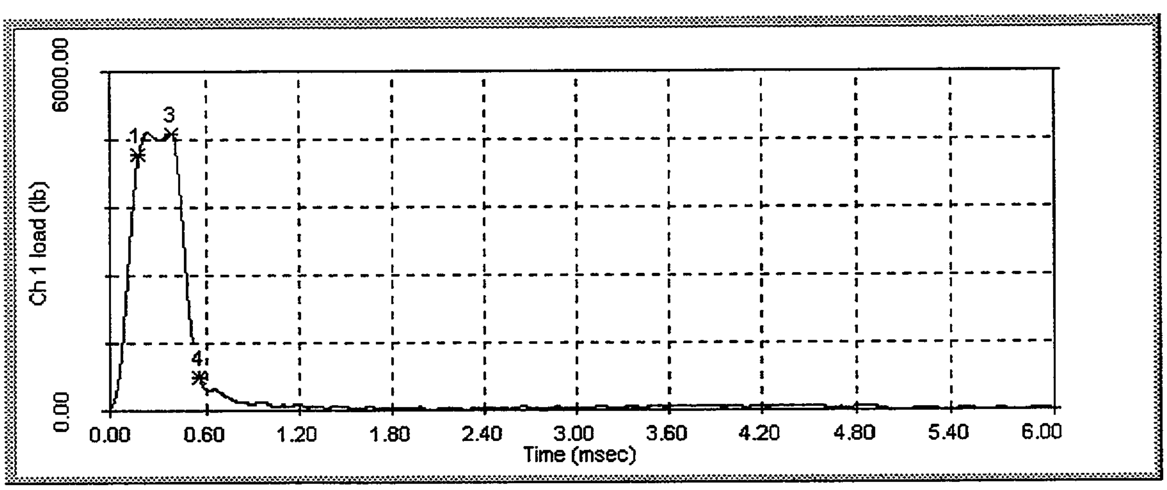
ET60, 300°F



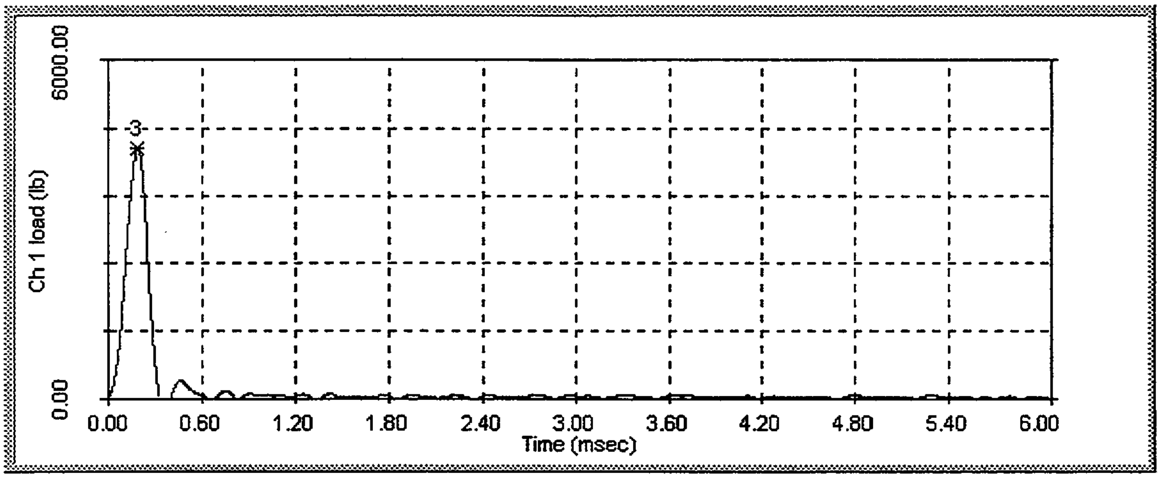
EW55, -100°F



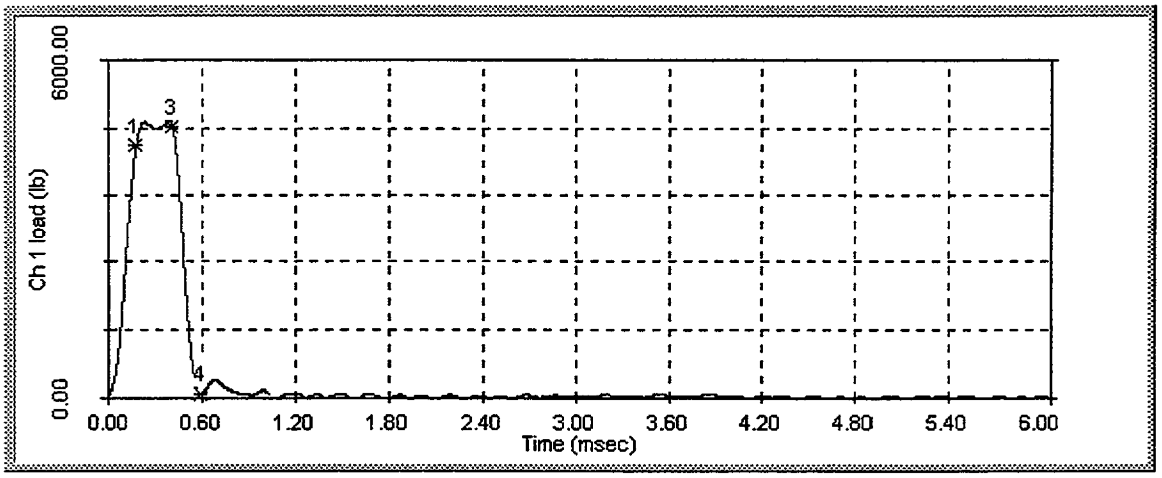
EW59, -75°F



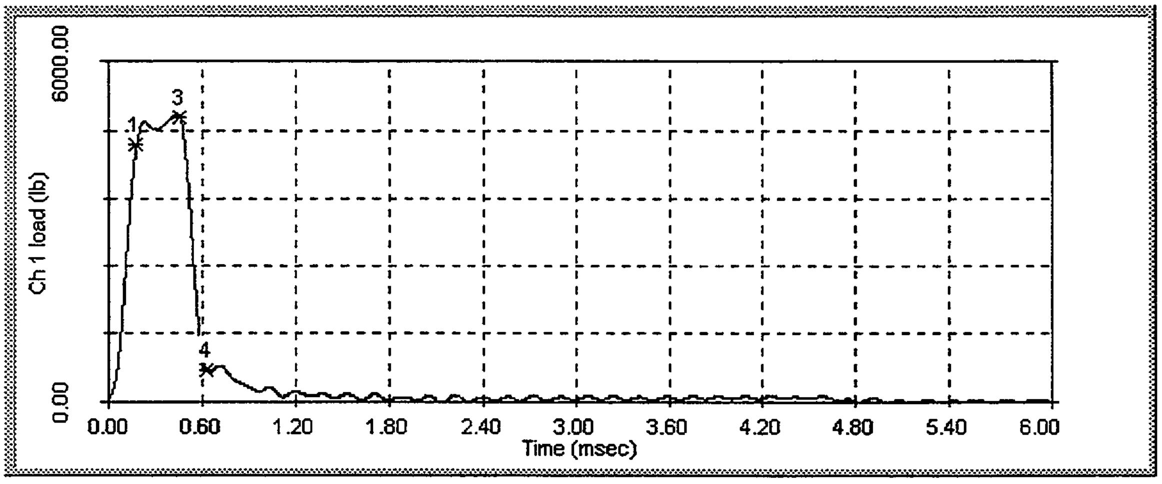
EW46, -50°F



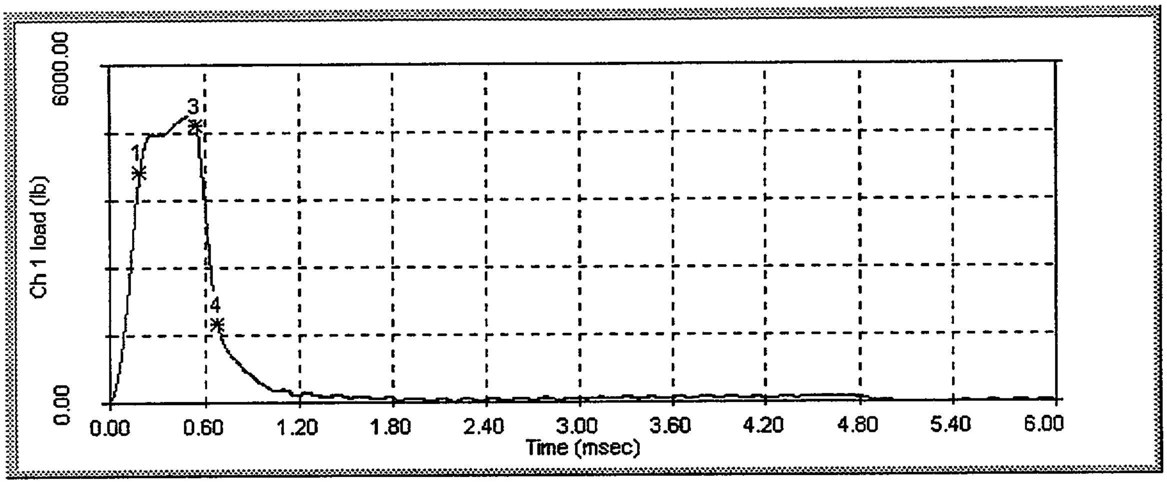
EW57, -50°F



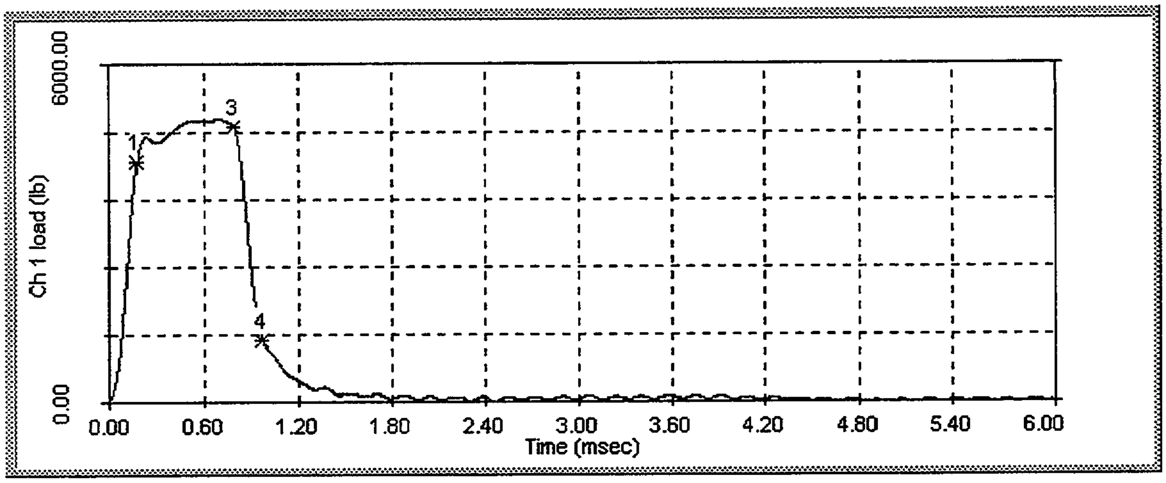
EW53, -45°F



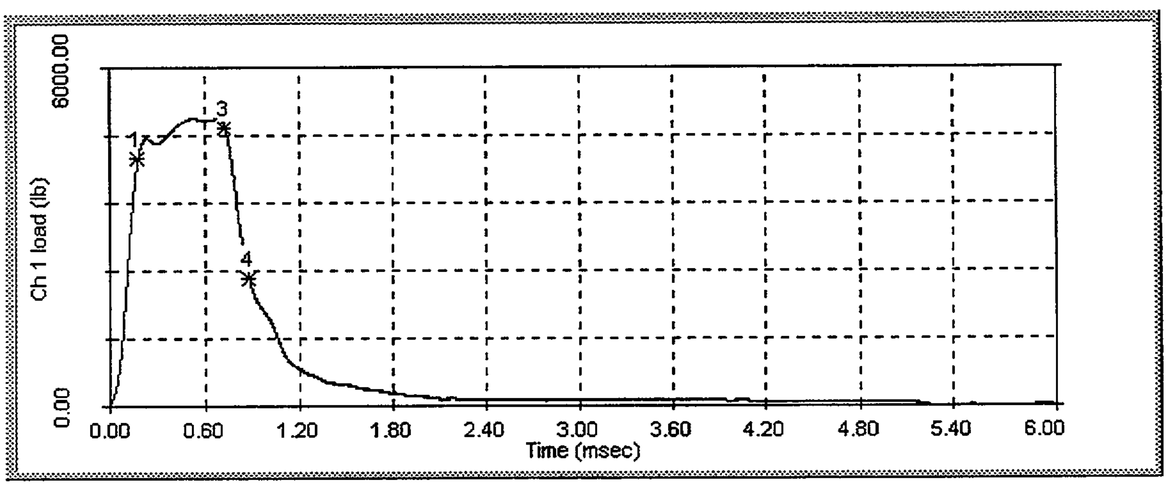
EW49, -40°F



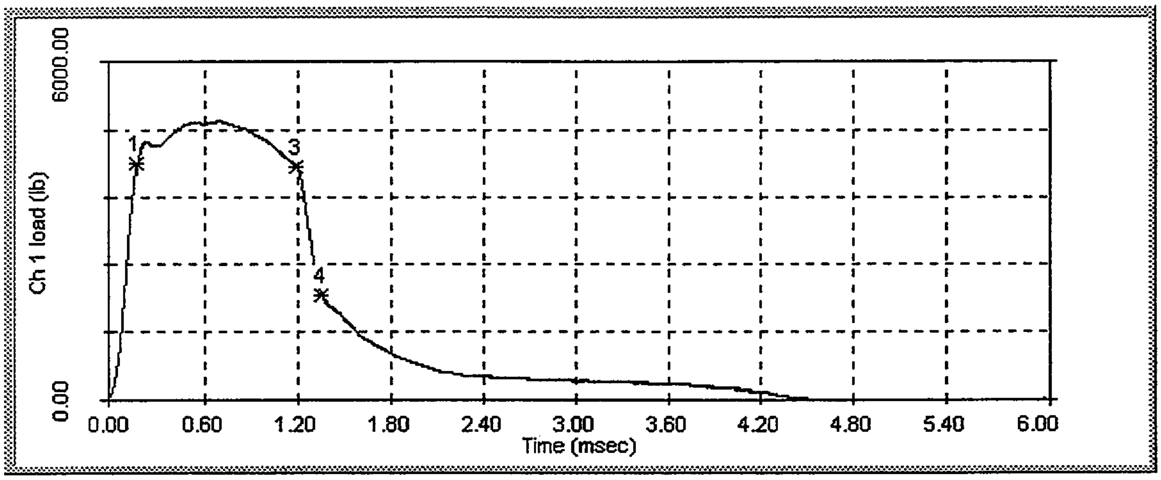
EW60, -25°F



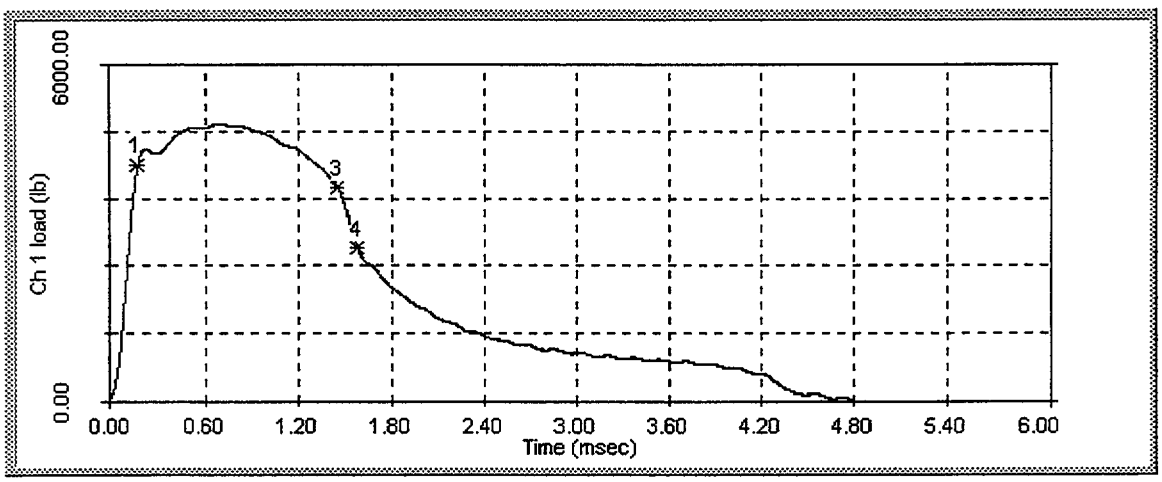
EW52, -20°F



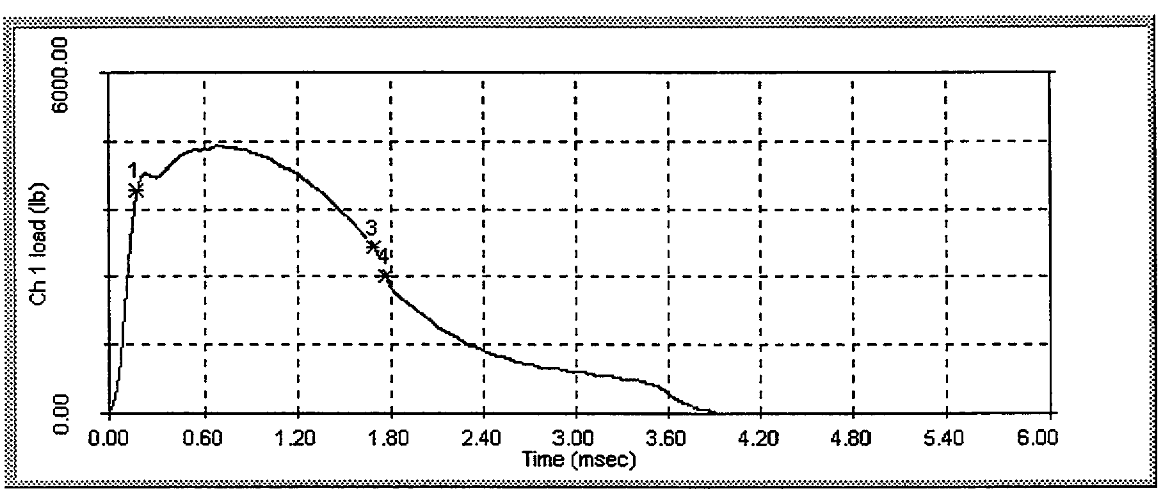
EW58, 0°F



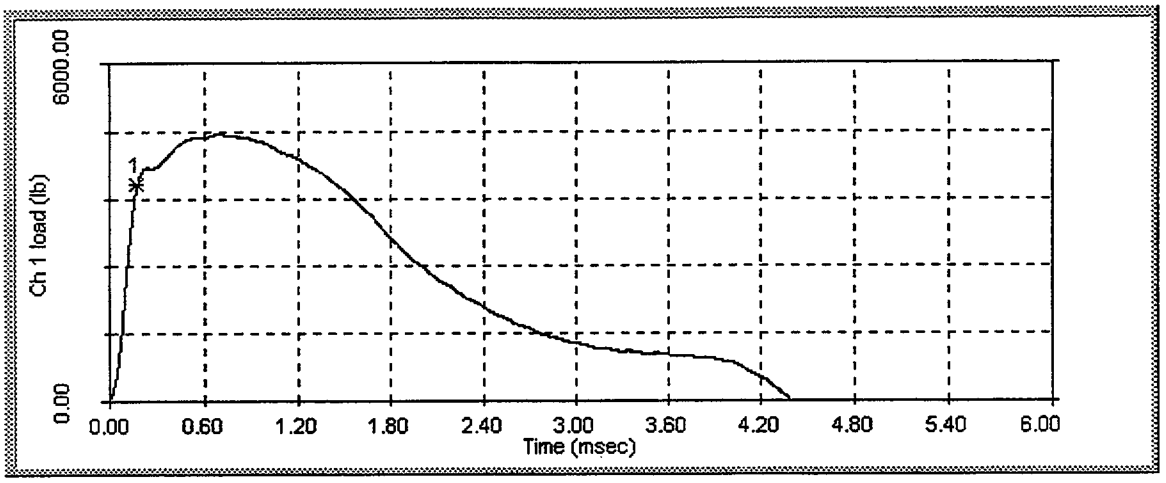
EW51, 25°F



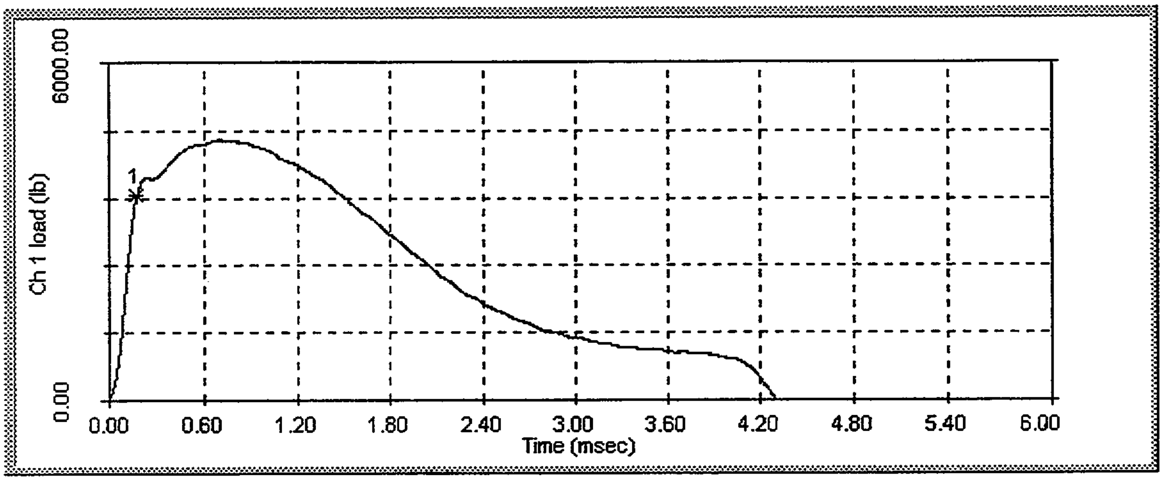
EW54, 70°F



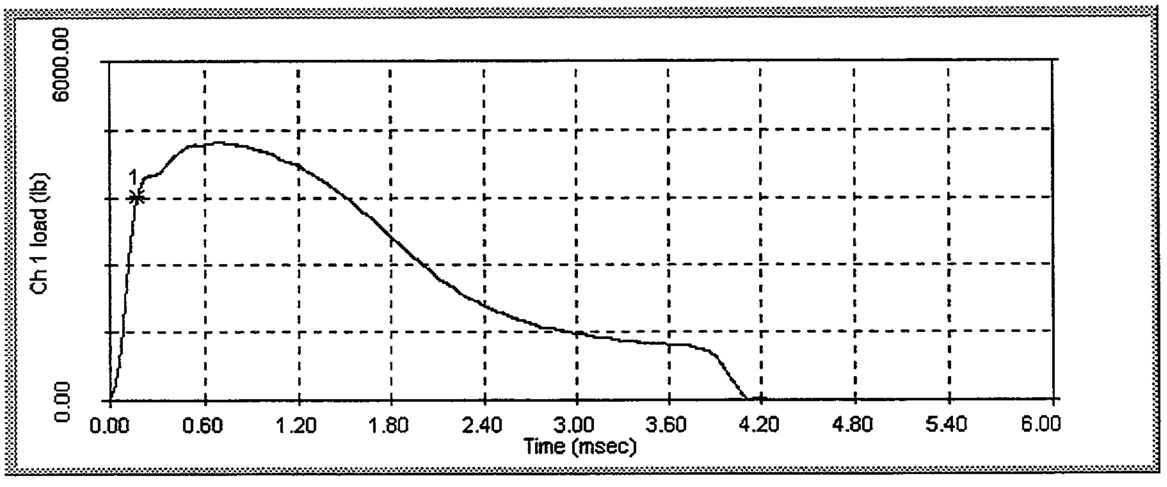
EW50, 110°F



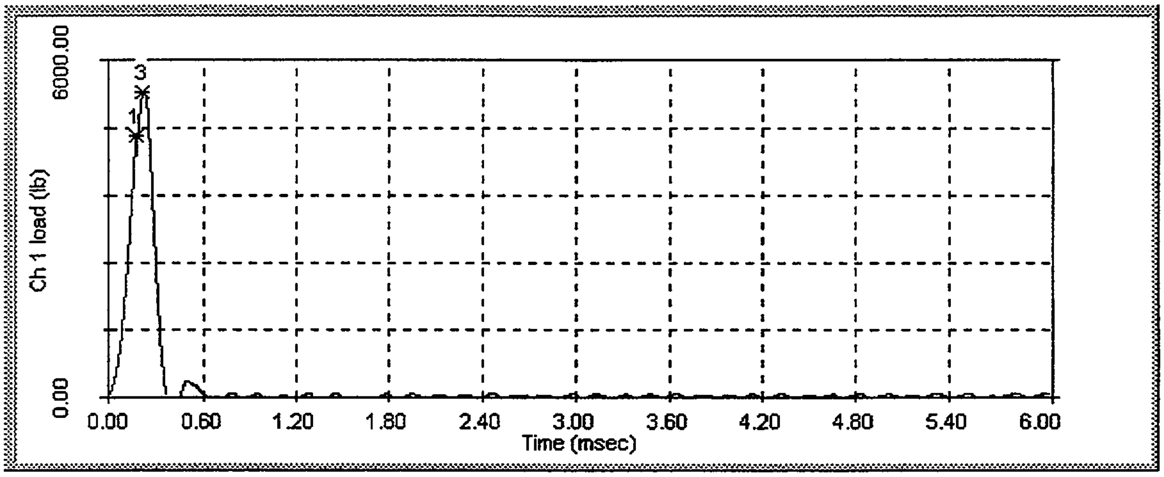
EW47, 150°F



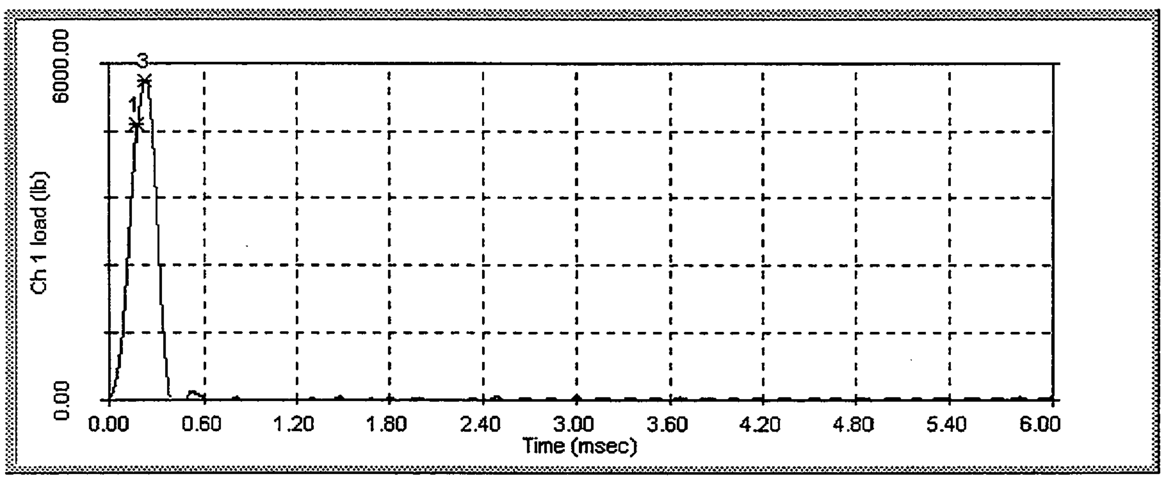
EW56, 200°F



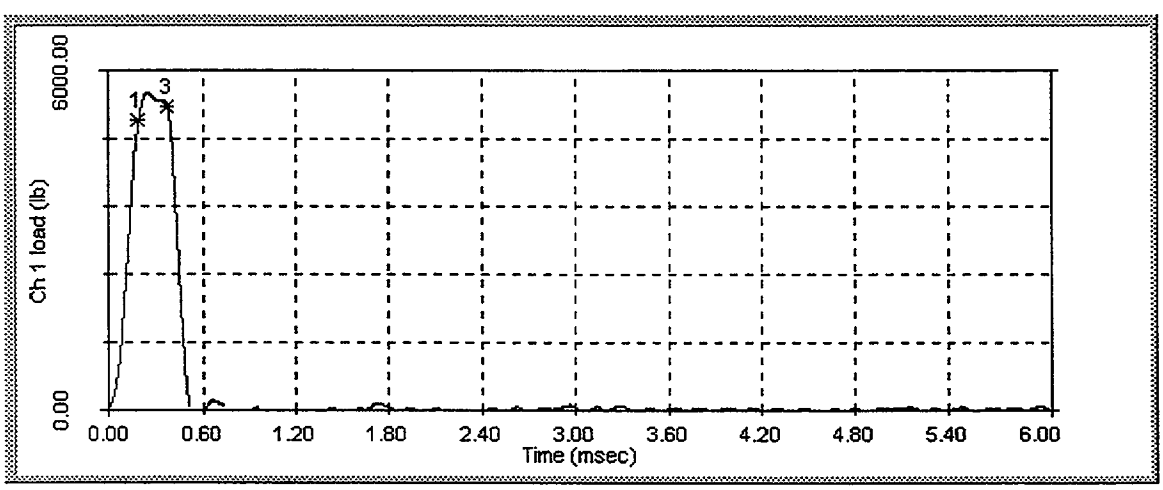
EW48, 250°F



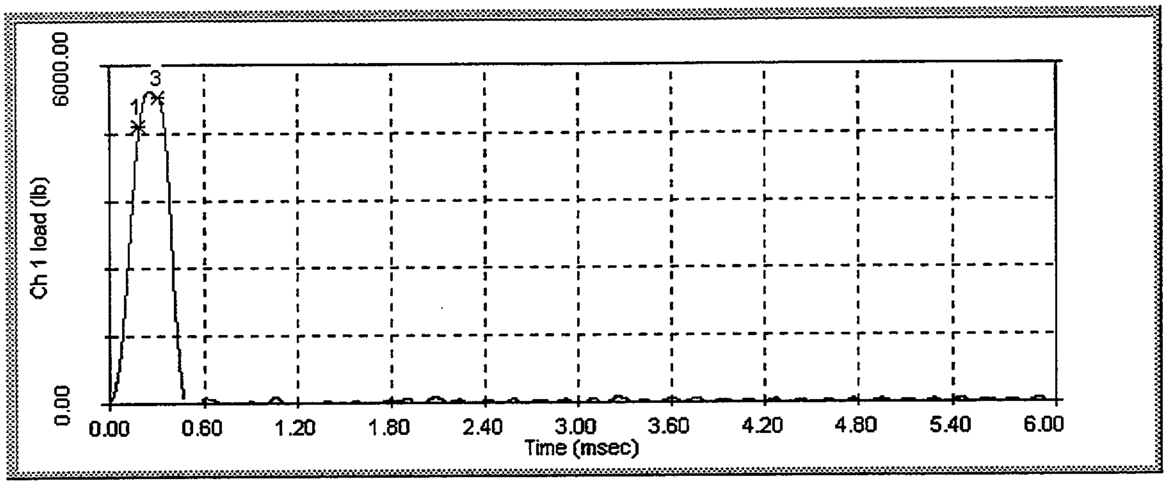
EH53, -200°F



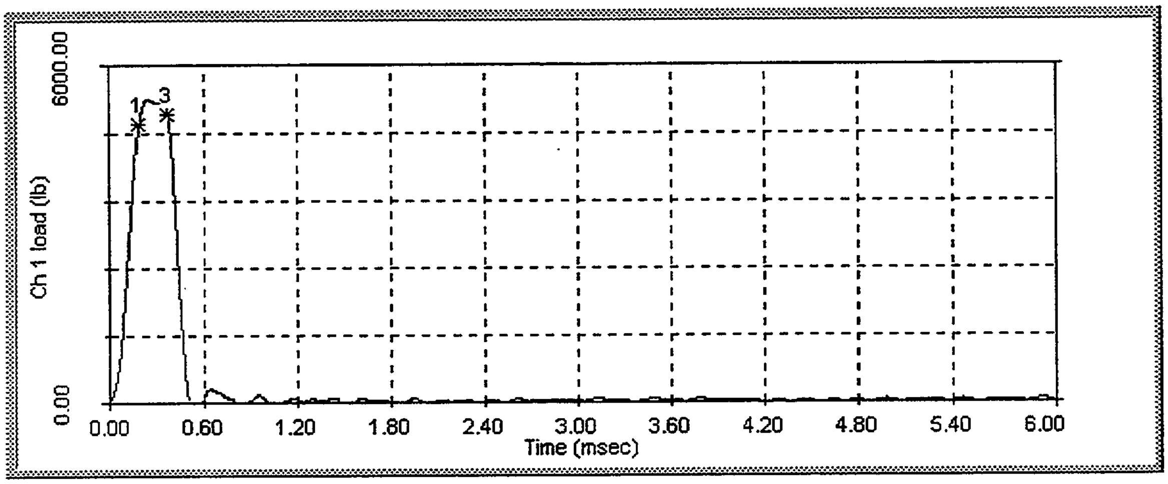
EH47, -175°F



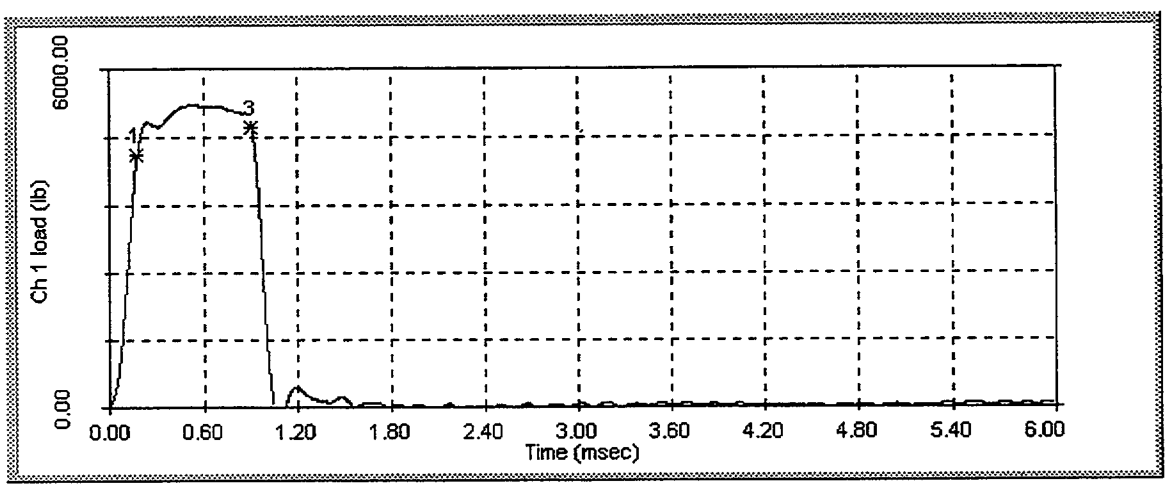
EH52, -135°F



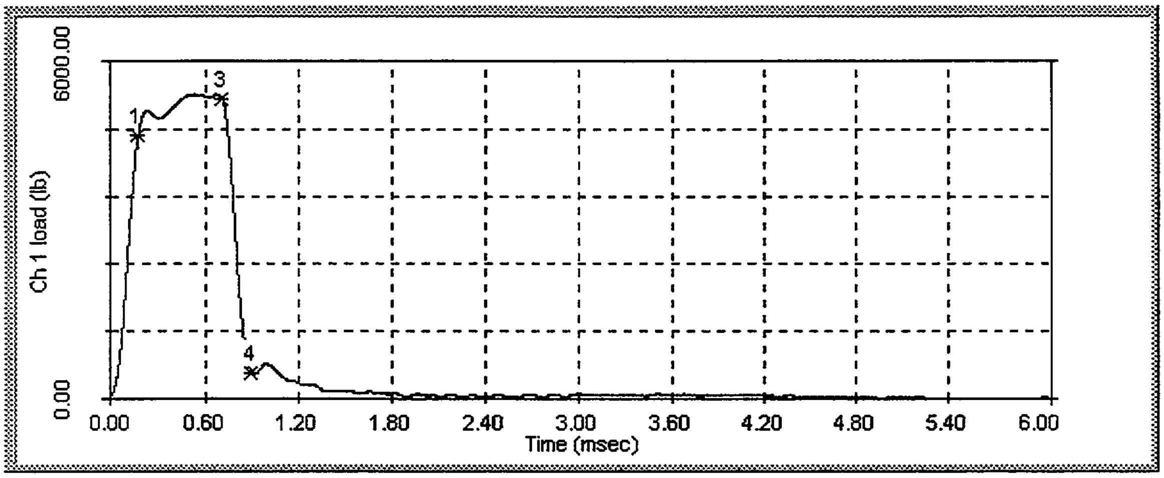
EH50, -125°F



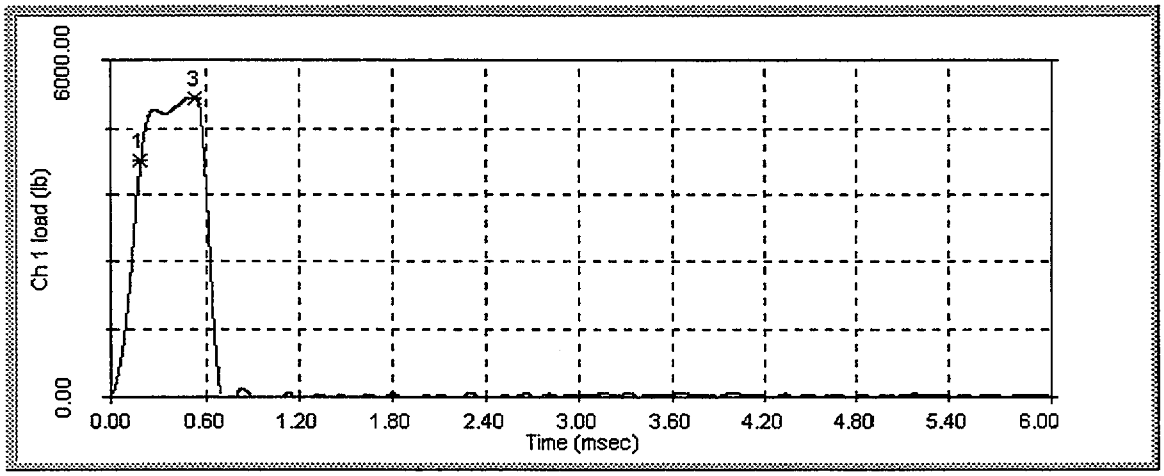
EH49, -110°F



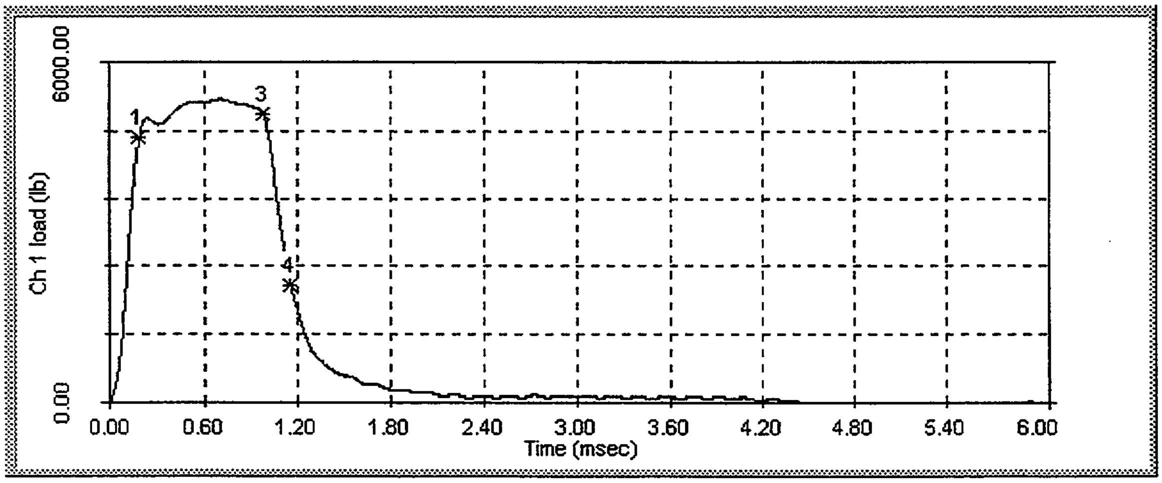
EH51, -100°F



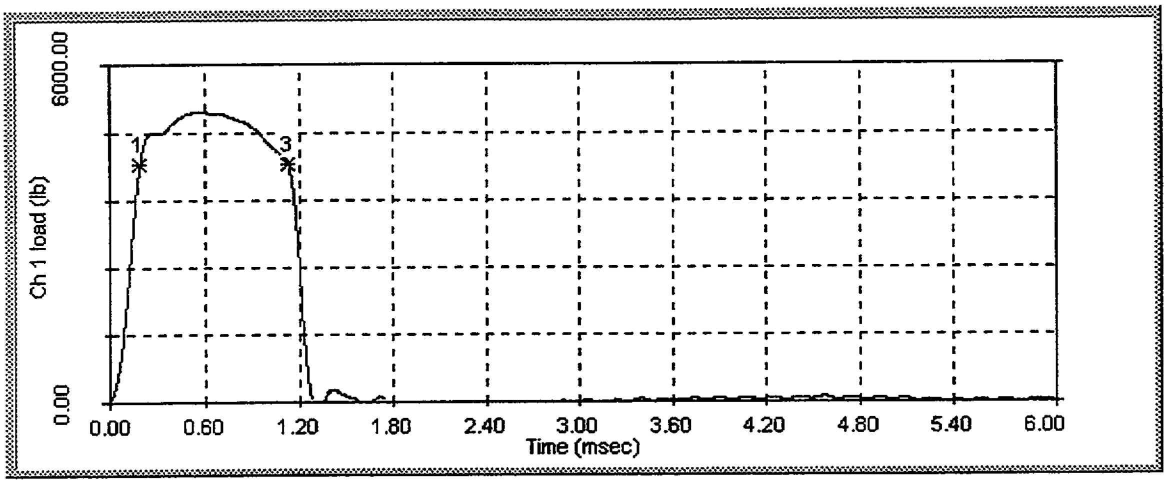
EH59, -100°F



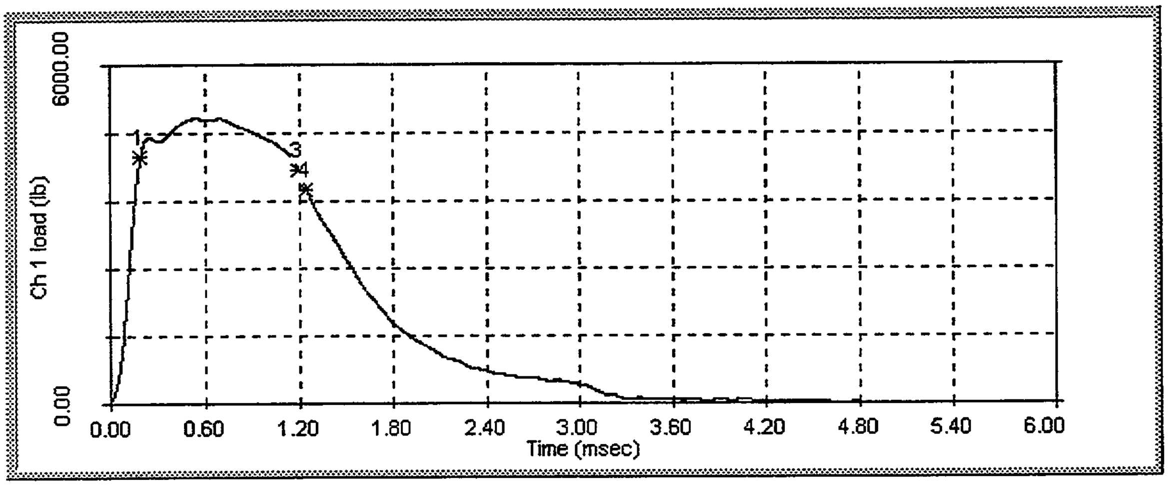
EH56, -80°F



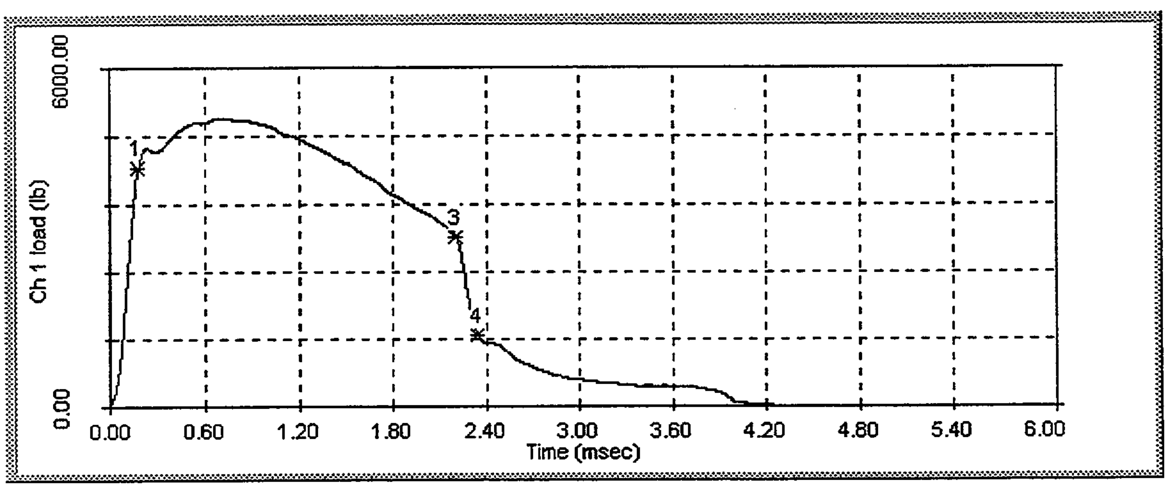
EH60, -65°F



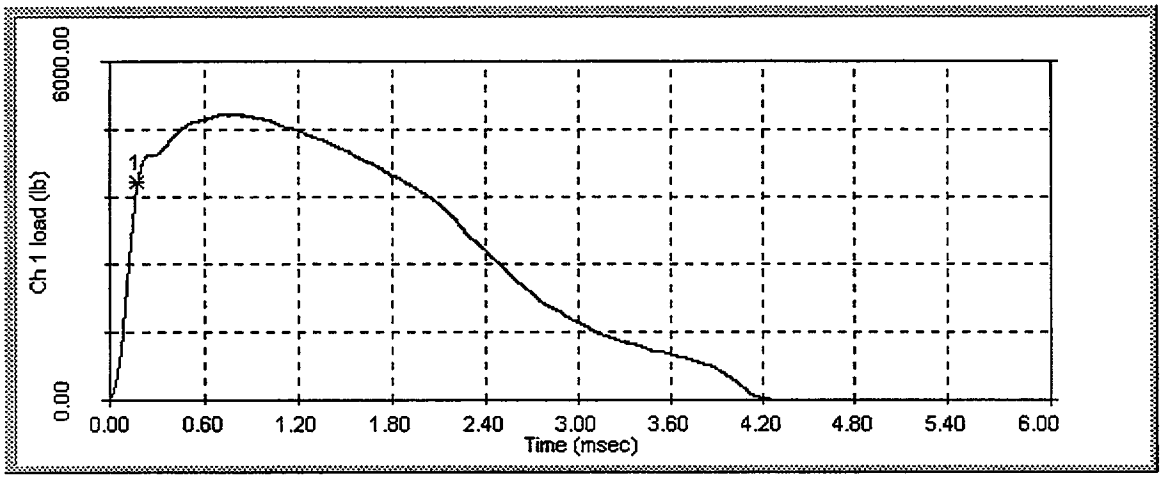
EH54, -50°F



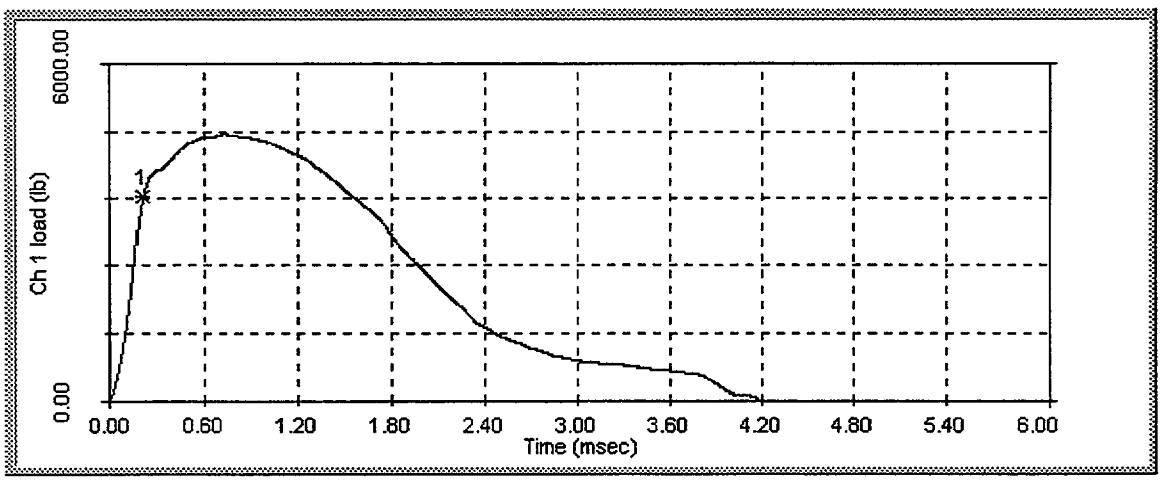
EH46, 0°F



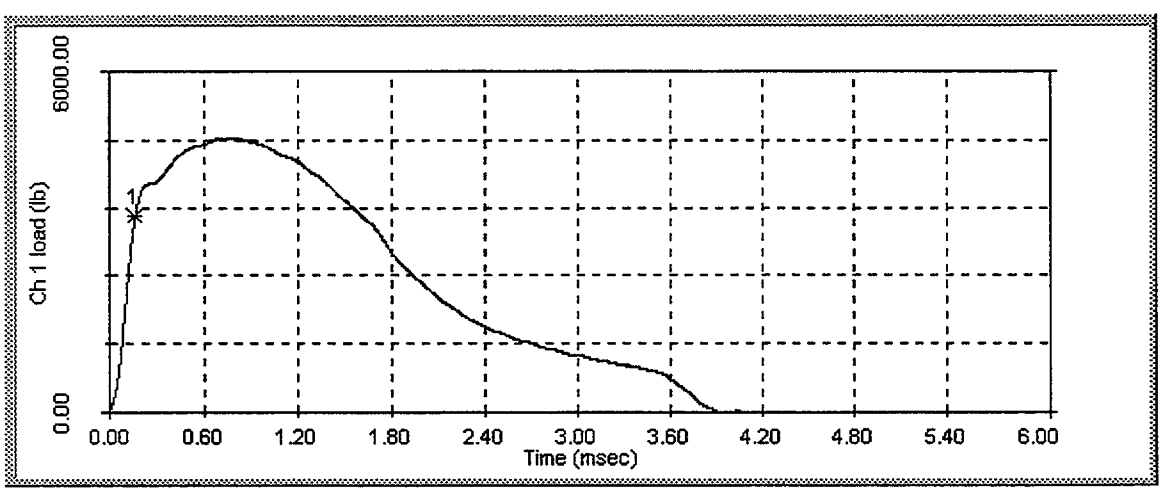
EH48, 50°F



EH58, 100°F



EH55, 150°F



EH57, 200°F

APPENDIX B

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

TABLE B-1
Changes in Average 30 ft-lb Temperatures for Intermediate Shell
Plate B9805-1 (Longitudinal Orientation)
Previous Fit vs. CVGRAPH 4.1

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔT_{30}	Unirradiated CVGRAPH	CVGRAPH Fit	ΔT_{30}
U	5°F	35°F	30°F	2.45°F	28.25°F	25.79°F
X	5°F	- -	- -	2.45°F	28.27°F	25.82°F

TABLE B-2
Changes in Average 50 ft-lb Temperatures for Intermediate Shell
Plate B9805-1 (Longitudinal Orientation)
Previous Fit vs. CVGRAPH 4.1

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔT_{50}	Unirradiated CVGRAPH	CVGRAPH Fit	ΔT_{50}
U	35°F	65°F	30°F	30.33°F	62.55°F	32.22°F
X	35°F	- -	- -	30.33°F	59.02°F	28.69°F

TABLE B-3
Changes in Average 35 mil Lateral Expansion Temperatures for Intermediate Shell
Plate B9805-1 (Longitudinal Orientation)
Previous Fit vs. CVGRAPH 4.1

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔT_{35}	Unirradiated CVGRAPH	CVGRAPH Fit	ΔT_{35}
U	30°F	45°F	15°F	23.24°F	45.47°F	22.23°F
X	30°F	- -	- -	23.24°F	72.34°F	49.1°F

TABLE B-4
Changes in Average Energy Absorption at Full Shear for Intermediate Shell Plate B9805-1 (Longitudinal Orientation)
Previous Fit vs. CVGRAPH 4.1

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔE	Unirradiated CVGRAPH	CVGRAPH Fit	ΔE
U	133ft-lb	135ft-lb	+2ft-lb	133ft-lb	135ft-lb	+2ft-lb
X	133ft-lb	- -	- -	133ft-lb	132ft-lb	-1ft-lb

TABLE B-5
Changes in Average 30 ft-lb Temperatures for Intermediate Shell Plate B9805-1 (Transverse Orientation)
Previous Fit vs. CVGRAPH 4.1

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔT_{30}	Unirradiated CVGRAPH	CVGRAPH Fit	ΔT_{30}
U	5°F	40°F	35°F	17.44°F	45.57°F	28.12°F
X	5°F	- -	- -	17.44°F	43.22°F	25.77°F

TABLE B-6
Changes in Average 50 ft-lb Temperatures for Intermediate Shell Plate B9805-1 (Transverse Orientation)
