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WCAP - 15171
Revision 1

# Analysis of Capsule Z from the Alabama Power Company Joseph M. Farley Unit 2 Reactor Vessel Radiation Surveillance Program

Westinghouse Energy Systems

**WCAP-15171, Revision 1**

# Analysis of Capsule Z from the Alabama Power Company Joseph M. Farley Unit 2 Reactor Vessel Radiation Surveillance Program

**E. Terek**
**J. D. Perock**
**R. G. Lott**

**February 2000**

Approved: ______________________
D. M. Trombola, Manager
Mechanical Systems Integration

Approved: ______________________
C. H. Boyd, Manager
Equipment & Materials Technology

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

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# PREFACE

Revision 1:

The purpose of this revision is to re-evaluate the credibility evaluation of the intermediate shell plate B7212-1 surveillance program data without rounding the individual Charpy test data points. Contained in Appendix D is the revised credibility evaluation and this revised evaluation indicates that both the intermediate shell plate B7212-1 and weld metal surveillance data are credible. The balance of the report has been updated, as necessary, to reflect this re-evaluation.

This report has been technically reviewed and verified by:

Reviewer:

| | | |
|---|---|---|
| Sections 1 through 5, 7, 8, Appendices A, B and C | T. J. Laubham | |
| Section 6 | S. L. Anderson | S. L. Anderson |

## EXECUTIVE SUMMARY

The purpose of this report is to document the results of the testing of surveillance capsule Z from the J. M. Farley Unit 2 reactor vessel. Capsule Z was removed at 13.24 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 interface vessel fluence after 13.24 EFPY of plant operation was $1.75 \times 10^{19}$ n/cm$^2$. A brief summary of the Charpy V-notch testing results can be found in Section 1 while the detailed results can be found in Sections 5 and 6. These results indicate that the measured 30 ft-lb shifts are in god agreement with the Regulatory Guide 1.99, Revision 2, predictions. All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation. The updated capsule removal schedule can be found in Section 7 and indicates that the remaining surveillance capsules are standby. A surveillance program credibility evaluation can be found in Appendix D. This evaluation indicates that the J. M. Farley Unit 2 surveillance program material (intermediate shell plate B7212-1 and weld metal Heat # BOLA) test data is credible.

# 1 SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance capsule Z, the fourth capsule to be removed from the J. M. Farley Unit 2 reactor pressure vessel, led to the following conclusions:

- The Charpy V-notch data presented in WCAP-8956[1], WCAP-10425[2], WCAP-11438[3], and WCAP-12471[4] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1, which is a hyperbolic tangent curve-fitting program. Appendix B presents a comparison of the Charpy V-Notch test results for each capsule based on hand fit vs. hyperbolic tangent fit. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

- Fluence projections for future operation were based on the assumption that the exposure rates averaged over Cycle 9 through 12 (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 5.28 x $10^{19}$ n/cm$^2$ after 13.24 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel intermediate shell plate B7212-1 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major rolling direction (Longitudinal orientation), to 5.28 x $10^{19}$ n/cm$^2$ (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 200.24°F and a 50 ft-lb transition temperature increase of 198.87°F. This results in an irradiated 30 ft-lb transition temperature of 177.59°F and an irradiated 50 ft-lb transition temperature of 208.74°F for the longitudinal oriented specimens.

- Irradiation of the reactor vessel intermediate shell plate B7212-1 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major rolling direction of the plate (Transverse orientation), to 5.28 x $10^{19}$ n/cm$^2$ (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 195.5°F and a 50 ft-lb transition temperature increase of 197.45°F. This results in an irradiated 30 ft-lb transition temperature of 188.06°F and an irradiated 50 ft-lb transition temperature of 231.12°F for transverse oriented specimens.

- Irradiation of the weld metal Charpy specimens to 5.28 x $10^{19}$ n/cm$^2$ (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 10.0°F and a 50 ft-lb transition temperature increase of 14.2°F. This results in an irradiated 30 ft-lb transition temperature of -24.7°F and an irradiated 50 ft-lb transition temperature of -1.4°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 5.28 x $10^{19}$ n/cm$^2$ (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 142.6°F and a 50 ft-lb transition temperature increase of 113.6°F. This results in an irradiated 30 ft-lb transition temperature of -32.8°F and an irradiated 50 ft-lb transition temperature of -3.2°F.

- The average upper shelf energy of the intermediate shell plate B7212-1 (Longitudinal orientation) resulted in an average energy decrease of 36 ft-lb after irradiation to 5.28 x $10^{19}$ n/$cm^2$ (E> 1.0 MeV). This results in an irradiated average upper shelf energy of 94 ft-lb for the longitudinal oriented specimens.

- The average upper shelf energy of the intermediate shell plate B7212-1 (Transverse orientation) resulted in an average energy decrease of 27 ft-lb after irradiation to 5.28 x $10^{19}$ n/$cm^2$ (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 68 ft-lb for the transverse oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted an average energy decrease of 11 ft-lb after irradiation to 5.28 x $10^{19}$ n/$cm^2$ (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 133 ft-lb for the weld metal specimens.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in an average energy decrease of 32 ft-lb after irradiation to 5.28 x $10^{19}$ n/$cm^2$ (E> 1.0MeV). This results in an irradiated average upper shelf energy of 126 ft-lb for the weld HAZ metal.

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

  — The measured 30 ft-lb shift in transition temperature of the transverse oriented surveillance plate material contained in capsule X is in good agreement with the Regulatory Guide 1.99, Revision 2, prediction (i.e. within 5°F of the predicted 30 ft-lb shift). The measured 30 ft-lb shift in transition temperature values of all other surveillance results are less than the Regulatory Guide 1.99, Revision 2, predictions.

  — The measured percent decrease in upper shelf energy (USE) of the capsule U surveillance plate material is in good agreement with the Regulatory Guide 1.99, Revision 2, prediction (i.e. within 1 or 2 percent of the predicted USE). The measured percent decrease in upper shelf energy for all other surveillance materials is less than the Regulatory Guide 1.99, Revision 2, predictions.

- The calculated and best estimate end-of-license (36 EFPY) neutron fluence (E> 1.0 MeV) at the core midplane for the J. M. Farley Unit 2 reactor vessel using the Regulatory Guide 1.99, Revision 2 attenuation formula (ie. Equation # 3 in the guide) is as follows:

  Calculated: Vessel inner radius* = 4.28 x $10^{19}$ n/cm$^2$
  Vessel 1/4 thickness = 2.67 x $10^{19}$ n/cm$^2$
  Vessel 3/4 thickness = 1.04 x $10^{19}$ n/cm$^2$

  Best Estimate: Vessel inner radius* = 3.71 x $10^{19}$ n/cm$^2$
  Vessel 1/4 thickness = 2.31 x $10^{19}$ n/cm$^2$
  Vessel 3/4 thickness = 8.99 x $10^{18}$ n/cm$^2$

  *Clad/base metal interface

- The credibility evaluation of the J. M. Farley Unit 2 surveillance program presented in Appendix D of this report indicates that the surveillance results for intermediate shell plate B7212-1 and the surveillance results for the weld metal 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 (36 EFPY) as required by 10CFR50, Appendix G[6].

- The calculated and best estimate end-of-license (54 EFPY) neutron fluence (E> 1.0 MeV) at the core midplane for the J. M. Farley Unit 2 reactor vessel using the Regulatory Guide 1.99, Revision 2 attenuation formula (ie. Equation # 3 in the guide) is as follows:

  Calculated: Vessel inner radius* = 6.29 x $10^{19}$ n/cm$^2$
  Vessel 1/4 thickness = 3.92 x $10^{19}$ n/cm$^2$
  Vessel 3/4 thickness = 1.52 x $10^{19}$ n/cm$^2$

  Best Estimate: Vessel inner radius* = 5.44 x $10^{19}$ n/cm$^2$
  Vessel 1/4 thickness = 3.39 x $10^{19}$ n/cm$^2$
  Vessel 3/4 thickness = 1.32 x $10^{19}$ n/cm$^2$

  *Clad/base metal interface

- All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are expected to maintain an upper shelf energy greater than 50 ft-lb through a life extension of the vessel (i.e. through 54 EFPY) as required by 10CFR50, Appendix G[6].

# 2 INTRODUCTION

This report presents the results of the examination of Capsule Z, the fourth capsule removed from the reactor in the continuing surveillance program which monitors the effects of neutron irradiation on the Alabama Power Company J. M. Farley Unit 2 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the J. M. Farley Unit 2 reactor pressure vessel materials was designed and recommended by the Westinghouse Electric Company. A description of the surveillance program and the preirradiation mechanical properties of the reactor vessel materials is presented in WCAP-8956, "Alabama Power Company Joseph M. Farley Nuclear Plant Unit No. 2 Reactor Vessel Radiation Surveillance Program[1]. The surveillance program was planned to cover the 40-year design life of the reactor pressure vessel and was based on ASTM E185-73, "Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels"[7]. Capsule Z was removed from the reactor after 13.24 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-8956[1], WCAP-10425[2], WCAP-11438[3], and WCAP-12471[4] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1, which is a hyperbolic tangent curve-fitting program. Appendix B presents a comparison of the Charpy V-Notch test results for each capsule based on hand fit vs. hyperbolic tangent fit. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

This report summarizes the testing of and the post-irradiation data obtained from surveillance capsule Z removed from the Alabama Power Company J. M. Farley Unit 2 reactor vessel and discusses the analysis of the data.

# 3 BACKGROUND

The ability of the large steel pressure vessel containing the reactor core and its primary coolant to resist fracture constitutes an important factor in ensuring safety in the nuclear industry. The beltline region of the reactor pressure vessel is the most critical region of the vessel because it is subjected to significant fast neutron bombardment. The overall effects of fast neutron irradiation on the mechanical properties of low alloy, ferritic pressure vessel steels such as SA533 Grade B Class 1 plate (base material of the J. M. Farley Unit 2 reactor pressure vessel beltline) are well documented in the literature. Generally, low alloy ferritic materials show an increase in hardness and tensile properties and a decrease in ductility and toughness during high-energy irradiation.

A method for ensuring the integrity of reactor pressure vessels has been presented in "Fracture Toughness Criteria for Protection Against Failure," Appendix G to Section XI of the ASME Boiler and Pressure Vessel Code[8]. The method uses fracture mechanics concepts and is based on the reference nil-ductility transition temperature ($RT_{NDT}$).

$RT_{NDT}$ is defined as the greater of either the drop weight nil-ductility transition temperature (NDTT per ASTM E-208[9]) or the temperature 60°F less than the 50 ft-lb (and 35-mil lateral expansion) temperature as determined from Charpy specimens oriented perpendicular (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 ($K_{Ia}$ curve) which appears in Appendix G to the ASME Code[8]. The $K_{Ia}$ curve is a lower bound of dynamic, crack arrest, and static fracture toughness results obtained from several heats of pressure vessel steel. When a given material is indexed to the $K_{Ia}$ curve, allowable stress intensity factors can be obtained for this material as a function of temperature. Allowable operating limits can then be determined using these allowable stress intensity factors.

$RT_{NDT}$ and, in turn, the operating limits of nuclear power plants can be adjusted to account for the effects of radiation on the reactor vessel material properties. The changes in mechanical properties of a given reactor pressure vessel steel, due to irradiation, can be monitored by a reactor surveillance program, such as the J. M. Farley Unit 2 reactor vessel radiation surveillance program[1], in which a surveillance capsule is periodically removed from the operating nuclear reactor and the encapsulated specimens tested. The increase in the average Charpy V-notch 30 ft-lb temperature ($\Delta RT_{NDT}$) 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 + $\Delta RT_{NDT}$) is used to index the material to the $K_{Ia}$ curve and, in turn, to set operating limits for the nuclear power plant that take into account the effects of irradiation on the reactor vessel materials.

# 4 DESCRIPTION OF PROGRAM

Six surveillance capsules for monitoring the effects of neutron exposure on the J. M. Farley Unit 2 reactor pressure vessel core region (beltline) materials were inserted in the reactor vessel prior to initial plant start-up. The six capsules were positioned in the reactor vessel between the neutron pads and the vessel wall as shown in Figure 4-1. The vertical center of the capsules is opposite the vertical center of the core. The capsules contain specimens made from intermediate shell plate B7212-1 (Heat No. C7466-1), weld metal fabricated with ¼-inch E8018C3 weld filler wire heat number BOLA, which is identical to that used in the actual fabrication of the intermediate shell longitudinal weld seam 19-923B.

Capsule Z was removed after 13.24 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 B7212-1 and manual arc weld metal identical intermediate shell longitudinal weld seam 19-923B. In addition, this capsule contained Charpy V-notch specimens from the weld Heat-Affected-Zone (HAZ) of intermediate shell plate B7212-1.

Test material obtained from intermediate shell plate B7212-1 (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 metal were machined from a stress-relieved weldment joining intermediate shell plate B7212-1 and intermediate shell plate B7203-1. All heat-affected-zone specimens were obtained from the weld heat-affected-zone of intermediate shell plate B7212-1.

Charpy V-notch impact specimens from intermediate shell plate B7212-1 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 was machined such that the direction of crack propagation in the specimen was in the welding direction.

Tensile specimens from intermediate shell plate B7212-1 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 B7212-1 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 material is presented in Tables 4-1 through 4-2. The chemical analysis reported in Table 4-1 was obtained from unirradiated material used in the surveillance program[1] and from irradiated capsule W specimens[3].

Capsule Z 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) |
| 1.75% Ag, 0.75% Sn, 97.5% Pb | Melting Point: 590°F (310°C) |

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

**Table 4-1 Chemical Composition (wt %) of the J. M. Farley Unit 2 Reactor Vessel Surveillance Materials**

| Element | Plate B7212-1 | | Weld Metal | |
|---|---|---|---|---|
| | Unirradiated Data | Capsule W[b] | Unirradiated Data | Capsule W[b] |
| C | 0.21 | 0.224 | <0.086 | 0.139 |
| Mn | 1.30 | 1.38 | 0.95 | 0.91 |
| P | 0.018 | 0.008 | 0.004 | 0.006 |
| S | 0.016 | 0.016 | 0.014 | 0.013 |
| Si | 0.24 | 0.208 | 0.34 | 0.291 |
| Ni | 0.60 | 0.59 | 0.90 | 0.88 |
| Mo | 0.49 | 0.49 | 0.23 | 0.243 |
| Cr | 0.15[a] | 0.153 | <0.01 | 0.27 |
| Cu | 0.20 | 0.186 | 0.03 | 0.026 |
| Al | 0.04 | - - | 0.003 | - - |
| Co | 0.027 | 0.005 | 0.010 | 0.005 |
| V | 0.003[a] | <0.002 | 0.006 | 0.003 |
| Sn | 0.011[a] | - - | 0.002 | - - |
| $N_2$ | 0.006[a] | - - | 0.007 | - - |

Notes:

a. Chemical Analysis by Westinghouse.
b. Chemical Analysis by Westinghouse on irradiated Charpy specimens CL-34 and CW-41removed from Capsule-W.
c. This weld was fabricated by CE, Inc. by a manual metal arc process with ¼ inch E8018C3 weld filler wire heat number BOLA. This weld is identical to that used for intermediate shell weld seam 19-923B.

**Table 4-2 Heat Treatment of the J. M. Farley Unit 2 Reactor Vessel Surveillance Material[1]**

| Material | Temperature (°F) | Time (hrs.) | Coolant |
|---|---|---|---|
| Surveillance Program Test | Austenitizing: 1550/1650 | 4 | Water-quenched |
| Plate B7212-1 | Tempered: 1225 ± 25 | 4 | Air Cooled |
| | Stress Relief: 1150± 25 | 18 | Furnace Cooled to 600°F |
| Weldment | 1150 ± 25 | 13 | Furnace Cooled |

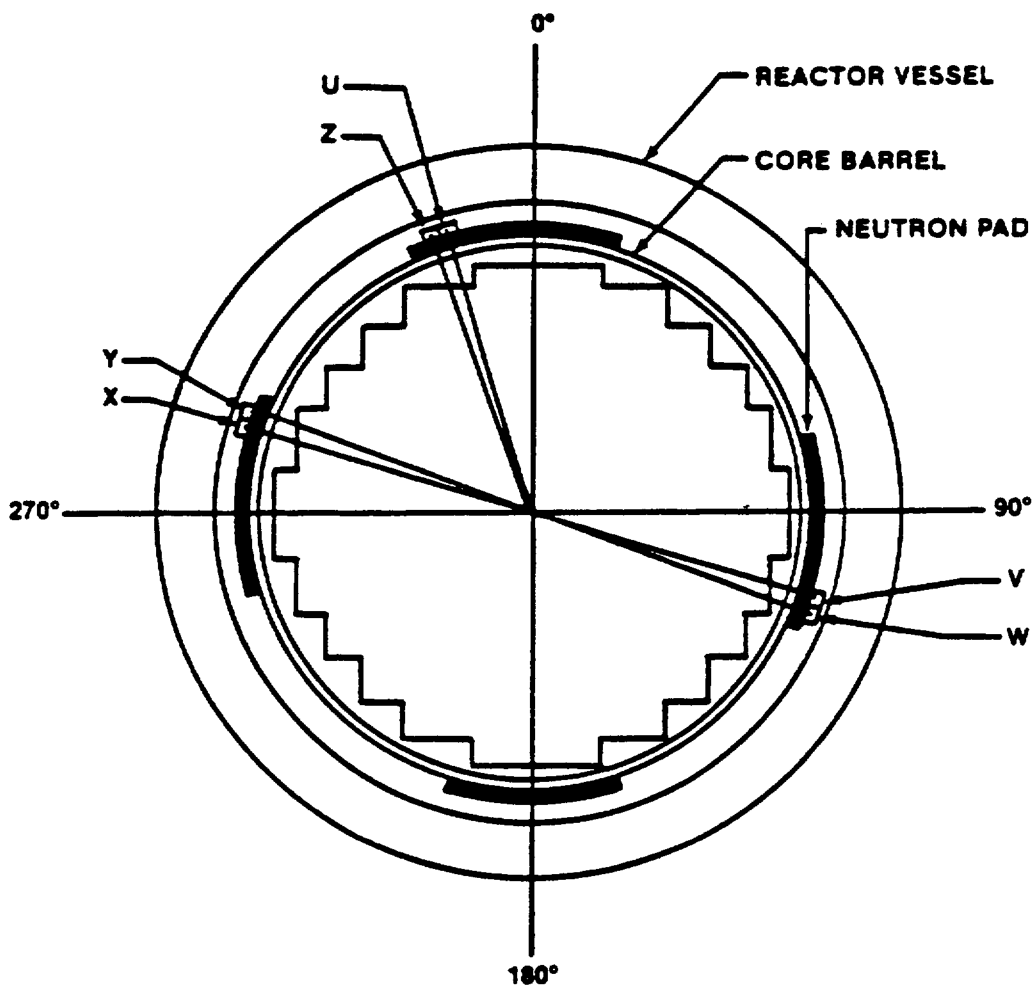



**Figure 4-1 Arrangement of Surveillance Capsules in the J. M. Farley Unit 2 Reactor Vessel**

**SPECIMEN CODE:**

**CT - PLATE B7212-1 (TRANSVERSE ORIENTATION)**

**CL - PLATE B7212-1 (LONGITUDINAL ORIENTATION)**

**CW - CORE REGION WELD METAL**

**CH - HEAT-AFFECTED-ZONE METAL**

**CAPSULE**

**Z**

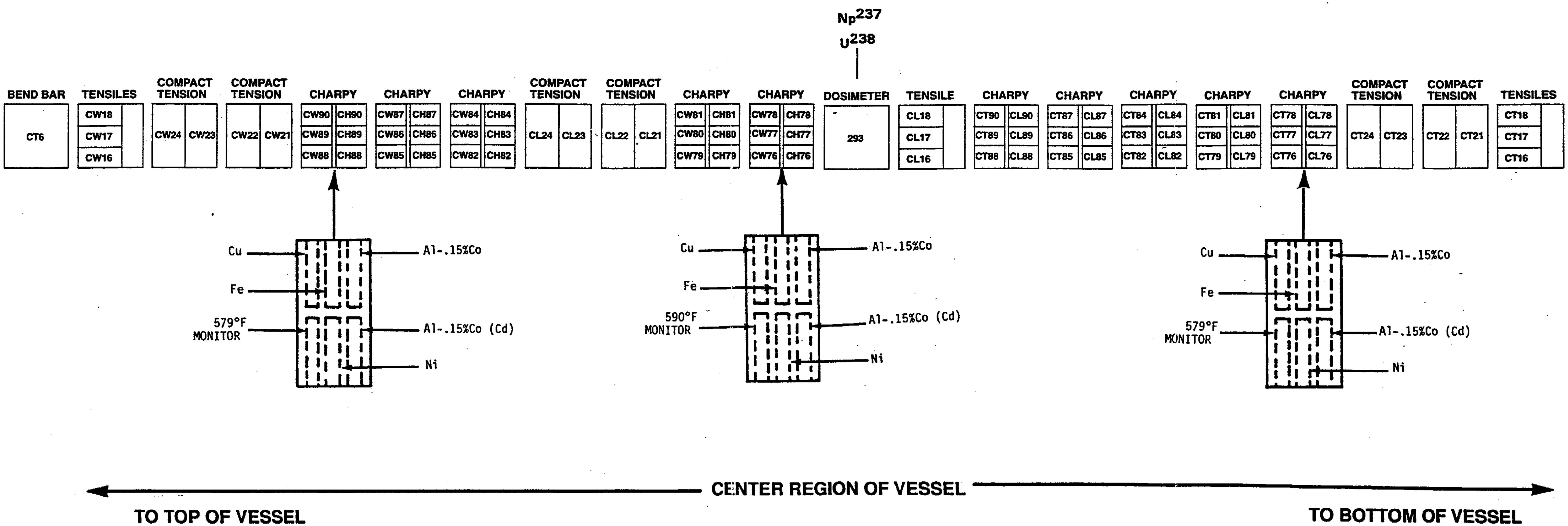



**Figure 4-2 Capsule Z Diagram Showing the Location of Specimens, Thermal Monitors, and Dosimeters**

# 5 TESTING OF SPECIMENS FROM CAPSULE Z

## 5.1 OVERVIEW

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

Upon receipt of the capsule at the hot cell laboratory, the specimens and spacer blocks were carefully removed, inspected for identification number, and checked against the master list in WCAP-8956[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 E23-93a[12] and RMF Procedure 8103, Revision 1, on a Tinius-Olsen Model 74, 358J machine. The tup (striker) of the Charpy impact test machine is instrumented with a GRC 930-I instrumentation system, feeding information into an IBM compatible computer. With this system, load-time and energy-time signals can be recorded in addition to the standard measurement of Charpy energy ($E_D$). From the load-time curve (Appendix A), the load of general yielding ($P_{GY}$), the time to general yielding ($t_{GY}$), the maximum load ($P_M$), and the time to maximum load ($t_M$) can be determined. Under some test conditions, a sharp drop in load indicative of fast fracture was observed. The load at which fast fracture was initiated is identified as the fast fracture load ($P_F$), and the load at which fast fracture terminated is identified as the arrest load ($P_A$). The energy at maximum load ($E_M$) was determined by comparing the energy-time record and the load-time record. The energy at maximum load is approximately equivalent to the energy required to initiate a crack in the specimen. Therefore, the propagation energy for the crack ($E_p$) is the difference between the total energy to fracture ($E_D$) and the energy at maximum load ($E_M$).

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

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

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 ($\phi$), notch root radius ($\rho$) and the type of loading (i.e., pure bending or three-point bending). In three-point bending, for a Charpy specimen in which $\phi$= 45° and $\rho$ = 0.010 inch, Equation 1 is valid with C = 1.21. Therefore, (for L = 4W),

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

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

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

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

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

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

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

Tensile tests were performed on a 20,000-pound Instron, split-console test machine (Model 1115) per ASTM Specification E8-93[14] and E21-92[15], and RMF Procedure 8102, Revision 1. All pull rods, grips, and pins were made of Inconel 718. The upper pull rod was connected through a universal joint to improve axiality of loading. The tests were conducted at a constant crosshead speed of 0.05 inches per minute throughout the test.

Extension measurements were made with a linear variable displacement transducer extensometer. The extensometer knife edges were spring-loaded to the specimen and operated through specimen failure. The extensometer gage length was 1.00 inch. The extensometer is rated as Class B-2 per ASTM E83-93[16].

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

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

## 5.2 CHARPY V-NOTCH IMPACT TEST RESULTS

The results of the Charpy V-notch impact tests performed on the various materials contained in capsule Z, which received a fluence of 5.28 x $10^{19}$ n/$cm^2$(E> 1.0 MeV) in 13.24 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 Z materials are summarized in Table 5-9. These results led to the following conclusions:

- Irradiation of the reactor vessel intermediate shell plate B7212-1 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major rolling direction (Longitudinal orientation), to 5.28 x $10^{19}$ n/$cm^2$ (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 200.24°F and a 50 ft-lb transition temperature increase of 198.87°F. This results in an irradiated 30 ft-lb transition temperature of 177.59°F and an irradiated 50 ft-lb transition temperature of 208.74°F for the longitudinal oriented specimens.

- Irradiation of the reactor vessel intermediate shell plate B7212-1 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major rolling direction of the plate (Transverse orientation), to 5.28 x $10^{19}$ n/$cm^2$ (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 195.5°F and a 50 ft-lb transition temperature increase of 197.45°F. This results in an irradiated 30 ft-lb transition temperature of 188.06°F and an irradiated 50 ft-lb transition temperature of 231.12°F for transverse oriented specimens.

- Irradiation of the weld metal Charpy specimens to 5.28 x $10^{19}$ n/$cm^2$ (E> 1.0MeV) resulted in a 30 ft-lb transition temperature increase of 10.0°F and a 50 ft-lb transition temperature increase of 14.2°F. This results in an irradiated 30 ft-lb transition temperature of -24.7°F and an irradiated 50 ft-lb transition temperature of -1.4°F.

- Irradiation of the weld Heat-Affected-Zone (HAZ) metal Charpy specimens to 5.28 x $10^{19}$ n/$cm^2$ (E> 1.0 MeV) resulted in a 30 ft-lb transition temperature increase of 142.6°F and a 50 ft-lb transition temperature increase of 113.6°F. This results in an irradiated 30 ft-lb transition temperature of -32.8°F and an irradiated 50 ft-lb transition temperature of -3.2°F.

- The average upper shelf energy of the intermediate shell plate B7212-1 (Longitudinal orientation) resulted in an average energy decrease of 36 ft-lb after irradiation to 5.28 x $10^{19}$ n/$cm^2$ (E > 1.0 MeV). This results in an irradiated average upper shelf energy of 94 ft-lb for the longitudinal oriented specimens.

- The average upper shelf energy of the intermediate shell plate B7212-1 (Transverse orientation) resulted in an average energy decrease of 27 ft-lb after irradiation to 5.28 x $10^{19}$ n/$cm^2$ (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 68 ft-lb for the transverse oriented specimens.

- The average upper shelf energy of the weld metal Charpy specimens resulted an average energy decrease of 11 ft-lb after irradiation to 5.28 x $10^{19}$ n/$cm^2$ (E> 1.0 MeV). Hence, this results in an irradiated average upper shelf energy of 133 ft-lb for the weld metal specimens.

- The average upper shelf energy of the weld HAZ metal Charpy specimens resulted in an average energy decrease of 32 ft-lb after irradiation to 5.28 x $10^{19}$ n/$cm^2$ (E> 1.0MeV). This results in an irradiated average upper shelf energy of 126 ft-lb for the weld HAZ metal.

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

  — The measured 30 ft-lb shift in transition temperature of the transverse oriented surveillance plate material contained in capsule X is in good agreement with the Regulatory Guide 1.99, Revision 2, prediction (i.e. within 5°F of the predicted 30 ft-lb shift). The measured 30 ft-lb shift in transition temperature values of all other surveillance results are less than the Regulatory Guide 1.99, Revision 2, predictions.

  — The measured percent decrease in upper shelf energy (USE) of the capsule U surveillance plate material is in good agreement with the Regulatory Guide 1.99, Revision 2, prediction (i.e. within 1 or 2 percent of the predicted USE). The measured percent decrease in upper shelf energy for all other 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 Z 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 (36 EFPY) as required by 10CFR50, Appendix G[6].

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

The Charpy V-notch data presented in WCAP-8956[1], WCAP-10425[2], WCAP-11438[3] and WCAP-12471[4] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a re-plot of all capsule data using CVGRAPH, Version 4.1. which is a hyperbolic tangent curve-fitting program. Appendix B presents a comparison of the Charpy V-Notch test results for each capsule based on hand fit vs. hyperbolic tangent fit. Appendix C presents the CVGRAPH, Version 4.1, Charpy V-notch plots and the program input data.

Appendix D of this report contains a credibility evaluation of the surveillance data from the J. M. Farley Unit 2 reactor vessel surveillance program. This evaluation indicates that the surveillance results for intermediate shell plate B7212-1 and the surveillance results for the weld metal are credible.

## 5.3 TENSILE TEST RESULTS

The results of the tensile tests performed on the various materials contained in capsule Z irradiated to 5.28 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 B7212-1 (longitudinal orientation) indicated that irradiation to 5.28 x $10^{19}$ n/cm$^2$ (E> 1.0 MeV) caused approximately a 25 ksi increase in the 0.2 percent offset yield strength and approximately a 15 to 20 ksi increase in the ultimate tensile strength when compared to unirradiated data[1] (Figure 5-17).

The results of the tensile tests performed on the intermediate shell plate B7212-1 (transverse orientation) indicated that irradiation to 5.28 x $10^{19}$ n/cm$^2$ (E> 1.0 MeV) caused an approximate increase of 30 ksi in the 0.2 percent offset yield strength and approximately a 20 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 5.28 x $10^{19}$ n/cm$^2$ (E> 1.0 MeV) caused approximately a 8 ksi increase in the 0.2 percent offset yield strength and approximately a 5 to 8 ksi increase in the ultimate tensile strength when compared to unirradiated data[1] (Figure 5-19).

The fractured tensile specimens for the intermediate shell plate B7212-1 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 5-25.

## 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 J. M. Farley Unit 2 Intermediate Shell Plate B7212-1 Irradiated to a Fluence of 5.28 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 | % |
| CL81 | 0 | -18 | 5 | 7 | 0 | 0.000 | 2 |
| CL80 | 72 | 22 | 21 | 28 | 11 | 0.279 | 5 |
| CL90 | 125 | 52 | 17 | 23 | 5 | 0.127 | 10 |
| CL79 | 150 | 66 | 20 | 27 | 12 | 0.305 | 20 |
| CL77 | 175 | 79 | 28 | 38 | 18 | 0.457 | 25 |
| CL84 | 190 | 88 | 39 | 53 | 27 | 0.686 | 35 |
| CL85 | 200 | 93 | 25 | 34 | 16 | 0.406 | 30 |
| CL86 | 210 | 99 | 60 | 81 | 40 | 1.016 | 60 |
| CL78 | 225 | 107 | 60 | 81 | 41 | 1.041 | 60 |
| CL83 | 250 | 121 | 74 | 100 | 52 | 1.321 | 80 |
| CL89 | 275 | 135 | 94 | 127 | 64 | 1.626 | 90 |
| CL87 | 300 | 149 | 90 | 122 | 63 | 1.600 | 100 |
| CL82 | 350 | 177 | 91 | 123 | 64 | 1.626 | 100 |
| CL76 | 400 | 204 | 96 | 130 | 67 | 1.702 | 100 |
| CL88 | 450 | 232 | 98 | 133 | 65 | 1.651 | 100 |

**Table 5-2 Charpy V-notch Data for the J. M. Farley Unit 2 Intermediate Shell Plate B7212-1 Irradiated to a Fluence of 5.28 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 | % |
| CT84 | 0 | -18 | 6 | 8 | 2 | 0.051 | 2 |
| CT87 | 72 | 22 | 4 | 5 | 0 | 0.000 | 10 |
| CT90 | 125 | 52 | 17 | 23 | 7 | 0.178 | 10 |
| CT83 | 150 | 66 | 22 | 30 | 15 | 0.381 | 15 |
| CT77 | 175 | 79 | 28 | 38 | 22 | 0.559 | 20 |
| CT80 | 190 | 88 | 31 | 42 | 22 | 0.559 | 35 |
| CT89 | 200 | 93 | 18 | 24 | 14 | 0.356 | 30 |
| CT88 | 200 | 93 | 25 | 34 | 19 | 0.483 | 35 |
| CT79 | 210 | 99 | 44 | 60 | 30 | 0.762 | 45 |
| CT82 | 225 | 107 | 61 | 83 | 44 | 1.118 | 80 |
| CT81 | 250 | 121 | 56 | 76 | 45 | 1.143 | 80 |
| CT86 | 275 | 135 | 64 | 87 | 43 | 1.092 | 100 |
| CT78 | 300 | 149 | 76 | 103 | 55 | 1.397 | 100 |
| CT76 | 350 | 177 | 69 | 94 | 52 | 1.321 | 100 |
| CT85 | 400 | 204 | 62 | 84 | 50 | 1.270 | 100 |

**Table 5-3 Charpy V-notch Data for the J. M. Farley Unit 2 Surveillance Weld Metal Irradiated to a Fluence of 5.28 x $10^{19}$ n/$cm^2$ (E> 1.0 MeV)**

| Sample | Temperature | | Impact Energy | | Lateral Expansion | | Shear |
|---|---|---|---|---|---|---|---|
| Number | F | C | ft-lbs | Joules | mils | mm | % |
| CW81 | -100 | -73 | 4 | 5 | 0 | 0.000 | 5 |
| CW88 | -60 | -51 | 7 | 9 | 1 | 0.025 | 10 |
| CW76 | -30 | -34 | 10 | 14 | 7 | 0.178 | 15 |
| CW78 | -6 | -21 | 13 | 18 | 10 | 0.254 | 20 |
| CW89 | 0 | -18 | 72 | 98 | 52 | 1.321 | 30 |
| CW90 | 5 | -15 | 86 | 117 | 58 | 1.473 | 40 |
| CW79 | 15 | -9 | 57 | 77 | 42 | 1.067 | 50 |
| CW85 | 15 | -9 | 77 | 104 | 55 | 1.397 | 45 |
| CW83 | 25 | -4 | 86 | 117 | 62 | 1.575 | 65 |
| CW87 | 30 | -1 | 91 | 123 | 63 | 1.600 | 75 |
| CW77 | 50 | 10 | 88 | 119 | 61 | 1.549 | 80 |
| CW86 | 100 | 38 | 105 | 142 | 78 | 1.981 | 90 |
| CW84 | 150 | 66 | 123 | 167 | 84 | 2.134 | 100 |
| CW80 | 195 | 91 | 151 | 205 | 81 | 2.057 | 100 |
| CW82 | 250 | 121 | 124 | 168 | 85 | 2.159 | 100 |

**Table 5-4 Charpy V-notch Data for the J. M. Farley Unit 2 Heat Affected Zone Material Irradiated to a Fluence of 5.28 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 | % |
| CH90 | -100 | -73 | 8 | 11 | 2 | 0.051 | 5 |
| CH82 | -60 | -51 | 16 | 22 | 5 | 0.127 | 20 |
| CH77 | -30 | -34 | 20 | 27 | 9 | 0.229 | 15 |
| CH83 | -20 | -29 | 68 | 92 | 46 | 1.168 | 40 |
| CH86 | -15 | -26 | 68 | 92 | 40 | 1.016 | 45 |
| CH85 | -10 | -23 | 8 | 11 | 4 | 0.102 | 25 |
| CH76 | -10 | -23 | 42 | 57 | 26 | 0.660 | 20 |
| CH78 | 0 | -18 | 44 | 60 | 25 | 0.635 | 25 |
| CH87 | 0 | -18 | 70 | 95 | 43 | 1.092 | 50 |
| CH80 | 10 | -12 | 7 | 9 | 1 | 0.025 | 10 |
| CH89 | 25 | -4 | 130 | 176 | 90 | 2.286 | 100 |
| CH88 | 50 | 10 | 68 | 92 | 40 | 1.016 | 55 |
| CH84 | 100 | 38 | 122 | 165 | 87 | 2.210 | 100 |
| CH79 | 150 | 66 | 115 | 156 | 88 | 2.235 | 100 |
| CH81 | 195 | 91 | 140 | 190 | 79 | 2.007 | 100 |

**Table 5-5 Instrumented Charpy Impact Test Results for the J. M. Farley Unit 2 Intermediate Shell Plate B7212-1 Irradiated to a Fluence of 5.28 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$^2$) | | | 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. $E_p/A$ | | | | | | | | |
| CL81 | 0 | 5 | 40 | 22 | 19 | 2661 | 0.13 | 2669 | 0.14 | 2661 | 0 | 89 | 89 |
| CL80 | 72 | 21 | 169 | 74 | 95 | 4267 | 0.17 | 4656 | 0.22 | 4551 | 0 | 142 | 149 |
| CL90 | 125 | 17 | 137 | 74 | 62 | 4137 | 0.17 | 4518 | 0.23 | 4434 | 0 | 138 | 144 |
| CL79 | 150 | 20 | 161 | 72 | 89 | 3920 | 0.17 | 4302 | 0.23 | 4229 | 0 | 131 | 137 |
| CL77 | 175 | 28 | 225 | 156 | 70 | 3936 | 0.17 | 4453 | 0.38 | 4418 | 60 | 131 | 140 |
| CL84 | 190 | 39 | 314 | 237 | 77 | 3872 | 0.17 | 4634 | 0.52 | 4617 | 200 | 129 | 142 |
| CL85 | 200 | 25 | 201 | 69 | 132 | 3896 | 0.17 | 4255 | 0.22 | 4106 | 448 | 130 | 136 |
| CL86 | 210 | 60 | 483 | 242 | 241 | 3799 | 0.17 | 4745 | 0.52 | 4523 | 1753 | 127 | 142 |
| CL78 | 225 | 60 | 483 | 233 | 250 | 3912 | 0.17 | 4723 | 0.50 | 4535 | 2033 | 130 | 144 |
| CL83 | 250 | 74 | 596 | 227 | 369 | 3663 | 0.17 | 4582 | 0.51 | 3469 | 1477 | 122 | 137 |
| CL89 | 275 | 94 | 757 | 234 | 523 | 3721 | 0.17 | 4702 | 0.52 | 2871 | 2460 | 124 | 140 |
| CL87 | 300 | 90 | 725 | 224 | 501 | 3839 | 0.17 | 4629 | 0.50 | N/A | N/A | 128 | 141 |
| CL82 | 350 | 91 | 733 | 228 | 504 | 3778 | 0.17 | 4549 | 0.51 | N/A | N/A | 126 | 139 |
| CL76 | 400 | 96 | 773 | 233 | 540 | 3659 | 0.17 | 4497 | 0.53 | N/A | N/A | 122 | 136 |
| CL88 | 450 | 98 | 789 | 222 | 567 | 3697 | 0.17 | 4468 | 0.51 | N/A | N/A | 123 | 136 |

**Table 5-6 Instrumented Charpy Impact Test Results for the J. M. Farley Unit 2 Intermediate Shell Plate B7212-1 Irradiated to a Fluence of 5.28 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) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CT84 | 0 | 6 | 48 | 26 | 22 | 3015 | 0.15 | 3027 | 0.14 | 3015 | 0 | 100 | 101 |
| CT87 | 72 | 4 | 32 | 12 | 21 | 1505 | 0.11 | 1511 | 0.12 | 1505 | 75 | 50 | 50 |
| CT90 | 125 | 17 | 137 | 71 | 66 | 3990 | 0.17 | 4355 | 0.23 | 4253 | 0 | 133 | 139 |
| CT83 | 150 | 22 | 177 | 70 | 107 | 3934 | 0.17 | 4283 | 0.23 | 4189 | 69 | 131 | 137 |
| CT77 | 175 | 28 | 225 | 153 | 72 | 3860 | 0.17 | 4329 | 0.38 | 4310 | 252 | 129 | 136 |
| CT80 | 190 | 31 | 250 | 137 | 113 | 3898 | 0.17 | 4281 | 0.34 | 4227 | 991 | 130 | 136 |
| CT88 | 200 | 18 | 145 | 74 | 71 | 3780 | 0.17 | 4190 | 0.24 | 3997 | 974 | 126 | 133 |
| CT89 | 200 | 25 | 201 | 55 | 147 | 3791 | 0.17 | 4052 | 0.20 | 4043 | 832 | 126 | 131 |
| CT79 | 210 | 44 | 354 | 202 | 152 | 3798 | 0.17 | 4426 | 0.47 | 4241 | 1690 | 126 | 137 |
| CT82 | 225 | 61 | 491 | 226 | 265 | 3940 | 0.17 | 4719 | 0.49 | 4440 | 2393 | 131 | 144 |
| CT81 | 250 | 56 | 451 | 168 | 283 | 3370 | 0.17 | 4152 | 0.43 | 3291 | 2236 | 112 | 125 |
| CT86 | 275 | 64 | 515 | 180 | 335 | 3884 | 0.17 | 4425 | 0.42 | N/A | N/A | 129 | 138 |
| CT78 | 300 | 76 | 612 | 209 | 403 | 3802 | 0.17 | 4529 | 0.48 | N/A | N/A | 127 | 139 |
| CT76 | 350 | 69 | 556 | 200 | 355 | 3699 | 0.17 | 4412 | 0.47 | N/A | N/A | 123 | 135 |
| CT85 | 400 | 62 | 499 | 162 | 337 | 3682 | 0.17 | 4284 | 0.40 | N/A | N/A | 123 | 133 |

**Table 5-7 Instrumented Charpy Impact Test Results for the J. M. Farley Unit 2 Surveillance Weld Metal Irradiated to a Fluence of 5.28 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) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CW81 | -100 | 4 | 32 | 17 | 15 | 2153 | 0.12 | 2161 | 0.13 | 2153 | 0 | 72 | 72 |
| CW88 | -60 | 7 | 56 | 26 | 30 | 3036 | 0.15 | 3036 | 0.15 | 3036 | 0 | 101 | 101 |
| CW76 | -30 | 10 | 7 | 15 | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| CW78 | -6 | 13 | 105 | 33 | 72 | 3315 | 0.16 | 3315 | 0.16 | 3315 | 622 | 110 | 110 |
| CW89 | 0 | 72 | 580 | 311 | 269 | 3560 | 0.17 | 4259 | 0.70 | 3872 | 139 | 119 | 130 |
| CW90 | 5 | 86 | 692 | 311 | 381 | 3604 | 0.17 | 4300 | 0.70 | 3677 | 158 | 120 | 132 |
| CW79 | 15 | 57 | 459 | 297 | 162 | 3680 | 0.17 | 4156 | 0.67 | 4045 | 1048 | 123 | 130 |
| CW85 | 15 | 77 | 620 | 304 | 316 | 3563 | 0.17 | 4191 | 0.69 | 3563 | 788 | 119 | 129 |
| CW83 | 25 | 86 | 692 | 302 | 390 | 3560 | 0.17 | 4181 | 0.69 | 3735 | 1504 | 119 | 129 |
| CW87 | 30 | 91 | 733 | 309 | 424 | 3620 | 0.17 | 4262 | 0.69 | 3701 | 1059 | 121 | 131 |
| CW77 | 50 | 88 | 709 | 302 | 406 | 3533 | 0.17 | 4166 | 0.70 | 3666 | 1205 | 118 | 128 |
| CW86 | 100 | 105 | 845 | 291 | 555 | 3494 | 0.17 | 3985 | 0.69 | 2836 | 1788 | 116 | 125 |
| CW84 | 150 | 123 | 990 | 348 | 642 | 3290 | 0.17 | 3880 | 0.84 | N/A | N/A | 110 | 119 |
| CW80 | 195 | 151 | 1216 | 356 | 859 | 2936 | 0.17 | 3853 | 0.87 | N/A | N/A | 98 | 113 |
| CW82 | 250 | 124 | 998 | 265 | 734 | 3088 | 0.17 | 3718 | 0.68 | N/A | N/A | 103 | 113 |

*** Data not recorded due to computer malfunction.

**Table 5-8 Instrumented Charpy Impact Test Results for the J. M. Farley Unit 2 Heat-Affected-Zone (HAZ) Metal Irradiated to a Fluence of 5.28 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) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CH90 | -100 | 8 | 64 | 39 | 26 | 3862 | 0.16 | 3929 | 0.17 | 3862 | 0 | 129 | 130 |
| CH82 | -60 | 16 | 129 | 72 | 56 | 4417 | 0.17 | 4860 | 0.22 | 4860 | 0 | 147 | 154 |
| CH77 | -30 | 20 | 161 | 71 | 90 | 4136 | 0.17 | 4511 | 0.22 | 4336 | 0 | 138 | 144 |
| CH83 | -20 | 68 | 548 | 220 | 328 | 4262 | 0.17 | 4676 | 0.47 | 3938 | 148 | 142 | 149 |
| CH86 | -15 | 68 | 548 | 248 | 300 | 4306 | 0.17 | 4769 | 0.51 | 4433 | 438 | 143 | 151 |
| CH85 | -10 | 8 | 64 | 33 | 31 | 3457 | 0.16 | 3465 | 0.16 | 3457 | 0 | 115 | 115 |
| CH76 | -10 | 42 | 338 | 246 | 92 | 4218 | 0.17 | 4704 | 0.51 | 4597 | 0 | 140 | 149 |
| CH78 | 0 | 44 | 354 | 236 | 119 | 4025 | 0.17 | 4494 | 0.52 | 4385 | 506 | 134 | 142 |
| CH87 | 0 | 70 | 564 | 240 | 324 | 4185 | 0.17 | 4657 | 0.51 | 4308 | 761 | 139 | 147 |
| CH80 | 10 | 7 | 56 | 29 | 27 | 3218 | 0.16 | 3228 | 0.15 | 3218 | 0 | 107 | 107 |
| CH89 | 25 | 130 | 1047 | 241 | 806 | 4105 | 0.17 | 4677 | 0.52 | N/A | N/A | 137 | 146 |
| CH88 | 50 | 68 | 548 | 240 | 307 | 4006 | 0.17 | 4558 | 0.52 | 4349 | 900 | 133 | 143 |
| CH84 | 100 | 122 | 982 | 318 | 664 | 3858 | 0.17 | 4407 | 0.68 | N/A | N/A | 128 | 138 |
| CH79 | 150 | 115 | 926 | 301 | 625 | 3661 | 0.17 | 4306 | 0.67 | N/A | N/A | 122 | 133 |
| CH81 | 195 | 140 | 1127 | 310 | 817 | 3653 | 0.17 | 4347 | 0.68 | N/A | N/A | 122 | 133 |

**Table 5-9 Effect of Irradiation to 5.28 x $10^{19}$ n/$cm^2$ (E>1.0 MeV) on the Notch Toughness Properties of the J. M. Farley Unit 2 Reactor Vessel Surveillance Materials**

| Material | Average 30 (ft-lb)[a] Transition Temperature (°F) | | | Average 35 mil Lateral[b] Expansion Temperature (°F) | | | Average 50 ft-lb[a] Transition Temperature (°F) | | | Average Energy Absorption[a] at Full Shear (ft-lb) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Unirradiated | Irradiated | ΔT | Unirradiated | Irradiated | ΔT | Unirradiated | Irradiated | ΔT | Unirradiated | Irradiated | ΔT |
| Inter. Shell Plate B7212-1 (Long.) | -22.65 | 177.56 | 200.24 | 1.6 | 212.3 | 210.7 | 9.87 | 208.74 | 198.87 | 130 | 94 | -36 |
| Inter. Shell Plate B7212-1 (Trans.) | -7.44 | 188.06 | 195.5 | 27.2 | 225.6 | 198.4 | 33.66 | 231.12 | 197.45 | 95 | 68 | -27 |
| Weld Metal | -34.7 | -24.7 | 10.0 | -23.0 | -0.5 | 22.5 | -15.6 | -1.4 | 14.2 | 144 | 133 | -11 |
| HAZ Metal | -175.4 | -32.8 | 142.6 | -111.3 | 5.1 | 116.4 | -116.8 | -3.2 | 113.6 | 158 | 126 | -32 |

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 J. M. Farley Unit 2 Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper Shelf Energy Decreases with Regulatory Guide 1.99, Revision 2, Predictions**

| Material | Capsule | Fluence ($x 10^{19}$ n/cm$^2$) | 30 ft-lb Transition Temperature Shift | | Upper Shelf Energy Decrease | |
|---|---|---|---|---|---|---|
| | | | Predicted (°F) [(a)] | Measured (°F) [(b)] | Predicted (%) [(a)] | Measured (%)[(c)] |
| Intermediate Shell Plate B7212-1 (Longitudinal) | U | 0.644 | 131.1 | 105.79 | 26 | 28 |
| | W | 1.85 | 174.3 | 168.05 | 34 | 22 |
| | X | 3.19 | 195.2 | 164.86 | 38 | 26 |
| | Z | 5.28 | 210.1 | 200.24 | 43 | 28 |
| Intermediate Shell Plate B7212-1 (Transverse) | U | 0.644 | 131.1 | 124.01 | 26 | 27 |
| | W | 1.85 | 174.3 | 168.18 | 34 | 20 |
| | X | 3.19 | 195.2 | 200.01 | 38 | 27 |
| | Z | 5.28 | 210.1 | 195.5 | 43 | 28 |
| Weld Metal | U | 0.644 | 36.1 | 0.0[(d)] | 17 | 8 |
| | W | 1.85 | 48.0 | 6.7 | 22 | 0 |
| | X | 3.19 | 53.7 | 0.0[(d)] | 25 | 0 |
| | Z | 5.28 | 57.8 | 10.0 | 28 | 8 |
| HAZ Metal | U | 0.644 | -- | 98.9 | -- | 30 |
| | W | 1.85 | -- | 147.7 | -- | 20 |
| | X | 3.19 | -- | 109.6 | -- | 19 |
| | Z | 5.28 | -- | 142.6 | -- | 20 |

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 U and capsule X $\Delta RT_{NDT}$ values are -28.7°F and -15.34°F respectively. This physically should not occur, therefore for conservatism a value of zero will be reported.

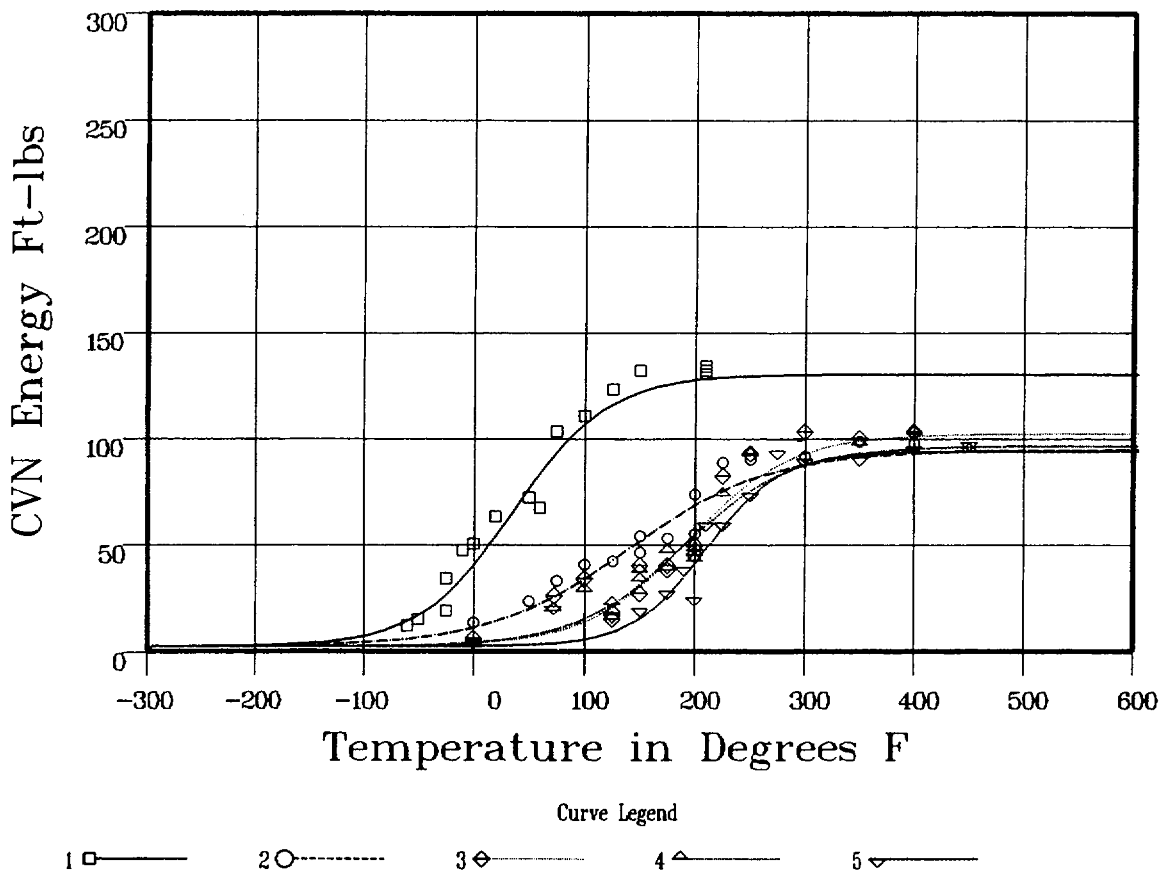
| Table 5-11 Tensile Properties of the J. M. Farley Unit 2 Reactor Vessel Surveillance Materials Irradiated to 5.28 x $10^{19}$ n/$cm^2$ (E > 1.0 MeV) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Material** | **Sample Number** | **Test Temp. (°F)** | **0.2% Yield Strength (ksi)** | **Ultimate Strength (ksi)** | **Fracture Load (kip)** | **Fracture Stress (ksi)** | **Fracture Strength (ksi)** | **Uniform Elongation (%)** | **Total Elongation (%)** | **Reduction in Area (%)** |
| Intermediate Plate B8805-3 (Longitudinal) | CL16 | 200 | 94.2 | 110.3 | 3.76 | 237.7 | 76.7 | 9.9 | 21.4 | 68 |
| | CL17 | 300 | 91.7 | 110.7 | 4.19 | 200.7 | 85.3 | 9.3 | 17.6 | 57 |
| | CL18 | 550 | 85.1 | 105.7 | 4.22 | 135.5 | 85.9 | 8.5 | 12.1 | 37 |
| Intermediate Plate B8805-3 (Transverse) | CT16 | 73 | 99.3 | 116.5 | 4.70 | 184.7 | 95.7 | 10.5 | 18.0 | 48 |
| | CT17 | 250 | 89.1 | 106.5 | 4.00 | 191.7 | 81.5 | 9.3 | 18.1 | 57 |
| | CT18 | 550 | 84.0 | 105.1 | 4.18 | 189.8 | 85.1 | 9.0 | 16.1 | 55 |
| Weld Metal | CW16 | 25 | 79.5 | 90.5 | 2.66 | 203.7 | 54.2 | 10.8 | 2.6 | 73 |
| | CW17 | 100 | 76.4 | 85.6 | 2.56 | 198.6 | 52.1 | 10.5 | 23.7 | 74 |
| | CW18 | 550 | 62.6 | 82.3 | 2.46 | 194.2 | 50.1 | 9.3 | 21.9 | 74 |

# INTERMEDIATE SHELL B7212-1 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:13:18 on 02-22-2000

Results

| Curve | Fluence | LSE | d-LSE | USE | d-USE | T @ 30 | d-T @ 30 | T @ 50 | d-T @ 50 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 2.19 | 0 | 130.19 | 0 | -22.65 | 0 | 9.87 | 0 |
| 2 | 0 | 2.19 | 0 | 94.4 | -35.79 | 83.14 | 105.79 | 140.89 | 131.02 |
| 3 | 0 | 2.19 | 0 | 102 | -28.19 | 145.4 | 168.05 | 185.48 | 175.61 |
| 4 | 0 | 2.19 | 0 | 96.3 | -33.88 | 142.21 | 164.86 | 186.24 | 176.37 |
| 5 | 0 | 2.19 | 0 | 93.8 | -36.38 | 177.59 | 200.24 | 208.74 | 198.87 |




Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat# |
|---|---|---|---|---|---|
| 1 | FA2 | UNIRR | PLATE SA533B1 | LT | B7212-1 |
| 2 | FA2 | U | PLATE SA533B1 | LT | B7212-1 |
| 3 | FA2 | W | PLATE SA533B1 | LT | B7212-1 |
| 4 | FA2 | X | PLATE SA533B1 | LT | B7212-1 |
| 5 | FA2 | Z | PLATE SA533B1 | LT | B7212-1 |

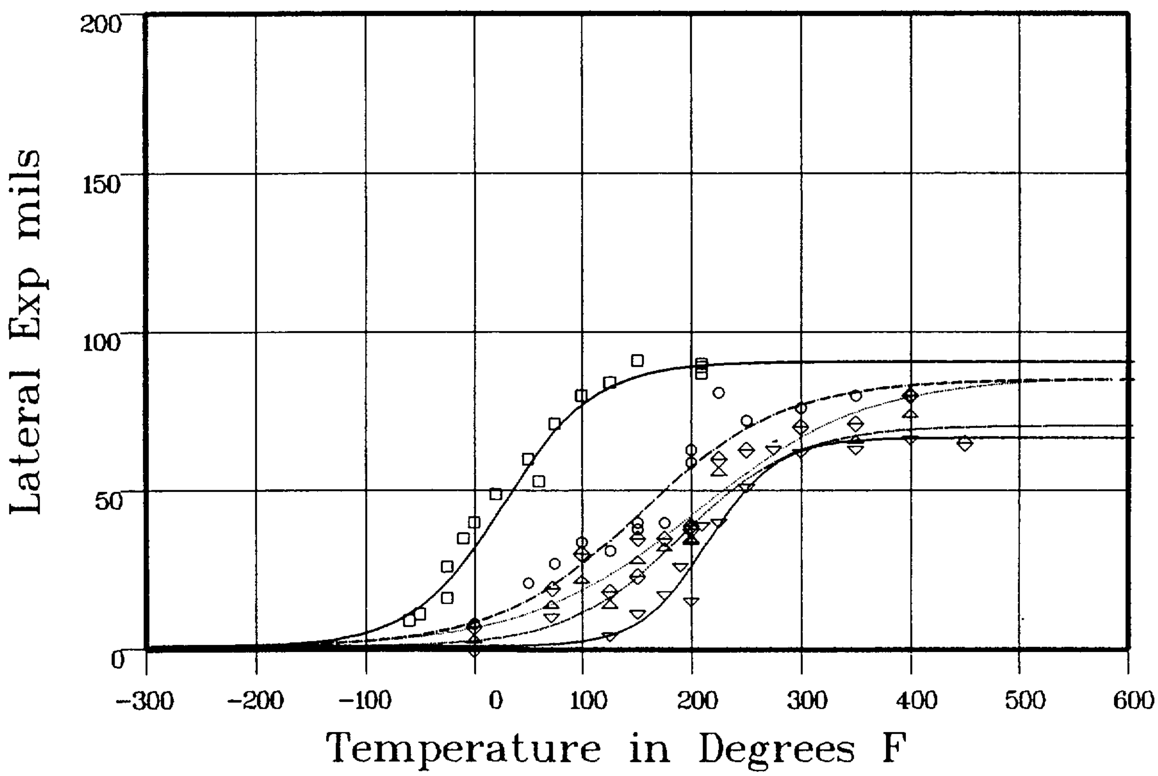
**Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for J. M. Farley Unit 2 Reactor Vessel Intermediate Shell Plate B7212-1 (Longitudinal Orientation)**

# INTERMEDIATE SHELL PLATE B7212-1 (LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:52:55 on 12-21-1998

Results

| Curve | Fluence | USE | d-USE | T @ LE35 | d-T @ LE35 |
|---|---|---|---|---|---|
| 1 | 0 | 90.65 | 0 | 1.64 | 0 |
| 2 | 0 | 85.02 | -5.63 | 122.15 | 120.51 |
| 3 | 0 | 85.83 | -4.81 | 167.56 | 165.92 |
| 4 | 0 | 70.41 | -20.24 | 183.03 | 181.39 |
| 5 | 0 | 66.63 | -24.02 | 212.3 | 210.66 |




Curve Legend

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

Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat# |
|---|---|---|---|---|---|
| 1 | FA2 | UNIRR | PLATE SA533B1 | LT | B7212-1 |
| 2 | FA2 | U | PLATE SA533B1 | LT | B7212-1 |
| 3 | FA2 | W | PLATE SA533B1 | LT | B7212-1 |
| 4 | FA2 | X | PLATE SA533B1 | LT | B7212-1 |
| 5 | FA2 | Z | PLATE SA533B1 | LT | B7212-1 |

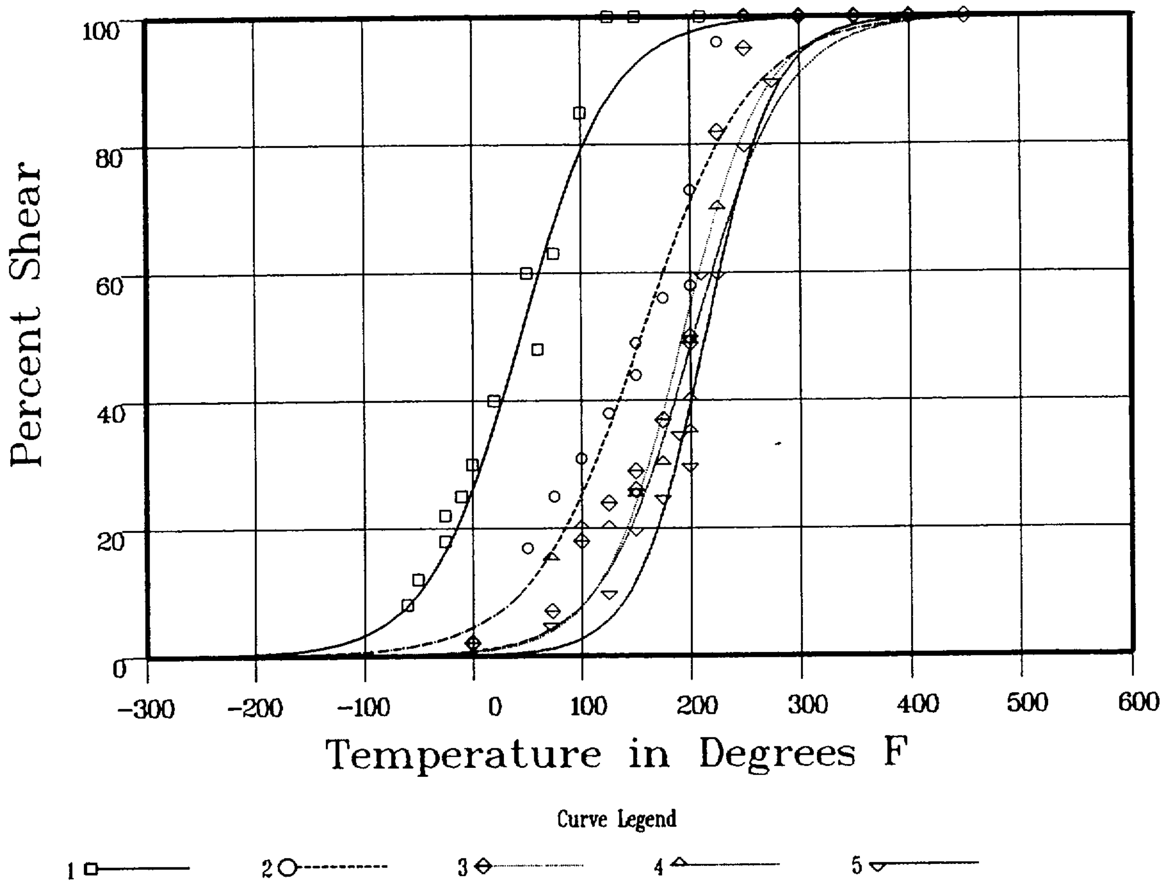
**Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for J. M. Farley Unit 2 Reactor Vessel Intermediate Shell Plate B7212-1 (Longitudinal Orientation)**

# INTERMEDIATE SHELL PLATE B7212-1(LONGITUDINAL)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:24:19 on 12-21-1998

Results

| Curve | Fluence | T @ 50% Shear | d-T @ 50% Shear |
|---|---|---|---|
| 1 | 0 | 39.37 | 0 |
| 2 | 0 | 150.29 | 110.91 |
| 3 | 0 | 188.43 | 149.06 |
| 4 | 0 | 198.28 | 158.9 |
| 5 | 0 | 209.06 | 169.68 |




Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat# |
|---|---|---|---|---|---|
| 1 | FA2 | UNIRR | PLATE SA533B1 | LT | B7212-1 |
| 2 | FA2 | U | PLATE SA533B1 | LT | B7212-1 |
| 3 | FA2 | W | PLATE SA533B1 | LT | B7212-1 |
| 4 | FA2 | X | PLATE SA533B1 | LT | B7212-1 |
| 5 | FA2 | Z | PLATE SA533B1 | LT | B7212-1 |

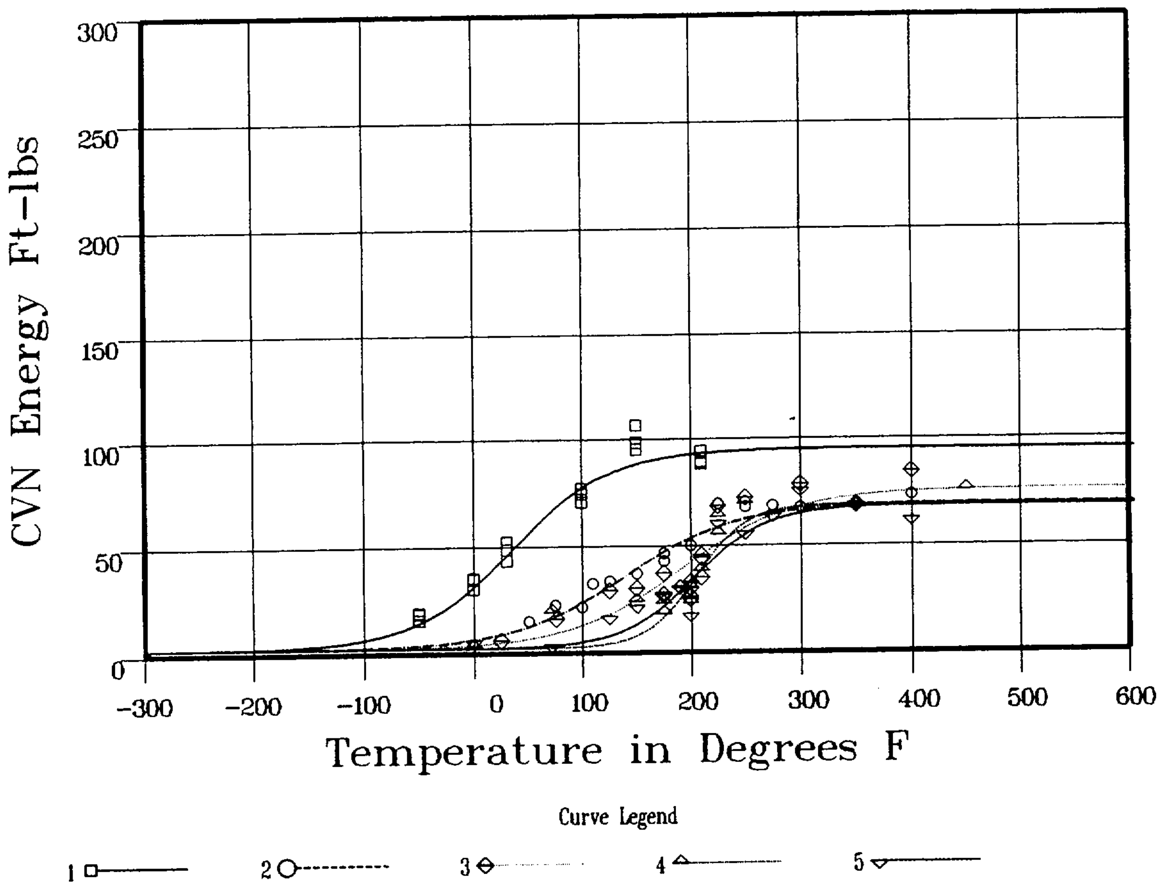
**Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for J. M. Farley Unit 2 Reactor Vessel Intermediate Shell Plate B7212-1 (Longitudinal Orientation)**

# INTERMEDIATE SHELL B7212-1 (TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:33:51 on 02-22-2000

Results

| Curve | Fluence | LSE | d-LSE | USE | d-USE | T @ 30 | d-T @ 30 | T @ 50 | d-T @ 50 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 2.19 | 0 | 95 | 0 | -7.44 | 0 | 33.66 | 0 |
| 2 | 0 | 2.19 | 0 | 68.9 | -26.09 | 116.56 | 124.01 | 181.83 | 148.17 |
| 3 | 0 | 2.19 | 0 | 75.5 | -19.5 | 160.74 | 168.18 | 218.29 | 184.62 |
| 4 | 0 | 2.19 | 0 | 68.5 | -26.5 | 192.57 | 200.01 | 222.03 | 188.36 |
| 5 | 0 | 2.19 | 0 | 67.8 | -27.19 | 188.06 | 195.5 | 231.12 | 197.45 |




Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat# |
|---|---|---|---|---|---|
| 1 | FA2 | UNIRR | PLATE SA533B1 | TL | B7212-1 |
| 2 | FA2 | U | PLATE SA533B1 | TL | B7212-1 |
| 3 | FA2 | W | PLATE SA533B1 | TL | B7212-1 |
| 4 | FA2 | X | PLATE SA533B1 | TL | B7212-1 |
| 5 | FA2 | Z | PLATE SA533B1 | TL | B7212-1 |

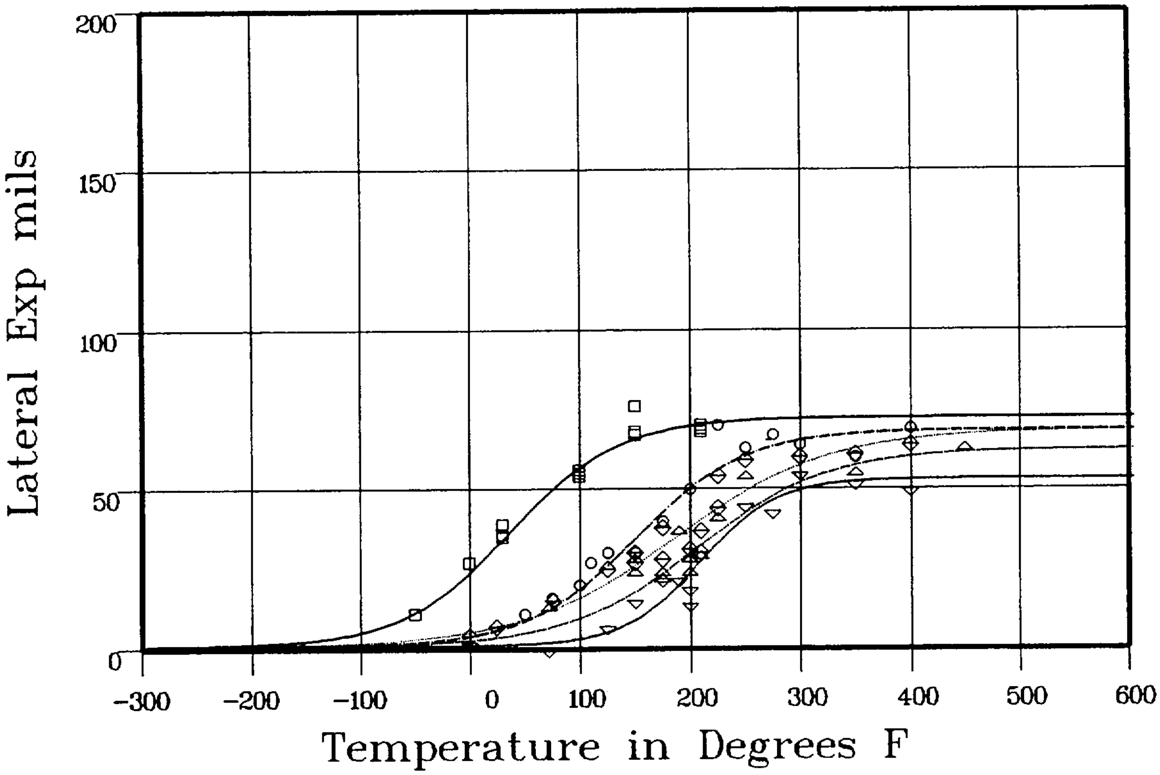
**Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for J. M. Farley Unit 2 Reactor Vessel Intermediate Shell Plate B7212-1 (Transverse Orientation)**

# INTERMEDIATE SHELL PLATE B7212-1(TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:07:18 on 12-21-1998

Results

| Curve | Fluence | USE | d-USE | T @ LE35 | d-T @ LE35 |
|---|---|---|---|---|---|
| 1 | 0 | 72.35 | 0 | 27.23 | 0 |
| 2 | 0 | 68.48 | -3.86 | 146.53 | 119.29 |
| 3 | 0 | 68.54 | -3.8 | 182.16 | 154.92 |
| 4 | 0 | 62.45 | -9.89 | 214.41 | 187.17 |
| 5 | 0 | 53.13 | -19.21 | 225.59 | 198.35 |




Curve Legend

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

Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat# |
|---|---|---|---|---|---|
| 1 | FA2 | UNIRR | PLATE SA533B1 | TL | B7212-1 |
| 2 | FA2 | U | PLATE SA533B1 | TL | B7212-1 |
| 3 | FA2 | W | PLATE SA533B1 | TL | B7212-1 |
| 4 | FA2 | X | PLATE SA533B1 | TL | B7212-1 |
| 5 | FA2 | Z | PLATE SA533B1 | TL | B7212-1 |

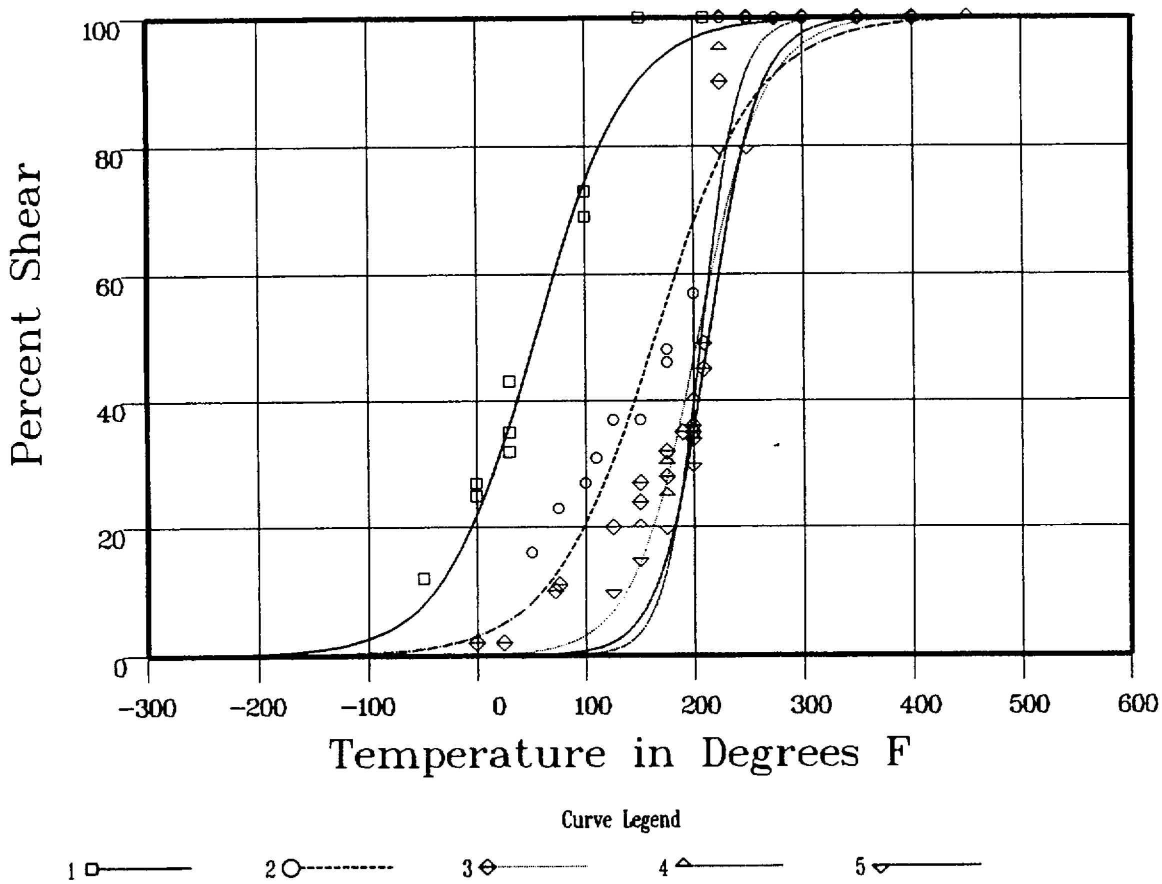
**Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for J. M. Farley Unit 2 Reactor Vessel Intermediate Shell Plate B7212-1 (Transverse Orientation)**

# INTERMEDIATE SHELL PLATE B7212-1(TRANSVERSE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:14:51 on 12-21-1998

Results

| Curve | Fluence | T @ 50% Shear | d-T @ 50% Shear |
|---|---|---|---|
| 1 | 0 | 49.68 | 0 |
| 2 | 0 | 159.64 | 109.96 |
| 3 | 0 | 199.68 | 150 |
| 4 | 0 | 202.96 | 153.28 |
| 5 | 0 | 209.53 | 159.84 |




Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat# |
|---|---|---|---|---|---|
| 1 | FA2 | UNIRR | PLATE SA533B1 | TL | B7212-1 |
| 2 | FA2 | U | PLATE SA533B1 | TL | B7212-1 |
| 3 | FA2 | W | PLATE SA533B1 | TL | B7212-1 |
| 4 | FA2 | X | PLATE SA533B1 | TL | B7212-1 |
| 5 | FA2 | Z | PLATE SA533B1 | TL | B7212-1 |

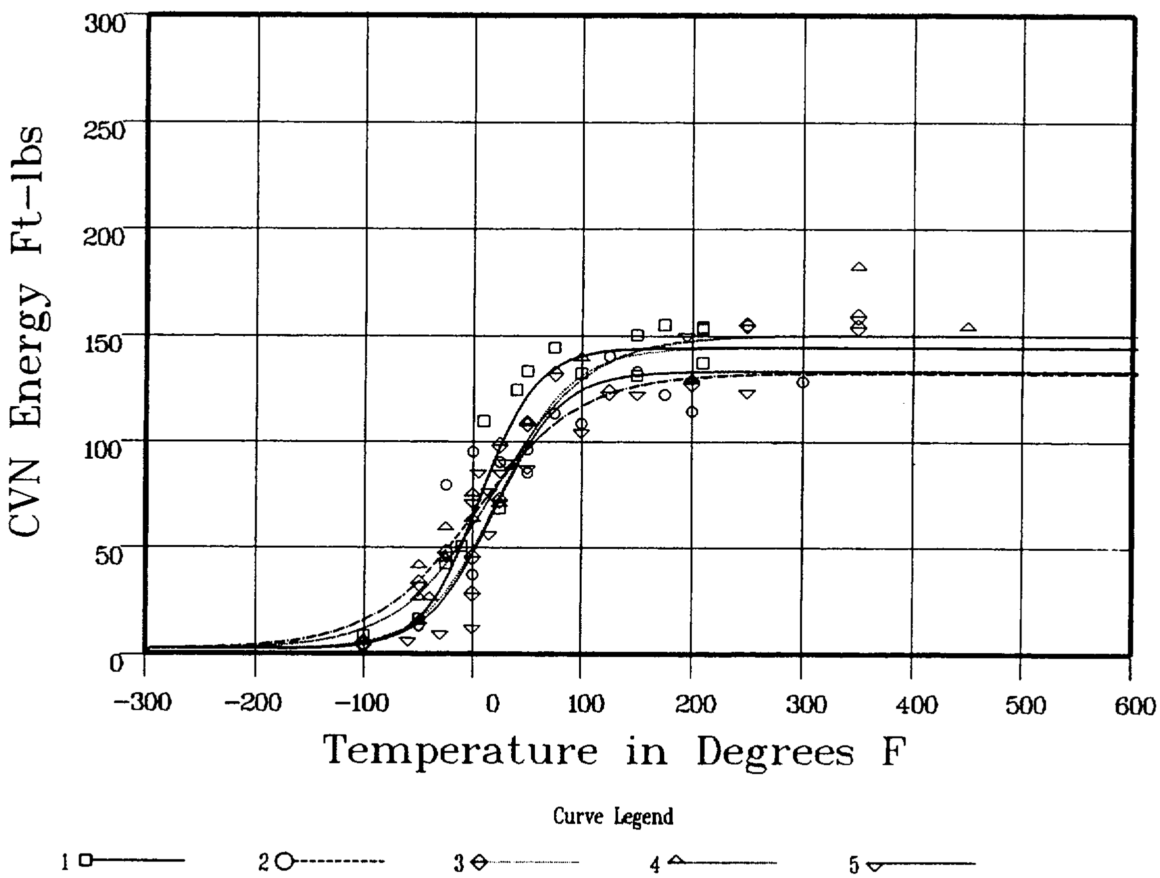
**Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for J. M. Farley Unit 2 Reactor Vessel Intermediate Shell Plate B7212-1 (Transverse Orientation)**

# SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:43:31 on 12-21-1998

Results

| Curve | Fluence | LSE | d-LSE | USE | d-USE | T @ 30 | d-T @ 30 | T @ 50 | d-T @ 50 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 2.19 | 0 | 144 | 0 | -34.69 | 0 | -15.55 | 0 |
| 2 | 0 | 2.19 | 0 | 132 | -12 | -63.4 | -28.7 | -26.87 | -11.31 |
| 3 | 0 | 2.19 | 0 | 144 | 0 | -27.99 | 6.69 | -3.56 | 11.99 |
| 4 | 0 | 2.19 | 0 | 150 | 6 | -50.03 | -15.34 | -17.82 | -2.26 |
| 5 | 0 | 2.19 | 0 | 133 | -11 | -24.65 | 10.03 | -1.43 | 14.12 |




Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat# |
|---|---|---|---|---|---|
| 1 | FA2 | UNIRR | WELD | | BOLA |
| 2 | FA2 | U | WELD | | BOLA |
| 3 | FA2 | W | WELD | | BOLA |
| 4 | FA2 | X | WELD | | BOLA |
| 5 | FA2 | Z | WELD | | BOLA |

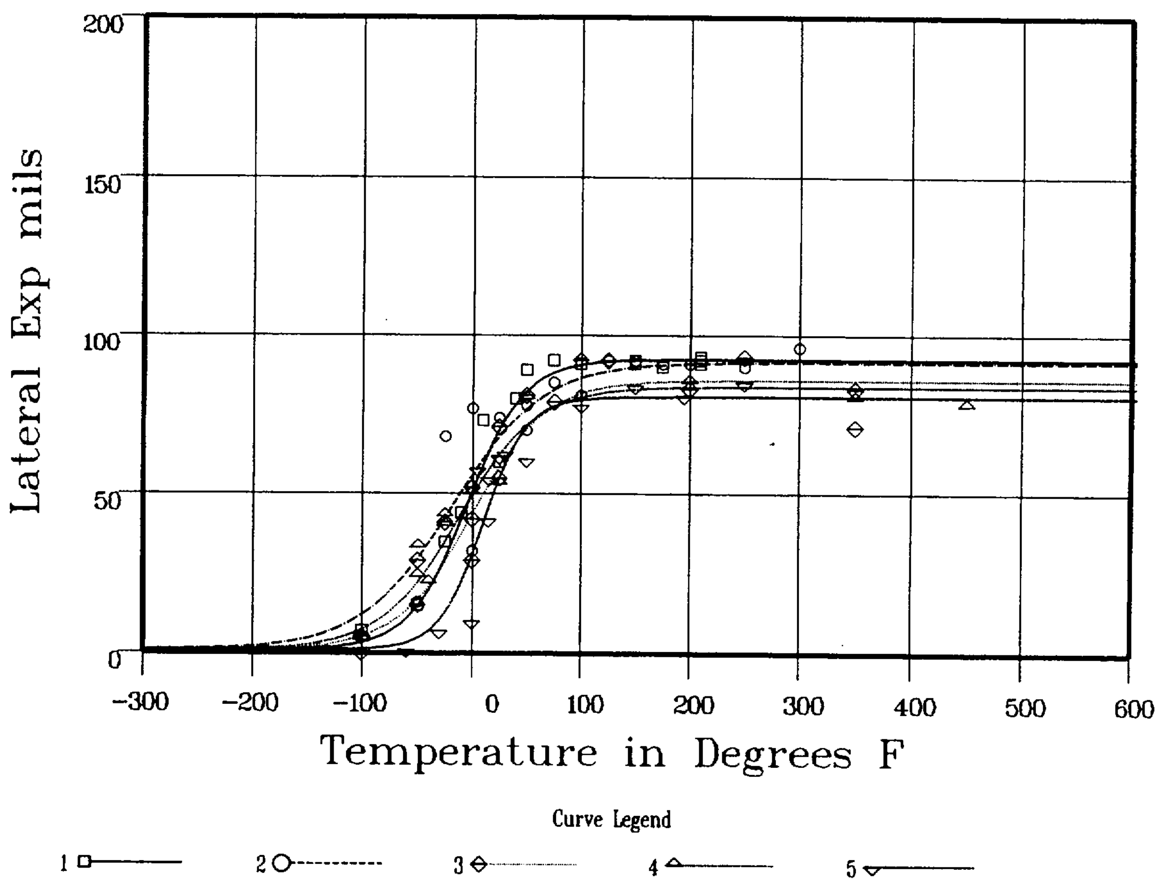
**Figure 5-7 Charpy V-Notch Impact Energy vs. Temperature for J. M. Farley Unit 2 Reactor Vessel Weld Metal**

# SURVIELLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:04:10 on 12-21-1998

Results

| Curve | Fluence | USE | d-USE | T @ LE35 | d-T @ LE35 |
|---|---|---|---|---|---|
| 1 | 0 | 92.34 | 0 | -23.04 | 0 |
| 2 | 0 | 91.47 | -.86 | -44.05 | -21.01 |
| 3 | 0 | 85.75 | -6.58 | -18.68 | 4.36 |
| 4 | 0 | 83.77 | -8.57 | -29.9 | -6.86 |
| 5 | 0 | 80.6 | -11.73 | -.47 | 22.57 |




Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat# |
|---|---|---|---|---|---|
| 1 | FA2 | UNIRR | WELD | | BOLA |
| 2 | FA2 | U | WELD | | BOLA |
| 3 | FA2 | W | WELD | | BOLA |
| 4 | FA2 | X | WELD | | BOLA |
| 5 | FA2 | Z | WELD | | BOLA |

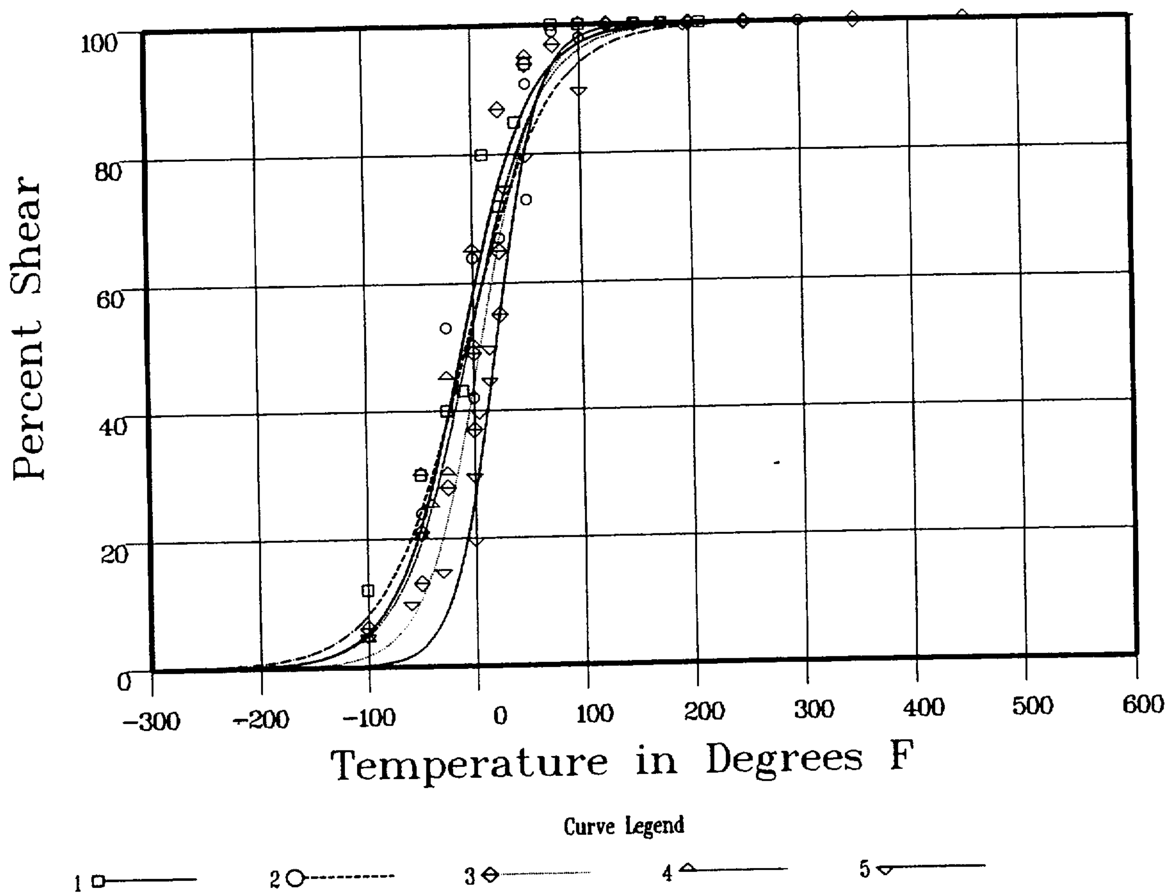
**Figure 5-8 Charpy V-Notch Lateral Expansion vs. Temperature for J. M. Farley Unit 2 Reactor Vessel Weld Metal**

# SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:15:15 on 12-21-1998

Results

| Curve | Fluence | T @ 50% Shear | d-T @ 50% Shear |
|---|---|---|---|
| 1 | 0 | -15 | 0 |
| 2 | 0 | -11.25 | 3.75 |
| 3 | 0 | 1.87 | 16.87 |
| 4 | 0 | -8.9 | 6.09 |
| 5 | 0 | 15.93 | 30.93 |




Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat# |
|---|---|---|---|---|---|
| 1 | FA2 | UNIRR | WELD | | BOLA |
| 2 | FA2 | U | WELD | | BOLA |
| 3 | FA2 | W | WELD | | BOLA |
| 4 | FA2 | X | WELD | | BOLA |
| 5 | FA2 | Z | WELD | | BOLA |

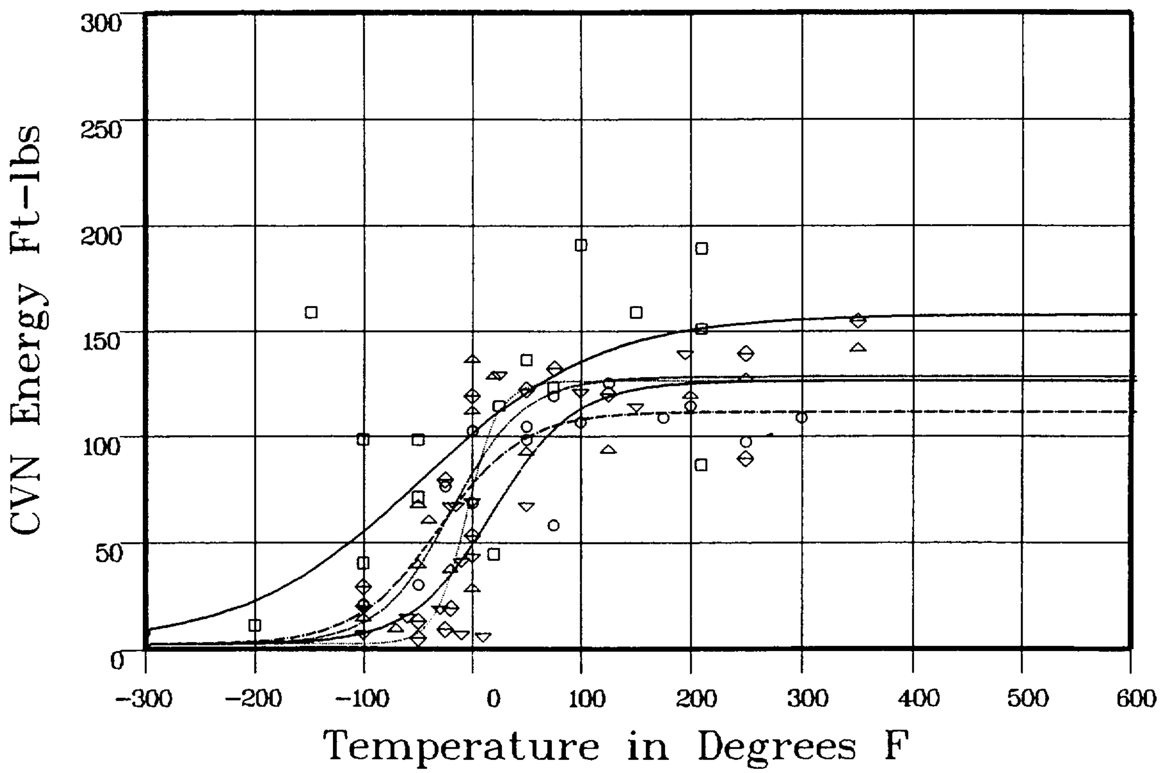
**Figure 5-9 Charpy V-Notch Percent Shear vs Temperature for J. M. Farley Unit 2 Reactor Vessel Weld Metal**

# HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 15:29:42 on 12-21-1998

Results

| Curve | Fluence | LSE | d-LSE | USE | d-USE | T @ 30 | d-T @ 30 | T @ 50 | d-T @ 50 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 2.19 | 0 | 158 | 0 | -175.37 | 0 | -116.81 | 0 |
| 2 | 0 | 2.19 | 0 | 111 | -47 | -76.45 | 98.91 | -44.57 | 72.24 |
| 3 | 0 | 2.19 | 0 | 126 | -32 | -27.68 | 147.69 | -16.22 | 100.58 |
| 4 | 0 | 2.19 | 0 | 128 | -30 | -65.79 | 109.57 | -39.9 | 76.91 |
| 5 | 0 | 2.19 | 0 | 126 | -32 | -32.76 | 142.61 | -3.16 | 113.64 |




Curve Legend

1 □—— 2 ○------ 3 ◇—— 4 △—— 5 ▽——

Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat# |
|---|---|---|---|---|---|
| 1 | FA2 | UNIRR | HEAT AFFD ZONE | | B7212-1 |
| 2 | FA2 | U | HEAT AFFD ZONE | | B7212-1 SIDE OF WELD |
| 3 | FA2 | W | HEAT AFFD ZONE | | B7212-1 SIDE OF WELD |
| 4 | FA2 | X | HEAT AFFD ZONE | | B7212-1 SIDE OF WELD |
| 5 | FA2 | Z | HEAT AFFD ZONE | | B7212-1 SIDE OF WELD |

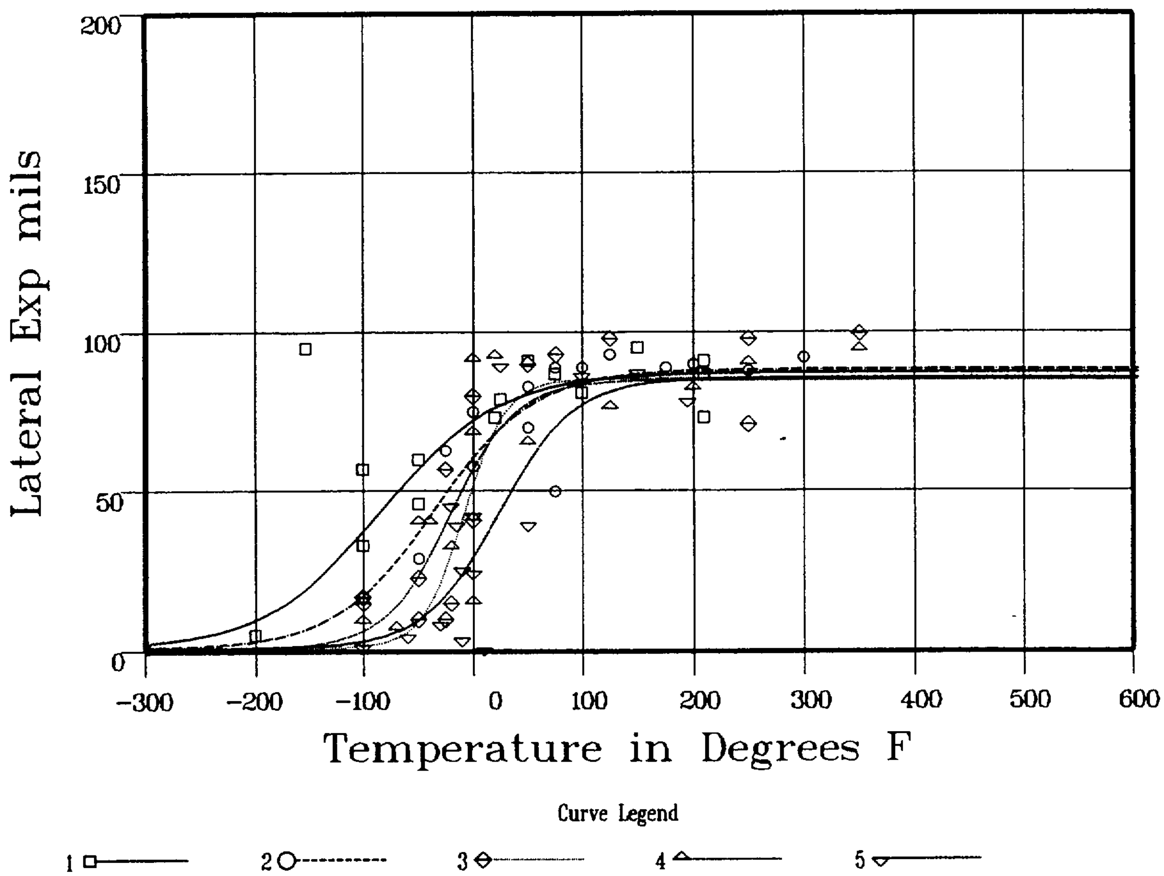
**Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for J. M. Farley Unit 2 Reactor Vessel Heat-Affected-Zone Material**

# HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:45:43 on 12-22-1998

Results

| Curve | Fluence | USE | d-USE | T @ LE35 | d-T @ LE35 |
|---|---|---|---|---|---|
| 1 | 0 | 87.32 | 0 | -111.25 | 0 |
| 2 | 0 | 88.27 | .94 | -59.55 | 51.69 |
| 3 | 0 | 85.49 | -1.83 | -20.27 | 90.98 |
| 4 | 0 | 84.97 | -2.35 | -36.76 | 74.49 |
| 5 | 0 | 85.57 | -1.75 | 5.1 | 116.36 |




Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat# |
|---|---|---|---|---|---|
| 1 | FA2 | UNIRR | HEAT AFFD ZONE | | B7212-1 SIDE OF WELD |
| 2 | FA2 | U | HEAT AFFD ZONE | | B7212-1 SIDE OF WELD |
| 3 | FA2 | W | HEAT AFFD ZONE | | B7212-1 SIDE OF WELD |
| 4 | FA2 | X | HEAT AFFD ZONE | | B7212-1 SIDE OF WELD |
| 5 | FA2 | Z | HEAT AFFD ZONE | | B7212-1 SIDE OF WELD |

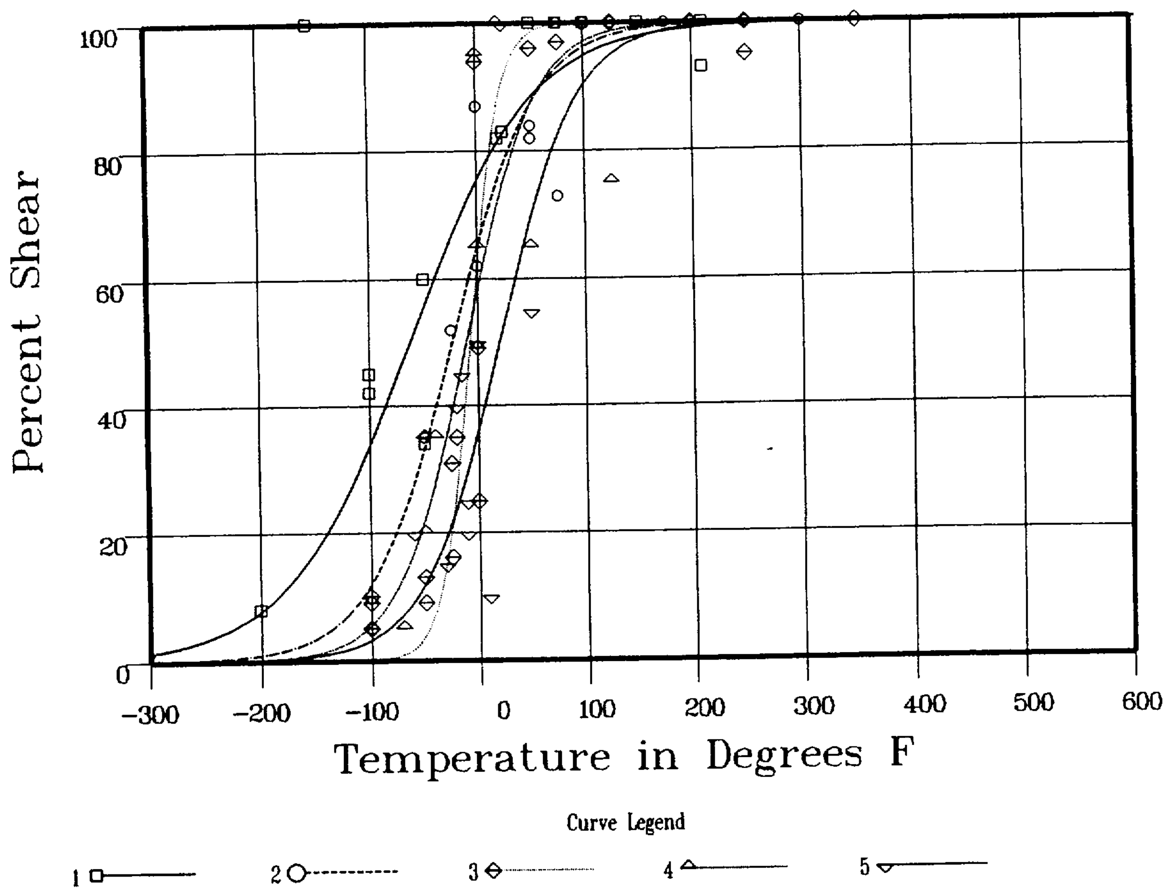
**Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for J. M. Farley Unit 2 Reactor Vessel Heat-Affected-Zone Material**

## HEAT AFFECTED ZONE

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:48:27 on 12-22-1998

Results

| Curve | Fluence | T @ 50% Shear | d-T @ 50% Shear |
|---|---|---|---|
| 1 | 0 | -67.03 | 0 |
| 2 | 0 | -28.12 | 38.9 |
| 3 | 0 | -11.25 | 55.78 |
| 4 | 0 | -15 | 52.03 |
| 5 | 0 | 15.93 | 82.96 |




Data Set(s) Plotted

| Curve | Plant | Capsule | Material | Ori. | Heat# |
|---|---|---|---|---|---|
| 1 | FA2 | UNIRR | HEAT AFFD ZONE | | B7212-1 SIDE OF WELD |
| 2 | FA2 | U | HEAT AFFD ZONE | | B7212-1 SIDE OF WELD |
| 3 | FA2 | W | HEAT AFFD ZONE | | B7212-1 SIDE OF WELD |
| 4 | FA2 | X | HEAT AFFD ZONE | | B7212-1 SIDE OF WELD |
| 5 | FA2 | Z | HEAT AFFD ZONE | | B7212-1 SIDE OF WELD |

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

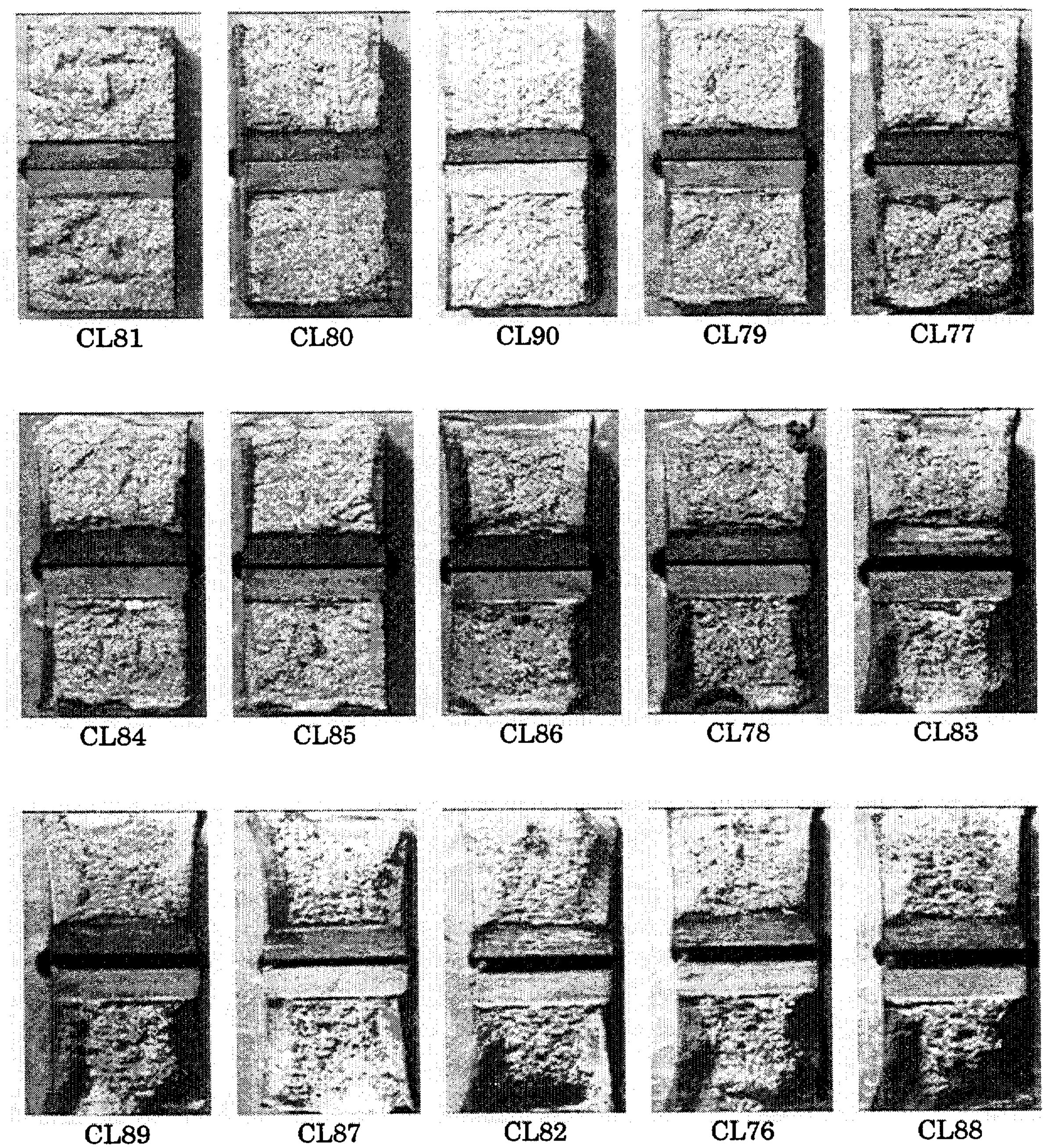



**Figure 5-13 Charpy Impact Specimen Fracture Surfaces for J. M. Farley Unit 2 Reactor Vessel Intermediate Shell Plate B7212-1 (Longitudinal Orientation)**

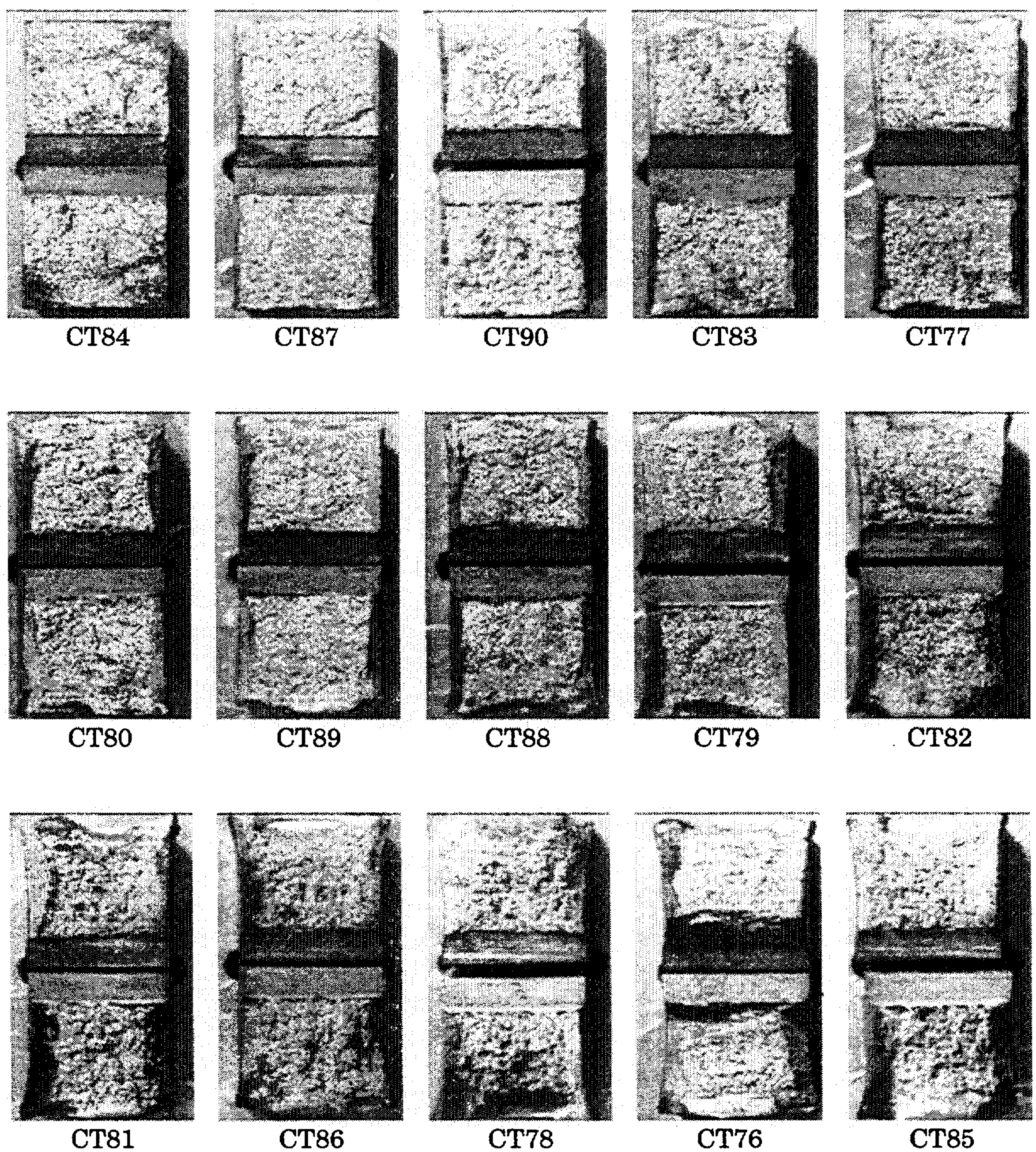



**Figure 5-14 Charpy Impact Specimen Fracture Surfaces for J. M. Farley Unit 2 Reactor Vessel Intermediate Shell Plate B7212-1 (Transverse Orientation)**

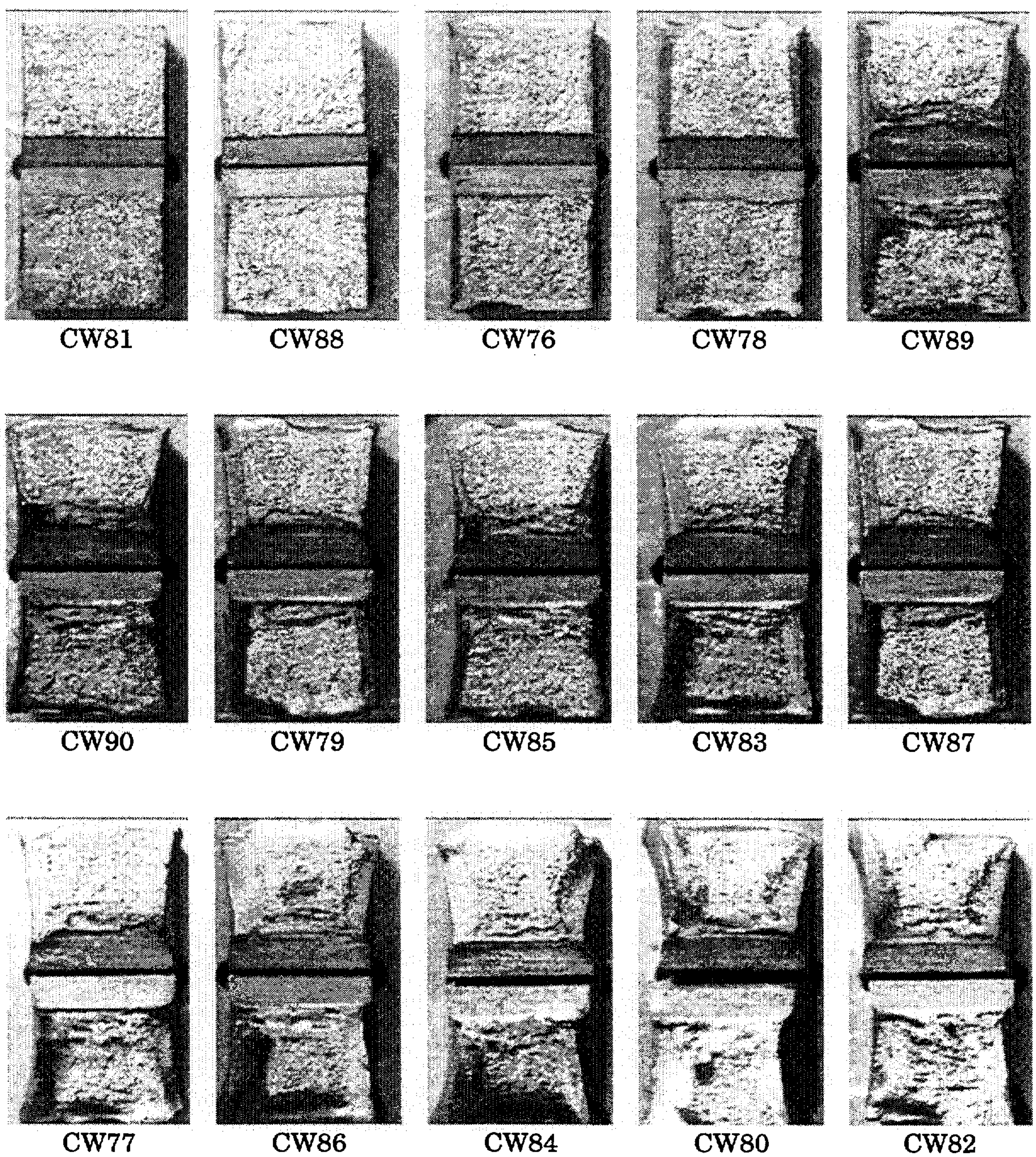



**Figure 5-15 Charpy Impact Specimen Fracture Surfaces for J. M. Farley Unit 2 Reactor Vessel Weld Metal**

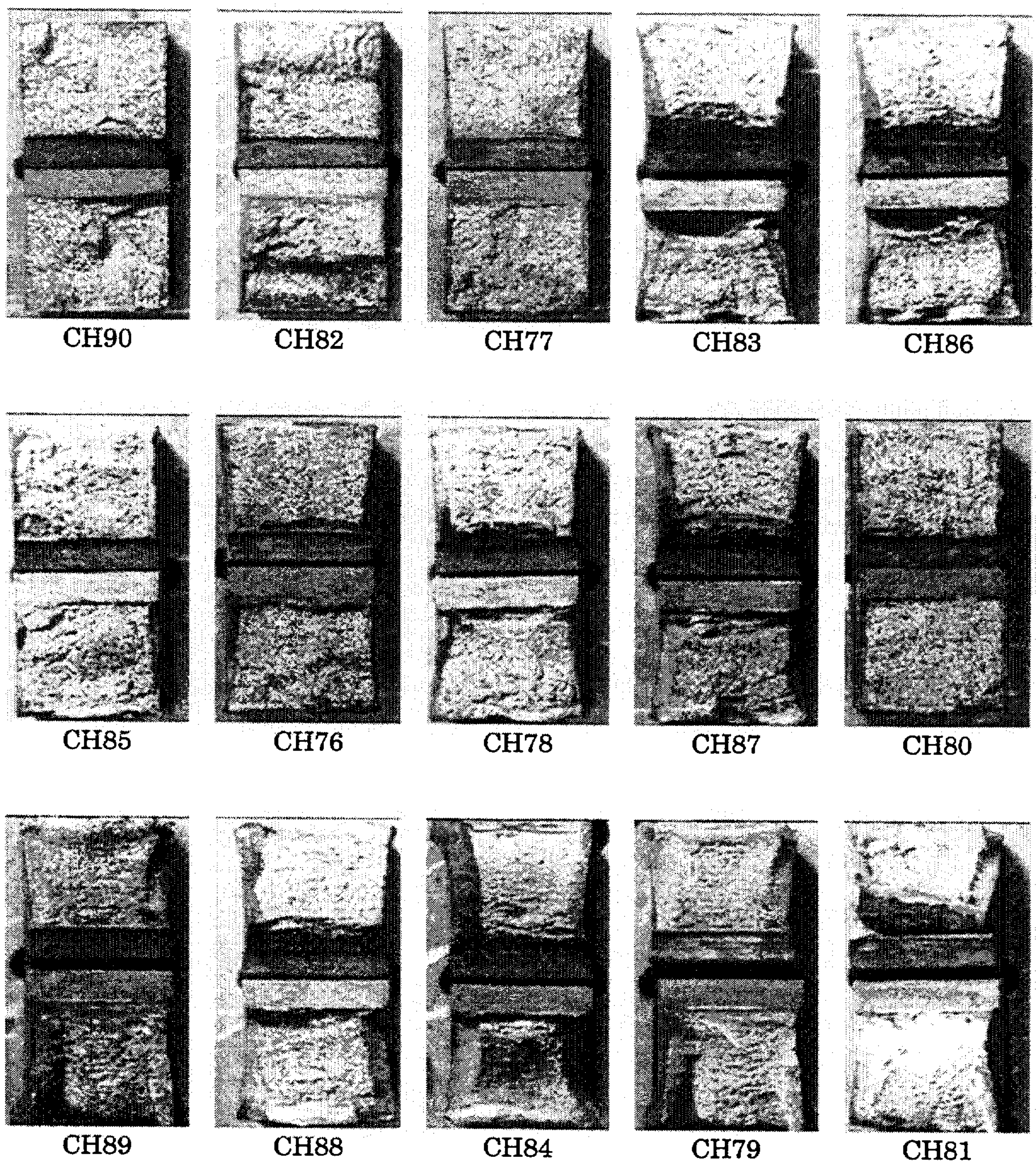



**Figure 5-16 Charpy Impact Specimen Fracture Surfaces for J. M. Farley Unit 2 Reactor Vessel Heat-Affected-Zone Metal**

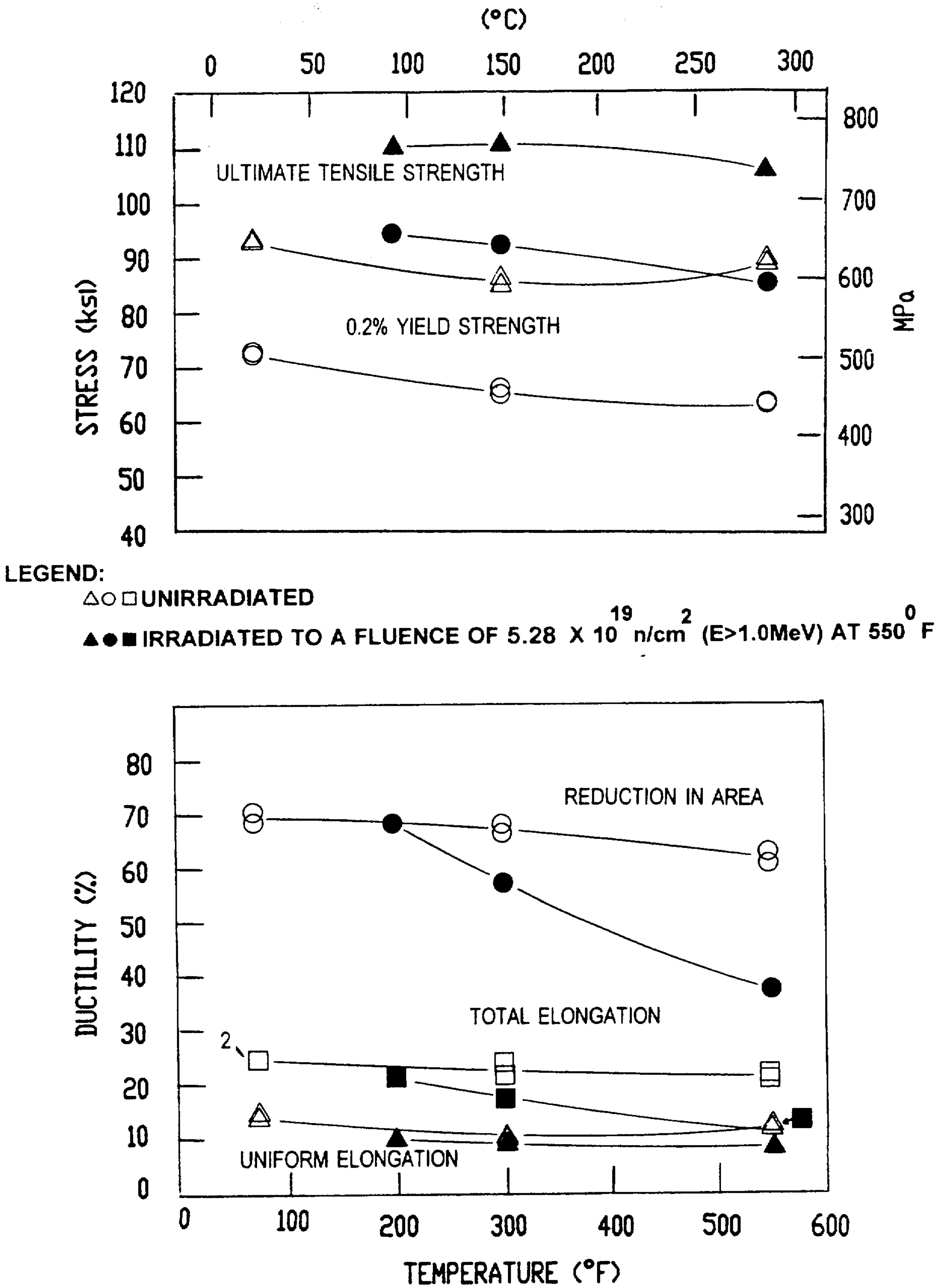



**Figure 5-17 Tensile Properties for J. M. Farley Unit 2 Reactor Vessel Intermediate Shell Plate B7212-1 (Longitudinal Orientation)**

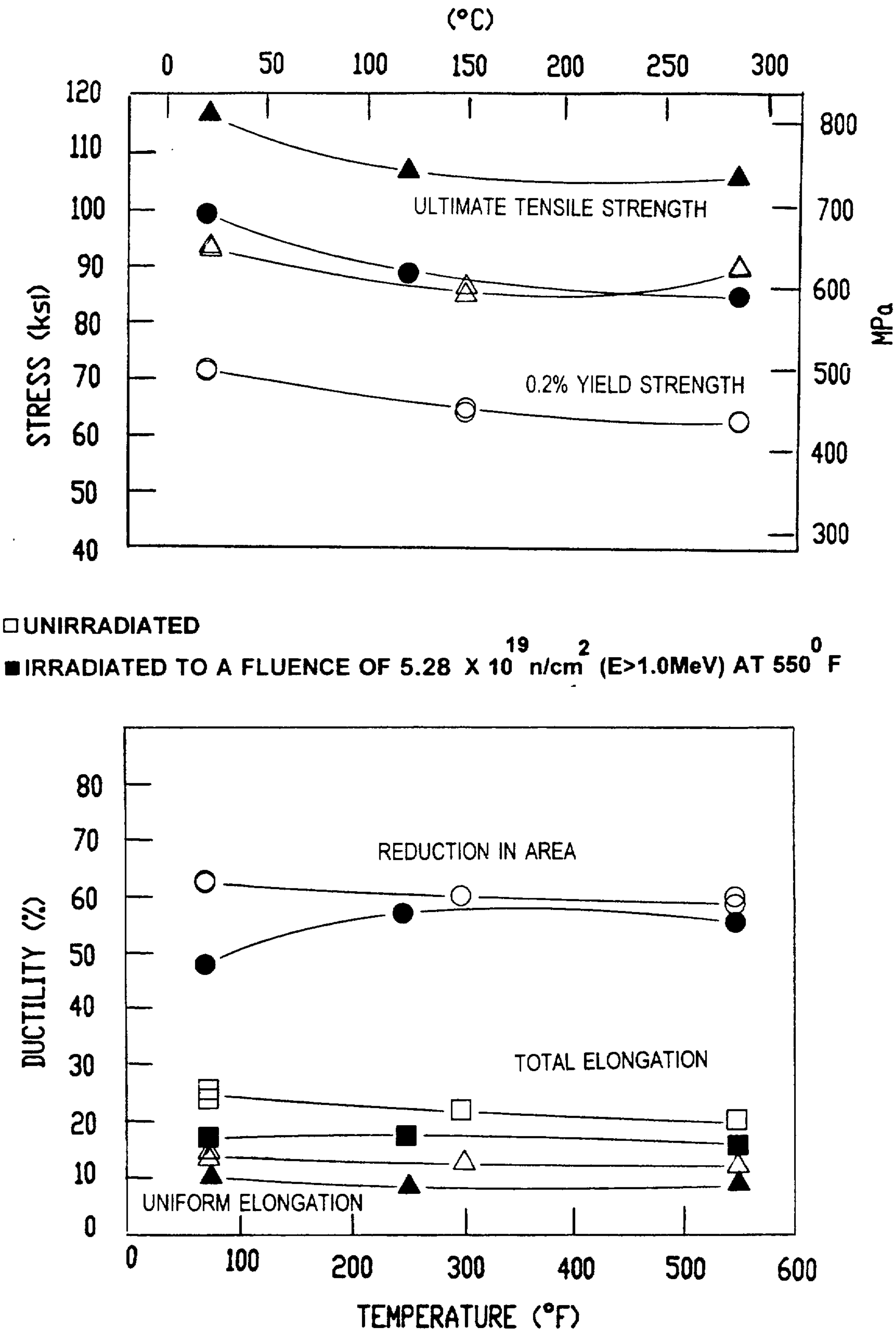



**Figure 5-18 Tensile Properties for J. M. Farley Unit 2 Reactor Vessel Intermediate Shell Plate B7212-1 (Transverse Orientation)**

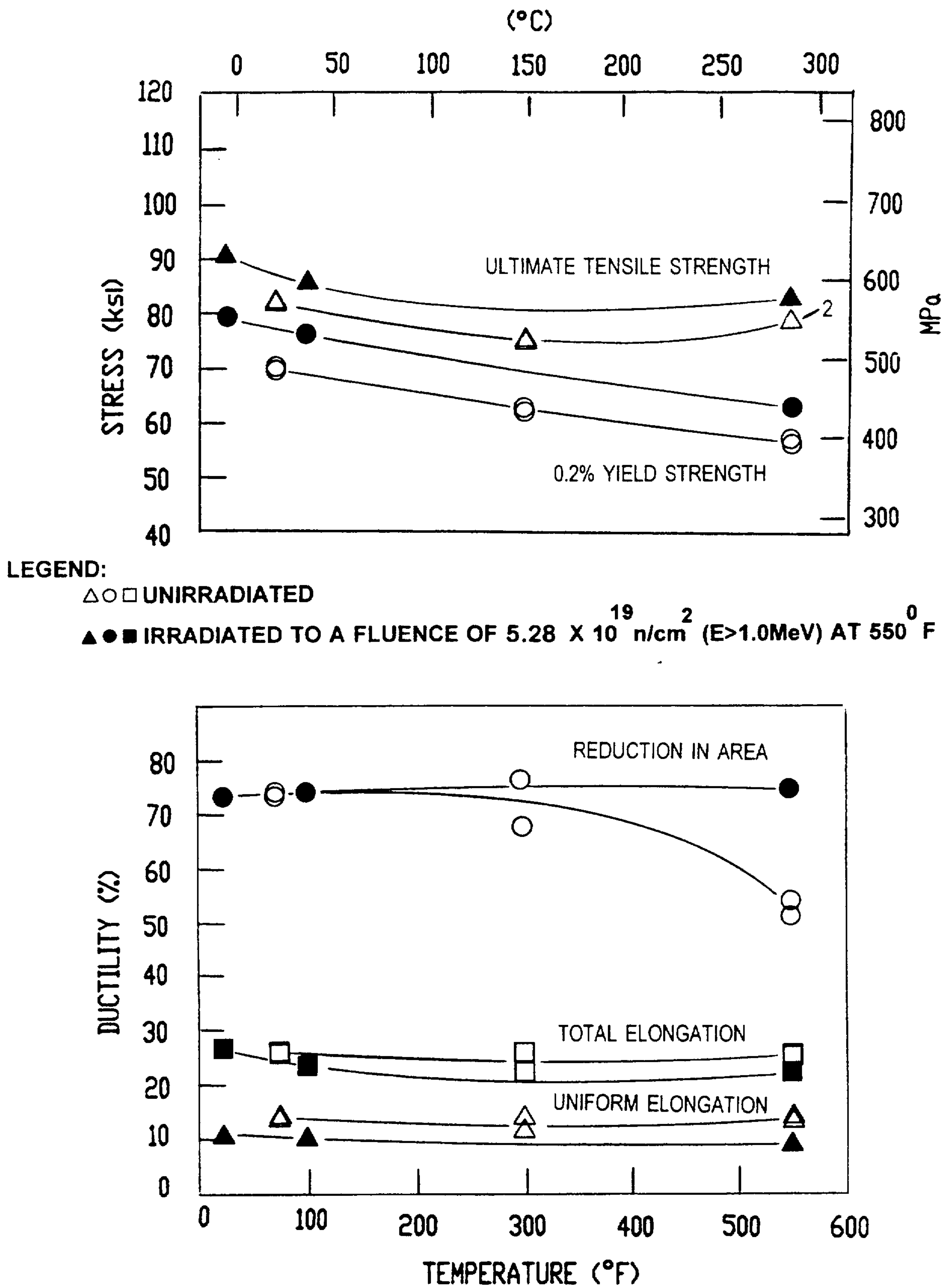
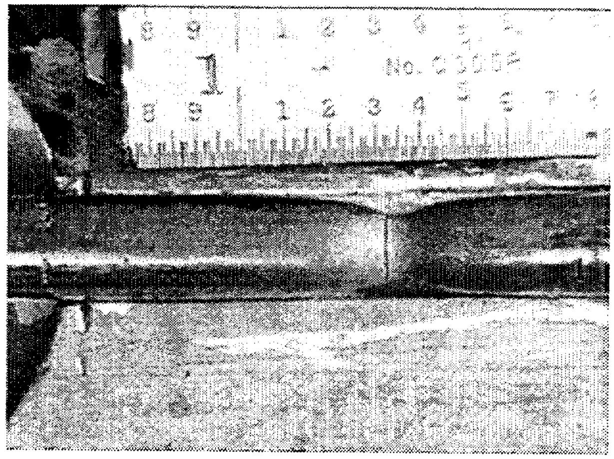
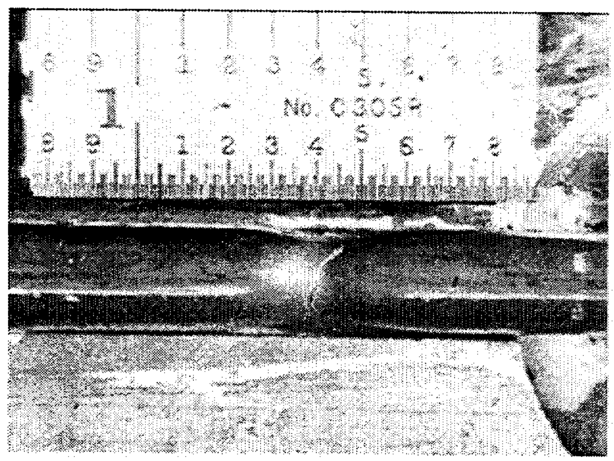


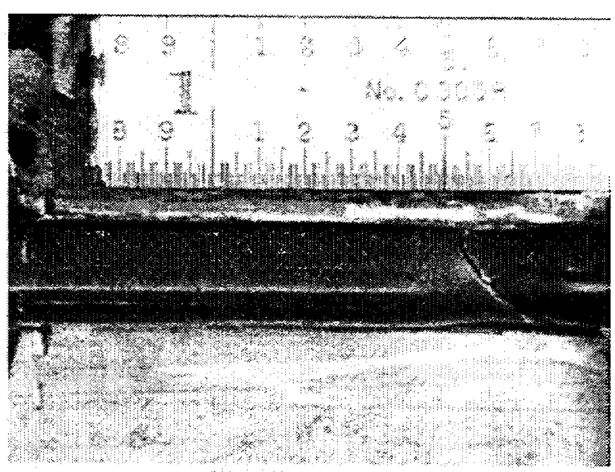

**Figure 5-19 Tensile Properties for J. M. Farley Unit 2 Reactor Vessel Weld Metal**



Specimen CL16

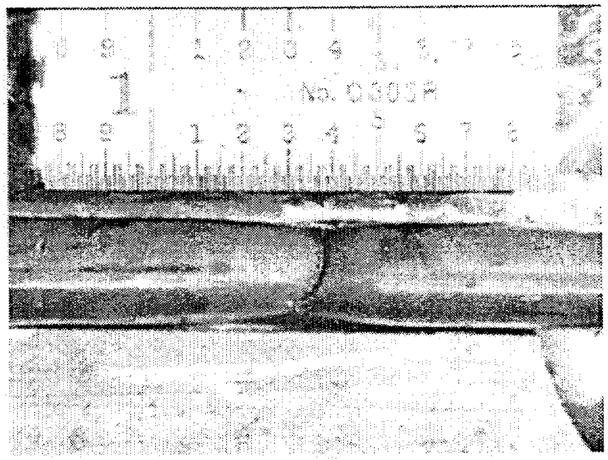


Specimen CL17

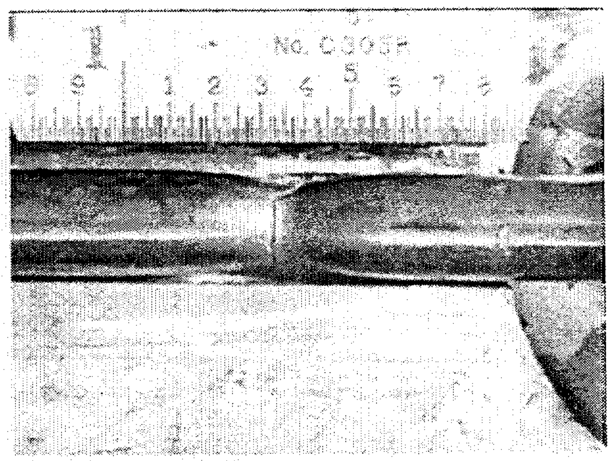


Specimen CL18

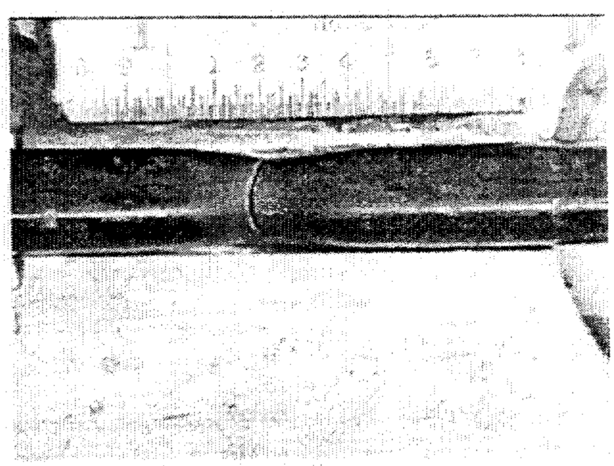
**Figure 5-20 Fractured Tensile Specimens from J. M. Farley Unit 2 Reactor Vessel Intermediate Shell Plate B7212-1 (Longitudinal Orientation)**



Specimen CT16

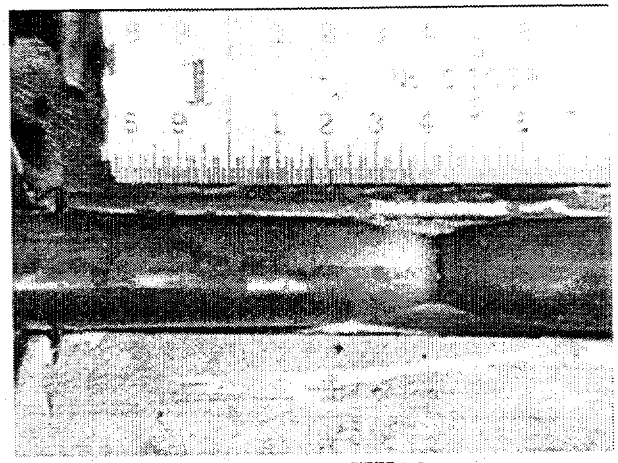


Specimen CT17

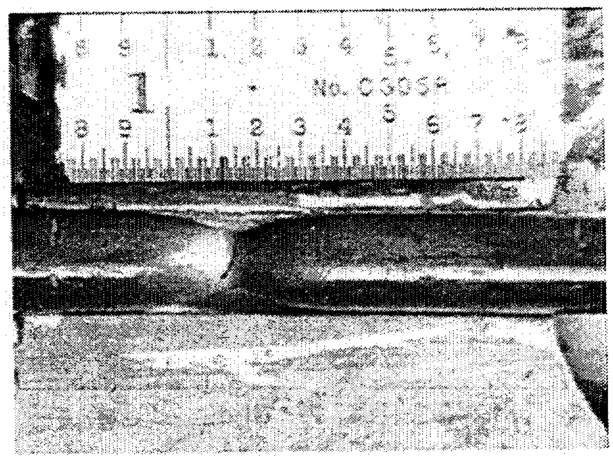


Specimen CT18

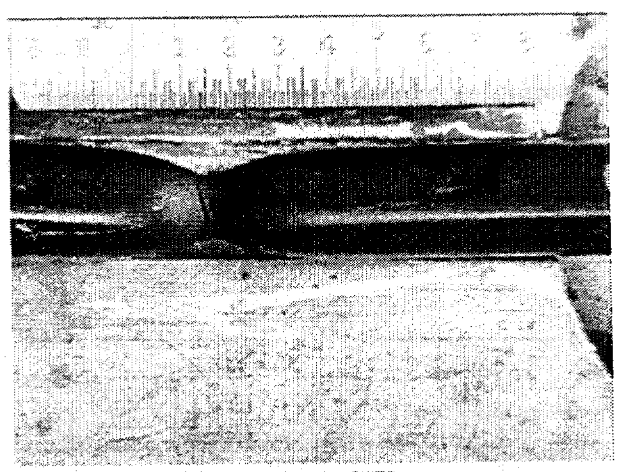
**Figure 5-21 Fractured Tensile Specimens from J. M. Farley Unit 2 Reactor Vessel Intermediate Shell Plate B7212-1 (Transverse Orientation)**



Specimen CW16



Specimen CW17



Specimen CW18

**Figure 5-22 Fractured Tensile Specimens from J. M. Farley Unit 2 Reactor Vessel Weld Metal**

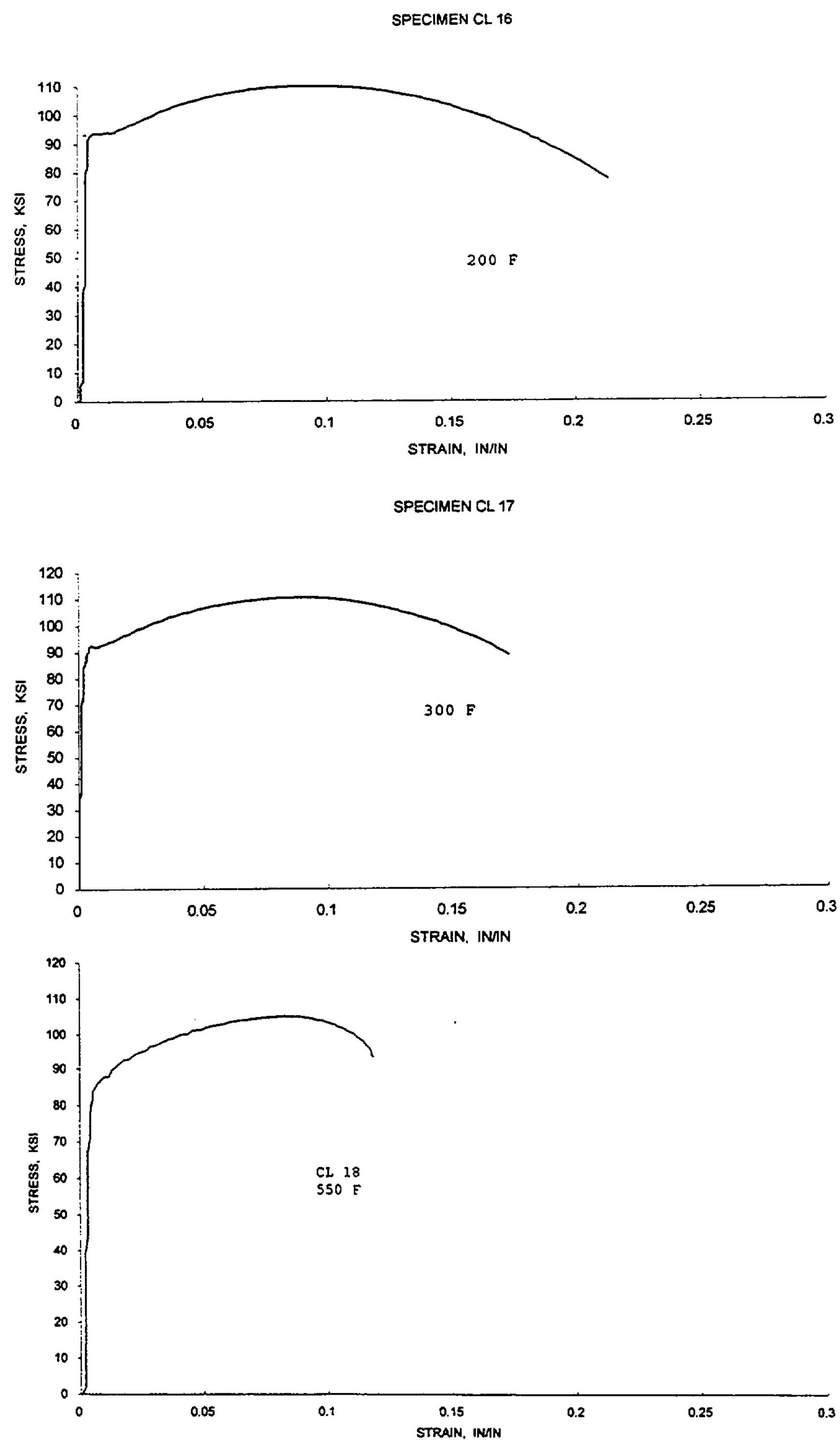
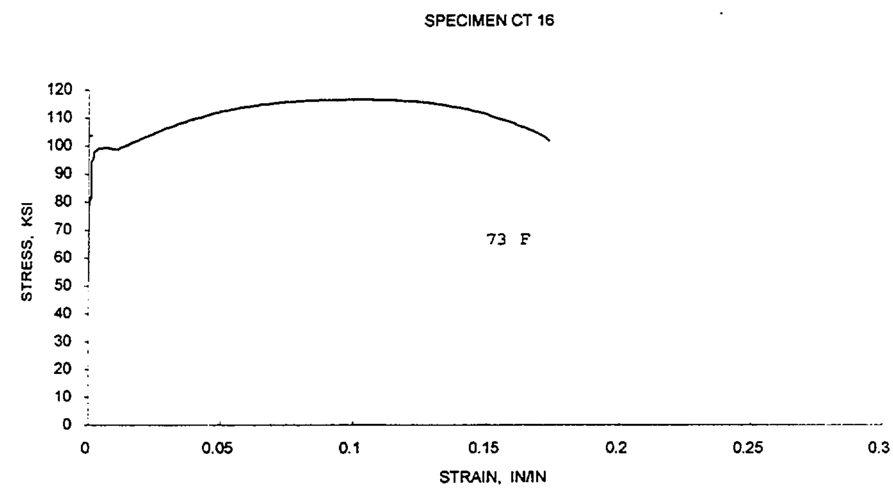
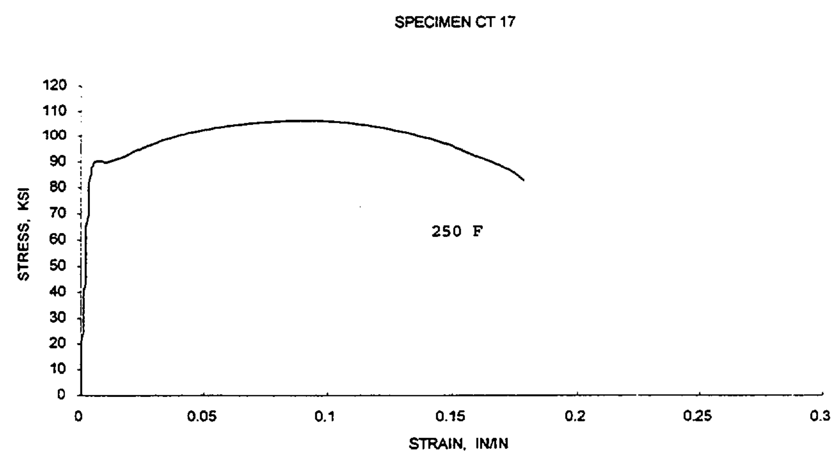



**Figure 5-23 Engineering Stress-Strain Curves for Intermediate Shell Plate B7212-1Tensile Specimens CL16, CL17 and CL18 (Longitudinal Orientation)**



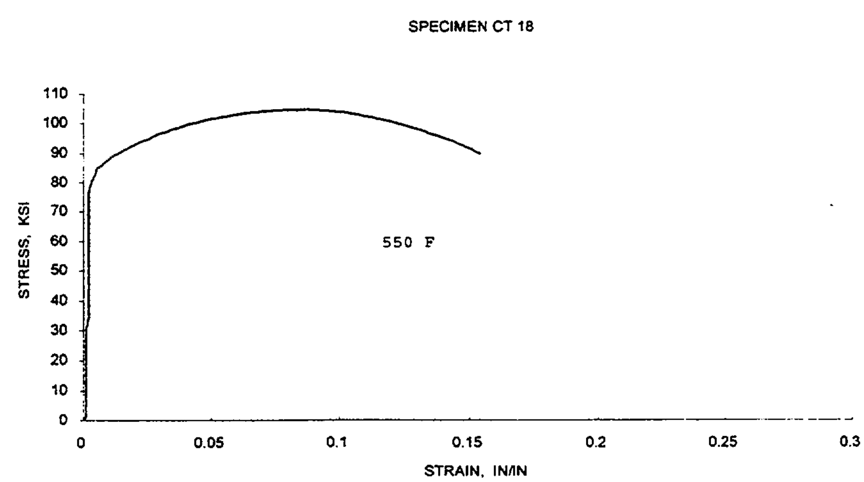




**Figure 5-24 Engineering Stress-Strain Curves for Intermediate Shell Plate B7212-1 Tensile Specimens CT16, CT17 and CT18 (Transverse Orientation)**

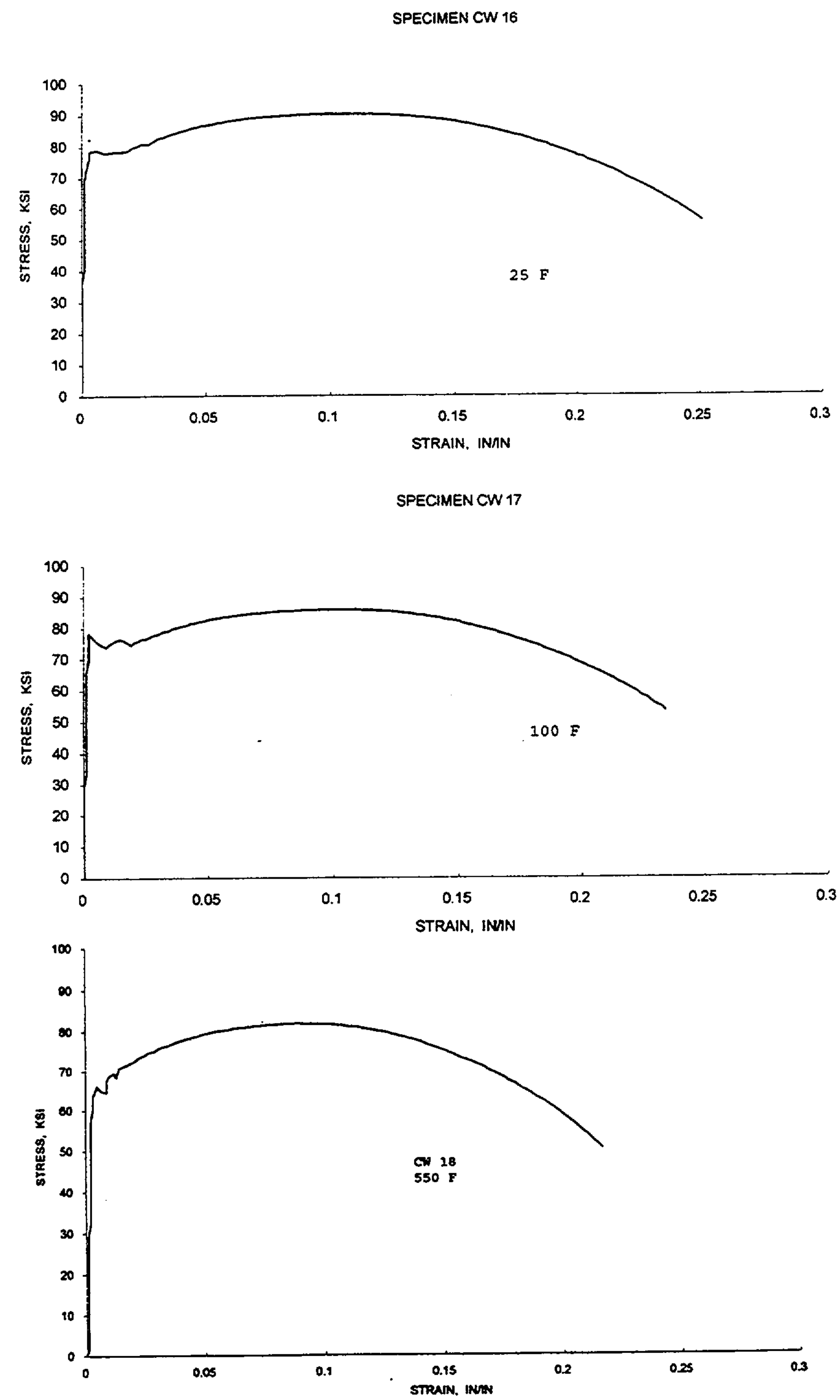



**Figure 5-25 Engineering Stress-Strain Curves for Weld Metal Tensile Specimens CW16, CW17 and CW18**

# 6 RADIATION ANALYSIS AND NEUTRON DOSIMETRY

## 6.1 INTRODUCTION

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

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

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

This section provides the results of the neutron dosimetry evaluations performed in conjunction with the analysis of test specimens contained in surveillance Capsules U, W, X, and Z which were withdrawn during the first, fourth, sixth, and twelfth fuel cycles, respectively. This evaluation is based on current state-of-the-art methodology and nuclear data including neutron transport and dosimetry cross-section libraries derived from the ENDF/B-VI data base. This report provides a consistent up-to-date neutron exposure data base for use in evaluating the material properties of the Farley Unit 2 reactor vessel.

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

## 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 are included in the reactor design to constitute the reactor vessel surveillance program. The capsules are located at azimuthal angles of 107°, 110°, 287°, 290°, 340°, and 343° 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 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[17] and the BUGLE-96 cross-section library[18]. The BUGLE-96 library is a 47 energy group ENDF/B-VI based data set produced specifically for light water reactor applications. In these analyses, anisotropic scattering was treated with a $P_3$ expansion of the scattering cross-sections and the angular discretization was modeled with an $S_8$ order of angular quadrature.

The core power distribution utilized in the reference forward transport calculation was derived from statistical studies of long-term operation of Westinghouse 3-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:

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

where:

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

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

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

Although the adjoint importance functions used in this analysis were based on a response function defined by the threshold neutron flux $\phi(E > 1.0\ \text{MeV})$, prior calculations[19] have shown that, while the implementation of low leakage loading patterns significantly impacts both the magnitude and spatial distribution of the neutron field, changes in the relative neutron energy spectrum are of second order.

Thus, for a given location, the ratio of [dpa/sec]/[$\phi$(E > 1.0 MeV)] is insensitive to changing core source distributions. In the application of these adjoint importance functions to the Farley Unit 2 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 fuel cycle design data for the first twelve operating cycles of Farley Unit 2[20 through 32].

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, W, X, and Z 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 (17° and 20°) for both the reference and the plant specific core power distributions. The plant-specific data, based on the adjoint transport analysis, are meant to establish the absolute comparison of measurement with analysis. The reference data derived from the forward calculation are provided as a conservative exposure evaluation against which plant specific fluence calculations can be compared. Similar data are given in Table 6-2 for the reactor vessel inner radius. Again, the three pertinent exposure parameters are listed for the reference and Cycles 1 to 12 plant specific power distributions.

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

Radial gradient information applicable to $\phi$(E > 1.0 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 MeV) at the ¼T depth in the reactor vessel wall along the 0° azimuth is given by:

$$\phi_{1/4T}(0°) = \phi(199.95, 0°)\, F(204.95, 0°)$$

where:

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

$\phi(199.95, 0°)$ = Projected or calculated neutron flux at the vessel inner radius on the 0° azimuth.

$F(204.95, 0°)$ = Ratio of the neutron flux at the ¼T position to the flux at the vessel inner radius for the 0° azimuth. This data is obtained from Table 6-3.

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

## 6.3 Neutron Dosimetry

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

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

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

The specific activity of each of the neutron monitors was determined using established ASTM procedures[34 through 47]. Following sample preparation and weighing, the activity of each monitor was determined by means of a lithium-drifted germanium, Ge(Li), gamma spectrometer. The irradiation history of the Farley Unit 2 reactor was obtained from Southern Nuclear Company personnel[32] and data reported in NUREG-0020, "Licensed Operating Reactors Status Summary Report," for the Cycles 1 to 12 operating periods. The irradiation history applicable to the exposure of Capsules U, W, X, and Z 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.

$\lambda$ = 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, W, X, and Z 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[48]. 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, $\phi$, 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 $\alpha$ 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, $\phi_g$, by the multi-group reaction cross-section, $\sigma_{ig}$. 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[49]. 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[50], 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 $\gamma$ ($\theta$ specifies the strength of the latter term). The value of $\delta$ 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 $\theta$ is close to 1. Strong long-range correlations (or anti-correlations) were justified based on information presented by R. E. Maerker[51]. 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 Capsules U, W, X, and Z dosimetry are given in Table 6-9. The data summarized in this table include fast neutron exposure evaluations in terms of $\Phi(E > 1.0$ MeV), $\Phi(E > 0.1$ MeV), and dpa. In general, excellent results were achieved in the fits of the best estimate spectra to the individual measured reaction rates. The measured, calculated and best estimate reaction rates for each reaction are given in Table 6-10. An examination of Table 6-10 shows that, in all cases, the reaction rates calculated with the best estimate spectra match the measured reaction rates to better than 7%. 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, W, X, and Z are presented. The results for the Capsules U, W, X, and Z dosimetry evaluation [BE/C ratio of 0.87 for $\Phi(E > 1.0$ MeV)] are consistent with results obtained from similar evaluations of dosimetry from other reactors using methodologies based on ENDF/B-VI cross-sections.

## 6.4 Projections of Reactor Vessel Exposure

The best estimate exposure of the Farley Unit 2 reactor vessel was developed using a combination of absolute plant specific transport calculations and all available plant specific measurement data. In the case of Farley Unit 2, the measurement data base contains measurements from the 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 Farley Unit 2, the derived plant specific bias factors were 0.87, 0.92, 0.91 for $\Phi(E > 1.0\ MeV)$, $\Phi(E > 0.1\ MeV)$, 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 Farley Unit 2, the derived uncertainties in the bias factor, K, and the additional uncertainty from the analytical sensitivity studies combine to yield a net uncertainty of ± 12%

Based on this best estimate approach, neutron exposure projections at key locations on the reactor vessel inner radius are given in Table 6-13; furthermore, calculated neutron exposure projections are also provided for comparison purposes. Along with the current (13.24 EFPY) exposure, projections are also provided for exposure periods of 20 EFPY, 36 EFPY, and 54 EFPY. Projections for future operation were based on the assumption that the Cycles 9 through 12 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 Farley Unit 2 reactor vessel, exposure projections to 20, 36, and 54 EFPY were also employed. Data based on both a $\Phi(E > 1.0 \text{ MeV})$ slope and a plant-specific dpa slope through the vessel wall are provided in Table 6-14.

