Westinghouse Non-Proprietary Class 3

WCAP-16527-NP
Revision 0

March 2006

Analysis of Capsule X from FirstEnergy Nuclear Operating Company Beaver Valley Unit 2 Reactor Vessel Radiation Surveillance Program

Westinghouse

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-16527-NP, Revision 0

Analysis of Capsule X from FirstEnergy Nuclear Operating Company Beaver Valley Unit 2 Reactor Vessel Radiation Surveillance Program

B.N. Burgos
J. Conermann
S.L. Anderson

March 2006

Approved: *(Electronically Approved*)*
J.S. Carlson, Manager
Primary Component Asset Management

* Electronically Approved Records are Authenticated in the Electronic Document Management System

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

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF FIGURES (Cont.)

PREFACE

This report has been technically reviewed and verified by:

Reviewer:

All Sections D.M. Chapman _(Electronically Approved*)_

* Electronically Approved Records are Authenticated in the Electronic Document Management System

EXECUTIVE SUMMARY

The purpose of this report is to document the results of the testing of Reactor Vessel Surveillance Capsule X from Beaver Valley Unit 2. Capsule X was removed at 13.94 EFPY and post irradiation mechanical tests of the Charpy V-notch and tensile specimens were performed. A fluence evaluation utilizing the NRC approved neutron transport and dosimetry cross-section libraries was derived from the ENDF/B-VI database. Capsule X received a fluence of 5.601 x 10^{19} n/cm^2 after irradiation to 13.94 EFPY. The peak clad/base metal interface vessel fluence after 13.94 EFPY of plant operation was 1.521 x 10^{19} n/cm^2.

This evaluation led to the following conclusions: 1) Five out of the eight measured 30 ft-lb shift in transition temperature values of the intermediate shell plate B9004-2 (longitudinal & transverse) are greater than the Regulatory Guide 1.99, Revision 2 [Ref. 1], predictions. However, the shift values are less than the two sigma allowance by Regulatory Guide 1.99, Revision 2. 2) All of the measured 30 ft-lb shifts in transition temperature values of the weld metal are less than the Regulatory Guide 1.99, Revision 2, predictions. 3) The measured percent decrease in upper shelf energy for all the surveillance materials contained in the Beaver Valley Unit 2 surveillance program are less than the Regulatory Guide 1.99, Revision 2 predictions. 4) All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are predicted 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 [Ref. 2]. 5) The Beaver Valley Unit 2 surveillance data from the intermediate shell plate B9004-2 and the surveillance weld metal were found to be credible. This evaluation can be found in Appendix D.

Lastly, a brief summary of the Charpy V-notch testing can be found in Section 1. All Charpy V-notch data was plotted using a symmetric hyperbolic tangent curve fitting program.

1 SUMMARY OF RESULTS

The analysis of the reactor vessel materials contained in surveillance Capsule X, the fourth capsule removed and tested from the Beaver Valley Unit 2 reactor pressure vessel, led to the following conclusions:

- The Charpy V-notch data presented in WCAP-9615, Revision 1 [Ref. 3], WCAP-12406 [Ref. 4], WCAP-14484 [Ref. 5], WCAP-15675 [Ref. 6] and STC Letter Report STD-MCE-05-36 [Ref. 7] were fitted using CVGRAPH, Version 5.0.2, which is a hyperbolic tangent curve-fitting program. Appendix C presents the CVGRAPH, Version 5.0.2, Charpy V-notch plots and the program input data.

- Capsule X received an average fast neutron fluence (E> 1.0 MeV) of 5.601 x 10^{19} n/cm^2 after 13.94 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel intermediate shell plate B9004-2 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (longitudinal orientation), resulted in an irradiated 30 ft-lb transition temperature of 133.6°F and an irradiated 50 ft-lb transition temperature of 185.3°F. This results in a 30 ft-lb transition temperature increase of 98.0°F and a 50 ft-lb transition temperature increase of 105.0°F, relative to the unirradiated values, for the longitudinal oriented specimens. See Table 5-9.

- Irradiation of the reactor vessel intermediate shell plate B9004-2 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (transverse orientation), resulted in an irradiated 30 ft-lb transition temperature of 143.9°F and an irradiated 50 ft-lb transition temperature of 212.7°F. This results in a 30 ft-lb transition temperature increase of 104.1°F and a 50 ft-lb transition temperature increase of 121.5°F, relative to the unirradiated values, for the longitudinal oriented specimens. See Table 5-9.