Previous Fit vs. CVGRAPH 4.1

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔT_{50}	Unirradiated CVGRAPH	CVGRAPH Fit	ΔT_{50}
U	60°F	95°F	35°F	54.8°F	84.65°F	29.85°F
X	60°F	- -	- -	54.8°F	81.04°F	26.24°F

TABLE B-7
Changes in Average 35 mil Lateral Expansion Temperatures for Intermediate Shell
Plate B9805-1 (Transverse Orientation)
Previous Fit vs. CVGRAPH 4.1

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔT_{35}	Unirradiated CVGRAPH	CVGRAPH Fit	ΔT_{35}
U	35°F	65°F	30°F	48.9°F	70.01°F	21.11°F
X	35°F	- -	- -	48.9°F	91.49°F	42.59°F

TABLE B-8
Changes in Average Energy Absorption at Full Shear for Intermediate Shell
Plate B9805-1 (Transverse Orientation)
Previous Fit vs. CVGRAPH 4.1

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔE	Unirradiated CVGRAPH	CVGRAPH Fit	ΔE
U	111ft-lb	108ft-lb	-3ft-lb	111ft-lb	108ft-lb	-3ft-lb
X	111ft-lb	- -	- -	111ft-lb	110ft-lb	-1ft-lb

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

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔT_{30}	Unirradiated CVGRAPH	CVGRAPH Fit	ΔT_{30}
U	-35°F	5°F	40°F	-36.96°F	-6.58°F	30.37°F
X	-35°F	- -	- -	-36.96°F	-43.74°F	-6.78°F

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

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔT_{50}	Unirradiated CVGRAPH	CVGRAPH Fit	ΔT_{50}
U	-15°F	20°F	35°F	-17.29°F	14.94°F	32.24°F
X	-15°F	- -	- -	-17.29°F	-21.79°F	-4.49°F

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

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔT_{35}	Unirradiated CVGRAPH	CVGRAPH Fit	ΔT_{35}
U	-20°F	15°F	35°F	-15.34°F	9.24°F	24.58°F
X	-20°F	- -	- -	-15.34°F	-14.68°F	0.66°F

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

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔE	Unirradiated CVGRAPH	CVGRAPH Fit	ΔE
U	143ft-lb	135ft-lb	-8ft-lb	143ft-lb	135ft-lb	-8ft-lb
X	143ft-lb	- -	- -	143ft-lb	142ft-lb	-1ft-lb

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

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔT_{30}	Unirradiated CVGRAPH	CVGRAPH Fit	ΔT_{30}
U	-130°F	-100°F	30°F	-171.86°F	-115.39°F	56.46°F
X	-130°F	- -	- -	-171.86°F	-127.89°F	43.96°F

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

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔT_{50}	Unirradiated CVGRAPH	CVGRAPH Fit	ΔT_{50}
U	-95°F	-70°F	25°F	-127.71°F	-82.95°F	44.76°F
X	-95°F	- -	- -	-127.71°F	-95.95°F	31.76°F

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

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔT_{35}	Unirradiated CVGRAPH	CVGRAPH Fit	ΔT_{35}
U	-105°F	-65°F	40°F	-120.34°F	-66.18°F	54.16°F
X	-105°F	- -	- -	-120.34°F	-66.16°F	54.18°F

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

Capsule	Unirradiated Hand Fit	Irradiated Hand Fit	ΔE	Unirradiated CVGRAPH	CVGRAPH Fit	ΔE
U	142ft-lb	140ft-lb	-2ft-lb	142ft-lb	140ft-lb	-2ft-lb
X	142ft-lb	- -	- -	142ft-lb	144ft-lb	+2ft-lb

APPENDIX C

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

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

TABLE C-1
Upper Shelf Energy Values Fixed in CVGRAPH

Material	Unirradiated	Capsule U	Capsule X
Intermediate Shell Plate B9805-1 (Longitudinal Orientation)	133 ft-lb	135 ft-lb	132 ft-lb
Intermediate Shell Plate B9805-1 (Transverse Orientation)	111 ft-lb	108 ft-lb	110 ft-lb
Weld Metal (Heat # 4P6052)	143 ft-lb	135 ft-lb	142 ft-lb
HAZ Material	142 ft-lb	140 ft-lb	144 ft-lb