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

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

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

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

Figure 6-1

Plan View of a Dual Reactor Vessel Surveillance Capsule

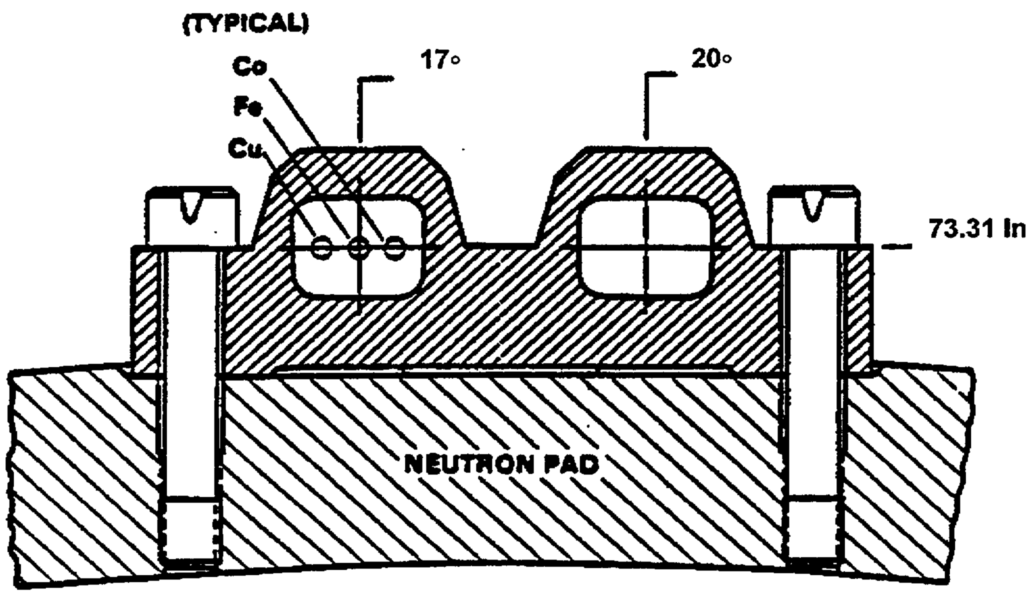


Table 6-1
Calculated Fast Neutron Exposure Rates and Iron Atom Displacement Rates at the Surveillance Capsule Center

| | $\phi$(E > 1.0 MeV) (n/cm$^2$-sec) | |
|---|---|---|
| Cycle No. | 17° | 20° |
| Reference | 2.31E+11 | 2.00E+11 |
| 1 | 1.92E+11 | 1.66E+11 |
| 2 | 2.01E+11 | 1.73E+11 |
| 3 | 1.82E+11 | 1.55E+11 |
| 4 | 1.50E+11 | 1.30E+11 |
| 5 | 1.45E+11 | 1.25E+11 |
| 6 | 1.34E+11 | 1.18E+11 |
| 7 | 1.41E+11 | 1.26E+11 |
| 8 | 1.33E+11 | 1.17E+11 |
| 9 | 1.23E+11 | 1.09E+11 |
| 10 | 1.33E+11 | 1.18E+11 |
| 11 | 1.20E+11 | 1.01E+11 |
| 12 | 1.20E+11 | 1.07E+11 |

| | $\phi$(E > 0.1 MeV) (n/cm$^2$-sec) | |
|---|---|---|
| Cycle No. | 17° | 20° |
| Reference | 1.13E+12 | 9.37E+11 |
| 1 | 9.40E+11 | 7.80E+11 |
| 2 | 9.81E+11 | 8.10E+11 |
| 3 | 8.89E+11 | 7.27E+11 |
| 4 | 7.34E+11 | 6.11E+11 |
| 5 | 7.09E+11 | 5.88E+11 |
| 6 | 6.54E+11 | 5.54E+11 |
| 7 | 6.89E+11 | 5.90E+11 |
| 8 | 6.49E+11 | 5.48E+11 |
| 9 | 6.02E+11 | 5.10E+11 |
| 10 | 6.52E+11 | 5.55E+11 |
| 11 | 5.85E+11 | 4.74E+11 |
| 12 | 5.89E+11 | 5.01E+11 |

Table 6-1 Cont'd
Calculated Fast Neutron Exposure Rates and Iron Atom Displacement Rates at the Surveillance Capsule Center

| | Iron Atom Displacement Rate (dpa/sec) | |
|---|---|---|
| Cycle No. | 17° | 20° |
| Reference | 4.67E-10 | 3.94E-10 |
| 1 | 3.88E-10 | 3.28E-10 |
| 2 | 4.05E-10 | 3.41E-10 |
| 3 | 3.67E-10 | 3.06E-10 |
| 4 | 3.03E-10 | 2.57E-10 |
| 5 | 2.93E-10 | 2.47E-10 |
| 6 | 2.70E-10 | 2.33E-10 |
| 7 | 2.85E-10 | 2.48E-10 |
| 8 | 2.68E-10 | 2.30E-10 |
| 9 | 2.49E-10 | 2.15E-10 |
| 10 | 2.69E-10 | 2.33E-10 |
| 11 | 2.42E-10 | 1.99E-10 |
| 12 | 2.43E-10 | 2.11E-10 |

Table 6-2

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

| | $\phi$(E > 1.0 MeV) (n/cm$^2$-sec) | | | |
|---|---|---|---|---|
| Cycle No. | 0° | 15° | 30° | 45° |
| Reference | 6.92E+10 | 3.84E+10 | 2.81E+10 | 1.89E+10 |
| 1 | 5.80E+10 | 3.23E+10 | 2.38E+10 | 1.65E+10 |
| 2 | 6.06E+10 | 3.37E+10 | 2.47E+10 | 1.71E+10 |
| 3 | 5.54E+10 | 3.06E+10 | 2.05E+10 | 1.27E+10 |
| 4 | 4.43E+10 | 2.52E+10 | 1.80E+10 | 1.29E+10 |
| 5 | 4.09E+10 | 2.44E+10 | 1.73E+10 | 1.14E+10 |
| 6 | 3.64E+10 | 2.24E+10 | 1.73E+10 | 1.21E+10 |
| 7 | 3.93E+10 | 2.37E+10 | 1.86E+10 | 1.27E+10 |
| 8 | 3.60E+10 | 2.23E+10 | 1.71E+10 | 1.23E+10 |
| 9 | 3.35E+10 | 2.07E+10 | 1.63E+10 | 1.20E+10 |
| 10 | 3.52E+10 | 2.23E+10 | 1.73E+10 | 1.25E+10 |
| 11 | 4.27E+10 | 2.07E+10 | 1.49E+10 | 1.16E+10 |
| 12 | 2.97E+10 | 2.01E+10 | 1.50E+10 | 1.07E+10 |

| | $\phi$(E > 0.1 MeV) (n/cm$^2$-sec) | | | |
|---|---|---|---|---|
| Cycle No. | 0° | 15° | 30° | 45° |
| Reference | 1.81E+11 | 9.35E+10 | 6.07E+10 | 4.03E+10 |
| 1 | 1.51E+11 | 7.86E+10 | 5.13E+10 | 3.51E+10 |
| 2 | 1.58E+11 | 8.20E+10 | 5.33E+10 | 3.63E+10 |
| 3 | 1.44E+11 | 7.46E+10 | 4.41E+10 | 2.71E+10 |
| 4 | 1.16E+11 | 6.14E+10 | 3.87E+10 | 2.76E+10 |
| 5 | 1.07E+11 | 5.93E+10 | 3.73E+10 | 2.42E+10 |
| 6 | 9.51E+10 | 5.47E+10 | 3.73E+10 | 2.59E+10 |
| 7 | 1.03E+11 | 5.76E+10 | 4.00E+10 | 2.70E+10 |
| 8 | 9.39E+10 | 5.43E+10 | 3.68E+10 | 2.62E+10 |
| 9 | 8.75E+10 | 5.05E+10 | 3.52E+10 | 2.55E+10 |
| 10 | 9.18E+10 | 5.44E+10 | 3.73E+10 | 2.65E+10 |
| 11 | 1.11E+11 | 5.04E+10 | 3.20E+10 | 2.48E+10 |
| 12 | 7.76E+10 | 4.88E+10 | 3.24E+10 | 2.29E+10 |

Table 6-2 Cont'd

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

| | Iron Atom Displacement Rate (dpa/sec) | | | |
|---|---|---|---|---|
| Cycle No. | 0° | 15° | 30° | 45° |
| Reference | 1.10E-10 | 6.06E-11 | 4.32E-11 | 2.93E-11 |
| 1 | 9.23E-11 | 5.09E-11 | 3.65E-11 | 2.55E-11 |
| 2 | 9.64E-11 | 5.31E-11 | 3.79E-11 | 2.64E-11 |
| 3 | 8.81E-11 | 4.83E-11 | 3.14E-11 | 1.97E-11 |
| 4 | 7.04E-11 | 3.97E-11 | 2.76E-11 | 2.00E-11 |
| 5 | 6.51E-11 | 3.84E-11 | 2.65E-11 | 1.76E-11 |
| 6 | 5.80E-11 | 3.54E-11 | 2.66E-11 | 1.88E-11 |
| 7 | 6.26E-11 | 3.73E-11 | 2.85E-11 | 1.96E-11 |
| 8 | 5.73E-11 | 3.51E-11 | 2.62E-11 | 1.91E-11 |
| 9 | 5.34E-11 | 3.27E-11 | 2.51E-11 | 1.85E-11 |
| 10 | 5.60E-11 | 3.52E-11 | 2.66E-11 | 1.93E-11 |
| 11 | 6.80E-11 | 3.26E-11 | 2.28E-11 | 1.80E-11 |
| 12 | 4.73E-11 | 3.16E-11 | 2.31E-11 | 1.66E-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° |
| 199.95 | 1.000 | 1.000 | 1.000 | 1.000 |
| 200.54 | 0.961 | 0.962 | 0.961 | 0.963 |
| 201.72 | 0.861 | 0.863 | 0.864 | 0.868 |
| 202.89 | 0.754 | 0.760 | 0.758 | 0.765 |
| 204.07 | 0.653 | 0.661 | 0.658 | 0.667 |
| 204.95 | 0.585 | 0.595 | 0.591 | 0.601 |
| 205.25 | 0.562 | 0.573 | 0.568 | 0.578 |
| 206.42 | 0.482 | 0.494 | 0.488 | 0.499 |
| 207.60 | 0.412 | 0.424 | 0.417 | 0.429 |
| 208.78 | 0.351 | 0.364 | 0.356 | 0.368 |
| 209.95 | 0.299 | 0.311 | 0.304 | 0.315 |
| 211.13 | 0.254 | 0.266 | 0.258 | 0.269 |
| 212.30 | 0.215 | 0.227 | 0.219 | 0.229 |
| 213.48 | 0.182 | 0.193 | 0.186 | 0.195 |
| 214.66 | 0.153 | 0.164 | 0.157 | 0.166 |
| 214.95 | 0.147 | 0.158 | 0.151 | 0.159 |
| 215.83 | 0.129 | 0.139 | 0.132 | 0.141 |
| 217.01 | 0.107 | 0.118 | 0.111 | 0.119 |
| 218.19 | 0.089 | 0.099 | 0.093 | 0.100 |
| 219.36 | 0.071 | 0.083 | 0.076 | 0.084 |
| 219.95 | 0.068 | 0.080 | 0.073 | 0.081 |

Note: Base Metal Inner Radius = 199.95 cm
Base Metal ¼T = 204.95 cm
Base Metal ½T = 209.95 cm
Base Metal ¾T = 214.95 cm
Base Metal Outer Radius = 219.95 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° |
| 199.95 | 1.000 | 1.000 | 1.000 | 1.000 |
| 200.54 | 1.005 | 1.011 | 1.007 | 1.011 |
| 201.72 | 0.982 | 0.995 | 0.989 | 0.998 |
| 202.89 | 0.940 | 0.961 | 0.951 | 0.965 |
| 204.07 | 0.891 | 0.919 | 0.904 | 0.923 |
| 204.95 | 0.852 | 0.885 | 0.867 | 0.889 |
| 205.25 | 0.839 | 0.873 | 0.855 | 0.878 |
| 206.42 | 0.786 | 0.825 | 0.804 | 0.830 |
| 207.60 | 0.733 | 0.776 | 0.753 | 0.781 |
| 208.78 | 0.681 | 0.728 | 0.703 | 0.733 |
| 209.95 | 0.630 | 0.680 | 0.655 | 0.686 |
| 211.13 | 0.581 | 0.633 | 0.607 | 0.639 |
| 212.30 | 0.533 | 0.586 | 0.561 | 0.593 |
| 213.48 | 0.486 | 0.540 | 0.516 | 0.548 |
| 214.66 | 0.441 | 0.496 | 0.472 | 0.505 |
| 214.95 | 0.430 | 0.485 | 0.462 | 0.494 |
| 215.83 | 0.397 | 0.452 | 0.430 | 0.462 |
| 217.01 | 0.353 | 0.408 | 0.388 | 0.420 |
| 218.19 | 0.308 | 0.365 | 0.347 | 0.380 |
| 219.36 | 0.261 | 0.321 | 0.307 | 0.340 |
| 219.95 | 0.251 | 0.312 | 0.298 | 0.332 |

Note: Base Metal Inner Radius = 199.95 cm
Base Metal ¼T = 204.95 cm
Base Metal ½T = 209.95 cm
Base Metal ¾T = 214.95 cm
Base Metal Outer Radius = 219.95 cm

Table 6-5

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

| RADIUS (cm) | AZIMUTHAL ANGLE 0° | 15° | 30° | 45° |
|---|---|---|---|---|
| 199.95 | 1.000 | 1.000 | 1.000 | 1.000 |
| 200.54 | 0.968 | 0.971 | 0.967 | 0.969 |
| 201.72 | 0.889 | 0.897 | 0.885 | 0.889 |
| 202.89 | 0.805 | 0.821 | 0.798 | 0.804 |
| 204.07 | 0.725 | 0.747 | 0.715 | 0.724 |
| 204.95 | 0.670 | 0.695 | 0.659 | 0.668 |
| 205.25 | 0.651 | 0.678 | 0.640 | 0.650 |
| 206.42 | 0.584 | 0.615 | 0.572 | 0.583 |
| 207.60 | 0.524 | 0.558 | 0.511 | 0.523 |
| 208.78 | 0.470 | 0.506 | 0.456 | 0.469 |
| 209.95 | 0.421 | 0.458 | 0.408 | 0.421 |
| 211.13 | 0.376 | 0.414 | 0.364 | 0.377 |
| 212.30 | 0.336 | 0.374 | 0.325 | 0.338 |
| 213.48 | 0.299 | 0.337 | 0.290 | 0.303 |
| 214.66 | 0.265 | 0.303 | 0.258 | 0.271 |
| 214.95 | 0.258 | 0.295 | 0.251 | 0.264 |
| 215.83 | 0.234 | 0.272 | 0.229 | 0.242 |
| 217.01 | 0.205 | 0.242 | 0.203 | 0.216 |
| 218.19 | 0.177 | 0.214 | 0.178 | 0.191 |
| 219.36 | 0.149 | 0.188 | 0.156 | 0.170 |
| 219.95 | 0.143 | 0.183 | 0.151 | 0.166 |

Note: Base Metal Inner Radius = 199.95 cm
Base Metal ¼T = 204.95 cm
Base Metal ½T = 209.95 cm
Base Metal ¾T = 214.95 cm
Base Metal Outer Radius = 219.95 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 | 312.1 d | |
| Nickel | $^{58}Ni$ (n,p) | 0.6808 | E > 1.0 MeV | 70.88 d | |
| Uranium-238 | $^{238}U$ (n,f) | 1.0000 | 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 Twelve Fuel Cycles
of the Farley Unit 2 Reactor
(Reference Power of 2775 MWt)

| Year | Month | Thermal Generat. (MW-hr) | Year | Month | Thermal Generat. (MW-hr) | Year | Month | Thermal Generat. (MW-hr) |
|---|---|---|---|---|---|---|---|---|
| 1981 | 5 | 49210 | 1984 | 9 | 944645 | 1988 | 1 | 1971889 |
| 1981 | 6 | 369436 | 1984 | 10 | 1813687 | 1988 | 2 | 1806542 |
| 1981 | 7 | 118595 | 1984 | 11 | 1906767 | 1988 | 3 | 1973062 |
| 1981 | 8 | 1830227 | 1984 | 12 | 1771677 | 1988 | 4 | 1906960 |
| 1981 | 9 | 1837261 | 1985 | 1 | 239473 | 1988 | 5 | 1973062 |
| 1981 | 10 | 1948774 | 1985 | 2 | 0 | 1988 | 6 | 1904396 |
| 1981 | 11 | 1818795 | 1985 | 3 | 368968 | 1988 | 7 | 1973019 |
| 1981 | 12 | 1912506 | 1985 | 4 | 1861582 | 1988 | 8 | 1973083 |
| 1982 | 1 | 1707819 | 1985 | 5 | 1925137 | 1988 | 9 | 1767980 |
| 1982 | 2 | 10186 | 1985 | 6 | 1865725 | 1988 | 10 | 1975740 |
| 1982 | 3 | 1541170 | 1985 | 7 | 1769634 | 1988 | 11 | 1690586 |
| 1982 | 4 | 1855620 | 1985 | 8 | 1739953 | 1988 | 12 | 1938045 |
| 1982 | 5 | 1913932 | 1985 | 9 | 1867238 | 1989 | 1 | 1967158 |
| 1982 | 6 | 1836202 | 1985 | 10 | 1943516 | 1989 | 2 | 1687171 |
| 1982 | 7 | 1925451 | 1985 | 11 | 1874503 | 1989 | 3 | 1516400 |
| 1982 | 8 | 1963933 | 1985 | 12 | 1962073 | 1989 | 4 | 0 |
| 1982 | 9 | 1814278 | 1986 | 1 | 1798238 | 1989 | 5 | 172773 |
| 1982 | 10 | 1387065 | 1986 | 2 | 1755415 | 1989 | 6 | 1786822 |
| 1982 | 11 | 0 | 1986 | 3 | 1945120 | 1989 | 7 | 1864633 |
| 1982 | 12 | 1572848 | 1986 | 4 | 239320 | 1989 | 8 | 1971608 |
| 1983 | 1 | 1967195 | 1986 | 5 | 396193 | 1989 | 9 | 1456223 |
| 1983 | 2 | 1778710 | 1986 | 6 | 1744613 | 1989 | 10 | 1848890 |
| 1983 | 3 | 1969863 | 1986 | 7 | 1625000 | 1989 | 11 | 1815074 |
| 1983 | 4 | 1899797 | 1986 | 8 | 1865663 | 1989 | 12 | 1971879 |
| 1983 | 5 | 1970049 | 1986 | 9 | 1871967 | 1990 | 1 | 1970306 |
| 1983 | 6 | 1905327 | 1986 | 10 | 1966262 | 1990 | 2 | 1631313 |
| 1983 | 7 | 1960067 | 1986 | 11 | 1905245 | 1990 | 3 | 1971205 |
| 1983 | 8 | 1966925 | 1986 | 12 | 1970404 | 1990 | 4 | 1694856 |
| 1983 | 9 | 937869 | 1987 | 1 | 789042 | 1990 | 5 | 1168621 |
| 1983 | 10 | 163398 | 1987 | 2 | 1756640 | 1990 | 6 | 1907902 |
| 1983 | 11 | 1479567 | 1987 | 3 | 1839164 | 1990 | 7 | 1970982 |
| 1983 | 12 | 1917263 | 1987 | 4 | 1873088 | 1990 | 8 | 1970095 |
| 1984 | 1 | 1711893 | 1987 | 5 | 1972677 | 1990 | 9 | 1907101 |
| 1984 | 2 | 1845593 | 1987 | 6 | 1771494 | 1990 | 10 | 755300 |
| 1984 | 3 | 1895910 | 1987 | 7 | 1970667 | 1990 | 11 | 0 |
| 1984 | 4 | 1845190 | 1987 | 8 | 1782971 | 1990 | 12 | 0 |
| 1984 | 5 | 1950480 | 1987 | 9 | 1909196 | 1991 | 1 | 1459221 |
| 1984 | 6 | 1909440 | 1987 | 10 | 119759 | 1991 | 2 | 1744114 |
| 1984 | 7 | 1968023 | 1987 | 11 | 0 | 1991 | 3 | 1971550 |
| 1984 | 8 | 1951599 | 1987 | 12 | 240584 | 1991 | 4 | 1237745 |

Table 6-7 Cont'd

Monthly Thermal Generation During the First Twelve Fuel Cycles
of the Farley Unit 2 Reactor
(Reference Power of 2775 MWt)

| Year | Month | Thermal Generat. (MW-hr) | Year | Month | Thermal Generat. (MW-hr) | Year | Month | Thermal Generat. (MW-hr) |
|---|---|---|---|---|---|---|---|---|
| 1991 | 5 | 1965554 | 1994 | 9 | 1909440 | 1998 | 1 | 1972558 |
| 1991 | 6 | 1905656 | 1994 | 10 | 1975737 | 1998 | 2 | 1782144 |
| 1991 | 7 | 1966074 | 1994 | 11 | 1905343 | 1998 | 3 | 1715128 |
| 1991 | 8 | 1874009 | 1994 | 12 | 1709587 | | | |
| 1991 | 9 | 1901630 | 1995 | 1 | 1728025 | | | |
| 1991 | 10 | 1973717 | 1995 | 2 | 1742523 | | | |
| 1991 | 11 | 1784506 | 1995 | 3 | 555111 | | | |
| 1991 | 12 | 1971598 | 1995 | 4 | 76112 | | | |
| 1992 | 1 | 1853267 | 1995 | 5 | 493007 | | | |
| 1992 | 2 | 1845792 | 1995 | 6 | 880008 | | | |
| 1992 | 3 | 367169 | 1995 | 7 | 1896021 | | | |
| 1992 | 4 | 0 | 1995 | 8 | 1865019 | | | |
| 1992 | 5 | 513304 | 1995 | 9 | 1909440 | | | |
| 1992 | 6 | 1783981 | 1995 | 10 | 1776999 | | | |
| 1992 | 7 | 1877441 | 1995 | 11 | 1772332 | | | |
| 1992 | 8 | 1965981 | 1995 | 12 | 1939487 | | | |
| 1992 | 9 | 1779781 | 1996 | 1 | 1867751 | | | |
| 1992 | 10 | 1742799 | 1996 | 2 | 1809698 | | | |
| 1992 | 11 | 1890054 | 1996 | 3 | 1832081 | | | |
| 1992 | 12 | 1952058 | 1996 | 4 | 1895146 | | | |
| 1993 | 1 | 1879525 | 1996 | 5 | 1880613 | | | |
| 1993 | 2 | 1114049 | 1996 | 6 | 1907027 | | | |
| 1993 | 3 | 1936119 | 1996 | 7 | 1973088 | | | |
| 1993 | 4 | 1885890 | 1996 | 8 | 1972155 | | | |
| 1993 | 5 | 1902839 | 1996 | 9 | 1891141 | | | |
| 1993 | 6 | 1889227 | 1996 | 10 | 696495 | | | |
| 1993 | 7 | 1906713 | 1996 | 11 | 0 | | | |
| 1993 | 8 | 1952573 | 1996 | 12 | 749110 | | | |
| 1993 | 9 | 1433273 | 1997 | 1 | 1972929 | | | |
| 1993 | 10 | 0 | 1997 | 2 | 1688502 | | | |
| 1993 | 11 | 0 | 1997 | 3 | 1973088 | | | |
| 1993 | 12 | 1104196 | 1997 | 4 | 1906788 | | | |
| 1994 | 1 | 1953209 | 1997 | 5 | 1971338 | | | |
| 1994 | 2 | 1772701 | 1997 | 6 | 1909440 | | | |
| 1994 | 3 | 1962548 | 1997 | 7 | 1973008 | | | |
| 1994 | 4 | 1893222 | 1997 | 8 | 1971815 | | | |
| 1994 | 5 | 1963755 | 1997 | 9 | 1909440 | | | |
| 1994 | 6 | 1903898 | 1997 | 10 | 1975501 | | | |
| 1994 | 7 | 1973017 | 1997 | 11 | 1908804 | | | |
| 1994 | 8 | 1881896 | 1997 | 12 | 1951236 | | | |

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,$\alpha$) $^{60}Co$ | Top | 6.42E+04 | 5.50E+05 | 8.39E-17 |
| | Middle | 6.47E+04 | 5.54E+05 | 8.46E-17 |
| | Bottom | 6.79E+04 | 5.82E+05 | 8.87E-17 |
| $^{54}Fe$ (n,p) $^{54}Mn$ | Top | 1.68E+06 | 5.68E+06 | 9.00E-15 |
| | Middle | 1.62E+06 | 5.48E+06 | 8.68E-15 |
| | Bottom | 1.71E+06 | 5.78E+06 | 9.17E-15 |
| $^{58}Ni$ (n,p) $^{58}Co$ | Top | 5.17E+06 | 8.64E+07 | 1.24E-14 |
| | Middle | 4.84E+06 | 8.09E+07 | 1.16E-14 |
| | Bottom | 5.29E+06 | 8.84E+07 | 1.27E-14 |
| $^{59}Co$ (n,$\gamma$) $^{60}Co$ | Top | 1.36E+07 | 1.17E+08 | 7.60E-12 |
| | Middle | 1.42E+07 | 1.22E+08 | 7.94E-12 |
| | Bottom | 1.40E+07 | 1.20E+08 | 7.83E-12 |
| $^{59}Co$ (n,$\gamma$) $^{60}Co$ (Cd) | Top | 7.76E+06 | 6.65E+07 | 4.34E-12 |
| | Middle | 8.09E+06 | 6.93E+07 | 4.52E-12 |
| | Bottom | 7.82E+06 | 6.70E+07 | 4.37E-12 |
| $^{238}U$ (n,f) $^{137}Cs$ (Cd) | Middle | 2.29E+05 | 9.65E+06 | 6.34E-14 |
| | Including $^{235}U$, $^{239}Pu$, and $\gamma$-fission corrections | | | 5.32E-14 |
| $^{237}Np$ (n,f) $^{137}Cs$ (Cd) | Middle | 2.15E+06 | 9.06E+07 | 5.78E-13 |
| | Including $\gamma$-fission correction | | | 5.74E-13 |

Table 6-8 Cont'd

Measured Sensor Activities and Reaction Rates

Surveillance Capsule W

| Reaction | Location | Measured Activity (dps/gm) | Saturated Activity (dps/gm) | Reaction Rate (rps/atom) |
|---|---|---|---|---|
| $^{63}Cu\ (n,\alpha)\ ^{60}Co$ | Top | 1.53E+05 | 4.52E+05 | 6.89E-17 |
| | Middle | 1.55E+05 | 4.57E+05 | 6.98E-17 |
| | Bottom | 1.69E+05 | 4.99E+05 | 7.61E-17 |
| $^{54}Fe\ (n,p)\ ^{54}Mn$ | Top | 2.11E+06 | 4.58E+06 | 7.27E-15 |
| | Middle | 2.05E+06 | 4.45E+06 | 7.06E-15 |
| | Bottom | 2.19E+06 | 4.76E+06 | 7.54E-15 |
| $^{58}Ni\ (n,p)\ ^{58}Co$ | Top | 7.28E+06 | 7.21E+07 | 1.03E-14 |
| | Middle | 6.91E+06 | 6.84E+07 | 9.79E-15 |
| | Bottom | 8.04E+06 | 7.96E+07 | 1.14E-14 |
| $^{59}Co\ (n,\gamma)\ ^{60}Co$ | Top | 2.77E+07 | 8.17E+07 | 5.33E-12 |
| | Middle | 2.92E+07 | 8.62E+07 | 5.62E-12 |
| | Bottom | 2.78E+07 | 8.20E+07 | 5.35E-12 |
| $^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd) | Top | 1.56E+07 | 4.60E+07 | 3.00E-12 |
| | Middle | 1.64E+07 | 4.84E+07 | 3.16E-12 |
| | Bottom | 1.62E+07 | 4.78E+07 | 3.12E-12 |
| $^{238}U\ (n,f)\ ^{137}Cs$ (Cd) | Middle | 5.70E+05 | 7.01E+06 | 4.60E-14 |
| | Including $^{235}U$, $^{239}Pu$, and $\gamma$-fission corrections | | | 3.67E-14 |
| $^{237}Np\ (n,f)\ ^{137}Cs$ (Cd) | Middle | 5.54E+06 | 6.81E+07 | 4.35E-13 |
| | Including $\gamma$-fission correction | | | 4.32E-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 | 2.27E+05 | 4.73E+05 | 7.21E-17 |
| | Middle | 2.21E+05 | 4.60E+05 | 7.02E-17 |
| | Bottom | 2.33E+05 | 4.85E+05 | 7.40E-17 |
| $^{54}Fe\ (n,p)\ ^{54}Mn$ | Top | 2.85E+06 | 4.52E+06 | 7.17E-15 |
| | Middle | 2.80E+06 | 4.44E+06 | 7.05E-15 |
| | Bottom | 2.95E+06 | 4.68E+06 | 7.42E-15 |
| $^{58}Ni\ (n,p)\ ^{58}Co$ | Top | 3.24E+07 | 7.33E+07 | 1.05E-14 |
| | Middle | 3.07E+07 | 6.95E+07 | 9.94E-15 |
| | Bottom | 3.34E+07 | 7.56E+07 | 1.08E-14 |
| $^{59}Co\ (n,\gamma)\ ^{60}Co$ | Top | 4.90E+07 | 1.02E+08 | 6.66E-12 |
| | Middle | 5.09E+07 | 1.06E+08 | 6.91E-12 |
| | Bottom | 5.06E+07 | 1.05E+08 | 6.87E-12 |
| $^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd) | Top | 2.90E+07 | 6.04E+07 | 3.94E-12 |
| | Middle | 2.76E+07 | 5.75E+07 | 3.75E-12 |
| | Bottom | 2.75E+07 | 5.73E+07 | 3.74E-12 |
| | Bottom | 2.67E+07 | 5.56E+07 | 3.63E-12 |

No fission monitors present in the capsule.

Table 6-8 Cont'd

Measured Sensor Activities and Reaction Rates

Surveillance Capsule Z

| Reaction | Location | Measured Activity (dps/gm) | Saturated Activity (dps/gm) | Reaction Rate (rps/atom) |
|---|---|---|---|---|
| $^{63}Cu$ (n,α) $^{60}Co$ | Top | 2.90E+05 | 4.78E+05 | 7.29E-17 |
| | Middle | 2.81E+05 | 4.63E+05 | 7.06E-17 |
| | Bottom | 3.00E+05 | 4.94E+05 | 7.54E-17 |
| $^{54}Fe$ (n,p) $^{54}Mn$ | Top | 2.17E+06 | 4.82E+06 | 7.64E-15 |
| | Middle | 2.06E+06 | 4.57E+06 | 7.25E-15 |
| | Bottom | 2.21E+06 | 4.91E+06 | 7.78E-15 |
| $^{58}Ni$ (n,p) $^{58}Co$ | Top | 7.13E+06 | 7.58E+07 | 1.09E-14 |
| | Middle | 6.86E+06 | 7.29E+07 | 1.04E-14 |
| | Bottom | 7.42E+06 | 7.89E+07 | 1.13E-14 |
| $^{59}Co$ (n,γ) $^{60}Co$ | Top | 4.37E+07 | 7.20E+07 | 4.70E-12 |
| | Middle | 4.49E+07 | 7.40E+07 | 4.83E-12 |
| | Bottom | 4.30E+07 | 7.09E+07 | 4.62E-12 |
| $^{59}Co$ (n,γ) $^{60}Co$ (Cd) | Top | 2.41E+07 | 3.97E+07 | 2.59E-12 |
| | Middle | 2.52E+07 | 4.15E+07 | 2.71E-12 |
| | Bottom | 2.42E+07 | 3.99E+07 | 2.60E-12 |
| $^{238}U$ (n,f) $^{137}Cs$ (Cd) | Middle | 2.12E+06 | 8.62E+06 | 5.66E-14 |
| | Including $^{235}U$, $^{239}Pu$, and γ-fission corrections | | | 3.89E-14 |
| $^{237}Np$ (n,f) $^{137}Cs$ (Cd) | Middle | 1.12E+07 | 4.55E+07 | 2.90E-13 |
| | Including γ-fission correction | | | 2.89E-13 |

The reaction rate for $^{237}Np$ (n,f) $^{137}Cs$ for Capsule Z was not used in the FERRET least squares evaluation due to the inconsistency of the $^{237}Np$ (n,f) $^{137}Cs$ measurement relative to the 3-loop neutron pad plant data base[1].

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[1] E. P. Lippincott, "Westinghouse Surveillance Capsule Neutron Fluence Reevaluation," Westinghouse Electric Company, WCAP-14044, April 1994.

Table 6-9

Summary of Neutron Dosimetry Results
Surveillance Capsules U, W, X, and Z

Best Estimate Flux and Fluence for Capsule U

| Quantity | Flux [n/cm²-sec] | Quantity | Fluence [n/cm²] | Uncertainty |
|---|---|---|---|---|
| ϕ (E > 1.0 MeV) | 1.66E+11 | Φ (E > 1.0 MeV) | 5.58E+18 | 7% |
| ϕ (E > 0.1 MeV) | 8.95E+11 | Φ (E > 0.1 MeV) | 3.00E+19 | 16% |
| ϕ (E < 0.414 eV) | 1.34E+11 | Φ (E < 0.414 eV) | 4.48E+18 | 29% |
| dpa/sec | 3.60E-10 | dpa | 1.21E-02 | 11% |

Best Estimate Flux and Fluence for Capsule W

| Quantity | Flux [n/cm²-sec] | Quantity | Fluence [n/cm²] | Uncertainty |
|---|---|---|---|---|
| ϕ (E > 1.0 MeV) | 1.27E+11 | Φ (E > 1.0 MeV) | 1.51E+19 | 7% |
| ϕ (E > 0.1 MeV) | 6.47E+11 | Φ (E > 0.1 MeV) | 7.73E+19 | 16% |
| ϕ (E < 0.414 eV) | 9.27E+10 | Φ (E < 0.414 eV) | 1.11E+19 | 29% |
| dpa/sec | 2.66E-10 | dpa | 3.17E-02 | 11% |

Best Estimate Flux and Fluence for Capsule X

| Quantity | Flux [n/cm²-sec] | Quantity | Fluence [n/cm²] | Uncertainty |
|---|---|---|---|---|
| ϕ (E > 1.0 MeV) | 1.29E+11 | Φ (E > 1.0 MeV) | 2.50E+19 | 12% |
| ϕ (E > 0.1 MeV) | 6.74E+11 | Φ (E > 0.1 MeV) | 1.31E+20 | 24% |
| ϕ (E < 0.414 eV) | 1.19E+11 | Φ (E < 0.414 eV) | 2.30E+19 | 28% |
| dpa/sec | 2.75E-10 | dpa | 5.32E-02 | 18% |

Best Estimate Flux and Fluence for Capsule Z

| Quantity | Flux [n/cm²-sec] | Quantity | Fluence [n/cm²] | Uncertainty |
|---|---|---|---|---|
| ϕ (E > 1.0 MeV) | 1.26E+11 | Φ (E > 1.0 MeV) | 5.28E+19 | 10% |
| ϕ (E > 0.1 MeV) | 5.91E+11 | Φ (E > 0.1 MeV) | 2.47E+20 | 21% |
| ϕ (E < 0.414 eV) | 8.27E+10 | Φ (E < 0.414 eV) | 3.45E+19 | 29% |
| dpa/sec | 2.51E-10 | dpa | 1.05E-01 | 15% |

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 |
|---|---|---|---|---|---|---|
| $^{63}Cu\ (n,\alpha)$ | 8.57E-17 | 8.19E-17 | 8.34E-17 | 0.97 | 1.02 | 1.05 |
| $^{54}Fe\ (n,p)$ | 8.95E-15 | 1.00E-14 | 9.00E-15 | 1.01 | 0.90 | 0.90 |
| $^{58}Ni\ (n,p)$ | 1.22E-14 | 1.43E-14 | 1.27E-14 | 1.04 | 0.89 | 0.85 |
| $^{238}U\ (n,f)\ (Cd)$ | 5.32E-14 | 5.80E-14 | 5.02E-14 | 0.94 | 0.87 | 0.92 |
| $^{237}Np\ (n,f)\ (Cd)$ | 5.75E-13 | 6.21E-13 | 5.65E-13 | 0.98 | 0.91 | 0.93 |
| $^{59}Co\ (n,\gamma)$ | 7.79E-12 | 6.12E-12 | 7.74E-12 | 0.99 | 1.26 | 1.27 |
| $^{59}Co\ (n,\gamma)\ (Cd)$ | 4.41E-12 | 4.71E-12 | 4.43E-12 | 1.00 | 0.94 | 0.94 |

Surveillance Capsule W

| Reaction | Measured | Calculated | Best Estimate | BE / Meas | BE/ Calc | Meas/Calc |
|---|---|---|---|---|---|---|
| $^{63}Cu\ (n,\alpha)$ | 7.16E-17 | 7.22E-17 | 7.04E-17 | 0.98 | 0.98 | 0.99 |
| $^{54}Fe\ (n,p)$ | 7.29E-15 | 8.55E-15 | 7.42E-15 | 1.02 | 0.87 | 0.85 |
| $^{58}Ni\ (n,p)$ | 1.05E-14 | 1.21E-14 | 1.04E-14 | 0.99 | 0.86 | 0.87 |
| $^{238}U\ (n,f)\ (Cd)$ | 3.67E-14 | 4.77E-14 | 3.92E-14 | 1.07 | 0.82 | 0.77 |
| $^{237}Np\ (n,f)\ (Cd)$ | 4.32E-13 | 4.90E-13 | 4.20E-13 | 0.97 | 0.86 | 0.88 |
| $^{59}Co\ (n,\gamma)$ | 5.44E-12 | 4.51E-12 | 5.40E-12 | 0.99 | 1.20 | 1.21 |
| $^{59}Co\ (n,\gamma)\ (Cd)$ | 3.09E-12 | 3.48E-12 | 3.11E-12 | 1.01 | 0.89 | 0.89 |

Table 6-10 Cont'd

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

Surveillance Capsule X

| Reaction | Measured | Calculated | Best Estimate | BE / Meas | BE/ Calc | Meas/Calc |
|---|---|---|---|---|---|---|
| $^{63}$Cu (n,α) | 7.21E-17 | 7.02E-17 | 7.04E-17 | 0.98 | 1.00 | 1.03 |
| $^{54}$Fe (n,p) | 7.21E-15 | 8.61E-15 | 7.42E-15 | 1.03 | 0.86 | 0.84 |
| $^{58}$Ni (n,p) | 1.04E-14 | 1.23E-14 | 1.04E-14 | 1.00 | 0.85 | 0.85 |
| $^{238}$U (n,f) (Cd) | | | | | | |
| $^{237}$Np (n,f) (Cd) | | | | | | |
| $^{59}$Co (n,γ) | 6.81E-12 | 5.25E-12 | 6.76E-12 | 0.99 | 1.29 | 1.30 |
| $^{59}$Co (n,γ) (Cd) | 3.76E-12 | 4.04E-12 | 3.78E-12 | 1.01 | 0.94 | 0.93 |

Surveillance Capsule Z

| Reaction | Measured | Calculated | Best Estimate | BE / Meas | BE/ Calc | Meas/Calc |
|---|---|---|---|---|---|---|
| $^{63}$Cu (n,α) | 7.30E-17 | 5.89E-17 | 7.19E-17 | 0.98 | 1.22 | 1.24 |
| $^{54}$Fe (n,p) | 7.56E-15 | 6.97E-15 | 7.70E-15 | 1.02 | 1.10 | 1.08 |
| $^{58}$Ni (n,p) | 1.09E-14 | 9.85E-15 | 1.07E-14 | 0.98 | 1.09 | 1.11 |
| $^{238}$U (n,f) (Cd) | 3.89E-14 | 3.89E-14 | 4.00E-14 | 1.03 | 1.03 | 1.00 |
| $^{237}$Np (n,f) (Cd) | | | | | | |
| $^{59}$Co (n,γ) | 4.72E-12 | 3.67E-12 | 4.68E-12 | 0.99 | 1.28 | 1.29 |
| $^{59}$Co (n,γ) (Cd) | 2.63E-12 | 2.84E-12 | 2.65E-12 | 1.01 | 0.93 | 0.93 |

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 | 1.13E+07 | 28 | 9.12E-03 | 3.96E+10 |
| 2 | 1.49E+01 | 2.42E+07 | 29 | 5.53E-03 | 4.08E+10 |
| 3 | 1.35E+01 | 8.97E+07 | 30 | 3.36E-03 | 1.32E+10 |
| 4 | 1.16E+01 | 2.45E+08 | 31 | 2.84E-03 | 1.29E+10 |
| 5 | 1.00E+01 | 5.52E+08 | 32 | 2.40E-03 | 1.28E+10 |
| 6 | 8.61E+00 | 9.54E+08 | 33 | 2.04E-03 | 3.84E+10 |
| 7 | 7.41E+00 | 2.27E+09 | 34 | 1.23E-03 | 3.91E+10 |
| 8 | 6.07E+00 | 3.42E+09 | 35 | 7.49E-04 | 3.79E+10 |
| 9 | 4.97E+00 | 7.05E+09 | 36 | 4.54E-04 | 2.79E+10 |
| 10 | 3.68E+00 | 8.48E+09 | 37 | 2.75E-04 | 3.14E+10 |
| 11 | 2.87E+00 | 1.67E+10 | 38 | 1.67E-04 | 3.21E+10 |
| 12 | 2.23E+00 | 2.38E+10 | 39 | 1.01E-04 | 3.37E+10 |
| 13 | 1.74E+00 | 3.42E+10 | 40 | 6.14E-05 | 3.39E+10 |
| 14 | 1.35E+00 | 4.10E+10 | 41 | 3.73E-05 | 3.30E+10 |
| 15 | 1.11E+00 | 8.11E+10 | 42 | 2.26E-05 | 3.15E+10 |
| 16 | 8.21E-01 | 9.14E+10 | 43 | 1.37E-05 | 3.00E+10 |
| 17 | 6.39E-01 | 1.11E+11 | 44 | 8.32E-06 | 2.77E+10 |
| 18 | 4.98E-01 | 7.44E+10 | 45 | 5.04E-06 | 2.42E+10 |
| 19 | 3.88E-01 | 1.24E+11 | 46 | 3.06E-06 | 2.18E+10 |
| 20 | 3.02E-01 | 1.23E+11 | 47 | 1.86E-06 | 1.93E+10 |
| 21 | 1.83E-01 | 1.36E+11 | 48 | 1.13E-06 | 1.12E+10 |
| 22 | 1.11E-01 | 7.74E+10 | 49 | 6.83E-07 | 1.33E+10 |
| 23 | 6.74E-02 | 7.66E+10 | 50 | 4.14E-07 | 2.13E+10 |
| 24 | 4.09E-02 | 3.73E+10 | 51 | 2.51E-07 | 2.19E+10 |
| 25 | 2.55E-02 | 4.72E+10 | 52 | 1.52E-07 | 2.18E+10 |
| 26 | 1.99E-02 | 1.87E+10 | 53 | 9.24E-08 | 6.87E+10 |
| 27 | 1.50E-02 | 3.58E+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 W

| Group # | Energy (MeV) | Flux (n/cm$^2$-sec) | Group # | Energy (MeV) | Flux (n/cm$^2$-sec) |
|---|---|---|---|---|---|
| 1 | 1.73E+01 | 9.42E+06 | 28 | 9.12E-03 | 2.84E+10 |
| 2 | 1.49E+01 | 2.03E+07 | 29 | 5.53E-03 | 2.93E+10 |
| 3 | 1.35E+01 | 7.52E+07 | 30 | 3.36E-03 | 9.43E+09 |
| 4 | 1.16E+01 | 2.06E+08 | 31 | 2.84E-03 | 9.19E+09 |
| 5 | 1.00E+01 | 4.65E+08 | 32 | 2.40E-03 | 9.06E+09 |
| 6 | 8.61E+00 | 8.04E+08 | 33 | 2.04E-03 | 2.72E+10 |
| 7 | 7.41E+00 | 1.92E+09 | 34 | 1.23E-03 | 2.75E+10 |
| 8 | 6.07E+00 | 2.90E+09 | 35 | 7.49E-04 | 2.68E+10 |
| 9 | 4.97E+00 | 5.90E+09 | 36 | 4.54E-04 | 1.99E+10 |
| 10 | 3.68E+00 | 6.87E+09 | 37 | 2.75E-04 | 2.19E+10 |
| 11 | 2.87E+00 | 1.33E+10 | 38 | 1.67E-04 | 2.25E+10 |
| 12 | 2.23E+00 | 1.81E+10 | 39 | 1.01E-04 | 2.37E+10 |
| 13 | 1.74E+00 | 2.55E+10 | 40 | 6.14E-05 | 2.38E+10 |
| 14 | 1.35E+00 | 3.03E+10 | 41 | 3.73E-05 | 2.30E+10 |
| 15 | 1.11E+00 | 5.89E+10 | 42 | 2.26E-05 | 2.20E+10 |
| 16 | 8.21E-01 | 6.57E+10 | 43 | 1.37E-05 | 2.10E+10 |
| 17 | 6.39E-01 | 7.89E+10 | 44 | 8.32E-06 | 1.93E+10 |
| 18 | 4.98E-01 | 5.30E+10 | 45 | 5.04E-06 | 1.69E+10 |
| 19 | 3.88E-01 | 8.82E+10 | 46 | 3.06E-06 | 1.52E+10 |
| 20 | 3.02E-01 | 8.75E+10 | 47 | 1.86E-06 | 1.35E+10 |
| 21 | 1.83E-01 | 9.72E+10 | 48 | 1.13E-06 | 7.83E+09 |
| 22 | 1.11E-01 | 5.53E+10 | 49 | 6.83E-07 | 9.26E+09 |
| 23 | 6.74E-02 | 5.47E+10 | 50 | 4.14E-07 | 1.48E+10 |
| 24 | 4.09E-02 | 2.68E+10 | 51 | 2.51E-07 | 1.52E+10 |
| 25 | 2.55E-02 | 3.38E+10 | 52 | 1.52E-07 | 1.51E+10 |
| 26 | 1.99E-02 | 1.34E+10 | 53 | 9.24E-08 | 4.76E+10 |
| 27 | 1.50E-02 | 2.57E+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 | 9.43E+06 | 28 | 9.12E-03 | 3.19E+10 |
| 2 | 1.49E+01 | 2.03E+07 | 29 | 5.53E-03 | 3.31E+10 |
| 3 | 1.35E+01 | 7.58E+07 | 30 | 3.36E-03 | 1.07E+10 |
| 4 | 1.16E+01 | 2.08E+08 | 31 | 2.84E-03 | 1.05E+10 |
| 5 | 1.00E+01 | 4.68E+08 | 32 | 2.40E-03 | 1.05E+10 |
| 6 | 8.61E+00 | 8.07E+08 | 33 | 2.04E-03 | 3.16E+10 |
| 7 | 7.41E+00 | 1.91E+09 | 34 | 1.23E-03 | 3.24E+10 |
| 8 | 6.07E+00 | 2.86E+09 | 35 | 7.49E-04 | 3.15E+10 |
| 9 | 4.97E+00 | 5.86E+09 | 36 | 4.54E-04 | 2.33E+10 |
| 10 | 3.68E+00 | 6.92E+09 | 37 | 2.75E-04 | 2.63E+10 |
| 11 | 2.87E+00 | 1.34E+10 | 38 | 1.67E-04 | 2.75E+10 |
| 12 | 2.23E+00 | 1.85E+10 | 39 | 1.01E-04 | 2.84E+10 |
| 13 | 1.74E+00 | 2.61E+10 | 40 | 6.14E-05 | 2.84E+10 |
| 14 | 1.35E+00 | 3.10E+10 | 41 | 3.73E-05 | 2.76E+10 |
| 15 | 1.11E+00 | 6.06E+10 | 42 | 2.26E-05 | 2.62E+10 |
| 16 | 8.21E-01 | 6.79E+10 | 43 | 1.37E-05 | 2.49E+10 |
| 17 | 6.39E-01 | 8.21E+10 | 44 | 8.32E-06 | 2.30E+10 |
| 18 | 4.98E-01 | 5.52E+10 | 45 | 5.04E-06 | 2.01E+10 |
| 19 | 3.88E-01 | 9.20E+10 | 46 | 3.06E-06 | 1.81E+10 |
| 20 | 3.02E-01 | 9.21E+10 | 47 | 1.86E-06 | 1.60E+10 |
| 21 | 1.83E-01 | 1.03E+11 | 48 | 1.13E-06 | 9.29E+09 |
| 22 | 1.11E-01 | 5.92E+10 | 49 | 6.83E-07 | 1.12E+10 |
| 23 | 6.74E-02 | 5.93E+10 | 50 | 4.14E-07 | 1.81E+10 |
| 24 | 4.09E-02 | 2.91E+10 | 51 | 2.51E-07 | 1.89E+10 |
| 25 | 2.55E-02 | 3.73E+10 | 52 | 1.52E-07 | 1.90E+10 |
| 26 | 1.99E-02 | 1.49E+10 | 53 | 9.24E-08 | 6.28E+10 |
| 27 | 1.50E-02 | 2.87E+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 Z

| Group # | Energy (MeV) | Flux (n/cm$^2$-sec) | Group # | Energy (MeV) | Flux (n/cm$^2$-sec) |
|---|---|---|---|---|---|
| 1 | 1.73E+01 | 8.91E+06 | 28 | 9.12E-03 | 2.49E+10 |
| 2 | 1.49E+01 | 1.94E+07 | 29 | 5.53E-03 | 2.58E+10 |
| 3 | 1.35E+01 | 7.34E+07 | 30 | 3.36E-03 | 8.31E+09 |
| 4 | 1.16E+01 | 2.04E+08 | 31 | 2.84E-03 | 8.10E+09 |
| 5 | 1.00E+01 | 4.68E+08 | 32 | 2.40E-03 | 7.98E+09 |
| 6 | 8.61E+00 | 8.22E+08 | 33 | 2.04E-03 | 2.39E+10 |
| 7 | 7.41E+00 | 1.99E+09 | 34 | 1.23E-03 | 2.41E+10 |
| 8 | 6.07E+00 | 3.02E+09 | 35 | 7.49E-04 | 2.34E+10 |
| 9 | 4.97E+00 | 6.17E+09 | 36 | 4.54E-04 | 1.73E+10 |
| 10 | 3.68E+00 | 7.17E+09 | 37 | 2.75E-04 | 1.89E+10 |
| 11 | 2.87E+00 | 1.37E+10 | 38 | 1.67E-04 | 1.91E+10 |
| 12 | 2.23E+00 | 1.85E+10 | 39 | 1.01E-04 | 2.04E+10 |
| 13 | 1.74E+00 | 2.55E+10 | 40 | 6.14E-05 | 2.05E+10 |
| 14 | 1.35E+00 | 2.95E+10 | 41 | 3.73E-05 | 2.00E+10 |
| 15 | 1.11E+00 | 5.59E+10 | 42 | 2.26E-05 | 1.92E+10 |
| 16 | 8.21E-01 | 6.09E+10 | 43 | 1.37E-05 | 1.84E+10 |
| 17 | 6.39E-01 | 7.17E+10 | 44 | 8.32E-06 | 1.70E+10 |
| 18 | 4.98E-01 | 4.74E+10 | 45 | 5.04E-06 | 1.49E+10 |
| 19 | 3.88E-01 | 7.77E+10 | 46 | 3.06E-06 | 1.34E+10 |
| 20 | 3.02E-01 | 7.64E+10 | 47 | 1.86E-06 | 1.19E+10 |
| 21 | 1.83E-01 | 8.43E+10 | 48 | 1.13E-06 | 6.95E+09 |
| 22 | 1.11E-01 | 4.78E+10 | 49 | 6.83E-07 | 8.23E+09 |
| 23 | 6.74E-02 | 4.73E+10 | 50 | 4.14E-07 | 1.31E+10 |
| 24 | 4.09E-02 | 2.32E+10 | 51 | 2.51E-07 | 1.36E+10 |
| 25 | 2.55E-02 | 2.94E+10 | 52 | 1.52E-07 | 1.35E+10 |
| 26 | 1.99E-02 | 1.17E+10 | 53 | 9.24E-08 | 4.25E+10 |
| 27 | 1.50E-02 | 2.25E+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 Farley Unit 2 Surveillance Capsules U, W, X, and Z

CAPSULE U

| | Calculated | Best Estimate | BE/C |
|---|---|---|---|
| Φ(E > 1.0 MeV) [n/cm$^2$] | 6.44E+18 | 5.58E+18 | 0.87 |
| Φ(E > 0.1 MeV) [n/cm$^2$] | 3.15E+19 | 3.00E+19 | 0.95 |
| dpa | 1.30E-02 | 1.21E-02 | 0.93 |

CAPSULE W

| | Calculated | Best Estimate | BE/C |
|---|---|---|---|
| Φ(E > 1.0 MeV) [n/cm$^2$] | 1.85E+19 | 1.51E+19 | 0.81 |
| Φ(E > 0.1 MeV) [n/cm$^2$] | 8.70E+19 | 7.73E+19 | 0.89 |
| dpa | 3.66E-02 | 3.17E-02 | 0.87 |

CAPSULE X

| | Calculated | Best Estimate | BE/C |
|---|---|---|---|
| Φ(E > 1.0 MeV) [n/cm$^2$] | 3.19E+19 | 2.50E+19 | 0.78 |
| Φ(E > 0.1 MeV) [n/cm$^2$] | 1.56E+20 | 1.31E+20 | 0.84 |
| dpa | 6.45E-02 | 5.32E-02 | 0.83 |

CAPSULE Z

| | Calculated | Best Estimate | BE/C |
|---|---|---|---|
| Φ(E > 1.0 MeV) [n/cm$^2$] | 5.28E+19 | 5.28E+19 | 1.00 |
| Φ(E > 0.1 MeV) [n/cm$^2$] | 2.48E+20 | 2.47E+20 | 1.00 |
| dpa | 1.04E-01 | 1.05E-01 | 1.01 |

AVERAGE BE/C RATIOS

| | BE/C |
|---|---|
| Φ(E > 1.0 MeV) [n/cm$^2$] | 0.87 |
| Φ(E > 0.1 MeV) [n/cm$^2$] | 0.92 |
| dpa | 0.91 |

Table 6-13

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

Best Estimate

| 13.24 EPFY | 0° | 15°[a] | 30°[a] | 45° |
|---|---|---|---|---|
| E>1.0 MeV (n/cm$^2$) | 1.51E+19 | 8.83E+18 | 6.55E+18 | 4.59E+18 |
| E>0.1 MeV (n/cm$^2$) | 4.18E+19 | 2.28E+19 | 1.50E+19 | 1.04E+19 |
| dpa | 2.52E-02 | 1.46E-02 | 1.05E-02 | 7.43E-03 |
| 20 EFPY | | | | |
| E>1.0 MeV (n/cm$^2$) | 2.16E+19 | 1.27E+19 | 9.48E+18 | 6.75E+18 |
| E>0.1 MeV (n/cm$^2$) | 5.99E+19 | 3.28E+19 | 2.17E+19 | 1.53E+19 |
| dpa | 3.60E-02 | 2.10E-02 | 1.52E-02 | 1.09E-02 |
| 36 EFPY | | | | |
| E>1.0 MeV (n/cm$^2$) | 3.71E+19 | 2.19E+19 | 1.64E+19 | 1.19E+19 |
| E>0.1 MeV (n/cm$^2$) | 1.03E+20 | 5.65E+19 | 3.75E+19 | 2.68E+19 |
| dpa | 6.18E-02 | 3.61E-02 | 2.64E-02 | 1.92E-02 |
| 54 EFPY | | | | |
| E>1.0 MeV (n/cm$^2$) | 5.44E+19 | 3.21E+19 | 2.42E+19 | 1.76E+19 |
| E>0.1 MeV (n/cm$^2$) | 1.51E+20 | 8.31E+19 | 5.54E+19 | 3.98E+19 |
| dpa | 9.07E-02 | 5.31E-02 | 3.89E-02 | 2.85E-02 |

Note:

a) Maximum neutron exposure projection reported for 15° and 30° vessel location representing the octant containing the 15° 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

| 13.24 EPFY | 0° | 15°[a] | 30°[a] | 45° |
|---|---|---|---|---|
| E>1.0 MeV (n/cm$^2$) | 1.75E+19 | 1.02E+19 | 7.56E+18 | 5.30E+18 |
| E>0.1 MeV (n/cm$^2$) | 4.56E+19 | 2.48E+19 | 1.63E+19 | 1.13E+19 |
| dpa | 2.78E-02 | 1.61E-02 | 1.16E-02 | 8.21E-03 |
| 20 EFPY | | | | |
| E>1.0 MeV (n/cm$^2$) | 2.50E+19 | 1.47E+19 | 1.10E+19 | 7.80E+18 |
| E>0.1 MeV (n/cm$^2$) | 6.52E+19 | 3.57E+19 | 2.36E+19 | 1.66E+19 |
| dpa | 3.98E-02 | 2.31E-02 | 1.68E-02 | 1.21E-02 |
| 36 EFPY | | | | |
| E>1.0 MeV (n/cm$^2$) | 4.28E+19 | 2.52E+19 | 1.90E+19 | 1.37E+19 |
| E>0.1 MeV (n/cm$^2$) | 1.12E+20 | 6.15E+19 | 4.09E+19 | 2.92E+19 |
| dpa | 6.82E-02 | 3.98E-02 | 2.91E-02 | 2.12E-02 |
| 54 EFPY | | | | |
| E>1.0 MeV (n/cm$^2$) | 6.29E+19 | 3.71E+19 | 2.80E+19 | 2.04E+19 |
| E>0.1 MeV (n/cm$^2$) | 1.64E+20 | 9.05E+19 | 6.03E+19 | 4.34E+19 |
| dpa | 1.00E-01 | 5.86E-02 | 4.30E-02 | 3.15E-02 |

Note:

a) Maximum neutron exposure projection reported for 15° and 30° vessel location representing the octant containing the 15° neutron pad span.

Table 6-14

Neutron Exposure Values within the Farley Unit 2 Reactor Vessel

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

| 20 EFPY | 0° | 15°[a] | 30°[a] | 45° |
|---|---|---|---|---|
| Surface | 2.16E+19 | 1.27E+19 | 9.48E+18 | 6.75E+18 |
| 1/4 T | 1.27E+19 | 7.63E+18 | 5.66E+18 | 4.06E+18 |
| 3/4 T | 6.46E+18 | 4.00E+18 | 2.95E+18 | 2.13E+18 |
| 36 EFPY | | | | |
| Surface | 3.71E+19 | 2.19E+19 | 1.64E+19 | 1.19E+19 |
| 1/4 T | 2.17E+19 | 1.31E+19 | 9.81E+18 | 7.13E+18 |
| 3/4 T | 1.11E+19 | 6.89E+18 | 5.11E+18 | 3.74E+18 |
| 54 EFPY | | | | |
| Surface | 5.44E+19 | 3.21E+19 | 2.42E+19 | 1.76E+19 |
| 1/4 T | 3.18E+19 | 1.93E+19 | 1.45E+19 | 1.06E+19 |
| 3/4 T | 1.63E+19 | 1.01E+19 | 7.54E+18 | 5.55E+18 |

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

| 20 EFPY | 0° | 15°[a] | 30°[a] | 45° |
|---|---|---|---|---|
| Surface | 2.16E+19 | 1.27E+19 | 9.48E+18 | 6.75E+18 |
| 1/4 T | 1.45E+19 | 8.72E+18 | 6.31E+18 | 4.52E+18 |
| 3/4 T | 9.11E+18 | 5.63E+18 | 3.95E+18 | 2.85E+18 |
| 36 EFPY | | | | |
| Surface | 3.71E+19 | 2.19E+19 | 1.64E+19 | 1.19E+19 |
| 1/4 T | 2.48E+19 | 1.50E+19 | 1.09E+19 | 7.94E+18 |
| 3/4 T | 1.56E+19 | 9.68E+18 | 6.84E+18 | 5.00E+18 |
| 54 EFPY | | | | |
| Surface | 5.44E+19 | 3.21E+19 | 2.42E+19 | 1.76E+19 |
| 1/4 T | 3.64E+19 | 2.21E+19 | 1.61E+19 | 1.18E+19 |
| 3/4 T | 2.29E+19 | 1.42E+19 | 1.01E+19 | 7.43E+18 |

Note:

a) Maximum neutron exposure projection reported for 15° and 30° vessel location representing the octant containing the 15° neutron pad span.

Table 6-14, cont'd

Neutron Exposure Values within the
Farley Unit 2 Reactor Vessel

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

| 20 EFPY | 0° | 15°[a] | 30°[a] | 45° |
|---|---|---|---|---|
| Surface | 2.50E+19 | 1.47E+19 | 1.10E+19 | 7.80E+18 |
| 1/4 T | 1.46E+19 | 8.81E+18 | 6.54E+18 | 4.69E+18 |
| 3/4 T | 7.47E+18 | 4.63E+18 | 3.41E+18 | 2.46E+18 |
| 36 EFPY | | | | |
| Surface | 4.28E+19 | 2.52E+19 | 1.90E+19 | 1.37E+19 |
| 1/4 T | 2.51E+19 | 1.52E+19 | 1.13E+19 | 8.23E+18 |
| 3/4 T | 1.28E+19 | 7.96E+18 | 5.90E+18 | 4.32E+18 |
| 54 EFPY | | | | |
| Surface | 6.29E+19 | 3.71E+19 | 2.80E+19 | 2.04E+19 |
| 1/4 T | 3.68E+19 | 2.23E+19 | 1.67E+19 | 1.22E+19 |
| 3/4 T | 1.88E+19 | 1.17E+19 | 8.71E+18 | 6.41E+18 |

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

| 20 EFPY | 0° | 15°[a] | 30°[a] | 45° |
|---|---|---|---|---|
| Surface | 2.50E+19 | 1.47E+19 | 1.10E+19 | 7.80E+18 |
| 1/4 T | 1.67E+19 | 1.01E+19 | 7.29E+18 | 5.22E+18 |
| 3/4 T | 1.05E+19 | 6.50E+18 | 4.56E+18 | 3.29E+18 |
| 36 EFPY | | | | |
| Surface | 4.28E+19 | 2.52E+19 | 1.90E+19 | 1.37E+19 |
| 1/4 T | 2.87E+19 | 1.73E+19 | 1.26E+19 | 9.17E+18 |
| 3/4 T | 1.80E+19 | 1.12E+19 | 7.90E+18 | 5.78E+18 |
| 54 EFPY | | | | |
| Surface | 6.29E+19 | 3.71E+19 | 2.80E+19 | 2.04E+19 |
| 1/4 T | 4.21E+19 | 2.55E+19 | 1.86E+19 | 1.36E+19 |
| 3/4 T | 2.65E+19 | 1.65E+19 | 1.17E+19 | 8.58E+18 |

Note:

a) Maximum neutron exposure projection reported for 15° and 30° vessel location representing the octant containing the 15° neutron pad span.

Table 6-15

Updated Lead Factors for the J. M. Farley Unit 2
Surveillance Capsules

| Capsule | Lead Factor |
|---|---|
| U[a] | 3.31 |
| W[b] | 2.86 |
| X[c] | 3.41 |
| Z[d] | 3.03 |
| V[e] | 3.47 |
| Y[e] | 3.03 |

[a] - Withdrawn at the end of Cycle 1.
[b] - Withdrawn at the end of Cycle 4.
[c] - Withdrawn at the end of Cycle 6.
[d] - Withdrawn at the end of Cycle 12.
[e] - Not withdrawn; on 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 J. M. Farley Unit 2 reactor vessel. This recommended removal schedule is applicable to 36 EFPY of operation.

**Table 7-1 J. M. Farley Unit 2 Reactor Vessel Surveillance Capsule Withdrawal Schedule**

| Capsule | Location | Lead Factor[(a)] | Removal Time (EFPY)[(b)] | Fluence ($n/cm^2$, E>1.0 MeV)[(a)] |
|---|---|---|---|---|
| U | 343° | 3.31 | 1.10 | $6.44 \times 10^{18}$ (c) |
| W | 110° | 2.86 | 3.97 | $1.85 \times 10^{19}$ (c) |
| X | 287° | 3.41 | 6.41 | $3.19 \times 10^{19}$ (c) |
| Z | 340° | 3.03 | 13.24 | $5.28 \times 10^{19}$ (c,d) |
| V | 107° | 3.47 | Standby | (e) |
| Y | 290° | 3.03 | Standby | (e) |

Notes:

(a) Updated in Capsule Z 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 (36 EFPY) fluence of $4.28 \times 10^{19}$ $n/cm^2$.

(e) Capsules V and Y will reach a fluence of $6.29 \times 10^{19}$ (E > 1.0 MeV), the 54 EFPY peak vessel fluence at approximately 13.8 and 16.2 EFPY, respectively. Per ASTM E185-82, these capsules may be held without testing following withdrawal.

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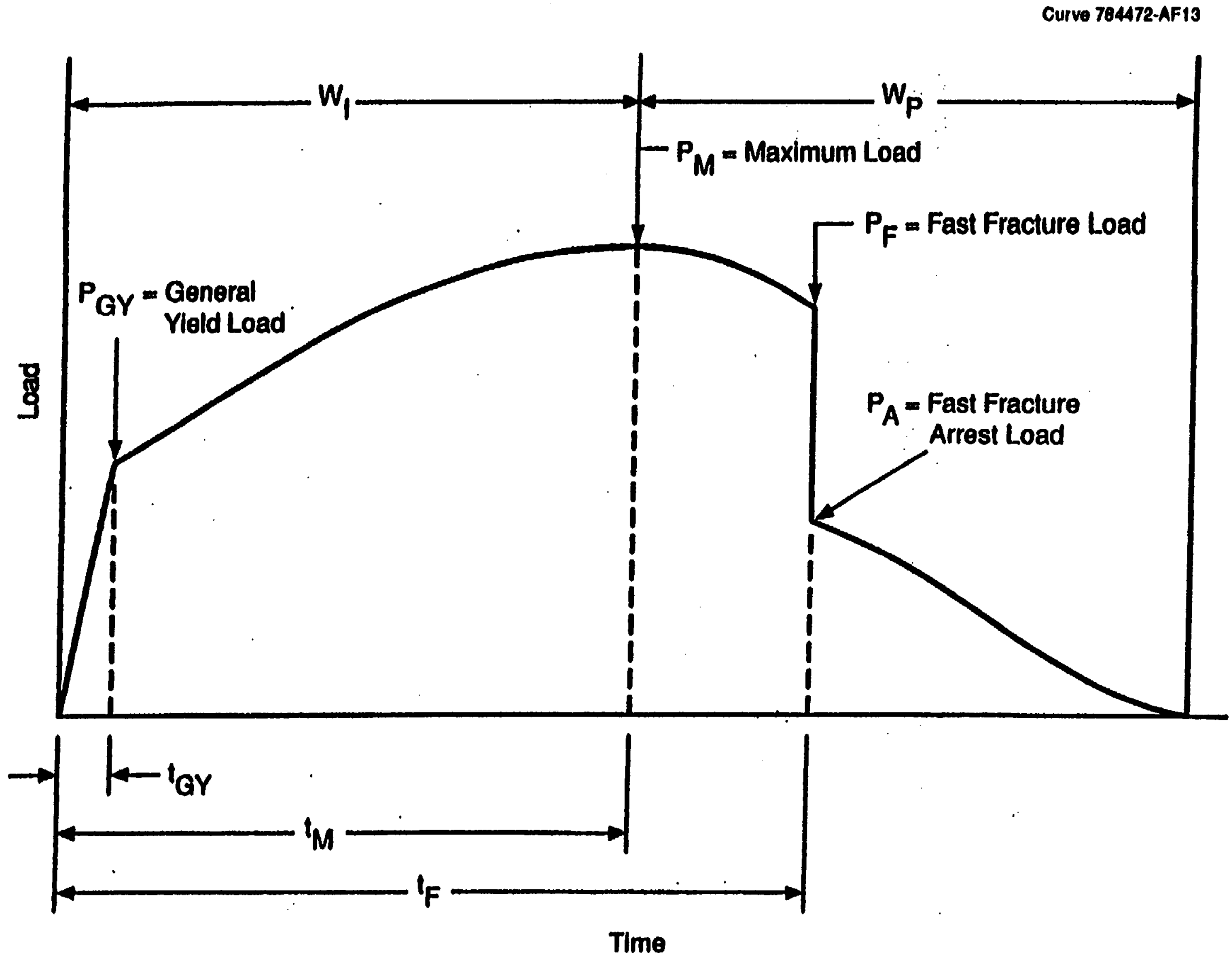
# APPENDIX A

# LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS




$W_I$ = Fracture Initiation Region

$W_P$ = Fracture Propagation Region

$t_{GY}$ = Time to General Yielding

$t_M$ = Time to Maximum Load

$t_F$ = Time to Fast (Brittle) Fracture Start

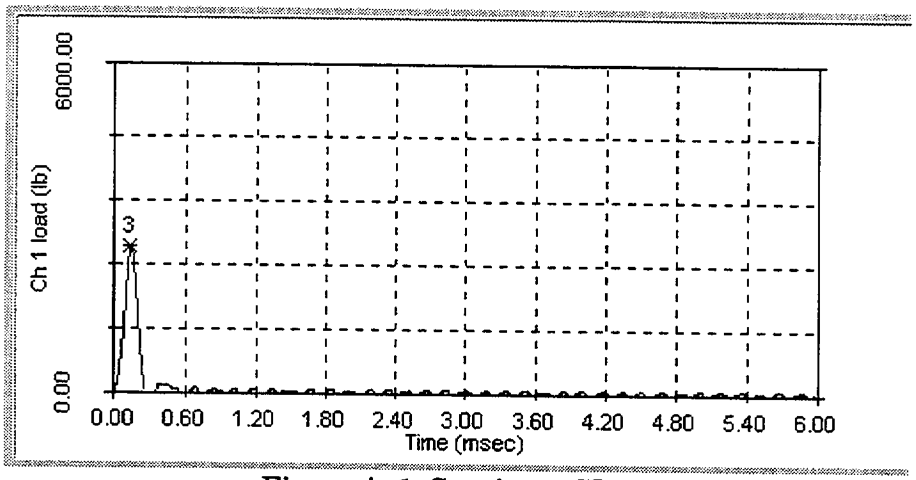


Figure A. 1 Specimen CL81

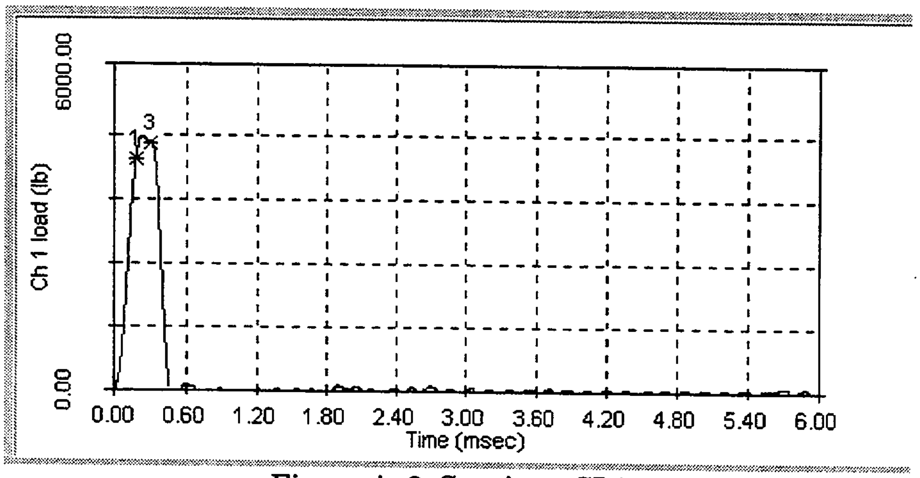


Figure A. 2 SpecimenCL80

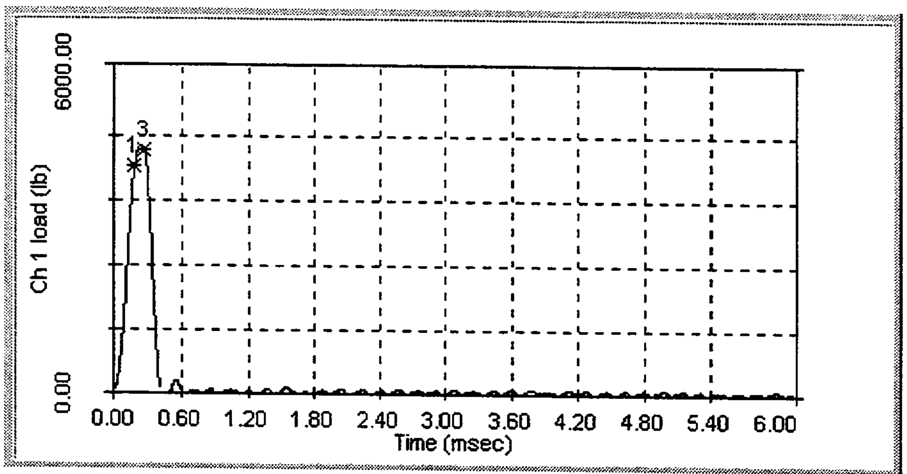


Figure A. 3 Specimen CL90

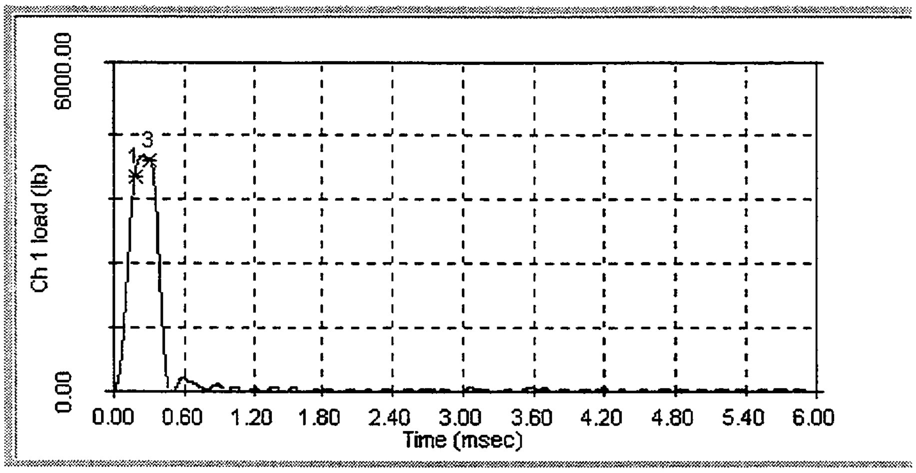



Figure A. 4 Specimen CL79

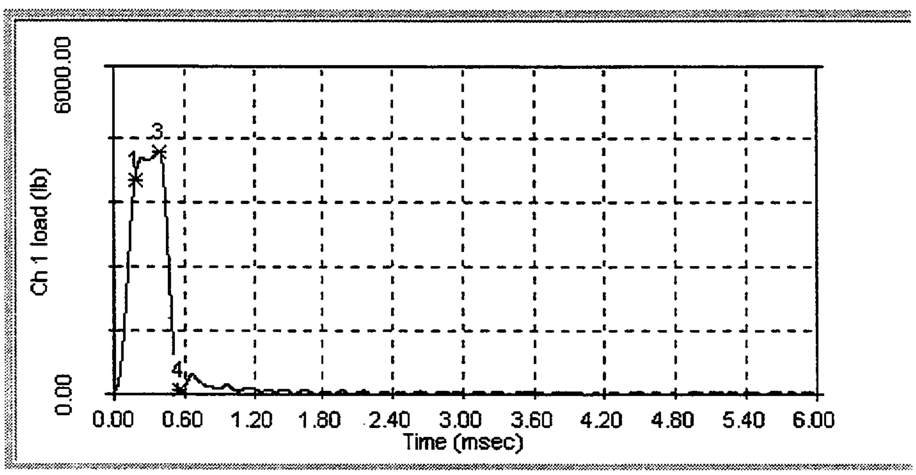



Figure A. 5 Specimen CL77

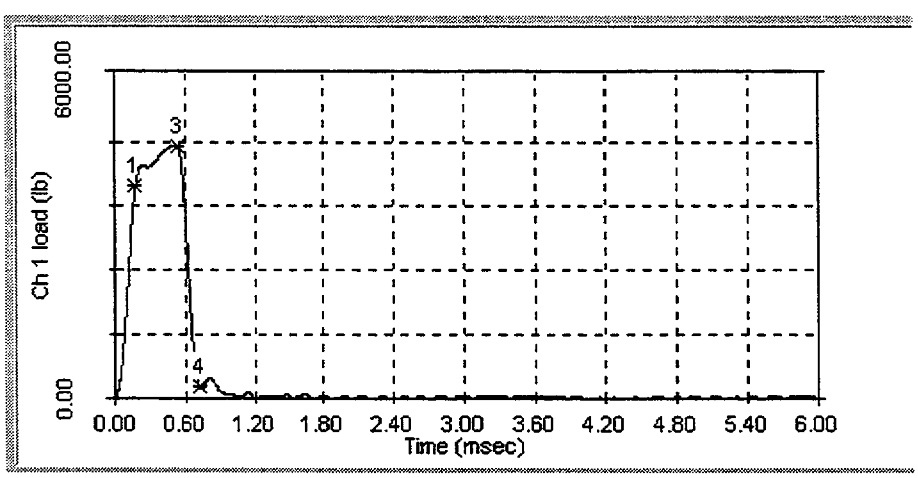



Figure A. 6 Specimen CL84

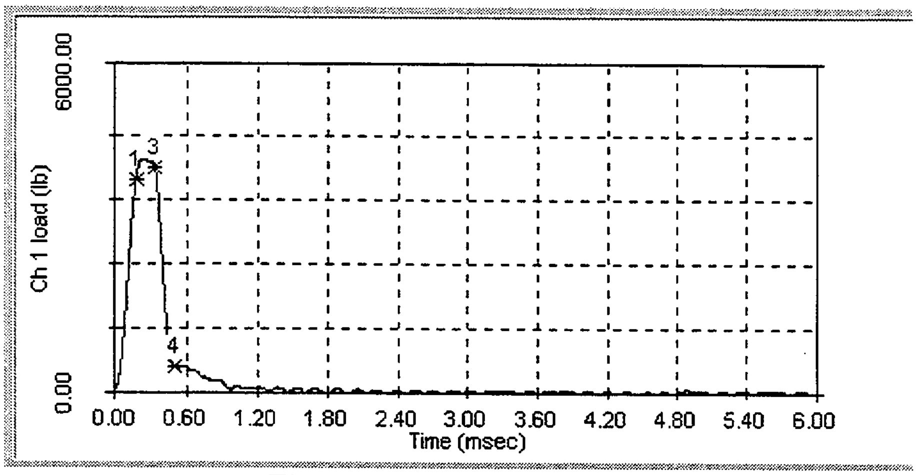



**Figure A. 7 Specimen CL85**

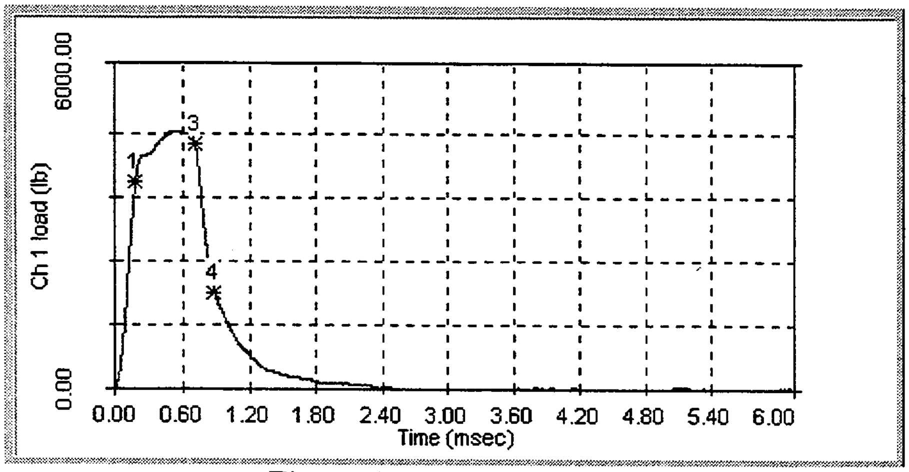



**Figure A. 8 Specimen CL86**

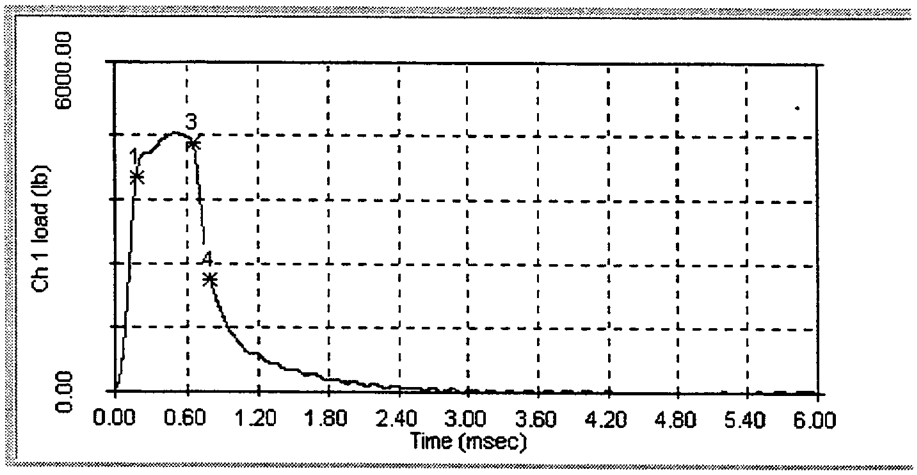



**Figure A. 9 Specimen CL78**

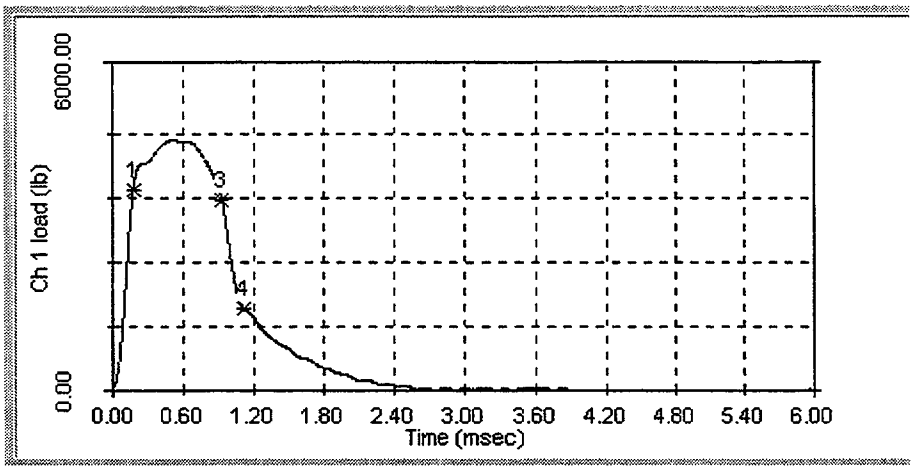



**Figure A. 10 Specimen CL83**

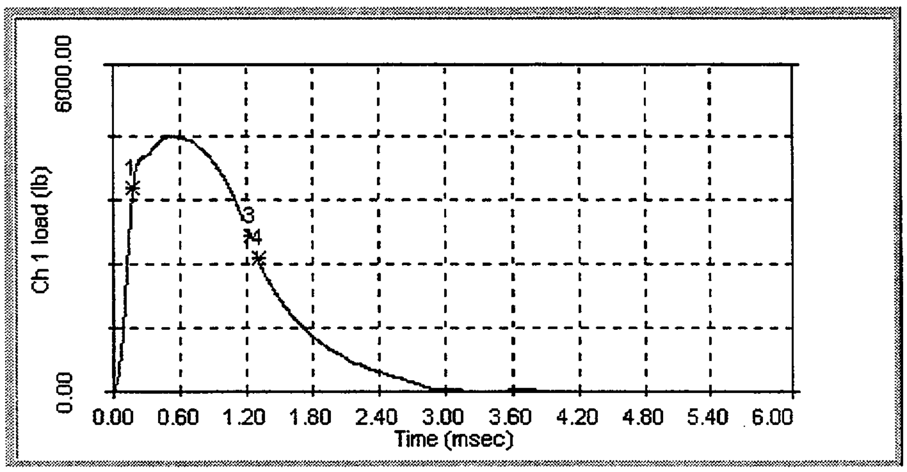



**Figure A. 11 Specimen CL89**

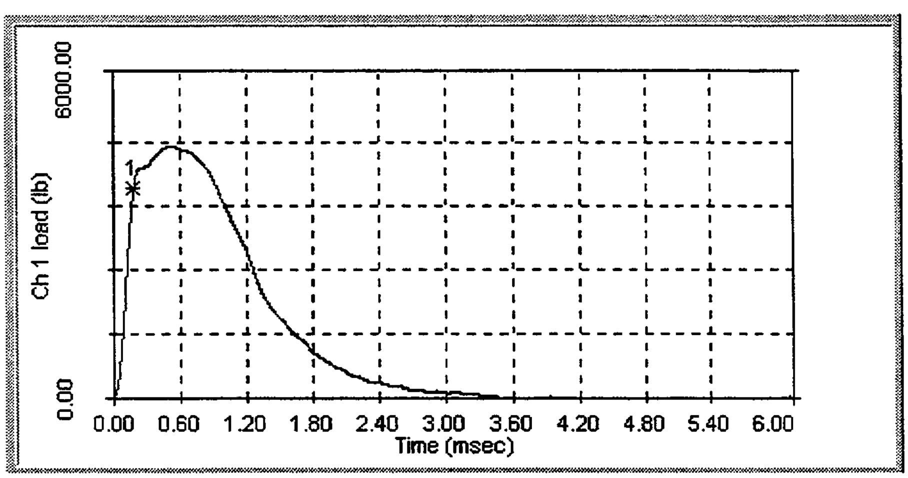



**Figure A. 12 Specimen CL87**

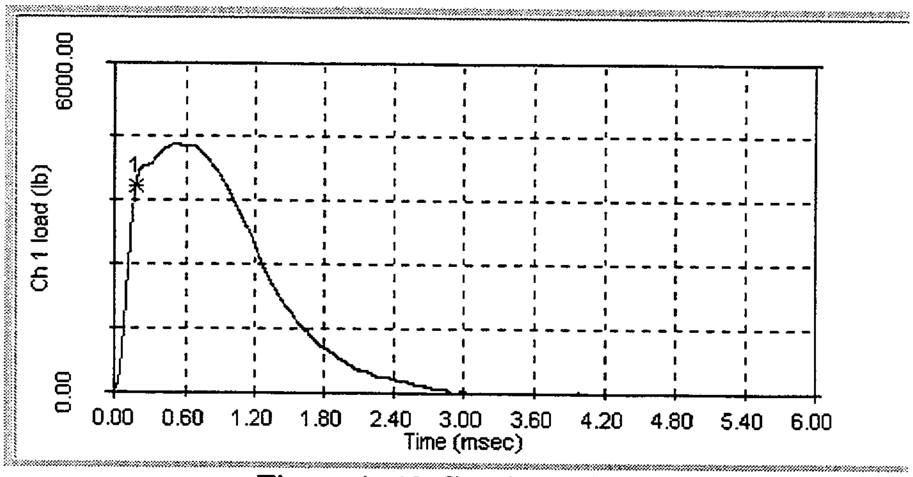



Figure A. 13 Specimen CL82

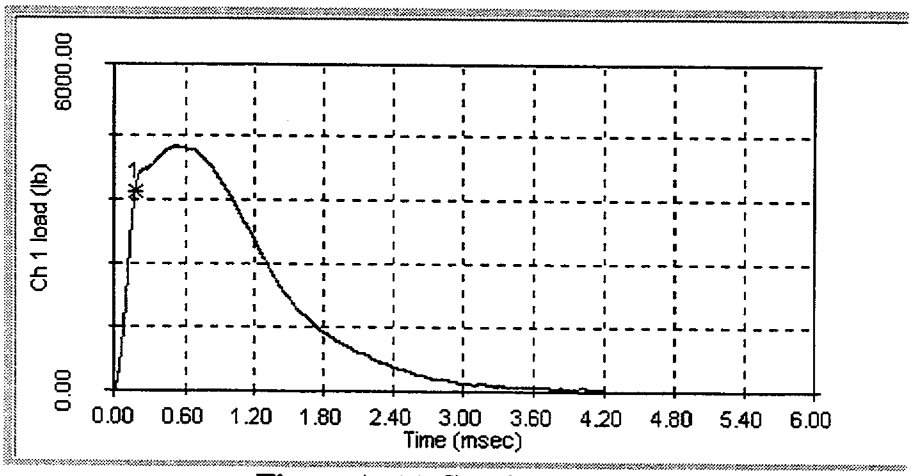



Figure A. 14 Specimen CL76

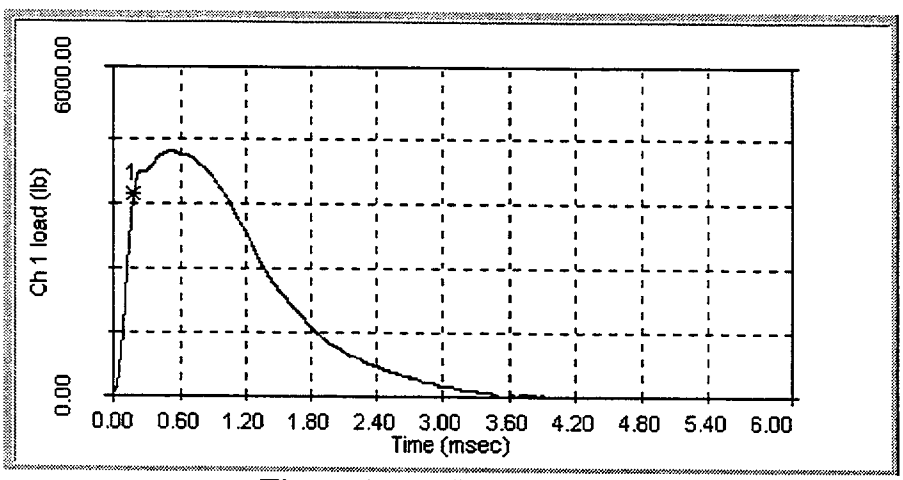



Figure A. 15 SpecimenCL88

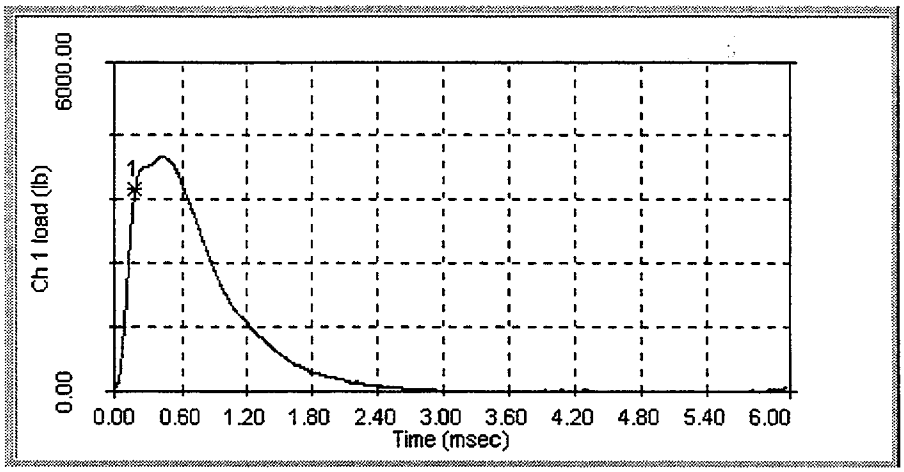



Figure A. 16 Specimen CT84

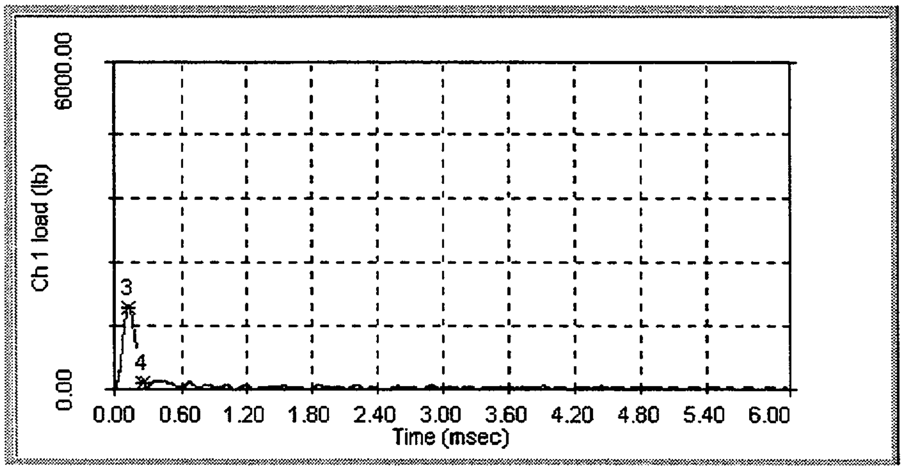



Figure A. 17 Specimen CT87

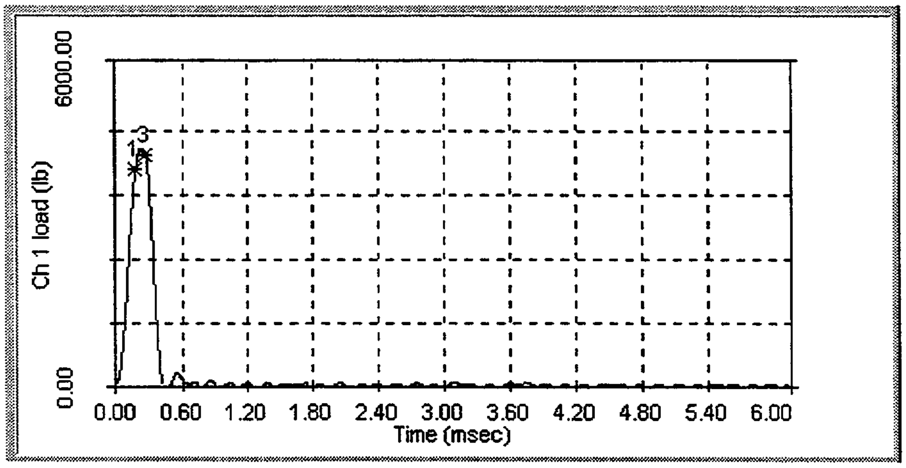



Figure A. 18 Specimen CT90

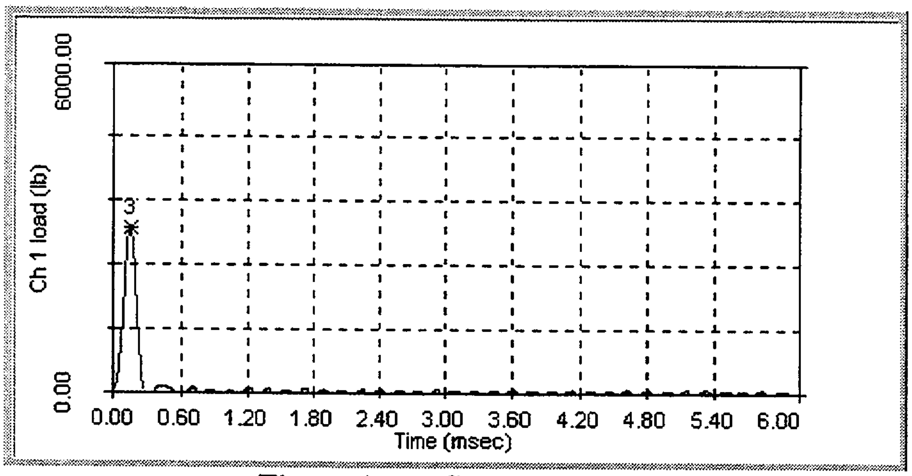



Figure A. 19 Specimen CT83

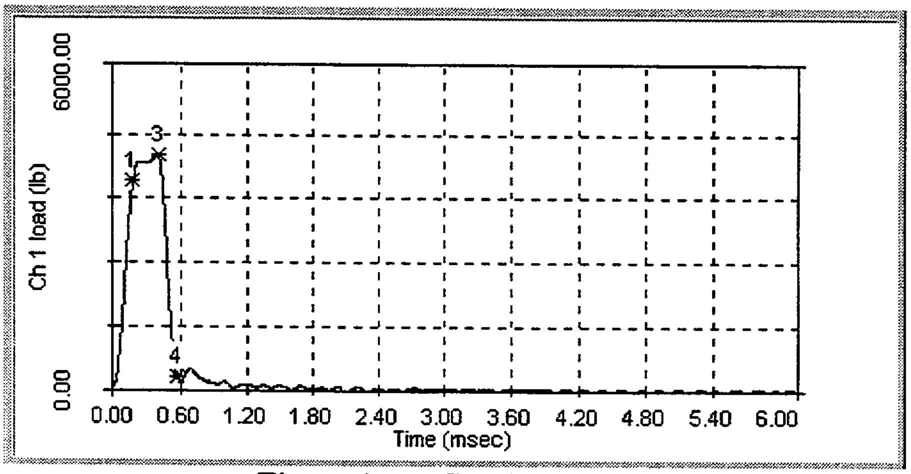



Figure A. 20 Specimen CT77

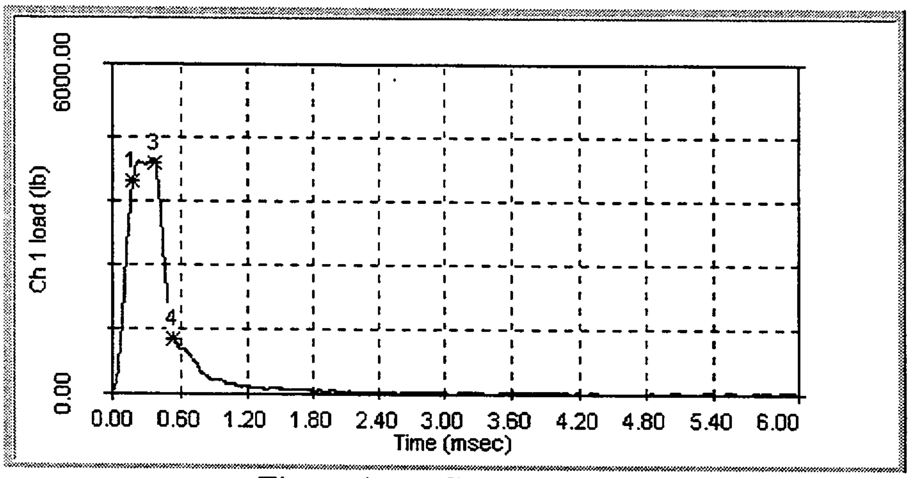



Figure A. 21 Specimen CT80

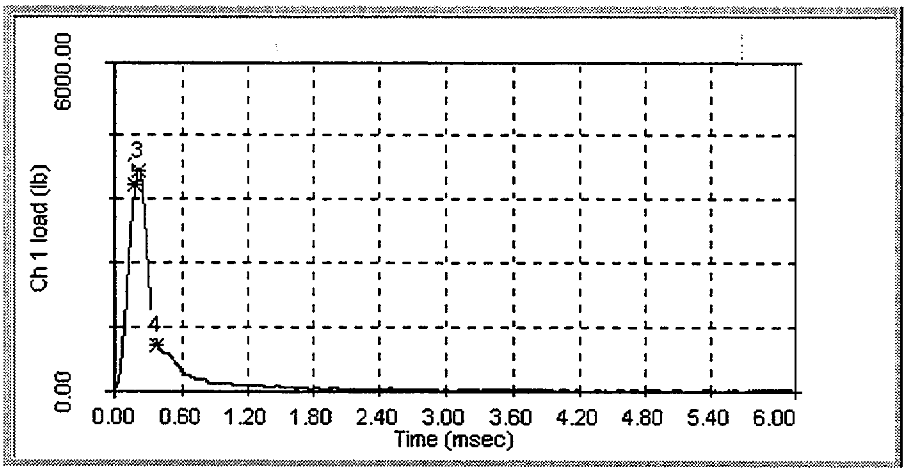



Figure A. 22 Specimen CT89

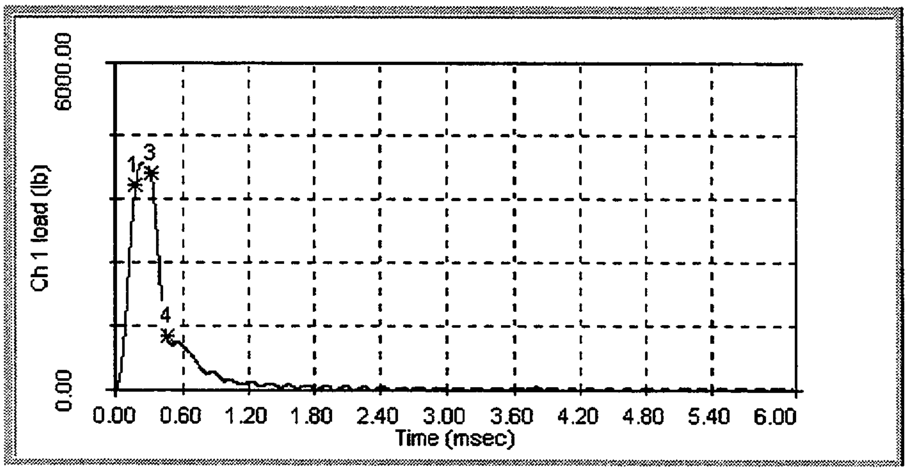



Figure A. 23 Specimen CT88

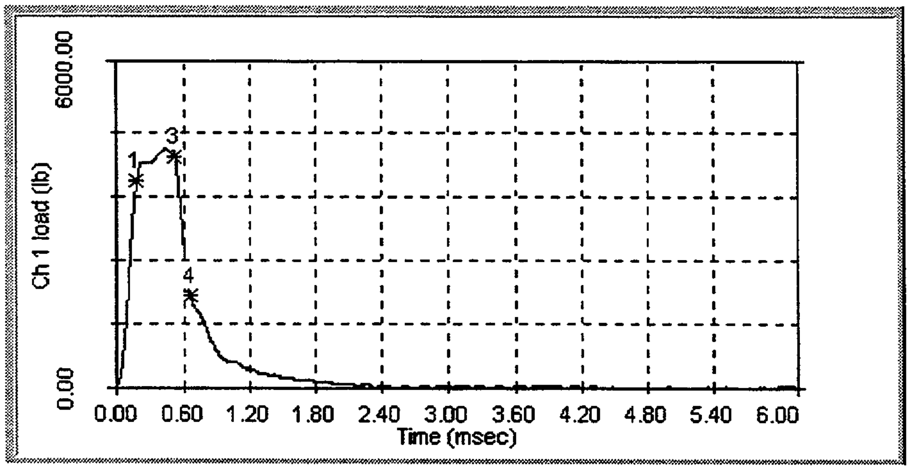



Figure A. 24 Specimen CT79

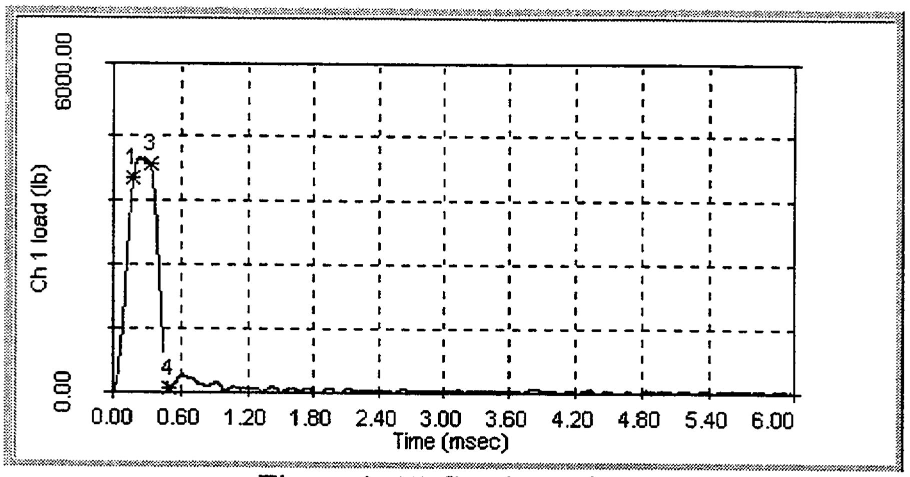



Figure A. 25 Specimen CT82

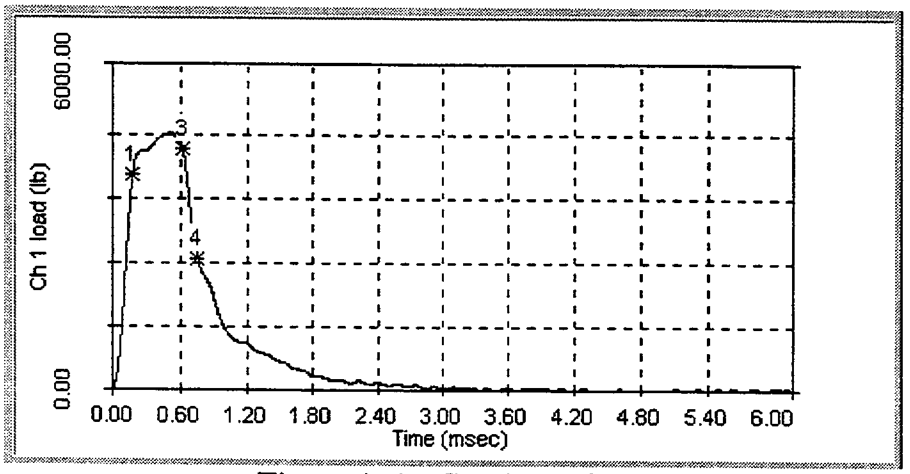



Figure A. 26 Specimen CT81

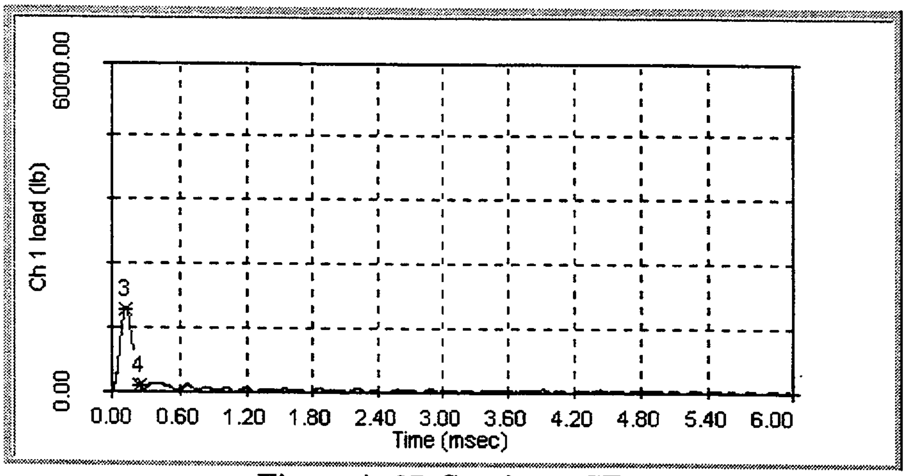



Figure A. 27 Specimen CT86

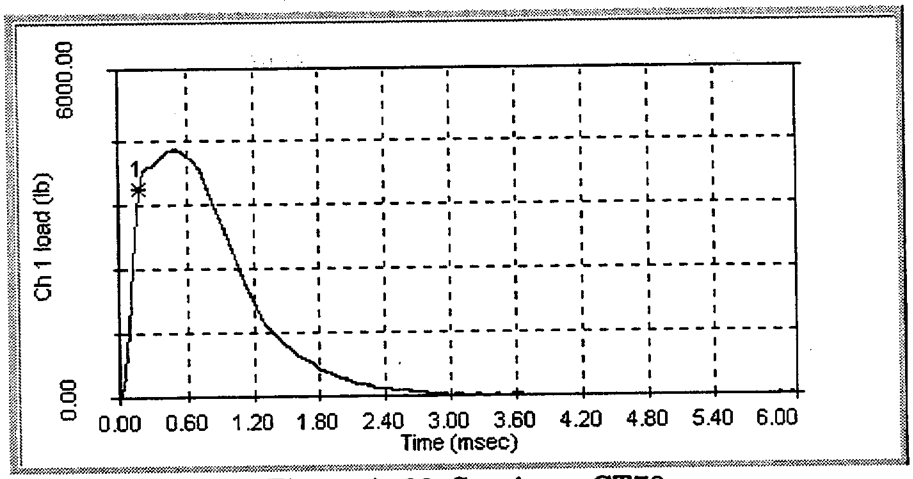


Figure A. 28 Specimen CT78

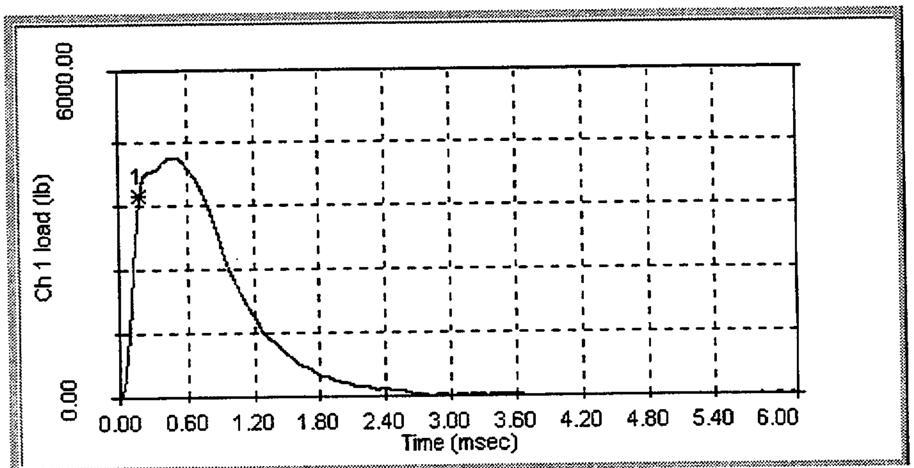


Figure A. 29 Specimen CT76

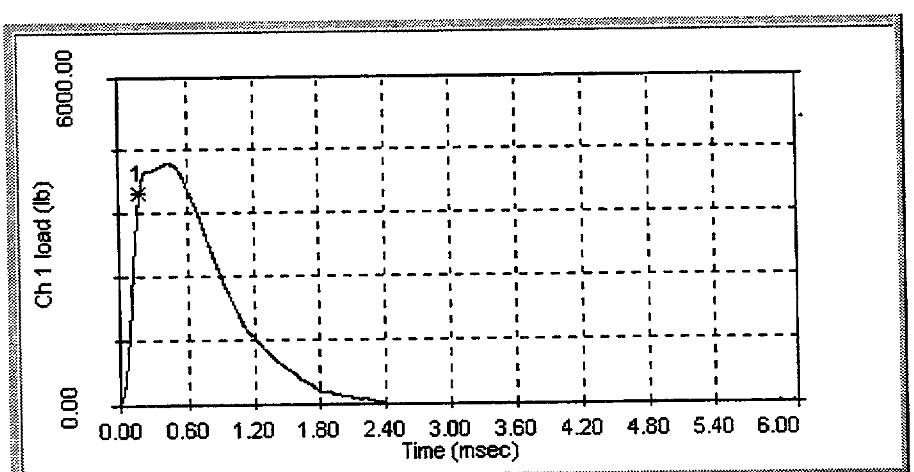


Figure A. 30 Specimen CT85

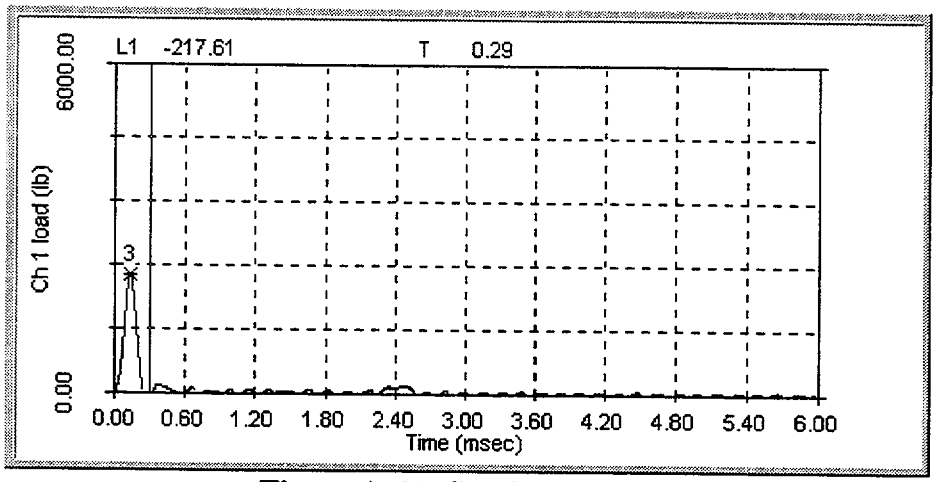



Figure A. 31 Specimen CW81

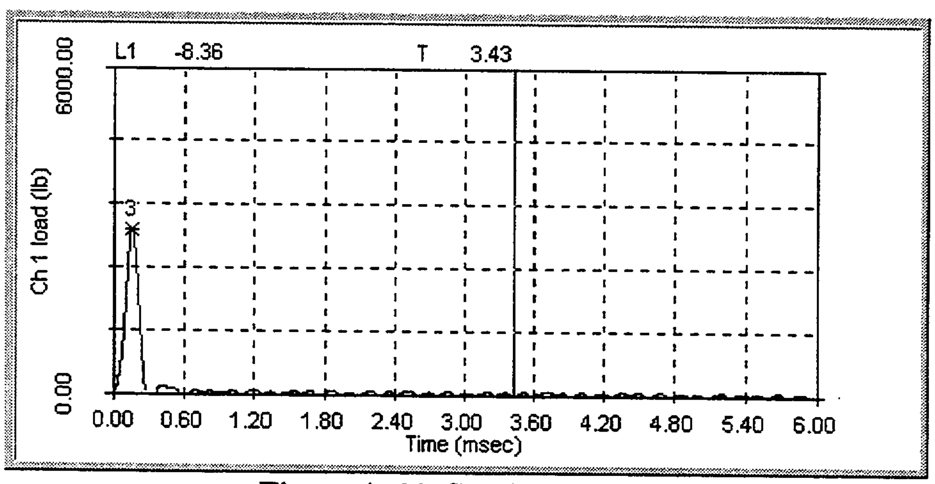



Figure A. 32 Specimen CW88

Data missing

Figure A. 33 Specimen CW76

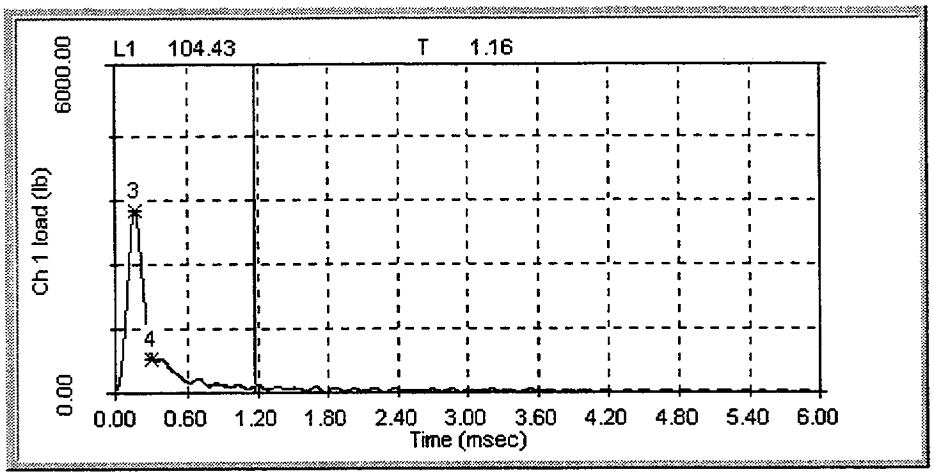



Figure A. 34 Specimen CW78

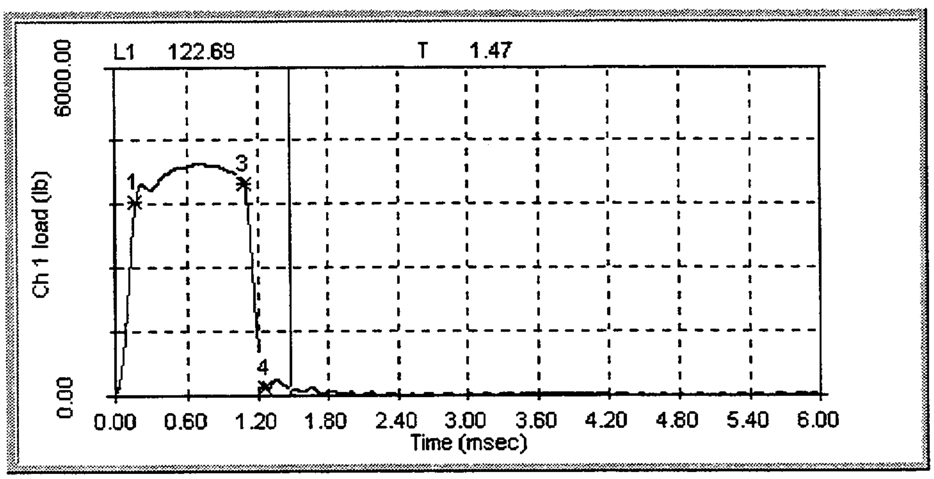



Figure A. 35 Specimen CW89

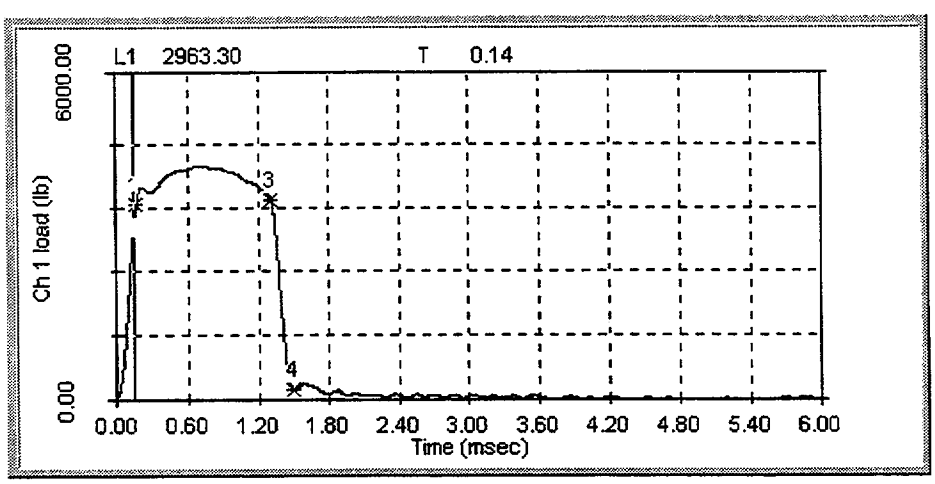



Figure A. 36 Specimen CW90

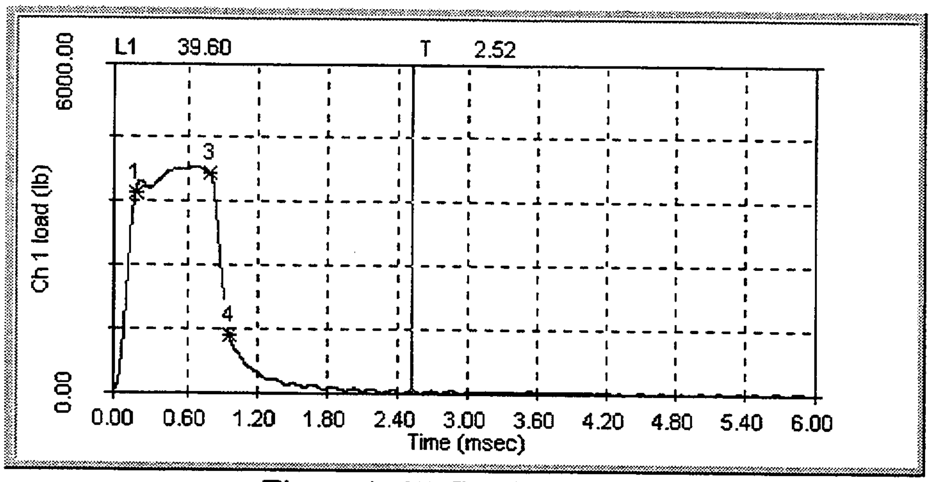



**Figure A. 37 Specimen CW79**

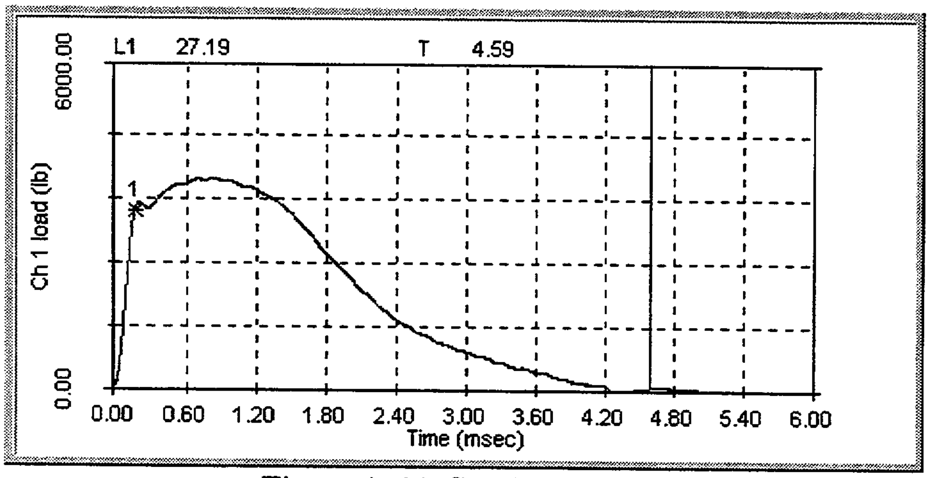



**Figure A. 38 Specimen CW85**

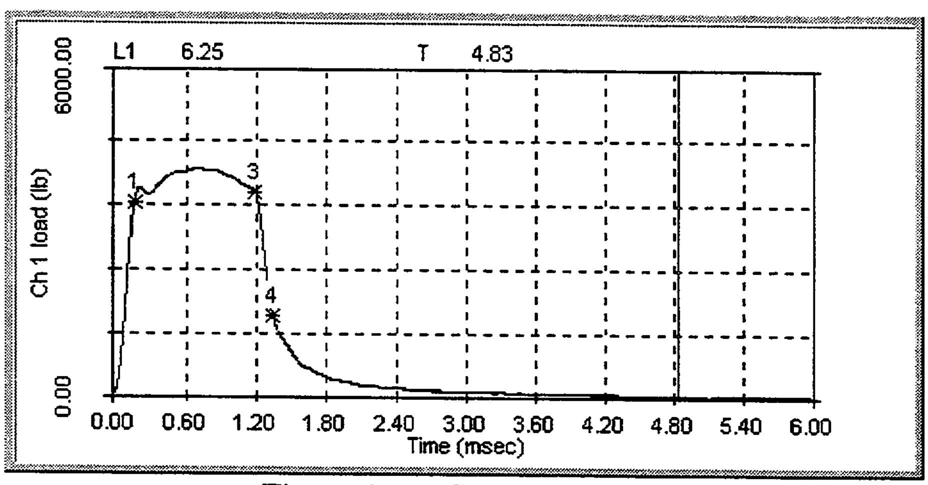



**Figure A. 39 Specimen CW83**

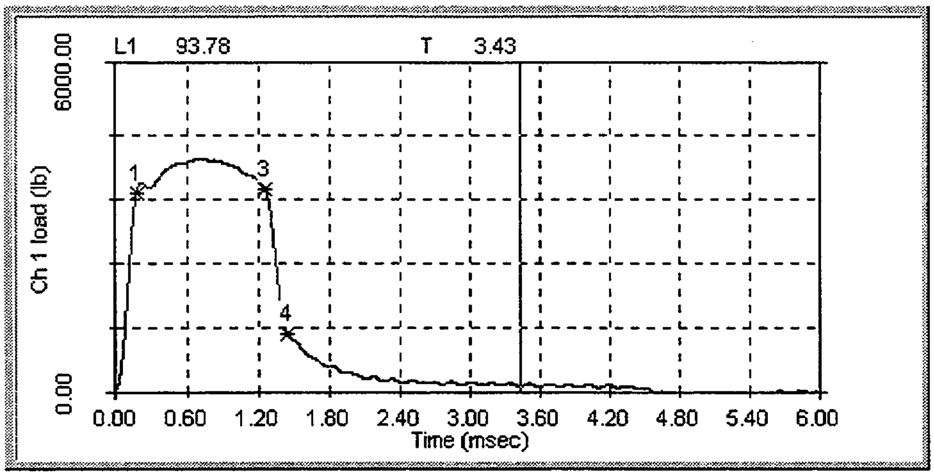



Figure A. 40 Specimen CW87

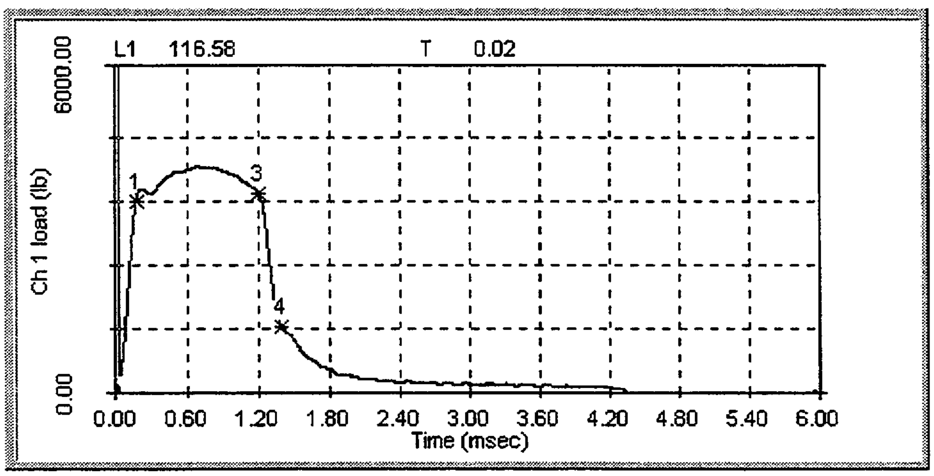



Figure A. 41 Specimen CW77

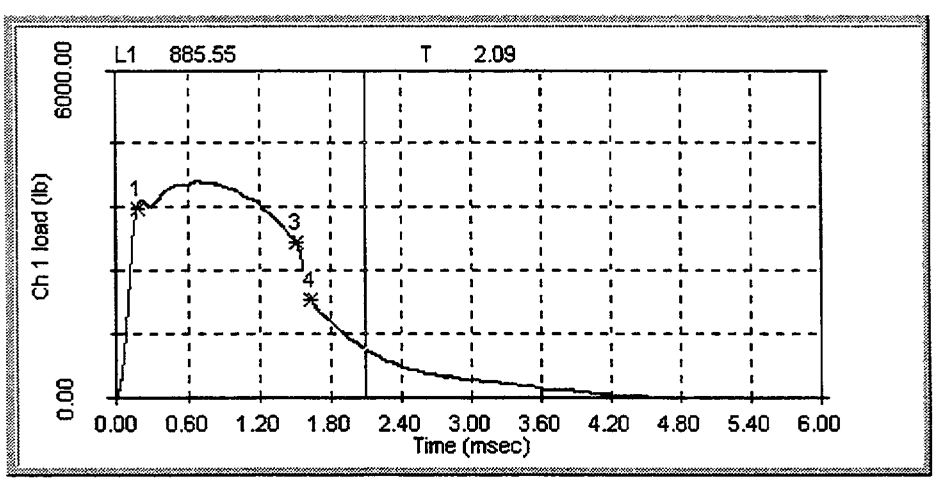



Figure A. 42 Specimen CW86

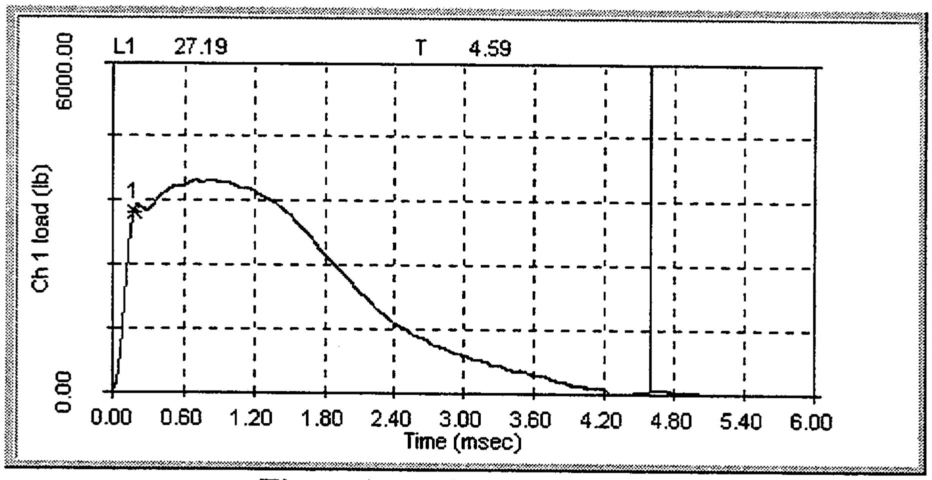



Figure A. 43 Specimen CW84

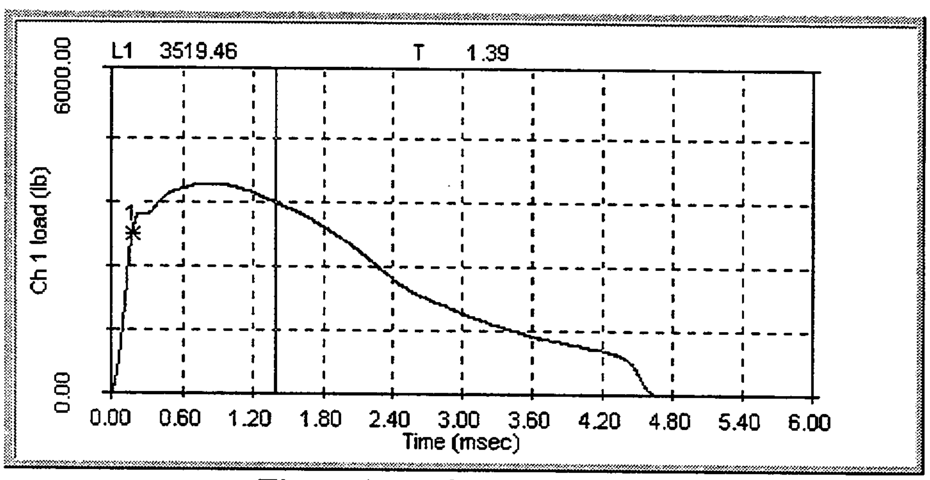



Figure A. 44 Specimen CW80

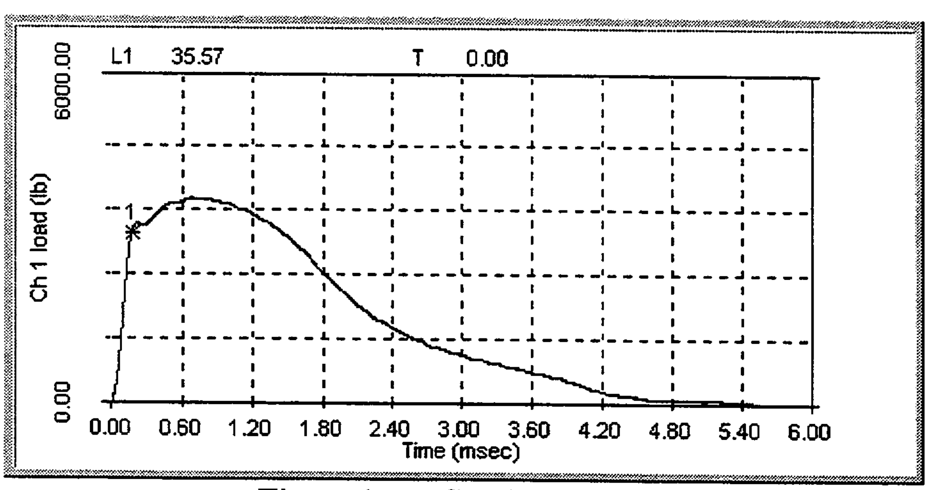



Figure A. 45 Specimen CW82

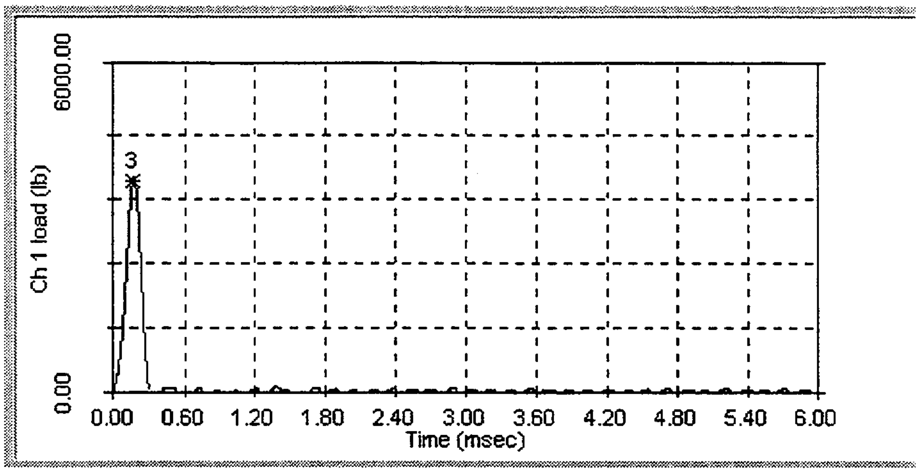



Figure A. 46 Specimen CH90

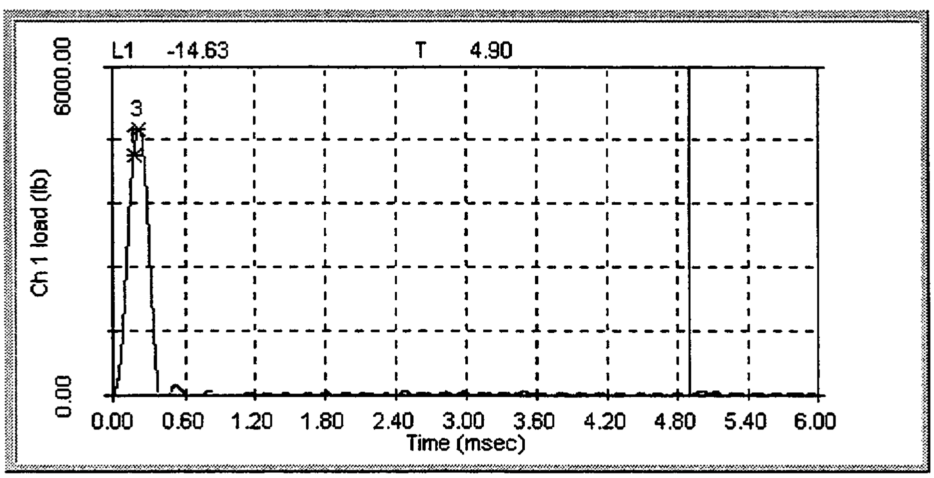



Figure A. 47 Specimen CH82

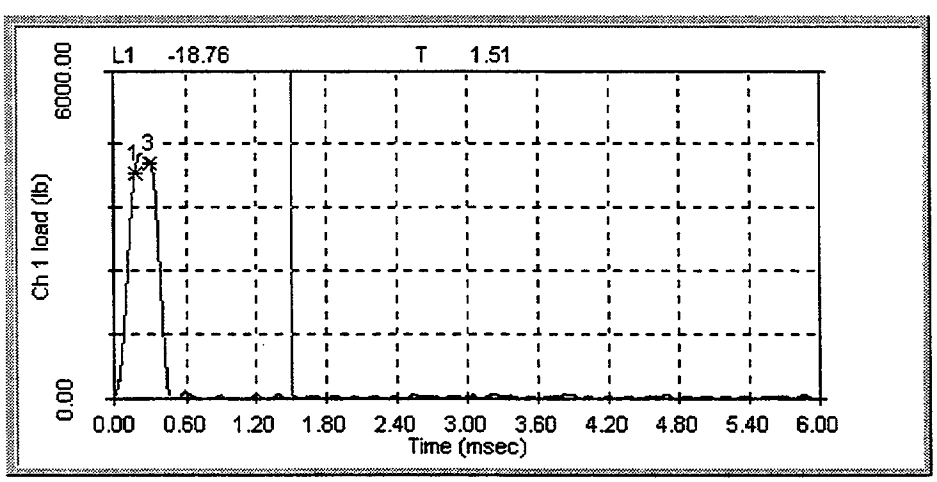



Figure A. 48 Specimen CH77

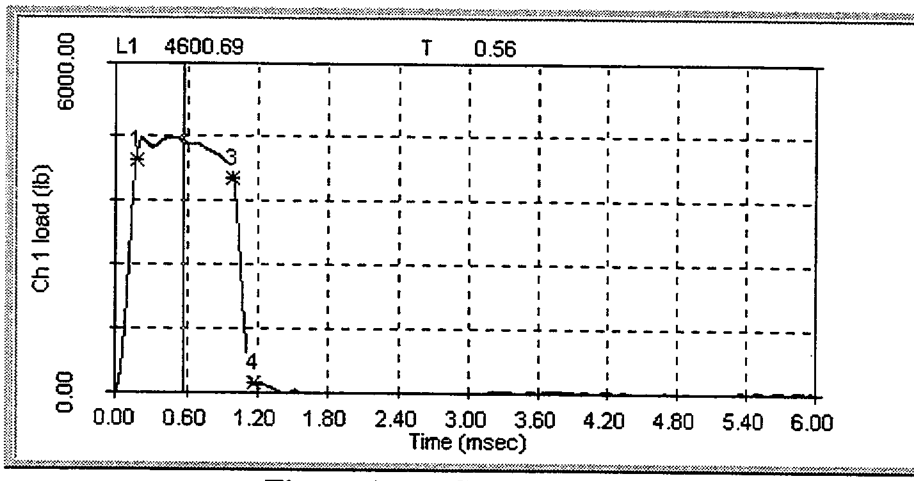



Figure A. 49 Specimen CH83

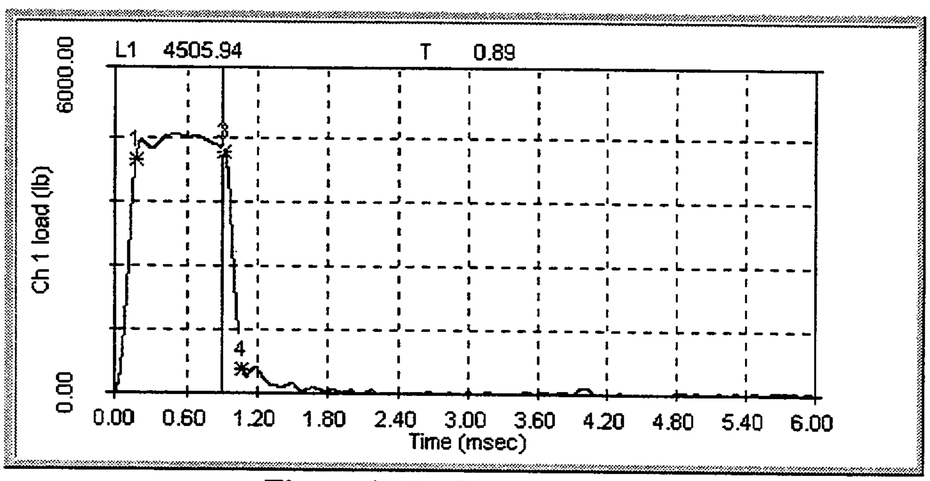



Figure A. 50 Specimen CH86

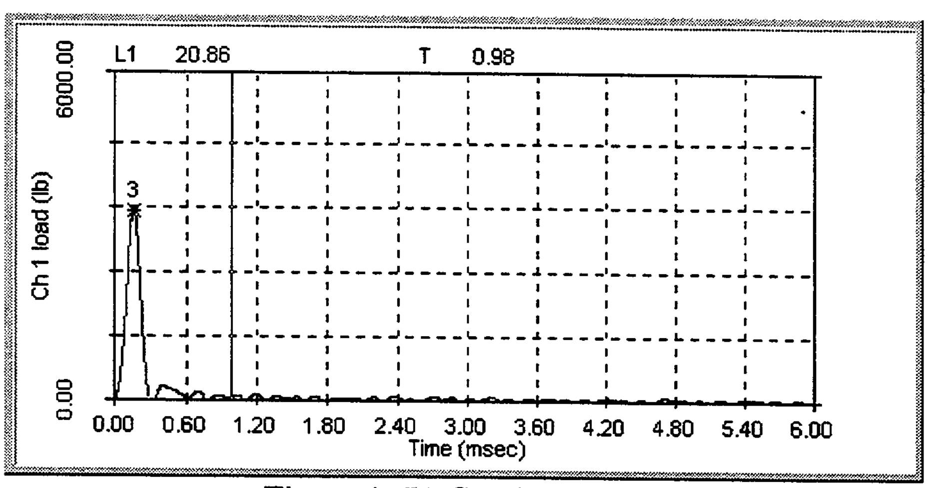



Figure A. 51 Specimen CH85

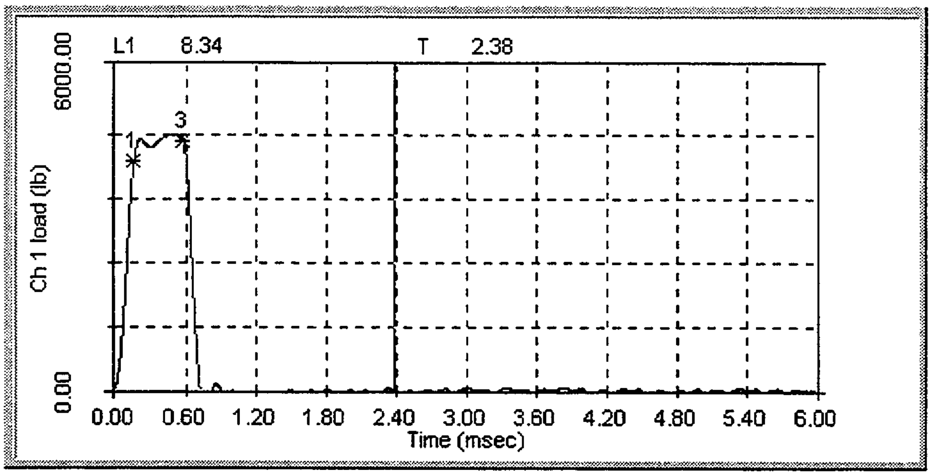



Figure A. 52 Specimen CH76

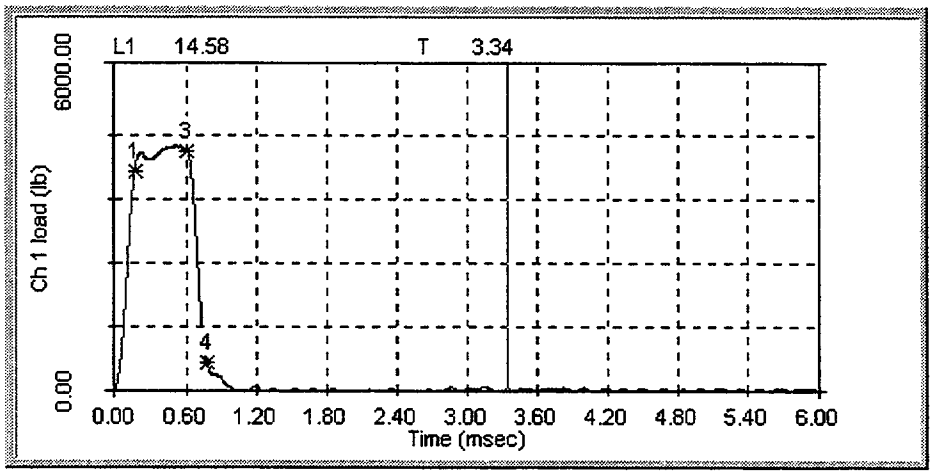



Figure A. 53 Specimen CH78

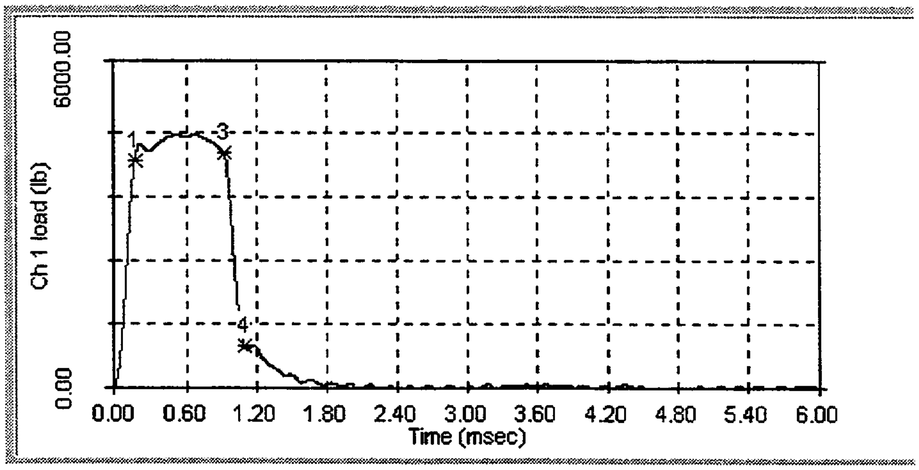



Figure A. 54 Specimen CH87

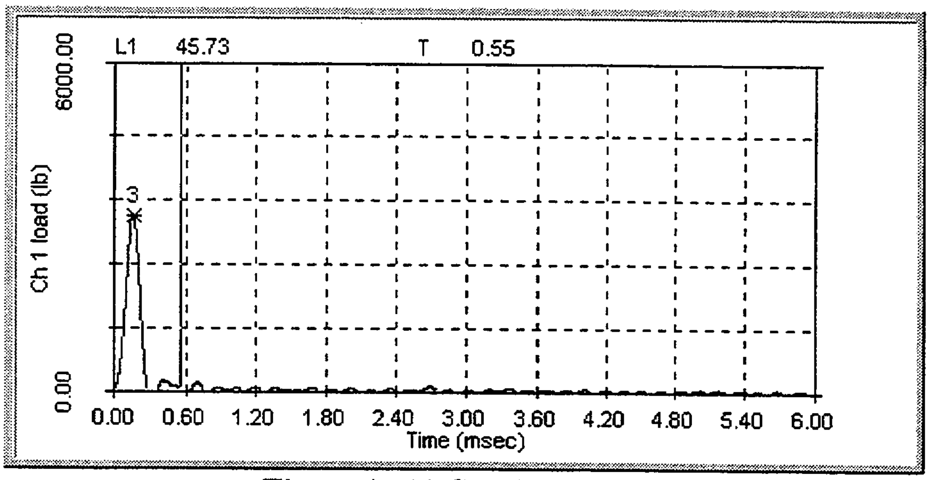



Figure A. 55 Specimen CH80

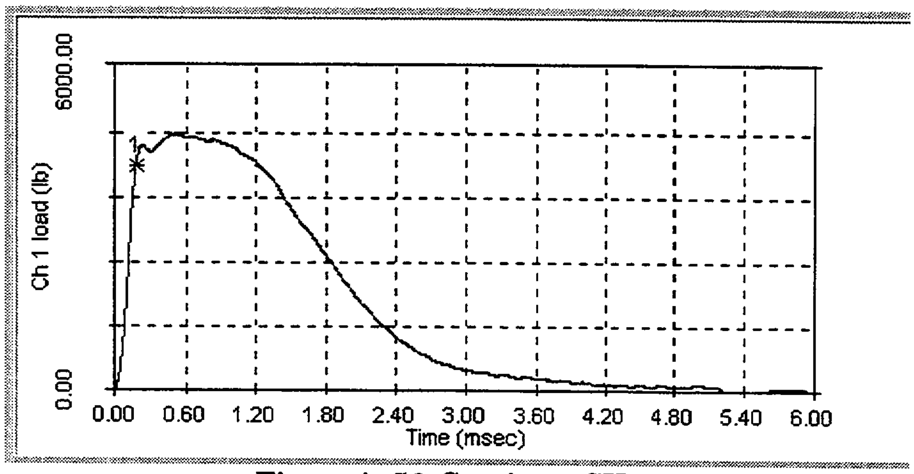



Figure A. 56 Specimen CH89

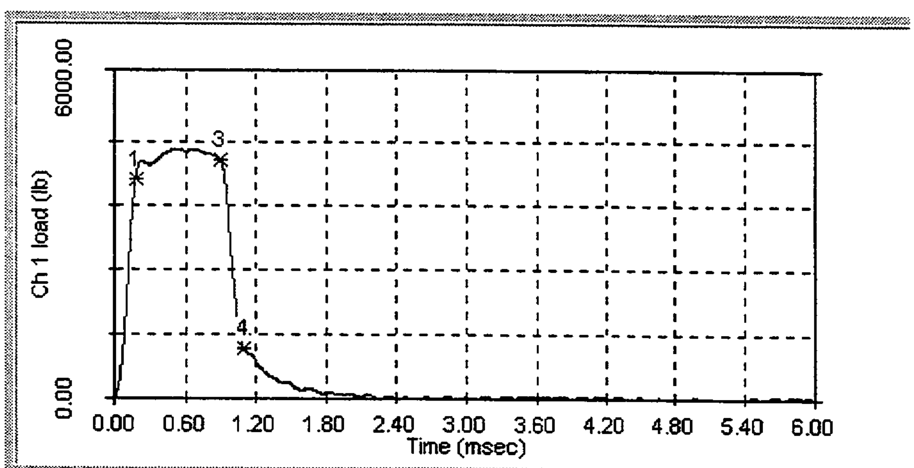



Figure A. 57 Specimen CH88

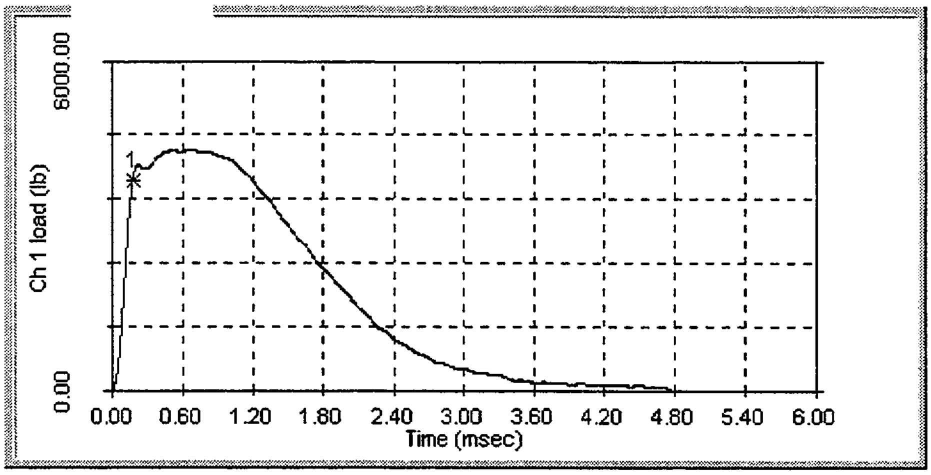



Figure A. 58 Specimen CH84

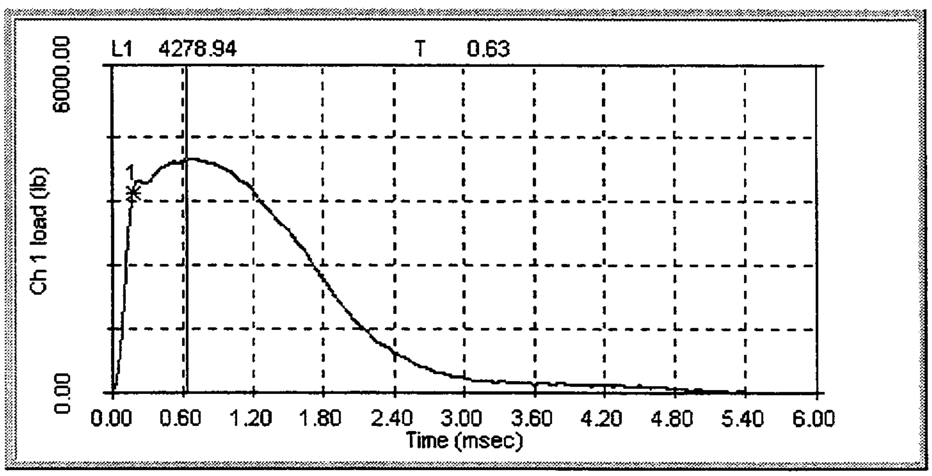



Figure A. 59 Specimen CH79

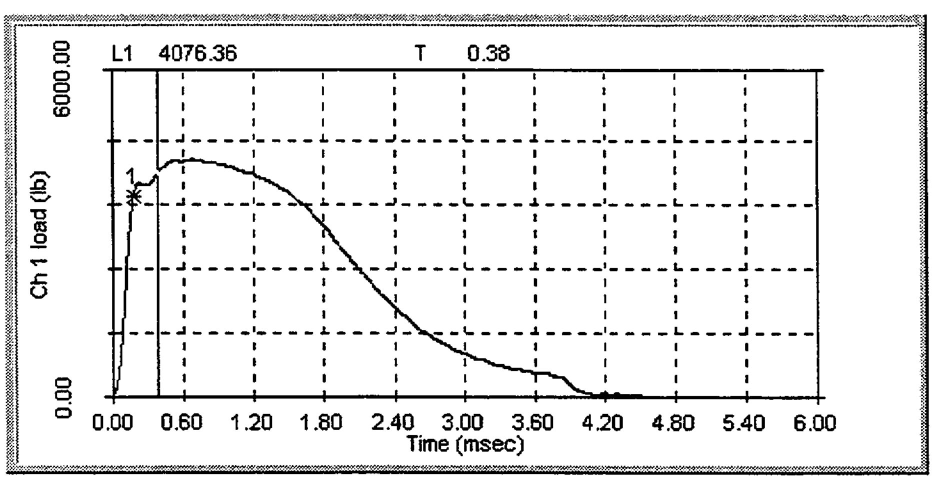



Figure A. 60 Specimen CH81

# APPENDIX B

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

**NOTE:**

**The CVGRAPH Charpy V-notch results given in this Appendix were developed by fixing the lower and upper shelf energy values to those given on page C-1 of Appendix C to this report.**

TABLE B-1

Changes in Average 30 ft-lb Temperatures for Intermediate Shell
Plate B7212-1 (Longitudinal Orientation)
Hand Fit vs. CVGRAPH 4.1

| Capsule | Unirradiated | Hand Fit | $\Delta T_{30}$ | Unirradiated | CVGRAPH Fit | $\Delta T_{30}$ |
|---|---|---|---|---|---|---|
| U | -23°F | 120°F | 133°F | - 22.65°F | 83.14°F | 105.79°F |
| W | -23°F | 142°F | 165°F | - 22.65°F | 145.4°F | 168.05°F |
| X | -23°F | 157°F | 180°F | - 22.65°F | 142.21°F | 164.86°F |
| Z | - - | - - | - - | - 22.65°F | 177.59°F | 200.24°F |

TABLE B-2

Changes in Average 50 ft-lb Temperatures for Intermediate Shell
Plate B7212-1 (Longitudinal Orientation)
Hand Fit vs. CVGRAPH 4.1

| Capsule | Unirradiated | Hand Fit | $\Delta T_{50}$ | Unirradiated | CVGRAPH Fit | $\Delta T_{50}$ |
|---|---|---|---|---|---|---|
| U | 8°F | 143°F | 135°F | 9.87°F | 140.89°F | 131.02°F |
| W | 8°F | 198°F | 190°F | 9.87°F | 185.48°F | 175.61°F |
| X | 8°F | 208°F | 200°F | 9.87°F | 186.24°F | 176.37°F |
| Z | 8°F | - - | - - | 9.87°F | 208.74°F | 198.87°F |

TABLE B-3

Changes in Average 35 mil Lateral Expansion Temperatures for Intermediate Shell Plate B7212-1 (Longitudinal Orientation)
Hand Fit vs. CVGRAPH 4.1

| Capsule | Unirradiated | Hand Fit | $\Delta T_{35}$ | Unirradiated | CVGRAPH Fit | $\Delta T_{35}$ |
|---|---|---|---|---|---|---|
| U | - 10°F | 118°F | 128°F | 1.6°F | 122.2°F | 120.6°F |
| W | - 10°F | 175°F | 185°F | 1.6°F | 167.6°F | 166.0°F |
| X | - 10°F | 175°F | 185°F | 1.6°F | 183.0°F | 181.4°F |
| Z | - 10°F | - - | - - | 1.6°F | 212.3°F | 210.7°F |

TABLE B-4

Changes in Average Energy Absorption at Full Shear for Intermediate Shell Plate B7212-1 (Longitudinal Orientation)
Hand Fit vs. CVGRAPH 4.1

| Capsule | Unirradiated | Hand Fit | ΔE | Unirradiated | CVGRAPH Fit | ΔE |
|---|---|---|---|---|---|---|
| U | 130 ft-lb | 94 ft-lb | - 36 ft-lb | 130 ft-lb | 94 ft-lb | - 36 ft-lb |
| W | 130 ft-lb | 102 ft-lb | - 28 ft-lb | 130 ft-lb | 102 ft-lb | - 28 ft-lb |
| X | 130 ft-lb | 94 ft-lb | - 36 ft-lb | 130 ft-lb | 96 ft-lb | - 34 ft-lb |
| Z | 130 ft-lb | - - | - - | 130 ft-lb | 94 ft-lb | - 36 ft-lb |

TABLE B-5

Changes in Average 30 ft-lb Temperatures for Intermediate Shell
Plate B7212-1 (Transverse Orientation)
Hand Fit vs. CVGRAPH 4.1

| Capsule | Unirradiated | Hand Fit | $\Delta T_{30}$ | Unirradiated | CVGRAPH Fit | $\Delta T_{30}$ |
|---|---|---|---|---|---|---|
| U | - 13°F | 120°F | 133°F | - 7.44°F | 116.56°F | 124.01°F |
| W | - 13°F | 152°F | 165°F | - 7.44°F | 160.74°F | 168.18°F |
| X | - 13°F | 177°F | 190°F | - 7.44°F | 192.57°F | 200.01°F |
| Z | - 13°F | - - | - - | - 7.44°F | 188.06°F | 195.5°F |

TABLE B-6

Changes in Average 50 ft-lb Temperatures for Intermediate Shell
Plate B7212-1 (Transverse Orientation)
Hand Fit vs. CVGRAPH 4.1

| Capsule | Unirradiated | Hand Fit | $\Delta T_{50}$ | Unirradiated | CVGRAPH Fit | $\Delta T_{50}$ |
|---|---|---|---|---|---|---|
| U | 8°F | 143°F | 135°F | 33.66°F | 181.83°F | 148.17°F |
| W | 8°F | 198°F | 190°F | 33.66°F | 218.29°F | 184.62°F |
| X | 8°F | 208°F | 200°F | 33.66°F | 222.03°F | 188.36°F |
| Z | 8°F | - - | - - | 33.66°F | 231.12°F | 197.45°F |

TABLE B-7

Changes in Average 35 mil Lateral Expansion Temperatures for Intermediate Shell
Plate B7212-1 (Transverse Orientation)
Hand Fit vs. CVGRAPH 4.1

| Capsule | Unirradiated | Hand Fit | $\Delta T_{35}$ | Unirradiated | CVGRAPH Fit | $\Delta T_{35}$ |
|---|---|---|---|---|---|---|
| U | 32°F | 160°F | 128°F | 27.2°F | 146.5°F | 119.3°F |
| W | 32°F | 190°F | 158°F | 27.2°F | 182.2°F | 155.0°F |
| X | 32°F | 222°F | 190°F | 27.2°F | 214.4°F | 187.2°F |
| Z | 32°F | - - | - - | 27.2°F | 225.6°F | 198.4°F |

TABLE B-8

Changes in Average Energy Absorption at Full Shear for Intermediate Shell
Plate B7212-1 (Transverse Orientation)
Hand Fit vs. CVGRAPH 4.1

| Capsule | Unirradiated | Hand Fit | $\Delta E$ | Unirradiated | CVGRAPH Fit | $\Delta E$ |
|---|---|---|---|---|---|---|
| U | 95 ft-lb | 69 ft-lb | - 26 ft-lb | 95 ft-lb | 69 ft-lb | - 26 ft-lb |
| W | 95 ft-lb | 76 ft-lb | - 19 ft-lb | 95 ft-lb | 76 ft-lb | - 19 ft-lb |
| X | 95 ft-lb | 69 ft-lb | - 26 ft-lb | 95 ft-lb | 69 ft-lb | - 26 ft-lb |
| Z | 95 ft-lb | - - | - - | 95 ft-lb | 68 ft-lb | - 27 ft-lb |

TABLE B-9

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

| Capsule | Unirradiated | Hand Fit | $\Delta T_{30}$ | Unirradiated | CVGRAPH Fit | $\Delta T_{30}$ |
|---|---|---|---|---|---|---|
| U | - 30°F | - 20°F | 10°F | - 34.7°F | - 63.4°F | - 28.7°F |
| W | - 30°F | - 20°F | 10°F | - 34.7°F | - 28.0°F | 6.7°F |
| X | - 30°F | - 20°F | 10°F | - 34.7°F | - 50.0°F | - 15.3°F |
| Z | - 30°F | - - | - - | - 34.7°F | - 24.7°F | 10.0°F |

TABLE B-10

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

| Capsule | Unirradiated | Hand Fit | $\Delta T_{50}$ | Unirradiated | CVGRAPH Fit | $\Delta T_{50}$ |
|---|---|---|---|---|---|---|
| U | - 1°F | 9°F | 10°F | - 15.6°F | - 26.9°F | - 11.3°F |
| W | - 1°F | 9°F | 10°F | - 15.6°F | - 3.6°F | 12.0°F |
| X | - 1°F | 9°F | 10°F | - 15.6°F | - 17.8°F | - 2.2°F |
| Z | - 1°F | - - | - - | - 15.6°F | - 1.4°F | 14.2°F |

TABLE B-11

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

| Capsule | Unirradiated | Hand Fit | $\Delta T_{35}$ | Unirradiated | CVGRAPH Fit | $\Delta T_{35}$ |
|---|---|---|---|---|---|---|
| U | - 20°F | - 17°F | 3°F | - 23.0°F | - 44.1°F | - 21.1°F |
| W | - 20°F | - 10°F | 10°F | - 23.0°F | - 18.7°F | 4.3°F |
| X | - 20°F | - 10°F | 10°F | - 23.0°F | - 29.9°F | - 6.9°F |
| Z | - 20°F | - - | - - | - 23.0°F | - 0.5°F | 22.5°F |

TABLE B-12

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

| Capsule | Unirradiated | Hand Fit | ΔE | Unirradiated | CVGRAPH Fit | ΔE |
|---|---|---|---|---|---|---|
| U | 144 ft-lb | 132 ft-lb | - 12 ft-lb | 144 ft-lb | 132 ft-lb | - 12 ft-lb |
| W | 144 ft-lb | 144 ft-lb | 0 ft-lb | 144 ft-lb | 144 ft-lb | 0 ft-lb |
| X | 144 ft-lb | 144 ft-lb | 0 ft-lb | 144 ft-lb | 150 ft-lb | 6 ft-lb |
| Z | 144 ft-lb | - - | - - | 144 ft-lb | 133 ft-lb | - 11 ft-lb |

TABLE B-13

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

| Capsule | Unirradiated | Hand Fit | $\Delta T_{30}$ | Unirradiated | CVGRAPH Fit | $\Delta T_{30}$ |
|---|---|---|---|---|---|---|
| U | - 131°F | - 73°F | 58°F | - 175.4°F | - 76.5°F | 98.9°F |
| W | - 131°F | - 22°F | 109°F | - 175.4°F | - 27.7°F | 147.7°F |
| X | - 131°F | - 21°F | 110°F | - 175.4°F | - 65.8°F | 109.6°F |
| Z | - 131°F | - - | - - | - 175.4°F | - 32.8°F | 142.6°F |

TABLE B-14

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

| Capsule | Unirradiated | Hand Fit | $\Delta T_{50}$ | Unirradiated | CVGRAPH Fit | $\Delta T_{50}$ |
|---|---|---|---|---|---|---|
| U | - 83°F | - 33°F | 50°F | - 116.8°F | - 44.6°F | 72.2°F |
| W | - 83°F | 0°F | 83°F | - 116.8°F | - 16.2°F | 100.6°F |
| X | - 83°F | 12°F | 95°F | - 116.8°F | - 39.9°F | 76.9°F |
| Z | - 83°F | - - | - - | - 116.8°F | - 3.2°F | 113.6°F |

TABLE B-15

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

| Capsule | Unirradiated | Hand Fit | $\Delta T_{35}$ | Unirradiated | CVGRAPH Fit | $\Delta T_{35}$ |
|---|---|---|---|---|---|---|
| U | - 91°F | - 38°F | 53°F | - 111.3°F | - 59.6°F | 51.7°F |
| W | - 91°F | - 5°F | 86°F | - 111.3°F | - 20.3°F | 91.0°F |
| X | - 91°F | - 5°F | 86°F | - 111.3°F | - 36.8°F | 74.5°F |
| Z | - 91°F | - - | - - | - 111.3°F | 5.1°F | 116.4°F |

TABLE B-16

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

| Capsule | Unirradiated | Hand Fit | ΔE | Unirradiated | CVGRAPH Fit | ΔE |
|---|---|---|---|---|---|---|
| U | 158 ft-lb | 111 ft-lb | - 47 ft-lb | 158 ft-lb | 111 ft-lb | - 47 ft-lb |
| W | 158 ft-lb | 126 ft-lb | - 32 ft-lb | 158 ft-lb | 126 ft-lb | - 32 ft-lb |
| X | 158 ft-lb | 126 ft-lb | - 32 ft-lb | 158 ft-lb | 128 ft-lb | - 30 ft-lb |
| Z | 158 ft-lb | - - | - - | 158 ft-lb | 126 ft-lb | - 32 ft-lb |

# APPENDIX C

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

Contained in Table C-1 are the upper shelf energy values used as input for the generation of the Charpy V-notch plots using CVGRAPH, Version 4.1. Lower shelf energy values were fixed at 2.2 ft-lb. The unirradiated and irradiated upper shelf energy values were calculated per the ASTM E185-82 definition of upper shelf energy, "the average energy value for all Charpy specimens (normally three) whose test temperature is above the upper end of the transition region. For specimens tested in sets of three at each test temperature, the set having the highest average may be regarded as defining the upper shelf energy."

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**Table C-1 Upper Shelf Energy Values Fixed in CVGRAPH**

| Material | Unirradiated | Capsule U | Capsule W | Capsule X | Capsule Z |
|---|---|---|---|---|---|
| Inter. Shell Plate B7212-1 (Longitudinal Orientation) | 130 ft-lb | 94 ft-lb | 102 ft-lb | 96 ft-lb | 94 ft-lb |
| Inter. Shell Plate B7212-1 (Transverse Orientation) | 95 ft-lb | 69 ft-lb | 76 ft-lb | 69 ft-lb | 68 ft-lb |
| Weld Metal (Heat # BOLA) | 144 ft-lb | 132 ft-lb | 144 ft-lb | 150 ft-lb | 133 ft-lb |
| HAZ Material | 158 ft-lb | 111 ft-lb | 126 ft-lb | 128 ft-lb | 126 ft-lb |

# UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:58:53 on 02-22-2000

Page 1

Coefficients of Curve 1

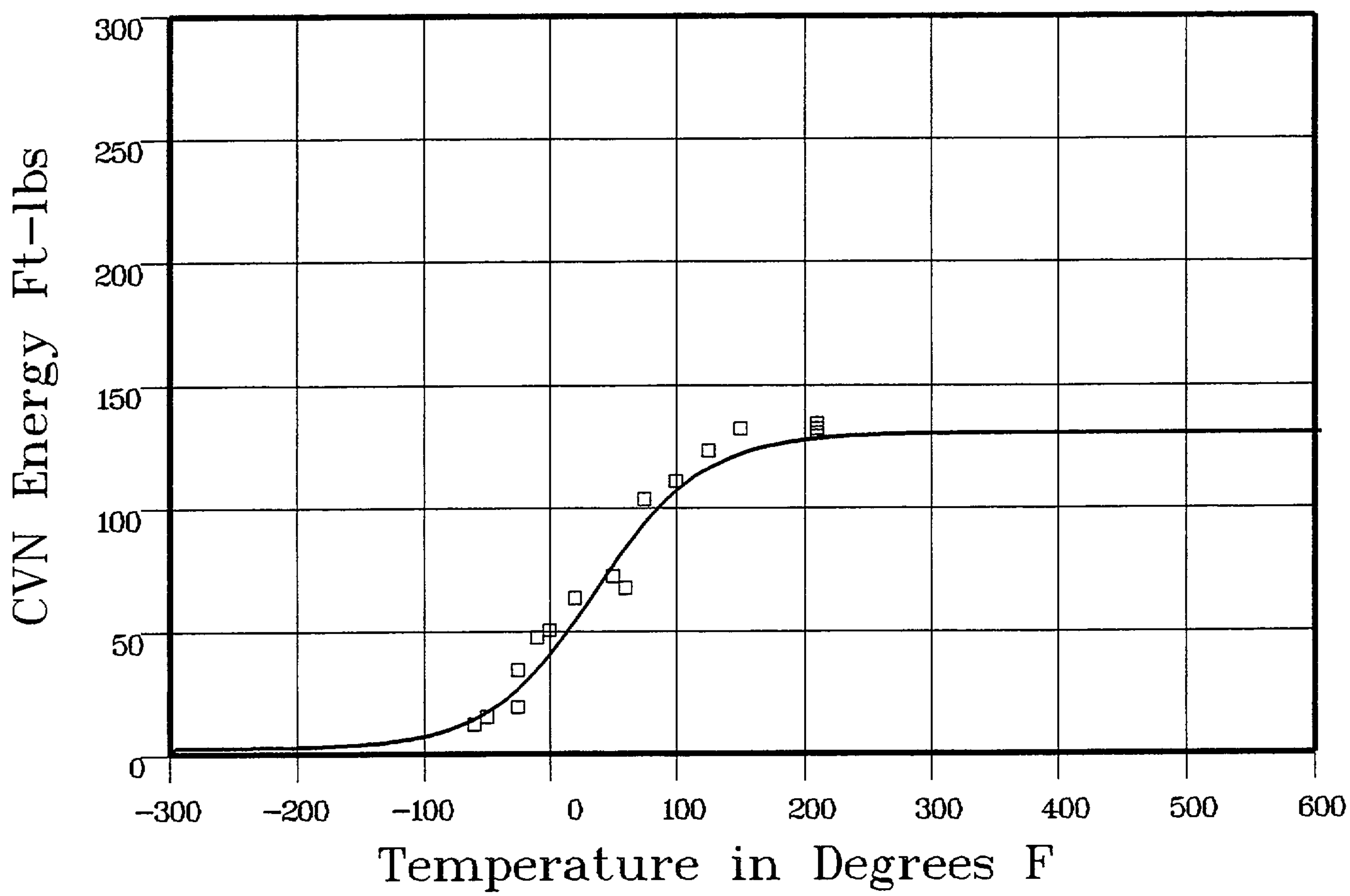
| A = 66.19 | B = 63.99 | C = 85.06 | T0 = 31.87 |
|---|---|---|---|

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

Upper Shelf Energy: 130.19 Fixed    Temp. at 30 ft-lbs: -22.6    Temp. at 50 ft-lbs: 9.8    Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1    Heat Number: B7212-1    Orientation: LT

Capsule: UNIRR    Total Fluence:




Data Set(s) Plotted

Plant: FA2    Cap.: UNIRR    Material: PLATE SA533B1    Ori.: LT    Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| -60 | 12 | 15.43 | -3.43 |
| -50 | 15 | 18.49 | -3.49 |
| -25 | 34 | 28.81 | 5.18 |
| -25 | 19 | 28.81 | -9.81 |
| -10 | 47 | 37.01 | 9.98 |
| 0 | 50 | 43.27 | 6.72 |
| 20 | 63 | 57.31 | 5.68 |
| 50 | 72 | 79.62 | -7.62 |
| 60 | 67 | 86.61 | -19.61 |

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

# UNIRRADIATED

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: UNIRR Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 75 | 103 | 96.11 | 6.88 |
| 100 | 110.5 | 108.72 | 1.77 |
| 125 | 123 | 117.3 | 5.69 |
| 150 | 132 | 122.69 | 9.3 |
| 210 | 132 | 128.27 | 3.72 |
| 210 | 134 | 128.27 | 5.72 |
| 210 | 130 | 128.27 | 1.72 |

SUM of RESIDUALS = 18.42

## CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:05:32 on 02-22-2000

Page 1

Coefficients of Curve 1

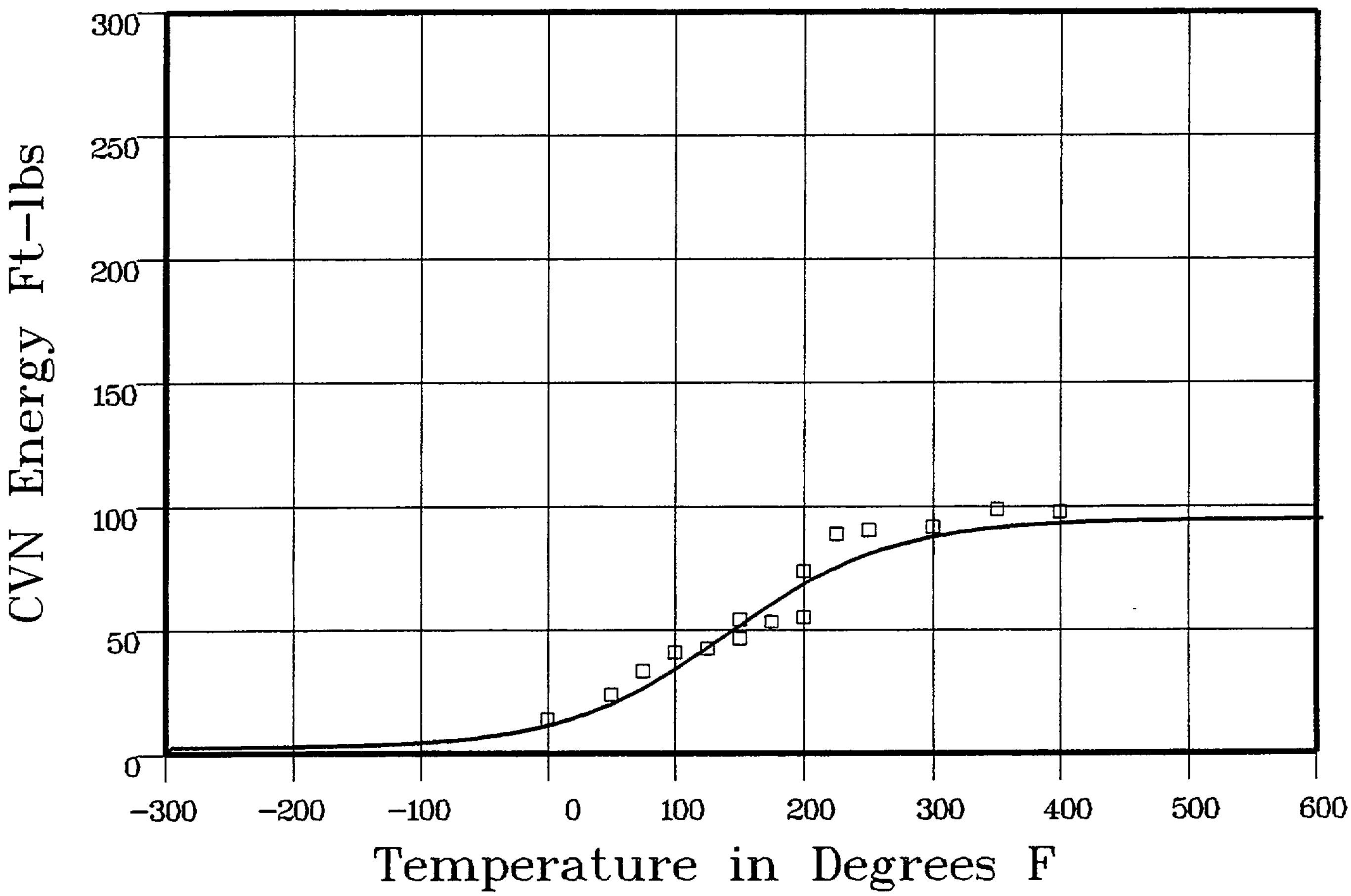
| A = 48.29 | B = 46.1 | C = 126.37 | T0 = 136.23 |
|---|---|---|---|

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

Upper Shelf Energy: 94.4 Fixed Temp. at 30 ft-lbs: 83.1 Temp. at 50 ft-lbs: 140.8 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: U Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: U Material: PLATE SA533B1 Ori.: LT Heat #: B7212-1

### Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 0 | 13.5 | 11.76 | 1.73 |
| 50 | 23.5 | 20.96 | 2.53 |
| 75 | 33 | 27.56 | 5.43 |
| 100 | 40.5 | 35.43 | 5.06 |
| 125 | 42 | 44.21 | -2.21 |
| 150 | 54 | 53.3 | .69 |
| 150 | 46 | 53.3 | -7.3 |
| 175 | 53 | 62.01 | -9.01 |
| 200 | 73.5 | 69.76 | 3.73 |

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

# CAPSULE U

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: U Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 200 | 55 | 69.76 | -14.76 |
| 225 | 88.5 | 76.23 | 12.26 |
| 250 | 90 | 81.32 | 8.67 |
| 300 | 91.5 | 87.97 | 3.52 |
| 350 | 98.5 | 91.37 | 7.12 |
| 400 | 97.5 | 93 | 4.49 |

SUM of RESIDUALS = 21.98

# CAPSULE W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:18:33 on 02-22-2000

Page 1

Coefficients of Curve 1

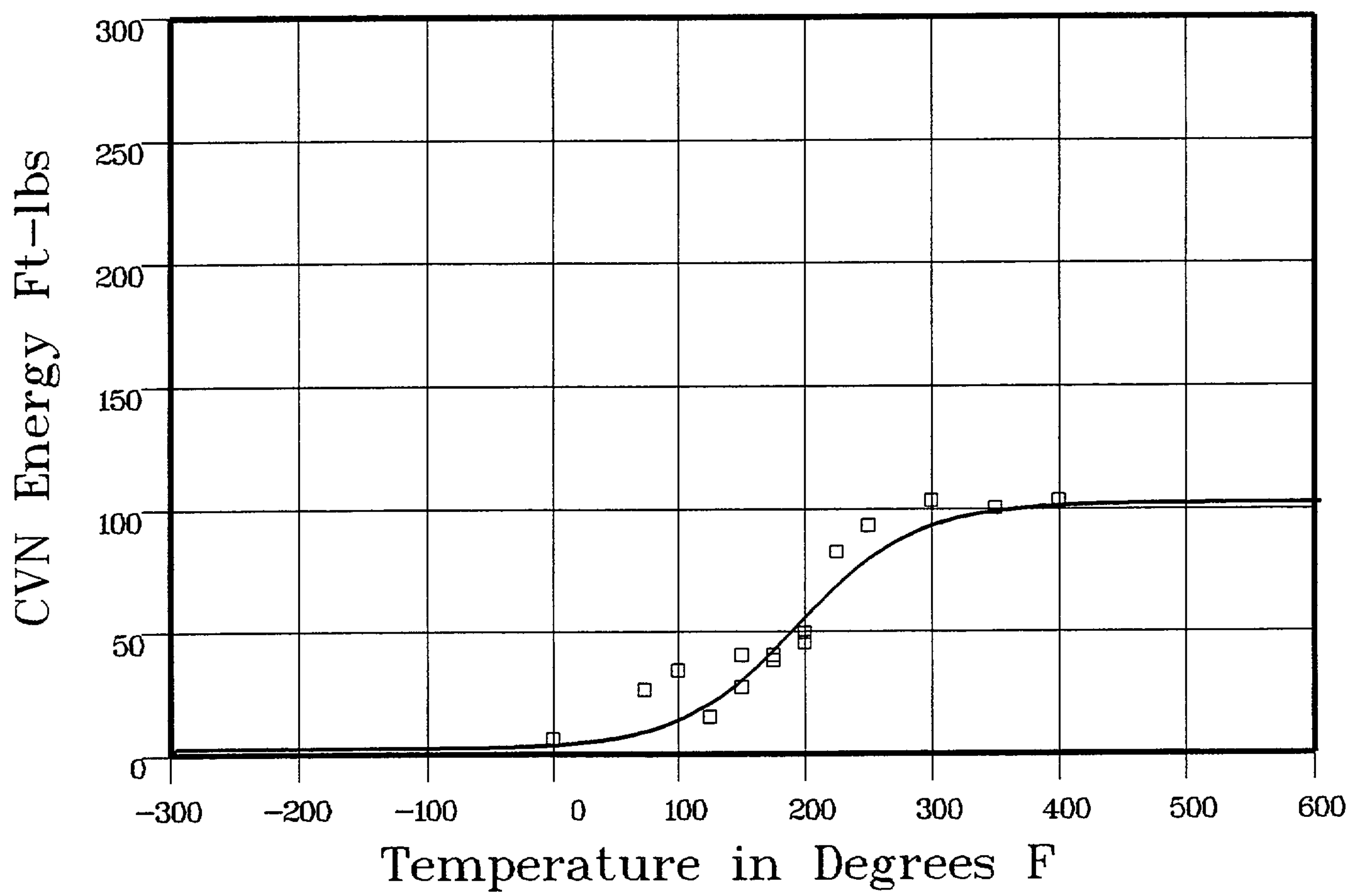
| A = 52.09 | B = 49.9 | C = 92.4 | T0 = 189.37 |
|---|---|---|---|

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

Upper Shelf Energy: 102 Fixed  Temp. at 30 ft-lbs: 145.4  Temp. at 50 ft-lbs: 185.4  Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1  Heat Number: B7212-1  Orientation: LT

Capsule: W  Total Fluence:




Data Set(s) Plotted

Plant: FA2  Cap.: W  Material: PLATE SA533B1  Ori.: LT  Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 0 | 6 | 3.82 | 2.17 |
| 73 | 26 | 9.63 | 16.36 |
| 100 | 34 | 14.8 | 19.19 |
| 125 | 15 | 22.04 | -7.04 |
| 150 | 27 | 32.03 | -5.03 |
| 150 | 40 | 32.03 | 7.96 |
| 175 | 38 | 44.39 | -6.39 |
| 175 | 40 | 44.39 | -4.39 |
| 200 | 45 | 57.81 | -12.81 |

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

# CAPSULE W

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: W Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 200 | 49 | 57.81 | -8.81 |
| 225 | 82 | 70.43 | 11.56 |
| 250 | 93 | 80.83 | 12.16 |
| 300 | 103 | 93.65 | 9.34 |
| 350 | 100 | 99 | .99 |
| 400 | 103 | 100.96 | 2.03 |

SUM of RESIDUALS = 37.28

# CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:24:09 on 02-22-2000

Page 1

Coefficients of Curve 1

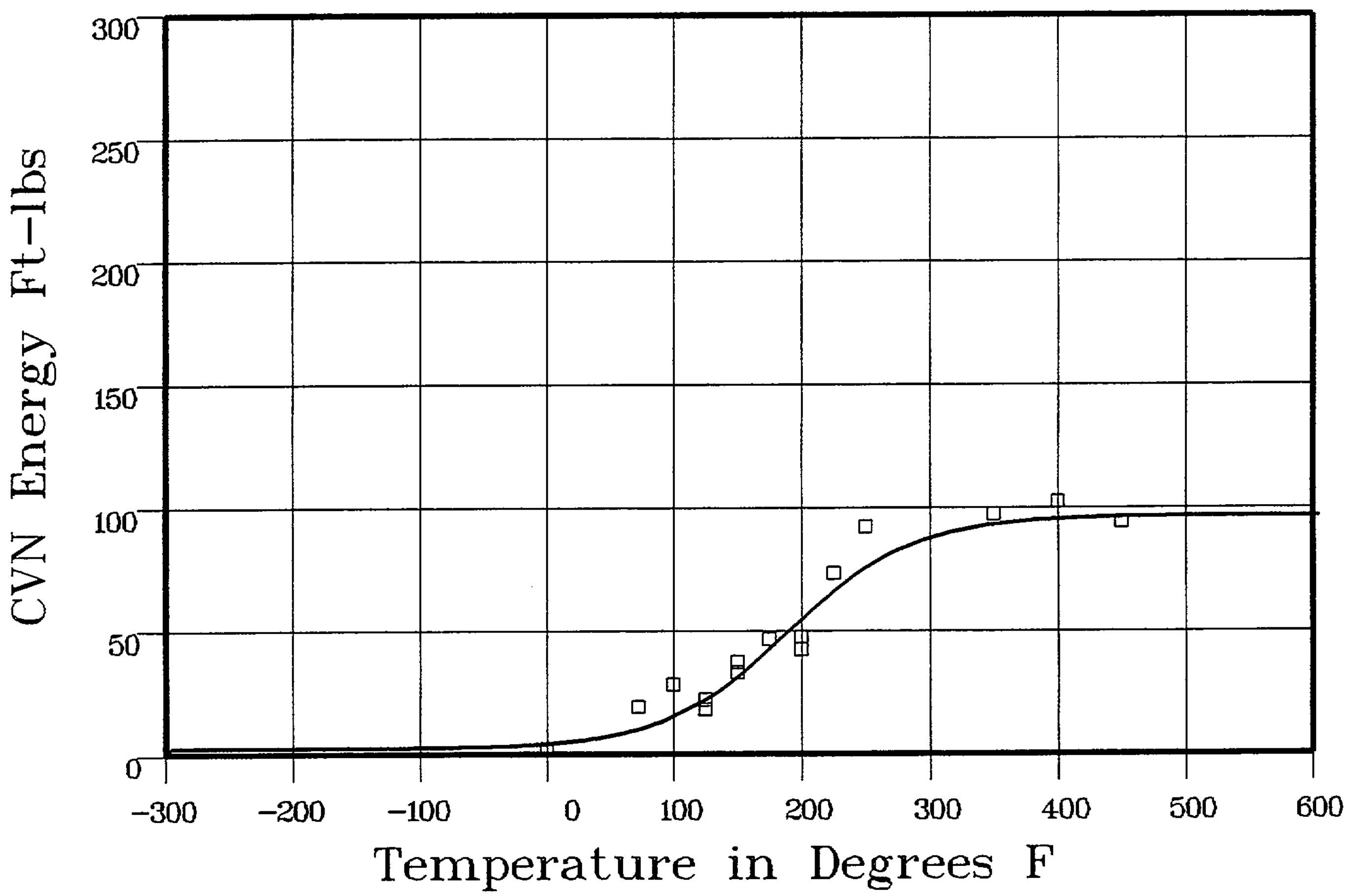
| A = 49.25 | B = 47.05 | C = 97.74 | T0 = 184.68 |
|---|---|---|---|

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

Upper Shelf Energy: 96.3 Fixed  Temp. at 30 ft-lbs: 142.2  Temp. at 50 ft-lbs: 186.2  Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1  Heat Number: B7212-1  Orientation: LT

Capsule: X  Total Fluence:




Data Set(s) Plotted

Plant: FA2  Cap.: X  Material: PLATE SA533B1  Ori.: LT  Heat #: B7212-1

**Charpy V-Notch Data**

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 0 | 2 | 4.3 | -2.3 |
| 72 | 19 | 10.72 | 8.27 |
| 100 | 28 | 16.33 | 11.66 |
| 125 | 22 | 23.62 | -1.62 |
| 125 | 18 | 23.62 | -5.62 |
| 150 | 37 | 33.21 | 3.78 |
| 150 | 33 | 33.21 | -.21 |
| 175 | 46 | 44.6 | 1.39 |
| 200 | 47 | 56.56 | -9.56 |

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

# CAPSULE X

Page 2

Material: PLATE SA533B1　　Heat Number: B7212-1　　Orientation: LT

Capsule: X　　Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 200 | 42 | 56.56 | -14.56 |
| 225 | 73 | 67.62 | 5.37 |
| 250 | 92 | 76.71 | 15.28 |
| 350 | 97 | 93.2 | 3.79 |
| 400 | 102 | 95.16 | 6.83 |
| 450 | 94 | 95.88 | -1.88 |

SUM of RESIDUALS = 20.6

# CAPSULE Z

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:29:47 on 02-22-2000

Page 1

Coefficients of Curve 1

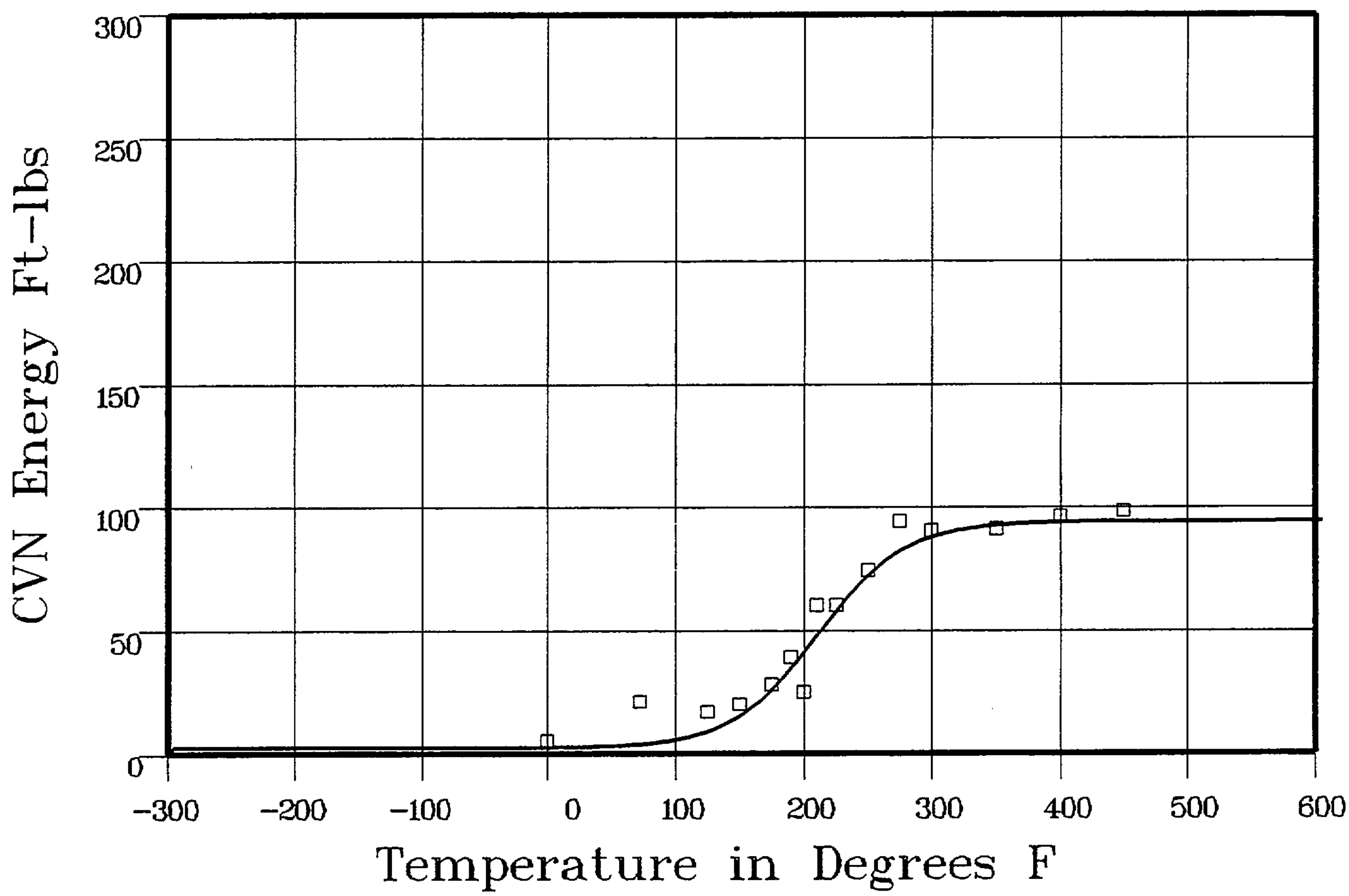
| A = 48 | B = 45.8 | C = 67.87 | T0 = 205.78 |
|---|---|---|---|

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

Upper Shelf Energy: 93.8 Fixed Temp. at 30 ft-lbs: 177.5 Temp. at 50 ft-lbs: 208.7 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: Z Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: Z Material: PLATE SA533B1 Ori.: LT Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 0 | 5 | 2.41 | 2.58 |
| 72 | 21 | 3.94 | 17.05 |
| 125 | 17 | 9.95 | 7.04 |
| 150 | 20 | 17.03 | 2.96 |
| 175 | 28 | 28.54 | -.54 |
| 190 | 39 | 37.53 | 1.46 |
| 200 | 25 | 44.1 | -19.1 |
| 210 | 60 | 50.84 | 9.15 |
| 225 | 60 | 60.63 | -.63 |

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

# CAPSULE Z

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: Z Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 250 | 74 | 74.22 | -.22 |
| 275 | 94 | 83.25 | 10.74 |
| 300 | 90 | 88.43 | 1.56 |
| 350 | 91 | 92.51 | -1.51 |
| 400 | 96 | 93.5 | 2.49 |
| 450 | 98 | 93.73 | 4.26 |

SUM of RESIDUALS = 37.32

# UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:52:55 on 12-21-1998

Page 1

Coefficients of Curve 1

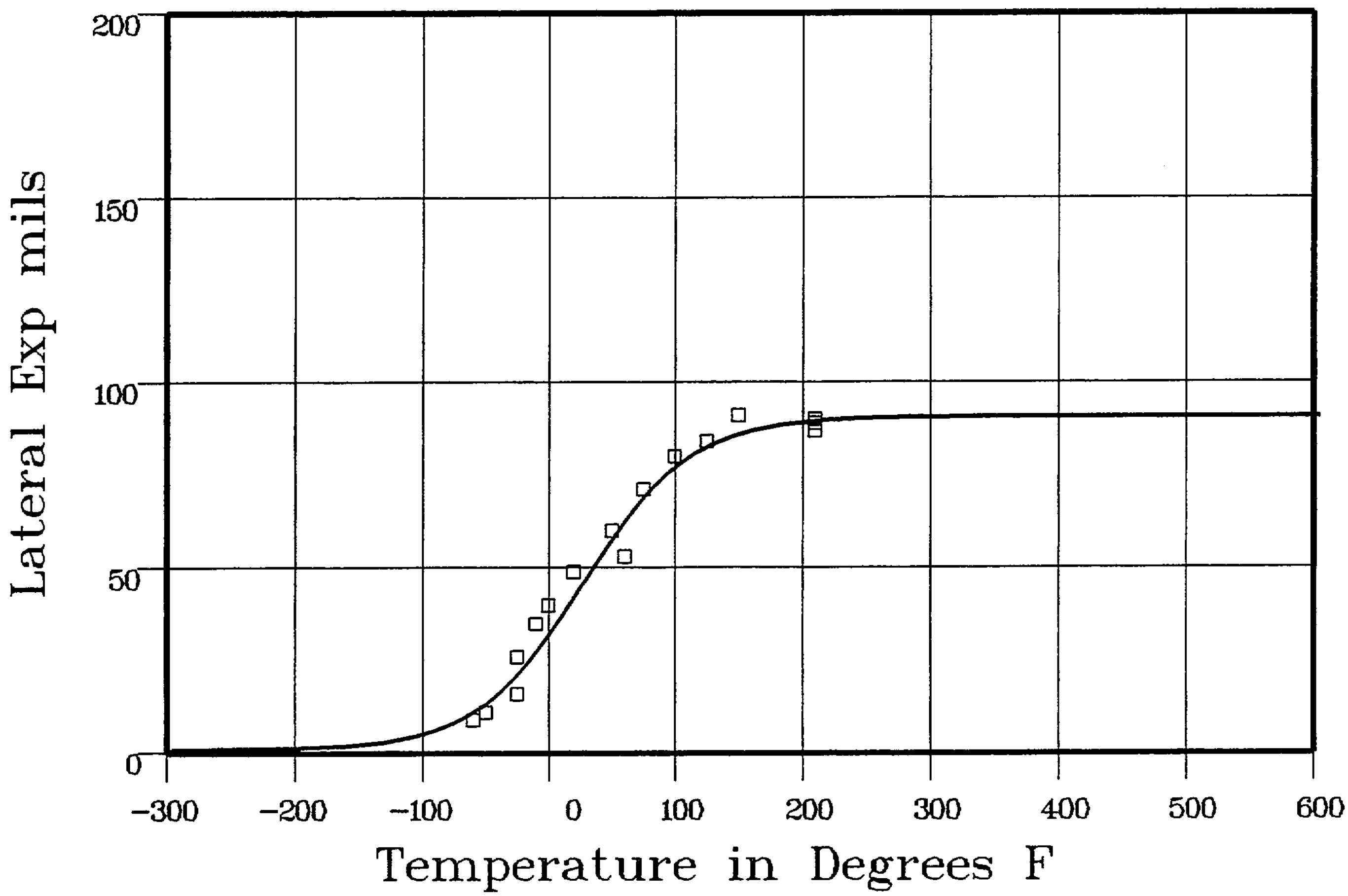
| A = 45.82 | B = 44.82 | C = 84.62 | T0 = 22.5 |
|---|---|---|---|

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

Upper Shelf L.E.: 90.65 Temperature at L.E. 35: 1.6 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: UNIRR Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: UNIRR Material: PLATE SA533B1 Ori.: LT Heat #: B7212-1

**Charpy V-Notch Data**

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| -60 | 9 | 12.17 | -3.17 |
| -50 | 11 | 14.69 | -3.69 |
| -25 | 26 | 23.01 | 2.98 |
| -25 | 16 | 23.01 | -7.01 |
| -10 | 35 | 29.41 | 5.58 |
| 0 | 40 | 34.18 | 5.81 |
| 20 | 49 | 44.5 | 4.49 |
| 50 | 60 | 59.9 | .09 |
| 60 | 53 | 64.48 | -11.48 |

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

# UNIRRADIATED

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: UNIRR Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed LE. | Differential |
|---|---|---|---|
| 75 | 71 | 70.54 | .45 |
| 100 | 80 | 78.28 | 1.71 |
| 125 | 84 | 83.35 | .64 |
| 150 | 91 | 86.45 | 4.54 |
| 210 | 89 | 89.6 | -.6 |
| 210 | 87 | 89.6 | -2.6 |
| 210 | 90 | 89.6 | .39 |

SUM of RESIDUALS = -1.84

# CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:52:55 on 12-21-1998

Page 1

Coefficients of Curve 2

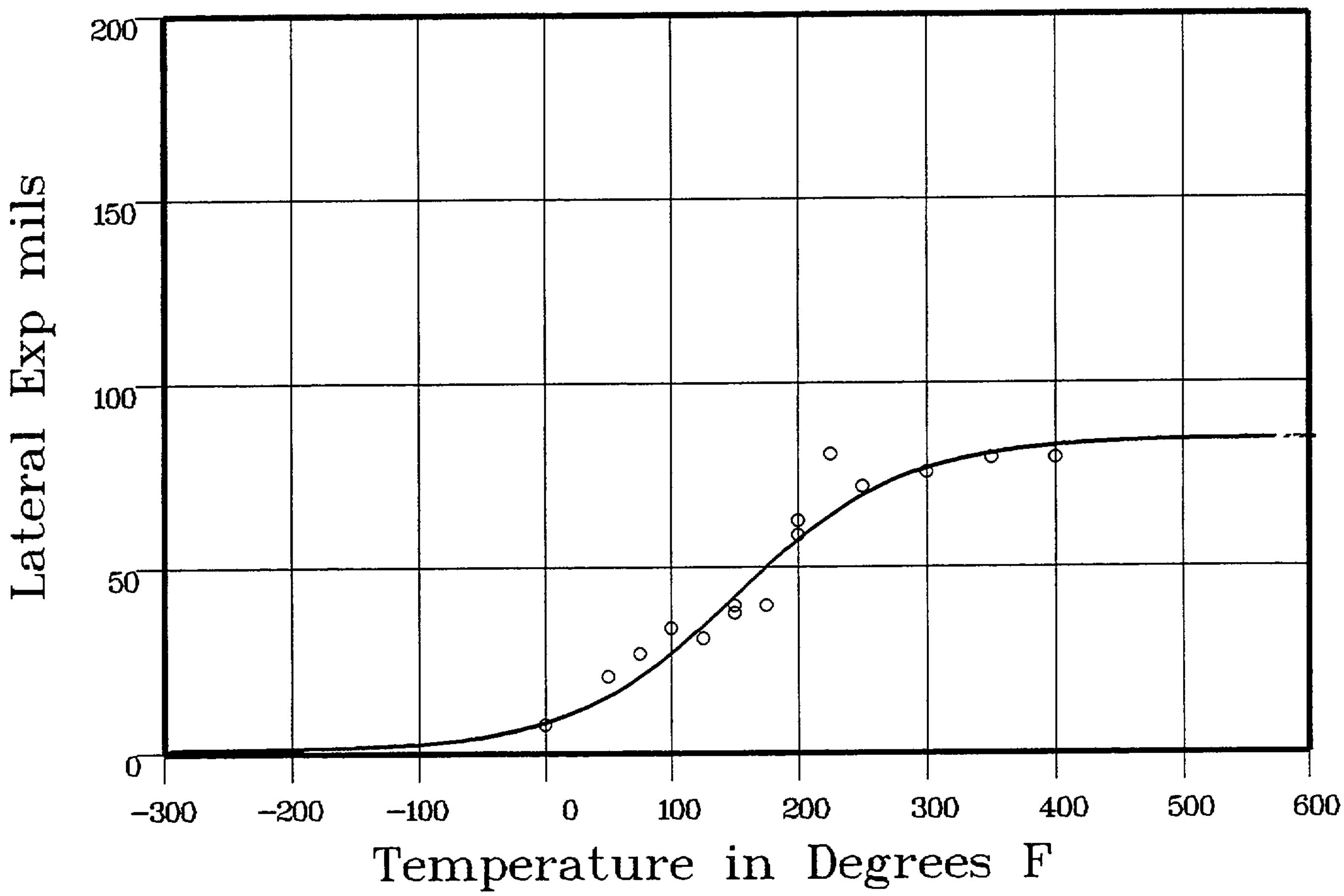
| A = 43.01 | B = 42.01 | C = 130.69 | T0 = 147.39 |
|---|---|---|---|

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

Upper Shelf L.E.: 85.02 Temperature at L.E. 35: 122.1 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: U Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: U Material: PLATE SA533B1 Ori.: LT Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 0 | 8 | 8.97 | -.97 |
| 50 | 21 | 16.44 | 4.55 |
| 75 | 27 | 21.86 | 5.13 |
| 100 | 34 | 28.41 | 5.58 |
| 125 | 31 | 35.88 | -4.88 |
| 150 | 38 | 43.85 | -5.85 |
| 150 | 40 | 43.85 | -3.85 |
| 175 | 40 | 51.75 | -11.75 |

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

# CAPSULE U

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: U Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 200 | 59 | 59.06 | -.06 |
| 200 | 63 | 59.06 | 3.93 |
| 225 | 81 | 65.39 | 15.6 |
| 250 | 72 | 70.55 | 1.44 |
| 300 | 76 | 77.61 | -1.61 |
| 350 | 80 | 81.4 | -1.4 |
| 400 | 80 | 83.3 | -3.3 |

SUM of RESIDUALS = 2.54

# CAPSULE W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:52:55 on 12-21-1998

Page 1

Coefficients of Curve 3

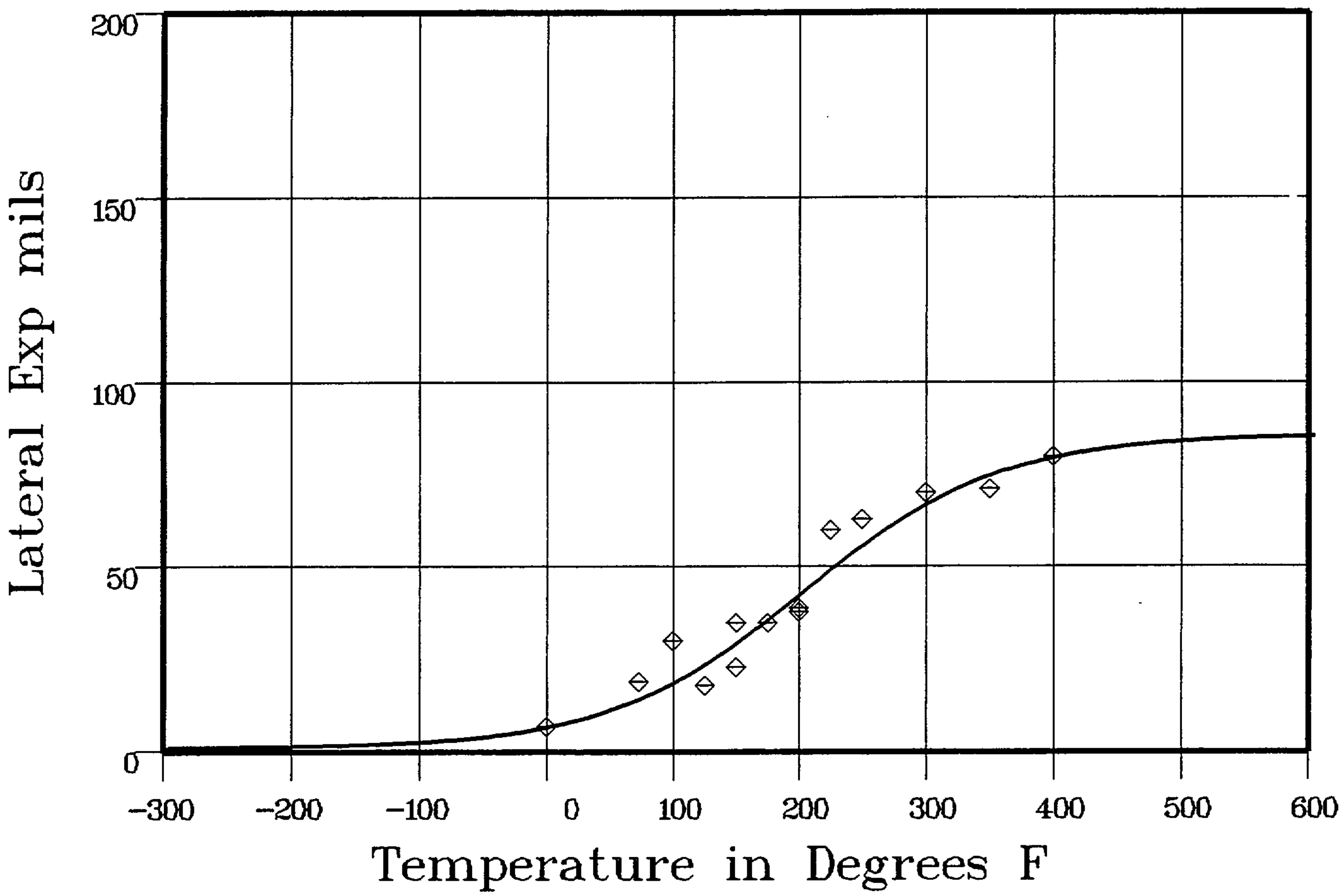
| A = 43.41 | B = 42.41 | C = 155.01 | T0 = 198.75 |
|---|---|---|---|

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

Upper Shelf L.E.: 85.83 Temperature at L.E. 35: 167.5 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: W Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: W Material: PLATE SA533B1 Ori.: LT Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 0 | 7 | 7.06 | -.06 |
| 73 | 19 | 14.98 | 4.01 |
| 100 | 30 | 19.54 | 10.45 |
| 125 | 18 | 24.63 | -6.63 |
| 150 | 23 | 30.5 | -7.5 |
| 150 | 35 | 30.5 | 4.49 |
| 175 | 35 | 36.97 | -1.97 |
| 175 | 35 | 36.97 | -1.97 |

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

# CAPSULE W

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: W Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 200 | 39 | 43.76 | -4.76 |
| 200 | 38 | 43.76 | -5.76 |
| 225 | 60 | 50.53 | 9.46 |
| 250 | 63 | 56.95 | 6.04 |
| 300 | 70 | 67.75 | 2.24 |
| 350 | 71 | 75.28 | -4.28 |
| 400 | 80 | 79.95 | .04 |

SUM of RESIDUALS = 3.81

# CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:52:55 on 12-21-1998

Page 1

Coefficients of Curve 4

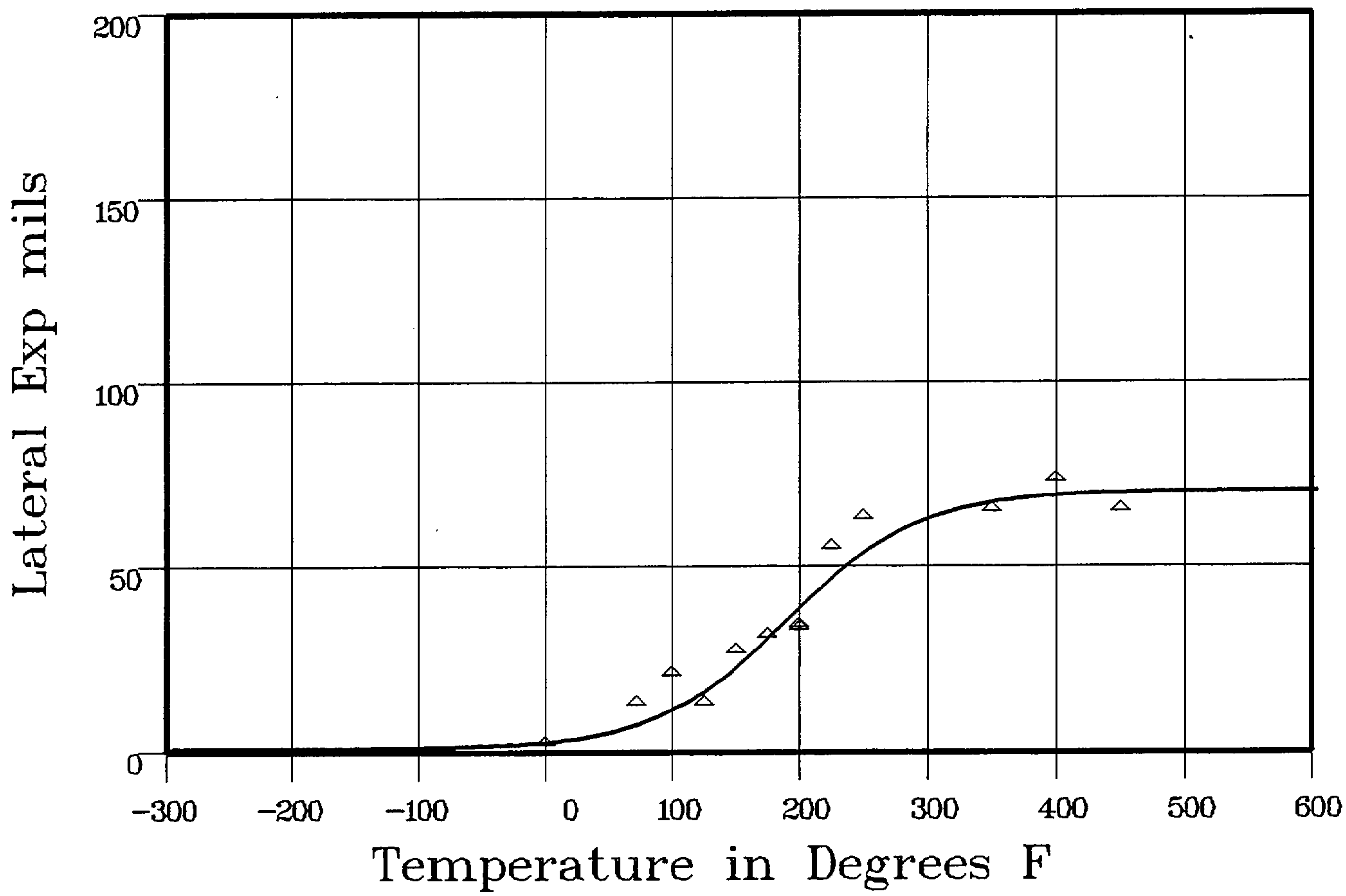
| A = 35.7 | B = 34.7 | C = 103.9 | T0 = 185.15 |
|---|---|---|---|

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

Upper Shelf L.E.: 70.41 Temperature at L.E. 35: 183 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: X Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: X Material: PLATE SA533B1 Ori.: LT Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 0 | 2 | 2.91 | -.91 |
| 72 | 13 | 8.06 | 4.93 |
| 100 | 21 | 12.28 | 8.71 |
| 125 | 13 | 17.59 | -4.59 |
| 125 | 13 | 17.59 | -4.59 |
| 150 | 27 | 24.39 | 2.6 |
| 150 | 27 | 24.39 | 2.6 |

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

# CAPSULE X

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: X Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 175 | 31 | 32.32 | -1.32 |
| 200 | 33 | 40.63 | -7.63 |
| 200 | 34 | 40.63 | -6.63 |
| 225 | 55 | 48.4 | 6.59 |
| 250 | 63 | 54.93 | 8.06 |
| 350 | 65 | 67.62 | -2.62 |
| 400 | 73 | 69.32 | 3.67 |
| 450 | 65 | 69.99 | -4.99 |
| | | SUM of RESIDUALS = | 3.9 |

# CAPSULE Z

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:52:55 on 12-21-1998

Page 1

Coefficients of Curve 5

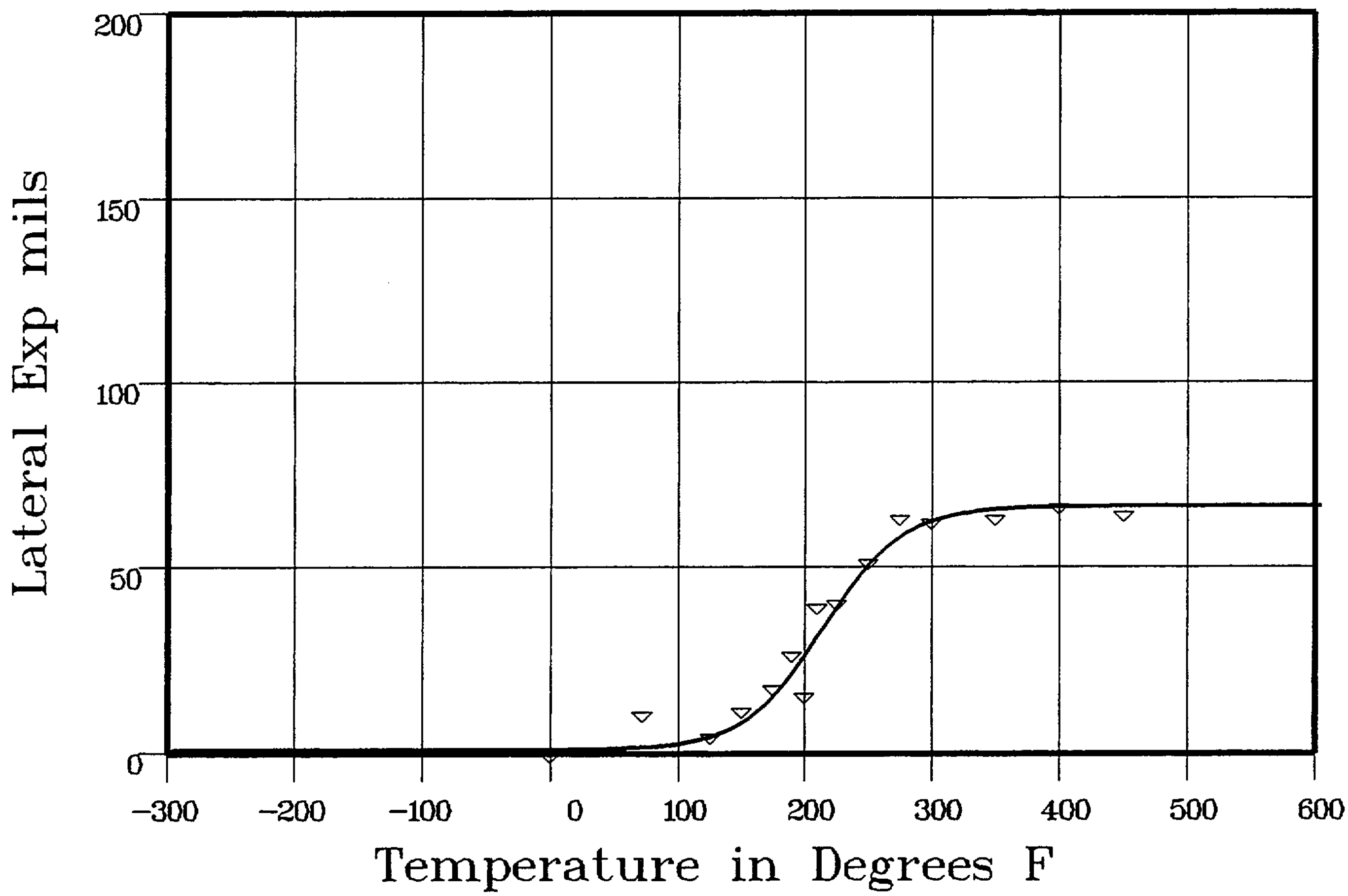
| A = 33.81 | B = 32.81 | C = 62.36 | T0 = 210.05 |
|---|---|---|---|

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

Upper Shelf L.E.: 66.63 Temperature at L.E. 35: 212.3 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: Z Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: Z Material: PLATE SA533B1 Ori.: LT Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 0 | 0 | 1.07 | -1.07 |
| 72 | 11 | 1.77 | 9.22 |
| 125 | 5 | 5.02 | -.02 |
| 150 | 12 | 9.34 | 2.65 |
| 175 | 18 | 17.09 | .9 |
| 190 | 27 | 23.61 | 3.38 |

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

# CAPSULE Z

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: Z Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 200 | 16 | 28.57 | -12.57 |
| 210 | 40 | 33.78 | 6.21 |
| 225 | 41 | 41.53 | -.53 |
| 250 | 52 | 52.36 | -.36 |
| 275 | 64 | 59.36 | 4.63 |
| 300 | 63 | 63.16 | -.16 |
| 350 | 64 | 65.9 | -1.9 |
| 400 | 67 | 66.48 | .51 |
| 450 | 65 | 66.6 | -1.6 |

SUM of RESIDUALS = 9.28

# UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:24:19 on 12-21-1998

Page 1

Coefficients of Curve 1

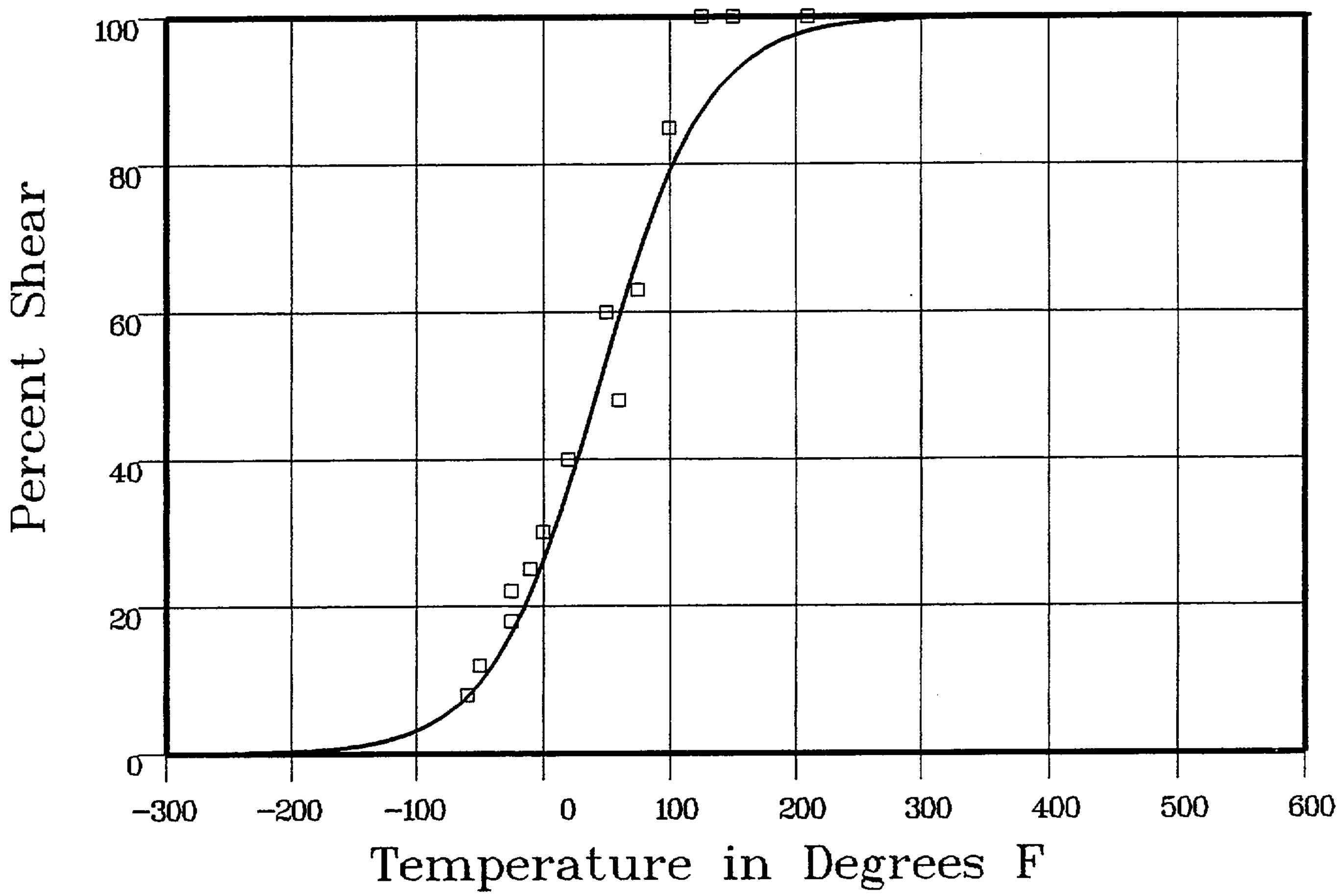
| A = 50 | B = 50 | C = 84.43 | T0 = 39.37 |
|---|---|---|---|

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

Temperature at 50% Shear: 39.3

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: UNIRR Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: UNIRR Material: PLATE SA533B1 Ori.: LT Heat #: B7212-1

**Charpy V-Notch Data**

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -60 | 8 | 8.67 | -.67 |
| -50 | 12 | 10.74 | 1.25 |
| -25 | 18 | 17.87 | .12 |
| -25 | 22 | 17.87 | 4.12 |
| -10 | 25 | 23.69 | 1.3 |
| 0 | 30 | 28.23 | 1.76 |
| 20 | 40 | 38.72 | 1.27 |
| 50 | 60 | 56.25 | 3.74 |
| 60 | 48 | 61.97 | -13.97 |

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

# UNIRRADIATED

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: UNIRR Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 75 | 63 | 69.92 | -6.92 |
| 100 | 85 | 80.78 | 4.21 |
| 125 | 100 | 88.37 | 11.62 |
| 150 | 100 | 93.21 | 6.78 |
| 210 | 100 | 98.27 | 1.72 |
| 210 | 100 | 98.27 | 1.72 |
| 210 | 100 | 98.27 | 1.72 |

SUM of RESIDUALS = 19.81

# CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve  Printed at 14:24:19 on 12-21-1998

Page 1

Coefficients of Curve 2

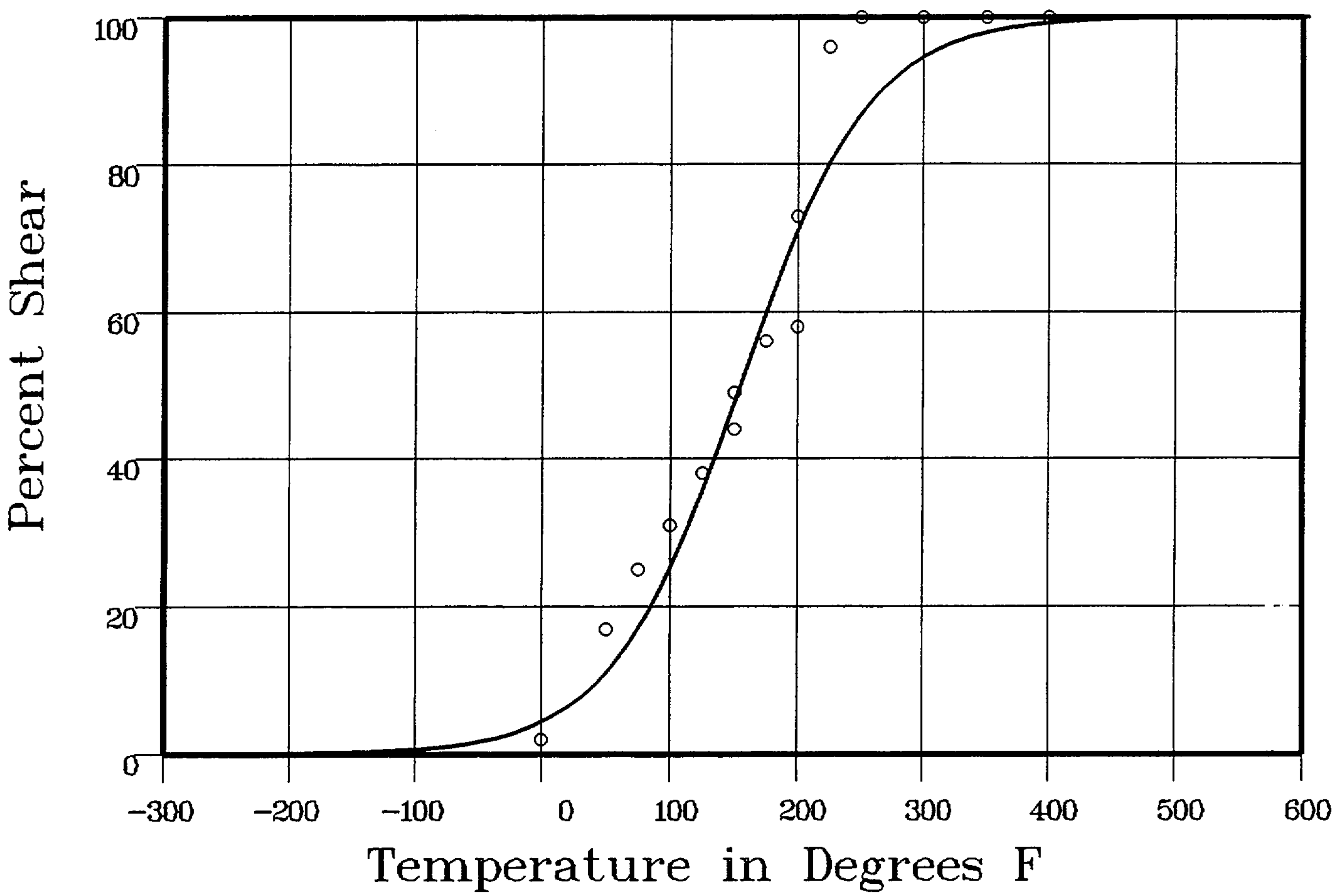
| A = 50 | B = 50 | C = 100.7 | T0 = 150.29 |
|---|---|---|---|

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

Temperature at 50% Shear: 150.2

Material: PLATE SA533B1  Heat Number: B7212-1  Orientation: LT

Capsule: U  Total Fluence:




Data Set(s) Plotted

Plant: FA2  Cap.: U  Material: PLATE SA533B1  Ori.: LT  Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 0 | 2 | 4.81 | -2.81 |
| 50 | 17 | 12 | 4.99 |
| 75 | 25 | 18.31 | 6.68 |
| 100 | 31 | 26.91 | 4.08 |
| 125 | 38 | 37.69 | .3 |
| 150 | 44 | 49.85 | -5.85 |
| 150 | 49 | 49.85 | -.85 |
| 175 | 56 | 62.02 | -6.02 |

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

# CAPSULE U

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: U Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 200 | 73 | 72.85 | .14 |
| 200 | 58 | 72.85 | -14.85 |
| 225 | 96 | 81.51 | 14.48 |
| 250 | 100 | 87.86 | 12.13 |
| 300 | 100 | 95.13 | 4.86 |
| 350 | 100 | 98.14 | 1.85 |
| 400 | 100 | 99.3 | .69 |

SUM of RESIDUALS = 19.84

# CAPSULE W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:24:19 on 12-21-1998

Page 1

Coefficients of Curve 3

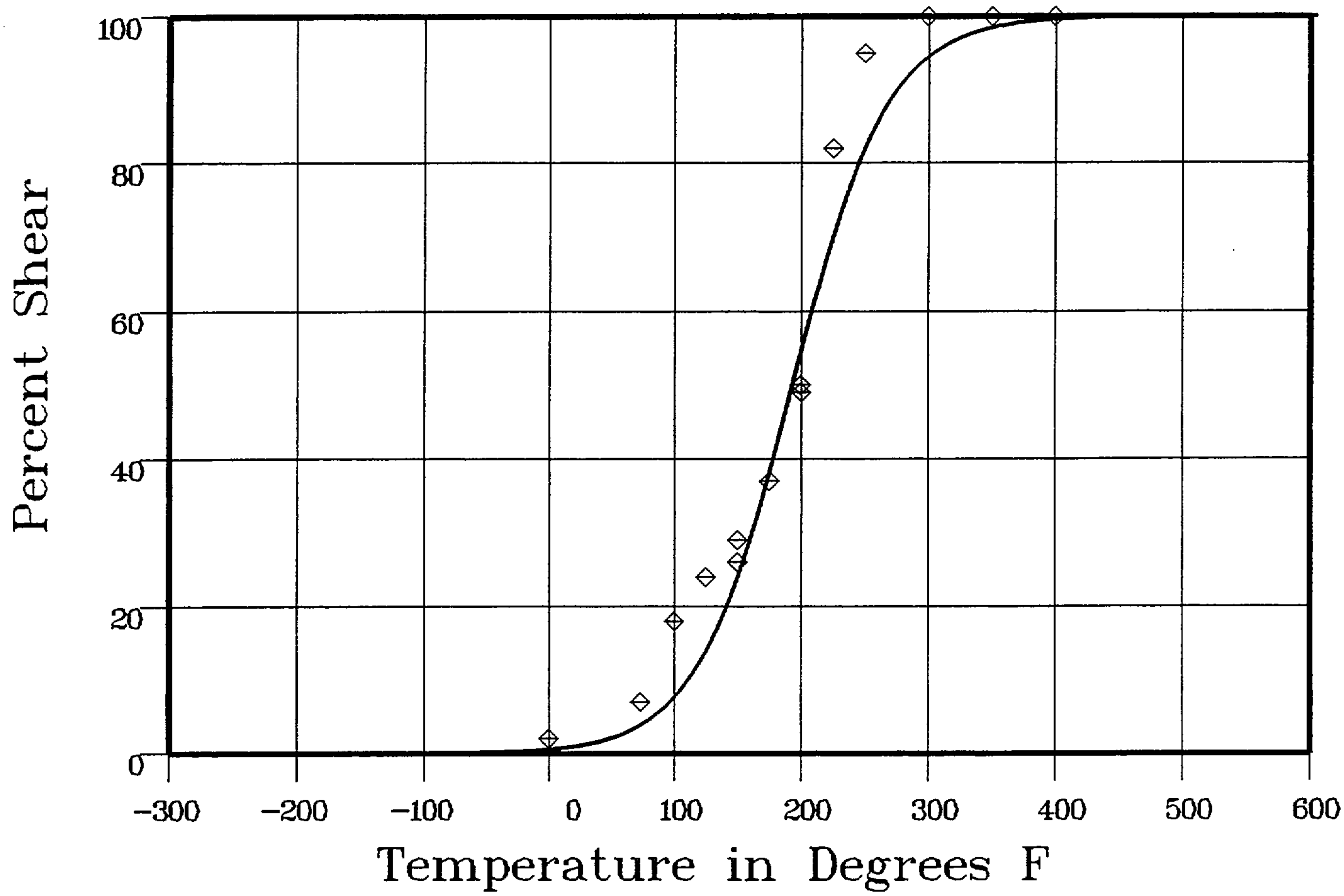
| A = 50 | B = 50 | C = 74.69 | T0 = 188.43 |
|---|---|---|---|

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

Temperature at 50% Shear: 188.4

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: W Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: W Material: PLATE SA533B1 Ori.: LT Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 0 | 2 | .63 | 1.36 |
| 73 | 7 | 4.34 | 2.65 |
| 100 | 18 | 8.56 | 9.43 |
| 125 | 24 | 15.46 | 8.53 |
| 150 | 26 | 26.32 | -.32 |
| 150 | 29 | 26.32 | 2.67 |
| 175 | 37 | 41.1 | -4.1 |
| 175 | 37 | 41.1 | -4.1 |

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

# CAPSULE W

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: W Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 200 | 50 | 57.67 | -7.67 |
| 200 | 49 | 57.67 | -8.67 |
| 225 | 82 | 72.69 | 9.3 |
| 250 | 95 | 83.86 | 11.13 |
| 300 | 100 | 95.19 | 4.8 |
| 350 | 100 | 98.69 | 1.3 |
| 400 | 100 | 99.65 | .34 |

SUM of RESIDUALS = 26.66

# CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:24:19 on 12-21-1998

Page 1

Coefficients of Curve 4

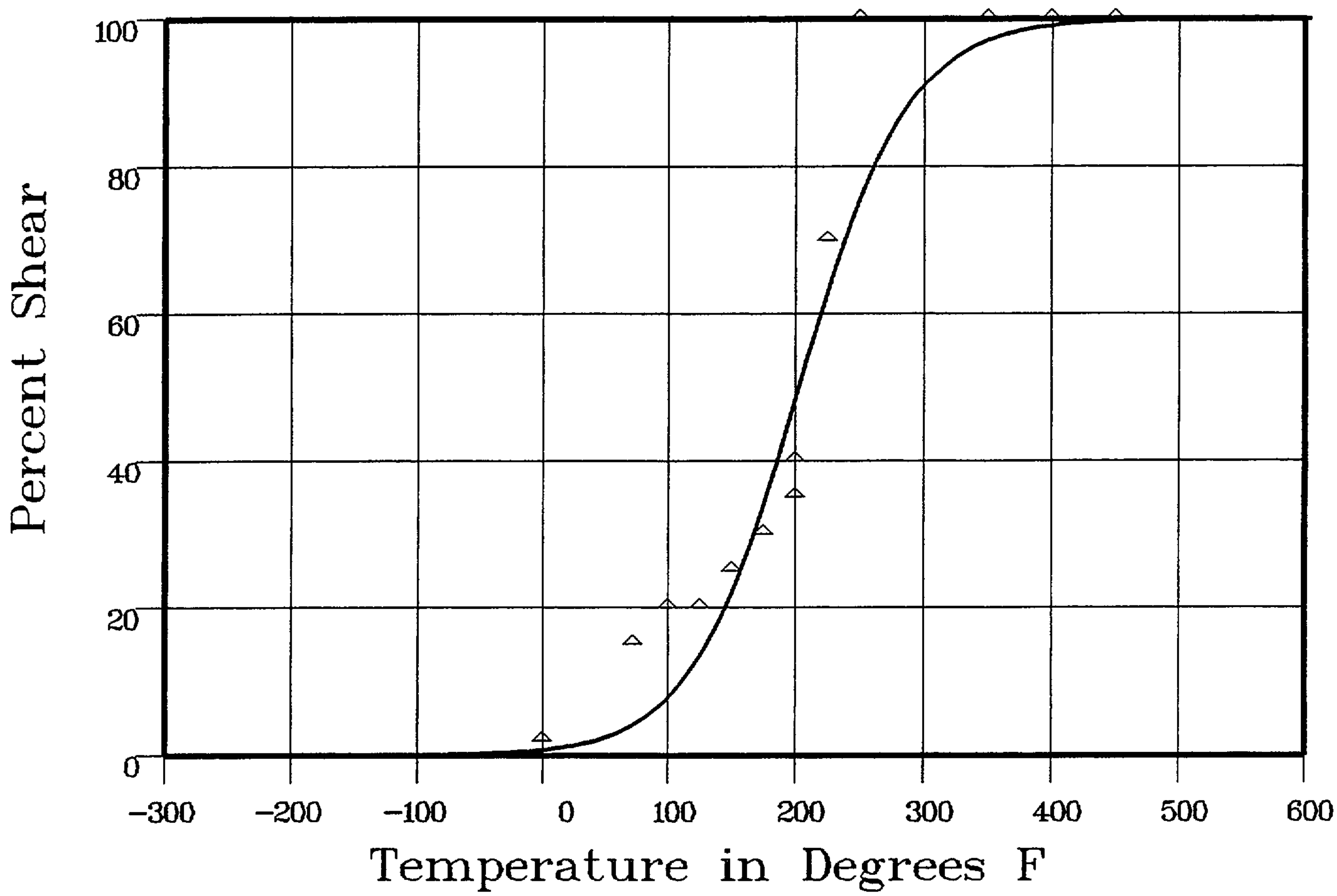
| A = 50 | B = 50 | C = 83.64 | T0 = 198.28 |
|---|---|---|---|

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

Temperature at 50% Shear: 198.2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: X Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: X Material: PLATE SA533B1 Ori.: LT Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 0 | 2 | .86 | 1.13 |
| 72 | 15 | 4.65 | 10.34 |
| 100 | 20 | 8.7 | 11.29 |
| 125 | 20 | 14.77 | 5.22 |
| 125 | 20 | 14.77 | 5.22 |
| 150 | 25 | 23.96 | 1.03 |
| 150 | 25 | 23.96 | 1.03 |

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

# CAPSULE X

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: X Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 175 | 30 | 36.43 | -6.43 |
| 200 | 40 | 51.02 | -11.02 |
| 200 | 35 | 51.02 | -16.02 |
| 225 | 70 | 65.44 | 4.55 |
| 250 | 100 | 77.49 | 22.5 |
| 350 | 100 | 97.41 | 2.58 |
| 400 | 100 | 99.2 | .79 |
| 450 | 100 | 99.75 | .24 |

SUM of RESIDUALS = 32.47

# CAPSULE Z

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:24:19 on 12-21-1998

Page 1

Coefficients of Curve 5

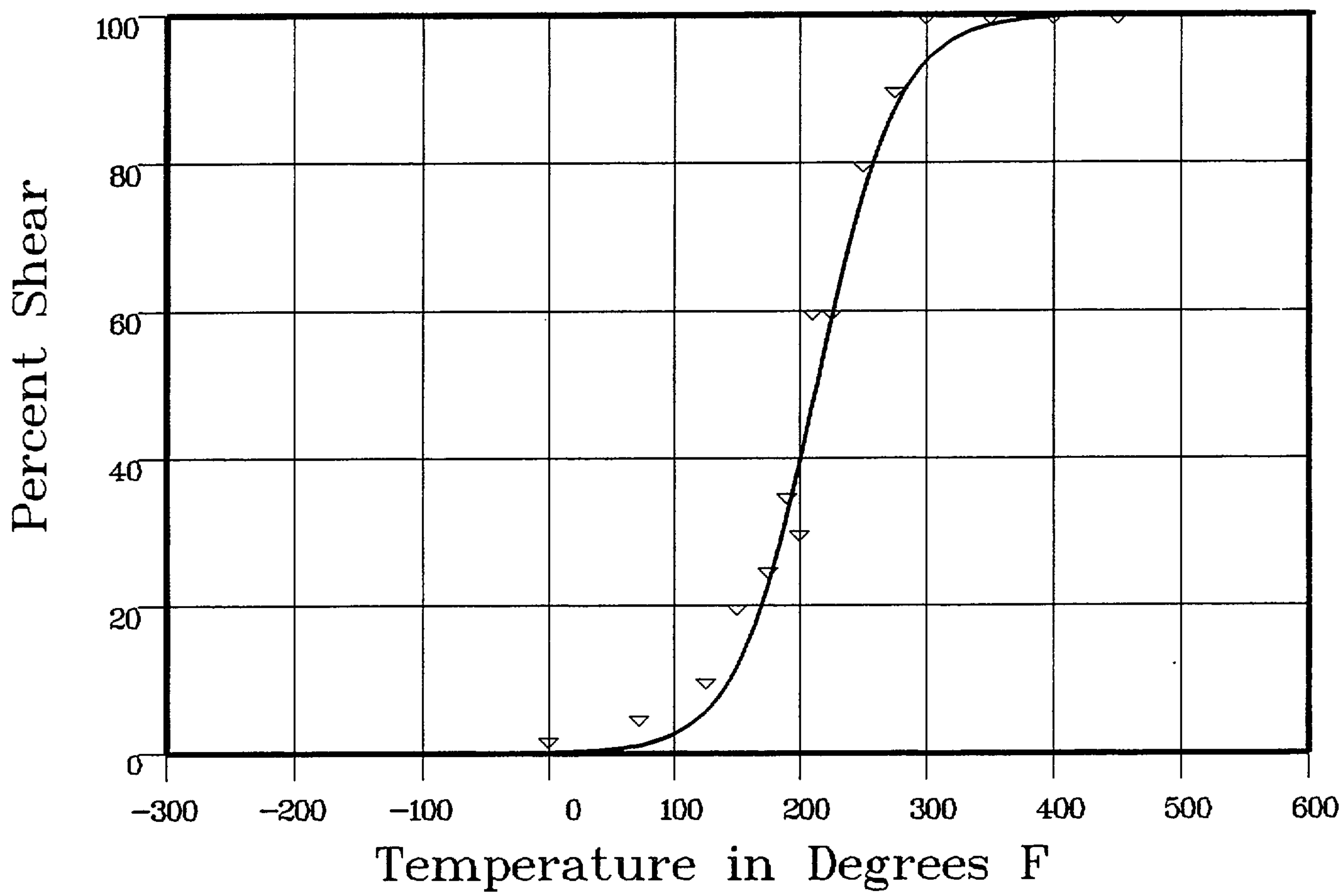
| A = 50 | B = 50 | C = 63.29 | T0 = 209.06 |
|---|---|---|---|

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

Temperature at 50% Shear: 209

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: Z Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: Z Material: PLATE SA533B1 Ori.: LT Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 0 | 2 | .13 | 1.86 |
| 72 | 5 | 1.29 | 3.7 |
| 125 | 10 | 6.56 | 3.43 |
| 150 | 20 | 13.39 | 6.6 |
| 175 | 25 | 25.42 | -.42 |
| 190 | 35 | 35.38 | -.38 |

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

# CAPSULE Z

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: LT

Capsule: Z Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 200 | 30 | 42.89 | -12.89 |
| 210 | 60 | 50.74 | 9.25 |
| 225 | 60 | 62.32 | -2.32 |
| 250 | 80 | 78.47 | 1.52 |
| 275 | 90 | 88.92 | 1.07 |
| 300 | 100 | 94.65 | 5.34 |
| 350 | 100 | 98.84 | 1.15 |
| 400 | 100 | 99.76 | .23 |
| 450 | 100 | 99.95 | .04 |

SUM of RESIDUALS = 18.22

# UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:01:19 on 02-22-2000

Page 1

Coefficients of Curve 1

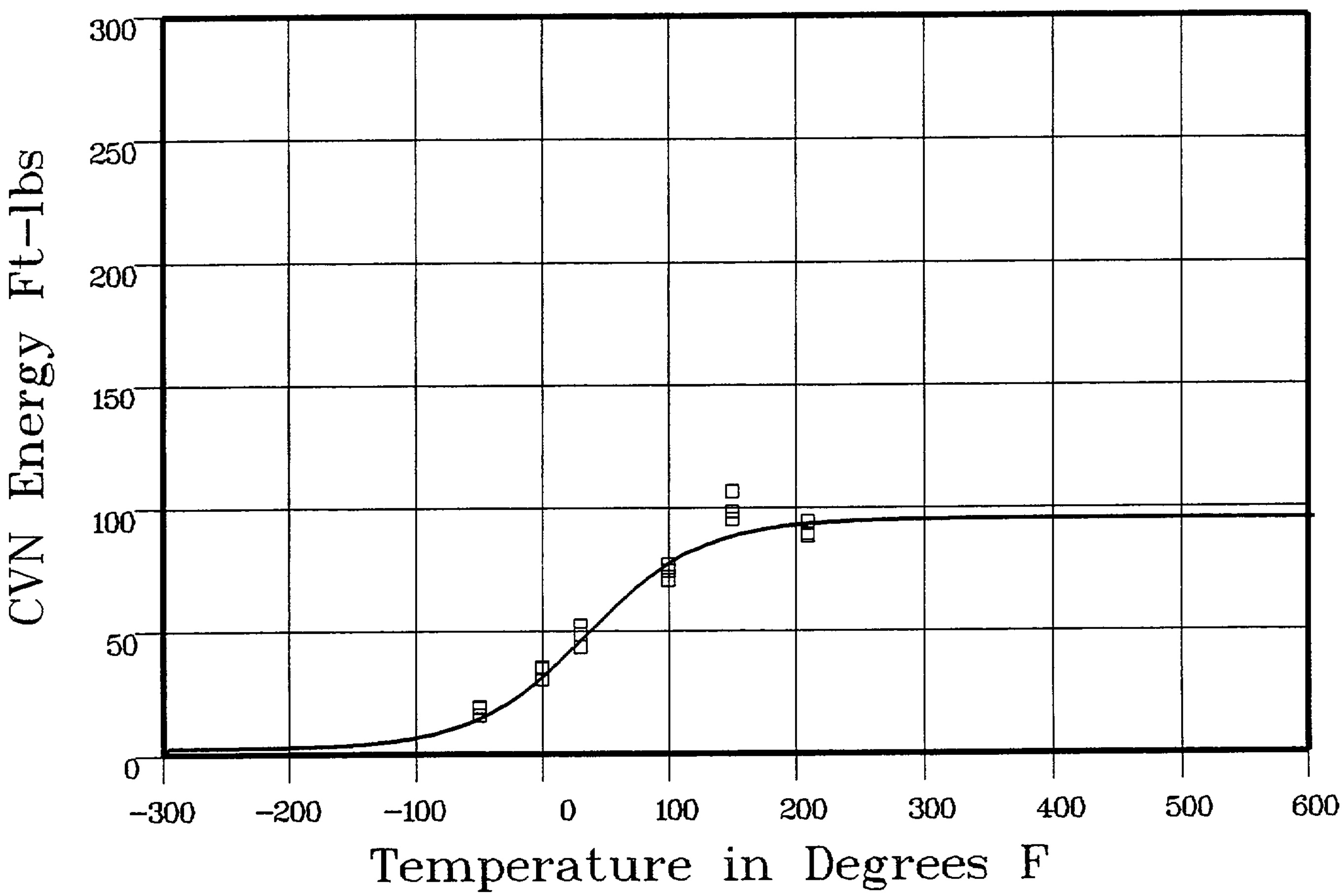
| A = 48.59 | B = 46.4 | C = 90.37 | T0 = 30.93 |
|---|---|---|---|

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

Upper Shelf Energy: 95 Fixed   Temp. at 30 ft-lbs: -7.4   Temp. at 50 ft-lbs: 33.6   Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1   Heat Number: B7212-1   Orientation: TL

Capsule: UNIRR   Total Fluence:




Data Set(s) Plotted

Plant: FA2   Cap.: UNIRR   Material: PLATE SA533B1   Ori.: TL   Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| -50 | 19 | 15.46 | 3.53 |
| -50 | 18.5 | 15.46 | 3.03 |
| -50 | 15.5 | 15.46 | .03 |
| 0 | 30 | 33.3 | -3.3 |
| 0 | 35 | 33.3 | 1.69 |
| 0 | 34.5 | 33.3 | 1.19 |
| 30 | 52 | 48.11 | 3.88 |
| 30 | 43 | 48.11 | -5.11 |
| 30 | 48 | 48.11 | -.11 |