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:06:24 on 04-04-2000

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Coefficients of Curve 1

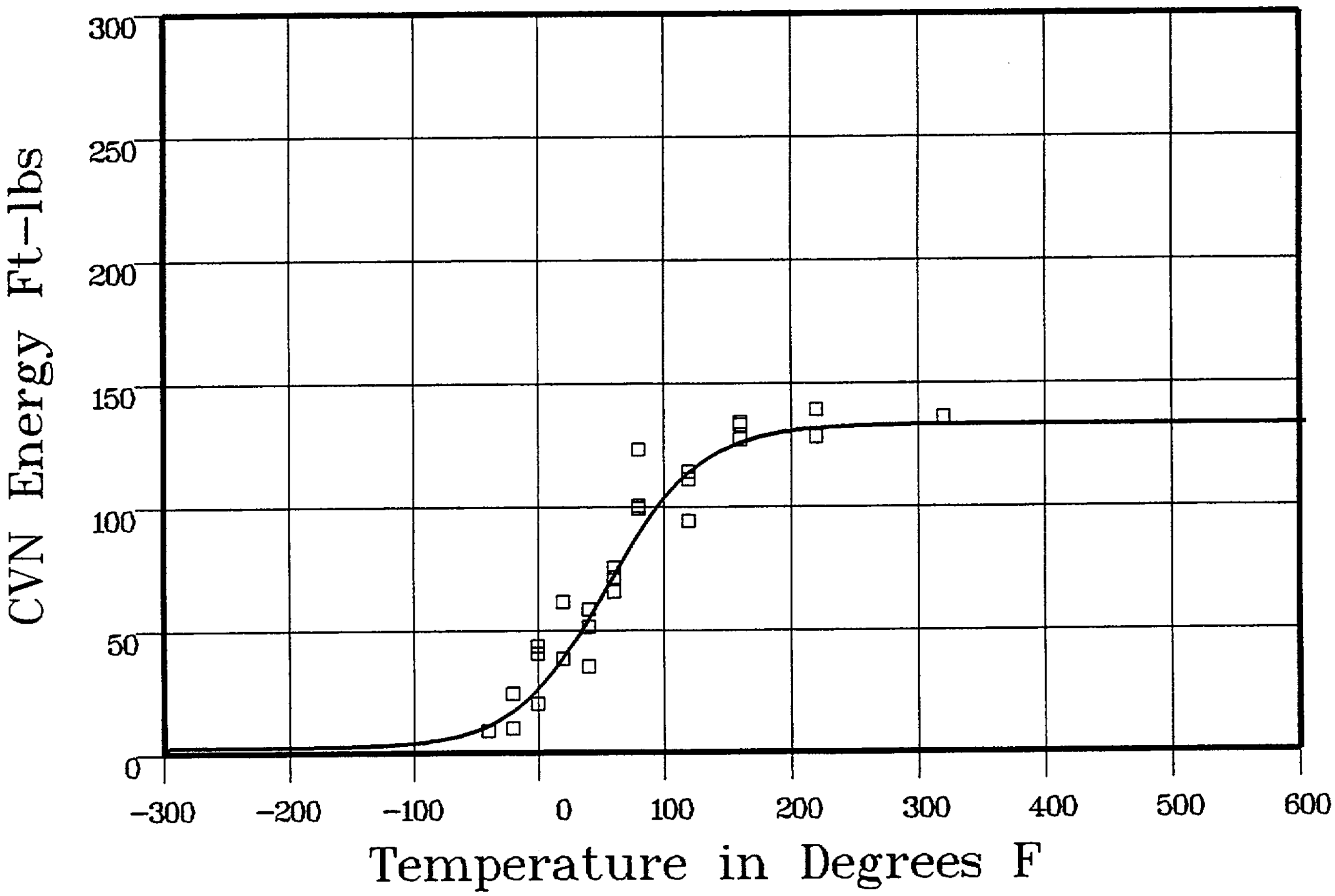
A = 67.59	B = 65.4	C = 73.55	T0 = 50.62

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

Upper Shelf Energy: 133 Fixed Temp. at 30 ft-lbs: 2.4 Temp. at 50 ft-lbs: 30.3 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: ML3 Cap.: UNIRR Material: PLATE SA533B1 Ori.: LT Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-40	9	12.45	-3.45
-40	9	12.45	-3.45
-20	24	18.91	5.08
-20	10	18.91	-8.91
0	40	28.56	11.43
0	43	28.56	14.43
0	20	28.56	-8.56
20	38	41.84	-3.84
20	61	41.84	19.15

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

UNIRRADIATED

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
40	58	58.21	-.21
40	35	58.21	-23.21
40	51	58.21	-7.21
60	75	75.89	-.89
60	65	75.89	-10.89
60	71	75.89	-4.89
80	123	92.41	30.58
80	100	92.41	7.58
80	99	92.41	6.58
120	111	115.77	-4.77
120	114	115.77	-1.77
120	94	115.77	-21.77
160	127	126.64	.35
160	133	126.64	6.35
160	134	126.64	7.35
220	139	131.7	7.29
220	128	131.7	-3.7
320	136	132.91	3.08
320	136	132.91	3.08

SUM of RESIDUALS = 14.8

CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:06:24 on 04-04-2000

Page 1

Coefficients of Curve 2

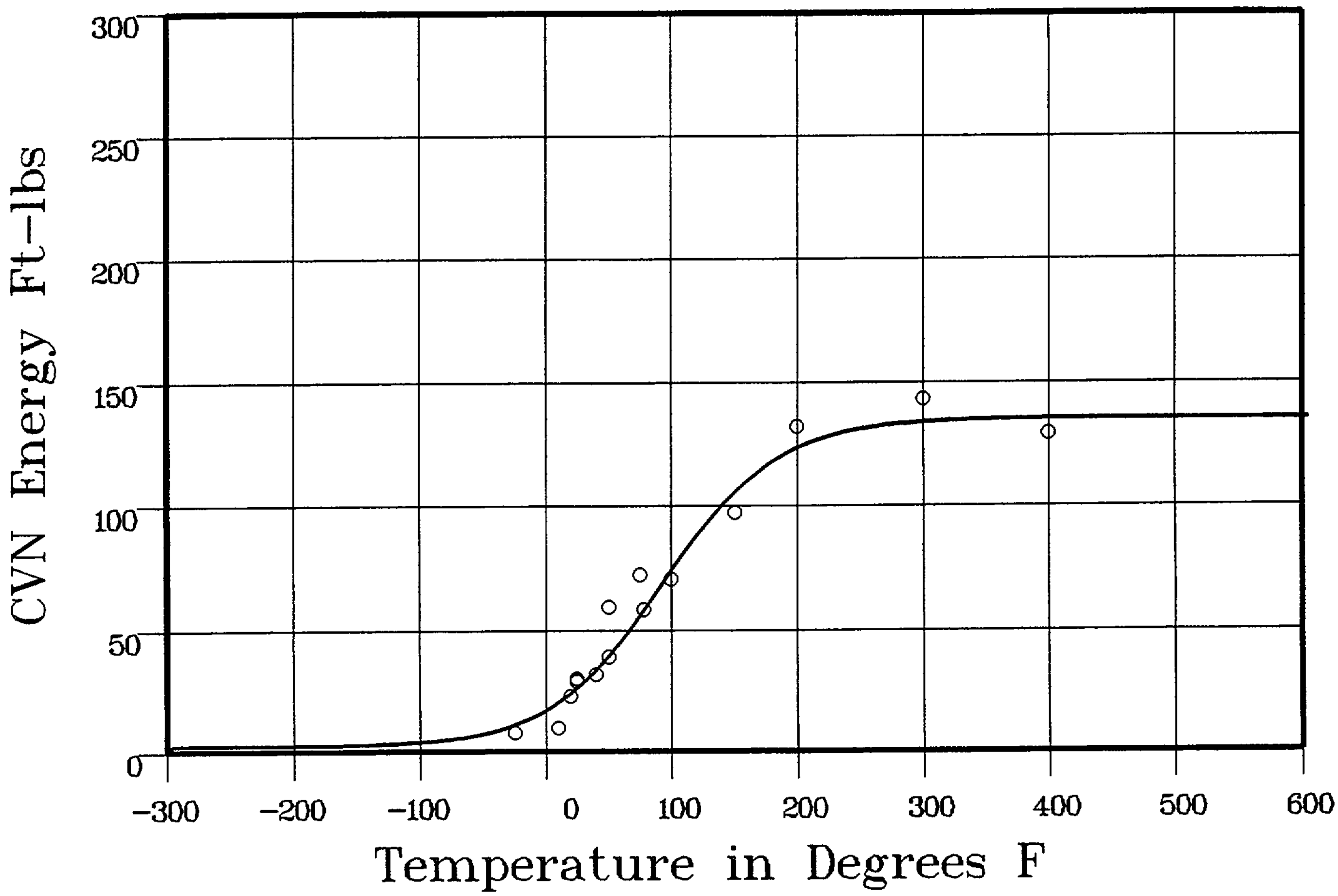
A = 68.59	B = 66.4	C = 91.07	T0 = 88.76

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

Upper Shelf Energy: 135 Fixed Temp. at 30 ft-lbs: 28.2 Temp. at 50 ft-lbs: 62.5 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: U Total Fluence: 4.49E18



Data Set(s) Plotted

Plant: ML3 Cap.: U Material: PLATE SA533B1 Ori.: LT Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	8	12.28	-4.28
10	10	22.2	-12.2
20	23	26.22	-3.22
25	30	28.46	1.53
25	29	28.46	.53
40	32	36.09	-4.09
50	39	41.92	-2.92
50	59	41.92	17.07

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

CAPSULE U

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: U Total Fluence: 4.49E18

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
75	72	58.63	13.36
78	58	60.78	-2.78
100	70	76.74	-6.74
150	97	107.54	-10.54
200	132	124.37	7.62
300	143	133.72	9.27
400	129	134.85	-5.85

SUM of RESIDUALS = -3.25

CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:06:24 on 04-04-2000

Page 1

Coefficients of Curve 3

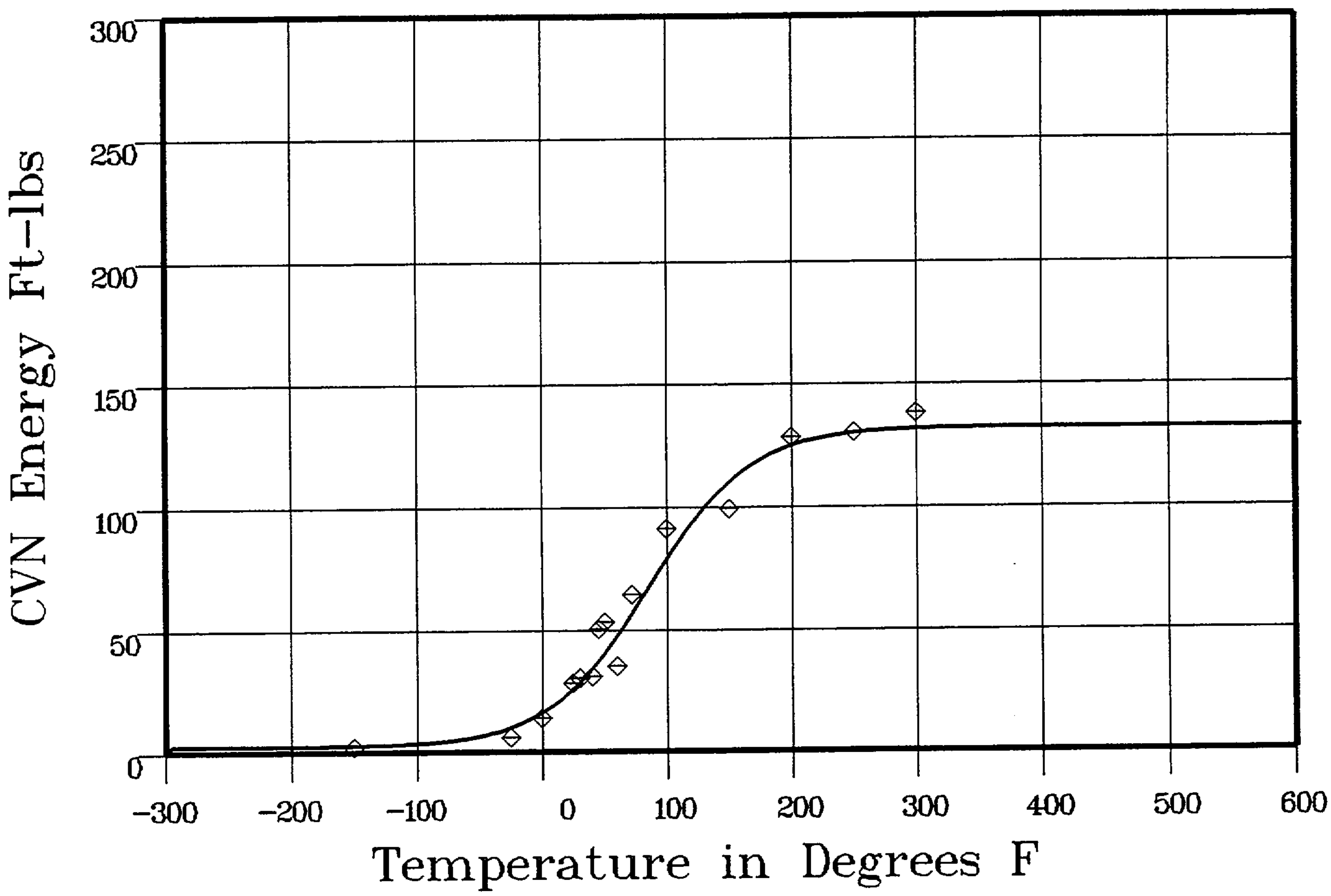
A = 67.09	B = 64.9	C = 80.89	T0 = 80.85

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

Upper Shelf Energy: 132 Fixed   Temp. at 30 ft-lbs: 28.2   Temp. at 50 ft-lbs: 59   Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1   Heat Number: C4039-2   Orientation: LT

Capsule: X   Total Fluence: 2.21E19



Data Set(s) Plotted

Plant: ML3   Cap.: X   Material: PLATE SA533B1   Ori.: LT   Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-150	2	2.62	-.62
-25	6	11.03	-5.03
0	14	17.68	-3.68
25	28	28.27	-.27
30	30	30.94	-.94
40	31	36.84	-5.84
45	50	40.07	9.92
50	53	43.47	9.52

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

CAPSULE X

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: X Total Fluence: 2.21E19

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
60	35	50.72	-15.72
72	64	60.02	3.97
100	91	82.17	8.82
150	99	112.1	-13.1
200	128	125.51	2.48
250	130	130.04	-.04
300	138	131.42	6.57

SUM of RESIDUALS = -3.98

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:11:14 on 04-04-2000

Page 1

Coefficients of Curve 1

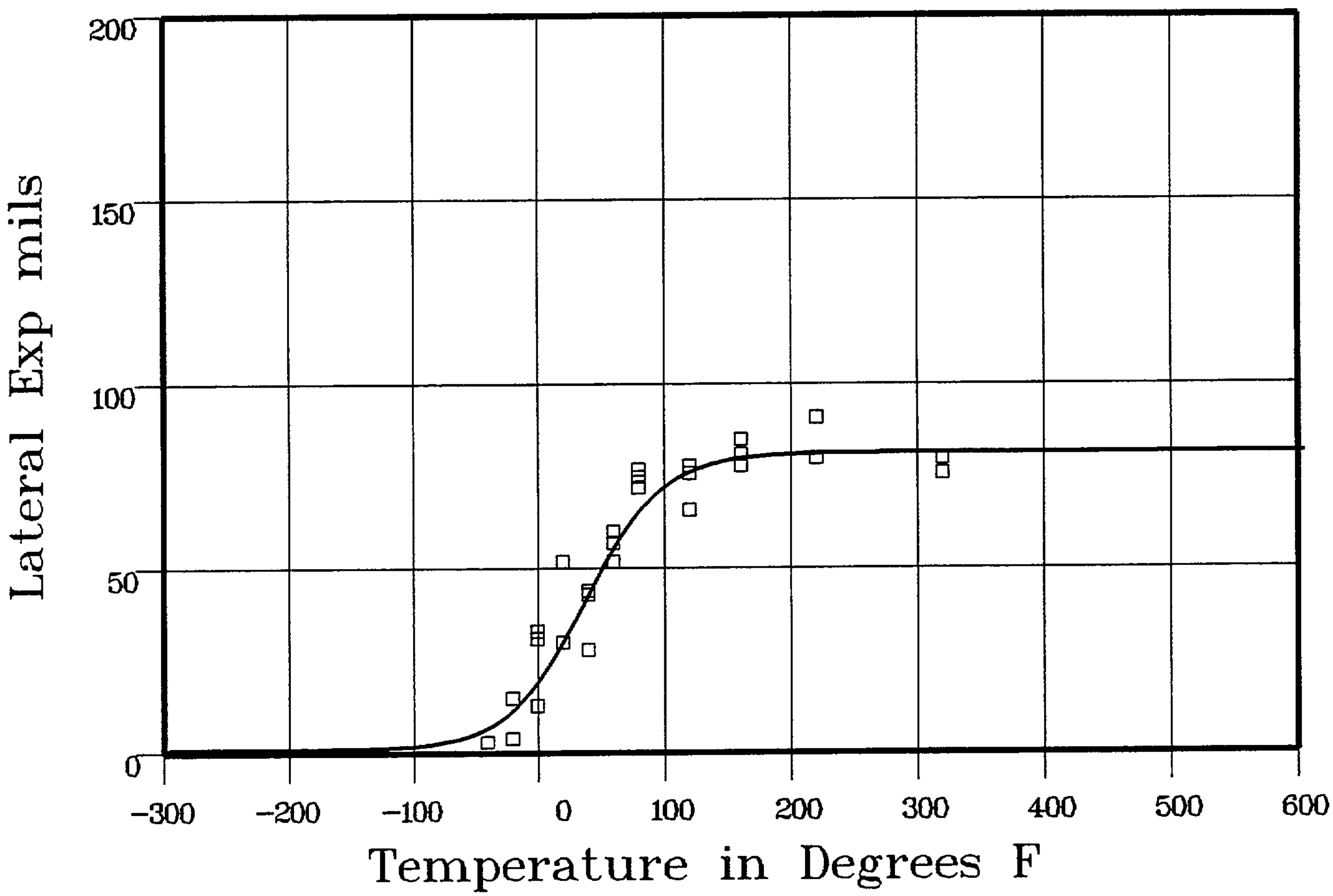
A = 41.23	B = 40.23	C = 61.23	T0 = 32.81

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

Upper Shelf L.E.: 81.47 Temperature at L.E. 35: 23.2 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: ML3 Cap.: UNIRR Material: PLATE SA533B1 Ori.: LT Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-40	3	7.82	-4.82
-40	3	7.82	-4.82
-20	15	13.17	1.82
-20	4	13.17	-9.17
0	31	21.52	9.47
0	33	21.52	11.47
0	13	21.52	-8.52
20	30	32.93	-2.93
20	52	32.93	19.06

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

UNIRRADIATED

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
40	44	45.94	-1.94
40	28	45.94	-17.94
40	43	45.94	-2.94
60	60	58.01	1.98
60	52	58.01	-6.01
60	57	58.01	-1.01
80	77	67.28	9.71
80	75	67.28	7.71
80	72	67.28	4.71
120	78	77.06	.93
120	76	77.06	-1.06
120	66	77.06	-11.06
160	78	80.23	-2.23
160	81	80.23	.76
160	85	80.23	4.76
220	80	81.29	-1.29
220	91	81.29	9.7
320	80	81.47	-1.47
320	76	81.47	-5.47

SUM of RESIDUALS = -.62

CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve   Printed at 14:11:14 on 04-04-2000

Page 1

Coefficients of Curve 2

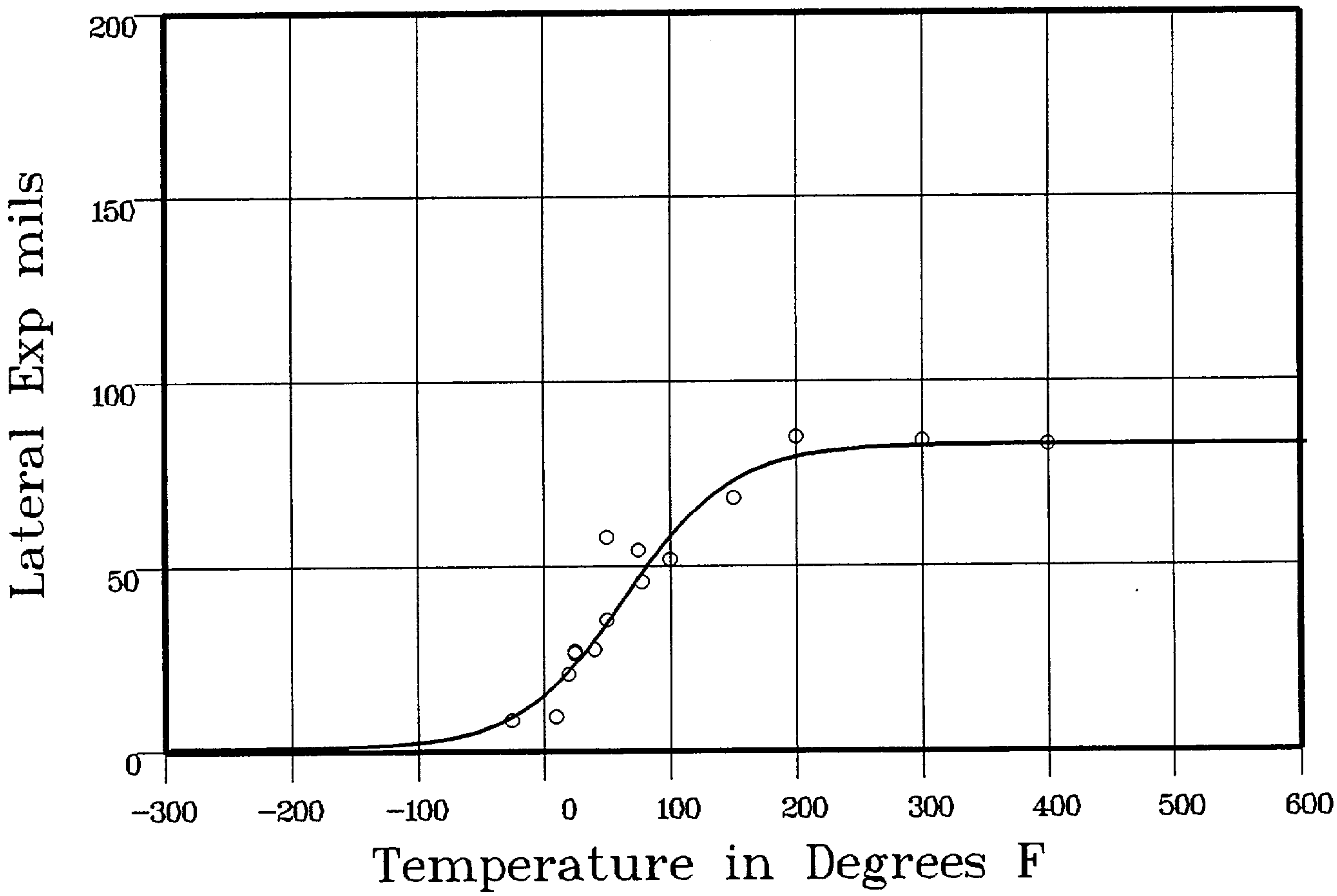
A = 41.93	B = 40.93	C = 84.89	T0 = 60

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

Upper Shelf L.E.: 82.87   Temperature at L.E. 35: 45.4   Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1   Heat Number: C4039-2   Orientation: LT

Capsule: U   Total Fluence: 4.49E18



Data Set(s) Plotted

Plant: ML3   Cap.: U   Material: PLATE SA533B1   Ori.: LT   Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	9	10.73	-1.73
10	10	20.27	-10.27
20	21.5	23.95	-2.45
25	27.5	25.95	1.54
25	27	25.95	1.04
40	28	32.46	-4.46
50	36	37.13	-1.13
50	58	37.13	20.86

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

CAPSULE U

Page 2

Material: PLATE SA533B1   Heat Number: C4039-2   Orientation: LT

Capsule: U   Total Fluence: 4.49E18

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
75	54.5	49.09	5.4
78	46	50.48	-4.48
100	52	59.91	-7.91
150	68.5	74.1	-5.6
200	85	79.95	5.04
300	84	82.58	1.41
400	83	82.84	.15

SUM of RESIDUALS = -2.62

CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:11:14 on 04-04-2000

Page 1

Coefficients of Curve 3

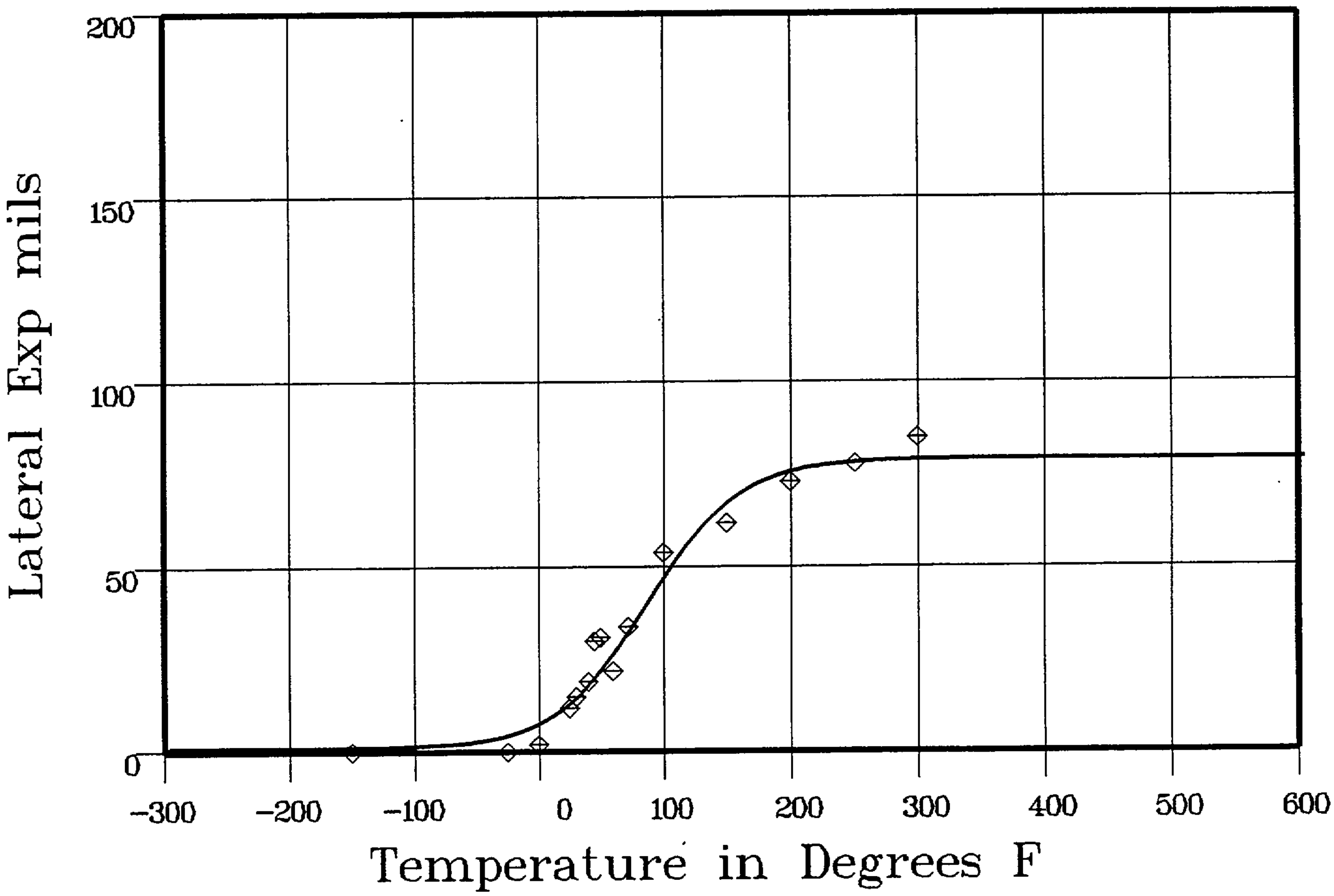
A = 40.1	B = 39.1	C = 73.38	T0 = 81.97

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

Upper Shelf L.E.: 79.2 Temperature at L.E. 35: 72.3 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: X Total Fluence: 2.21E19



Data Set(s) Plotted

Plant: ML3 Cap.: X Material: PLATE SA533B1 Ori.: LT Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-150	0	1.14	-1.14
-25	0	5.01	-5.01
0	2	8.56	-6.56
25	12	14.66	-2.66
30	15	16.26	-1.26
40	19	19.89	-.89
45	30	21.91	8.08
50	31	24.06	6.93

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

CAPSULE X

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: X Total Fluence: 2.21E19

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
60	22	28.73	-6.73
72	34	34.81	-.81
100	54	49.51	4.48
150	62	68.61	-6.61
200	73	76.19	-3.19
250	78	78.41	-.41
300	85	79	5.99

SUM of RESIDUALS = -9.8

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:15:02 on 04-04-2000

Page 1

Coefficients of Curve 1

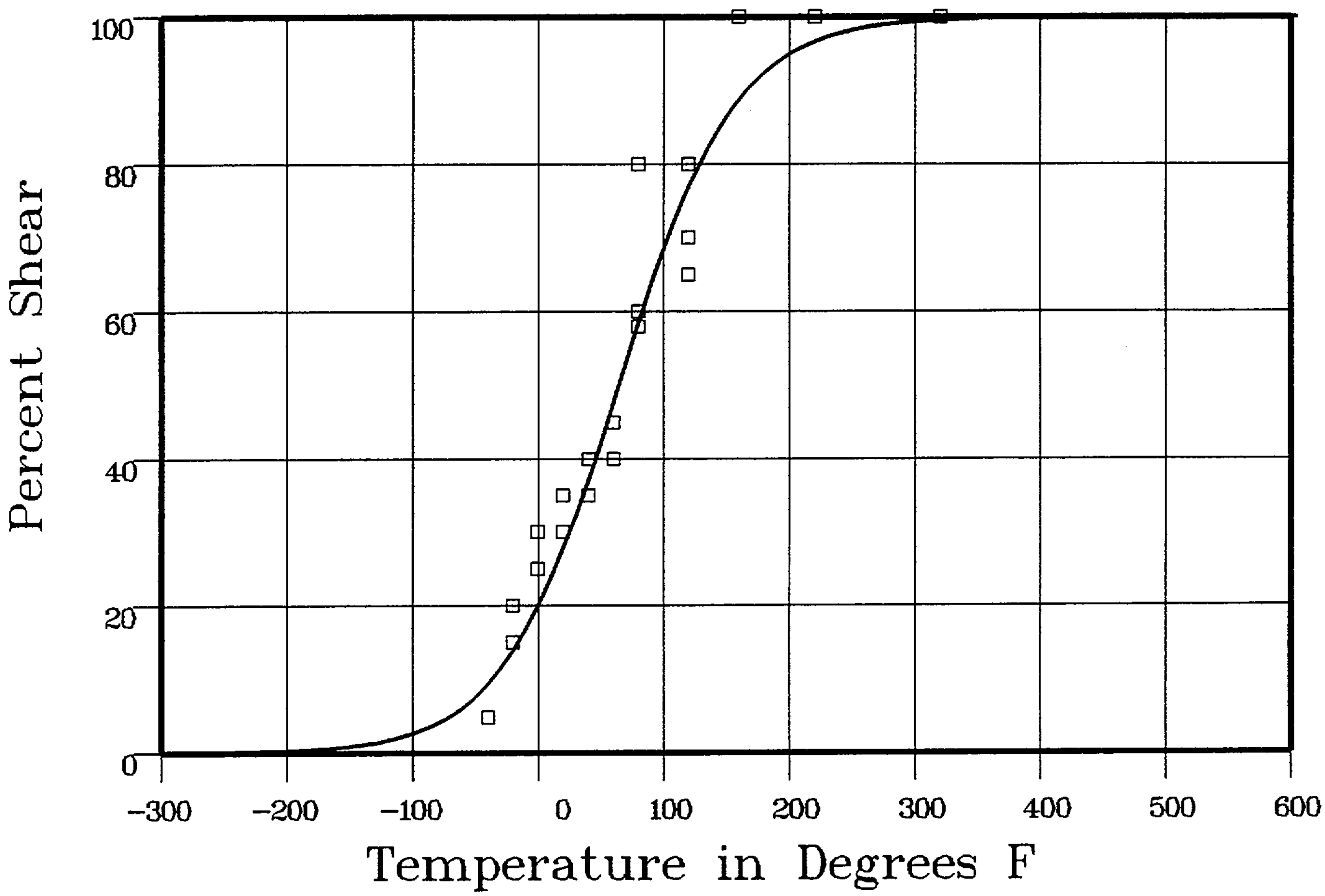
A = 50	B = 50	C = 92.54	T0 = 59.53

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

Temperature at 50% Shear: 59.5

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: ML3 Cap.: UNIRR Material: PLATE SA533B1 Ori.: LT Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40	5	10.42	-5.42
-40	5	10.42	-5.42
-20	20	15.2	4.79
-20	15	15.2	-.2
0	30	21.64	8.35
0	30	21.64	8.35
0	25	21.64	3.35
20	30	29.85	.14
20	35	29.85	5.14