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

# UNIRRADIATED

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: UNIRR Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 100 | 70 | 78.45 | -8.45 |
| 100 | 76.5 | 78.45 | -1.95 |
| 100 | 74 | 78.45 | -4.45 |
| 150 | 106 | 88.78 | 17.21 |
| 150 | 95 | 88.78 | 6.21 |
| 150 | 98 | 88.78 | 9.21 |
| 210 | 88 | 93.26 | -5.26 |
| 210 | 89 | 93.26 | -4.26 |
| 210 | 94 | 93.26 | .73 |

SUM of RESIDUALS = 13.77

# CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:08:13 on 02-22-2000

Page 1

Coefficients of Curve 1

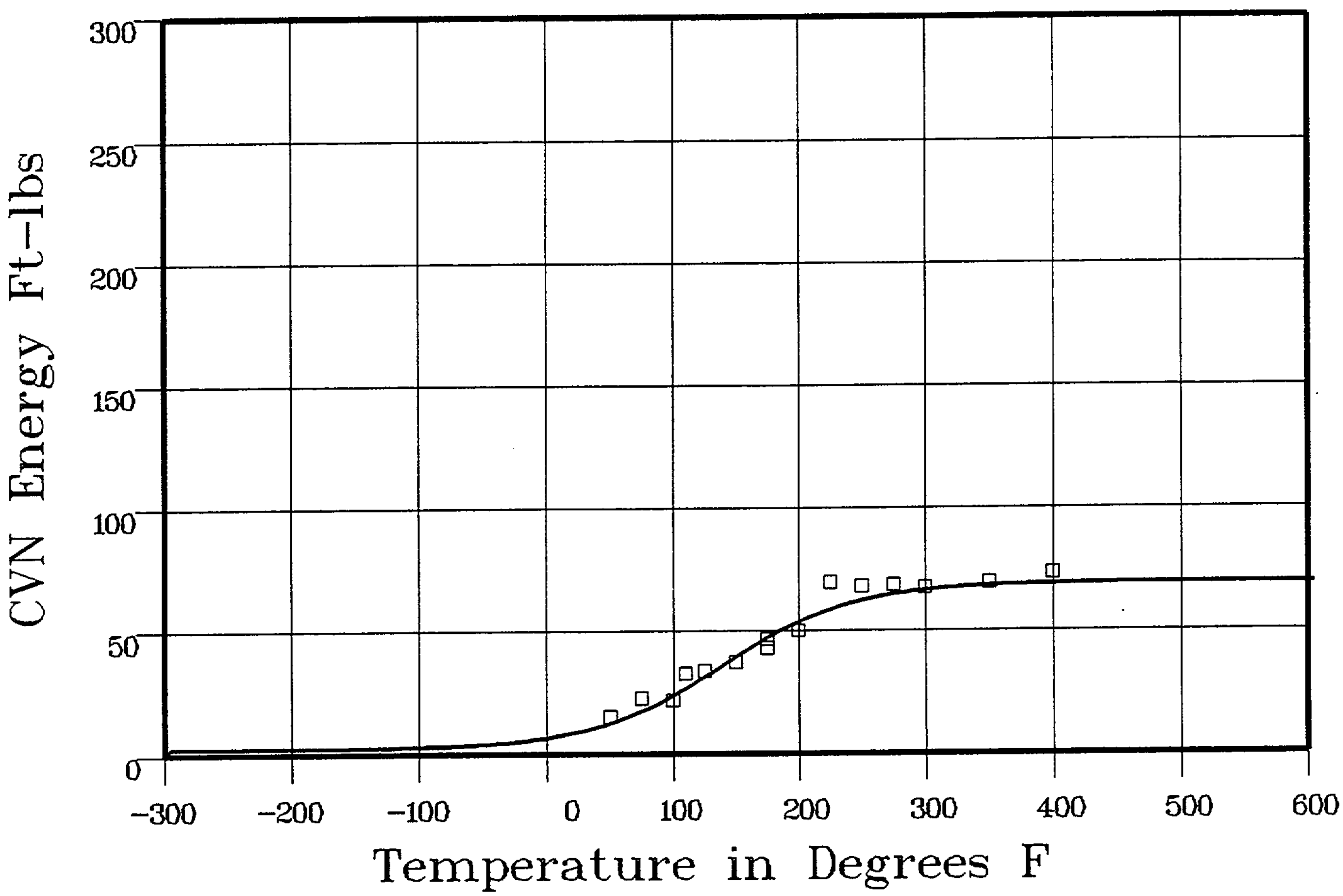
| A = 35.54 | B = 33.35 | C = 103.29 | T0 = 133.91 |
|---|---|---|---|

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

Upper Shelf Energy: 68.9 Fixed Temp. at 30 ft-lbs: 116.5 Temp. at 50 ft-lbs: 181.8 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: U Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 50 | 15 | 13.17 | 1.82 |
| 75 | 22.5 | 18.35 | 4.14 |
| 100 | 21.5 | 24.97 | -3.47 |
| 110 | 32.5 | 27.96 | 4.53 |
| 125 | 33.5 | 32.67 | .82 |
| 150 | 37 | 40.7 | -3.7 |
| 175 | 42.5 | 48.15 | -5.65 |
| 175 | 46 | 48.15 | -2.15 |
| 200 | 49.5 | 54.38 | -4.88 |

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

# CAPSULE U

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: U Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 225 | 69 | 59.13 | 9.86 |
| 250 | 67.5 | 62.52 | 4.97 |
| 275 | 68 | 64.82 | 3.17 |
| 300 | 67 | 66.32 | .67 |
| 350 | 69 | 67.89 | 1.1 |
| 400 | 73 | 68.51 | 4.48 |

SUM of RESIDUALS = 15.72

# CAPSULE W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:20:47 on 02-22-2000

Page 1

Coefficients of Curve 1

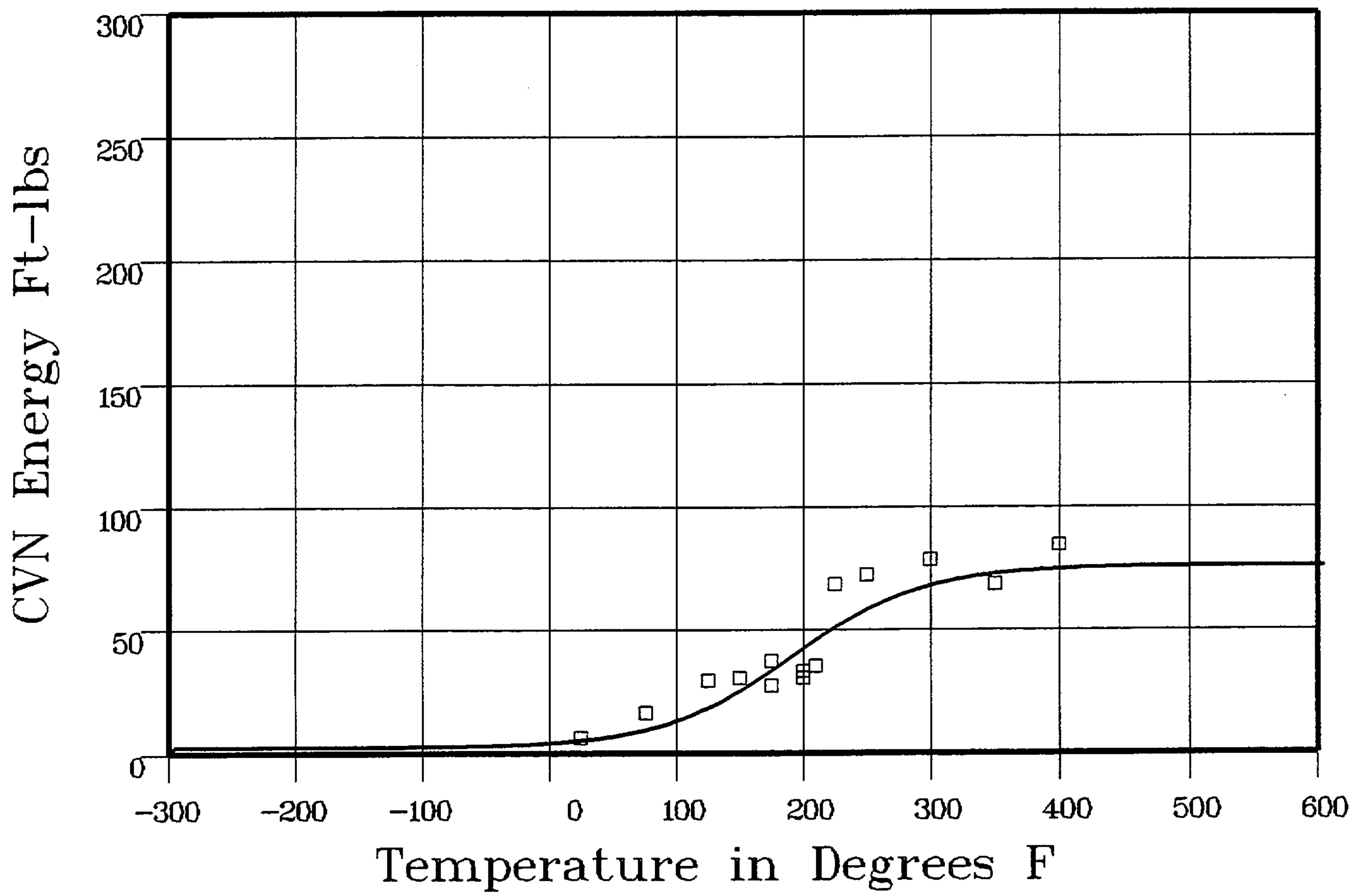
| A = 38.84 | B = 36.65 | C = 102.67 | T0 = 186.03 |
|---|---|---|---|

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

Upper Shelf Energy: 75.5 Fixed  Temp. at 30 ft-lbs: 160.7  Temp. at 50 ft-lbs: 218.2  Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1  Heat Number: B7212-1  Orientation: TL

Capsule: W  Total Fluence:




Data Set(s) Plotted

Plant: FA2  Cap.: W  Material: PLATE SA533B1  Ori.: TL  Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 25 | 6 | 5.25 | .74 |
| 76 | 16 | 9.89 | 6.1 |
| 125 | 29 | 19.31 | 9.68 |
| 150 | 30 | 26.49 | 3.5 |
| 150 | 30 | 26.49 | 3.5 |
| 175 | 27 | 34.92 | -7.92 |
| 175 | 37 | 34.92 | 2.07 |
| 200 | 33 | 43.8 | -10.8 |
| 200 | 30 | 43.8 | -13.8 |

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

# CAPSULE W

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: W Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 210 | 35 | 47.25 | -12.25 |
| 225 | 68 | 52.12 | 15.87 |
| 250 | 72 | 59.12 | 12.87 |
| 300 | 78 | 68.31 | 9.68 |
| 350 | 68 | 72.61 | -4.61 |
| 400 | 84 | 74.38 | 9.61 |

SUM of RESIDUALS = 24.28

# CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:25:35 on 02-22-2000

Page 1

Coefficients of Curve 1

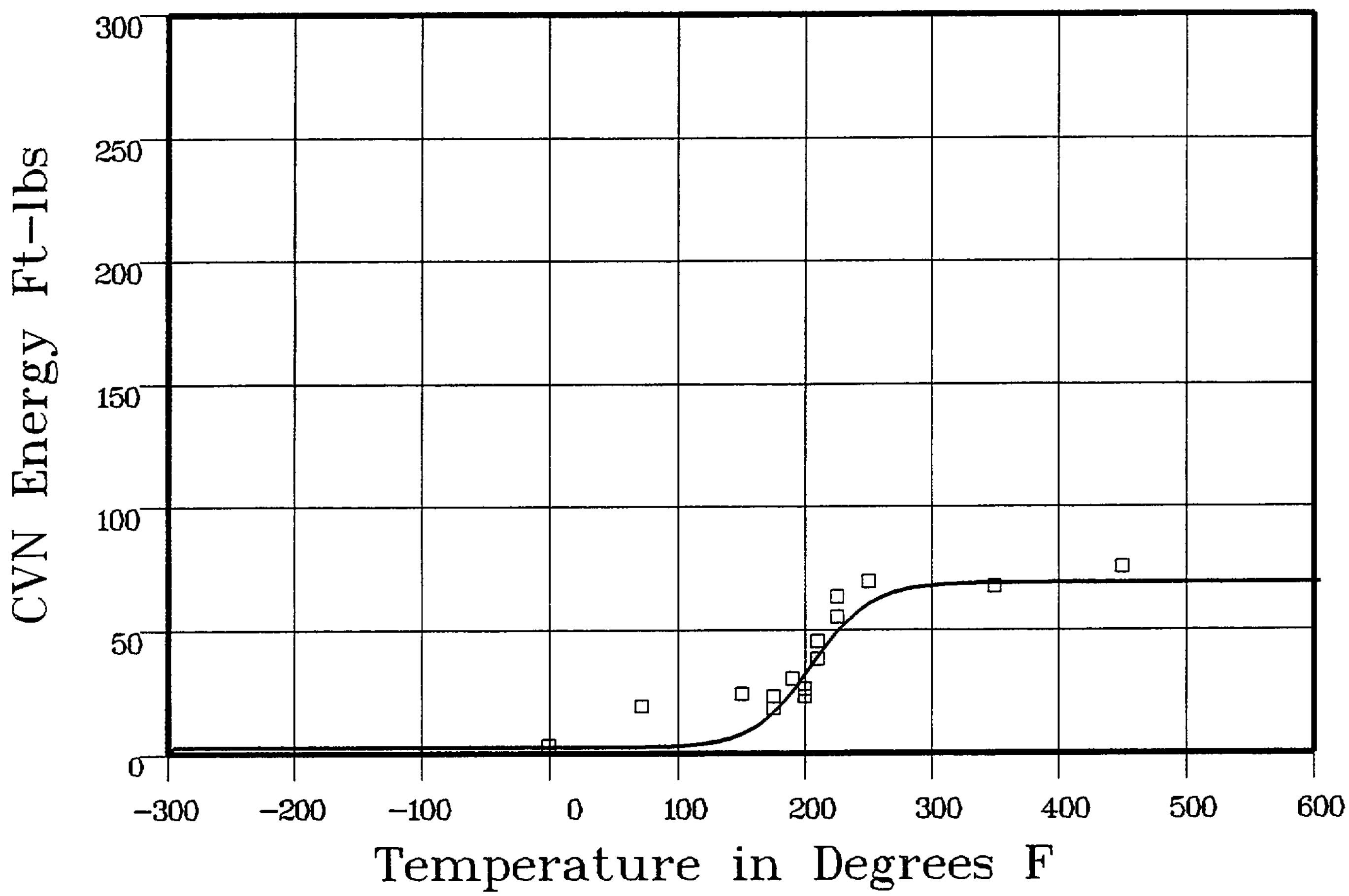
| A = 35.34 | B = 33.15 | C = 46.21 | T0 = 200.09 |
|---|---|---|---|

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

Upper Shelf Energy: 68.5 Fixed Temp. at 30 ft-lbs: 192.5 Temp. at 50 ft-lbs: 222 Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: X Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: X Material: PLATE SA533B1 Ori.: TL Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 0 | 3 | 2.21 | .78 |
| 72 | 19 | 2.45 | 16.54 |
| 150 | 24 | 9 | 14.99 |
| 175 | 23 | 18.93 | 4.06 |
| 175 | 18 | 18.93 | -.93 |
| 190 | 30 | 28.22 | 1.77 |
| 200 | 26 | 35.27 | -9.27 |
| 200 | 23 | 35.27 | -12.27 |
| 210 | 45 | 42.34 | 2.65 |

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

# CAPSULE X

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: X Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 210 | 38 | 42.34 | -4.34 |
| 225 | 63 | 51.66 | 11.33 |
| 225 | 55 | 51.66 | 3.33 |
| 250 | 69 | 61.64 | 7.35 |
| 350 | 67 | 68.39 | -1.39 |
| 450 | 75 | 68.49 | 6.5 |

SUM of RESIDUALS = 41.12

# CAPSULE Z

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 10:31:13 on 02-22-2000

Page 1

Coefficients of Curve 1

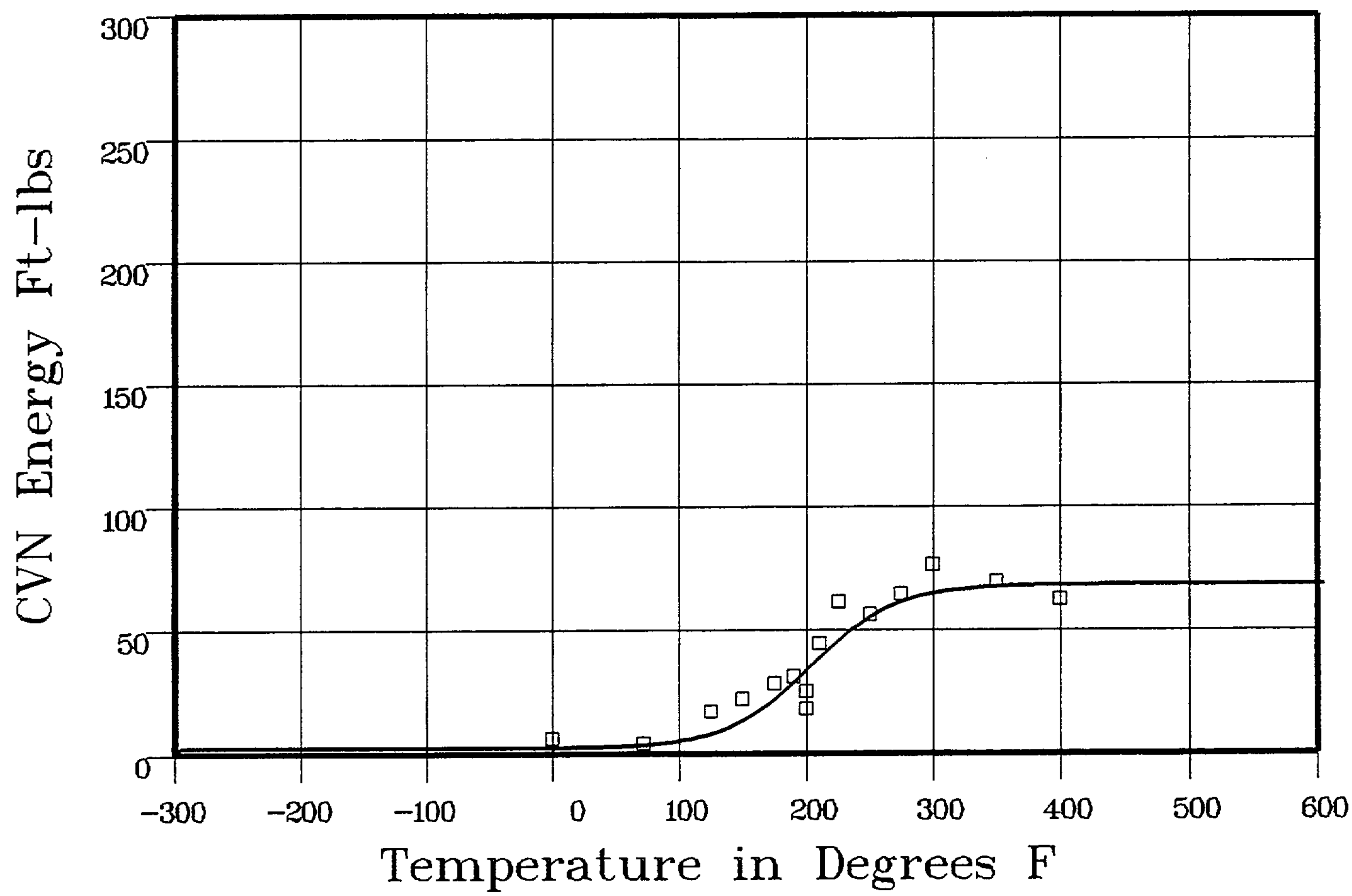
| A = 35 | B = 32.8 | C = 66.49 | T0 = 198.28 |
|---|---|---|---|

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

Upper Shelf Energy: 67.8 Fixed  Temp. at 30 ft-lbs: 188  Temp. at 50 ft-lbs: 231.1  Lower Shelf Energy: 2.19 Fixed

Material: PLATE SA533B1  Heat Number: B7212-1  Orientation: TL

Capsule: Z  Total Fluence:




Data Set(s) Plotted

Plant: FA2  Cap.: Z  Material: PLATE SA533B1  Ori.: TL  Heat #: B7212-1

**Charpy V-Notch Data**

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 0 | 6 | 2.36 | 3.63 |
| 72 | 4 | 3.63 | .36 |
| 125 | 17 | 8.71 | 8.28 |
| 150 | 22 | 14.64 | 7.35 |
| 175 | 28 | 23.96 | 4.03 |
| 190 | 31 | 30.93 | .06 |
| 200 | 25 | 35.84 | -10.84 |
| 200 | 18 | 35.84 | -17.84 |
| 210 | 44 | 40.72 | 3.27 |

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

# CAPSULE Z

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: Z Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 225 | 61 | 47.51 | 13.48 |
| 250 | 56 | 56.36 | -.36 |
| 275 | 64 | 61.86 | 2.13 |
| 300 | 76 | 64.86 | 11.13 |
| 350 | 69 | 67.12 | 1.87 |
| 400 | 62 | 67.64 | -5.64 |

SUM of RESIDUALS = 20.94

# UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:07:18 on 12-21-1998

Page 1

Coefficients of Curve 1

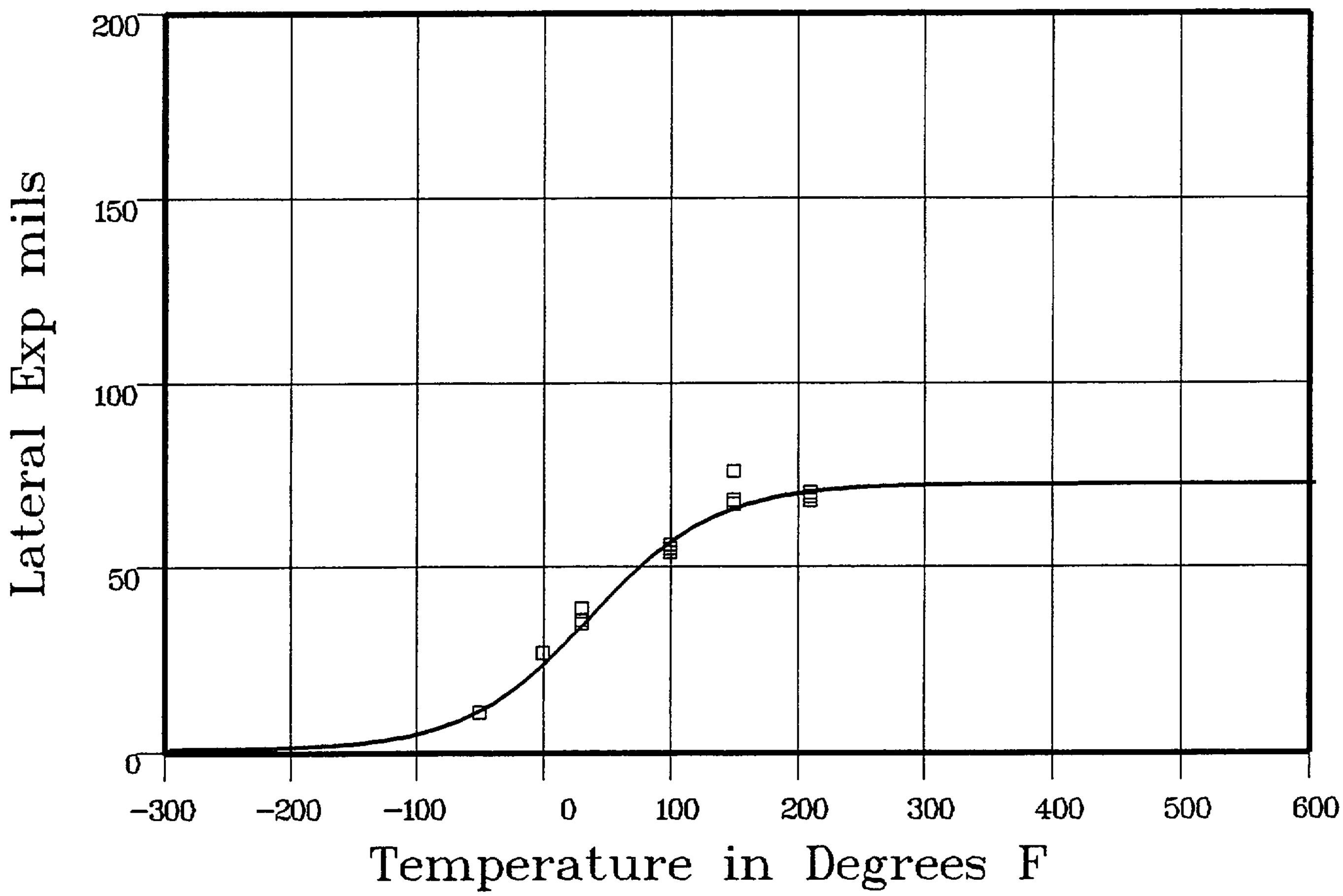
| A = 36.67 | B = 35.67 | C = 98.64 | T0 = 31.87 |
|---|---|---|---|

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

Upper Shelf L.E.: 72.35 Temperature at L.E. 35: 27.2 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: UNIRR Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: UNIRR Material: PLATE SA533B1 Ori.: TL Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| -50 | 11 | 12.4 | -1.4 |
| -50 | 11 | 12.4 | -1.4 |
| -50 | 11 | 12.4 | -1.4 |
| 0 | 27 | 25.53 | 1.46 |
| 0 | 27 | 25.53 | 1.46 |
| 0 | 27 | 25.53 | 1.46 |
| 30 | 39 | 35.99 | 3 |
| 30 | 35 | 35.99 | -.99 |
| 30 | 36 | 35.99 | 0 |

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

# UNIRRADIATED



Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: UNIRR Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 100 | 56 | 58.02 | -2.02 |
| 100 | 54 | 58.02 | -4.02 |
| 100 | 55 | 58.02 | -3.02 |
| 150 | 68 | 66.38 | 1.61 |
| 150 | 67 | 66.38 | .61 |
| 150 | 76 | 66.38 | 9.61 |
| 210 | 69 | 70.47 | -1.47 |
| 210 | 70 | 70.47 | -.47 |
| 210 | 68 | 70.47 | -2.47 |

SUM of RESIDUALS = .54

# CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve   Printed at 14:07:18 on 12-21-1998

Page 1

Coefficients of Curve 2

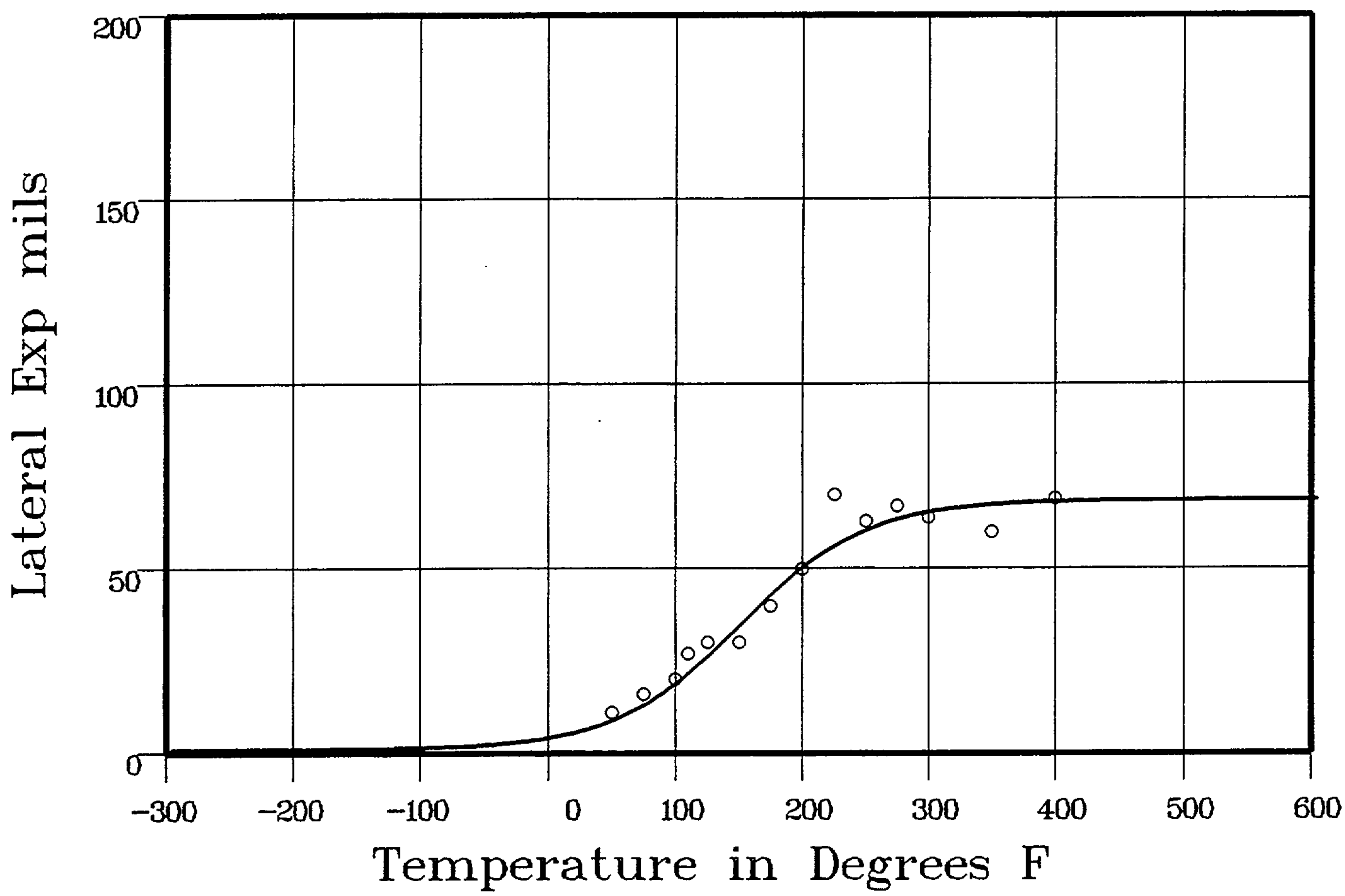
| A = 34.74 | B = 33.74 | C = 98.97 | T0 = 145.78 |
|---|---|---|---|

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

Upper Shelf L.E.: 68.48   Temperature at L.E. 35: 146.5   Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1   Heat Number: B7212-1   Orientation: TL

Capsule: U   Total Fluence:




Data Set(s) Plotted

Plant: FA2   Cap.: U   Material: PLATE SA533B1   Ori.: TL   Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 50 | 11 | 9.51 | 1.48 |
| 75 | 16 | 14.02 | 1.97 |
| 100 | 20 | 20.16 | -.16 |
| 110 | 27 | 23.04 | 3.95 |
| 125 | 30 | 27.76 | 2.23 |
| 150 | 30 | 36.18 | -6.18 |
| 175 | 40 | 44.42 | -4.42 |
| 175 | 40 | 44.42 | -4.42 |

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

# CAPSULE U

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: U Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 200 | 50 | 51.57 | -1.57 |
| 225 | 70 | 57.15 | 12.84 |
| 250 | 63 | 61.16 | 1.83 |
| 275 | 67 | 63.86 | 3.13 |
| 300 | 64 | 65.62 | -1.62 |
| 350 | 60 | 67.41 | -7.41 |
| 400 | 69 | 68.09 | .9 |

SUM of RESIDUALS = 2.57

# CAPSULE W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:07:18 on 12-21-1998

Page 1

Coefficients of Curve 3

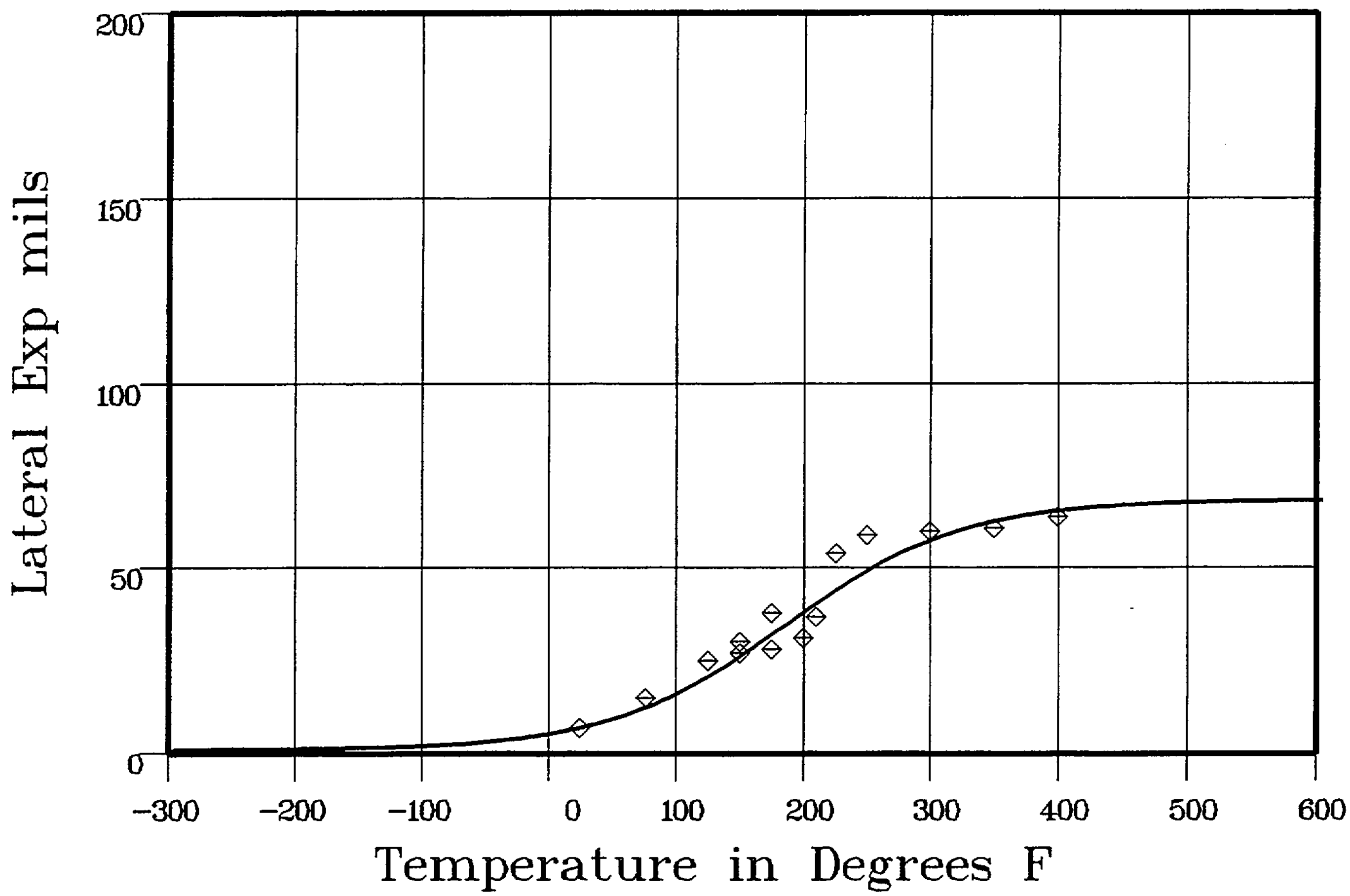
| A = 34.77 | B = 33.77 | C = 138.16 | T0 = 181.23 |
|---|---|---|---|

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

Upper Shelf L.E.: 68.54 Temperature at L.E. 35: 182.1 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: W Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: W Material: PLATE SA533B1 Ori.: TL Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 25 | 7 | 7.37 | -.37 |
| 76 | 15 | 13.08 | 1.91 |
| 125 | 25 | 21.73 | 3.26 |
| 150 | 27 | 27.26 | -.26 |
| 150 | 30 | 27.26 | 2.73 |
| 175 | 38 | 33.24 | 4.75 |
| 175 | 28 | 33.24 | -5.24 |
| 200 | 31 | 39.33 | -8.33 |

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

# CAPSULE W

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: W Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 200 | 31 | 39.33 | -8.33 |
| 210 | 37 | 41.7 | -4.7 |
| 225 | 54 | 45.12 | 8.87 |
| 250 | 59 | 50.31 | 8.68 |
| 300 | 60 | 58.27 | 1.72 |
| 350 | 61 | 63.14 | -2.14 |
| 400 | 64 | 65.81 | -1.81 |
| | | SUM of RESIDUALS = | .71 |

# CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:07:18 on 12-21-1998

Page 1

Coefficients of Curve 4

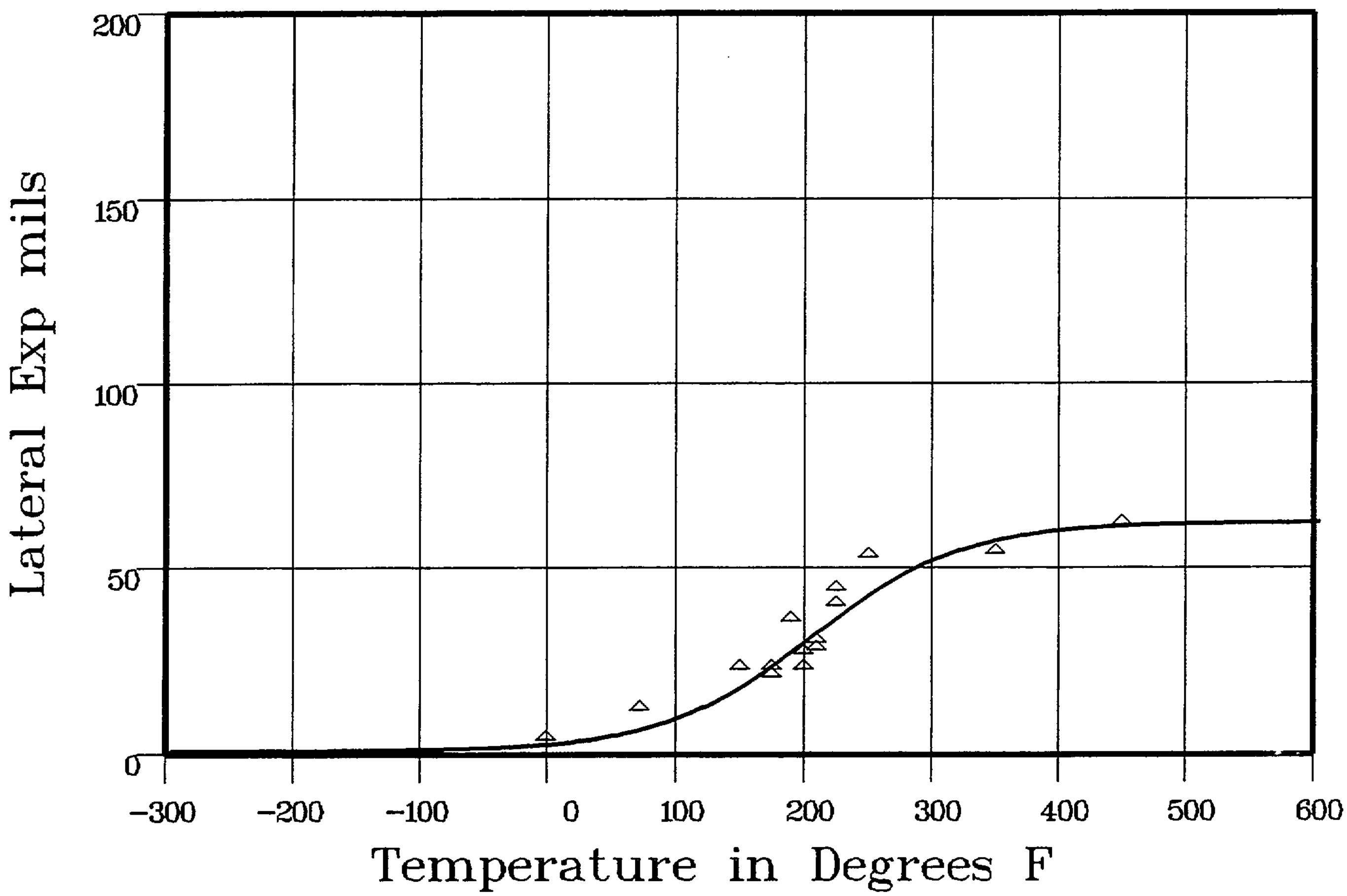
| A = 31.72 | B = 30.72 | C = 117.52 | T0 = 201.85 |
|---|---|---|---|

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

Upper Shelf L.E.: 62.45 Temperature at L.E. 35: 214.4 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: X Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: X Material: PLATE SA533B1 Ori.: TL Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 0 | 4 | 2.91 | 1.08 |
| 72 | 12 | 7.07 | 4.92 |
| 150 | 23 | 18.98 | 4.01 |
| 175 | 23 | 24.82 | -1.82 |
| 175 | 21 | 24.82 | -3.82 |
| 190 | 36 | 28.63 | 7.36 |
| 200 | 27 | 31.24 | -4.24 |

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

# CAPSULE X

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: X Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 200 | 23 | 31.24 | -8.24 |
| 210 | 28 | 33.85 | -5.85 |
| 210 | 30 | 33.85 | -3.85 |
| 225 | 44 | 37.7 | 6.29 |
| 225 | 40 | 37.7 | 2.29 |
| 250 | 53 | 43.65 | 9.34 |
| 350 | 54 | 57.88 | -3.88 |
| 450 | 62 | 61.57 | .42 |

SUM of RESIDUALS = 3.99

# CAPSULE Z

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:07:18 on 12-21-1998

Page 1

Coefficients of Curve 5

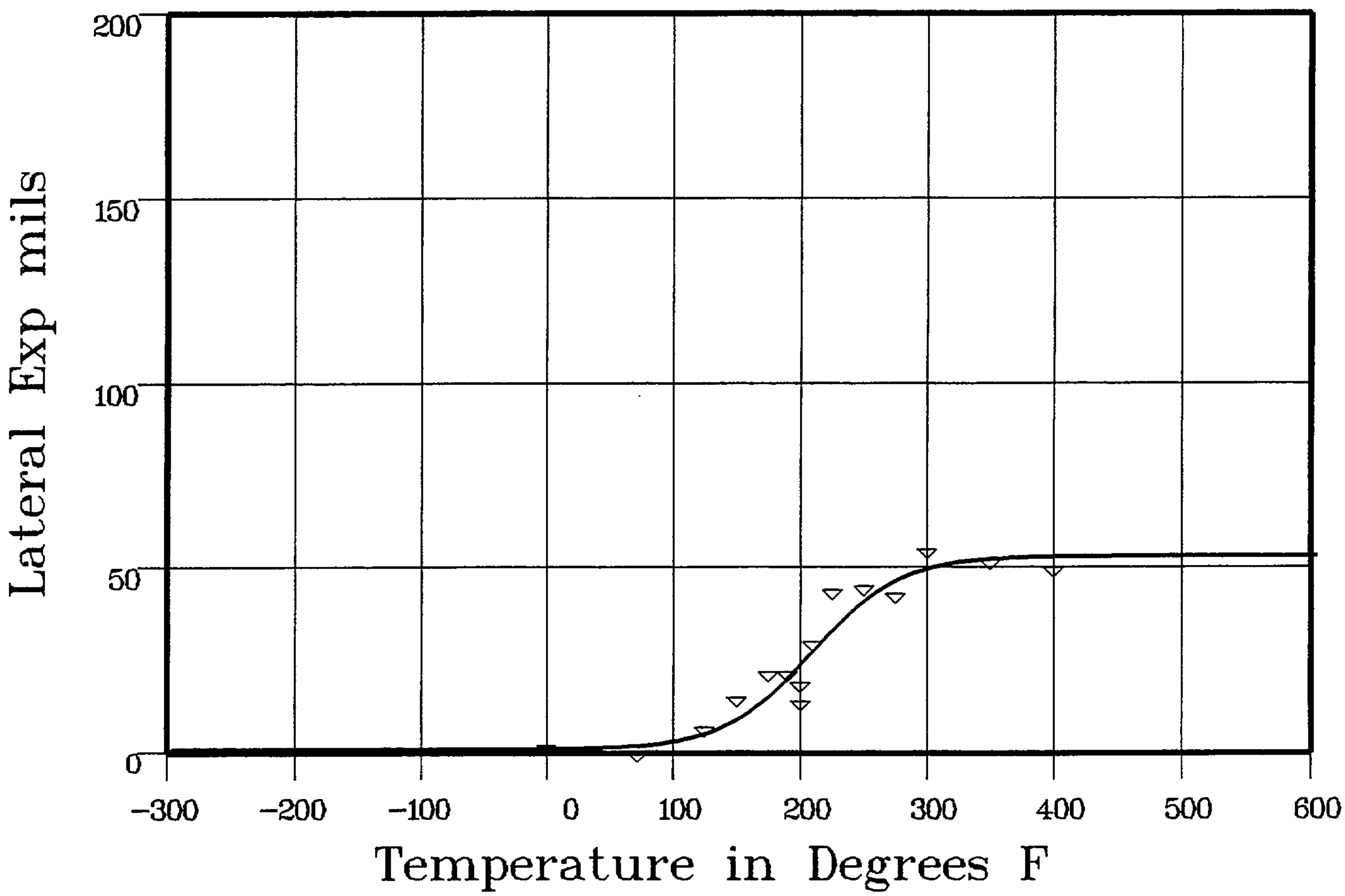
| A = 27.06 | B = 26.06 | C = 69.02 | T0 = 203.9 |
|---|---|---|---|

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

Upper Shelf L.E.: 53.13 Temperature at L.E. 35: 225.5 Lower Shelf L.E.: 1 Fixed

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: Z Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: Z Material: PLATE SA533B1 Ori.: TL Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 0 | 2 | 1.14 | .85 |
| 72 | 0 | 2.11 | -2.11 |
| 125 | 7 | 5.81 | 1.18 |
| 150 | 15 | 10.03 | 4.96 |
| 175 | 22 | 16.74 | 5.25 |
| 190 | 22 | 21.88 | .11 |

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

# CAPSULE Z

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: Z Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 200 | 19 | 25.59 | -6.59 |
| 200 | 14 | 25.59 | -11.59 |
| 210 | 30 | 29.36 | .63 |
| 225 | 44 | 34.79 | 9.2 |
| 250 | 45 | 42.28 | 2.71 |
| 275 | 43 | 47.24 | -4.24 |
| 300 | 55 | 50.1 | 4.89 |
| 350 | 52 | 52.39 | -.39 |
| 400 | 50 | 52.96 | -2.96 |

SUM of RESIDUALS = 1.92

# UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:14:51 on 12-21-1998

Page 1

Coefficients of Curve 1

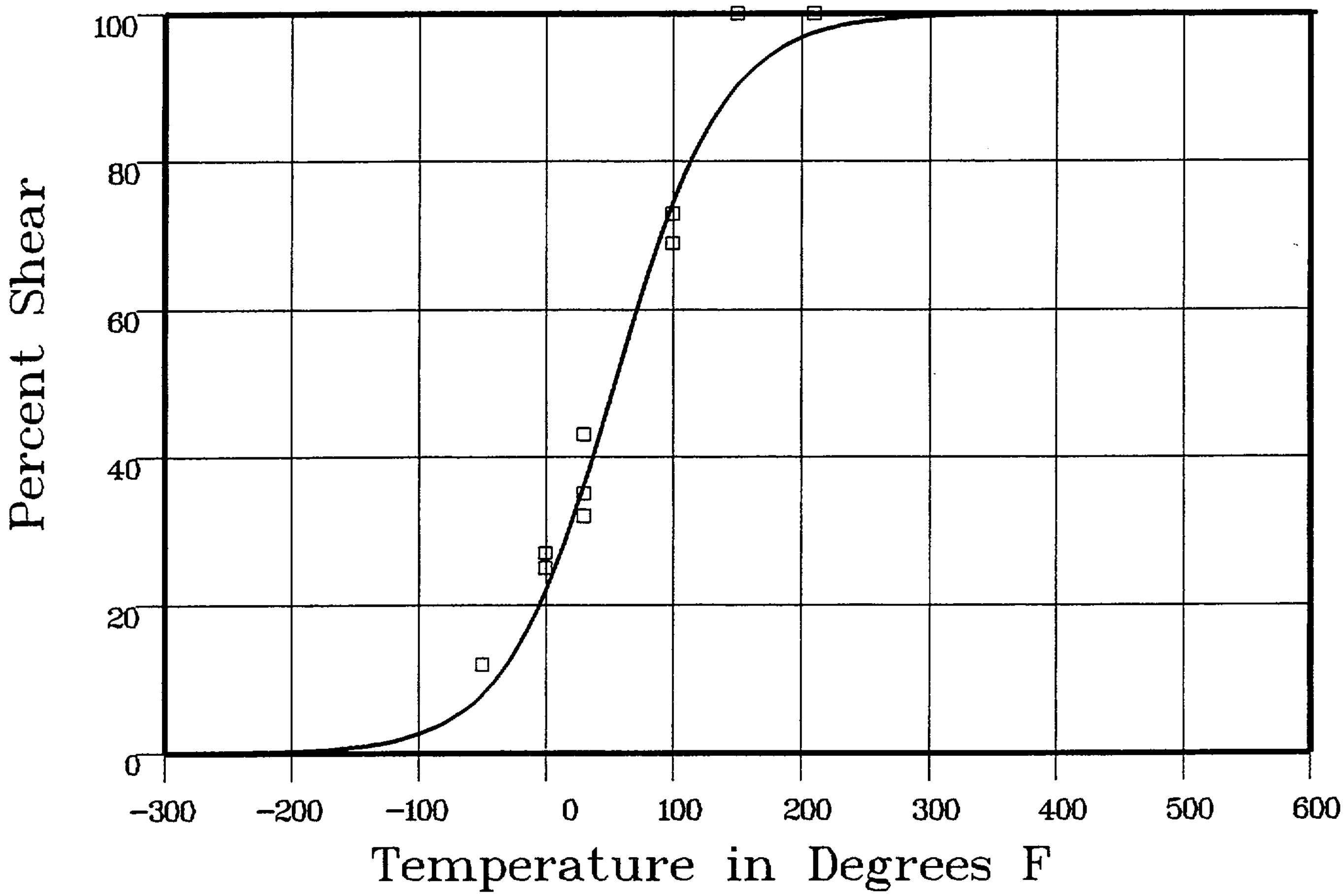
| A = 50 | B = 50 | C = 85.4 | T0 = 49.68 |
|---|---|---|---|

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

Temperature at 50% Shear: 49.6

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: UNIRR Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: UNIRR Material: PLATE SA533B1 Ori.: TL Heat #: B7212-1

**Charpy V-Notch Data**

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -50 | 12 | 8.83 | 3.16 |
| -50 | 12 | 8.83 | 3.16 |
| -50 | 12 | 8.83 | 3.16 |
| 0 | 25 | 23.8 | 1.19 |
| 0 | 25 | 23.8 | 1.19 |
| 0 | 27 | 23.8 | 3.19 |
| 30 | 43 | 38.67 | 4.32 |
| 30 | 32 | 38.67 | -6.67 |
| 30 | 35 | 38.67 | -3.67 |

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

# UNIRRADIATED

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: UNIRR Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 100 | 73 | 76.46 | -3.46 |
| 100 | 69 | 76.46 | -7.46 |
| 100 | 73 | 76.46 | -3.46 |
| 150 | 100 | 91.28 | 8.71 |
| 150 | 100 | 91.28 | 8.71 |
| 150 | 100 | 91.28 | 8.71 |
| 210 | 100 | 97.71 | 2.28 |
| 210 | 100 | 97.71 | 2.28 |
| 210 | 100 | 97.71 | 2.28 |

SUM of RESIDUALS = 27.69

# CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:14:51 on 12-21-1998

Page 1

Coefficients of Curve 2

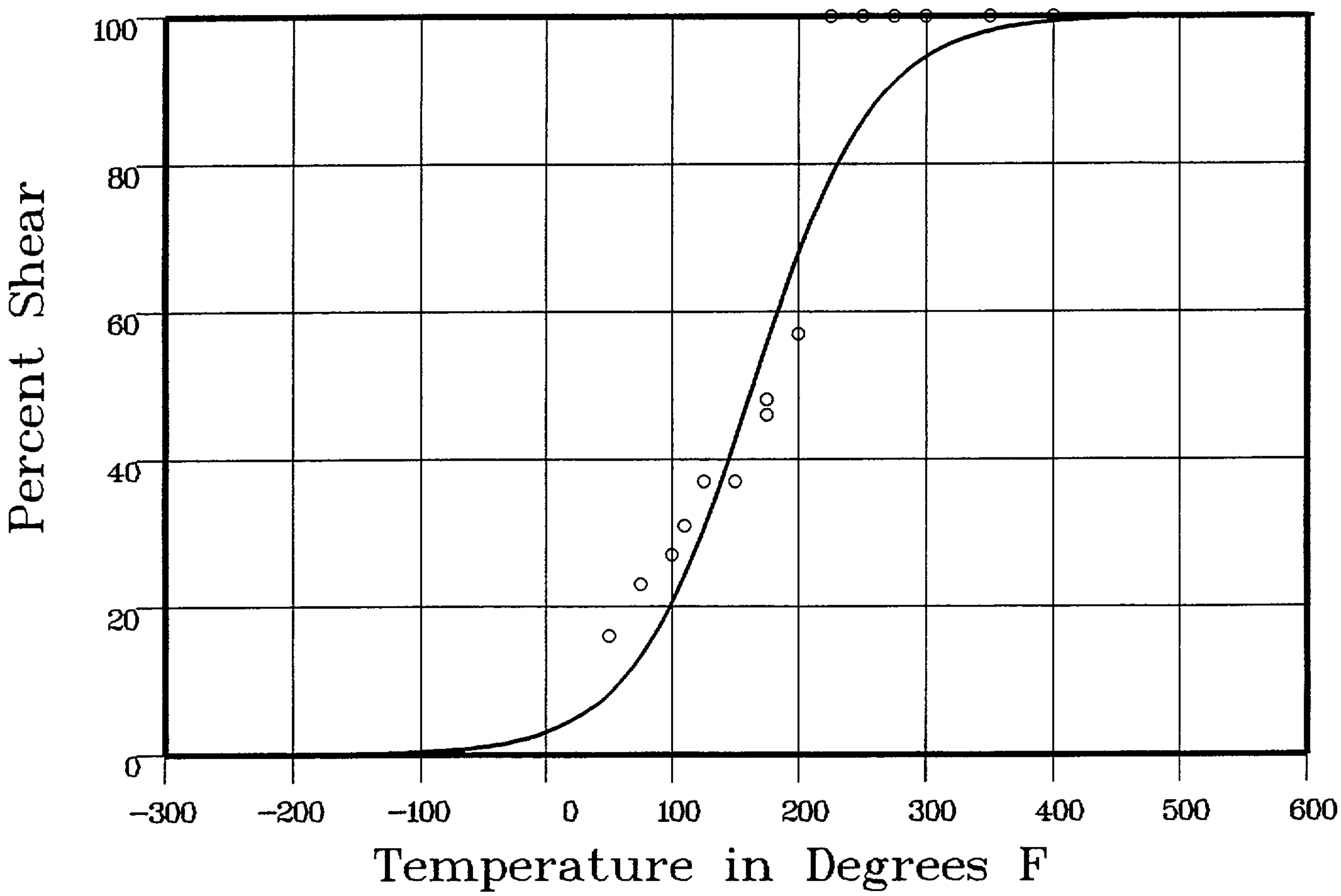
| A = 50 | B = 50 | C = 95.05 | T0 = 159.64 |
|---|---|---|---|

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

Temperature at 50% Shear: 159.6

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: U Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: U Material: PLATE SA533B1 Ori.: TL Heat #: B7212-1

**Charpy V-Notch Data**

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 50 | 16 | 9.05 | 6.94 |
| 75 | 23 | 14.41 | 8.58 |
| 100 | 27 | 22.18 | 4.81 |
| 110 | 31 | 26.02 | 4.97 |
| 125 | 37 | 32.54 | 4.45 |
| 150 | 37 | 44.94 | -7.94 |
| 175 | 48 | 58 | -10 |
| 175 | 46 | 58 | -12 |

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

# CAPSULE U

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: U Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 200 | 57 | 70.03 | -13.03 |
| 225 | 100 | 79.81 | 20.18 |
| 250 | 100 | 87 | 12.99 |
| 275 | 100 | 91.88 | 8.11 |
| 300 | 100 | 95.04 | 4.95 |
| 350 | 100 | 98.21 | 1.78 |
| 400 | 100 | 99.36 | .63 |

SUM of RESIDUALS = 35.46

# CAPSULE W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:14:51 on 12-21-1998

Page 1

Coefficients of Curve 3

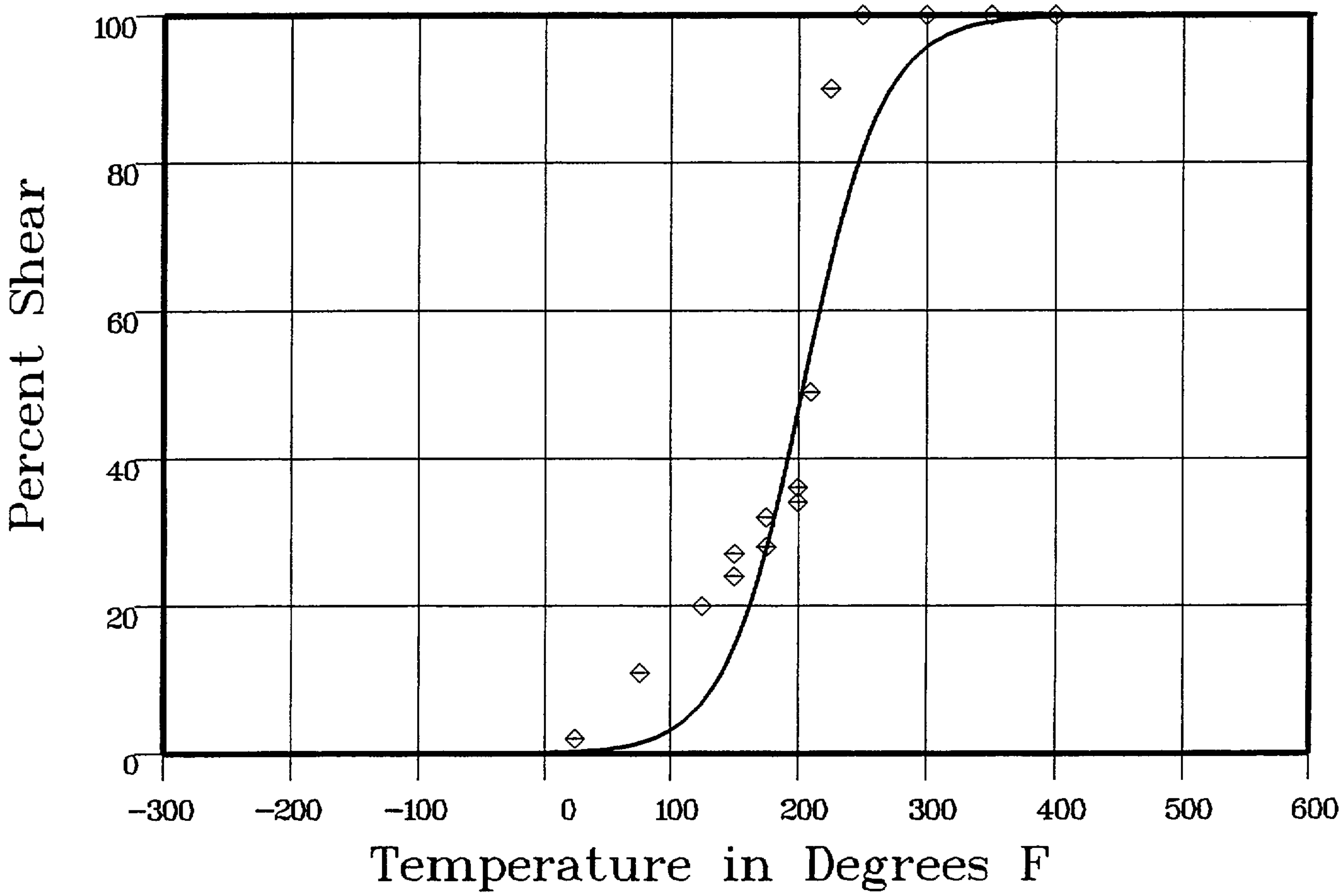
| A = 50 | B = 50 | C = 61.11 | T0 = 199.68 |
|---|---|---|---|

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

Temperature at 50% Shear: 199.6

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: W Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: W Material: PLATE SA533B1 Ori.: TL Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 25 | 2 | .32 | 1.67 |
| 76 | 11 | 1.71 | 9.28 |
| 125 | 20 | 7.98 | 12.01 |
| 150 | 24 | 16.43 | 7.56 |
| 150 | 27 | 16.43 | 10.56 |
| 175 | 32 | 30.83 | 1.16 |
| 175 | 28 | 30.83 | -2.83 |
| 200 | 34 | 50.25 | -16.25 |

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

# CAPSULE W

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: W Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 200 | 36 | 50.25 | -14.25 |
| 210 | 49 | 58.35 | -9.35 |
| 225 | 90 | 69.6 | 20.39 |
| 250 | 100 | 83.84 | 16.15 |
| 300 | 100 | 96.38 | 3.61 |
| 350 | 100 | 99.27 | .72 |
| 400 | 100 | 99.85 | .14 |

SUM of RESIDUALS = 40.6

# CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:14:51 on 12-21-1998
Page 1
Coefficients of Curve 4

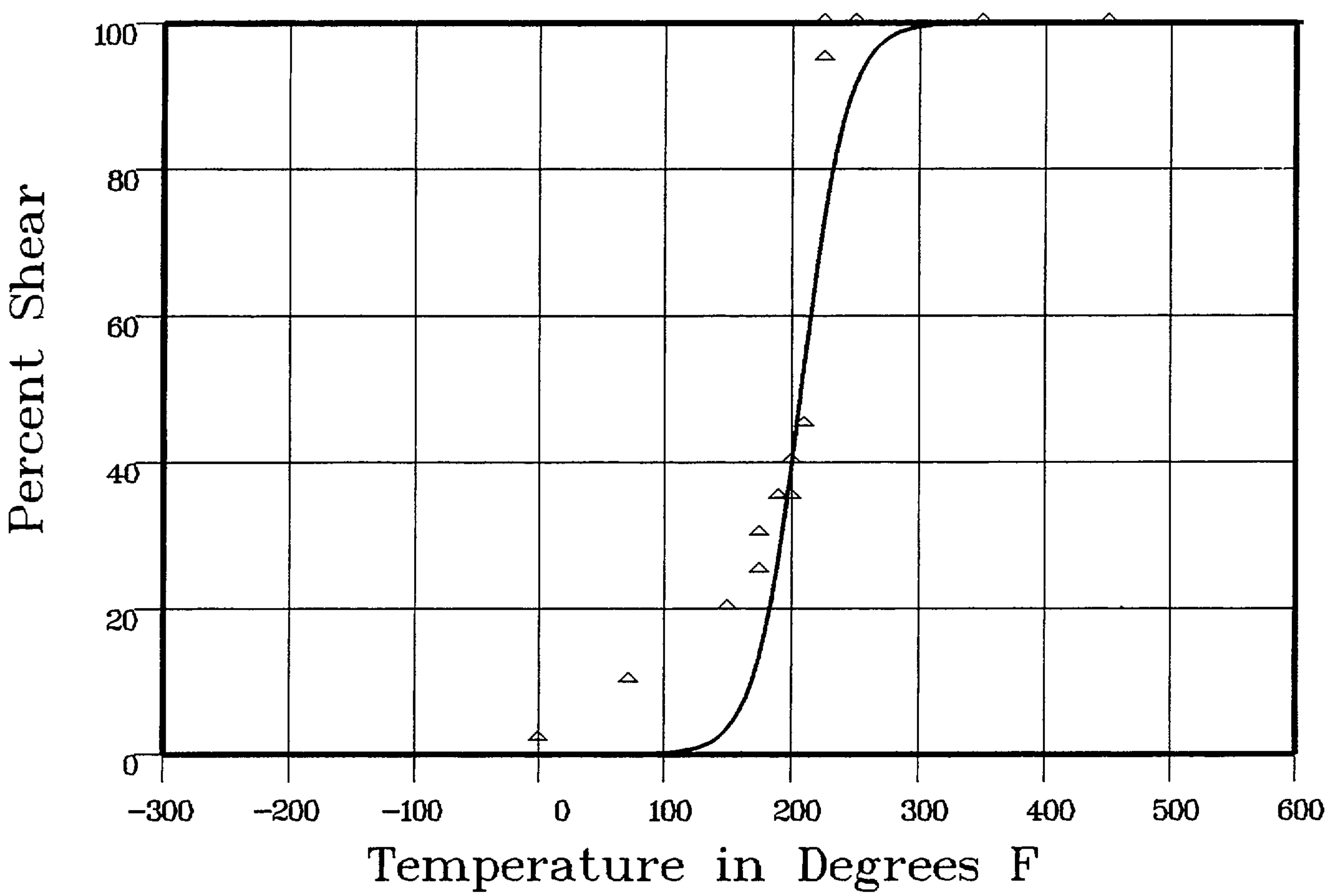
| A = 50 | B = 50 | C = 35.05 | T0 = 202.96 |
|---|---|---|---|

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

Temperature at 50% Shear: 202.9

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: X Total Fluence:




Data Set(s) Plotted
Plant: FA2 Cap.: X Material: PLATE SA533B1 Ori.: TL Heat #: B7212-1

**Charpy V-Notch Data**

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 0 | 2 | 0 | 1.99 |
| 72 | 10 | .05 | 9.94 |
| 150 | 20 | 4.64 | 15.35 |
| 175 | 25 | 16.85 | 8.14 |
| 175 | 30 | 16.85 | 13.14 |
| 190 | 35 | 32.3 | 2.69 |
| 200 | 40 | 45.77 | -5.77 |

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

# CAPSULE X

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: X Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 200 | 35 | 45.77 | -10.77 |
| 210 | 45 | 59.89 | -14.89 |
| 210 | 45 | 59.89 | -14.89 |
| 225 | 100 | 77.85 | 22.14 |
| 225 | 95 | 77.85 | 17.14 |
| 250 | 100 | 93.6 | 6.39 |
| 350 | 100 | 99.97 | .02 |
| 450 | 100 | 99.99 | 0 |

SUM of RESIDUALS = 50.65

# CAPSULE Z

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:14:51 on 12-21-1998
Page 1
Coefficients of Curve 5

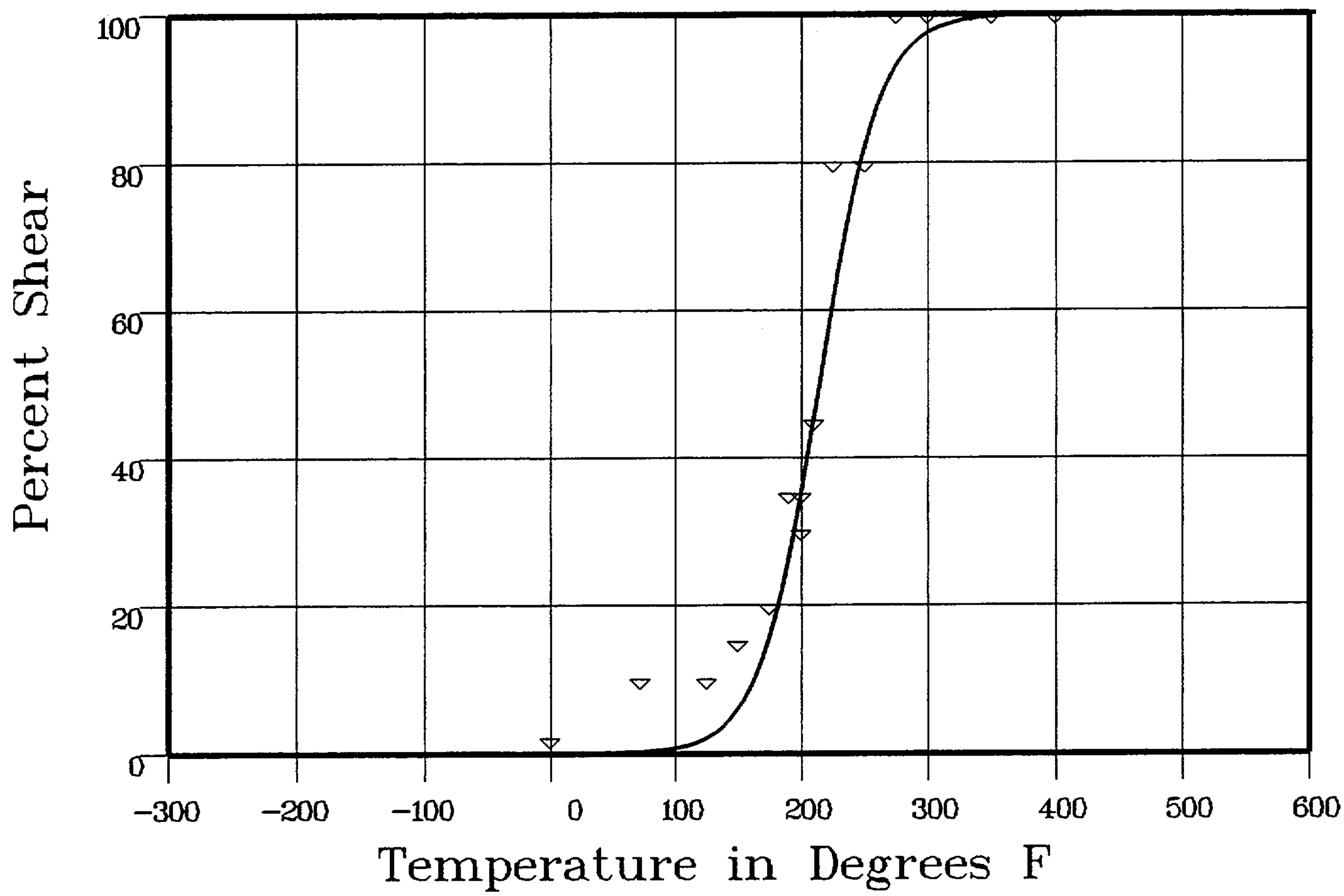
| A = 50 | B = 50 | C = 46.55 | T0 = 209.53 |
|---|---|---|---|

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

Temperature at 50% Shear: 209.5

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: Z Total Fluence:




Data Set(s) Plotted
Plant: FA2 Cap.: Z Material: PLATE SA533B1 Ori.: TL Heat #: B7212-1

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 0 | 2 | .01 | 1.98 |
| 72 | 10 | .27 | 9.72 |
| 125 | 10 | 2.57 | 7.42 |
| 150 | 15 | 7.19 | 7.8 |
| 175 | 20 | 18.49 | 1.5 |
| 190 | 35 | 30.17 | 4.82 |

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

# CAPSULE Z

Page 2

Material: PLATE SA533B1 Heat Number: B7212-1 Orientation: TL

Capsule: Z Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 200 | 35 | 39.9 | -4.9 |
| 200 | 30 | 39.9 | -9.9 |
| 210 | 45 | 50.5 | -5.5 |
| 225 | 80 | 66.02 | 13.97 |
| 250 | 80 | 85.04 | -5.04 |
| 275 | 100 | 94.33 | 5.66 |
| 300 | 100 | 97.98 | 2.01 |
| 350 | 100 | 99.76 | .23 |
| 400 | 100 | 99.97 | .02 |

SUM of RESIDUALS = 29.83

# UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:43:31 on 12-21-1998

Page 1

Coefficients of Curve 1

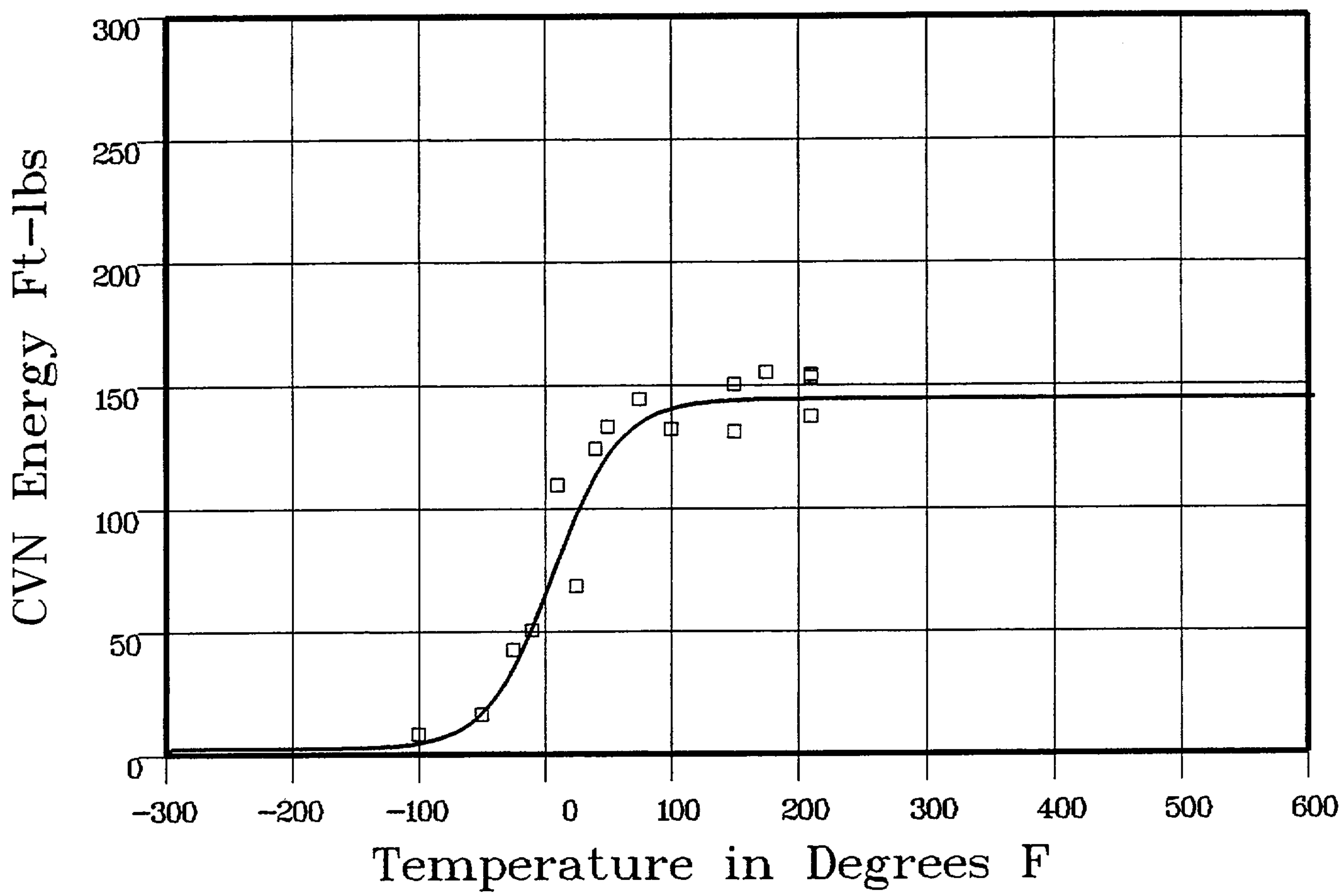
| A = 73.09 | B = 70.9 | C = 52.07 | T0 = 2.05 |
|---|---|---|---|

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

Upper Shelf Energy: 144 Fixed  Temp. at 30 ft-lbs: -34.6  Temp. at 50 ft-lbs: -15.5  Lower Shelf Energy: 2.19 Fixed

Material: WELD  Heat Number: BOLA  Orientation:

Capsule: UNIRR  Total Fluence:




Data Set(s) Plotted

Plant: FA2  Cap.: UNIRR  Material: WELD  Ori.:  Heat #: BOLA

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| -100 | 8 | 4.96 | 3.03 |
| -50 | 16 | 19.11 | -3.11 |
| -25 | 42 | 39.26 | 2.73 |
| -10 | 50 | 56.97 | -6.97 |
| 10 | 109 | 83.83 | 25.16 |
| 25 | 68 | 102.46 | -34.46 |
| 40 | 124 | 117.22 | 6.77 |
| 50 | 133 | 124.59 | 8.4 |
| 75 | 144 | 135.88 | 8.11 |

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

# UNIRRADIATED



Material: WELD Heat Number: BOLA Orientation:

Capsule: UNIRR Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 100 | 132 | 140.77 | -8.77 |
| 150 | 131 | 143.51 | -12.51 |
| 150 | 150 | 143.51 | 6.48 |
| 175 | 155 | 143.81 | 11.18 |
| 210 | 137 | 143.95 | -6.95 |
| 210 | 153 | 143.95 | 9.04 |
| 210 | 154 | 143.95 | 10.04 |

SUM of RESIDUALS = 18.18

# CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:43:31 on 12-21-1998

Page 1

Coefficients of Curve 2

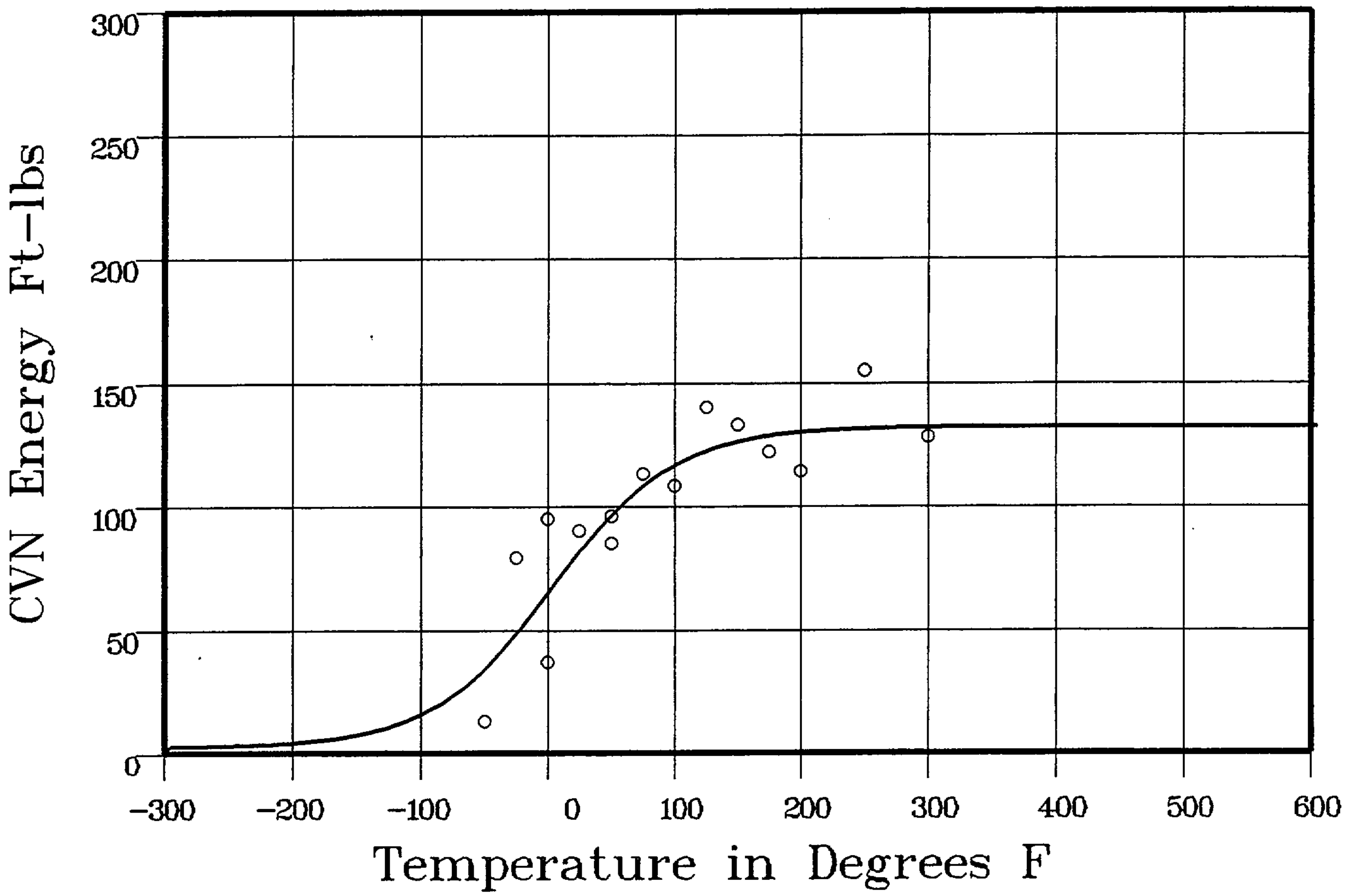
| A = 67.09 | B = 64.9 | C = 96.1 | T0 = -.93 |
|---|---|---|---|

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

Upper Shelf Energy: 132 Fixed Temp. at 30 ft-lbs: -63.4 Temp. at 50 ft-lbs: -26.8 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: BOLA Orientation:

Capsule: U Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: U Material: WELD Ori.: Heat #: BOLA

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| -50 | 13 | 36.57 | -23.57 |
| -25 | 79 | 51.18 | 27.81 |
| 0 | 37 | 67.73 | -30.73 |
| 0 | 95 | 67.73 | 27.26 |
| 25 | 90 | 84.2 | 5.79 |
| 50 | 85 | 98.6 | -13.6 |
| 50 | 96 | 98.6 | -2.6 |
| 75 | 113 | 109.83 | 3.16 |

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

# CAPSULE U

Page 2

Material: WELD Heat Number: BOLA Orientation:

Capsule: U Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 100 | 108 | 117.84 | -9.84 |
| 125 | 140 | 123.19 | 16.8 |
| 150 | 133 | 126.62 | 6.37 |
| 175 | 122 | 128.74 | -6.74 |
| 200 | 114 | 130.04 | -16.04 |
| 250 | 155 | 131.3 | 23.69 |
| 300 | 128 | 131.75 | -3.75 |

SUM of RESIDUALS = 4.01

# CAPSULE W

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:43:31 on 12-21-1998

Page 1

Coefficients of Curve 3

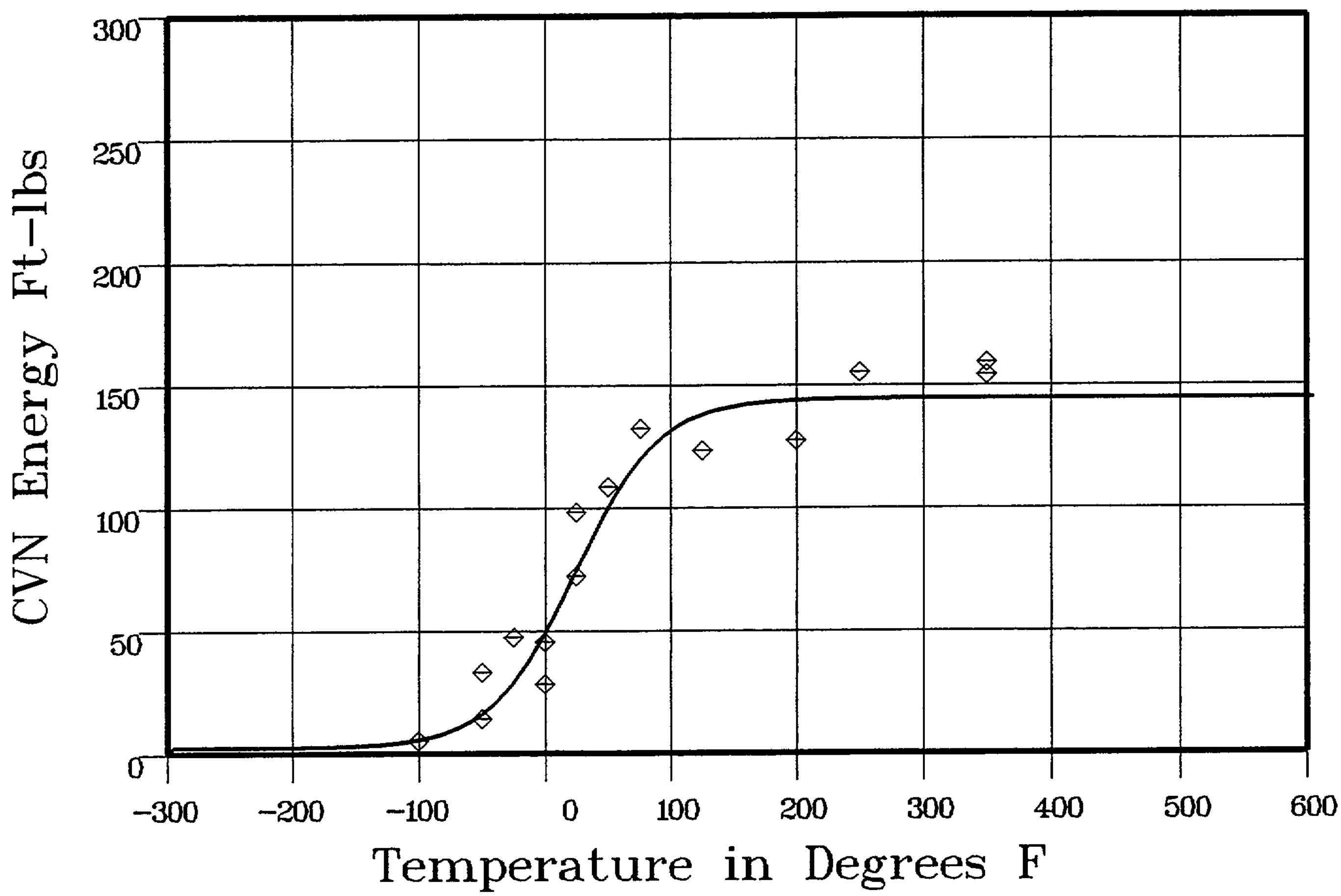
| A = 73.09 | B = 70.9 | C = 66.49 | T0 = 18.91 |
|---|---|---|---|

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

Upper Shelf Energy: 144 Fixed    Temp. at 30 ft-lbs: -27.9    Temp. at 50 ft-lbs: -3.5    Lower Shelf Energy: 2.19 Fixed

Material: WELD    Heat Number: BOLA    Orientation:

Capsule: W    Total Fluence:




Data Set(s) Plotted

Plant: FA2    Cap.: W    Material: WELD    Ori.:    Heat #: BOLA

**Charpy V-Notch Data**

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| -100 | 5 | 6.05 | -1.05 |
| -50 | 14 | 18.04 | -4.04 |
| -50 | 33 | 18.04 | 14.95 |
| -25 | 47 | 32.07 | 14.92 |
| 0 | 45 | 53.45 | -8.45 |
| 0 | 28 | 53.45 | -25.45 |
| 25 | 98 | 79.56 | 18.43 |
| 25 | 72 | 79.56 | -7.56 |

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

# CAPSULE W

Page 2

Material: WELD | Heat Number: BOLA | Orientation:

Capsule: W | Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 50 | 108 | 104.02 | 3.97 |
| 76 | 132 | 122.4 | 9.59 |
| 125 | 123 | 138.39 | -15.39 |
| 200 | 127 | 143.39 | -16.39 |
| 250 | 155 | 143.86 | 11.13 |
| 350 | 159 | 143.99 | 15 |
| 350 | 154 | 143.99 | 10 |

SUM of RESIDUALS = 19.66

# CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve   Printed at 13:43:31 on 12-21-1998
Page 1
Coefficients of Curve 4

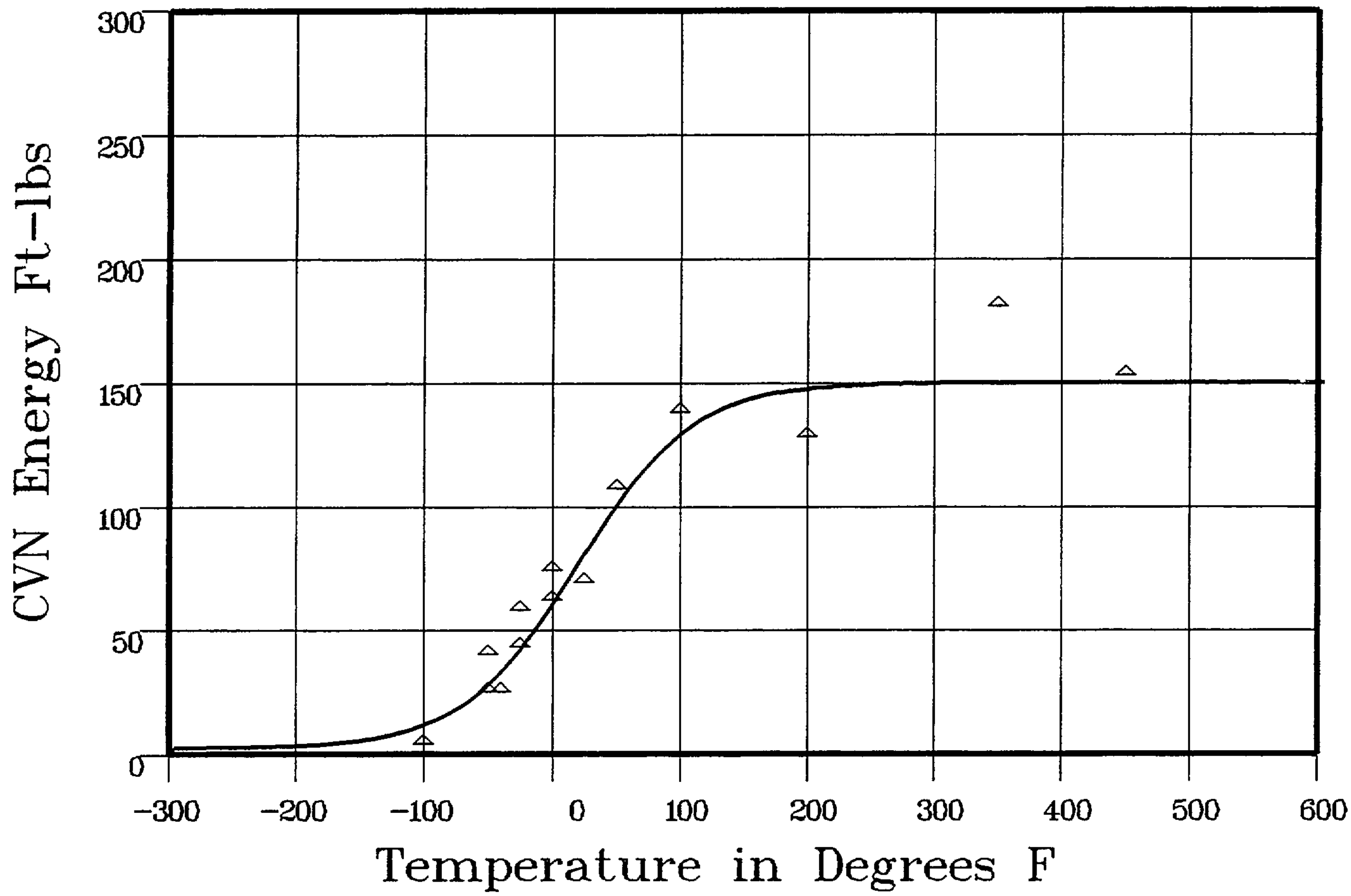
| A = 76.09 | B = 73.9 | C = 88.94 | T0 = 15 |
|---|---|---|---|

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

Upper Shelf Energy: 150 Fixed   Temp. at 30 ft-lbs: -50   Temp. at 50 ft-lbs: -17.8   Lower Shelf Energy: 2.19 Fixed

Material: WELD   Heat Number: BOLA   Orientation:

Capsule: X   Total Fluence:




Data Set(s) Plotted
Plant: FA2   Cap.: X   Material: WELD   Ori.:   Heat #: BOLA

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| -100 | 4 | 12.55 | -8.55 |
| -50 | 40 | 30.01 | 9.98 |
| -50 | 25 | 30.01 | -5.01 |
| -40 | 25 | 35.45 | -10.45 |
| -25 | 43 | 44.93 | -1.93 |
| -25 | 58 | 44.93 | 13.06 |
| 0 | 62 | 63.75 | -1.75 |

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

# CAPSULE X

Page 2

Material: WELD Heat Number: BOLA Orientation:

Capsule: X Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 0 | 74 | 63.75 | 10.24 |
| 25 | 69 | 84.37 | -15.37 |
| 50 | 107 | 103.76 | 3.23 |
| 100 | 138 | 130.95 | 7.04 |
| 200 | 128 | 147.72 | -19.72 |
| 350 | 181 | 149.92 | 31.07 |
| 450 | 153 | 149.99 | 3 |

SUM of RESIDUALS = 14.83

# CAPSULE Z

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:43:31 on 12-21-1998

Page 1

Coefficients of Curve 5

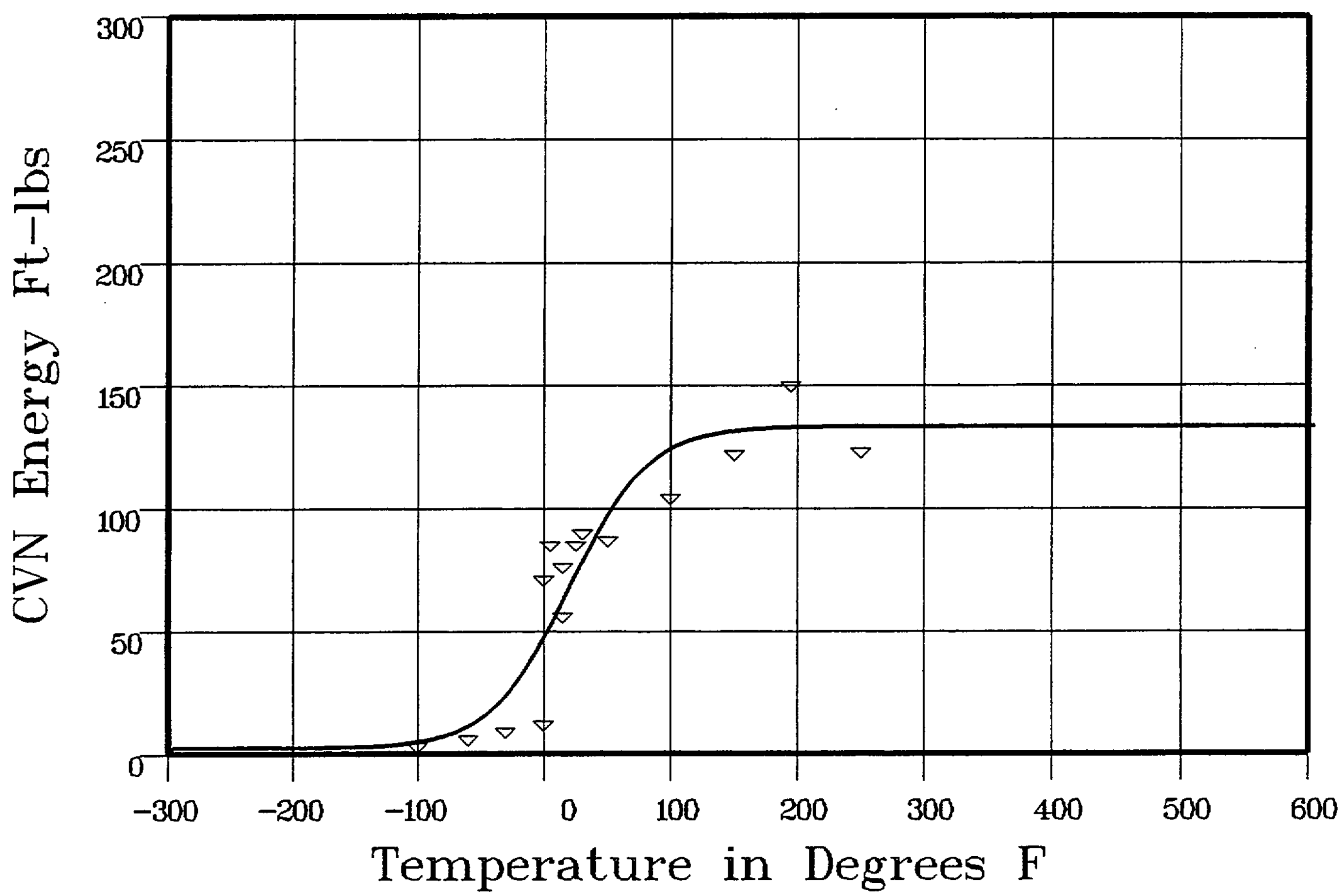
| A = 67.59 | B = 65.4 | C = 61.26 | T0 = 15.46 |
|---|---|---|---|

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

Upper Shelf Energy: 133 Fixed Temp. at 30 ft-lbs: -24.6 Temp. at 50 ft-lbs: -1.4 Lower Shelf Energy: 2.19 Fixed

Material: WELD Heat Number: BOLA Orientation:

Capsule: Z · Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: Z Material: WELD Ori.: Heat #: BOLA

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| -100 | 4 | 5.14 | -1.14 |
| -60 | 7 | 12.46 | -5.46 |
| -30 | 10 | 26.36 | -16.36 |
| 0 | 72 | 51.43 | 20.56 |
| 0 | 13 | 51.43 | -38.43 |
| 5 | 86 | 56.53 | 29.46 |

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

# CAPSULE Z

Page 2

Material: WELD    Heat Number: BOLA    Orientation:

Capsule: Z    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 15 | 77 | 67.09 | 9.9 |
| 15 | 57 | 67.09 | -10.09 |
| 25 | 86 | 77.69 | 8.3 |
| 30 | 91 | 82.82 | 8.17 |
| 50 | 88 | 100.99 | -12.99 |
| 100 | 105 | 125.2 | -20.2 |
| 150 | 123 | 131.4 | -8.4 |
| 195 | 151 | 132.62 | 18.37 |
| 250 | 124 | 132.93 | -8.93 |

SUM of RESIDUALS = -27.26

# UNIRRADIATED

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:04:10 on 12-21-1998

Page 1

Coefficients of Curve 1

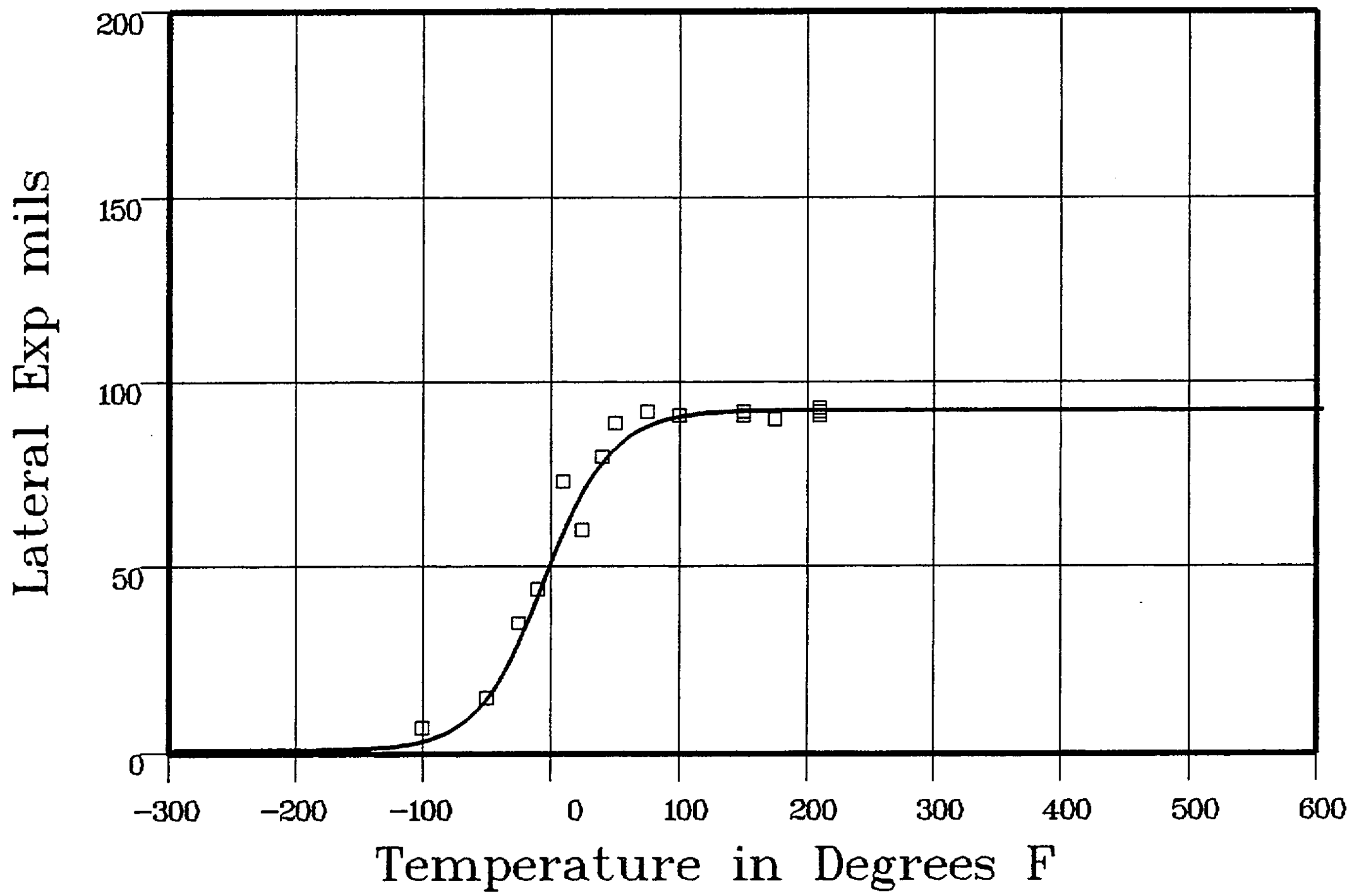
| A = 46.67 | B = 45.67 | C = 52.29 | T0 = -9.37 |
|---|---|---|---|

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

Upper Shelf L.E.: 92.34 Temperature at L.E. 35: -23 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: BOLA Orientation:

Capsule: UNIRR Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: UNIRR Material: WELD Ori.: Heat #: BOLA

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| -100 | 7 | 3.76 | 3.23 |
| -50 | 15 | 16.94 | -1.94 |
| -25 | 35 | 33.41 | 1.58 |
| -10 | 44 | 46.12 | -2.12 |
| 10 | 73 | 62.85 | 10.14 |
| 25 | 60 | 73 | -13 |
| 40 | 80 | 80.33 | -.33 |
| 50 | 89 | 83.79 | 5.2 |
| 75 | 92 | 88.85 | 3.14 |

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

# UNIRRADIATED

Page 2

Material: WELD    Heat Number: BOLA    Orientation:

Capsule: UNIRR    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 100 | 91 | 90.96 | .03 |
| 150 | 92 | 92.13 | -.13 |
| 150 | 91 | 92.13 | -1.13 |
| 175 | 90 | 92.26 | -2.26 |
| 210 | 92 | 92.32 | -.32 |
| 210 | 93 | 92.32 | .67 |
| 210 | 91 | 92.32 | -1.32 |

SUM of RESIDUALS = 1.42

# CAPSULE U (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:04:10 on 12-21-1998
Page 1
Coefficients of Curve 2

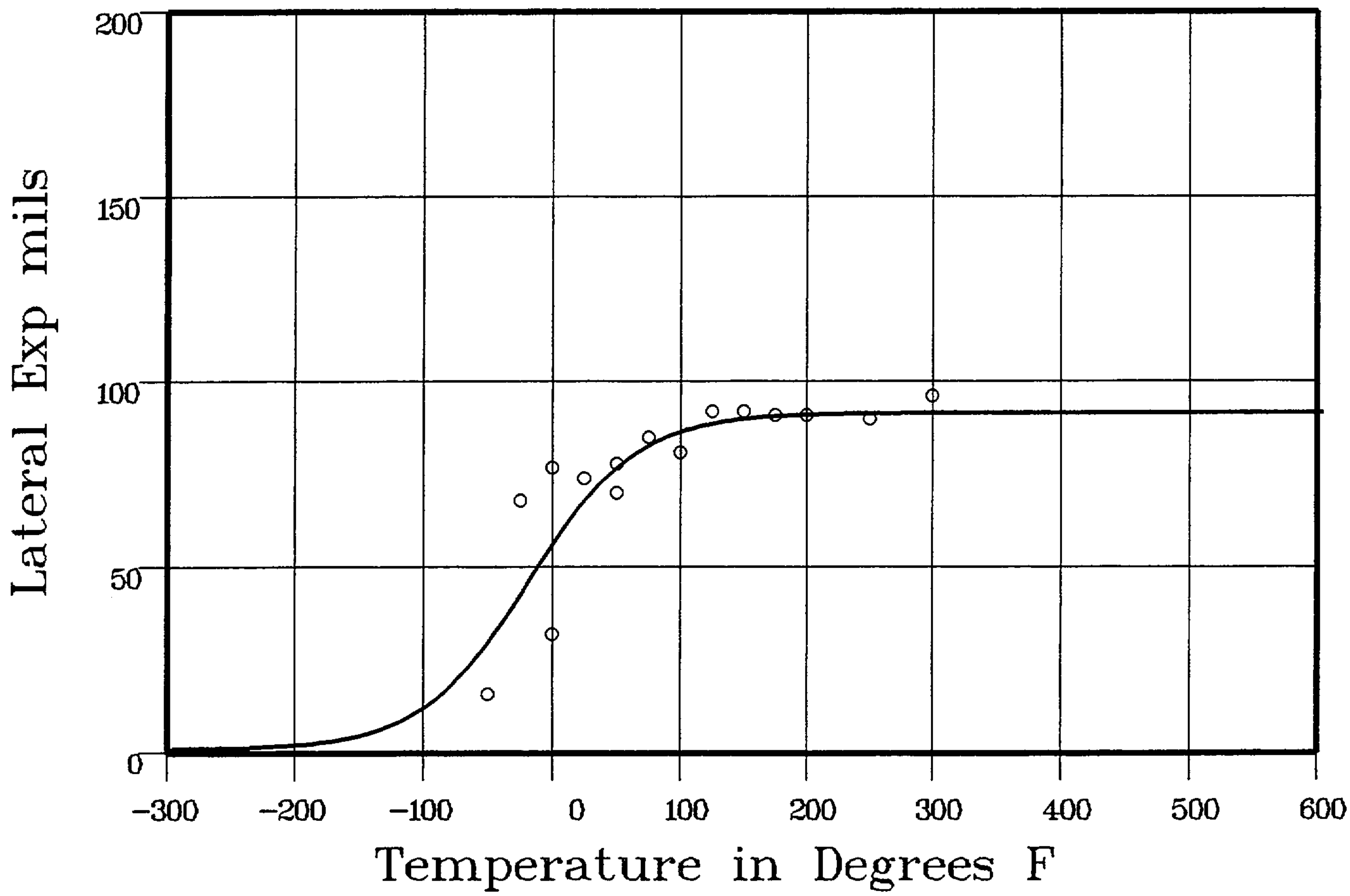
| A = 46.23 | B = 45.23 | C = 83.1 | T0 = -22.96 |
|---|---|---|---|

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

Upper Shelf L.E.: 91.47 Temperature at L.E. 35: -44 Lower Shelf L.E.: 1 Fixed

Material: WELD Heat Number: BOLA Orientation:

Capsule: U Total Fluence:




Data Set(s) Plotted
Plant: FA2 Cap.: U Material: WELD Ori.: Heat #: BOLA

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| -50 | 16 | 32.02 | -16.02 |
| -25 | 68 | 45.13 | 22.86 |
| 0 | 32 | 58.43 | -26.43 |
| 0 | 77 | 58.43 | 18.56 |
| 25 | 74 | 69.78 | 4.21 |
| 50 | 70 | 78.14 | -8.14 |
| 50 | 78 | 78.14 | -.14 |
| 75 | 85 | 83.65 | 1.34 |

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

# CAPSULE U (WELD)

Page 2

Material: WELD        Heat Number: BOLA        Orientation:

Capsule: U        Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 100 | 81 | 87.01 | -6.01 |
| 125 | 92 | 88.97 | 3.02 |
| 150 | 92 | 90.08 | 1.91 |
| 175 | 91 | 90.7 | .29 |
| 200 | 91 | 91.05 | -.05 |
| 250 | 90 | 91.34 | -1.34 |
| 300 | 96 | 91.43 | 4.56 |

SUM of RESIDUALS = -1.36

# CAPSULE W (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve  Printed at 17:04:10 on 12-21-1998
Page 1
Coefficients of Curve 3

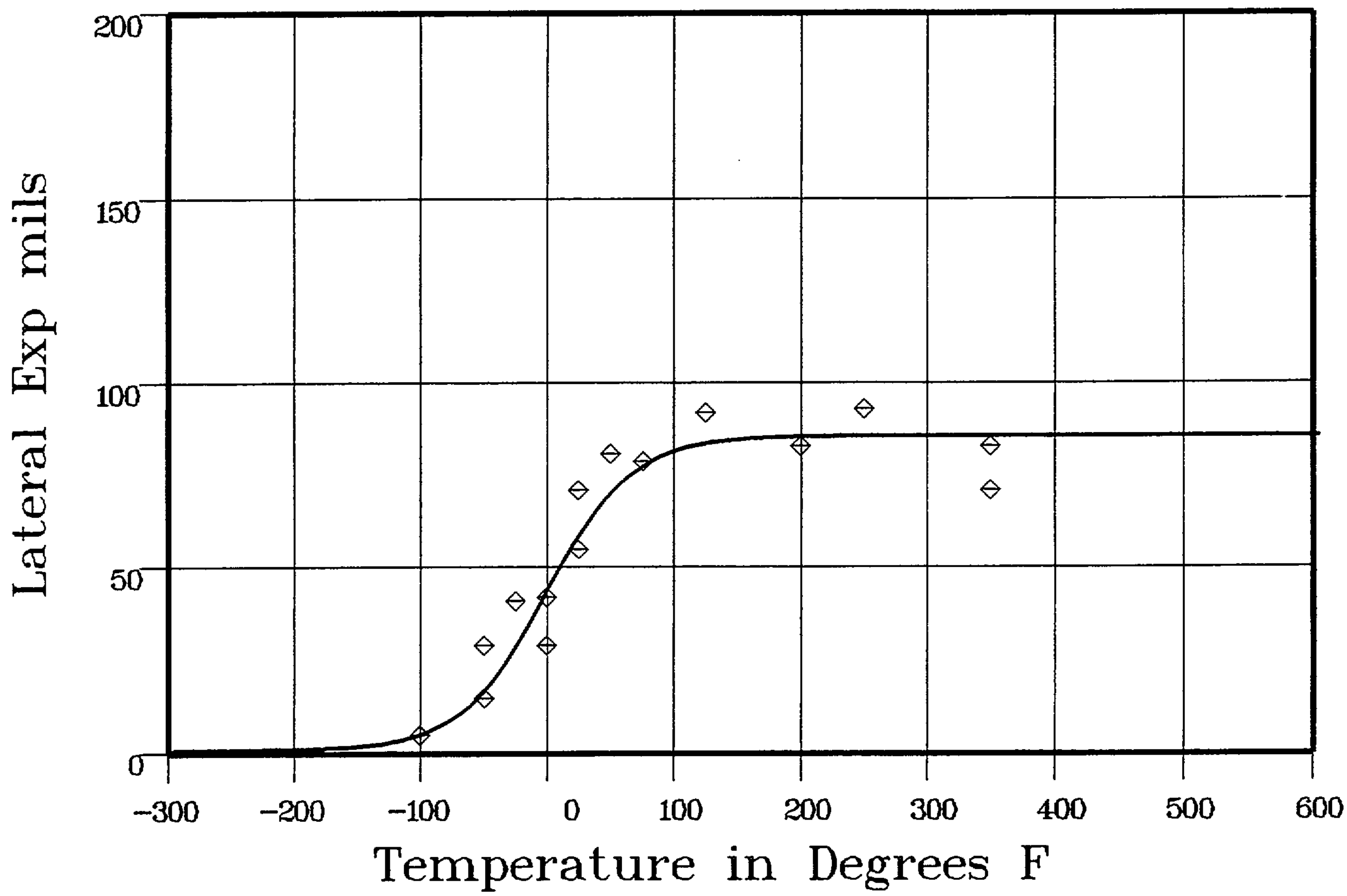
| A = 43.37 | B = 42.37 | C = 67.52 | T0 = -5.15 |
|---|---|---|---|

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

Upper Shelf L.E.: 85.75  Temperature at L.E. 35: -18.6  Lower Shelf L.E.: 1 Fixed

Material: WELD  Heat Number: BOLA  Orientation:

Capsule: W  Total Fluence:




Data Set(s) Plotted
Plant: FA2  Cap.: W  Material: WELD  Ori.:  Heat #: BOLA

**Charpy V-Notch Data**

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| -100 | 5 | 5.81 | -.81 |
| -50 | 15 | 18.75 | -3.75 |
| -50 | 29 | 18.75 | 10.24 |
| -25 | 41 | 31.27 | 9.72 |
| 0 | 42 | 46.6 | -4.6 |
| 0 | 29 | 46.6 | -17.6 |
| 25 | 71 | 61.13 | 9.86 |
| 25 | 55 | 61.13 | -6.13 |

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

# CAPSULE W (WELD)

Page 2

Material: WELD    Heat Number: BOLA    Orientation:

Capsule: W    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 50 | 81 | 71.91 | 9.08 |
| 76 | 79 | 78.73 | .26 |
| 125 | 92 | 83.99 | 8 |
| 200 | 83 | 85.56 | -2.56 |
| 250 | 93 | 85.71 | 7.28 |
| 350 | 83 | 85.75 | -2.75 |
| 350 | 71 | 85.75 | -14.75 |

SUM of RESIDUALS = 1.5

# CAPSULE X (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:04:10 on 12-21-1998
Page 1
Coefficients of Curve 4

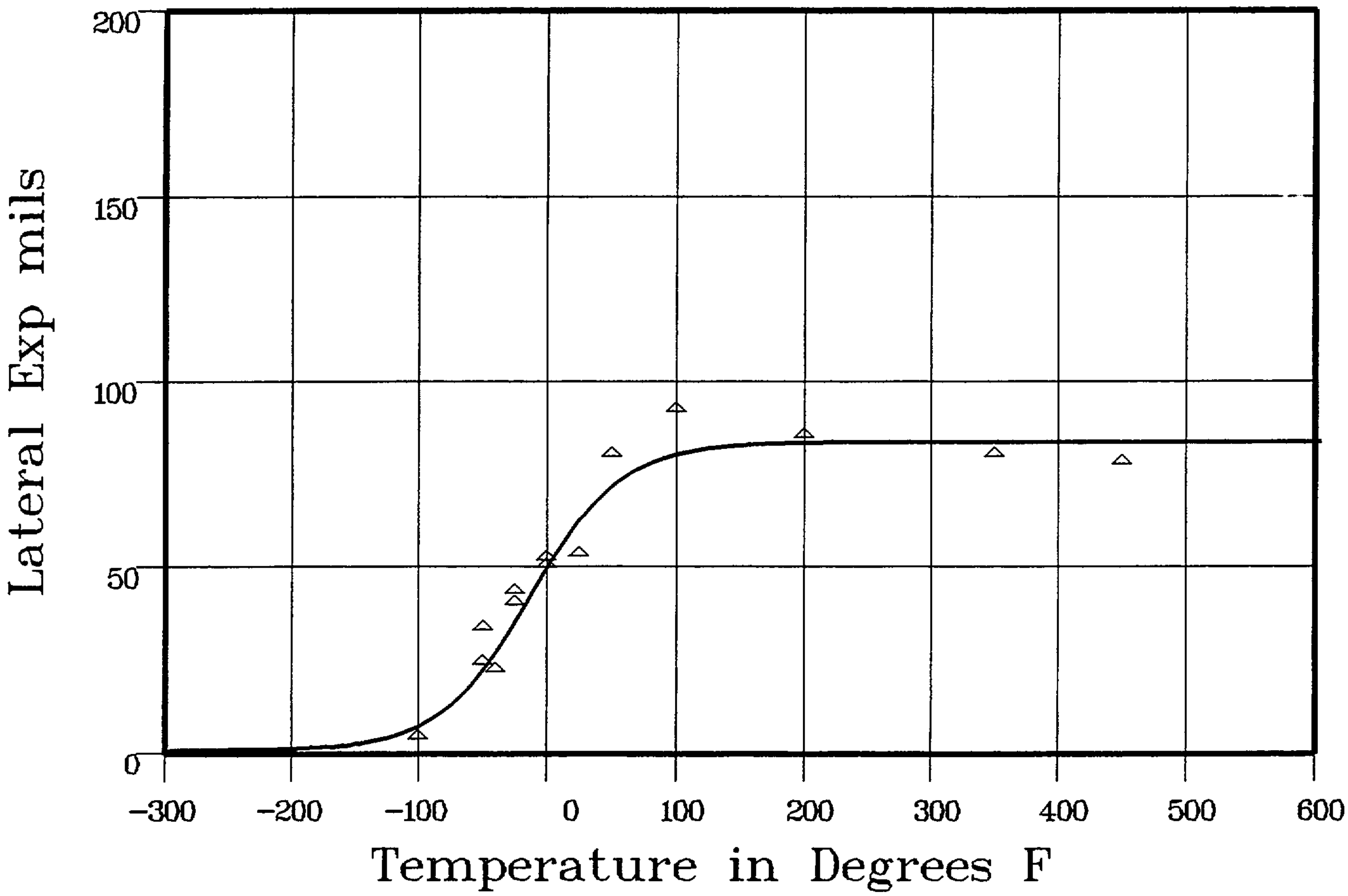
| A = 42.38 | B = 41.38 | C = 70.53 | T0 = -17.18 |
|---|---|---|---|

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

Upper Shelf L.E: 83.77 Temperature at L.E. 35: -29.9 Lower Shelf L.E: 1 Fixed

Material: WELD Heat Number: BOLA Orientation:

Capsule: X Total Fluence:




Data Set(s) Plotted
Plant: FA2 Cap.: X Material: WELD Ori.: Heat #: BOLA

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| -100 | 4 | 8.21 | -4.21 |
| -50 | 33 | 24.4 | 8.59 |
| -50 | 24 | 24.4 | -.4 |
| -40 | 22 | 29.44 | -7.44 |
| -25 | 40 | 37.81 | 2.18 |
| -25 | 43 | 37.81 | 5.18 |
| 0 | 50 | 52.27 | -2.27 |

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

# CAPSULE X (WELD)

Page 2

Material: WELD    Heat Number: BOLA    Orientation:

Capsule: X    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 0 | 52 | 52.27 | -.27 |
| 25 | 53 | 64.55 | -11.55 |
| 50 | 80 | 73.04 | 6.95 |
| 100 | 92 | 80.89 | 11.1 |
| 200 | 85 | 83.59 | 1.4 |
| 350 | 80 | 83.76 | -3.76 |
| 450 | 78 | 83.77 | -5.77 |

SUM of RESIDUALS = -.28

# CAPSULE Z (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve   Printed at 17:04:10 on 12-21-1998

Page 1

Coefficients of Curve 5

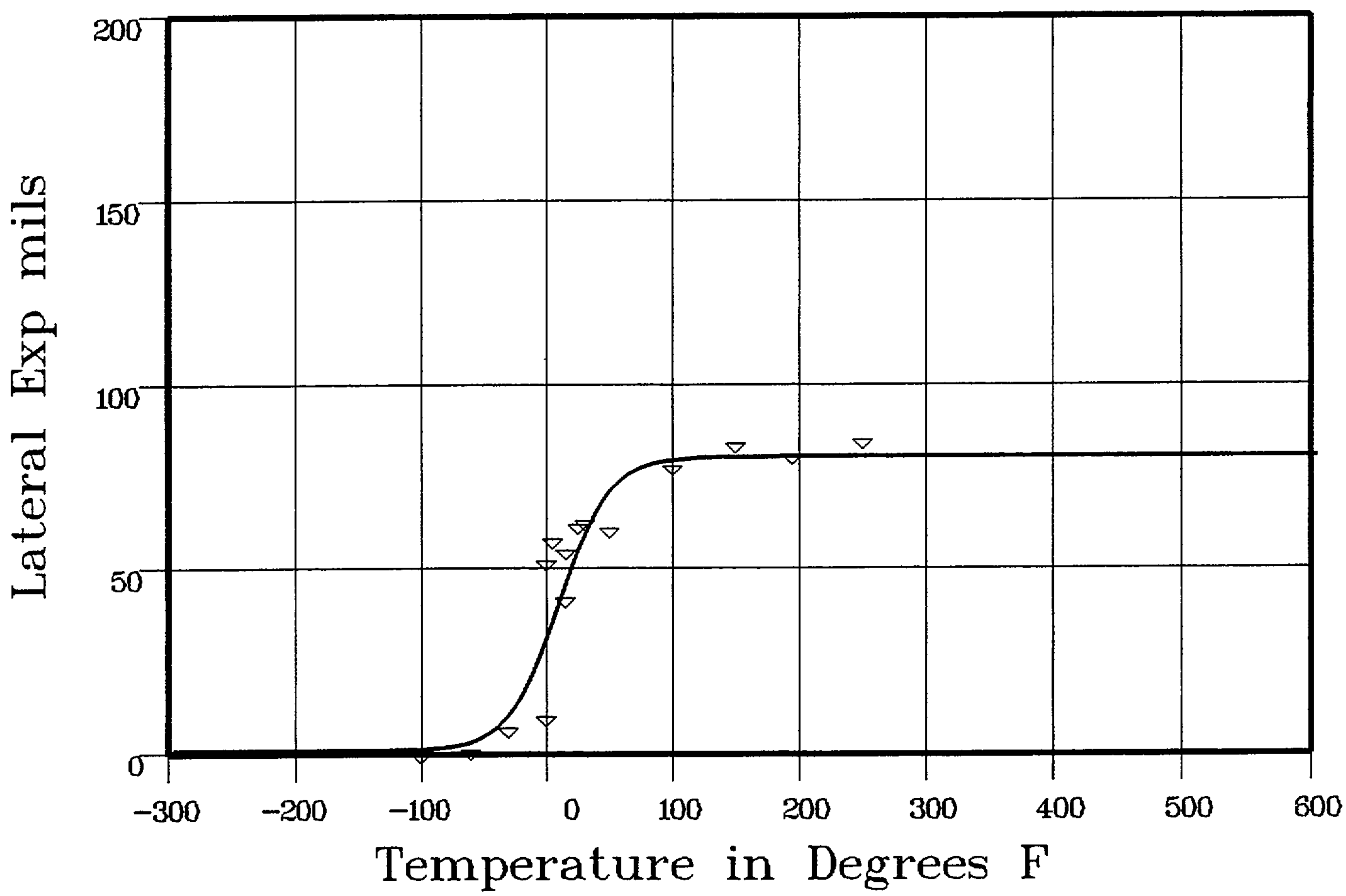
| A = 40.8 | B = 39.8 | C = 39.93 | T0 = 5.39 |
|---|---|---|---|

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

Upper Shelf L.E.: 80.6   Temperature at L.E. 35: -.4   Lower Shelf L.E.: 1 Fixed

Material: WELD   Heat Number: BOLA   Orientation:

Capsule: Z   Total Fluence:




Data Set(s) Plotted

Plant: FA2   Cap.: Z   Material: WELD   Ori.:   Heat #: BOLA

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| -100 | 0 | 1.4 | -1.4 |
| -60 | 1 | 3.9 | -2.9 |
| -30 | 7 | 12.56 | -5.56 |
| 0 | 52 | 35.46 | 16.53 |
| 0 | 10 | 35.46 | -25.46 |
| 5 | 58 | 40.41 | 17.58 |

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

# CAPSULE Z (WELD)

Page 2

Material: WELD Heat Number: BOLA Orientation:

Capsule: Z Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 15 | 55 | 50.19 | 4.8 |
| 15 | 42 | 50.19 | -8.19 |
| 25 | 62 | 58.91 | 3.08 |
| 30 | 63 | 62.63 | .36 |
| 50 | 61 | 72.9 | -11.9 |
| 100 | 78 | 79.91 | -1.91 |
| 150 | 84 | 80.54 | 3.45 |
| 195 | 81 | 80.59 | .4 |
| 250 | 85 | 80.6 | 4.39 |

SUM of RESIDUALS = -6.71

# UNIRRADIATED (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:15:15 on 12-21-1998
Page 1
Coefficients of Curve 1

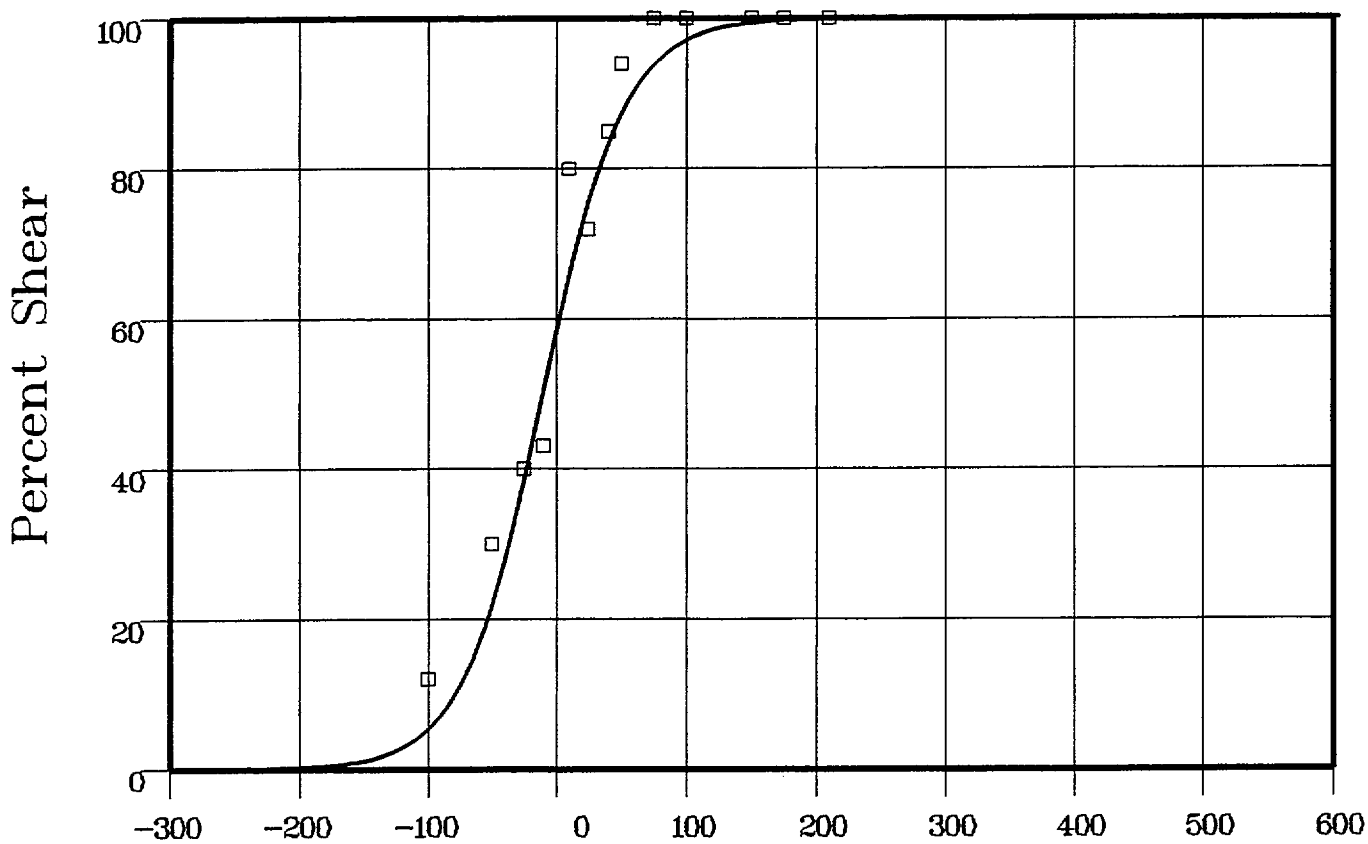
| A = 50 | B = 50 | C = 62.37 | T0 = -15 |
|---|---|---|---|

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

Temperature at 50% Shear: -15

Material: WELD Heat Number: BOLA Orientation:

Capsule: UNIRR Total Fluence:




Data Set(s) Plotted
Plant: FA2 Cap.: UNIRR Material: WELD Ori.: Heat #: BOLA

**Charpy V-Notch Data**

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100 | 12 | 6.14 | 5.85 |
| -50 | 30 | 24.56 | 5.43 |
| -25 | 40 | 42.05 | -2.05 |
| -10 | 43 | 53.99 | -10.99 |
| 10 | 80 | 69.03 | 10.96 |
| 25 | 72 | 78.28 | -6.28 |
| 40 | 85 | 85.36 | -.36 |
| 50 | 94 | 88.93 | 5.06 |
| 75 | 100 | 94.71 | 5.28 |

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

# UNIRRADIATED (WELD)

Page 2

Material: WELD Heat Number: BOLA Orientation:

Capsule: UNIRR Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 100 | 100 | 97.55 | 2.44 |
| 150 | 100 | 99.49 | .5 |
| 150 | 100 | 99.49 | .5 |
| 175 | 100 | 99.77 | .22 |
| 210 | 100 | 99.92 | .07 |
| 210 | 100 | 99.92 | .07 |
| 210 | 100 | 99.92 | .07 |

SUM of RESIDUALS = 16.8

# CAPSULE U (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:15:15 on 12-21-1998
Page 1
Coefficients of Curve 2

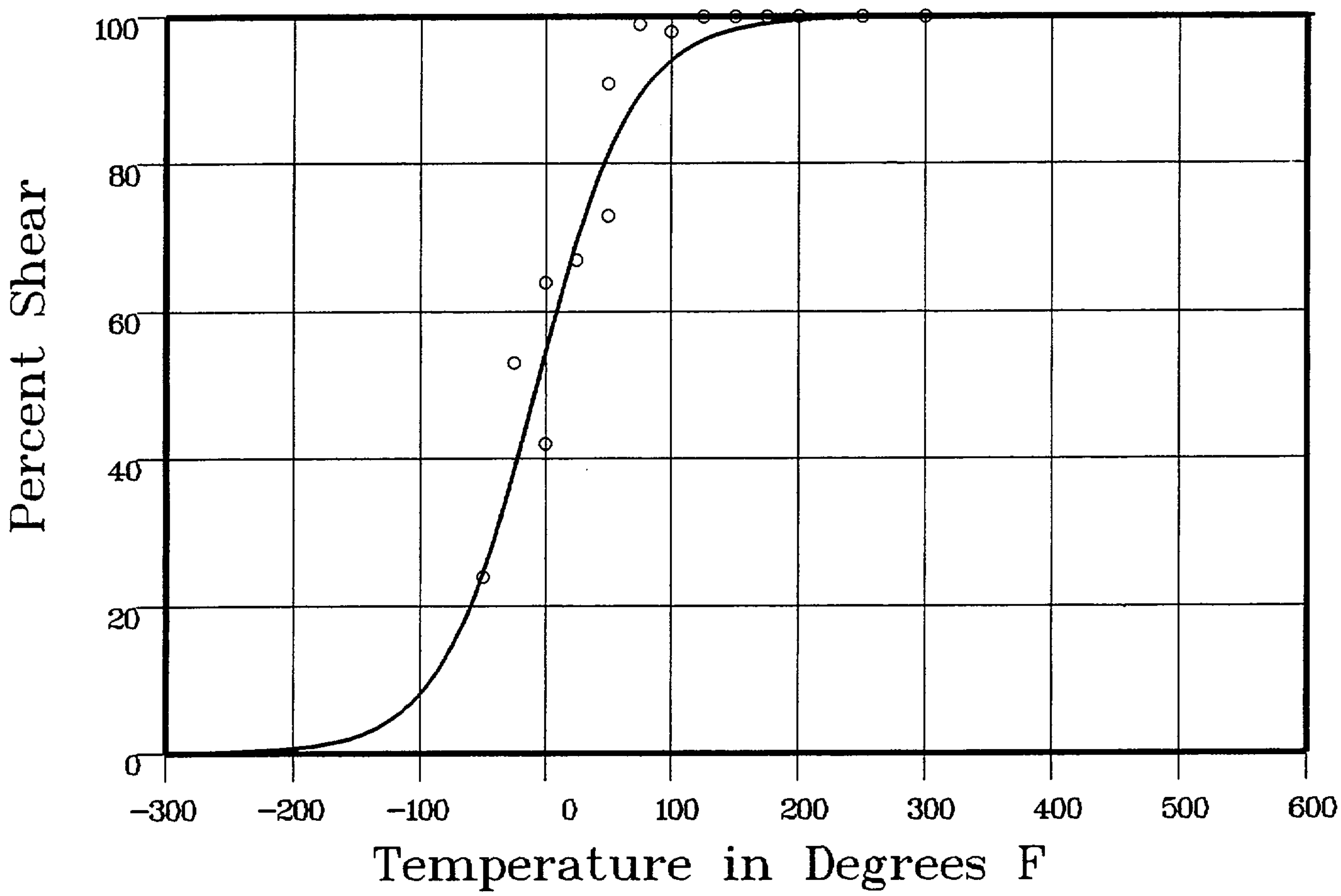
| A = 50 | B = 50 | C = 76.93 | T0 = -11.25 |
|---|---|---|---|

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

Temperature at 50% Shear: -11.2

Material: WELD Heat Number: BOLA Orientation:

Capsule: U Total Fluence:




Data Set(s) Plotted
Plant: FA2 Cap.: U Material: WELD Ori.: Heat #: BOLA

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -50 | 24 | 26.74 | -2.74 |
| -25 | 53 | 41.15 | 11.84 |
| 0 | 42 | 57.25 | -15.25 |
| 0 | 64 | 57.25 | 6.74 |
| 25 | 67 | 71.95 | -4.95 |
| 50 | 73 | 83.09 | -10.09 |
| 50 | 91 | 83.09 | 7.9 |
| 75 | 99 | 90.39 | 8.6 |

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

# CAPSULE U (WELD)

Page 2

Material: WELD Heat Number: BOLA Orientation:

Capsule: U Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 100 | 98 | 94.74 | 3.25 |
| 125 | 100 | 97.18 | 2.81 |
| 150 | 100 | 98.51 | 1.48 |
| 175 | 100 | 99.21 | .78 |
| 200 | 100 | 99.58 | .41 |
| 250 | 100 | 99.88 | .11 |
| 300 | 100 | 99.96 | .03 |

SUM of RESIDUALS = 10.92

# CAPSULE W (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve   Printed at 17:15:15 on 12-21-1998

Page 1

Coefficients of Curve 3

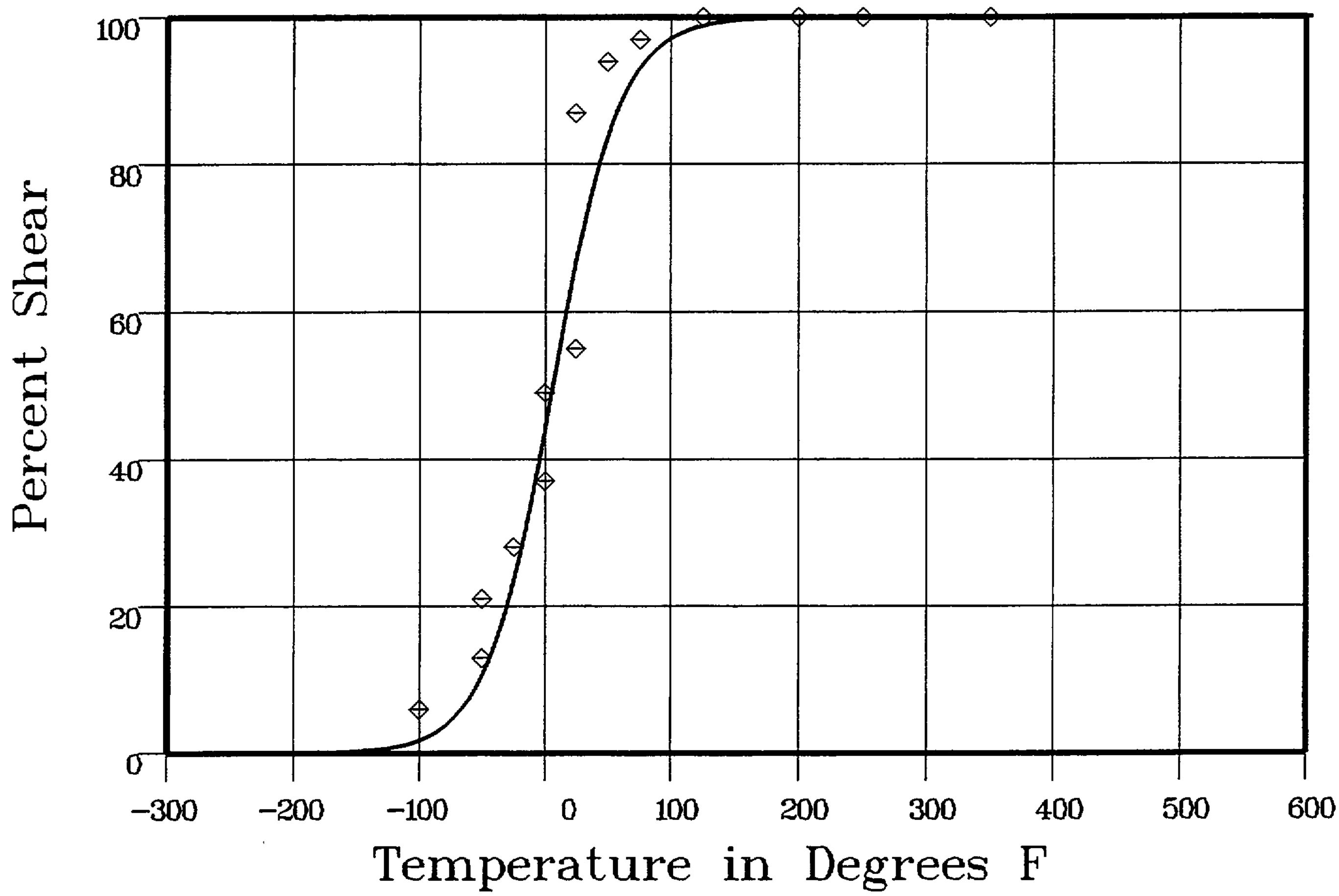
| A = 50 | B = 50 | C = 53.01 | T0 = 1.87 |
|---|---|---|---|

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

Temperature at 50% Shear:   1.8

Material: WELD   Heat Number: BOLA   Orientation:

Capsule: W   Total Fluence:




Data Set(s) Plotted

Plant: FA2   Cap.: W   Material: WELD   Ori.:   Heat #: BOLA

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100 | 6 | 2.09 | 3.9 |
| -50 | 13 | 12.37 | .62 |
| -50 | 21 | 12.37 | 8.62 |
| -25 | 28 | 26.62 | 1.37 |
| 0 | 49 | 48.23 | .76 |
| 0 | 37 | 48.23 | -11.23 |
| 25 | 87 | 70.52 | 16.47 |
| 25 | 55 | 70.52 | -15.52 |

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

# CAPSULE W (WELD)

Page 2

Material: WELD    Heat Number: BOLA    Orientation:

Capsule: W    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 50 | 94 | 86 | 7.99 |
| 76 | 97 | 94.24 | 2.75 |
| 125 | 100 | 99.04 | .95 |
| 200 | 100 | 99.94 | .05 |
| 250 | 100 | 99.99 | 0 |
| 350 | 100 | 99.99 | 0 |
| 350 | 100 | 99.99 | 0 |

SUM of RESIDUALS = 16.77

# CAPSULE X (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:15:15 on 12-21-1998

Page 1

Coefficients of Curve 4

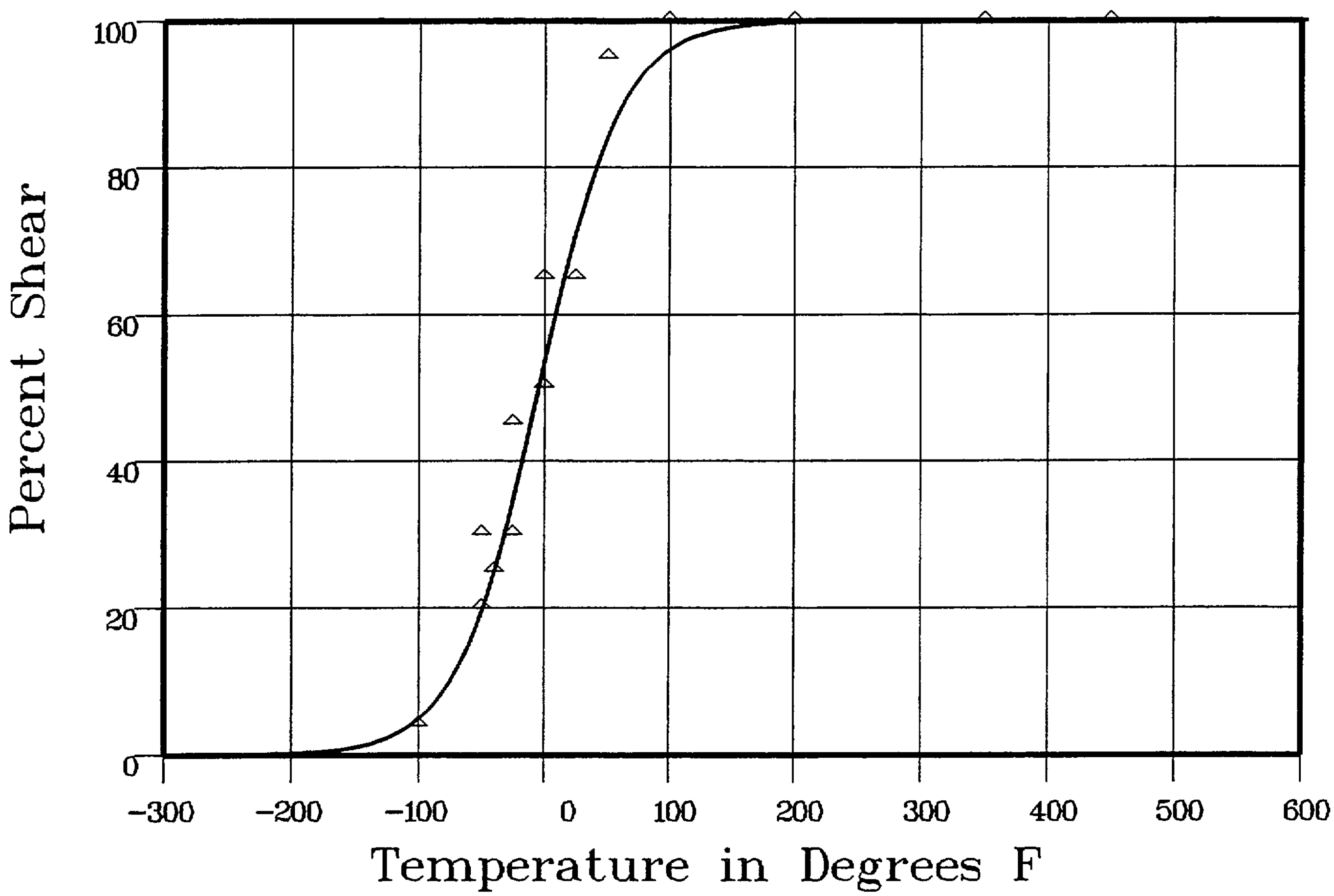
| A = 50 | B = 50 | C = 64.71 | T0 = -8.9 |
|---|---|---|---|

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

Temperature at 50% Shear: -8.9

Material: WELD Heat Number: BOLA Orientation:

Capsule: X Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: X Material: WELD Ori.: Heat #: BOLA

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100 | 4 | 5.64 | -1.64 |
| -50 | 30 | 21.92 | 8.07 |
| -50 | 20 | 21.92 | -1.92 |
| -40 | 25 | 27.66 | -2.66 |
| -25 | 30 | 37.81 | -7.81 |
| -25 | 45 | 37.81 | 7.18 |
| 0 | 50 | 56.83 | -6.83 |

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

# CAPSULE X (WELD)

Page 2

Material: WELD Heat Number: BOLA Orientation:

Capsule: X Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 0 | 65 | 56.83 | 8.16 |
| 25 | 65 | 74.03 | -9.03 |
| 50 | 95 | 86.06 | 8.93 |
| 100 | 100 | 96.66 | 3.33 |
| 200 | 100 | 99.84 | .15 |
| 350 | 100 | 99.99 | 0 |
| 450 | 100 | 99.99 | 0 |

SUM of RESIDUALS = 5.92

# CAPSULE Z (WELD)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:15:15 on 12-21-1998

Page 1

Coefficients of Curve 5

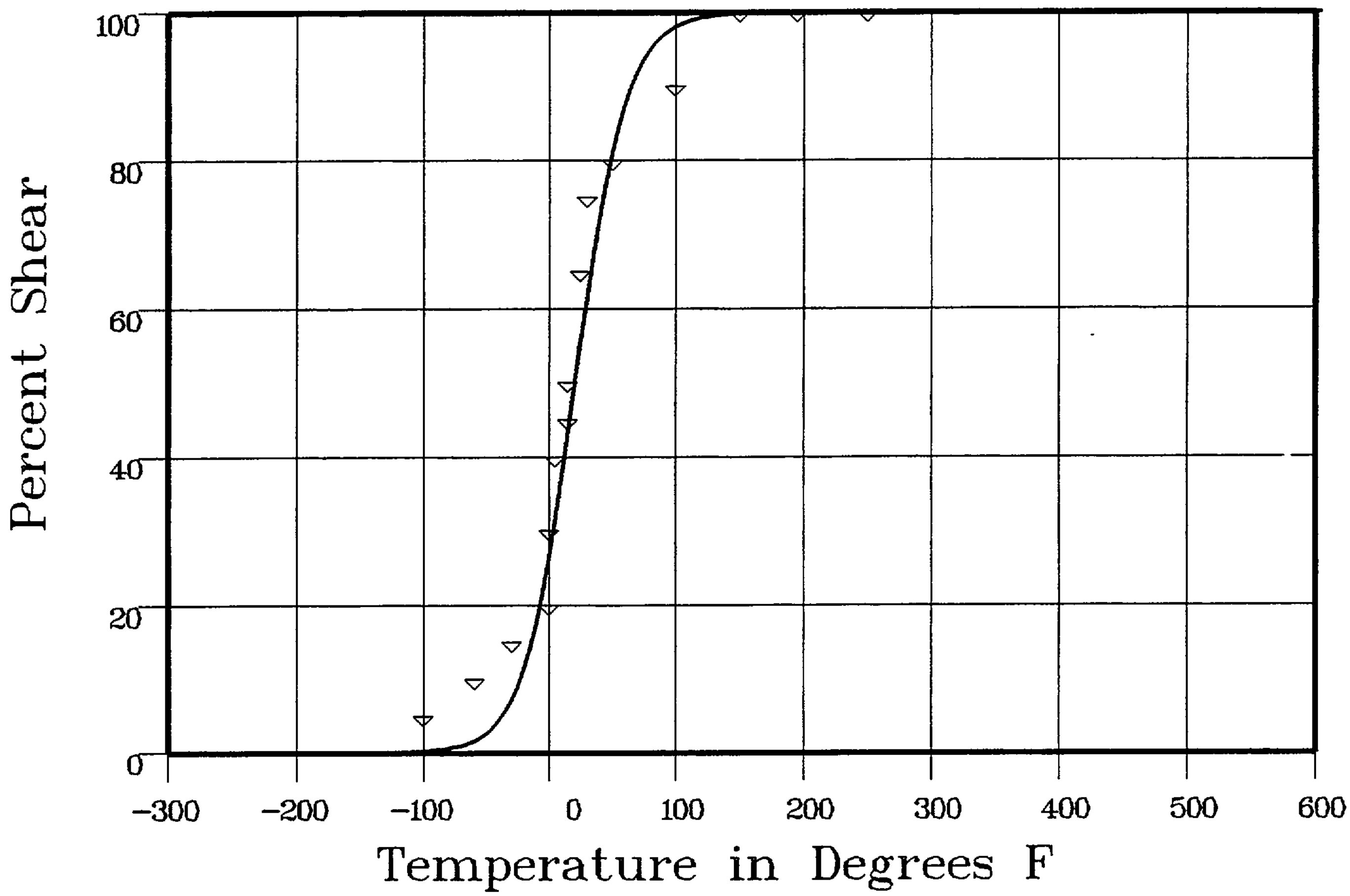
| A = 50 | B = 50 | C = 40.03 | T0 = 15.93 |
|---|---|---|---|

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

Temperature at 50% Shear: 15.9

Material: WELD Heat Number: BOLA Orientation:

Capsule: Z Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: Z Material: WELD Ori.: Heat #: BOLA

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100 | 5 | .3 | 4.69 |
| -60 | 10 | 2.2 | 7.79 |
| -30 | 15 | 9.15 | 5.84 |
| 0 | 30 | 31.08 | -1.08 |
| 0 | 20 | 31.08 | -11.08 |
| 5 | 40 | 36.67 | 3.32 |

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

# CAPSULE Z (WELD)

Page 2

Material: WELD    Heat Number: BOLA    Orientation:

Capsule: Z    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 15 | 45 | 48.82 | -3.82 |
| 15 | 50 | 48.82 | 1.17 |
| 25 | 65 | 61.12 | 3.87 |
| 30 | 75 | 66.87 | 8.12 |
| 50 | 80 | 84.57 | -4.57 |
| 100 | 90 | 98.52 | -8.52 |
| 150 | 100 | 99.87 | .12 |
| 195 | 100 | 99.98 | .01 |
| 250 | 100 | 99.99 | 0 |

SUM of RESIDUALS = 5.87

# UNIRRADIATED (HEAT AFFECTED ZONE)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 14:52:36 on 12-21-1998
Page 1
Coefficients of Curve 1

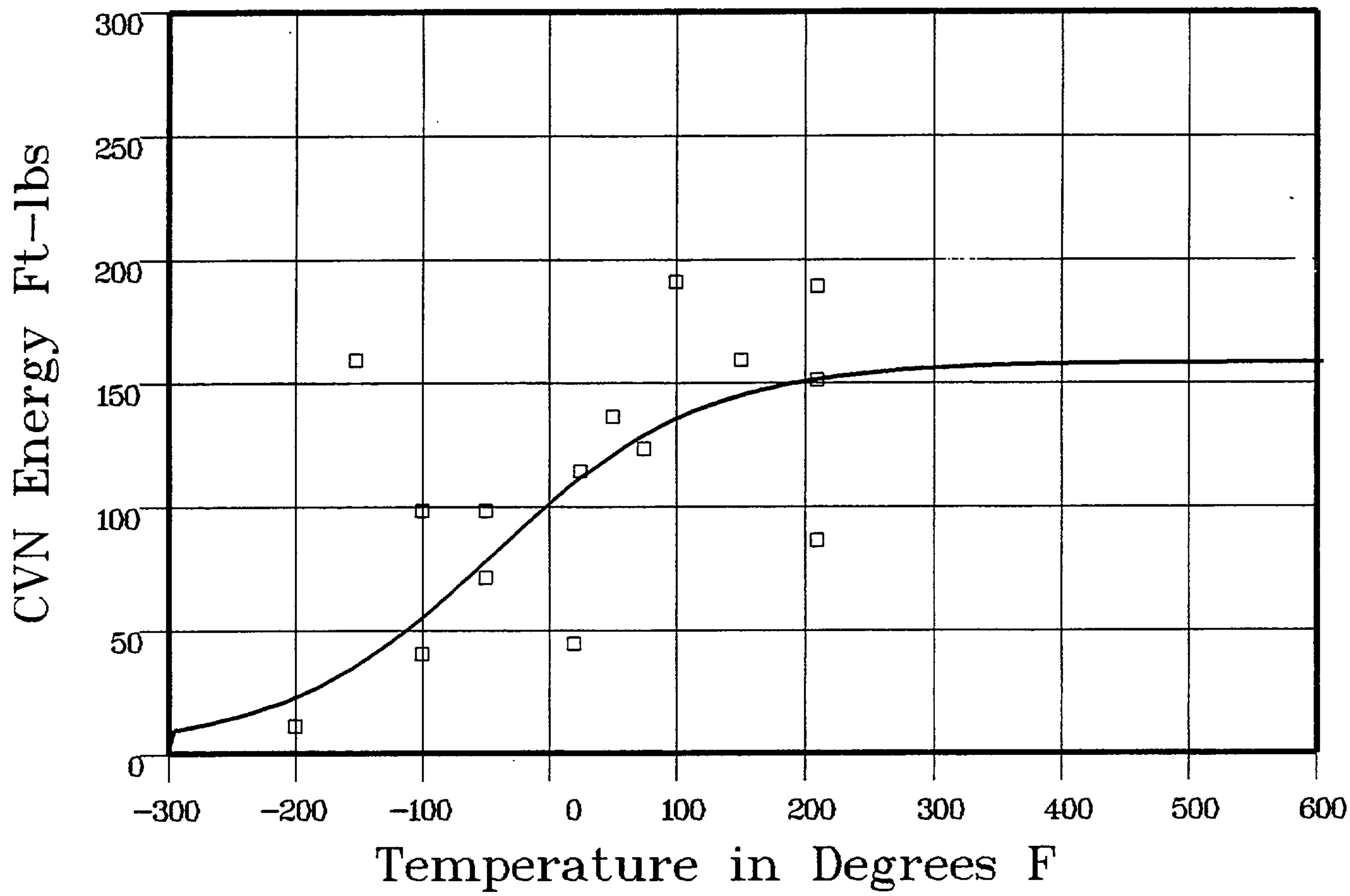
| A = 80.09 | B = 77.9 | C = 164.51 | T0 = -49.76 |
|---|---|---|---|

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

Upper Shelf Energy: 158 Fixed Temp. at 30 ft-lbs: -175.3 Temp. at 50 ft-lbs: -116.8 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: B7212-1 Orientation:

Capsule: UNIRR Total Fluence:




Data Set(s) Plotted
Plant: FA2 Cap.: UNIRR Material: HEAT AFFD ZONE Ori.: Heat #: B7212-1

**Charpy V-Notch Data**

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| -200 | 11 | 23.8 | -12.8 |
| -100 | 98 | 57.02 | 40.97 |
| -100 | 40 | 57.02 | -17.02 |
| -50 | 98 | 79.98 | 18.01 |
| -50 | 71 | 79.98 | -8.98 |
| 20 | 44 | 111.28 | -67.28 |
| 25 | 114 | 113.25 | .74 |
| 50 | 136 | 122.29 | 13.7 |
| 75 | 123 | 129.96 | -6.96 |

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

# UNIRRADIATED (HEAT AFFECTED ZONE)

Page 2

Material: HEAT AFFD ZONE　　Heat Number: B7212-1　　Orientation:

Capsule: UNIRR　　Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 100 | 191 | 136.28 | 54.71 |
| 150 | 159 | 145.37 | 13.62 |
| 210 | 86 | 151.64 | -65.64 |
| 210 | 189 | 151.64 | 37.35 |
| 210 | 151 | 151.64 | -.64 |

SUM of RESIDUALS = -.22

# CAPSULE U

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:55:16 on 12-21-1998

Page 1

Coefficients of Curve 2

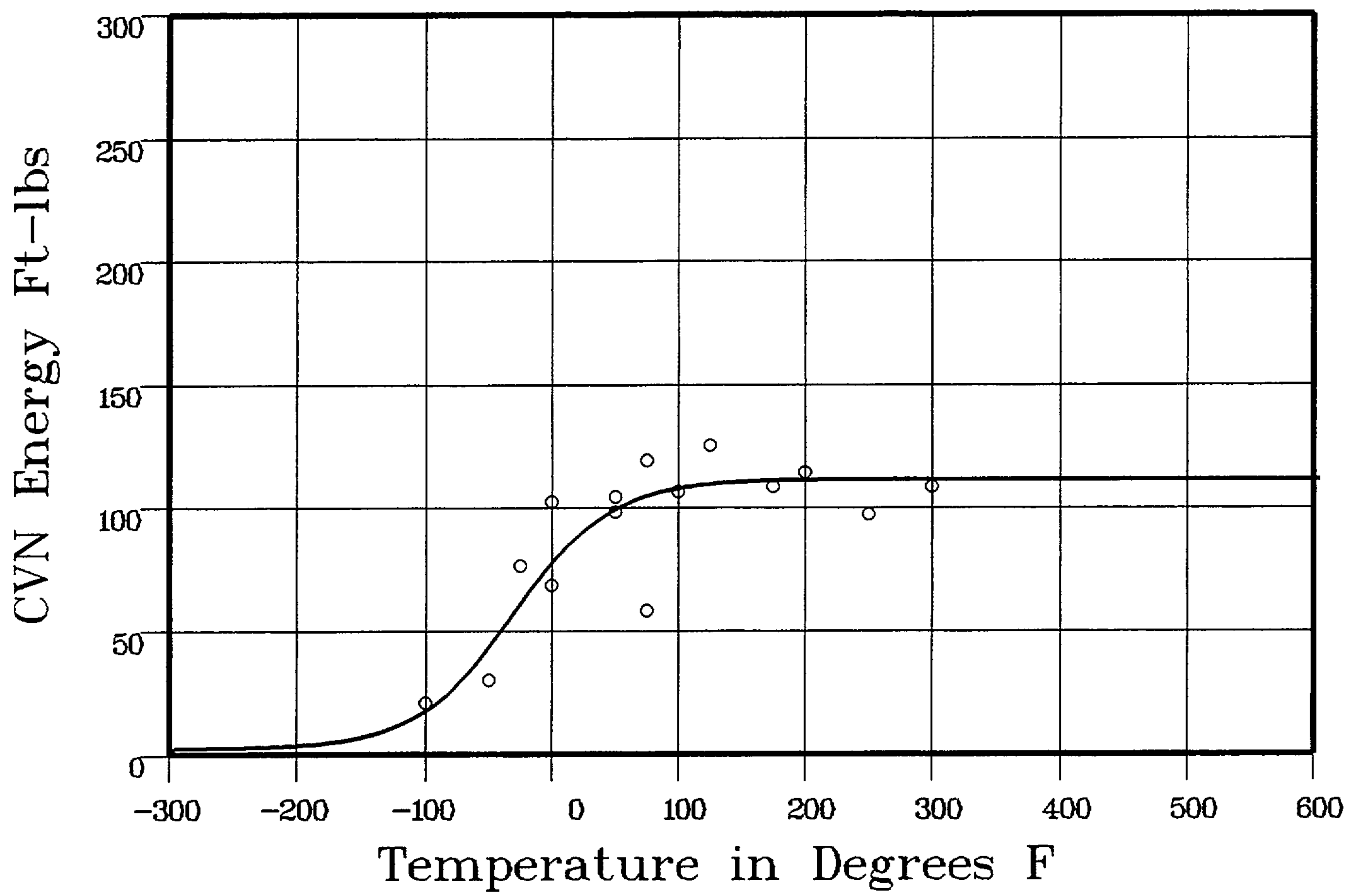
| A = 56.59 | B = 54.4 | C = 77.23 | T0 = -35.15 |
|---|---|---|---|

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

Upper Shelf Energy: 111 Fixed   Temp. at 30 ft-lbs: -76.4   Temp. at 50 ft-lbs: -44.5   Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFF'D ZONE   Heat Number: B7212-1 SIDE OF WELD   Orientation:

Capsule: U   Total Fluence:




Data Set(s) Plotted

Plant: FA2   Cap.: U   Material: HEAT AFF'D ZONE   Ori.:   Heat #: B7212-1 SIDE OF WELD

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| -100 | 21 | 19.3 | 1.69 |
| -50 | 30 | 46.27 | -16.27 |
| -25 | 76 | 63.71 | 12.28 |
| 0 | 68 | 79.78 | -11.78 |
| 0 | 102 | 79.78 | 22.21 |
| 50 | 104 | 100.19 | 3.8 |
| 50 | 98 | 100.19 | -2.19 |
| 75 | 58 | 105.06 | -47.06 |

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

# CAPSULE U

Page 2

Material: HEAT AFF'D ZONE    Heat Number: B7212-1 SIDE OF WELD    Orientation:

Capsule: U    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 75 | 119 | 105.06 | 13.93 |
| 100 | 106 | 107.8 | -1.8 |
| 125 | 125 | 109.3 | 15.69 |
| 175 | 108 | 110.53 | -2.53 |
| 200 | 114 | 110.75 | 3.24 |
| 250 | 97 | 110.93 | -13.93 |
| 300 | 108 | 110.98 | -2.98 |

SUM of RESIDUALS = -25.68

# CAPSULE W (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 16:41:00 on 12-21-1998
Page 1
Coefficients of Curve 1

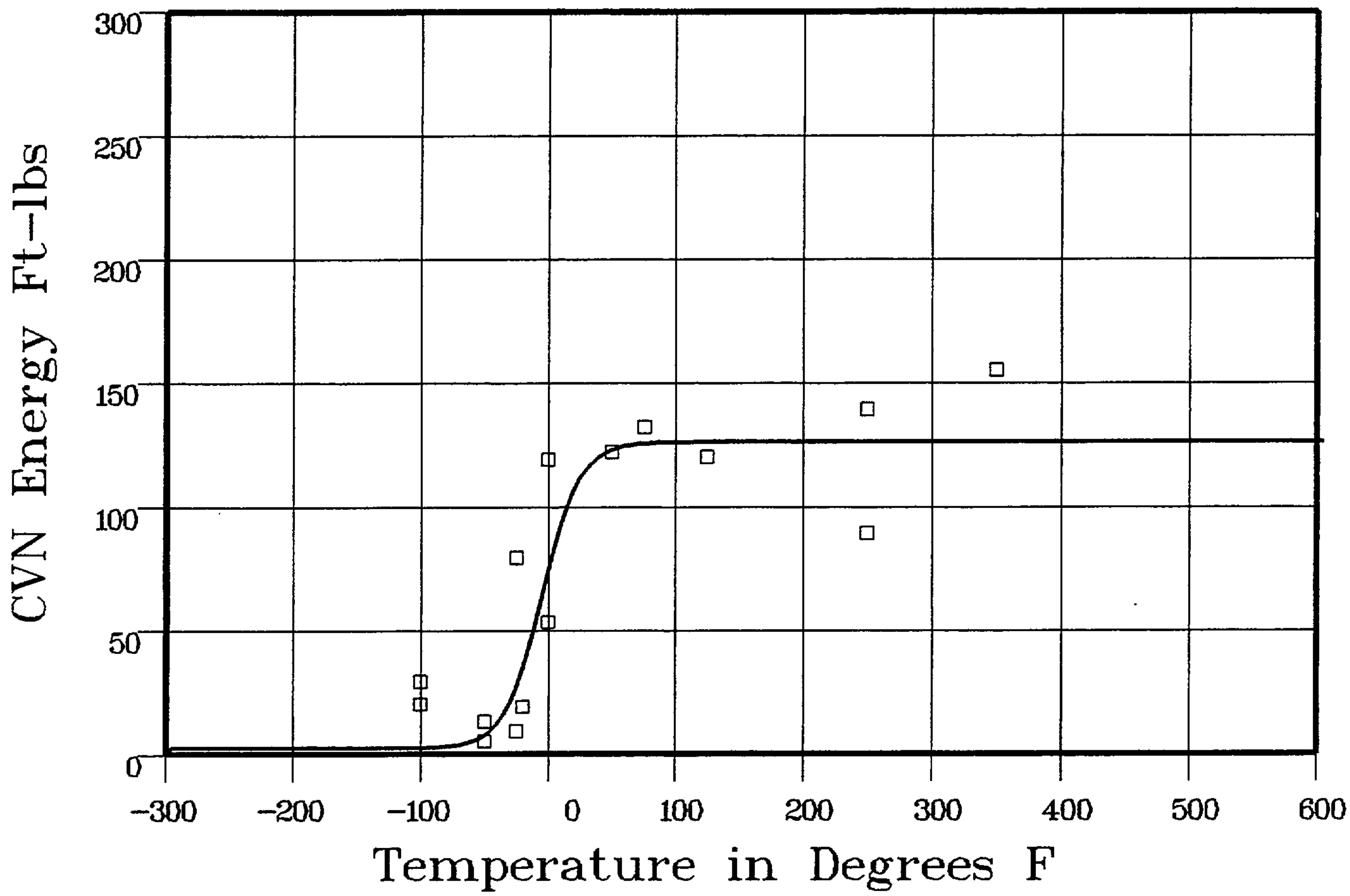
| A = 64.09 | B = 61.9 | C = 29.54 | T0 = -9.37 |
|---|---|---|---|