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

UNIRRADIATED

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
40	35	39.6	-4.6
40	40	39.6	.39
40	35	39.6	-4.6
60	45	50.25	-5.25
60	40	50.25	-10.25
60	45	50.25	-5.25
80	80	60.88	19.11
80	58	60.88	-2.88
80	60	60.88	-.88
120	80	78.69	1.3
120	70	78.69	-8.69
120	65	78.69	-13.69
160	100	89.76	10.23
160	100	89.76	10.23
160	100	89.76	10.23
220	100	96.97	3.02
220	100	96.97	3.02
320	100	99.64	.35
320	100	99.64	.35

SUM of RESIDUALS = 21.27

CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:15:02 on 04-04-2000
Page 1
Coefficients of Curve 2

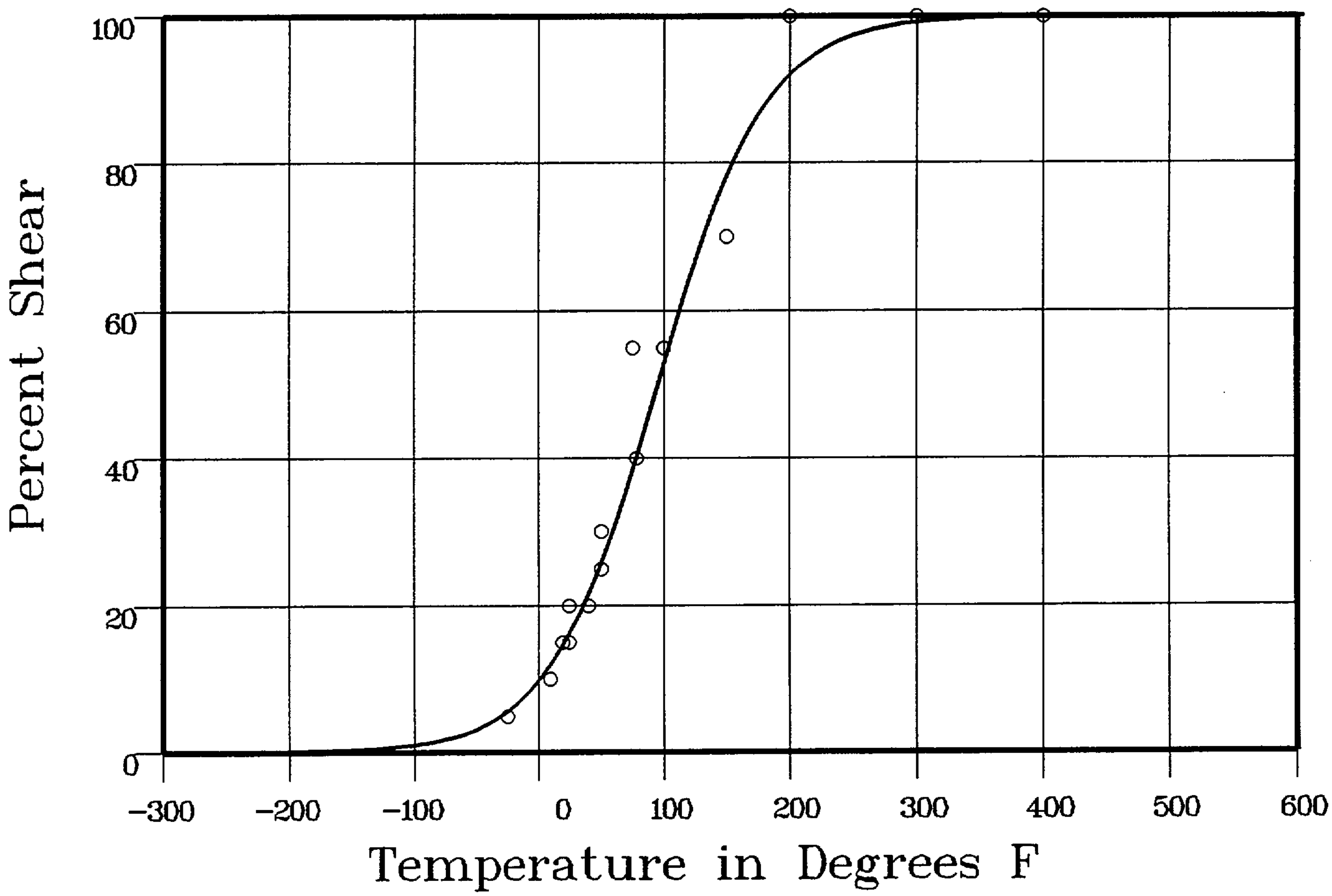
A = 50	B = 50	C = 85.59	T0 = 90.58

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

Temperature at 50% Shear: 90.5

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: U Total Fluence: 4.49E18



Data Set(s) Plotted
Plant: ML3 Cap.: U Material: PLATE SA533B1 Ori.: LT Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	5	6.29	-1.29
10	10	13.2	-3.2
20	15	16.12	-1.12
25	20	17.76	2.23
25	15	17.76	-2.76
40	20	23.47	-3.47
50	25	27.92	-2.92
50	30	27.92	2.07

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

CAPSULE U

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: U Total Fluence: 4.49E18

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
75	55	40.99	14
78	40	42.7	-2.7
100	55	55.47	-.47
150	70	80.02	-10.02
200	100	92.8	7.19
300	100	99.25	.74
400	100	99.92	.07

SUM of RESIDUALS = -1.64

CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:15:02 on 04-04-2000
Page 1
Coefficients of Curve 3

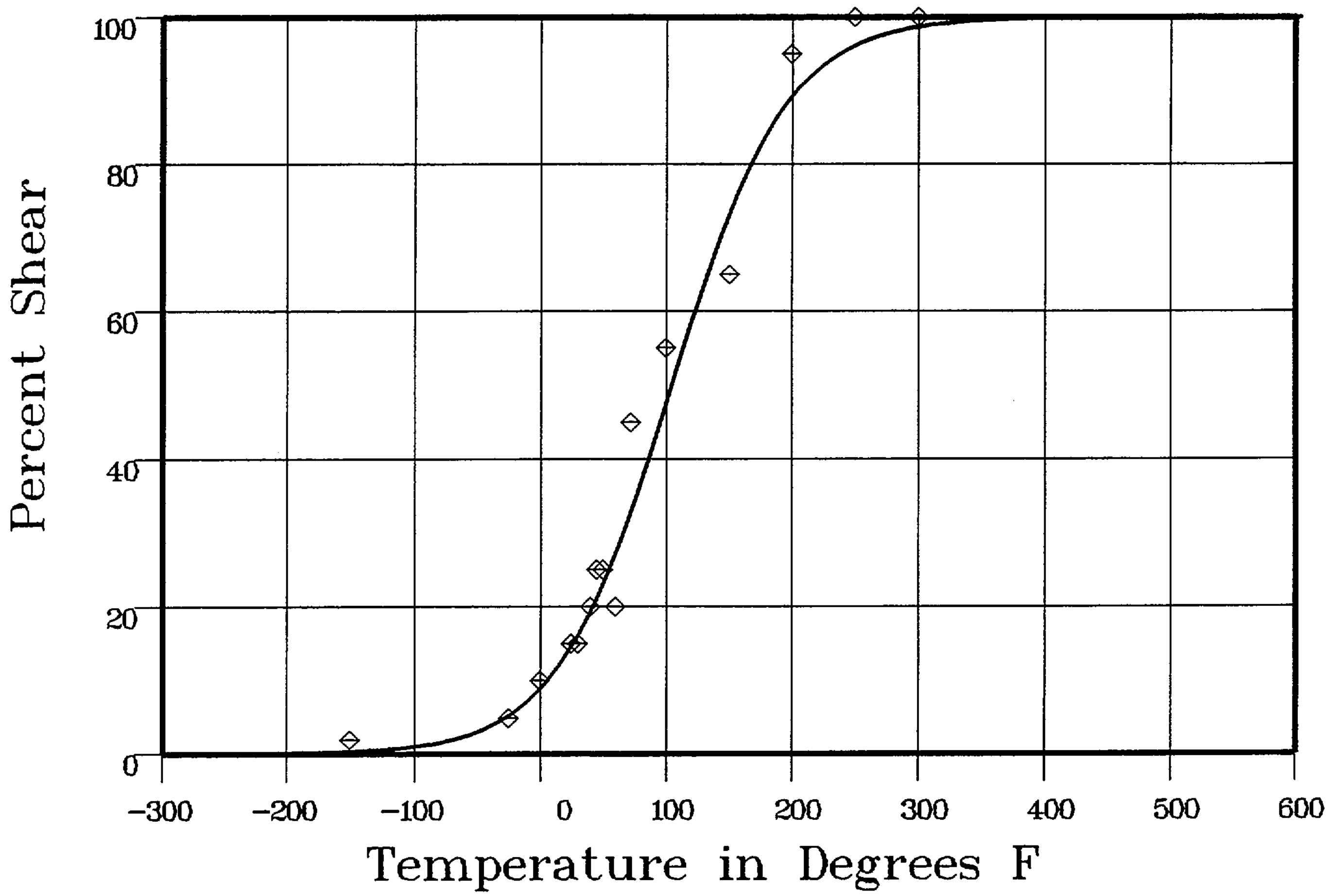
A = 50	B = 50	C = 90.3	T0 = 99.9

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

Temperature at 50% Shear: 99.9

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: X Total Fluence: 2.21E19



Data Set(s) Plotted
Plant: ML3 Cap.: X Material: PLATE SA533B1 Ori.: LT Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-150	2	.39	1.6
-25	5	5.91	-.91
0	10	9.86	.13
25	15	15.99	-.99
30	15	17.53	-2.53
40	20	20.97	-.97
45	25	22.86	2.13
50	25	24.87	.12

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

CAPSULE X

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: LT

Capsule: X Total Fluence: 2.21E19

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
60	20	29.23	-9.23
72	45	35.02	9.97
100	55	50.05	4.94
150	65	75.2	-10.2
200	95	90.17	4.82
250	100	96.52	3.47
300	100	98.82	1.17

SUM of RESIDUALS = 3.54

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:19:17 on 04-04-2000

Page 1

Coefficients of Curve 1

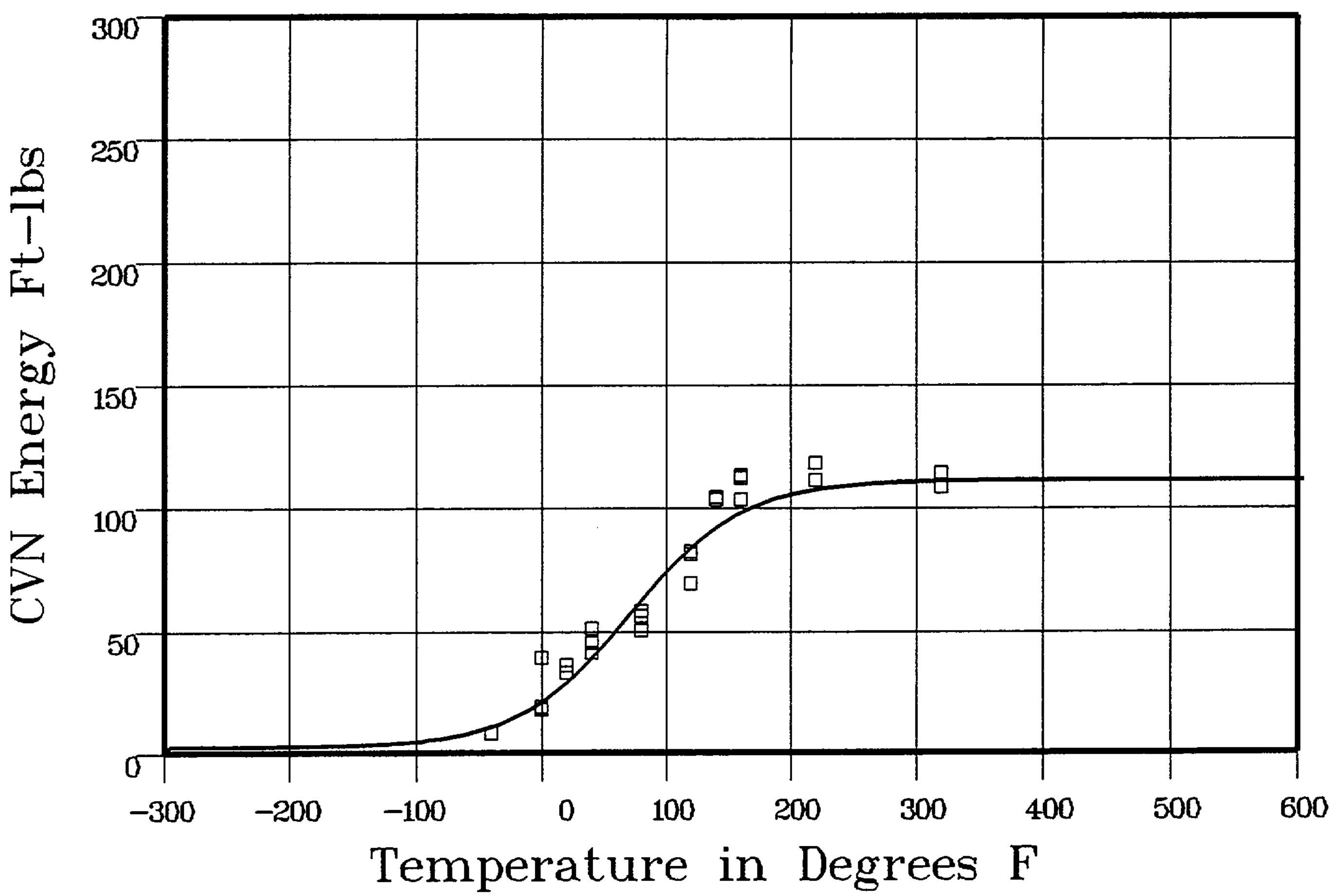
A = 56.59	B = 54.4	C = 90.49	T0 = 65.83

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

Upper Shelf Energy: 111 Fixed   Temp. at 30 ft-lbs: 17.4   Temp. at 50 ft-lbs: 54.8   Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1   Heat Number: C4039-2   Orientation: TL

Capsule: UNIRR   Total Fluence:



Data Set(s) Plotted

Plant: ML3   Cap.: UNIRR   Material: PLATE SA533B1   Ori.: TL   Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-40	8	11.76	-3.76
-40	8	11.76	-3.76
0	19	22.78	-3.78
0	39	22.78	16.21
0	18	22.78	-4.78
20	36	31.18	4.81
20	33	31.18	1.81
20	36	31.18	4.81
40	51	41.47	9.52

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

UNIRRADIATED

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
40	41	41.47	-.47
40	45	41.47	3.52
80	58	65.04	-7.04
80	50	65.04	-15.04
80	56	65.04	-9.04
120	81	85.75	-4.75
120	69	85.75	-16.75
120	82	85.75	-3.75
140	104	93.31	10.68
140	103	93.31	9.68
160	103	98.92	4.07
160	112	98.92	13.07
160	113	98.92	14.07
220	118	107.51	10.48
220	111	107.51	3.48
320	114	110.6	3.39
320	108	110.6	-2.6

SUM of RESIDUALS = 34.05

CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:19:17 on 04-04-2000
Page 1
Coefficients of Curve 2

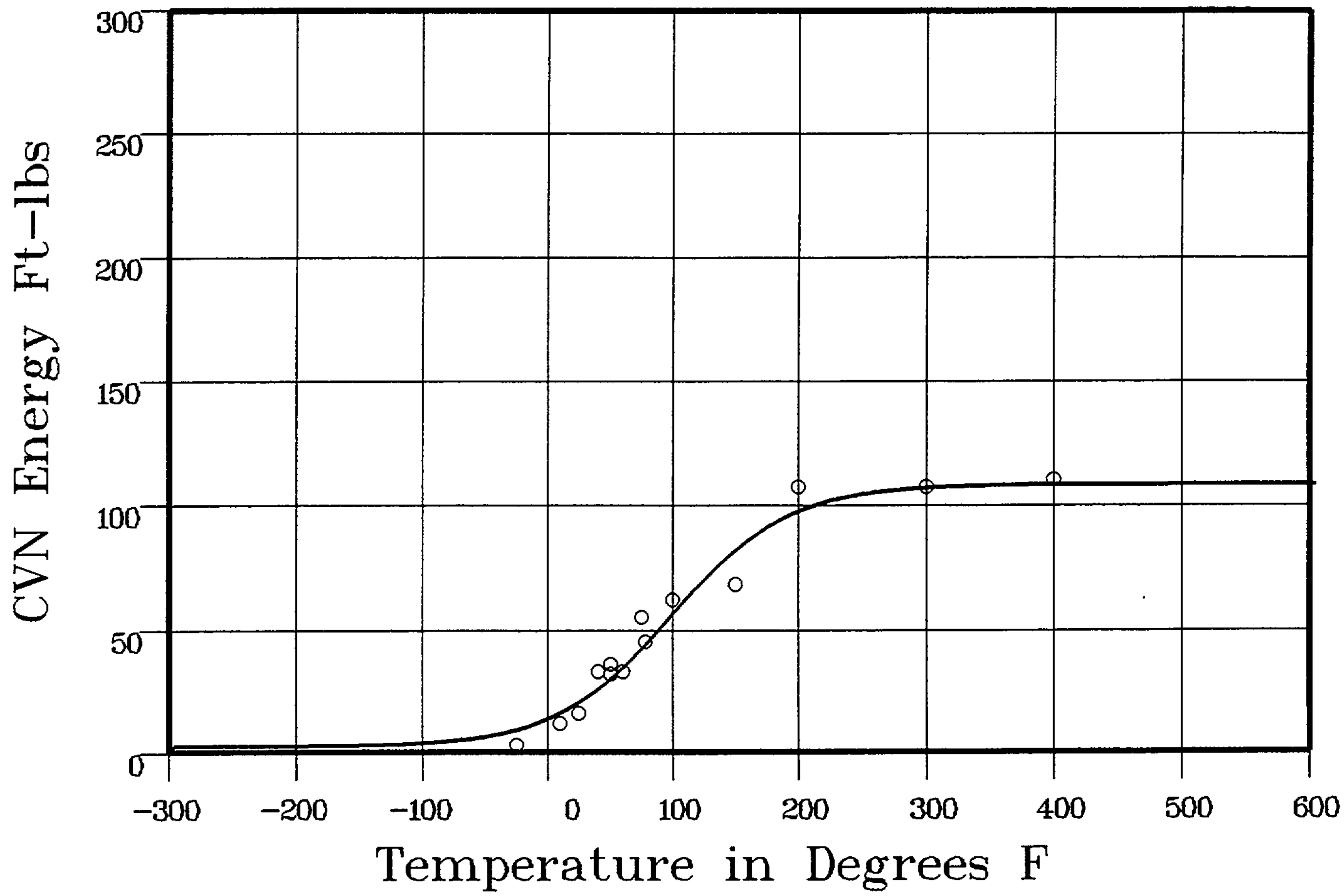
A = 55.09	B = 52.9	C = 93.25	T0 = 93.67

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

Upper Shelf Energy: 108 Fixed Temp. at 30 ft-lbs: 45.5 Temp. at 50 ft-lbs: 84.6 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: U Total Fluence: 4.49E18



Data Set(s) Plotted
Plant: ML3 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	3	9.89	-6.89
10	12	17.27	-5.27
25	16	21.93	-5.93
40	33	27.62	5.37
50	36	31.98	4.01
50	32	31.98	.01
60	33	36.78	-3.78
75	55	44.64	10.35

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

CAPSULE U

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: U Total Fluence: 4.49E18

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
78	45	46.29	-1.29
100	62	58.68	3.31
150	68	83.66	-15.66
200	107	98.18	8.81
300	107	106.74	.25
400	110	107.85	2.14

SUM of RESIDUALS = -4.55

CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:19:17 on 04-04-2000
Page 1
Coefficients of Curve 3

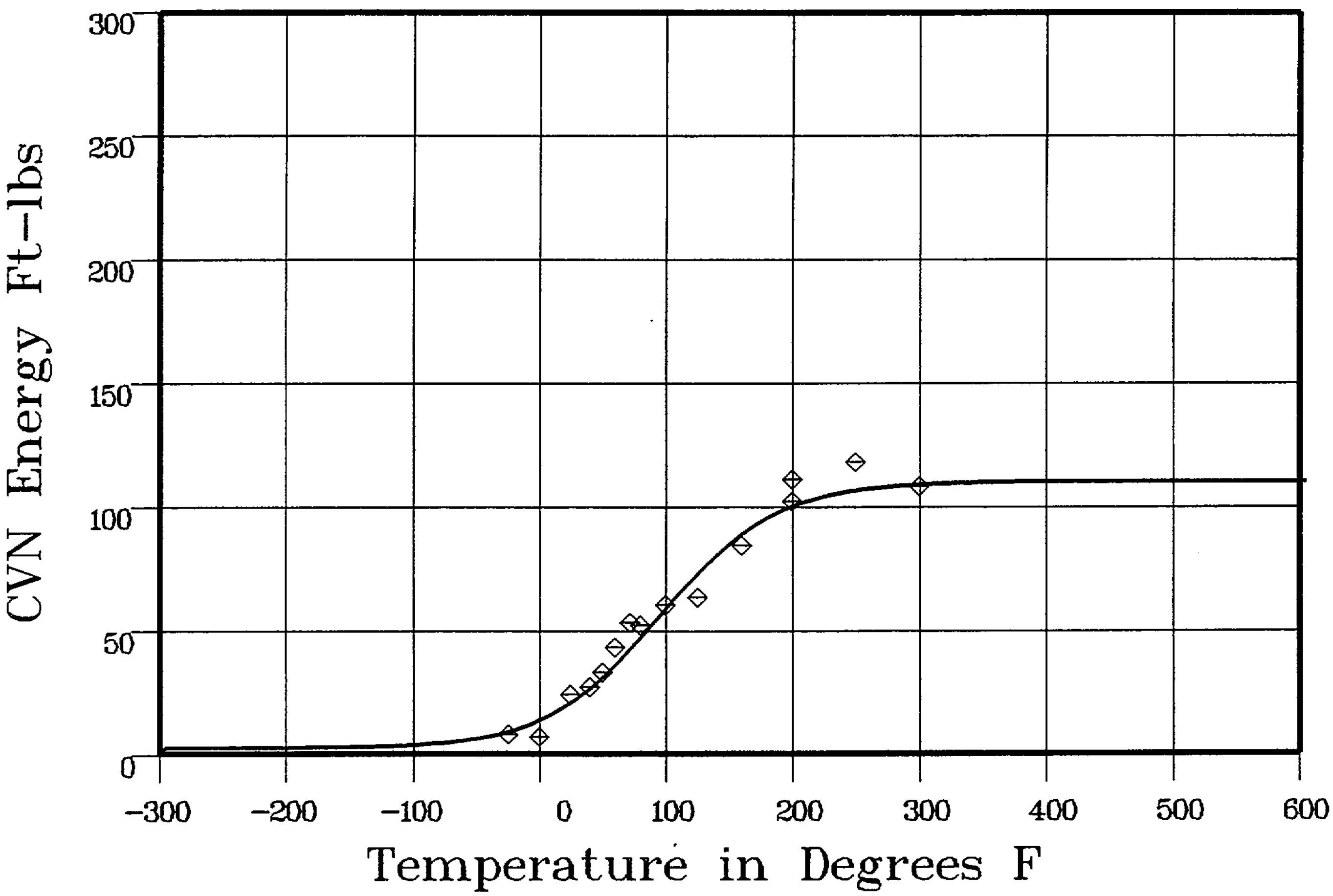
A = 56.09	B = 53.9	C = 91.17	T0 = 91.4

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

Upper Shelf Energy: 110 Fixed   Temp. at 30 ft-lbs: 43.2   Temp. at 50 ft-lbs: 81   Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1   Heat Number: C4039-2   Orientation: TL

Capsule: X   Total Fluence: 2.21E19



Data Set(s) Plotted
Plant: ML3   Cap.: X   Material: PLATE SA533B1   Ori.: TL   Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-25	8	9.98	-1.98
0	7	14.99	-7.99
25	24	22.57	1.42
40	27	28.56	-1.56
50	33	33.17	-.17
60	43	38.23	4.76
72	53	44.79	8.2
80	52	49.39	2.6

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

CAPSULE X

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: X Total Fluence: 2.21E19

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
100	60	61.16	-1.16
125	63	75.1	-12.1
160	84	90.41	-6.41
200	102	100.88	1.11
200	111	100.88	10.11
250	118	106.77	11.22
300	108	108.9	-.9

SUM of RESIDUALS = 7.15

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:22:18 on 04-04-2000

Page 1

Coefficients of Curve 1

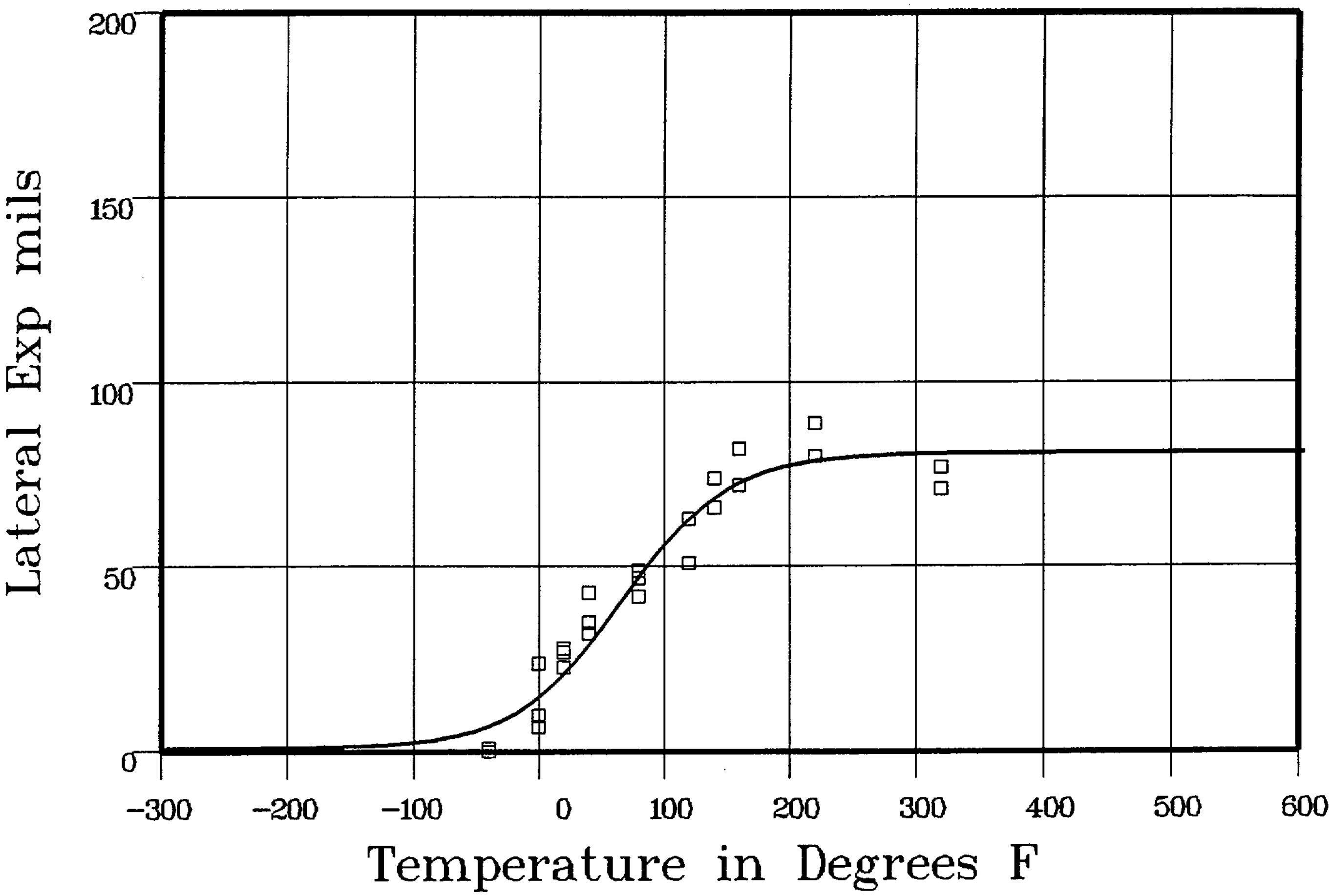
A = 40.97	B = 39.97	C = 86.07	T0 = 61.87

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

Upper Shelf L.E.: 80.95 Temperature at L.E. 35: 48.9 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: ML3 Cap.: UNIRR Material: PLATE SA533B1 Ori.: TL Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-40	1	7.85	-6.85
-40	0	7.85	-7.85
0	7	16.34	-9.34
0	24	16.34	7.65
0	10	16.34	-6.34
20	28	22.93	5.06
20	23	22.93	.06
20	27	22.93	4.06
40	43	31.03	11.96

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

UNIRRADIATED

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
40	32	31.03	.96
40	35	31.03	3.96
80	49	49.27	-.27
80	42	49.27	-7.27
80	47	49.27	-2.27
120	63	64.5	-1.5
120	51	64.5	-13.5
120	63	64.5	-1.5
140	66	69.76	-3.76
140	74	69.76	4.23
160	72	73.53	-1.53
160	82	73.53	8.46
160	82	73.53	8.46
220	89	78.97	10.02
220	80	78.97	1.02
320	77	80.75	-3.75
320	71	80.75	-9.75

SUM of RESIDUALS = -9.58

CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:22:18 on 04-04-2000

Page 1

Coefficients of Curve 2

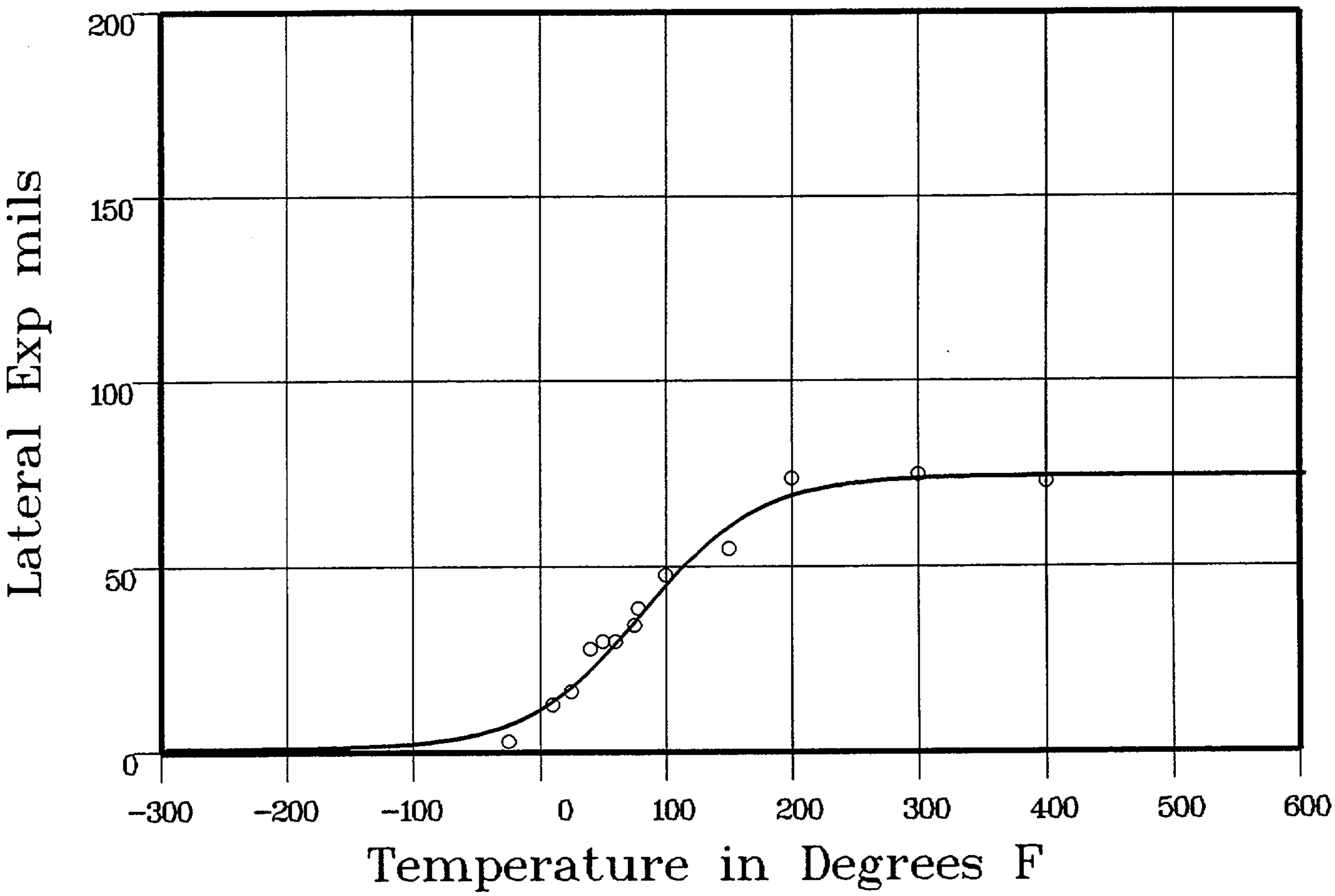
A = 37.72	B = 36.72	C = 92.19	T0 = 76.87

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

Upper Shelf L.E.: 74.45 Temperature at L.E. 35: 70 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: U Total Fluence: 4.49E18



Data Set(s) Plotted

Plant: ML3 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	3	8.26	-5.26
10	13	14.94	-1.94
25	16.5	18.99	-2.49
40	28	23.77	4.22
50	30	27.31	2.68
50	30	27.31	2.68
60	30	31.07	-1.07
75	34.5	36.98	-2.48

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

CAPSULE U

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: U Total Fluence: 4.49E18

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
78	39	38.17	.82
100	48	46.75	1.24
150	55	61.97	-6.97
200	74	69.7	4.29
300	75	73.87	1.12
400	73	74.38	-1.38

SUM of RESIDUALS = -4.54

CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:22:18 on 04-04-2000

Page 1

Coefficients of Curve 3

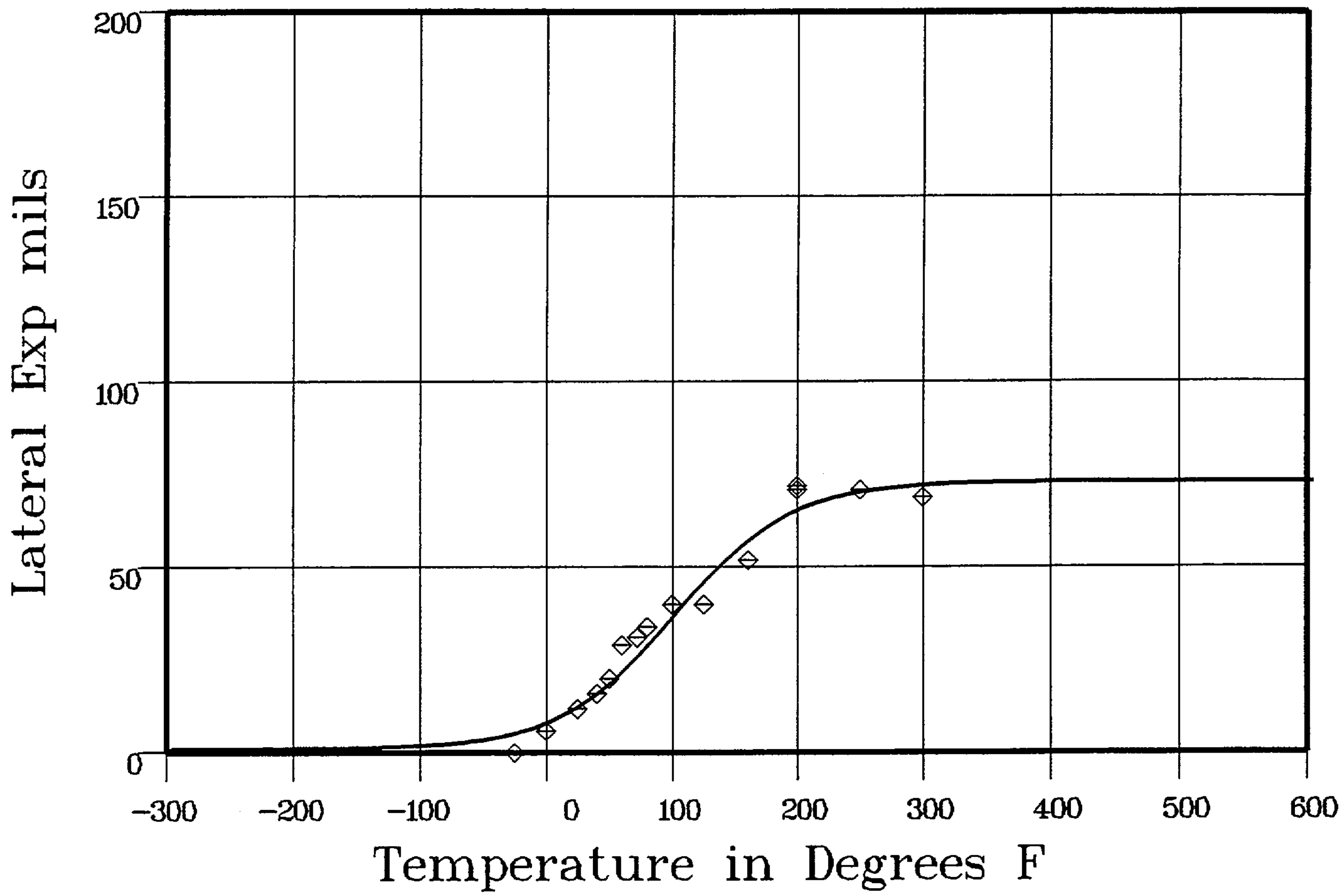
A = 37.15	B = 36.15	C = 92.65	T0 = 97.03

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

Upper Shelf L.E.: 73.31 Temperature at L.E. 35: 91.4 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: X Total Fluence: 2.21E19



Data Set(s) Plotted

Plant: ML3 Cap.: X Material: PLATE SA533B1 Ori.: TL Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-25	0	5.84	-5.84
0	6	8.92	-2.92
25	12	13.61	-1.61
40	16	17.34	-1.34
50	20	20.23	-.23
60	29	23.42	5.57
72	31	27.61	3.38
80	34	30.58	3.41

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

CAPSULE X

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: X Total Fluence: 2.21E19

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
100	40	38.31	1.68
125	40	47.75	-7.75
160	52	58.53	-6.53
200	72	66.24	5.75
200	71	66.24	4.75
250	71	70.74	.25
300	69	72.41	-3.41

SUM of RESIDUALS = -4.84

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:24:54 on 04-04-2000

Page 1

Coefficients of Curve 1

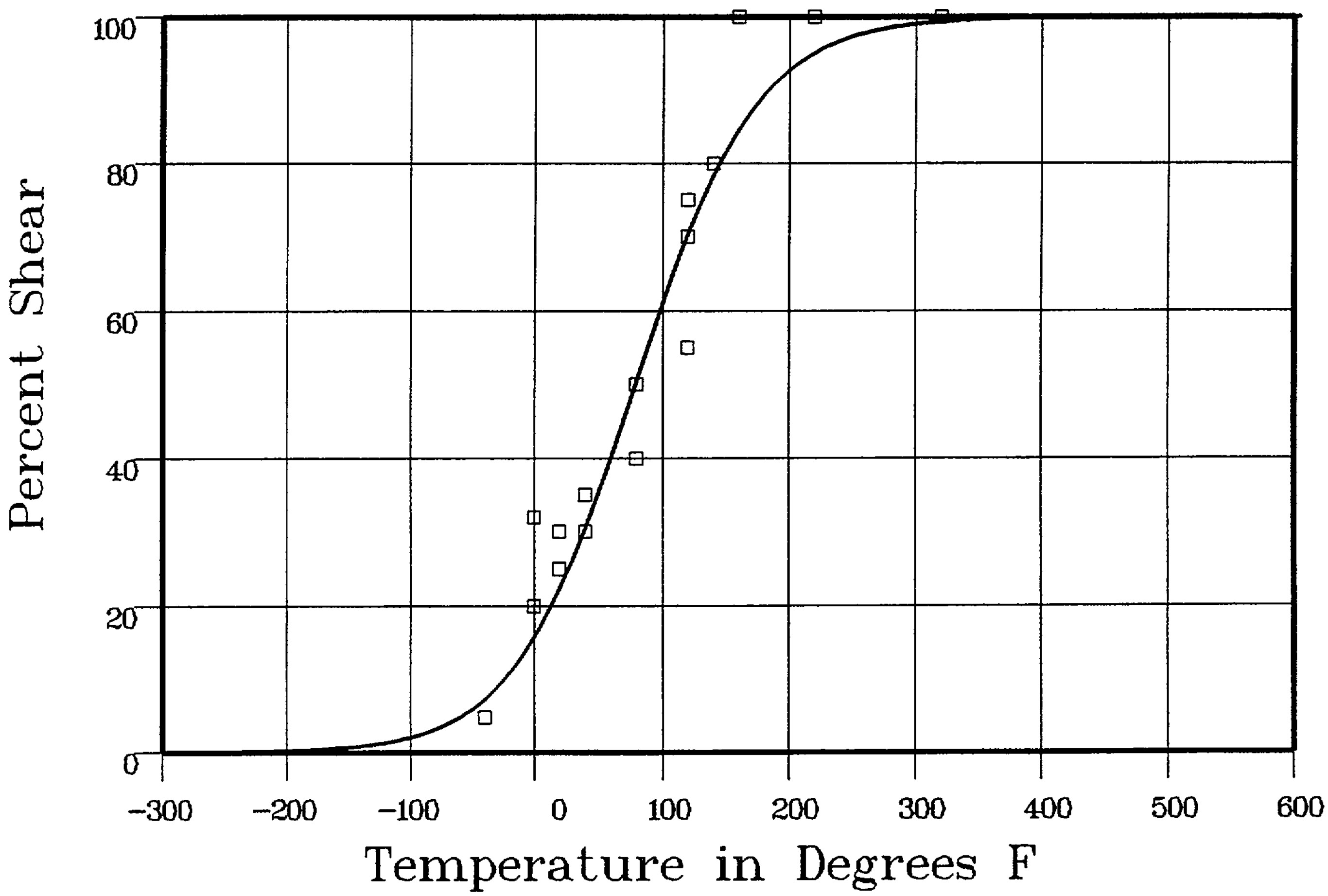
A = 50	B = 50	C = 94.72	T0 = 74.35

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

Temperature at 50% Shear: 74.3

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: ML3 Cap.: UNIRR Material: PLATE SA533B1 Ori.: TL Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40	5	8.2	-3.2
-40	5	8.2	-3.2
0	20	17.22	2.77
0	32	17.22	14.77
0	20	17.22	2.77
20	30	24.09	5.9
20	30	24.09	5.9
20	25	24.09	.9
40	35	32.62	2.37

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

UNIRRADIATED

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
40	30	32.62	-2.62
40	35	32.62	2.37
80	50	52.97	-2.97
80	40	52.97	-12.97
80	40	52.97	-12.97
120	75	72.38	2.61
120	55	72.38	-17.38
120	70	72.38	-2.38
140	80	79.99	0
140	80	79.99	0
160	100	85.91	14.08
160	100	85.91	14.08
160	100	85.91	14.08
220	100	95.58	4.41
220	100	95.58	4.41
320	100	99.44	.55
320	100	99.44	.55

SUM of RESIDUALS = 34.86

CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:24:54 on 04-04-2000
Page 1
Coefficients of Curve 2

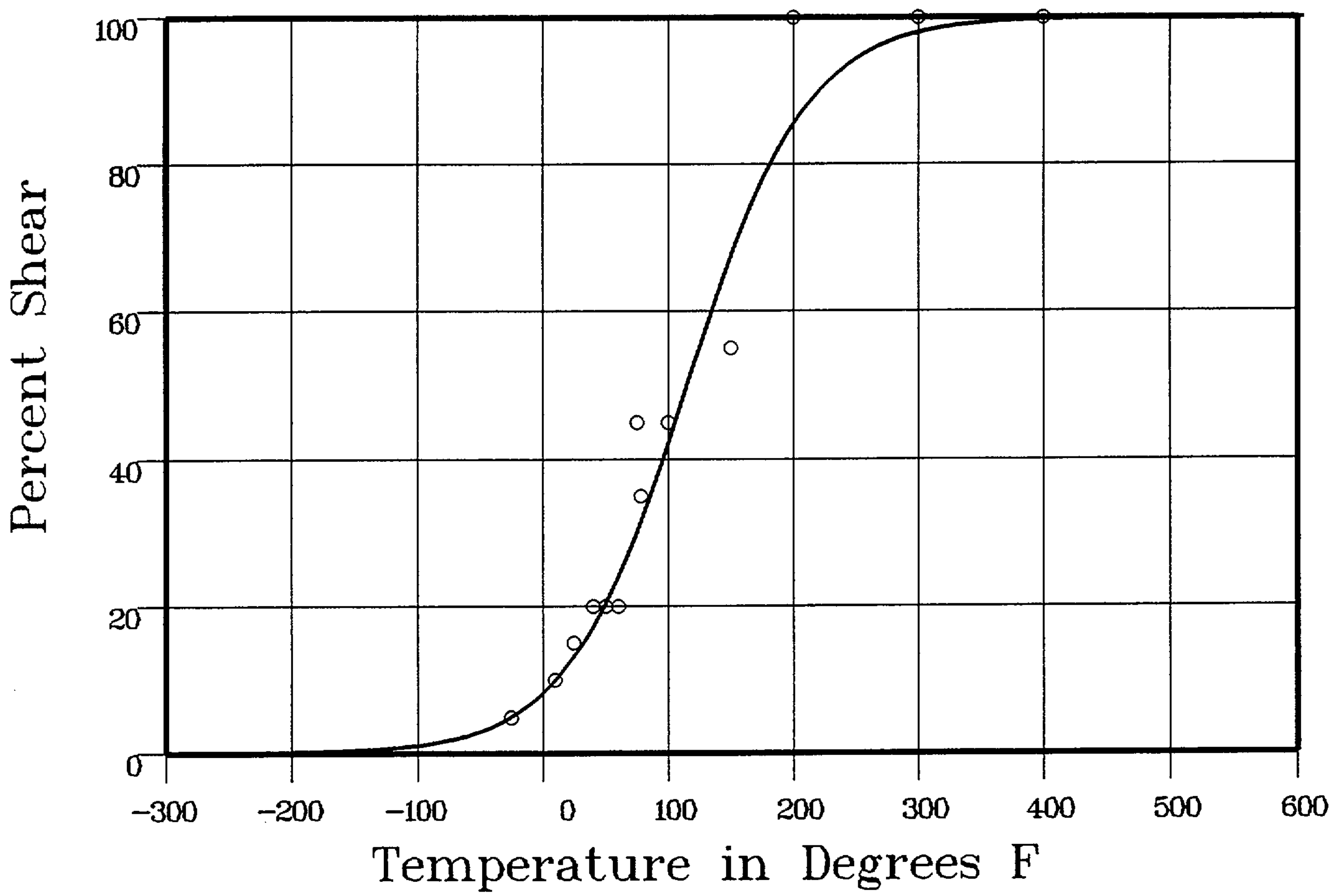
A = 50	B = 50	C = 95.69	T0 = 110.58

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

Temperature at 50% Shear: 110.5

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: U Total Fluence: 4.49E18



Data Set(s) Plotted
Plant: ML3 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	5	5.55	-.55
10	10	10.88	-.88
25	15	14.32	.67
40	20	18.61	1.38
50	20	21.99	-1.99
50	20	21.99	-1.99
60	20	25.78	-5.78
75	45	32.21	12.78

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

CAPSULE U

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: U Total Fluence: 4.49E18

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
78	35	33.6	1.39
100	45	44.49	.5
150	55	69.5	-14.5
200	100	86.63	13.36
300	100	98.12	1.87
400	100	99.76	.23

SUM of RESIDUALS = 6.51

CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:24:54 on 04-04-2000
Page 1
Coefficients of Curve 3

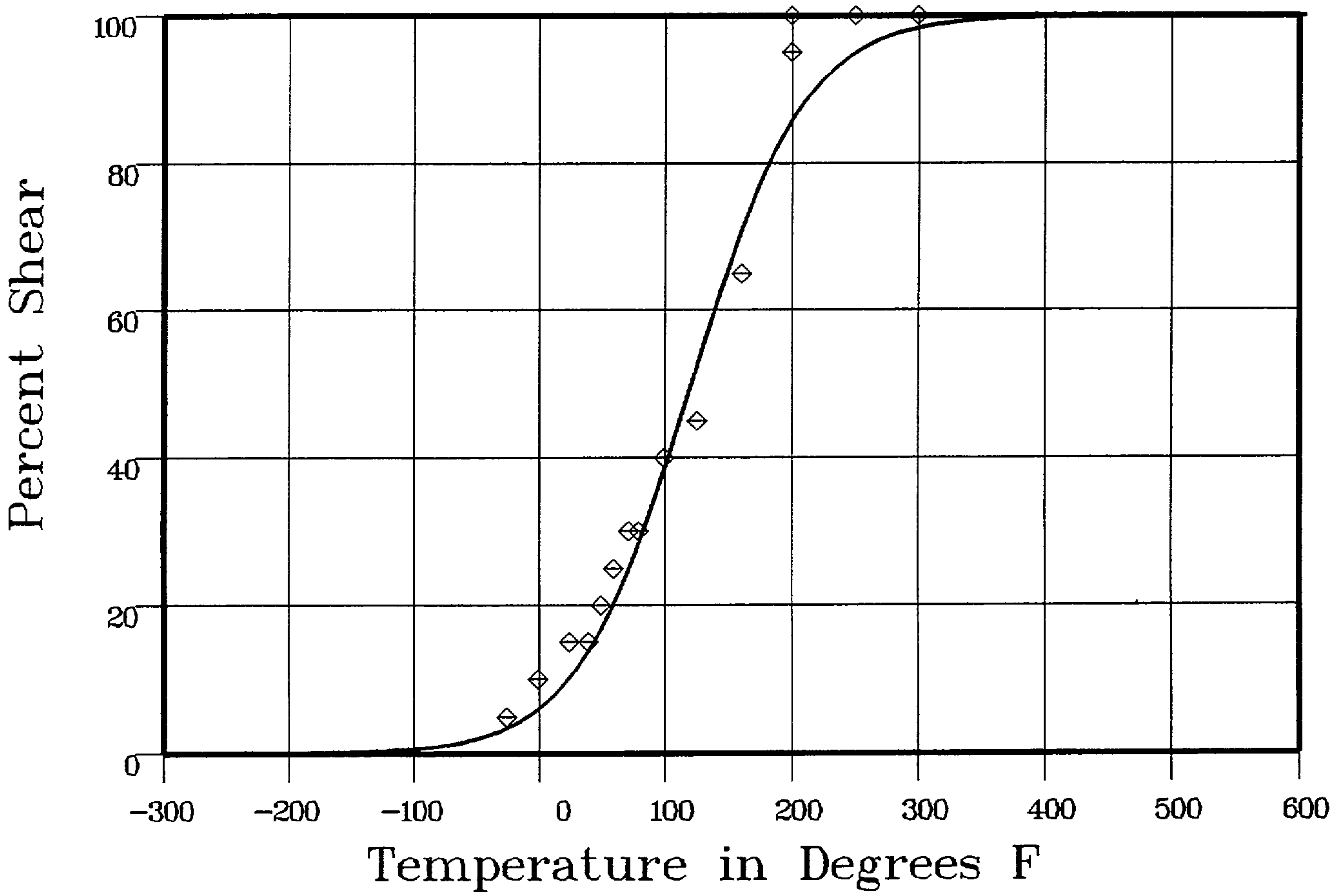
A = 50	B = 50	C = 88.21	T0 = 116.01

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

Temperature at 50% Shear: 116

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: X Total Fluence: 2.21E19



Data Set(s) Plotted
Plant: ML3 Cap.: X Material: PLATE SA533B1 Ori.: TL Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-25	5	3.92	1.07
0	10	6.72	3.27
25	15	11.27	3.72
40	15	15.14	-.14
50	20	18.29	1.7
60	25	21.92	3.07
72	30	26.93	3.06
80	30	30.65	-.65

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

CAPSULE X

Page 2

Material: PLATE SA533B1 Heat Number: C4039-2 Orientation: TL

Capsule: X Total Fluence: 2.21E19

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100	40	41.02	-1.02
125	45	55.07	-10.07
160	65	73.04	-8.04
200	95	87.03	7.96
200	100	87.03	12.96
250	100	95.42	4.57
300	100	98.47	1.52
		SUM of RESIDUALS =	23

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:29:11 on 04-04-2000

Page 1

Coefficients of Curve 1

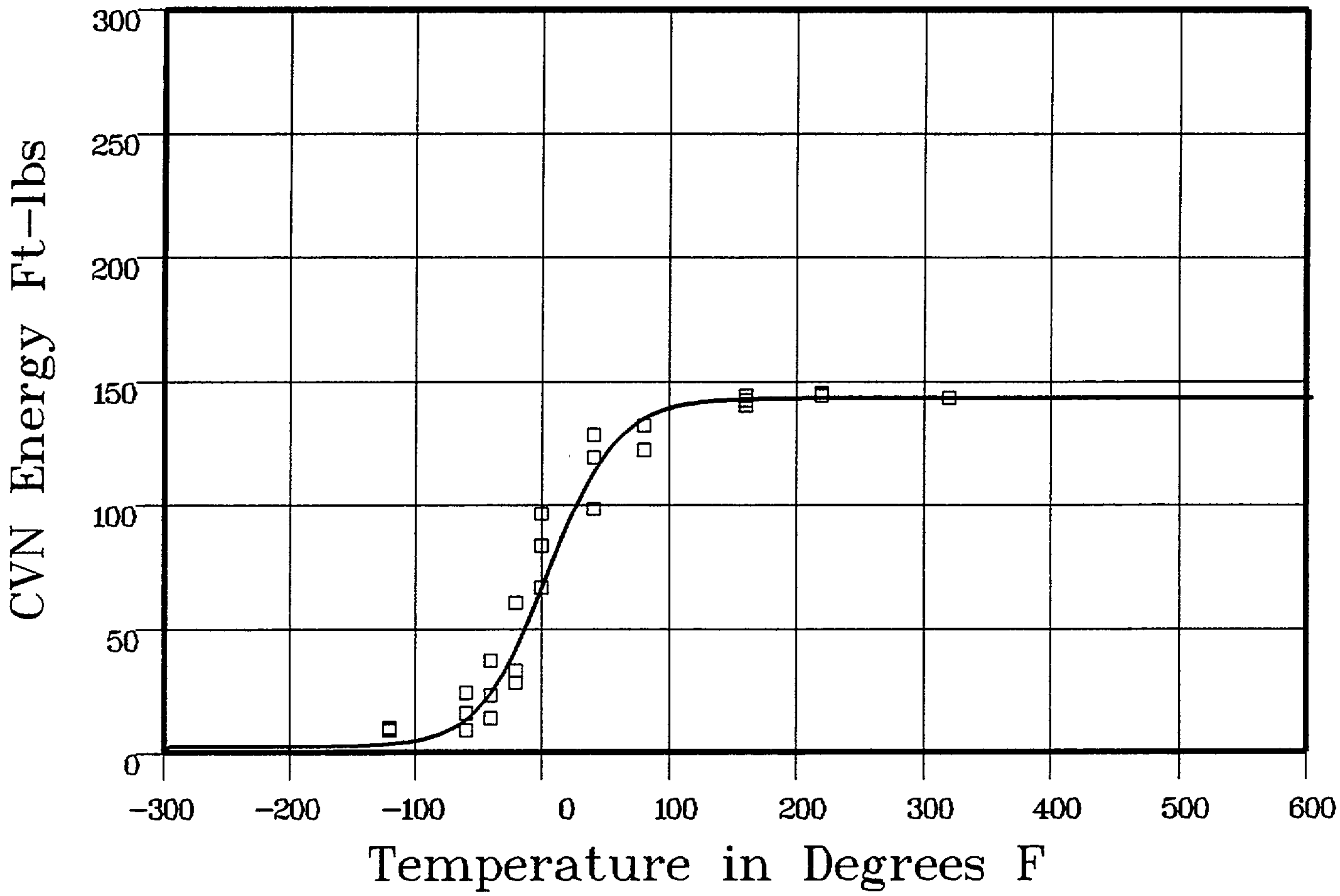
A = 72.59	B = 70.4	C = 53.38	T0 = .46

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

Upper Shelf Energy: 143 Fixed Temp. at 30 ft-lbs: -36.9 Temp. at 50 ft-lbs: -17.2 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 4P6052 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: ML3 Cap.: UNIRR Material: WELD Ori.: Heat #: 4P6052

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-120	10	3.72	6.27
-120	9	3.72	5.27
-60	16	15.43	.56
-60	24	15.43	8.56
-60	9	15.43	-6.43
-40	37	27.54	9.45
-40	14	27.54	-13.54
-40	23	27.54	-4.54
-20	60	46.85	13.14

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

UNIRRADIATED

Page 2

Material: WELD   Heat Number: 4P6052   Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-20	33	46.85	-13.85
-20	28	46.85	-18.85
0	96	71.98	24.01
0	66	71.98	-5.98
0	83	71.98	11.01
40	119	116.91	2.08
40	128	116.91	11.08
40	98	116.91	-18.91
80	122	136.19	-14.19
80	132	136.19	-4.19
80	132	136.19	-4.19
160	140	142.64	-2.64
160	144	142.64	1.35
160	142	142.64	-.64
220	145	142.96	2.03
220	144	142.96	1.03
320	143	142.99	0