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

Upper Shelf Energy: 126 Fixed Temp. at 30 ft-lbs: -27.6 Temp. at 50 ft-lbs: -16.2 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFF'D ZONE Heat Number: B7212-1 SIDE OF WELD Orientation:

Capsule: W Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: W Material: HEAT AFF'D ZONE Ori.: Heat #: B7212-1 SIDE OF WELD

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| -100 | 29 | 2.46 | 26.53 |
| -100 | 20 | 2.46 | 17.53 |
| -50 | 13 | 9.63 | 3.36 |
| -50 | 5 | 9.63 | -4.63 |
| -25 | 79 | 34.1 | 44.89 |
| -25 | 9 | 34.1 | -25.1 |
| -20 | 19 | 42.75 | -23.75 |
| 0 | 119 | 83.1 | 35.89 |
| 0 | 53 | 83.1 | -30.1 |

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

# CAPSULE W (HAZ)

Page 2

Material: HEAT AFFD ZONE Heat Number: B7212-1 SIDE OF WELD Orientation:

Capsule: W Total Fluence:

## Charpy V–Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 50 | 122 | 123.81 | -1.81 |
| 76 | 132 | 125.61 | 6.38 |
| 125 | 120 | 125.98 | -5.98 |
| 250 | 139 | 126 | 13 |
| 250 | 89 | 126 | -37 |
| 350 | 155 | 126 | 29 |

SUM of RESIDUALS = 48.18

# CAPSULE X

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:55:16 on 12-21-1998

Page 1

Coefficients of Curve 4

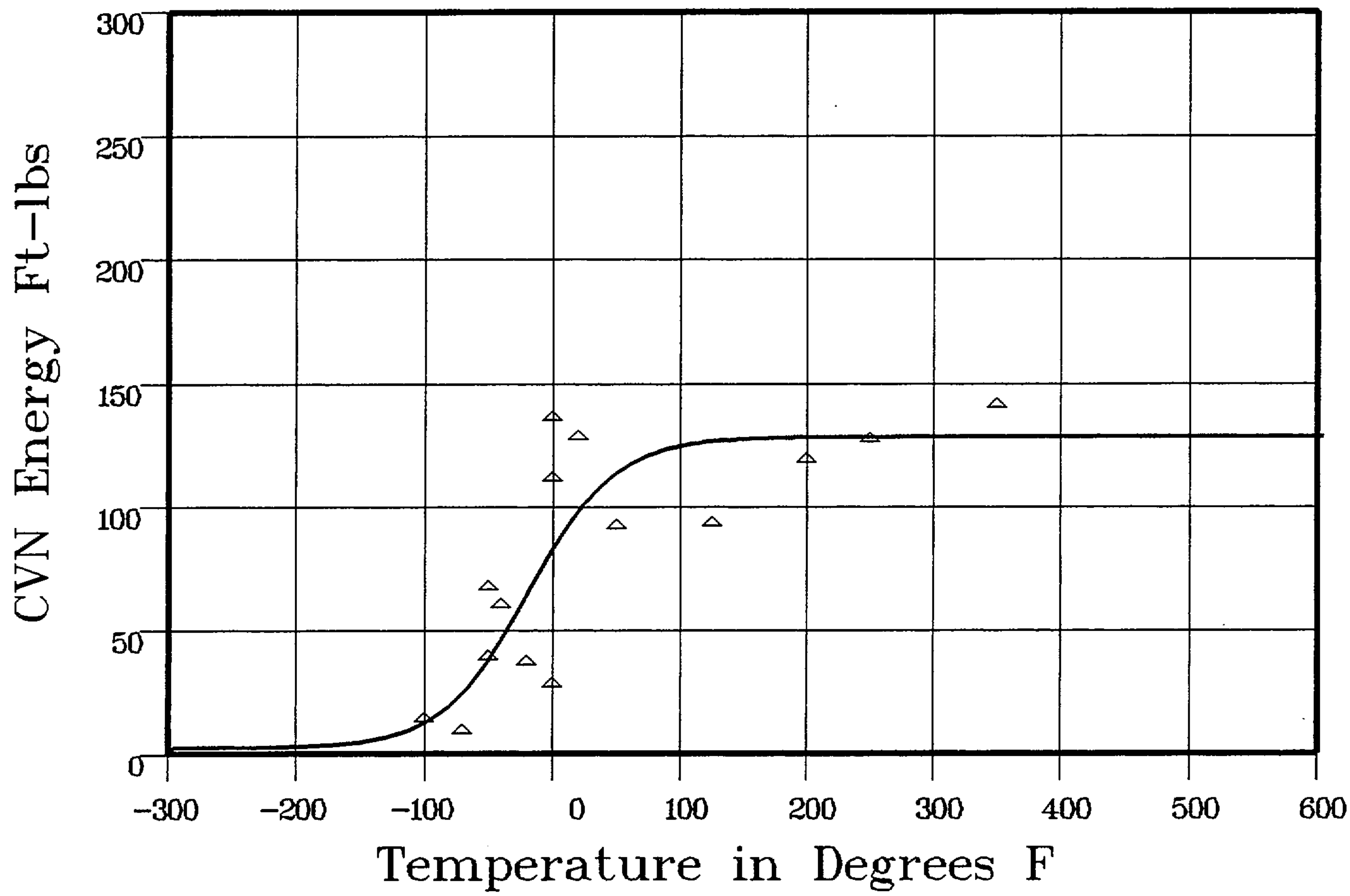
| A = 65.09 | B = 62.9 | C = 67.24 | T0 = -23.43 |
|---|---|---|---|

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

Upper Shelf Energy: 128 Fixed  Temp. at 30 ft-lbs: -65.7  Temp. at 50 ft-lbs: -39.9  Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE  Heat Number: B7212-1 SIDE OF WELD  Orientation:

Capsule: X  Total Fluence:




Data Set(s) Plotted

Plant: FA2  Cap.: X  Material: HEAT AFFD ZONE  Ori.:  Heat #: B7212-1 SIDE OF WELD

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| -100 | 13 | 13.9 | -.9 |
| -70 | 8 | 27.38 | -19.38 |
| -50 | 66 | 41.46 | 24.53 |
| -50 | 38 | 41.46 | -3.46 |
| -40 | 59 | 49.91 | 9.08 |
| -20 | 36 | 68.31 | -32.31 |
| 0 | 110 | 86.17 | 23.82 |

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

# CAPSULE X

Page 2

Material: HEAT AFFD ZONE    Heat Number: B7212-1 SIDE OF WELD    Orientation:

Capsule: X    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| 0 | 135 | 86.17 | 48.82 |
| 0 | 27 | 86.17 | -59.17 |
| 20 | 127 | 100.88 | 26.11 |
| 50 | 91 | 115.27 | -24.27 |
| 125 | 92 | 126.49 | -34.49 |
| 200 | 118 | 127.83 | -9.83 |
| 250 | 126 | 127.96 | -1.96 |
| 350 | 140 | 127.99 | 12 |

SUM of RESIDUALS = -41.44

# CAPSULE Z

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 13:55:16 on 12-21-1998

Page 1

Coefficients of Curve 5

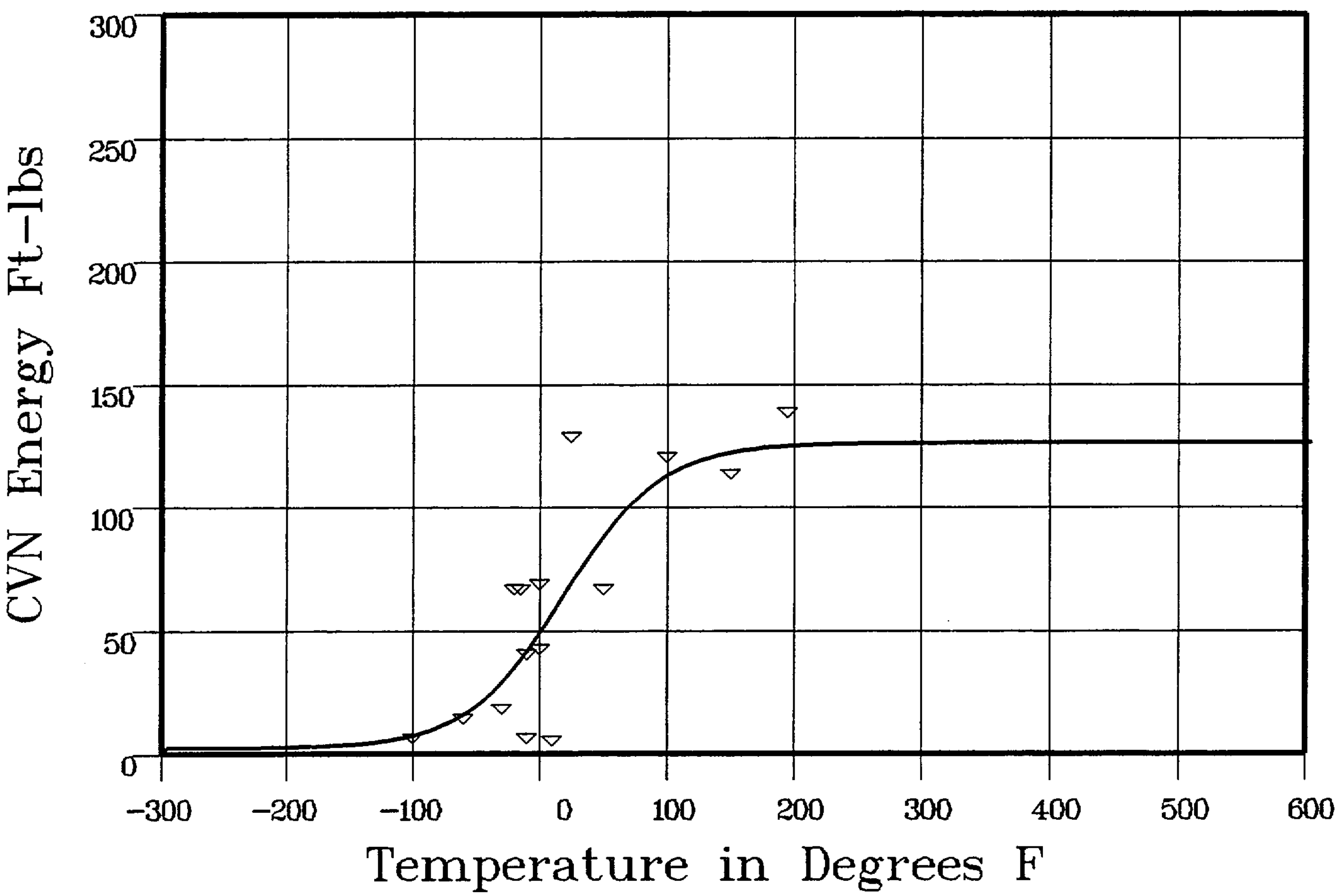
| A = 64.09 | B = 61.9 | C = 76.31 | T0 = 14.53 |
|---|---|---|---|

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

Upper Shelf Energy: 126 Fixed Temp. at 30 ft-lbs: -32.7 Temp. at 50 ft-lbs: -3.1 Lower Shelf Energy: 2.19 Fixed

Material: HEAT AFFD ZONE Heat Number: B7212-1 SIDE OF WELD Orientation:

Capsule: Z Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: Z Material: HEAT AFFD ZONE Ori.: Heat #: B7212-1 SIDE OF WELD

## Charpy V-Notch Data

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| -100 | 8 | 8.06 | -.06 |
| -60 | 16 | 17.57 | -1.57 |
| -30 | 20 | 31.59 | -11.59 |
| -20 | 68 | 37.85 | 30.14 |
| -15 | 68 | 41.27 | 26.72 |
| -10 | 42 | 44.86 | -2.86 |

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

# CAPSULE Z

Page 2

Material: HEAT AFFD ZONE    Heat Number: B7212-1 SIDE OF WELD    Orientation:

Capsule: Z    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input CVN Energy | Computed CVN Energy | Differential |
|---|---|---|---|
| -10 | 8 | 44.86 | -36.86 |
| 0 | 70 | 52.45 | 17.54 |
| 0 | 44 | 52.45 | -8.45 |
| 10 | 7 | 60.42 | -53.42 |
| 25 | 130 | 72.53 | 57.46 |
| 50 | 68 | 90.96 | -22.96 |
| 100 | 122 | 114.08 | 7.91 |
| 150 | 115 | 122.54 | -7.54 |
| 195 | 140 | 124.91 | 15.08 |

SUM of RESIDUALS = 9.52

# UNIRRADIATED (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:35:32 on 12-22-1998
Page 1
Coefficients of Curve 1

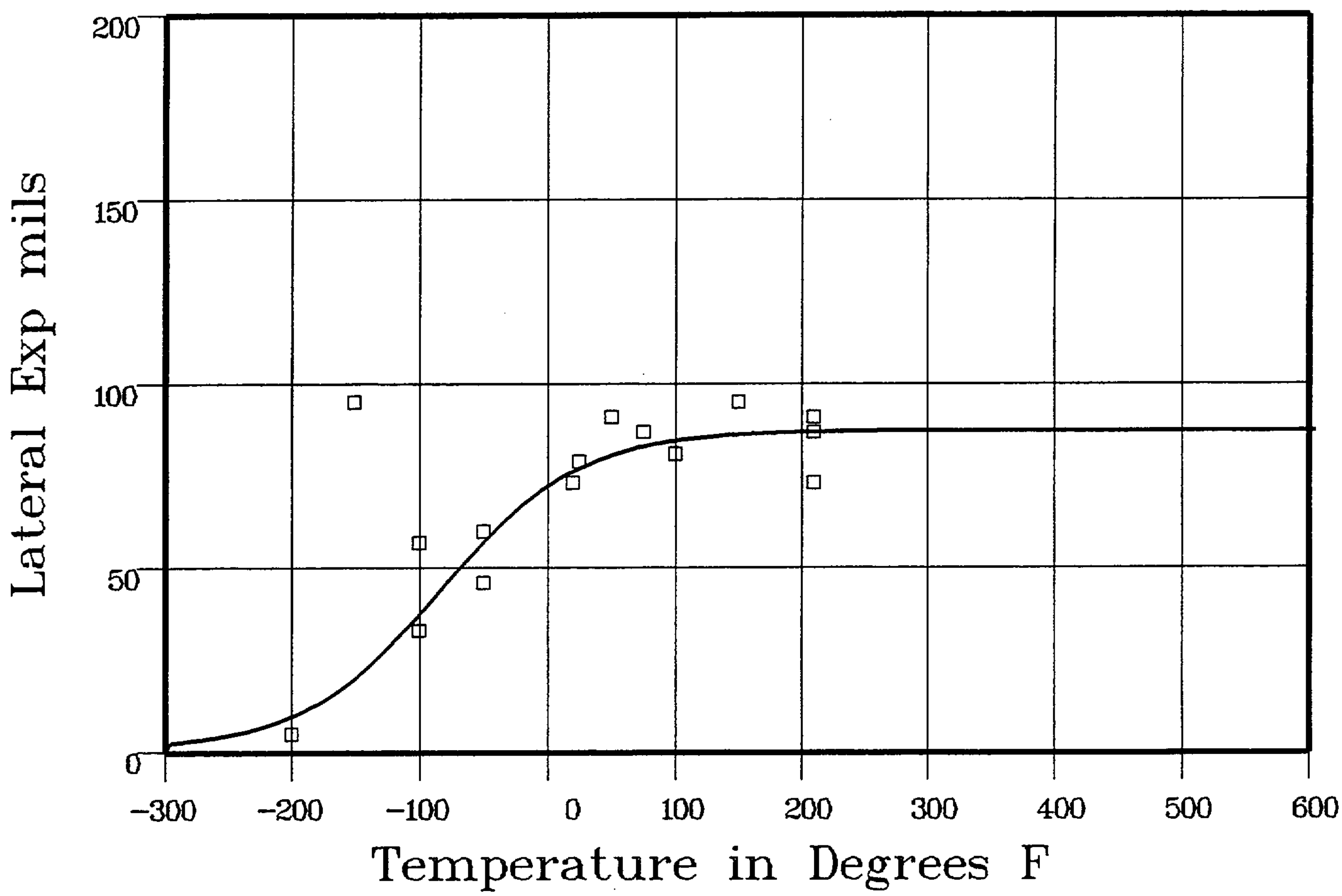
| A = 44.16 | B = 43.16 | C = 107.3 | T0 = -88.12 |
|---|---|---|---|

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

Upper Shelf L.E.: 87.32 Temperature at L.E. 35: -111.2 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFF'D ZONE Heat Number: B7212-1 SIDE OF WELD Orientation:

Capsule: UNIRR Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: UNIRR Material: HEAT AFF'D ZONE Ori.: Heat #: B7212-1 SIDE OF WELD

**Charpy V-Notch Data**

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| -200 | 5 | 10.54 | -5.54 |
| -100 | 33 | 39.4 | -6.4 |
| -100 | 57 | 39.4 | 17.59 |
| -50 | 46 | 58.88 | -12.88 |
| -50 | 60 | 58.88 | 1.11 |
| 20 | 73 | 77.17 | -4.17 |
| 25 | 79 | 77.98 | 1.01 |
| 50 | 91 | 81.21 | 9.78 |
| 75 | 87 | 83.38 | 3.61 |

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

# UNIRRADIATED (HAZ)

Page 2

Material: HEAT AFF'D ZONE　　Heat Number: B7212-1 SIDE OF WELD　　Orientation:

Capsule: UNIRR　　Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 100 | 81 | 84.81 | -3.81 |
| 150 | 95 | 86.32 | 8.67 |
| 210 | 73 | 86.99 | -13.99 |
| 210 | 91 | 86.99 | 4 |
| 210 | 87 | 86.99 | 0 |

SUM of RESIDUALS = -1.01

# CAPSULE U (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:23:24 on 12-21-1998

Page 1

Coefficients of Curve 2

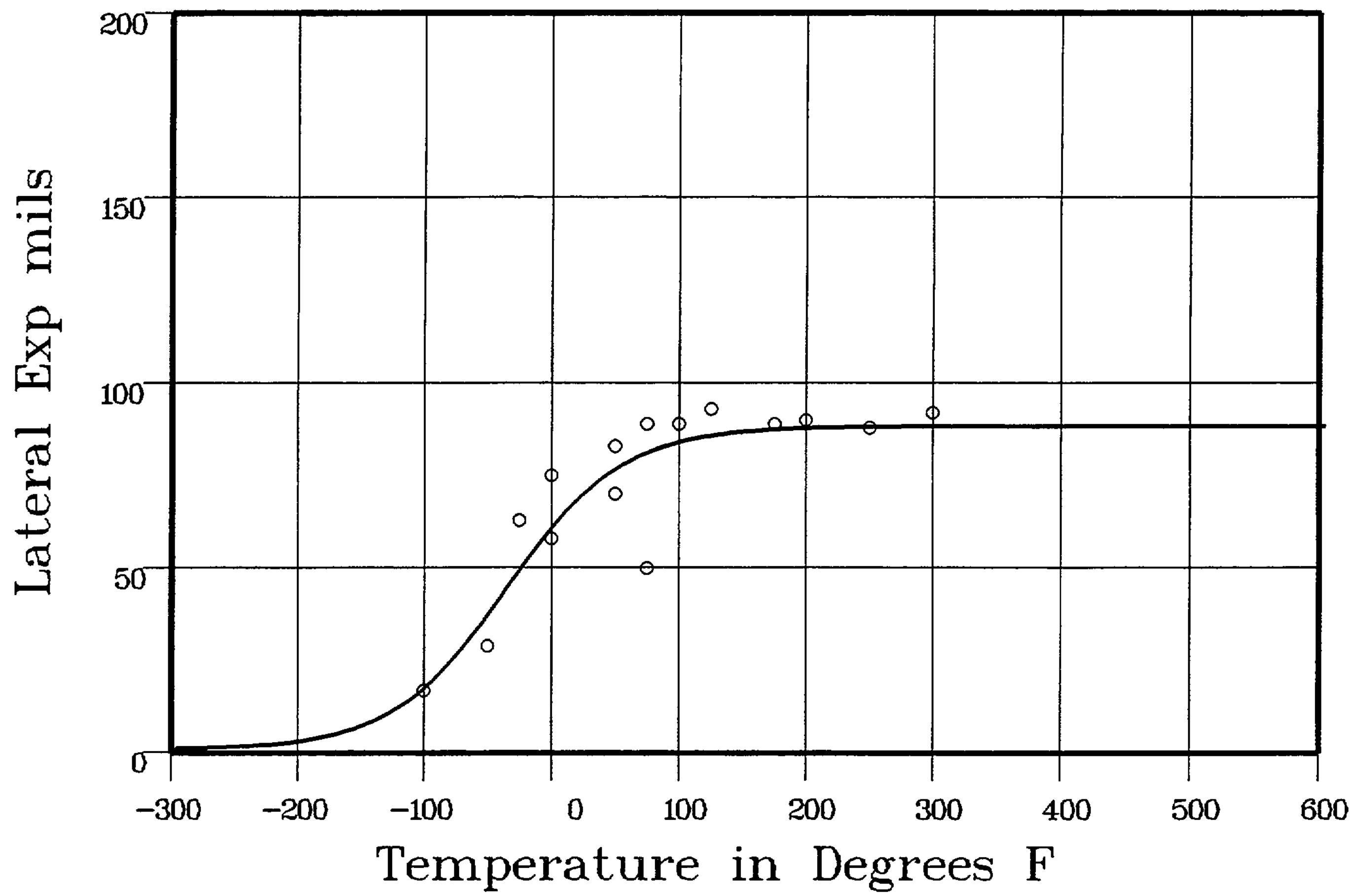
| A = 44.63 | B = 43.63 | C = 90.03 | T0 = -39.37 |
|---|---|---|---|

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

Upper Shelf L.E.: 88.27 Temperature at L.E. 35: -59.5 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: B7212-1 SIDE OF WELD Orientation:

Capsule: U Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: U Material: HEAT AFFD ZONE Ori.: Heat #: B7212-1 SIDE OF WELD

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| -100 | 17 | 19.01 | -2.01 |
| -50 | 29 | 39.51 | -10.51 |
| -25 | 63 | 51.54 | 11.45 |
| 0 | 58 | 62.59 | -4.59 |
| 0 | 75 | 62.59 | 12.4 |
| 50 | 83 | 77.73 | 5.26 |
| 50 | 70 | 77.73 | -7.73 |
| 75 | 50 | 81.9 | -31.9 |

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

# CAPSULE U (HAZ)

Page 2

Material: HEAT AFF'D ZONE     Heat Number: B7212-1 SIDE OF WELD     Orientation:

Capsule: U     Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 75 | 89 | 81.9 | 7.09 |
| 100 | 89 | 84.5 | 4.49 |
| 125 | 93 | 86.07 | 6.92 |
| 175 | 89 | 87.53 | 1.46 |
| 200 | 90 | 87.85 | 2.14 |
| 250 | 88 | 88.13 | -.13 |
| 300 | 92 | 88.23 | 3.76 |

SUM of RESIDUALS = -1.88

# CAPSULE W (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:23:24 on 12-21-1998

Page 1

Coefficients of Curve 3

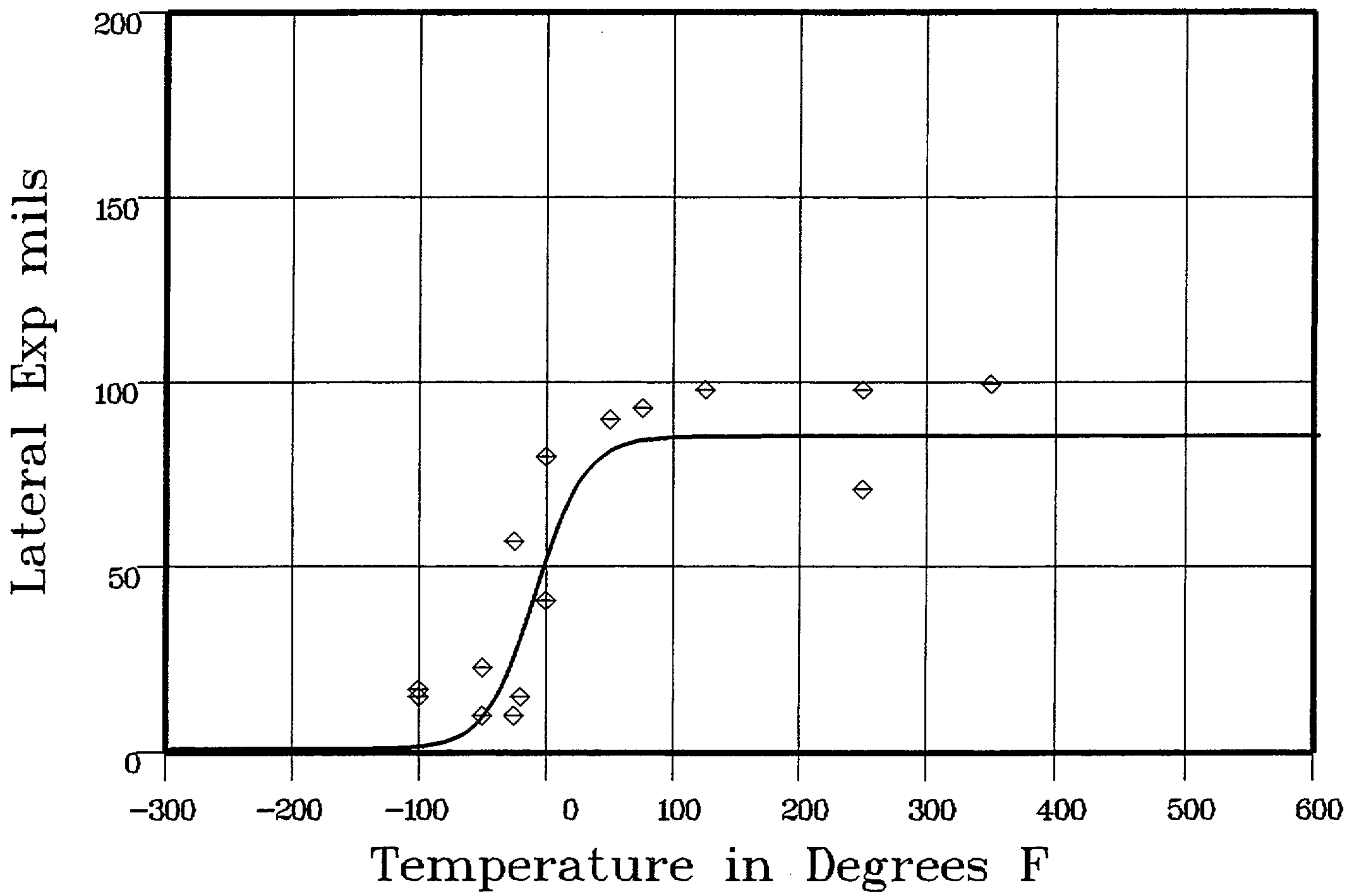
| A = 43.24 | B = 42.24 | C = 38.53 | T0 = -12.65 |
|---|---|---|---|

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

Upper Shelf L.E.: 85.49 Temperature at L.E. 35: -20.2 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: B7212-1 SIDE OF WELD Orientation:

Capsule: W Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: W Material: HEAT AFFD ZONE Ori.: Heat #: B7212-1 SIDE OF WELD

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| -100 | 15 | 1.89 | 13.1 |
| -100 | 17 | 1.89 | 15.1 |
| -50 | 23 | 11.63 | 11.36 |
| -50 | 10 | 11.63 | -1.63 |
| -25 | 57 | 30.15 | 26.84 |
| -25 | 10 | 30.15 | -20.15 |
| -20 | 15 | 35.29 | -20.29 |
| 0 | 80 | 56.64 | 23.35 |

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

# CAPSULE W (HAZ)

Page 2

Material: HEAT AFFD ZONE    Heat Number: B7212-1 SIDE OF WELD    Orientation:

Capsule: W    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 0 | 41 | 56.64 | -15.64 |
| 50 | 90 | 82.34 | 7.65 |
| 76 | 93 | 84.65 | 8.34 |
| 125 | 98 | 85.42 | 12.57 |
| 250 | 98 | 85.49 | 12.5 |
| 250 | 71 | 85.49 | -14.49 |
| 350 | 99.5 | 85.49 | 14 |

SUM of RESIDUALS = 72.63

# CAPSULE X (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 17:23:24 on 12-21-1998

Page 1

Coefficients of Curve 4

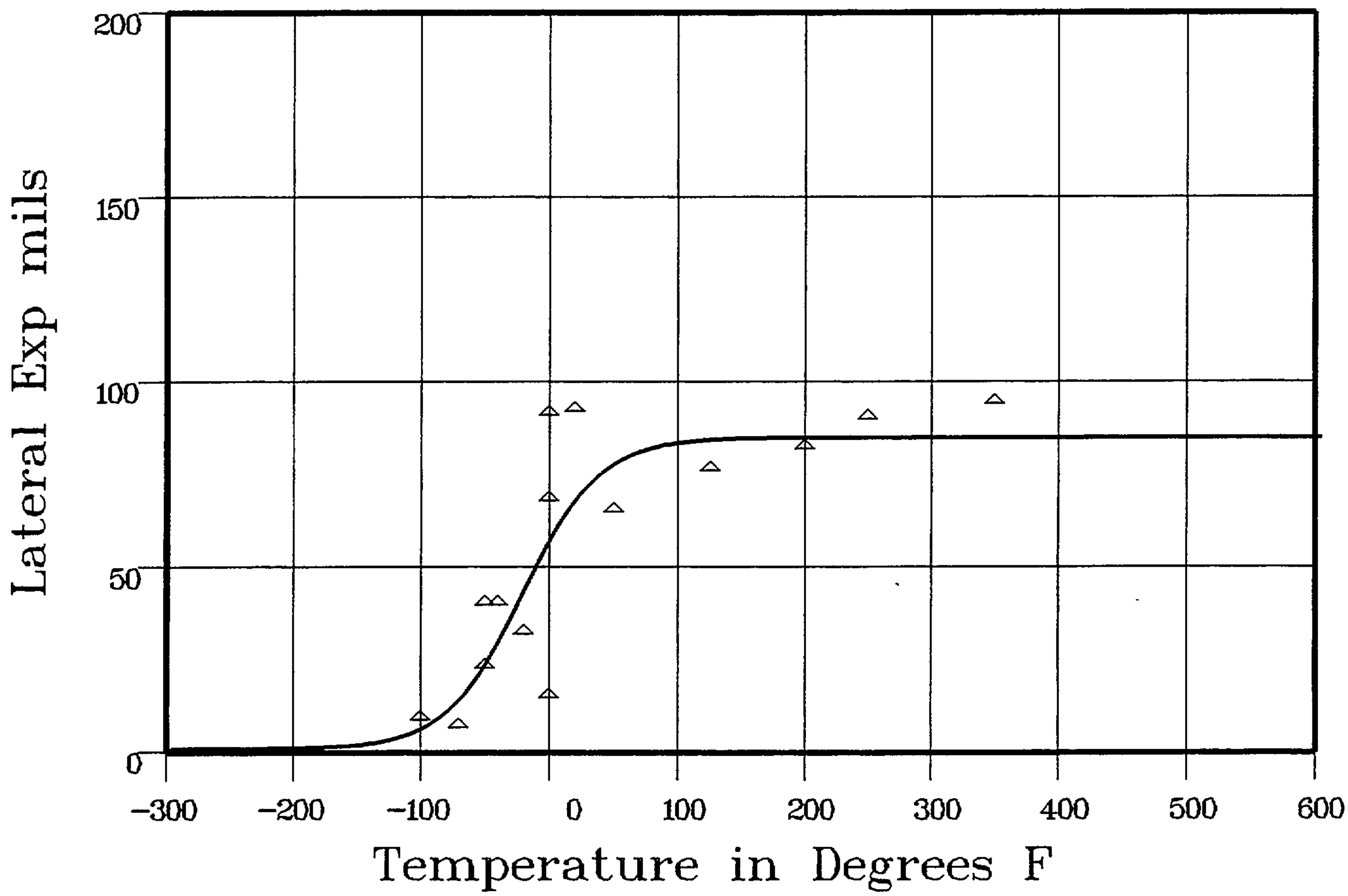
| A = 42.98 | B = 41.98 | C = 59.47 | T0 = -25.31 |
|---|---|---|---|

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

Upper Shelf L.E.: 84.97 Temperature at L.E. 35: -36.7 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: B7212-1 SIDE OF WELD Orientation:

Capsule: X Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: X Material: HEAT AFFD ZONE Ori.: Heat #: B7212-1 SIDE OF WELD

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| -100 | 9 | 7.3 | 1.69 |
| -70 | 7 | 16.28 | -9.28 |
| -50 | 40 | 26.49 | 13.5 |
| -50 | 23 | 26.49 | -3.49 |
| -40 | 40 | 32.82 | 7.17 |
| -20 | 32 | 46.72 | -14.72 |
| 0 | 15 | 59.84 | -44.84 |

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

# CAPSULE X (HAZ)

Page 2

Material: HEAT AFFD ZONE    Heat Number: B7212-1 SIDE OF WELD    Orientation:

Capsule: X    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| 0 | 68 | 59.84 | 8.15 |
| 0 | 91 | 59.84 | 31.15 |
| 20 | 92 | 69.94 | 22.05 |
| 50 | 65 | 78.79 | -13.79 |
| 125 | 76 | 84.44 | -8.44 |
| 200 | 82 | 84.93 | -2.93 |
| 250 | 90 | 84.96 | 5.03 |
| 350 | 94 | 84.97 | 9.02 |

SUM of RESIDUALS = .27

# CAPSULE Z (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 18:06:04 on 12-21-1998

Page 1

Coefficients of Curve 5

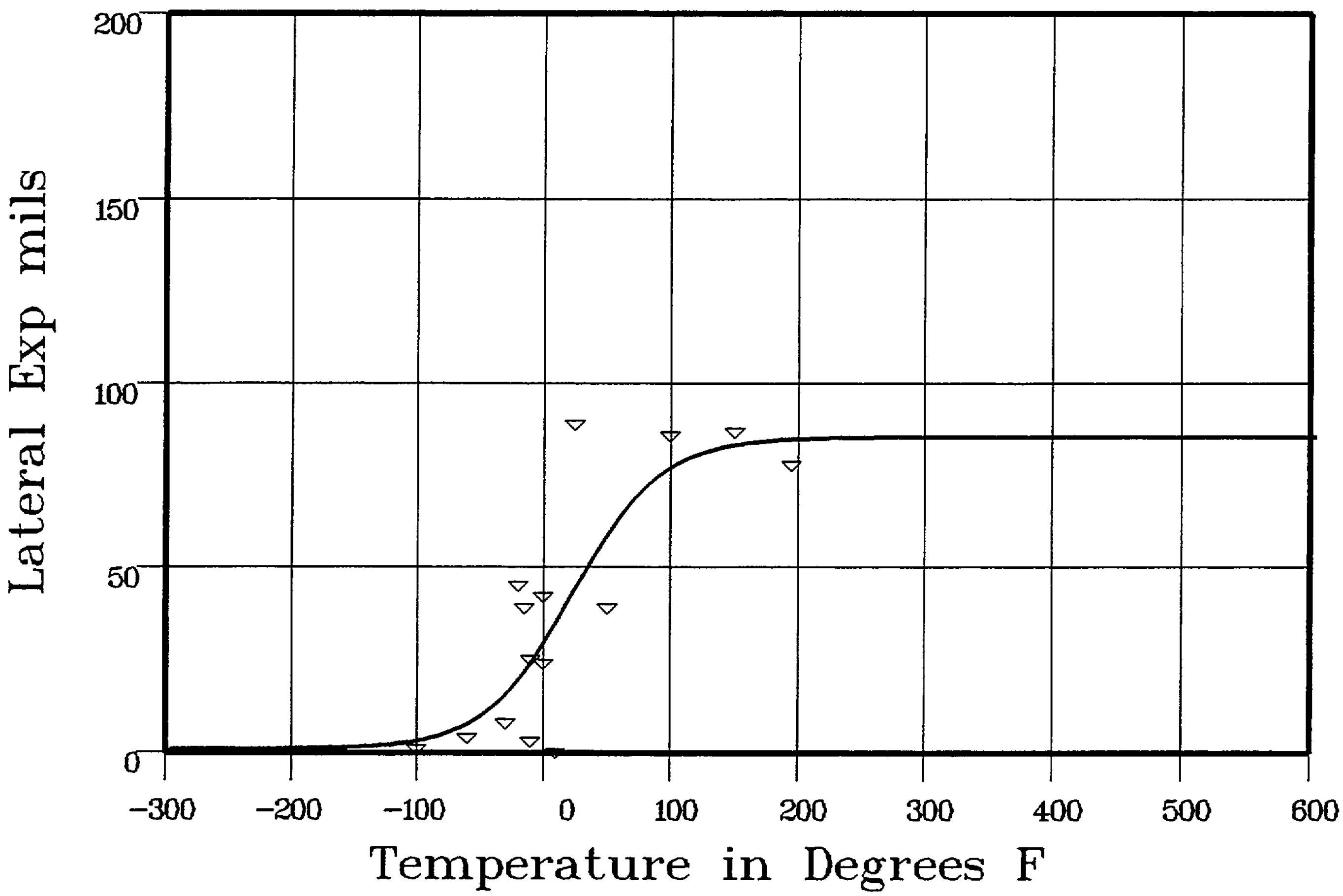
| | | | |
|---|---|---|---|
| A = 43.28 | B = 42.28 | C = 68.72 | T0 = 18.75 |

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

Upper Shelf L.E.: 85.57 Temperature at L.E. 35: 5.1 Lower Shelf L.E.: 1 Fixed

Material: HEAT AFFD ZONE Heat Number: B7212-1 SIDE OF WELD Orientation:

Capsule: Z Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: Z Material: HEAT AFFD ZONE Ori.: Heat #: B7212-1 SIDE OF WELD

## Charpy V-Notch Data

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| -100 | 2 | 3.58 | -1.58 |
| -60 | 5 | 8.76 | -3.76 |
| -30 | 9 | 17.48 | -8.48 |
| -20 | 46 | 21.68 | 24.31 |
| -15 | 40 | 24.04 | 15.95 |
| -10 | 26 | 26.56 | -.56 |

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

# CAPSULE Z (HAZ)

Page 2

Material: HEAT AFF'D ZONE     Heat Number: B7212-1 SIDE OF WELD     Orientation:

Capsule: Z     Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Lateral Expansion | Computed L.E. | Differential |
|---|---|---|---|
| -10 | 26 | 26.49 | -.49 |
| 0 | 43 | 31.99 | 11 |
| 0 | 25 | 31.99 | -6.99 |
| 10 | 1 | 37.93 | -36.93 |
| 25 | 90 | 47.21 | 42.78 |
| 50 | 40 | 61.52 | -21.52 |
| 100 | 87 | 78.69 | 8.3 |
| 150 | 88 | 84.16 | 3.83 |
| 195 | 79 | 85.47 | -6.47 |

SUM of RESIDUALS = -2.16

# UNIRRADIATED (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 09:33:55 on 12-22-1998

Page 1

Coefficients of Curve 1

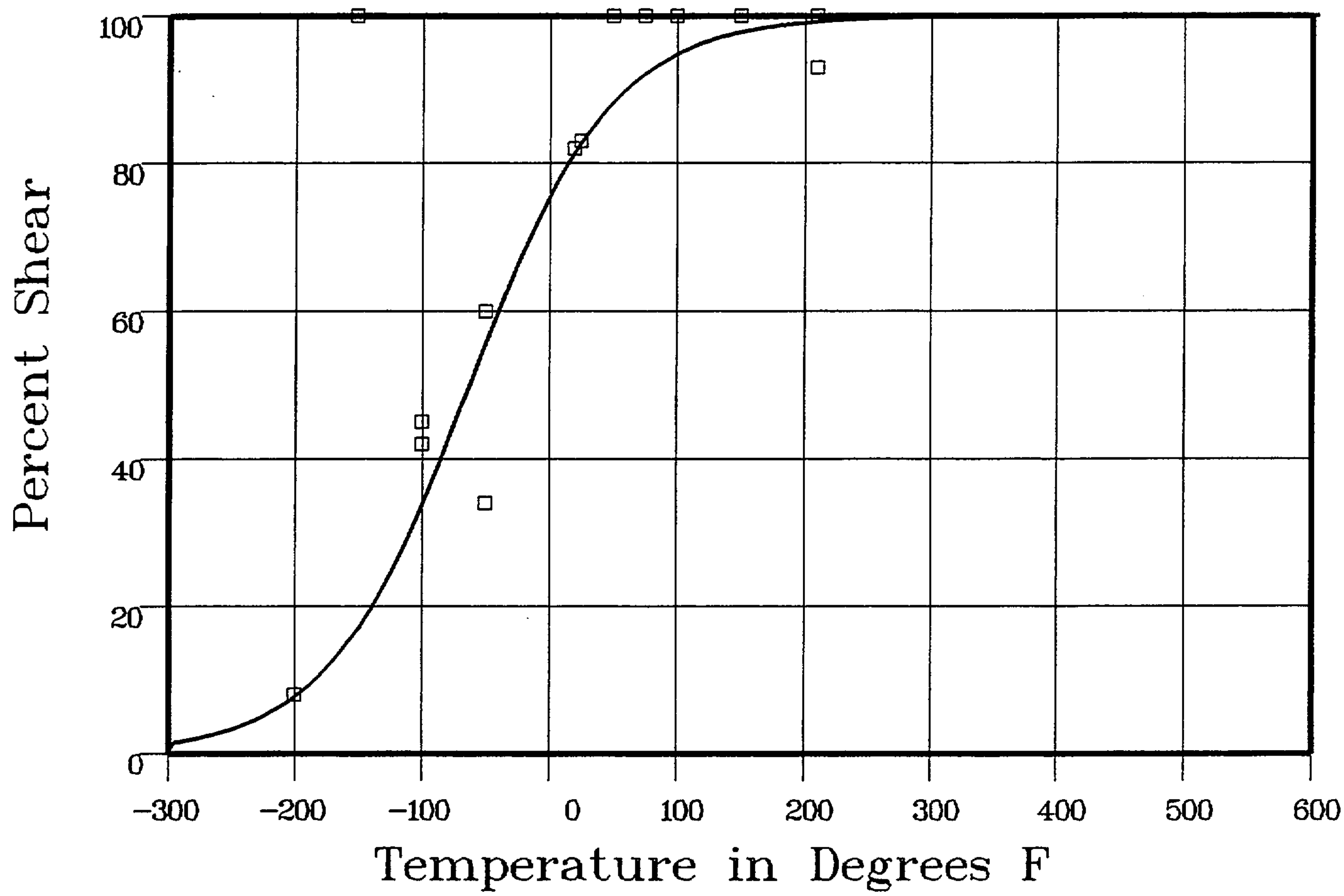
| A = 50 | B = 50 | C = 111.34 | T0 = -67.03 |
|---|---|---|---|

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

Temperature at 50% Shear: -67

Material: HEAT AFFD ZONE Heat Number: B7212-1 SIDE OF WELD Orientation:

Capsule: UNIRR Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: UNIRR Material: HEAT AFFD ZONE Ori.: Heat #: B7212-1 SIDE OF WELD

**Charpy V-Notch Data**

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -200 | 8 | 8.4 | -.4 |
| -100 | 42 | 35.61 | 6.38 |
| -100 | 45 | 35.61 | 9.38 |
| -50 | 34 | 57.58 | -23.58 |
| -50 | 60 | 57.58 | 2.41 |
| 20 | 82 | 82.68 | -.68 |
| 25 | 83 | 83.92 | -.92 |
| 50 | 100 | 89.11 | 10.88 |
| 75 | 100 | 92.76 | 7.23 |

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

# UNIRRADIATED (HAZ)

Page 2

Material: HEAT AFFD ZONE    Heat Number: B7212-1 SIDE OF WELD    Orientation:

Capsule: UNIRR    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 100 | 100 | 95.25 | 4.74 |
| 150 | 100 | 98.01 | 1.98 |
| 210 | 93 | 99.31 | -6.31 |
| 210 | 100 | 99.31 | .68 |
| 210 | 100 | 99.31 | .68 |

SUM of RESIDUALS = 12.48

# CAPSULE U (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 18:26:40 on 12-21-1998

Page 1

Coefficients of Curve 2

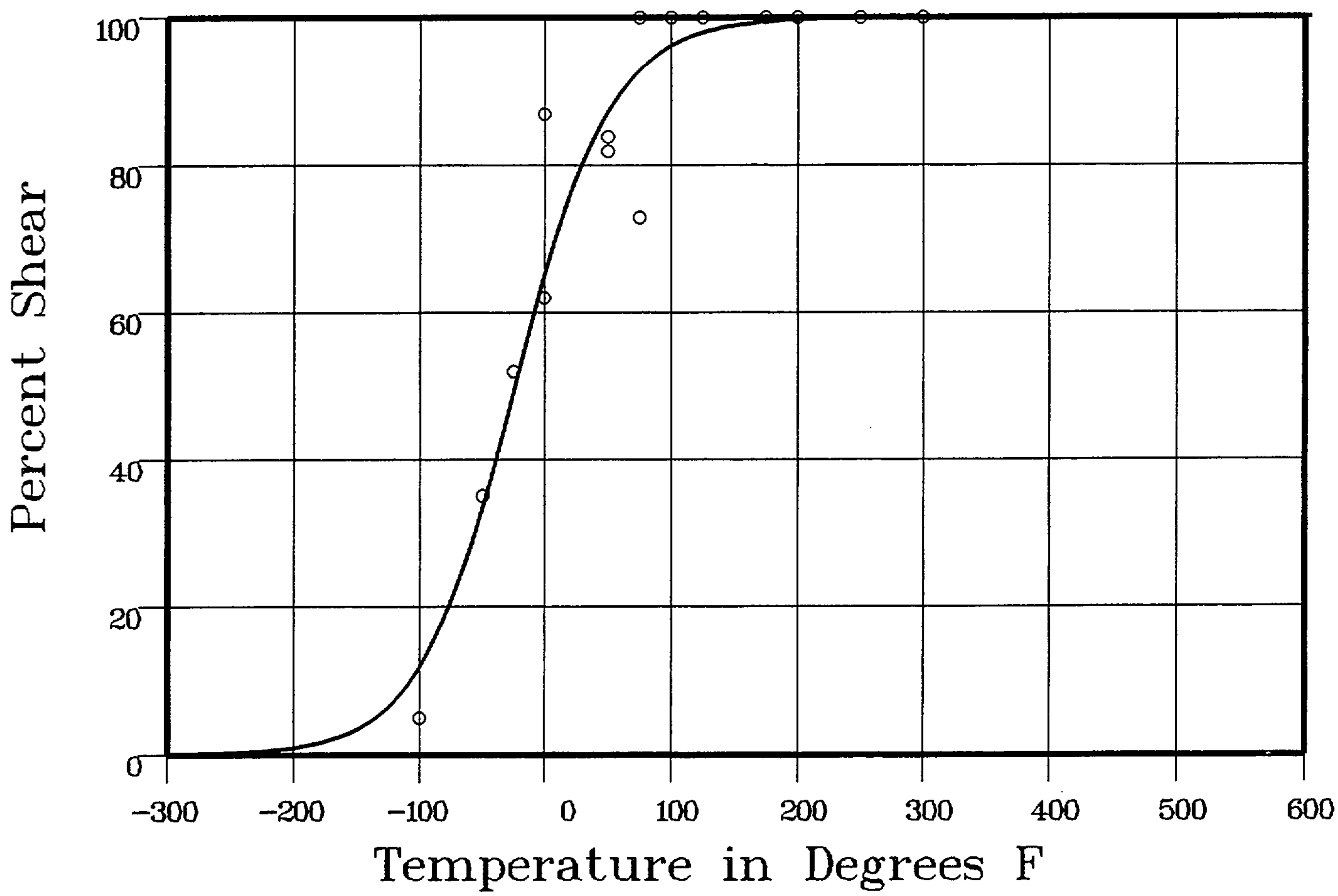
| A = 50 | B = 50 | C = 76.33 | T0 = -28.12 |
|---|---|---|---|

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

Temperature at 50% Shear: -28.1

Material: HEAT AFFD ZONE Heat Number: B7212-1 SIDE OF WELD Orientation:

Capsule: U Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap: U Material: HEAT AFFD ZONE Ori.: Heat #: B7212-1 SIDE OF WELD

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100 | 5 | 13.2 | -8.2 |
| -50 | 35 | 36.05 | -1.05 |
| -25 | 52 | 52.04 | -.04 |
| 0 | 62 | 67.63 | -5.63 |
| 0 | 87 | 67.63 | 19.36 |
| 50 | 82 | 88.56 | -6.56 |
| 50 | 84 | 88.56 | -4.56 |
| 75 | 73 | 93.71 | -20.71 |

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

# CAPSULE U (HAZ)

Page 2

Material: HEAT AFF'D ZONE    Heat Number: B7212-1 SIDE OF WELD    Orientation:

Capsule: U    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 75 | 100 | 93.71 | 6.28 |
| 100 | 100 | 96.63 | 3.36 |
| 125 | 100 | 98.22 | 1.77 |
| 175 | 100 | 99.51 | .48 |
| 200 | 100 | 99.74 | .25 |
| 250 | 100 | 99.93 | .06 |
| 300 | 100 | 99.98 | .01 |

SUM of RESIDUALS = -15.15

# CAPSULE W (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 18:26:40 on 12-21-1998

Page 1

Coefficients of Curve 3

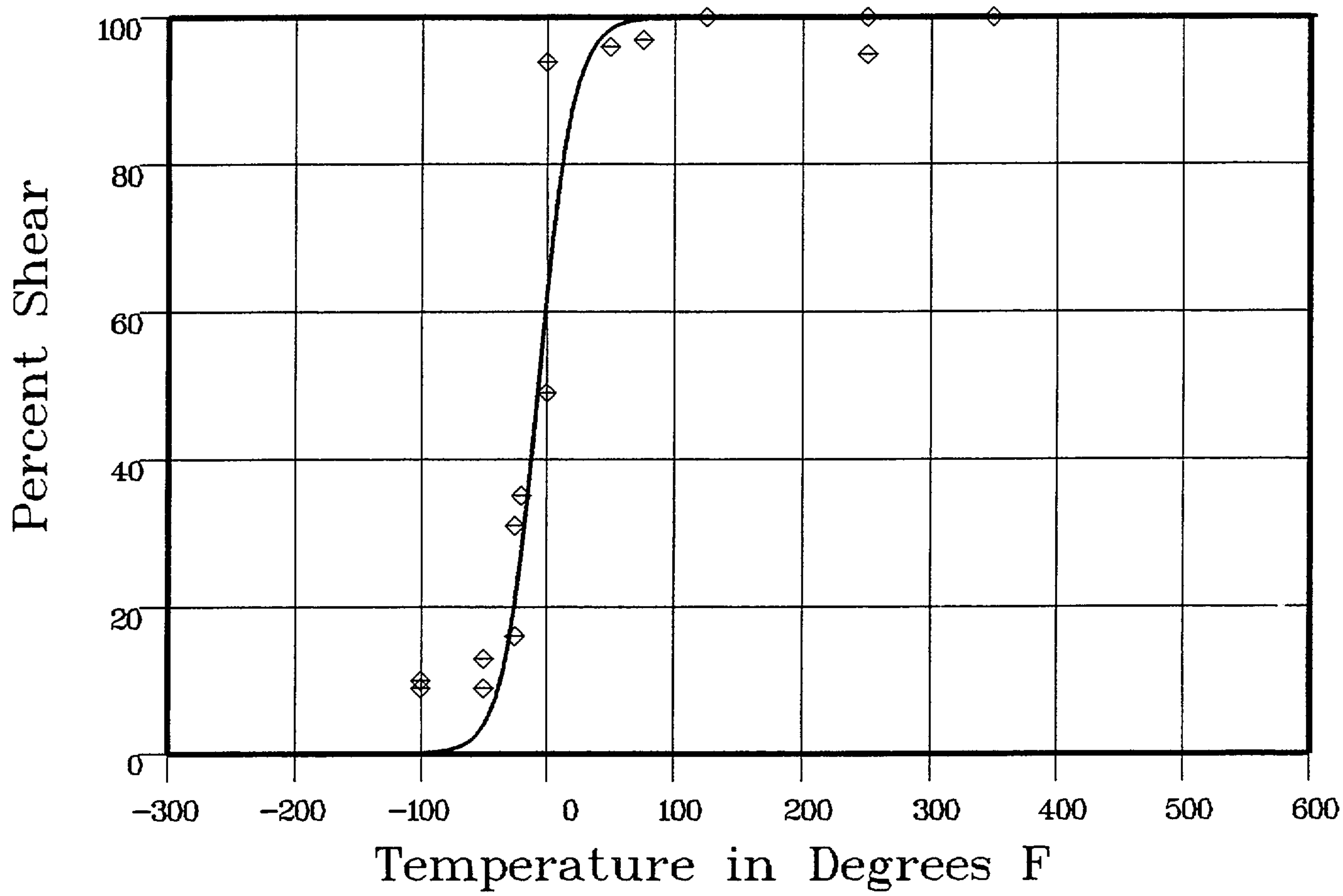
| A = 50 | B = 50 | C = 27.31 | T0 = -11.25 |
|---|---|---|---|

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

Temperature at 50% Shear: -11.2

Material: HEAT AFFD ZONE    Heat Number: B7212-1 SIDE OF WELD    Orientation:

Capsule: W    Total Fluence:




Data Set(s) Plotted

Plant: FA2    Cap.: W    Material: HEAT AFF'D ZONE    Ori.:    Heat #: B7212-1 SIDE OF WELD

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100 | 9 | .15 | 8.84 |
| -100 | 10 | .15 | 9.84 |
| -50 | 13 | 5.53 | 7.46 |
| -50 | 9 | 5.53 | 3.46 |
| -25 | 16 | 26.76 | -10.76 |
| -25 | 31 | 26.76 | 4.23 |
| -20 | 35 | 34.51 | .48 |
| 0 | 94 | 69.5 | 24.49 |

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

# CAPSULE W (HAZ)

Page 2

Material: HEAT AFFD ZONE     Heat Number: B7212-1 SIDE OF WELD     Orientation:

Capsule: W     Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 0 | 49 | 69.5 | -20.5 |
| 50 | 96 | 98.88 | -2.88 |
| 76 | 97 | 99.83 | -2.83 |
| 125 | 100 | 99.99 | 0 |
| 250 | 95 | 100 | -5 |
| 250 | 100 | 100 | 0 |
| 350 | 100 | 100 | 0 |

SUM of RESIDUALS = 16.87

# CAPSULE X (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 18:26:40 on 12-21-1998

Page 1

Coefficients of Curve 4

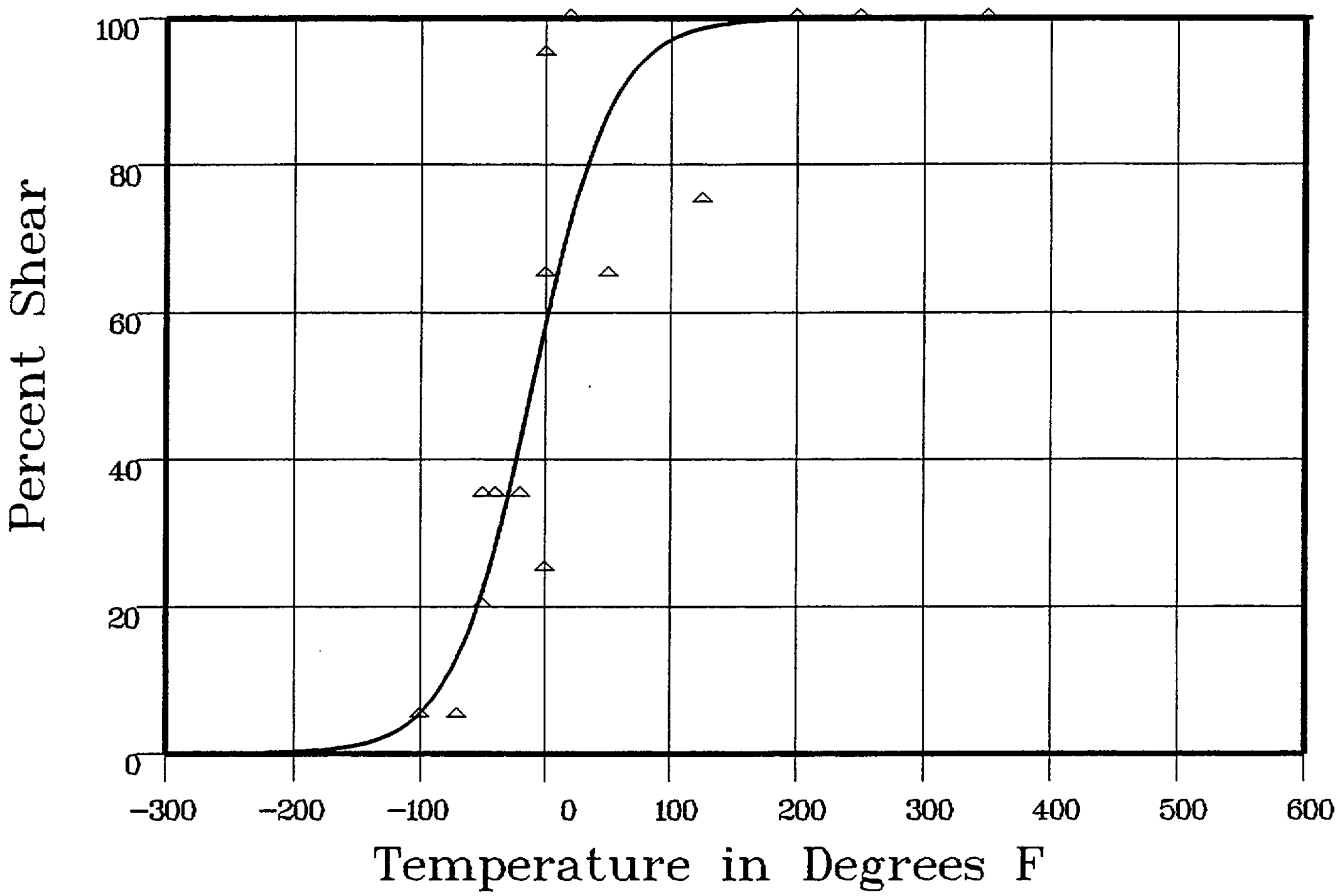
| A = 50 | B = 50 | C = 63.2 | T0 = -15 |
|---|---|---|---|

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

Temperature at 50% Shear: -15

Material: HEAT AFFD ZONE Heat Number: B7212-1 SIDE OF WELD Orientation:

Capsule: X Total Fluence:




Data Set(s) Plotted

Plant: FA2 Cap.: X Material: HEAT AFFD ZONE Ori.: Heat #: B7212-1 SIDE OF WELD

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100 | 5 | 6.35 | -1.35 |
| -70 | 5 | 14.92 | -9.92 |
| -50 | 35 | 24.83 | 10.16 |
| -50 | 20 | 24.83 | -4.83 |
| -40 | 35 | 31.19 | 3.8 |
| -20 | 35 | 46.05 | -11.05 |
| 0 | 25 | 61.64 | -36.64 |

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

# CAPSULE X (HAZ)

Page 2

Material: HEAT AFFD ZONE    Heat Number: B7212-1 SIDE OF WELD    Orientation:

Capsule: X    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| 0 | 65 | 61.64 | 3.35 |
| 0 | 95 | 61.64 | 33.35 |
| 20 | 100 | 75.16 | 24.83 |
| 50 | 65 | 88.66 | -23.66 |
| 125 | 75 | 98.82 | -23.82 |
| 200 | 100 | 99.88 | .11 |
| 250 | 100 | 99.97 | .02 |
| 350 | 100 | 99.99 | 0 |

SUM of RESIDUALS = -35.66

# CAPSULE Z (HAZ)

CVGRAPH 4.1 Hyperbolic Tangent Curve Printed at 18:26:40 on 12-21-1998

Page 1

Coefficients of Curve 5

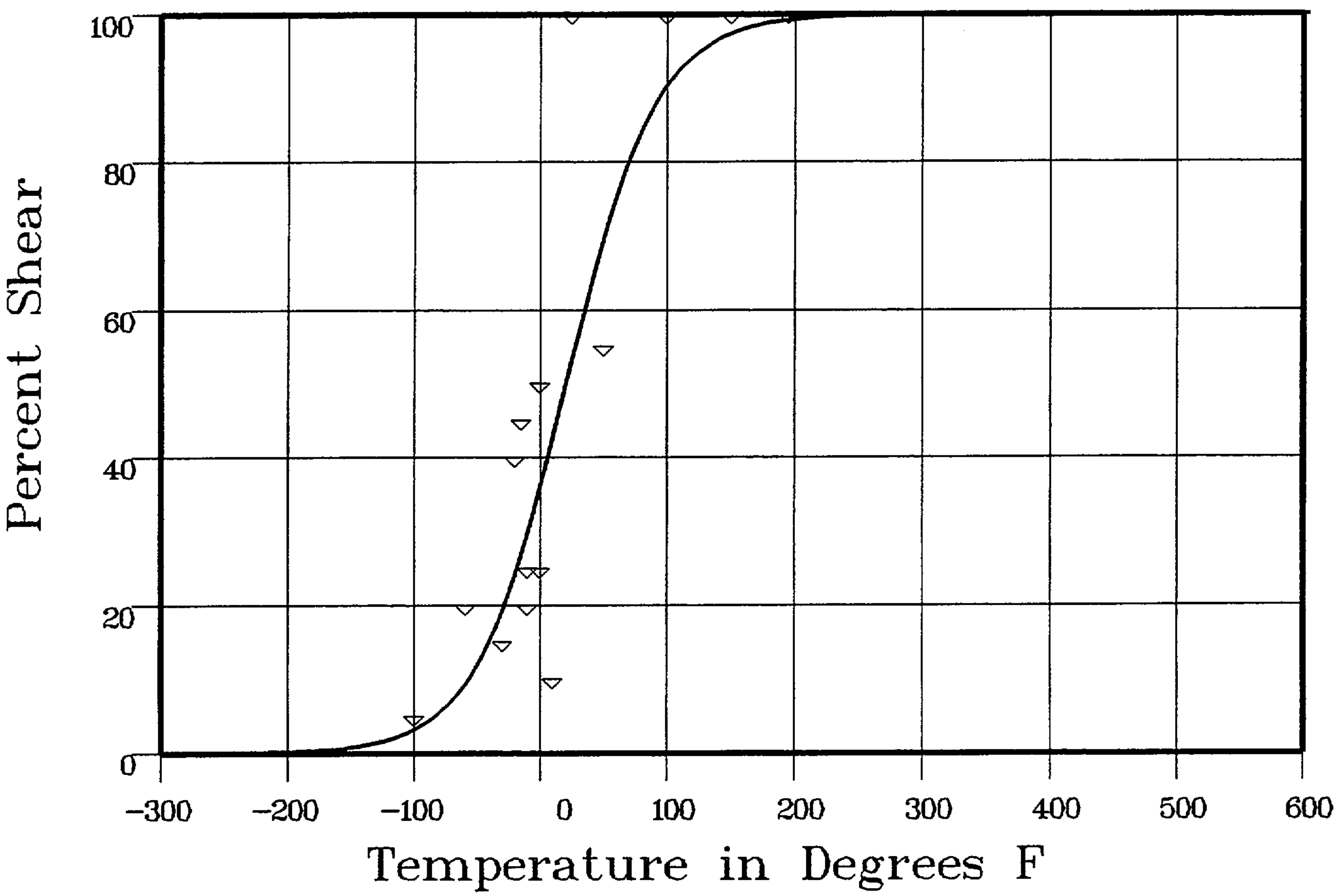
| A = 50 | B = 50 | C = 71.04 | T0 = 15.93 |
|---|---|---|---|

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

Temperature at 50% Shear: 15.9

Material: HEAT AFF'D ZONE     Heat Number: B7212-1 SIDE OF WELD     Orientation:

Capsule: Z     Total Fluence:




Data Set(s) Plotted

Plant: FA2     Cap.: Z     Material: HEAT AFF'D ZONE     Ori.:     Heat #: B7212-1 SIDE OF WELD

## Charpy V-Notch Data

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -100 | 5 | 3.68 | 1.31 |
| -60 | 20 | 10.54 | 9.45 |
| -30 | 15 | 21.53 | -6.53 |
| -20 | 40 | 26.66 | 13.33 |
| -15 | 45 | 29.5 | 15.49 |
| -10 | 20 | 32.51 | -12.51 |

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

# CAPSULE Z (HAZ)

Page 2

Material: HEAT AFFD ZONE    Heat Number: B7212-1 SIDE OF WELD    Orientation:

Capsule: Z    Total Fluence:

## Charpy V-Notch Data (Continued)

| Temperature | Input Percent Shear | Computed Percent Shear | Differential |
|---|---|---|---|
| -10 | 25 | 32.51 | -7.51 |
| 0 | 50 | 38.96 | 11.03 |
| 0 | 25 | 38.96 | -13.96 |
| 10 | 10 | 45.83 | -35.83 |
| 25 | 100 | 56.34 | 43.65 |
| 50 | 55 | 72.29 | -17.29 |
| 100 | 100 | 91.42 | 8.57 |
| 150 | 100 | 97.75 | 2.24 |
| 195 | 100 | 99.35 | .64 |

SUM of RESIDUALS = 12.09

# APPENDIX D

# J. M. FARLEY UNIT 2 SURVEILLANCE PROGRAM CREDIBILITY ANALYSIS

## INTRODUCTION:

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

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

The purpose of this evaluation is to apply the credibility requirements of Regulatory Guide 1.99, Revision 2, and 10 CFR Part 50.61 to the J. M. Farley Unit 2 reactor vessel surveillance data and determine if the J. M. Farley Unit 2 surveillance data is credible.

## EVALUATION

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

The beltline region of the reactor vessel is defined in Appendix G to 10 CFR Part 50, "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 J. M. Farley Unit 2 reactor vessel consists of the following beltline region materials:

- Intermediate shell plate B7203-1,
- Intermediate shell plate B7212-1,
- Lower shell plate B7210-2,
- Lower shell plate B7210-2,
- Intermediate shell longitudinal weld seam 19-923A (Heat # HODA)
- Intermediate shell longitudinal weld seam 19-923B (Heat # BOLA)
- Intermediate to lower shell circumferential weld seam 11-923 (Heat # 5P5622)
- Lower shell longitudinal weld seams 20-923 A & B (Heat # 83640)

Per WCAP-8956, the Farley Unit 2 surveillance program was based on ASTM E185-73, "Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels". Per Section 4.1 of ASTM E185-73, *"The base metal and weld metal to be included in the program should represent the material that may limit the operation of the reactor during its lifetime. The test material should be selected on the basis of initial transition temperature, upper shelf energy level, and estimated increase in transition temperature considering chemical composition (copper (Cu) and phosphorus (P)) and neutron fluence."*

At the time the Farley Unit 2 surveillance capsule program was developed, intermediate shell plate B7212-1 was judged to be most limiting and was therefore utilized in the surveillance program.

The Farley Unit 2 surveillance program weld was fabricated using the shielded metal arc welding process and E8018 stick electrodes, in a manner similar to that used to fabricate middle shell axial seams 19-923A (heat HODA) and B (heat BOLA). These electrodes were not copper-coated and do not exhibit the chemical variability found in copper-coated submerged arc weld wire. Although the surveillance weld material does not represent the limiting reactor vessel beltline weld, the results of mechanical property tests performed on the surveillance weld are considered to be representative of the property changes expected in the reactor vessel beltline seams. The NRC explicitly approved the selection of the Farley Unit 2 surveillance weld material on the basis that the limiting beltline material (i.e., intermediate plate B7212-1) was included in the surveillance program and conservative methods of analysis contained in Regulatory Guide 1.99 were available to predict the radiation characteristics of the limiting beltline weld. The NRC incorporated an exemption to the requirements of Appendix H to 10 CFR Part 50 in the Farley Unit 2 Operating License, thereby approving the selected surveillance weld material based on the NRC evaluation provided in Section 5.2.1 of NUREG-0117.

Although the Farley Unit 2 surveillance weld material does not meet the requirements of Criterion 1, conservative methods of analysis are available to predict the radiation characteristics of the limiting beltline weld. The limiting beltline plate material is intermediate plate B7212-1 which is more limiting than any of the reactor vessel beltline welds and is included in the reactor vessel material surveillance program. Therefore, the Farley Unit 2 reactor vessel material surveillance program provides assurance that the radiation damage to the vessel can be adequately determined and the integrity of the Farley Unit 2 reactor vessel will be ensured during normal plant operations and anticipated operational occurrences. Therefore, the Farley Unit 2 surveillance program meets this criteria.

Criterion 2: Scatter in the plots of Charpy energy versus temperature for the irradiated and unirradiated conditions should be small enough to permit the determination of the 30 ft-lb temperature and upper shelf energy unambiguously.

Plots of Charpy energy versus temperature for the unirradiated and irradiated condition are presented Section 5 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 J. M. Farley Unit 2 surveillance materials unambiguously. Hence, the J. M. Farley Unit 2 surveillance program meets this criterion.

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

The functional form of the least squares method as described in Regulatory Position 2.1 will be utilized to determine a best-fit line for this data and to determine if the scatter of these $\Delta RT_{NDT}$ values about this line is less than 28°F for welds and less than 17°F for the plate.

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

TABLE D-1:
Calculation of the J. M. Farley Unit 2 Chemistry Factor Values
Based on Surveillance Capsule Data

| Material | Capsule | Capsule f[(a)] | FF[(b)] | $\Delta RT_{NDT}$[(c)] | FF*$\Delta RT_{NDT}$ | $FF^2$ |
|---|---|---|---|---|---|---|
| Inter. Shell Plate B7212-1 (Longitudinal) | U | 0.644 | 0.88 | 105.8 | 93.1 | 0.77 |
| | W | 1.85 | 1.17 | 168.06 | 196.6 | 1.37 |
| | X | 3.19 | 1.31 | 164.86 | 216.0 | 1.72 |
| | Z | 5.28 | 1.41 | 200.24 | 282.3 | 1.99 |
| Inter. Shell Plate B7212-1 (Transverse) | U | 0.644 | 0.88 | 124.01 | 109.1 | 0.77 |
| | W | 1.85 | 1.17 | 168.18 | 196.9 | 1.37 |
| | X | 3.19 | 1.31 | 200.01 | 262.0 | 1.72 |
| | Z | 5.28 | 1.41 | 195.5 | 275.7 | 1.99 |
| | | | | SUM: | 1631.6 | 11.7 |
| | $CF_{B8628-1} = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (1631.6) \div (11.7) = 139.5°F$ | | | | | |
| Surveillance Weld Material[(d)] | U[(e)] | 0.644 | 0.88 | 0.0 | 0.0 | 0.77 |
| | W | 1.85 | 1.17 | 6.7 | 7.8 | 1.37 |
| | X[(e)] | 3.19 | 1.31 | 0.0 | 0.0 | 1.72 |
| | Z | 5.28 | 1.41 | 10.0 | 14.1 | 1.99 |
| | | | | SUM: | 21.9 | 5.85 |
| | $CF_{Surv. Weld} = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (21.9) \div (5.85) = 3.7°F$ | | | | | |

Notes:

(a) f = Measured fluence from capsule Z dosimetry analysis results (See Section 6 of this report).

(b) FF = fluence factor = $f^{(0.28 - 0.1*\log f)}$.

(c) $\Delta RT_{NDT}$ values are the measured 30 ft-lb shift values (See Section 5 of this report).

(d) These measured $\Delta RT_{NDT}$ values do not include the adjustment ratio procedure of Reg. Guide 1.99 Revision 2, Position 2.1, since this calculation is based on the actual surveillance weld metal measured shift values and based on the copper and nickel content the ratio would be 1 (i.e. 41/41 = 1). In addition, the only surveillance data available is from the J. M. Farley Unit 2 reactor vessel, therefore, no temperature adjustment is required.

(e) The measured $\Delta RT_{NDT}$ values for capsules U and X are -28.7°F and -15.3°F, respectfully. These values are assumed to be 0°F in this analysis since using the negative numbers will give a negative chemistry factor value and this should phically not happen. In addition, using 0°F will result in a higher chemistryfactor for other calculations (i.e. PTS, P-T curves, etc.).

The scatter of $\Delta RT_{NDT}$ values about the functional form of a best-fit line drawn as described in Regulatory Position 2.1 is presented in Table D-2.

TABLE D-2

Best Fit Evaluation for J. M. Farley Unit 2 Surveillance Materials

| **Base Material** | **CF (°F)** | **FF** | **Measured $\Delta RT_{NDT}$ (30 ft-lb) (°F)** | **Best Fit[(a)] $\Delta RT_{NDT}$ (°F)** | **Scatter of $\Delta RT_{NDT}$ (°F)** | **< 17°F (Base Metals) < 28°F (Weld Metal)** |
|---|---|---|---|---|---|---|
| Inter. Shell | 139.2 | 0.88 | 105.8 | 122.8 | 17 | Yes |
| Plate B7212-1 | 139.2 | 1.17 | 168.06 | 163.2 | -4.9 | Yes |
| (Longitudinal) | 139.2 | 1.31 | 164.86 | 182.7 | 17.8 | No |
| | 139.2 | 1.41 | 200.24 | 196.7 | -3.5 | Yes |
| Inter. Shell | 139.2 | 0.88 | 124.01 | 122.8 | -1.2 | Yes |
| Plate B7212-1 | 139.2 | 1.17 | 168.18 | 163.2 | -5.0 | Yes |
| (Transverse) | 139.2 | 1.31 | 200.01 | 182.7 | -17.3 | No |
| | 139.2 | 1.41 | 195.5 | 196.7 | 1.2 | Yes |
| Surveillance Weld | 3.7 | 0.88 | 0.0 | 3.3 | -3.3 | Yes |
| Metal | 3.7 | 1.17 | 6.7 | 4.3 | -2.4 | Yes |
| | 3.7 | 1.31 | 0.0 | 4.8 | -4.8 | Yes |
| | 3.7 | 1.41 | 10.0 | 5.2 | -4.8 | Yes |

NOTES:

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

Table D-2 indicates all the scatter is within the acceptable range for credible surveillance weld data. Therefore, the weld data meets this criteria.

Table D-2 indicates that one of the measured plate $\Delta RT_{NDT}$ values is below the lower bound 1σ of 17°F by less than 1°F. This indicates that the best fit line would slightly over predict this measured $\Delta RT_{NDT}$ value. Table 2 also indicates that one of the measured $\Delta RT_{NDT}$ values is above the upper bound 1σ of 17°F by less than 1°F. From a statistical point of view, ±1σ (17°F) would be expected to encompass 68% of the data. It is still statistically acceptable to have two of the data points fall outside the ±1σ bounds. The fact that two of the measured $\Delta RT_{NDT}$ values are less than 1°F outside of the 1σ bound of 17°F can be attributed to several factors, such as 1) the inherent uncertainty in Charpy test data, 2) the use of a symmetric hyperbolic tangent Charpy curve fitting program versus an asymmetric hyperbolic tangent Charpy curve fitting program versus a hand drawn curve using engineering judgement, and/or 3) rounding errors.

Looking at the data given in Table 2, all measured $\Delta RT_{NDT}$ values are below or within the upper bound 1σ of 17°F except one. The one data point that is above 1σ is only above by .8°F. Hence, based on the above evaluation, the plate data meets the intent of this criteria.

The best fit surveillance data is shown graphically in Figures D-1 and D-1 which follow.

Figure D-1

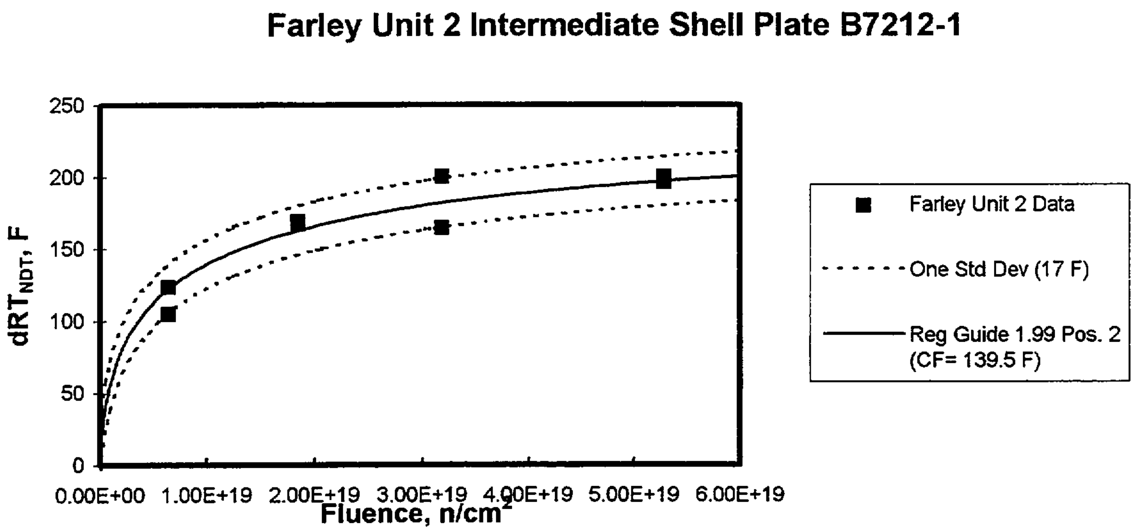
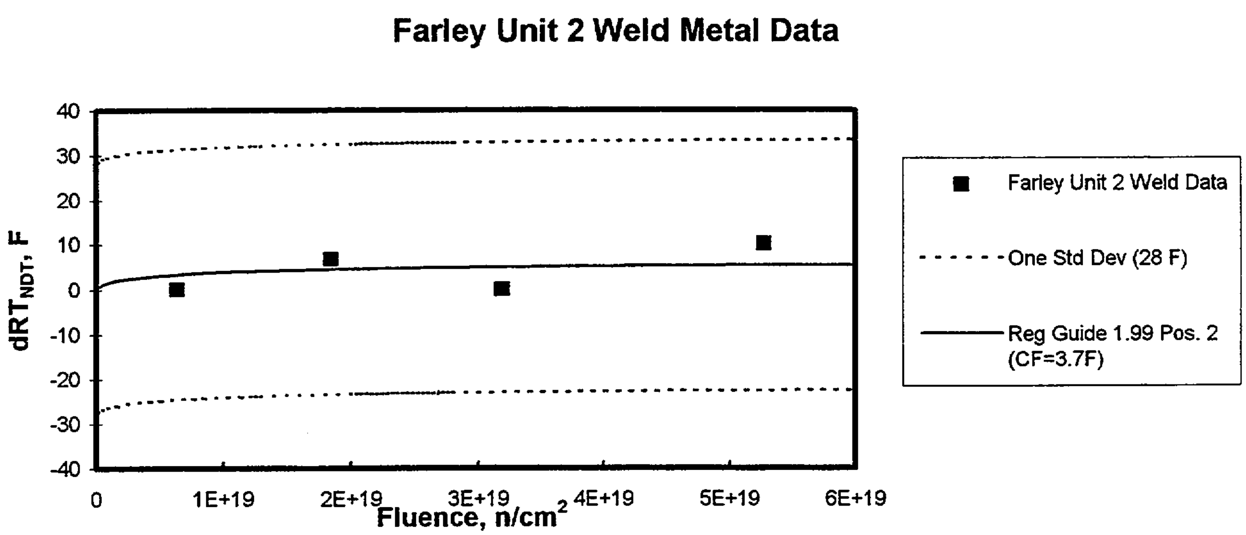



Figure D-2



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 J. M. Farley Unit 2 surveillance program does not contain correlation monitor material. Therefore, this criterion is not applicable to the J. M. Farley Unit 2 surveillance program.

**CONCLUSION:**

Based on the preceding responses to all five criteria of Regulatory Guide 1.99, Revision 2, Section B and 10 CFR 50.61, the J. M. Farley Unit 2 surveillance data is credible.