SUM of RESIDUALS = -12.1

CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:29:11 on 04-04-2000

Page 1

Coefficients of Curve 2

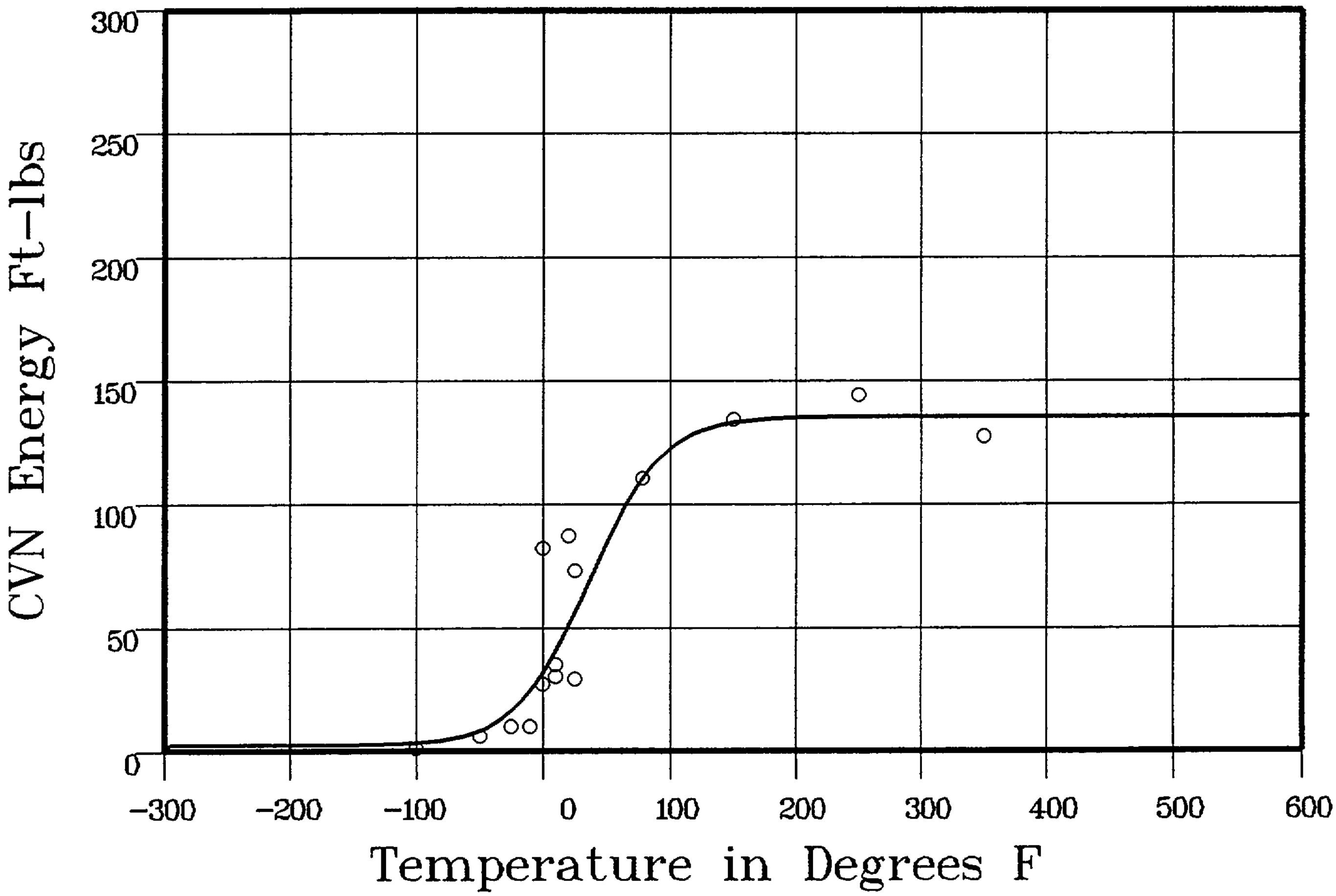
A = 68.59	B = 66.4	C = 57.17	T0 = 31.4

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

Upper Shelf Energy: 135 Fixed   Temp. at 30 ft-lbs: -6.5   Temp. at 50 ft-lbs: 14.9   Lower Shelf Energy: 2.19 Fixed

Material: WELD   Heat Number: 4P6052   Orientation:

Capsule: U   Total Fluence: 4.49E18



Data Set(s) Plotted

Plant: ML3   Cap.: U   Material: WELD   Ori.:   Heat #: 4P6052

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	1	3.52	-2.52
-50	6	9.47	-3.47
-25	10	18.41	-8.41
-10	10	27.46	-17.46
0	82	35.4	46.59
0	27	35.4	-8.4
10	30	44.84	-14.84
10	35	44.84	-9.84

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

CAPSULE U

Page 2

Material: WELD   Heat Number: 4P6052   Orientation:

Capsule: U   Total Fluence: 4.49E18

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
20	87	55.52	31.47
25	73	61.19	11.8
25	29	61.19	-32.19
78	110	113.23	-3.23
150	134	132.93	1.06
250	144	134.93	9.06
350	127	134.99	-7.99

SUM of RESIDUALS = -8.39

CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:29:11 on 04-04-2000

Page 1

Coefficients of Curve 3

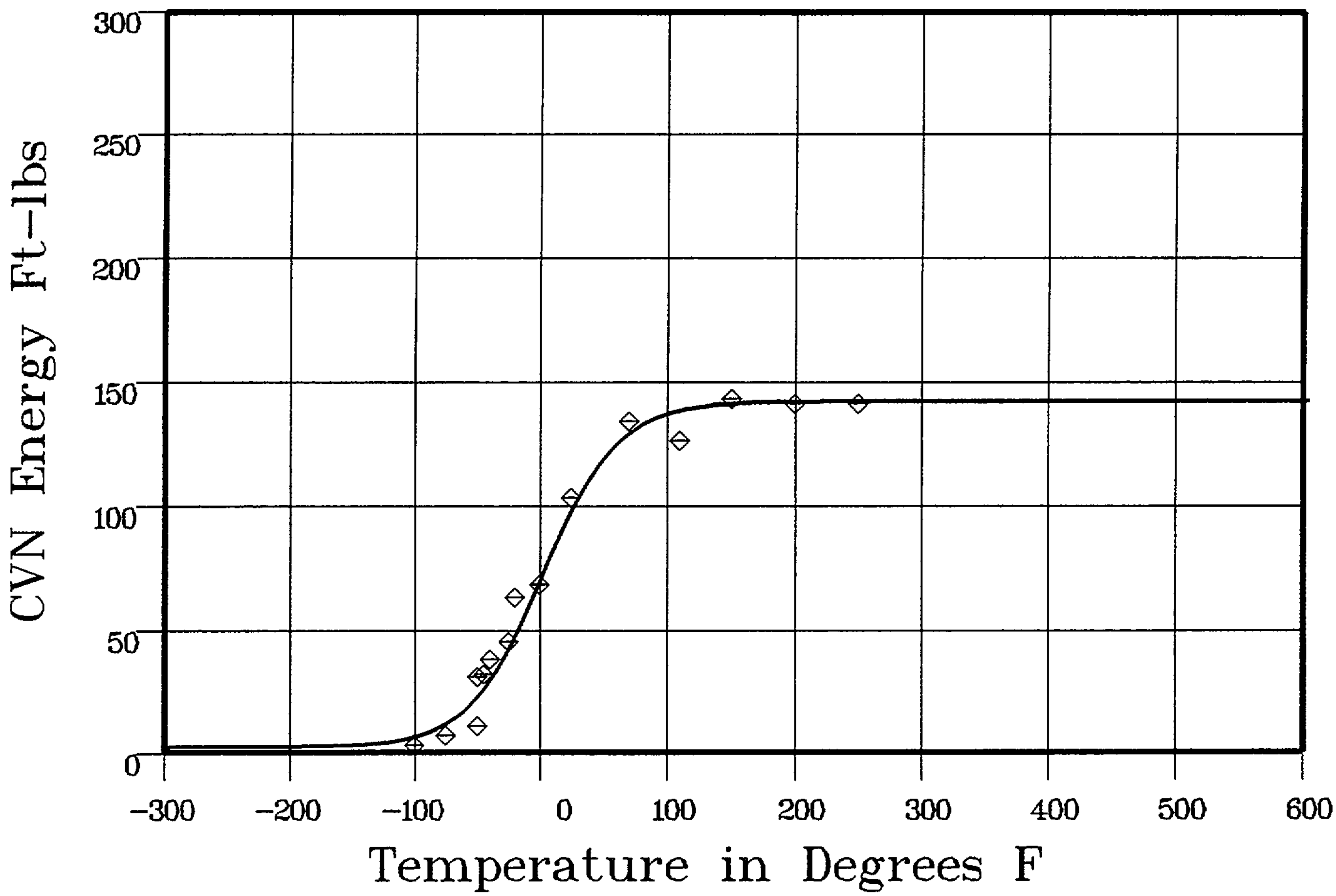
A = 72.09	B = 69.9	C = 59.42	T0 = -2.34

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

Upper Shelf Energy: 142 Fixed Temp. at 30 ft-lbs: -43.7 Temp. at 50 ft-lbs: -21.7 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: 4P6052 Orientation:

Capsule: X Total Fluence: 2.21E19



Data Set(s) Plotted

Plant: ML3 Cap.: X Material: WELD Ori.: Heat #: 4P6052

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-100	3	7.23	-4.23
-75	7	13.35	-6.35
-50	31	25.6	5.39
-50	11	25.6	-14.6
-45	32	29.07	2.92
-40	38	32.91	5.08
-25	45	46.66	-1.66
-20	63	51.92	11.07

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

CAPSULE X

Page 2

Material: WELD   Heat Number: 4P6052   Orientation:

Capsule: X   Total Fluence: 2.21E19

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
0	68	74.85	-6.85
25	103	102.17	.82
70	134	130.73	3.26
110	126	138.88	-12.88
150	143	141.17	1.82
200	141	141.84	-.84
250	141	141.97	-.97

SUM of RESIDUALS = -18.01

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:35:57 on 04-04-2000

Page 1

Coefficients of Curve 1

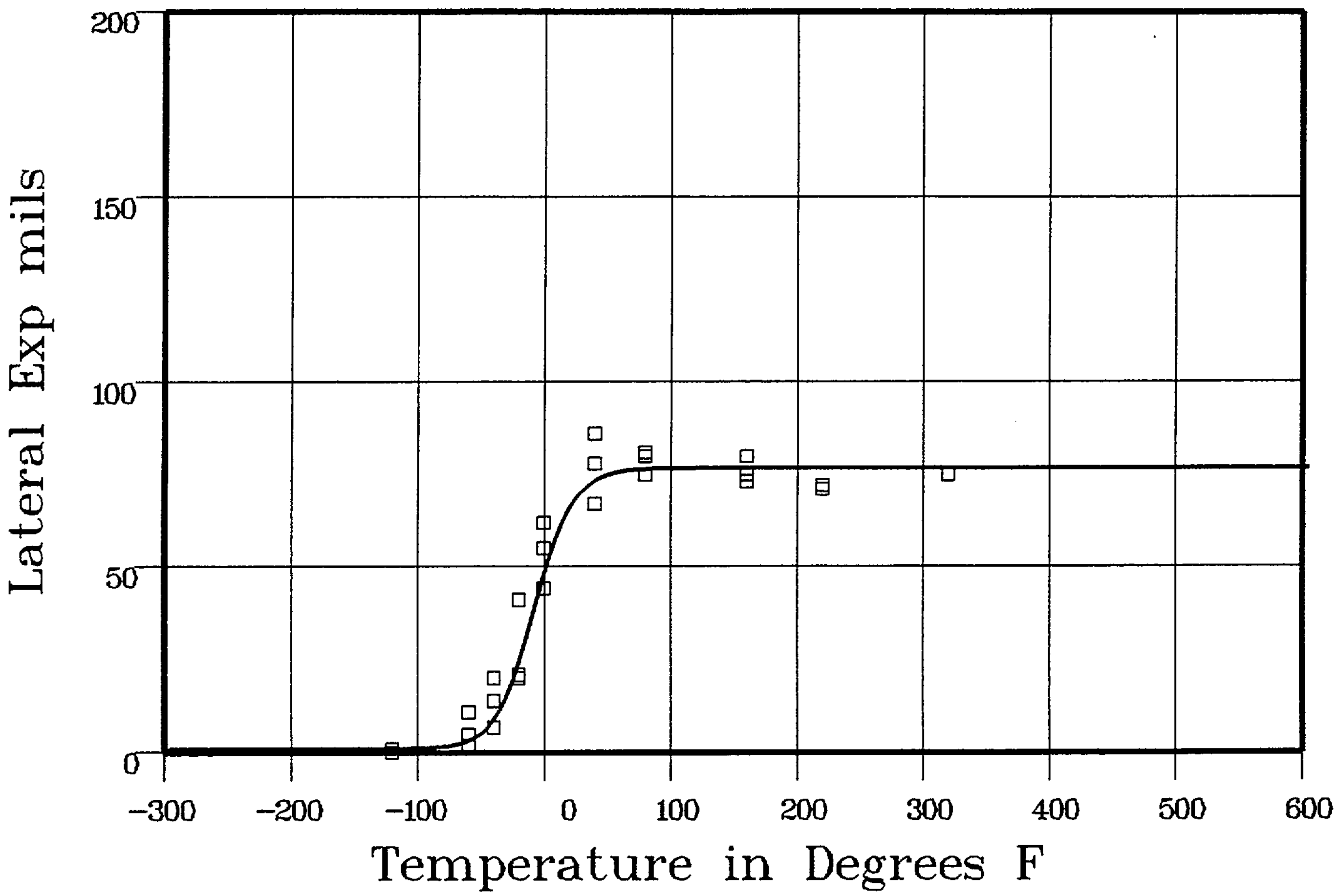
A = 38.86	B = 37.86	C = 30.82	T0 = -12.18

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

Upper Shelf L.E.: 76.73 Temperature at L.E. 35: -15.3 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 4P6052 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: ML3 Cap.: UNIRR Material: WELD Ori.: Heat #: 4P6052

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-120	1	1.06	-.06
-120	0	1.06	-1.06
-60	5	4.25	.74
-60	11	4.25	6.74
-60	2	4.25	-2.25
-40	20	11.7	8.29
-40	7	11.7	-4.7
-40	14	11.7	2.29
-20	41	29.47	11.52

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

UNIRRADIATED

Page 2

Material: WELD Heat Number: 4P6052 Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-20	21	29.47	-8.47
-20	20	29.47	-9.47
0	62	53.1	8.89
0	44	53.1	-9.1
0	55	53.1	1.89
40	78	74.25	3.74
40	86	74.25	11.74
40	67	74.25	-7.25
80	81	76.54	4.45
80	75	76.54	-1.54
80	80	76.54	3.45
160	80	76.73	3.26
160	75	76.73	-1.73
160	73	76.73	-3.73
220	72	76.73	-4.73
220	71	76.73	-5.73
320	75	76.73	-1.73

SUM of RESIDUALS = 5.47

CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:35:57 on 04-04-2000
Page 1
Coefficients of Curve 2

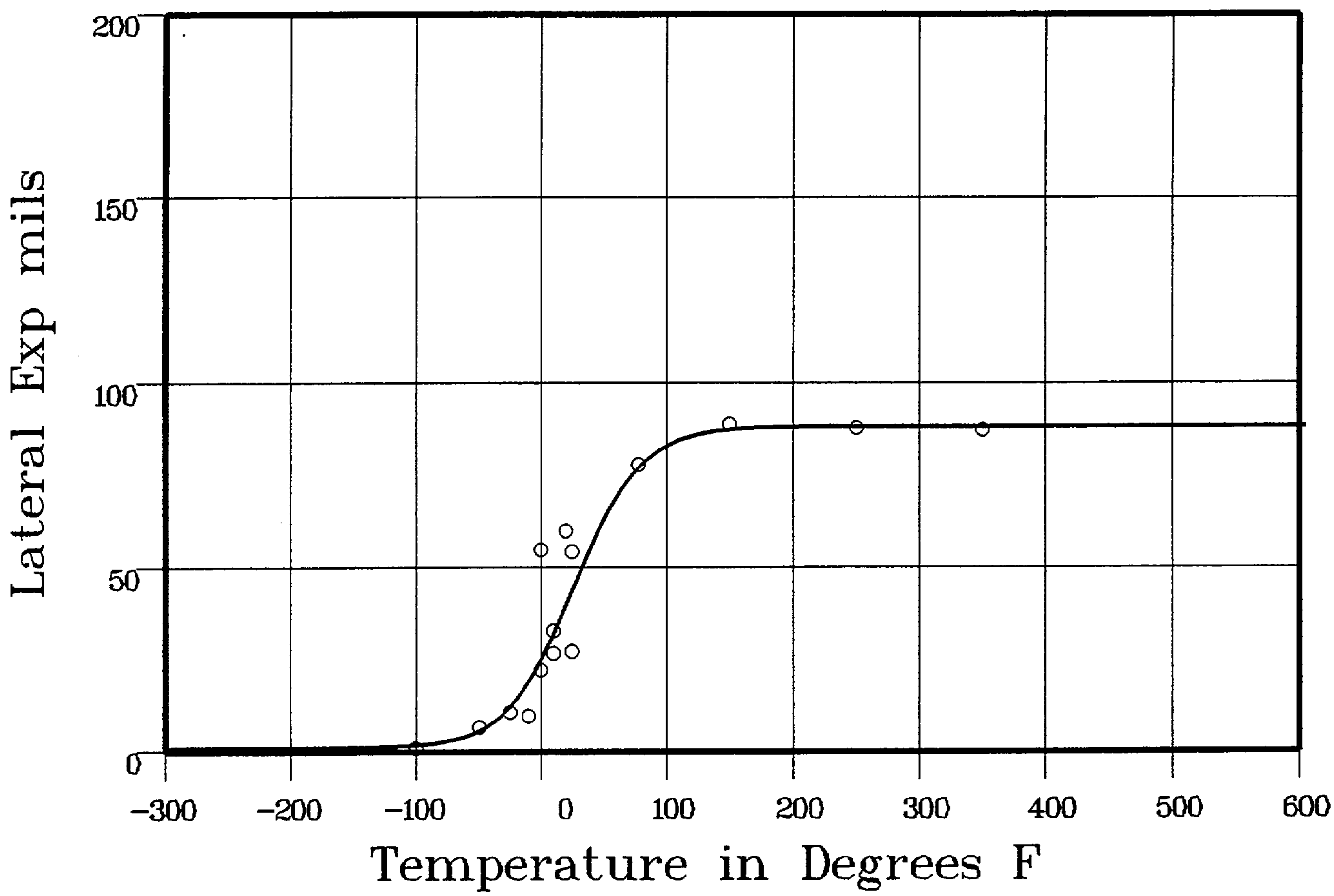
A = 44.65	B = 43.65	C = 54.11	T0 = 21.4

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

Upper Shelf L.E.: 88.3 Temperature at L.E. 35: 9.2 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 4P6052 Orientation:

Capsule: U Total Fluence: 4.49E18



Data Set(s) Plotted
Plant: ML3 Cap.: U Material: WELD Ori.: Heat #: 4P6052

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	1	1.97	-.97
-50	7	6.82	.17
-25	11	14.31	-3.31
-10	10	21.82	-11.82
0	55	28.23	26.76
0	22.5	28.23	-5.73
10	27	35.58	-8.58
10	33	35.58	-2.58

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

CAPSULE U

Page 2

Material: WELD   Heat Number: 4P6052   Orientation:

Capsule: U   Total Fluence: 4.49E18

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
20	60	43.51	16.48
25	54.5	47.54	6.95
25	27.5	47.54	-20.04
78	78	78.7	-.7
150	89	87.55	1.44
250	88	88.28	-.28
350	87.5	88.3	-.8

SUM of RESIDUALS = -3.02

CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:35:57 on 04-04-2000

Page 1

Coefficients of Curve 3

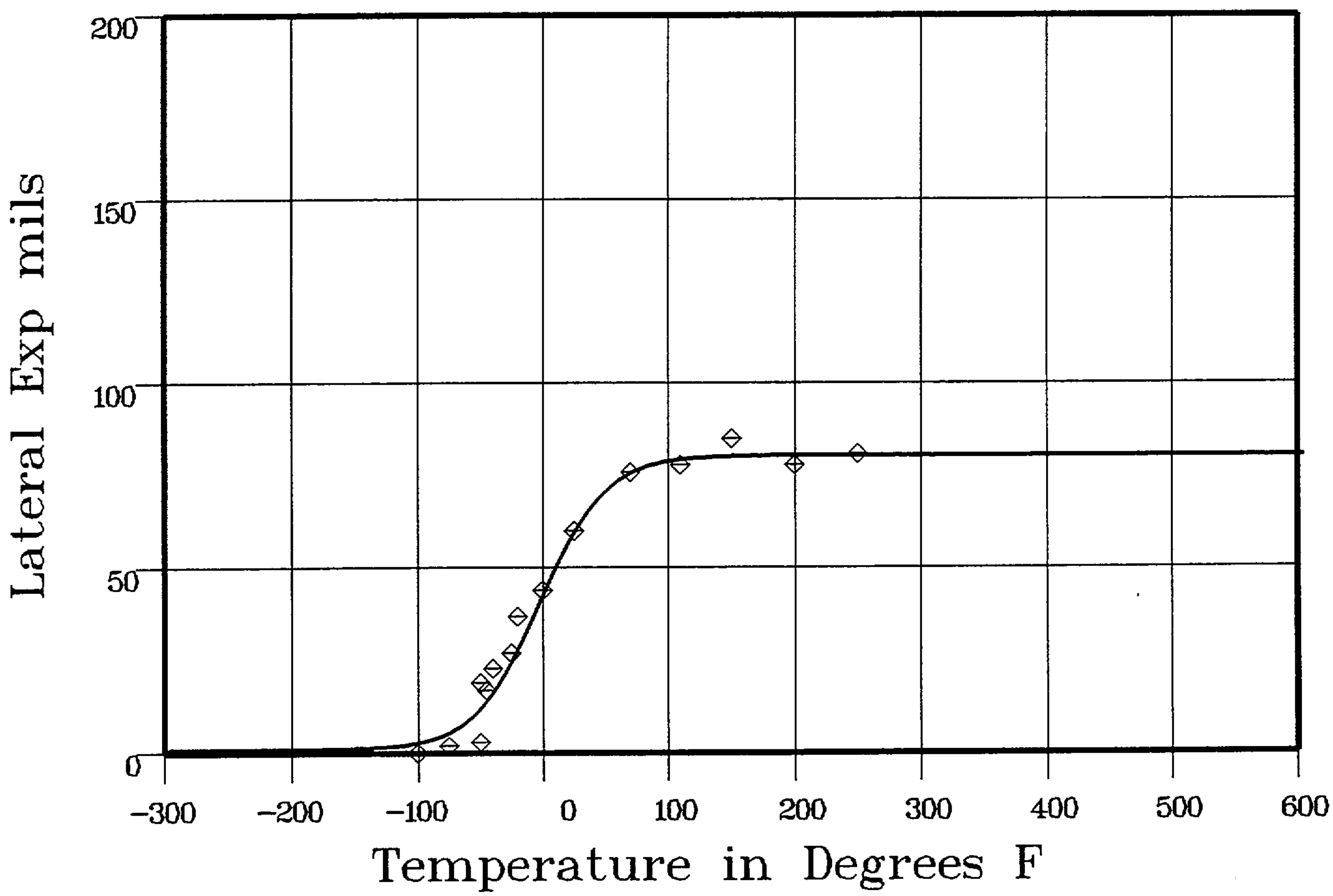
A = 40.75	B = 39.75	C = 52.48	T0 = -7.03

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

Upper Shelf L.E.: 80.51 Temperature at L.E. 35: -14.6 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: 4P6052 Orientation:

Capsule: X Total Fluence: 2.21E19



Data Set(s) Plotted

Plant: ML3 Cap.: X Material: WELD Ori.: Heat #: 4P6052

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-100	0	3.23	-3.23
-75	2	6.54	-4.54
-50	19	13.94	5.05
-50	3	13.94	-10.94
-45	17	16.14	.85
-40	23	18.61	4.38
-25	27	27.65	-.65
-20	37	31.12	5.87

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

CAPSULE X

Page 2

Material: WELD   Heat Number: 4P6052   Orientation:

Capsule: X   Total Fluence: 2.21E19

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
0	44	46.05	-2.05
25	60	62.39	-2.39
70	76	76.5	-.5
110	78	79.6	-1.6
150	85	80.31	4.68
200	78	80.48	-2.48
250	81	80.5	.49

SUM of RESIDUALS = -7.07

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:38:56 on 04-04-2000

Page 1

Coefficients of Curve 1

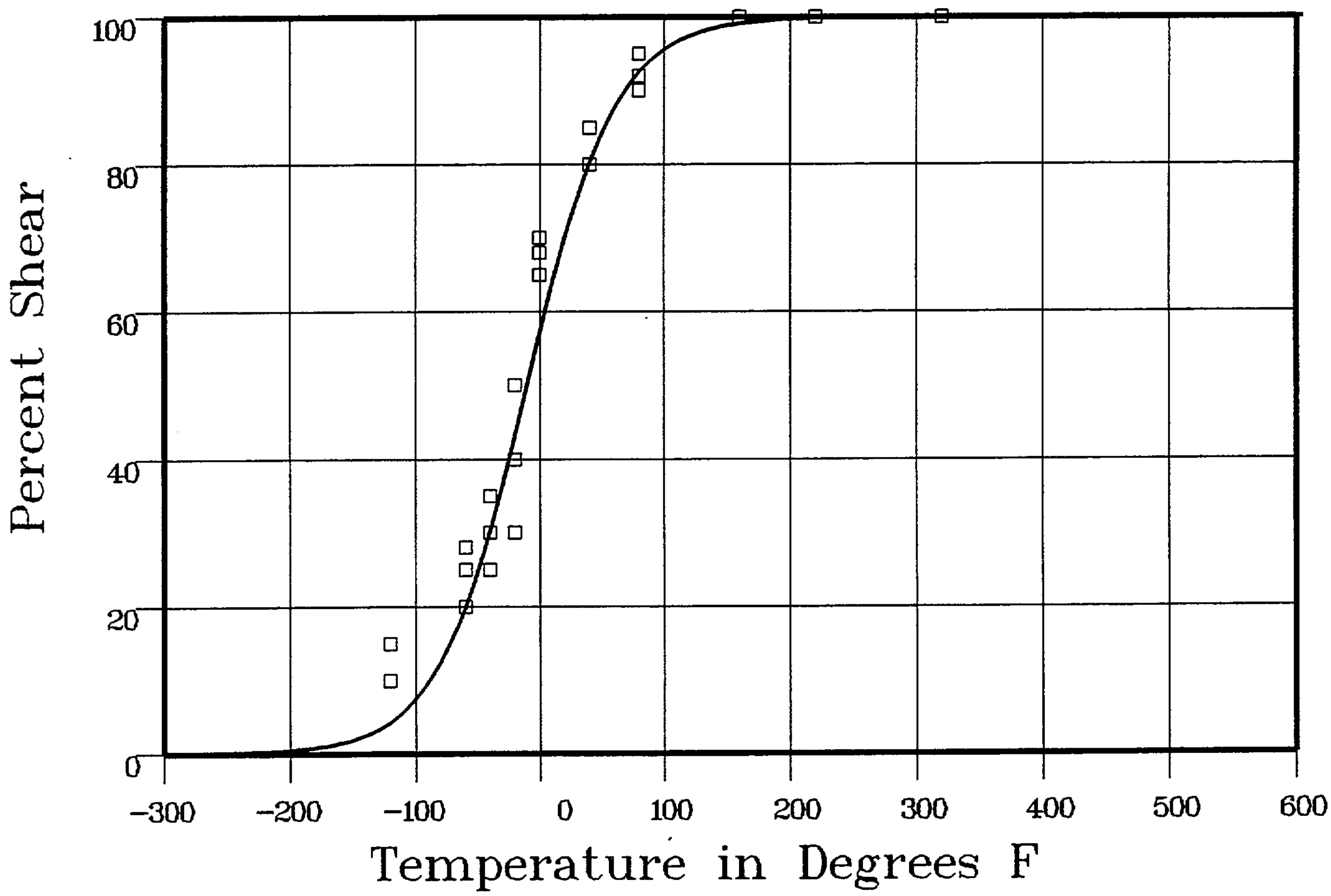
A = 50	B = 50	C = 71.58	T0 = -15

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

Temperature at 50% Shear: -15

Material: WELD Heat Number: 4P6052 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: ML3 Cap.: UNIRR Material: WELD Ori.: Heat #: 4P6052

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-120	15	5.05	9.94
-120	10	5.05	4.94
-60	28	22.14	5.85
-60	20	22.14	-2.14
-60	25	22.14	2.85
-40	30	33.21	-3.21
-40	25	33.21	-8.21
-40	35	33.21	1.78
-20	50	46.51	3.48

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

UNIRRADIATED

Page 2

Material: WELD Heat Number: 4P6052 Orientation:

Capsule: UNIRR Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-20	40	46.51	-6.51
-20	30	46.51	-16.51
0	65	60.32	4.67
0	70	60.32	9.67
0	68	60.32	7.67
40	80	82.29	-2.29
40	85	82.29	2.7
40	80	82.29	-2.29
80	90	93.42	-3.42
80	95	93.42	1.57
80	92	93.42	-1.42
160	100	99.25	.74
160	100	99.25	.74
160	100	99.25	.74
220	100	99.85	.14
220	100	99.85	.14
320	100	99.99	0

SUM of RESIDUALS = 11.65

CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:38:56 on 04-04-2000

Page 1

Coefficients of Curve 2

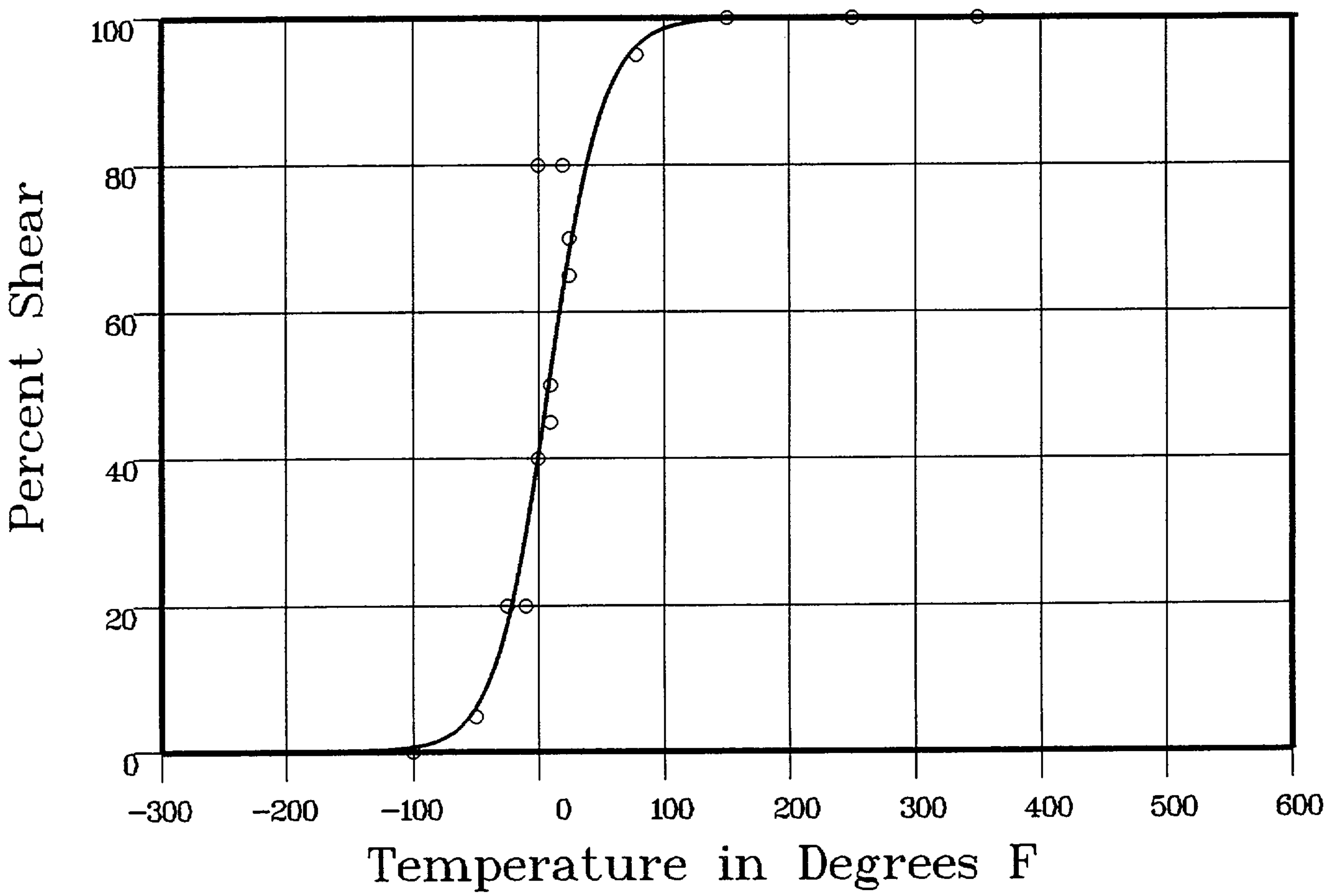
A = 50	B = 50	C = 43.16	T0 = 3.95

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

Temperature at 50% Shear: 3.9

Material: WELD Heat Number: 4P6052 Orientation:

Capsule: U Total Fluence: 4.49E18



Data Set(s) Plotted

Plant: ML3 Cap.: U Material: WELD Ori.: Heat #: 4P6052

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	0	.8	-.8
-50	5	7.58	-2.58
-25	20	20.72	-.72
-10	20	34.37	-14.37
0	80	45.43	34.56
0	40	45.43	-5.43
10	50	56.95	-6.95
10	45	56.95	-11.95

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

CAPSULE U

Page 2

Material: WELD Heat Number: 4P6052 Orientation:

Capsule: U Total Fluence: 4.49E18

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
20	80	67.77	12.22
25	70	72.61	-2.61
25	65	72.61	-7.61
78	95	96.86	-1.86
150	100	99.88	.11
250	100	99.99	0
350	100	99.99	0

SUM of RESIDUALS = -8.01

CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:38:56 on 04-04-2000

Page 1

Coefficients of Curve 3

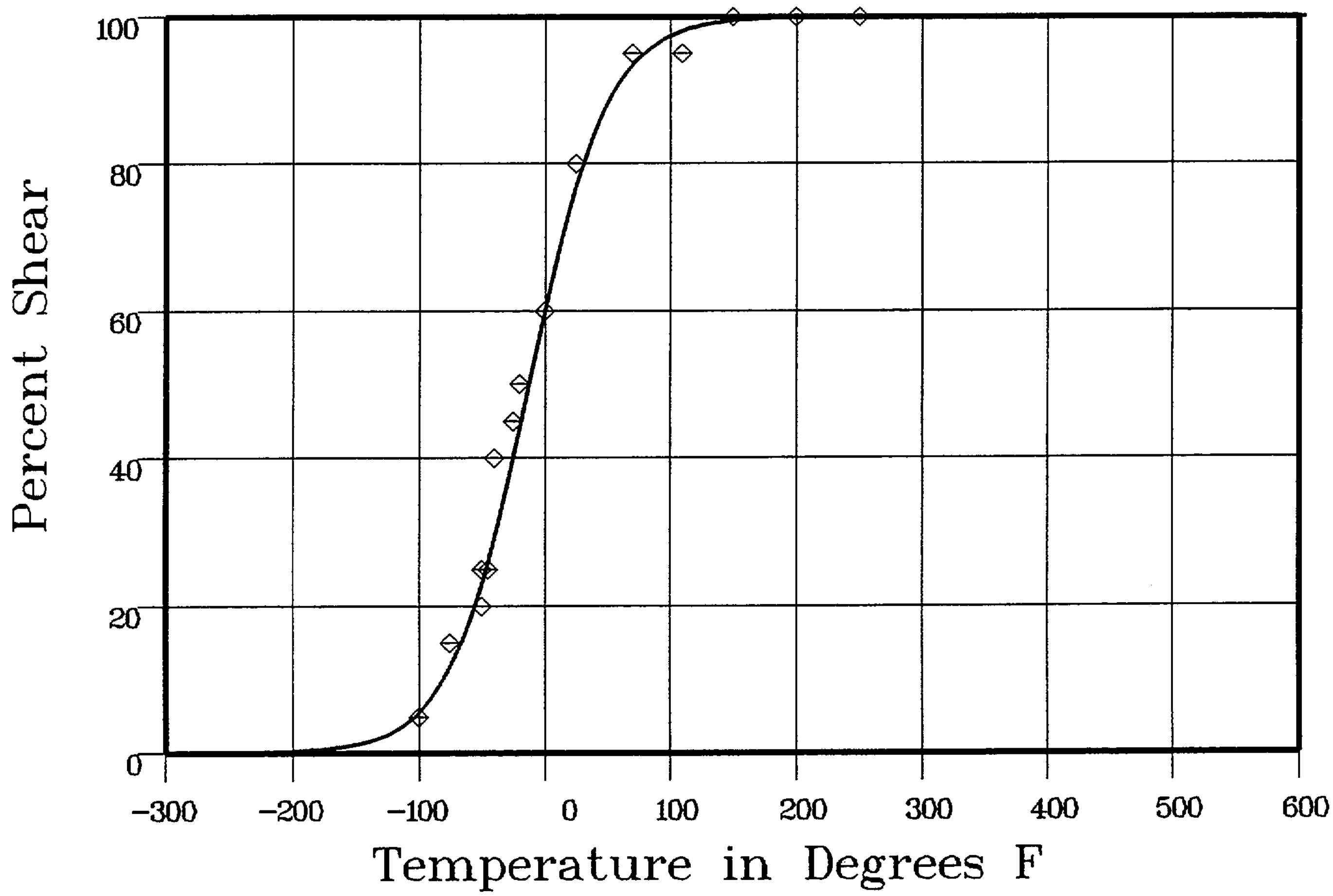
A = 50	B = 50	C = 62.1	T0 = -17.13

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

Temperature at 50% Shear: -17.1

Material: WELD   Heat Number: 4P6052   Orientation:

Capsule: X   Total Fluence: 2.21E19



Data Set(s) Plotted

Plant: ML3   Cap.: X   Material: WELD   Ori.:   Heat #: 4P6052

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100	5	6.48	-1.48
-75	15	13.43	1.56
-50	25	25.76	-.76
-50	20	25.76	-5.76
-45	25	28.96	-3.96
-40	40	32.38	7.61
-25	45	43.7	1.29
-20	50	47.69	2.3

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

CAPSULE X

Page 2

Material: WELD   Heat Number: 4P6052   Orientation:

Capsule: X   Total Fluence: 2.21E19

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
0	60	63.45	-3.45
25	80	79.52	.47
70	95	94.3	.69
110	95	98.36	-3.36
150	100	99.54	.45
200	100	99.9	.09
250	100	99.98	.01

SUM of RESIDUALS = -4.27

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:51:50 on 04-04-2000

Page 1

Coefficients of Curve 1

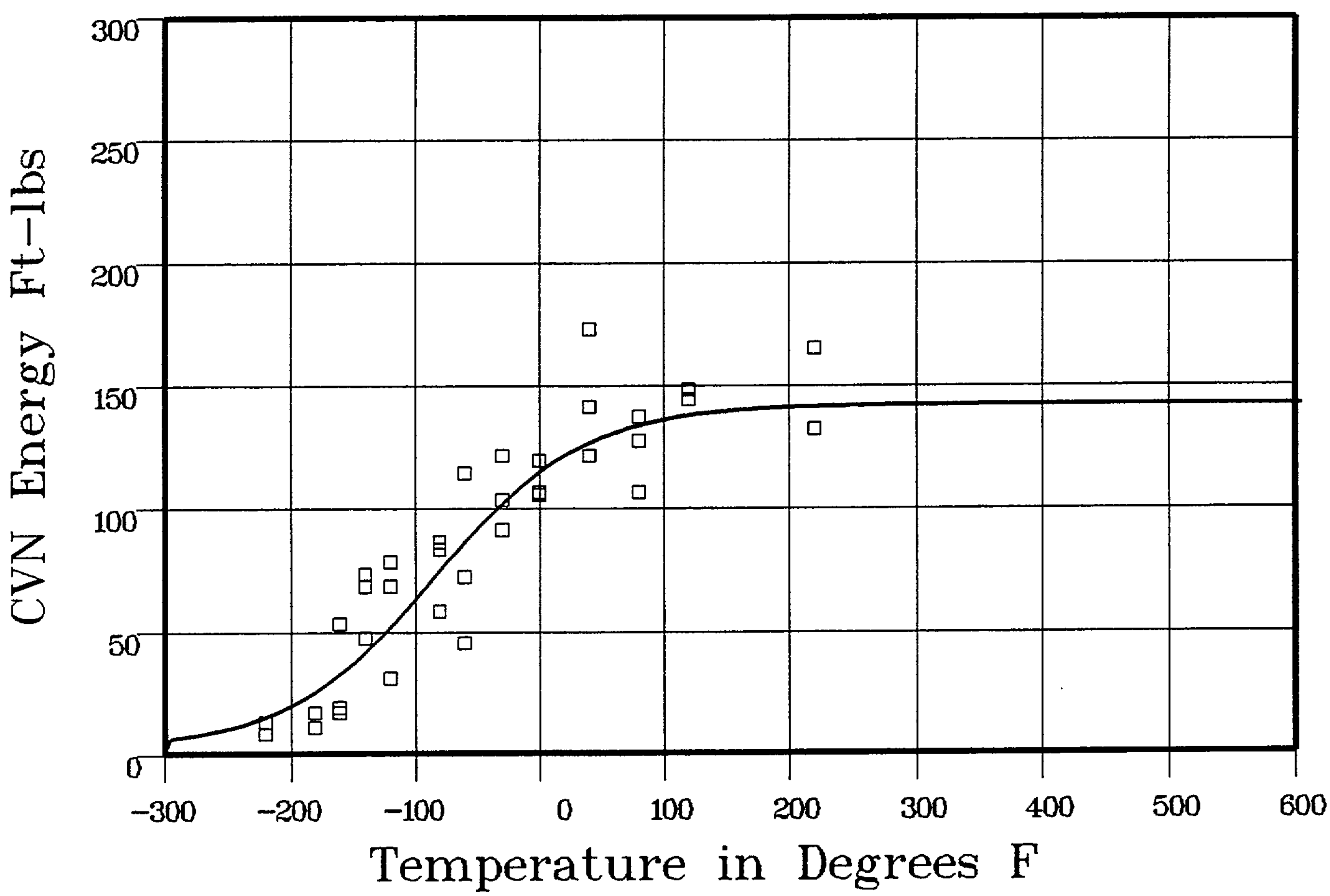
A = 72.09	B = 69.9	C = 119.5	T0 = -88.59

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

Upper Shelf Energy: 142 Fixed Temp. at 30 ft-lbs: -171.8 Temp. at 50 ft-lbs: -127.7 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: C4039-2 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: ML3 Cap.: UNIRR Material: HEAT AFFD ZONE Ori.: Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-220	13	16.15	-3.15
-220	8	16.15	-8.15
-180	17	27.08	-10.08
-180	11	27.08	-16.08
-160	19	34.68	-15.68
-160	53	34.68	18.31
-160	17	34.68	-17.68
-140	73	43.75	29.24
-140	47	43.75	3.24

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

UNIRRADIATED

Page 2

Material: HEAT AFFD ZONE   Heat Number: C4039-2   Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-140	68	43.75	24.24
-120	31	54.14	-23.14
-120	78	54.14	23.85
-120	68	54.14	13.85
-80	86	77.11	8.88
-80	58	77.11	-19.11
-80	83	77.11	5.88
-60	114	88.51	25.48
-60	72	88.51	-16.51
-60	45	88.51	-43.51
-30	121	103.86	17.13
-30	91	103.86	-12.86
-30	103	103.86	-.86
0	119	116.13	2.86
0	105	116.13	-11.13
0	106	116.13	-10.13
40	141	127.44	13.55
40	121	127.44	-6.44
40	173	127.44	45.55
80	106	134.14	-28.14
80	137	134.14	2.85
80	127	134.14	-7.14
120	144	137.86	6.13
120	148	137.86	10.13
220	132	141.2	-9.2
220	165	141.2	23.79

SUM of RESIDUALS = 15.95

CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:51:50 on 04-04-2000

Page 1

Coefficients of Curve 2

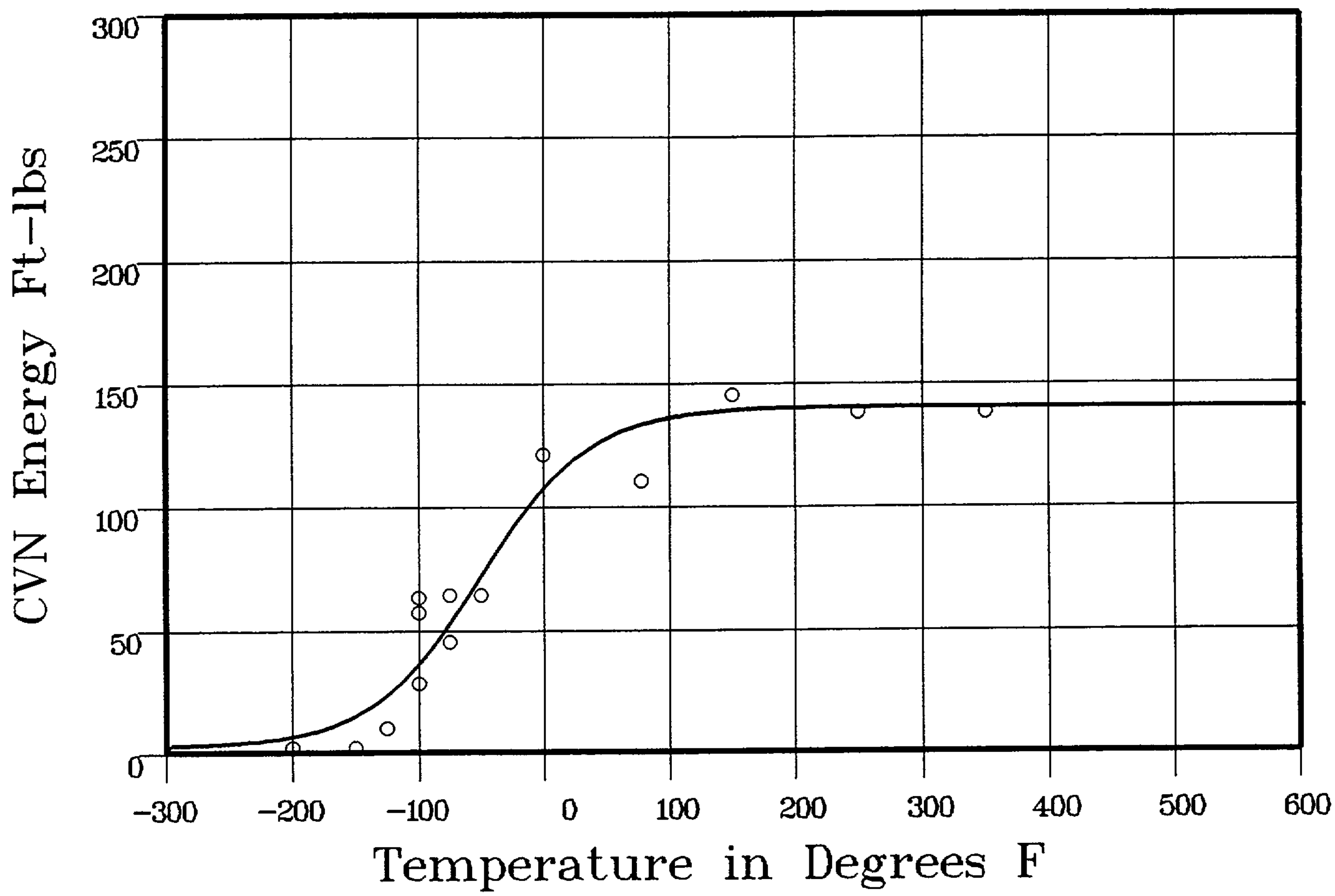
A = 71.09	B = 68.9	C = 87.36	T0 = -55.31

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

Upper Shelf Energy: 140 Fixed Temp. at 30 ft-lbs: -115.3 Temp. at 50 ft-lbs: -82.9 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: C4039-2 Orientation:

Capsule: U Total Fluence: 4.49E18



Data Set(s) Plotted

Plant: ML3 Cap.: U Material: HEAT AFFD ZONE Ori.: Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-200	2	7.04	-5.04
-150	2	16.35	-14.35
-125	10	25.43	-15.43
-100	28	38.63	-10.63
-100	63	38.63	24.36
-100	57	38.63	18.36
-75	45	55.83	-10.83
-75	64	55.83	8.16

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

CAPSULE U

Page 2

Material: HEAT AFFD ZONE   Heat Number: C4039-2   Orientation:

Capsule: U   Total Fluence: 4.49E18

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-50	64	75.28	-11.28
0	121	109.69	11.3
78	110	133.78	-23.78
150	145	138.75	6.24
250	138	139.87	-1.87
350	138	139.98	-1.98

SUM of RESIDUALS = -26.79

CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:51:50 on 04-04-2000

Page 1

Coefficients of Curve 3

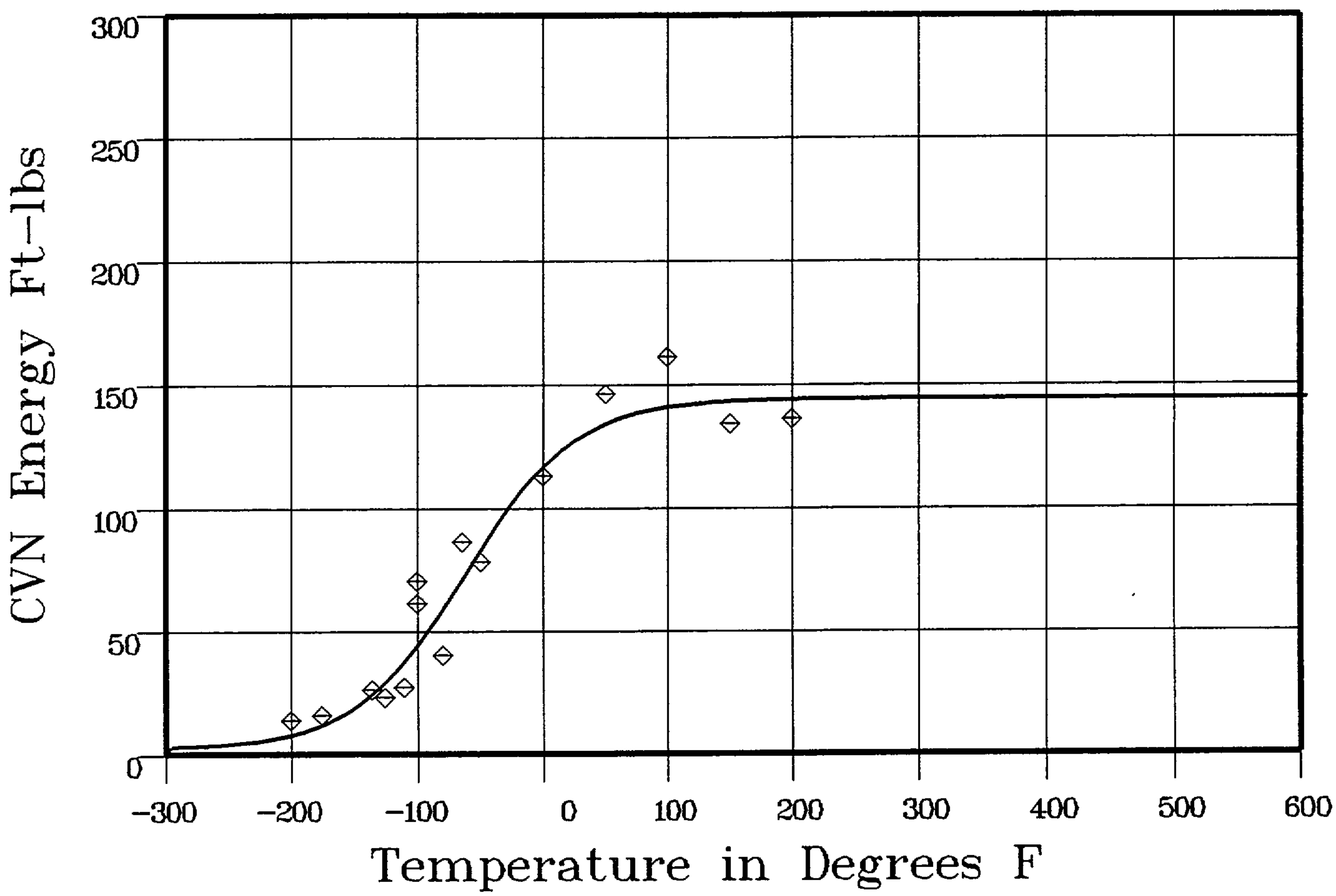
A = 73.09	B = 70.9	C = 86.92	T0 = -66.56

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

Upper Shelf Energy: 144 Fixed   Temp. at 30 ft-lbs: -127.8   Temp. at 50 ft-lbs: -95.9   Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE   Heat Number: C4039-2   Orientation:

Capsule: X   Total Fluence: 2.21E19



Data Set(s) Plotted

Plant: ML3   Cap.: X   Material: HEAT AFFD ZONE   Ori.:   Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-200	14	8.48	5.51
-175	16	13	2.99
-135	26	26.52	-.52
-125	23	31.51	-8.51
-110	27	40.35	-13.35
-100	61	47.09	13.9
-100	70	47.09	22.9
-80	40	62.22	-22.22

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

CAPSULE X

Page 2

Material: HEAT AFFD ZONE   Heat Number: C4039-2   Orientation:

Capsule: X   Total Fluence: 2.21E19

Charpy V-Notch Data (Continued)

Temperature	Input CVN Energy	Computed CVN Energy	Differential
-65	86	74.37	11.62
-50	78	86.44	-8.44
0	113	118.79	-5.79
50	146	134.91	11.08
100	161	140.99	20
150	134	143.03	-9.03
200	136	143.69	-7.69

SUM of RESIDUALS = 12.43

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:59:43 on 04-04-2000

Page 1

Coefficients of Curve 1

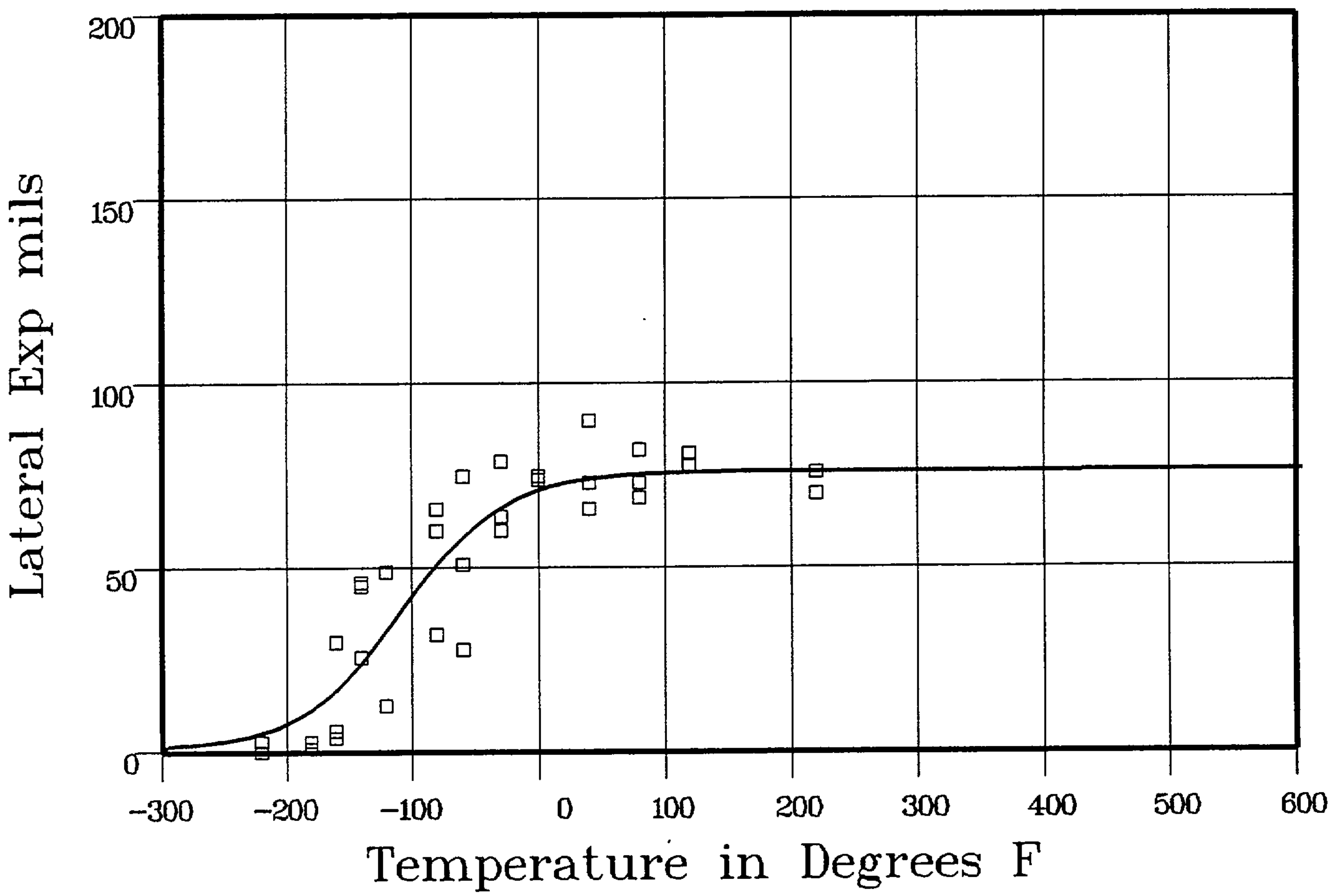
A = 38.6	B = 37.6	C = 81.66	T0 = -112.5

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

Upper Shelf L.E.: 76.2 Temperature at L.E. 35: -120.3 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: C4039-2 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: ML3 Cap.: UNIRR Material: HEAT AFFD ZONE Ori.: Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-220	3	6.04	-3.04
-220	0	6.04	-6.04
-180	3	13.08	-10.08
-180	1	13.08	-12.08
-160	6	18.9	-12.9
-160	30	18.9	11.09
-160	4	18.9	-14.9
-140	46	26.39	19.6
-140	26	26.39	-.39

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

UNIRRADIATED

Page 2

Material: HEAT AFFD ZONE   Heat Number: C4039-2   Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-140	45	26.39	18.6
-120	13	35.15	-22.15
-120	49	35.15	13.84
-120	49	35.15	13.84
-80	66	52.82	13.17
-80	32	52.82	-20.82
-80	60	52.82	7.17
-60	75	59.91	15.08
-60	51	59.91	-8.91
-60	28	59.91	-31.91
-30	79	67.39	11.6
-30	64	67.39	-3.39
-30	60	67.39	-7.39
0	74	71.7	2.29
0	75	71.7	3.29
0	74	71.7	2.29
40	73	74.44	-1.44
40	66	74.44	-8.44
40	90	74.44	15.55
80	73	75.53	-2.53
80	82	75.53	6.46
80	69	75.53	-6.53
120	81	75.94	5.05
120	78	75.94	2.05
220	70	76.18	-6.18
220	76	76.18	-.18

SUM of RESIDUALS = -18.35

CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:59:43 on 04-04-2000

Page 1

Coefficients of Curve 2

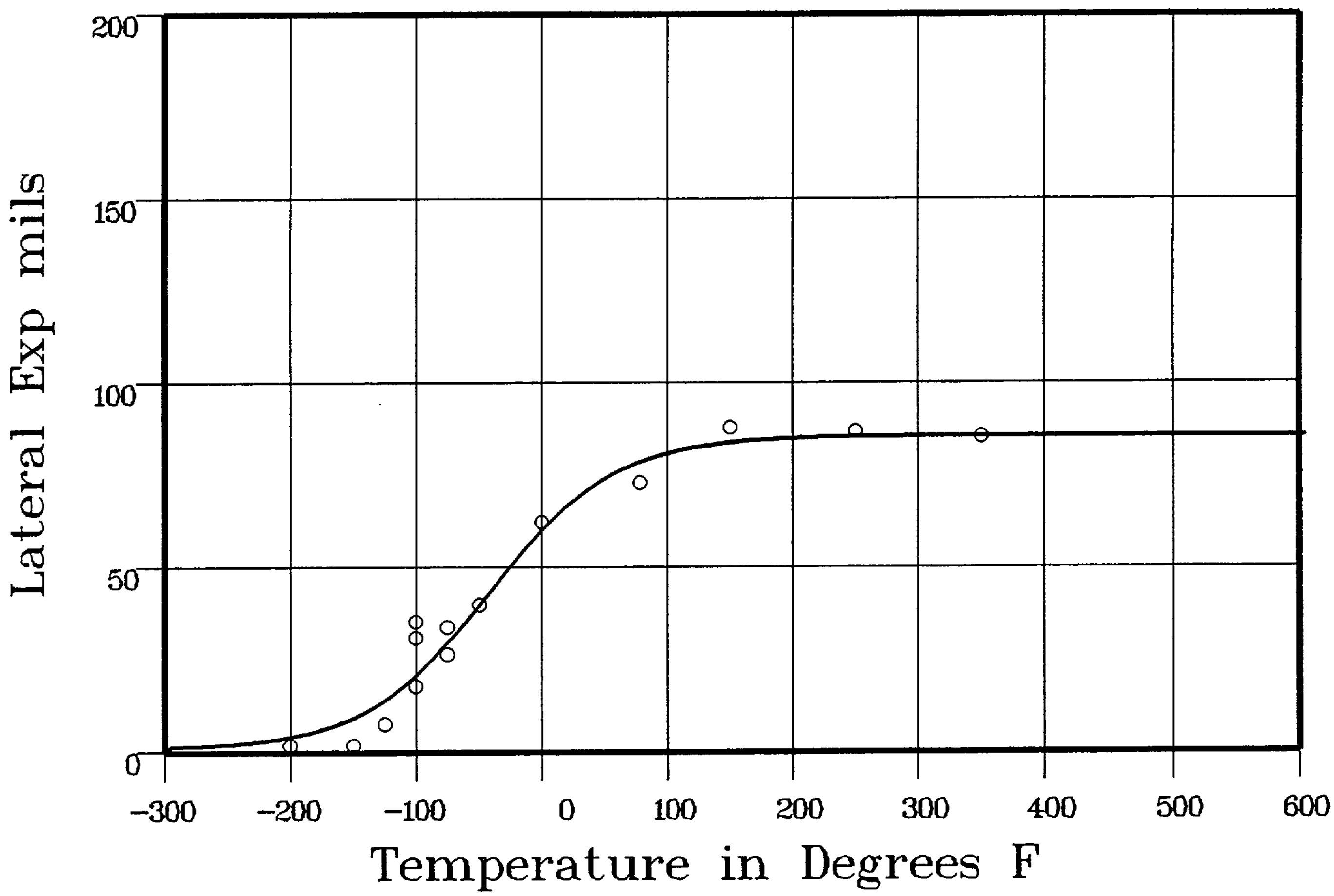
A = 43.29	B = 42.29	C = 98.99	T0 = -46.5

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

Upper Shelf L.E.: 85.59 Temperature at L.E. 35: -66.1 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFF'D ZONE Heat Number: C4039-2 Orientation:

Capsule: U Total Fluence: 4.49E18



Data Set(s) Plotted

Plant: ML3 Cap.: U Material: HEAT AFF'D ZONE Ori.: Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-200	2	4.64	-2.64
-150	2	10.3	-8.3
-125	8	15.37	-7.37
-100	18	22.43	-4.43
-100	35.5	22.43	13.06
-100	31	22.43	8.56
-75	26.5	31.44	-4.94
-75	34	31.44	2.55

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

CAPSULE U

Page 2

Material: HEAT AFFD ZONE   Heat Number: C4039-2   Orientation:

Capsule: U   Total Fluence: 4.49E18

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-50	40	41.8	-1.8
0	62.5	61.82	.67
78	73	79.26	-6.26
150	88	84.02	3.97
250	87	85.38	1.61
350	85.5	85.56	-.06

SUM of RESIDUALS = -5.38

CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:59:43 on 04-04-2000

Page 1

Coefficients of Curve 3

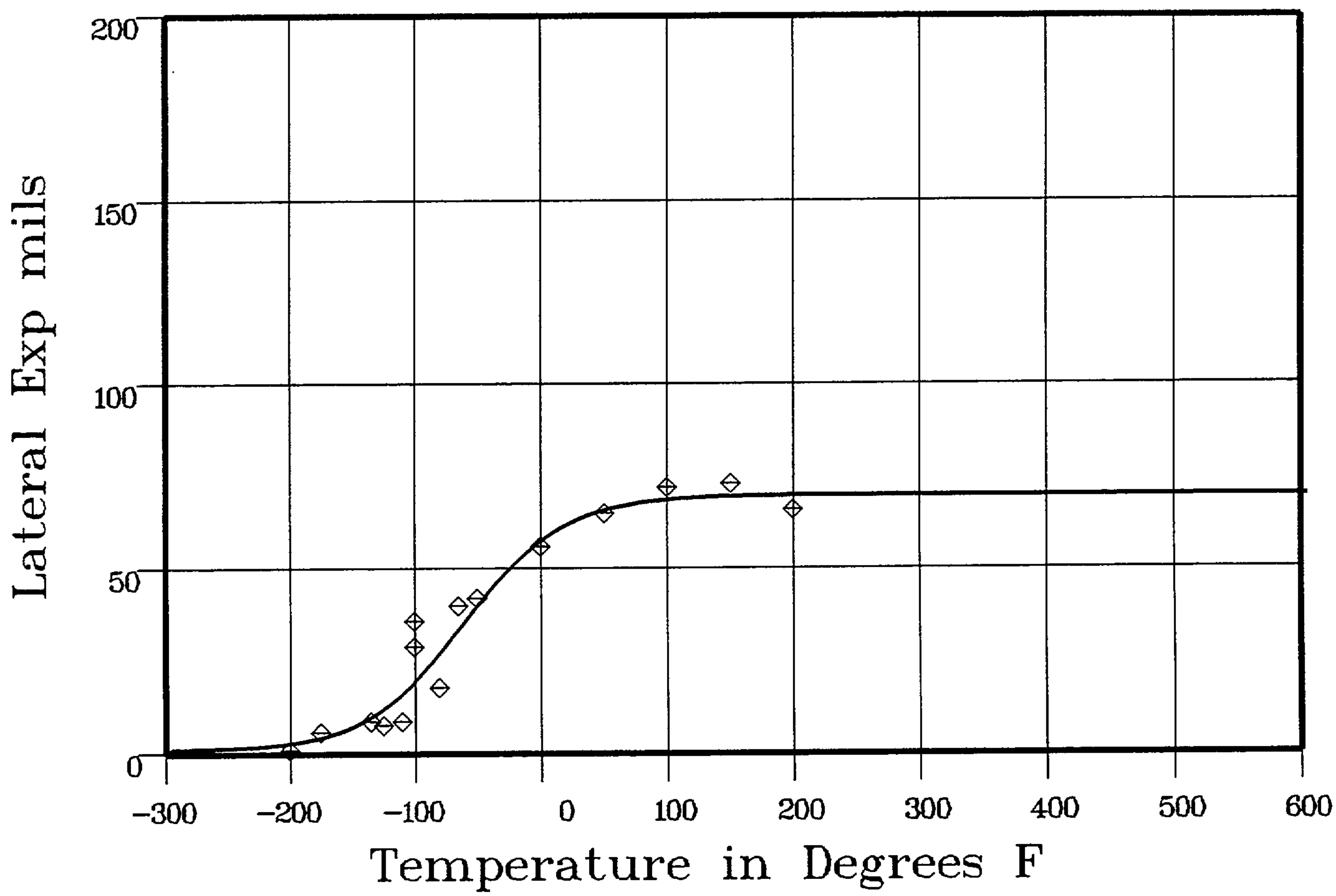
A = 35.45	B = 34.45	C = 79.38	T0 = -65.11

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

Upper Shelf L.E.: 69.91 Temperature at L.E. 35: -66.1 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: C4039-2 Orientation:

Capsule: X Total Fluence: 2.21E19



Data Set(s) Plotted

Plant: ML3 Cap.: X Material: HEAT AFFD ZONE Ori.: Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-200	1	3.22	-2.22
-175	6	5.06	.93
-135	9	11.1	-2.1
-125	8	13.48	-5.48
-110	9	17.81	-8.81
-100	29	21.21	7.78
-100	36	21.21	14.78
-80	18	29.06	-11.06

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

CAPSULE X

Page 2

Material: HEAT AFFD ZONE   Heat Number: C4039-2   Orientation:

Capsule: X   Total Fluence: 2.21E19

Charpy V-Notch Data (Continued)

Temperature	Input Lateral Expansion	Computed L.E.	Differential
-65	40	35.5	4.49
-50	42	41.93	.06
0	56	58.72	-2.72
50	65	66.31	-1.31
100	72	68.85	3.14
150	73	69.6	3.39
200	66	69.82	-3.82

SUM of RESIDUALS = -2.97

UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:23:17 on 04-05-2000
Page 1
Coefficients of Curve 1

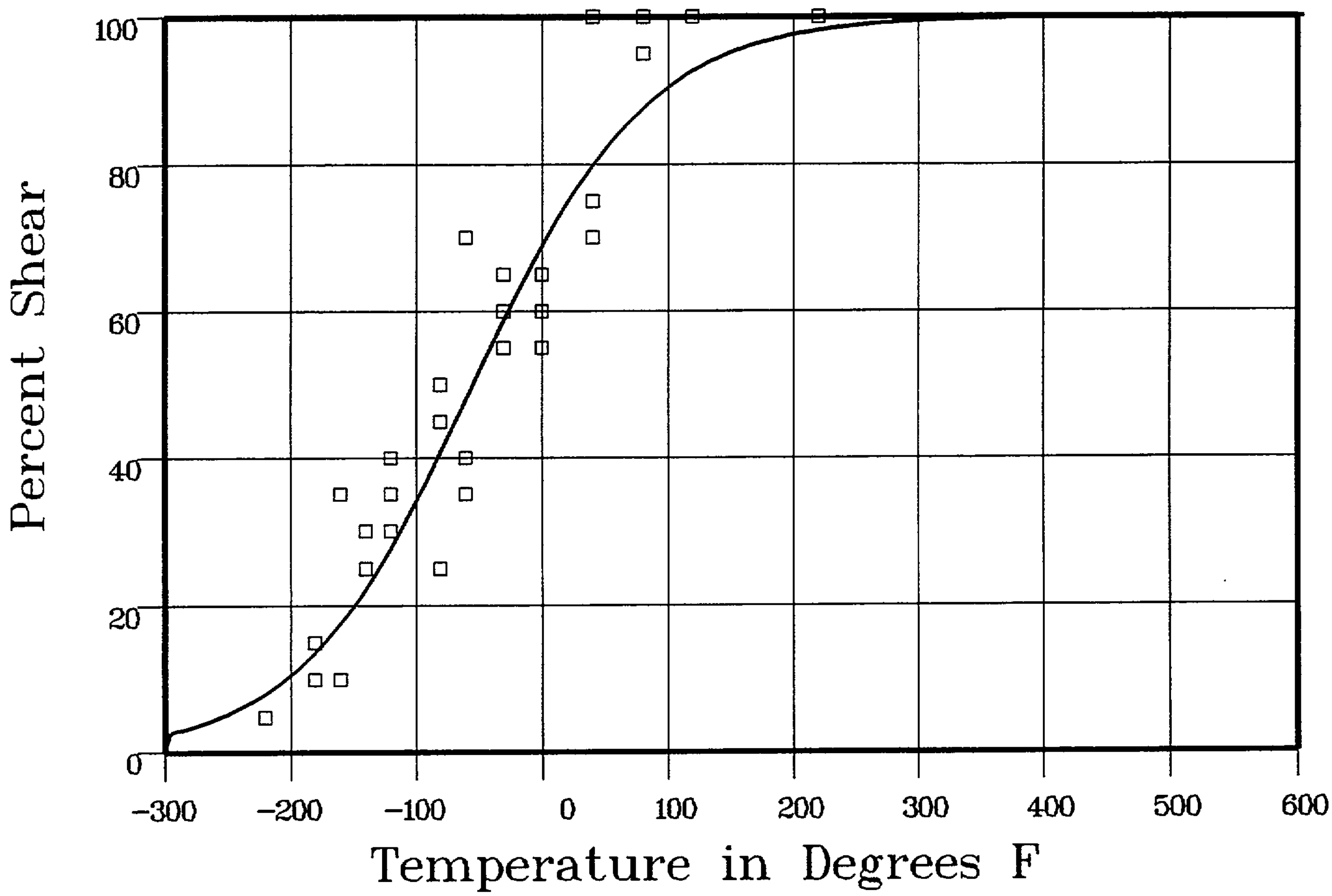
A = 50	B = 50	C = 136.92	T0 = -59.06

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

Temperature at 50% Shear: -59

Material: HEAT AFFD ZONE Heat Number: C4039-2 Orientation:

Capsule: UNIRR Total Fluence:



Data Set(s) Plotted

Plant: ML3 Cap.: UNIRR Material: HEAT AFFD ZONE Ori.: Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-220	5	8.7	-3.7
-220	5	8.7	-3.7
-180	15	14.59	.4
-180	10	14.59	-4.59
-160	10	18.62	-8.62
-160	35	18.62	16.37
-160	10	18.62	-8.62
-140	30	23.46	6.53
-140	25	23.46	1.53

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

UNIRRADIATED

Material: HEAT AFFD ZONE   Heat Number: C4039-2   Orientation:

Capsule: UNIRR   Total Fluence:

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-140	30	23.46	6.53
-120	30	29.1	.89
-120	40	29.1	10.89
-120	35	29.1	5.89
-80	50	42.41	7.58
-80	25	42.41	-17.41
-80	45	42.41	2.58
-60	70	49.65	20.34
-60	35	49.65	-14.65
-60	40	49.65	-9.65
-30	60	60.45	-.45
-30	55	60.45	-5.45
-30	65	60.45	4.54
0	65	70.32	-5.32
0	55	70.32	-15.32
0	60	70.32	-10.32
40	75	80.95	-5.95
40	70	80.95	-10.95
40	100	80.95	19.04
80	95	88.4	6.59
80	100	88.4	11.59
80	100	88.4	11.59
120	100	93.18	6.81
120	100	93.18	6.81
220	100	98.33	1.66
220	100	98.33	1.66

SUM of RESIDUALS = 25.14

CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:23:17 on 04-05-2000

Page 1

Coefficients of Curve 2

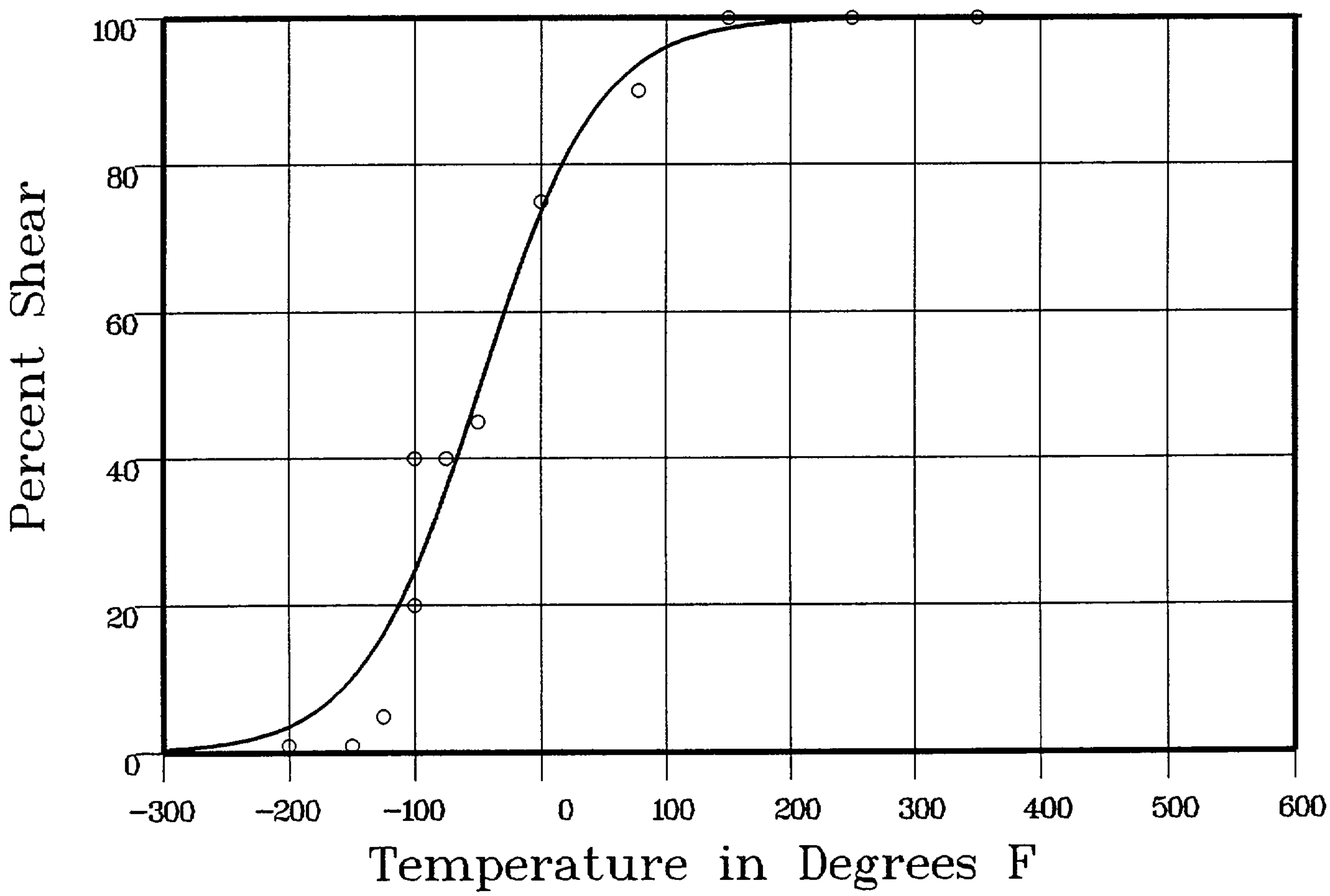
A = 50	B = 50	C = 93.34	T0 = -52.5

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

Temperature at 50% Shear: -52.5

Material: HEAT AFFD ZONE Heat Number: C4039-2 Orientation:

Capsule: U Total Fluence: 4.49E18



Data Set(s) Plotted

Plant: ML3 Cap.: U Material: HEAT AFFD ZONE Ori.: Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-200	1	4.06	-3.06
-150	1	11.01	-10.01
-125	5	17.46	-12.46
-100	20	26.54	-6.54
-100	40	26.54	13.45
-100	40	26.54	13.45
-75	40	38.17	1.82
-75	40	38.17	1.82

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

CAPSULE U

Page 2

Material: HEAT AFFD ZONE   Heat Number: C4039-2   Orientation:

Capsule: U   Total Fluence: 4.49E18

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50	45	51.33	-6.33
0	75	75.48	-.48
78	90	94.24	-4.24
150	100	98.71	1.28
250	100	99.84	.15
350	100	99.98	.01

SUM of RESIDUALS = -11.15

CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:23:17 on 04-05-2000

Page 1

Coefficients of Curve 3

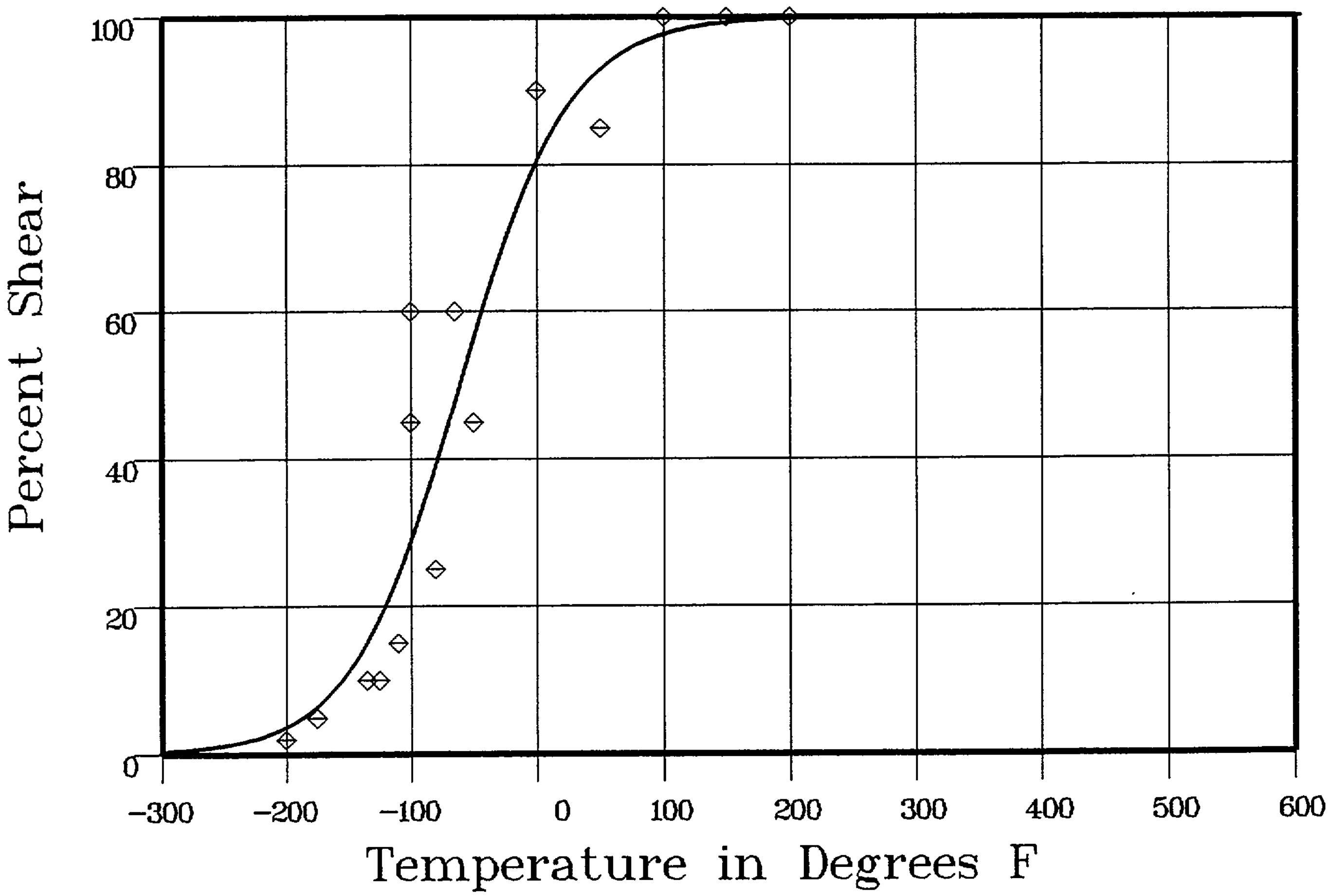
A = 50	B = 50	C = 85.95	T0 = -65.62

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

Temperature at 50% Shear: -65.6

Material: HEAT AFFD ZONE   Heat Number: C4039-2   Orientation:

Capsule: X   Total Fluence: 2.21E19



Data Set(s) Plotted

Plant: ML3   Cap.: X   Material: HEAT AFFD ZONE   Ori.:   Heat #: C4039-2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-200	2	4.2	-2.2
-175	5	7.27	-2.27
-135	10	16.59	-6.59
-125	10	20.07	-10.07
-110	15	26.25	-11.25
-100	60	31	28.99
-100	45	31	13.99
-80	25	41.71	-16.71

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

CAPSULE X

Page 2

Material: HEAT AFF'D ZONE   Heat Number: C4039-2   Orientation:

Capsule: X   Total Fluence: 2.21E19

Charpy V-Notch Data (Continued)

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-65	60	50.36	9.63
-50	45	58.99	-13.99
0	90	82.15	7.84
50	85	93.64	-8.64
100	100	97.92	2.07
150	100	99.34	.65
200	100	99.79	.2

SUM of RESIDUALS = -8.35

APPENDIX D

MILLSTONE UNIT 3 SURVEILLANCE PROGRAM CREDIBILITY ANALYSIS

INTRODUCTION:

Regulatory Guide 1.99, Revision 2 and 10 CFR Part 50.61, describe general procedures acceptable to the NRC staff for calculating the effects of neutron radiation embrittlement of the low-alloy steels currently used for light-water-cooled reactor vessels. Position C.2 of Regulatory Guide 1.99, Revision 2 and 10 CFR Part 50.61, describe the method for calculating the adjusted reference temperature and Charpy upper-shelf energy of reactor vessel beltline materials using surveillance capsule data. These methods can only be applied when two or more credible surveillance data sets become available from the reactor in question.

Per 10 CFR Part 50.61, Section c.2, "To verify that RT_{NDT} for each vessel beltline material is a bounding value for the specific reactor vessel, licensees shall consider plant-specific information that could affect the level of embrittlement. This information includes but is not limited to the reactor vessel operating temperature and any related surveillance program results." The Millstone Unit 3 beltline weld metal (Heat # 4P6052) is also contained in the Asco 2 and Seabrook 1 surveillance programs. Currently Westinghouse does not have the surveillance program results from Asco 2 or Seabrook 1. Hence, this credibility evaluation will be completed for the Millstone Unit 3 plate material only. The Millstone Unit 3 weld metal surveillance data will need to be evaluated once all the data is obtained from the Asco 2 and Seabrook 1 surveillance programs.

To date there has been two surveillance capsules removed from the Millstone Unit 3 reactor vessel. To use these surveillance data sets, they must be shown to be credible. In accordance with the discussion of Regulatory Guide 1.99, Revision 2 and/or 10 CFR Part 50.61, there are five requirements that must be met for the surveillance data to be judged credible.

The purpose of this evaluation is to apply the credibility requirements to the Millstone Unit 3 reactor vessel plate surveillance data and determine if the Millstone Unit 3 surveillance plate data is credible.

EVALUATION:

Criterion 1: Materials in the capsules should be those judged most likely to be controlling with regard to radiation embrittlement.

The beltline region of the reactor vessel is defined in Appendix G to 10 CFR Part 50, "Fracture Toughness Requirements", as follows:

> "the reactor vessel (shell material including welds, heat affected zones, and plates or forgings) that directly surrounds the effective height of the active core and adjacent regions of the reactor vessel that are predicted to experience sufficient neutron radiation damage to be considered in the selection of the most limiting material with regard to radiation damage."

The Millstone Unit 3 reactor vessel consists of the following beltline region materials:

- Intermediate Shell Plate B9805-1
- Intermediate Shell Plate B9805-2
- Intermediate Shell Plate B9805-3
- Lower Shell Plate B9820-1
- Lower Shell Plate B9820-2
- Lower Shell Plate B9820-3
- Intermediate Shell Longitudinal Weld Seams
- Intermediate to Lower Shell Circumferential Weld Seam
- Lower Shell Longitudinal Weld Seams

The Millstone Unit 3 surveillance program utilizes longitudinal and transverse test specimens from the intermediate shell plate B9805-1. The surveillance weld metal was fabricated with weld wire heat number 4P6052, Flux Type Linde 0091, Lot Number 0145.

All beltline weld seams were fabricated with the same weldment as the surveillance program weld metal. Hence, the surveillance weld metal is identical to the vessel weld metal fabricated with Heat # 4P6052, Linde 0091 flux, Lot # 0145. Thus, the weldment in the surveillance program meets this criteria.

At the time when the surveillance program material was selected it was believed that copper and phosphorus were the elements most important to embrittlement of reactor vessel steels.

The intermediate shell plate B9805-1 had an initial RT_{NDT} that was 20 to 60°F higher than the other beltline plate material initial RT_{NDT} values. In addition, all beltline plate materials had essentially the same copper and phosphorous content. Based on this evaluation of the beltline plate materials, intermediate shell plate B9805-1 was chosen for the surveillance program.

Based on the above discussion and the methodology in use at the time the program was developed, the Millstone Unit 3 surveillance plate material 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 and irradiated condition are presented Appendix C of this report.

Based on engineering judgment, the scatter in the data presented in these plots is small enough to permit the determination of the 30 ft-lb temperature and the upper shelf energy of the Millstone Unit 3 surveillance materials unambiguously. Hence, the Millstone Unit 3 surveillance program meets this criterion.

Criterion 3: When there are two or more sets of surveillance data from one reactor, the scatter of ΔRT_{NDT} values about a best-fit line drawn as described in Regulatory Position 2.1 normally should be less than 28°F for welds and 17°F for base metal. Even if the fluence range is large (two or more orders of magnitude), the scatter should not exceed twice those values. Even if the data fail this criterion for use in shift calculations, they may be credible for determining decrease in upper shelf energy if the upper shelf can be clearly determined, following the definition given in ASTM E185-82.

Note: The Millstone Unit 3 weld metal is also contained in the Asco 2 and Seabrook 1 surveillance programs. The data from these surveillance programs was not available at the time of this evaluation. Therefore, this criteria was not applied to the Millstone Unit 3 surveillance weld metal. If the weld metal surveillance data is to be used at some point in the future this crtieria we need to be addressed at that time. The functional form of the least squares method as described in Regulatory Position 2.1 will be utilized to determine a best-fit line for the plate data and to determine if the scatter of the measured plate ΔRT_{NDT} values about this best fit line is less than 17°F.

Following is the calculation of the best fit line as described in Regulatory Position 2.1 of Regulatory Guide 1.99, Revision 2.

TABLE D-1
Millstone Unit 3 Surveillance Capsule Data

Material	Capsule	F(1)	FF(2)	ΔRT_{NDT}(3)	FF x ΔRT_{NDT}	FF^2
Intermediate Shell Plate B9805-1 (Longitudinal)	U	0.449	0.777	25.79°F	20.04°F	0.604
	X	2.21	1.215	25.82°F	31.37°F	1.476
Intermediate Shell Plate B9805-1 (Transverse)	U	0.449	0.777	28.12°F	21.85°F	0.604
	X	2.21	1.215	25.77°F	31.31°F	1.476
				SUM	104.57°F	4.16
	$CF_{B9805\text{-}1} = \Sigma(FF \times \Delta RT_{NDT}) \div \Sigma(FF^2) = 104.57°F \div 4.16 = 25.1°F$					

(1) F = Calculated Fluence (10^{19} n/cm^2, E > 1.0 MeV)
(2) FF = Fluence Factor = $F^{(0.28 - 0.1 * \log F)}$
(3) These values are the measured values

TABLE D-2
Best Fit Evaluation for Millstone Unit 3 Surveillance Plate Material

Base Material	**CF (°F)**	**FF**	**Measured ΔRT_{NDT} (30ft-lb) (°F)**	**Best Fit(a) ΔRT_{NDT} (°F)**	**Scatter of ΔRT_{NDT} (°F)**	**< 17°F (Base Metals)**
Intermediate Shell Plate B9805-1 (Longitudinal)	25.1	0.777	25.79	19.5	-6.29	Yes
	25.1	1.215	25.82	30.5	4.68	Yes
Intermediate Shell Plate B9805-1 (Transverse)	25.1	0.777	28.12	19.5	-8.62	Yes
	25.1	1.215	25.77	30.5	4.73	Yes

NOTES:
(a) Best Fit Line Per Equation 2 of Reg. Guide 1.99 Rev. 2 Position 1.1.

Table D-2 indicates that the Plate B9805-1 data scatter is within the acceptable range for credible surveillance data.

Based on this discussion the Millstone Unit 3 Plate B9805-2 surveillance material meets this criteria.

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

The capsule specimens are located in the reactor between the core barrel and the vessel wall and are positioned opposite the center of the core. The test capsules are in baskets attached to the neutron pads. The location of the specimens with respect to the reactor vessel beltline provides assurance that the reactor vessel wall and the specimens experience equivalent operating conditions such that the temperatures will not differ by more than 25°F. Hence, this criteria is met.

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

The Millstone Unit 3 surveillance program does not contain correlation monitor material. Therefore, this criterion is not applicable to the Millstone Unit 3 surveillance program.

CONCLUSION:

Based on the preceding responses to all five criteria of Regulatory Guide 1.99, Revision 2, Section B 10 CFR 50.61, the Millstone Unit 3 surveillance Plate B9805-1 data is credible.