- Irradiation of the weld metal (*heat number 83652*) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -16.9°F and an irradiated 50 ft-lb transition temperature of 10.0°F. This results in a 30 ft-lb transition temperature increase of 22.9 °F and a 50 ft-lb transition temperature increase of 31.7 °F relative to the unirradiated values. See Table 5-9.

- The average upper shelf energy of the intermediate shell plate B9004-2 (longitudinal orientation) resulted in an average energy decrease of 14 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 81 ft-lb for the longitudinal oriented specimens. See Table 5-9.

- The average upper shelf energy of the intermediate shell plate B9004-2 (transverse orientation) resulted in an average energy decrease of 5 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 74 ft-lb for the longitudinal oriented specimens. See Table 5-9.

- The average upper shelf energy of the weld metal Charpy specimens resulted in an average energy decrease of 6 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 133 ft-lb for the weld metal specimens. See Table 5-9.

- A comparison, as presented in Table 5-10, of the Beaver Valley Unit 2 reactor vessel surveillance material test results with the Regulatory Guide 1.99, Revision 2 [Ref. 1] predictions led to the following conclusions:

  - Five out of the eight measured 30 ft-lb shifts in transition temperature values of the intermediate shell plate B9004-2 (longitudinal & transverse) are greater than the Regulatory Guide 1.99, Revision 2, predictions. However, the shift values are less than the two sigma allowance by Regulatory Guide 1.99, Revision 2.

  - All of the measured 30 ft-lb shifts in transition temperature value of the weld metal contained in Capsule X are less than the Regulatory Guide 1.99, Revision 2, predictions.

  - The measured percent decrease in upper shelf energy for all the surveillance materials contained in the Beaver Valley Unit 2 surveillance program are less than 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 and are predicted 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 [Ref. 2].

- The calculated end-of-license (36 EFPY) neutron fluence (E> 1.0 MeV) at the core midplane for the Beaver Valley Unit 2 reactor vessel using the Regulatory Guide 1.99, Revision 2 attenuation formula (i.e., Equation #3 in the guide) are as follows:

  Calculated: Vessel inner radius* = 4.113×10^{19} n/cm^2

  Vessel 1/4 thickness = 2.572×10^{19} n/cm^2

  Vessel 3/4 thickness = 1.006×10^{18} n/cm^2

  *Clad/base metal interface. (From Table 6-2)

- The credibility evaluation of the Beaver Valley Unit 2 surveillance program is presented in Appendix D of this report. The evaluation concluded that the Beaver Valley Unit 2 surveillance results are credible.

2 INTRODUCTION

This report presents the results of the examination of Capsule X, the fourth capsule removed from the reactor in the continuing surveillance program which monitors the effects of neutron irradiation on the FirstEnergy Nuclear Operating Company (FENOC) Beaver Valley Unit 2 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the FENOC Beaver Valley Unit 2 reactor pressure vessel materials was designed and recommended by the Westinghouse Electric Corporation. A description of the surveillance program and the pre-irradiation mechanical properties of the reactor vessel materials are presented in WCAP-9615, Revision 1, "Duquesne Light Company Beaver Valley Unit 2 Reactor Vessel Radiation Surveillance Program" [Ref. 3]. The surveillance program was planned to cover the 40-year design life of the reactor pressure vessel and was based on ASTM E185-73, "Recommended Practice for Surveillance Tests on Structural Materials for Nuclear Reactors" [Ref. 8]. Capsule X was removed from the reactor after 13.94 EFPY of exposure and shipped to the Westinghouse Science and Technology Department Hot Cell Facility, where the post-irradiation mechanical testing of the Charpy V-notch impact and tensile surveillance specimens was performed.

This report summarizes the testing of and the post-irradiation data obtained from surveillance Capsule X removed from the FENOC Beaver Valley 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-1 (base material of the Beaver Valley 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 [Ref. 9]. 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 [Ref. 10]) or the temperature 60°F less than the 50 ft-lb (and 35-mil lateral expansion) temperature as determined from Charpy specimens oriented perpendicular (transverse) to the major working direction of the plate. The RT_{NDT} of a given material is used to index that material to a reference stress intensity factor curve (K_{Ic} curve) which appears in Appendix G to the ASME Code [Ref. 9]. The K_{Ic} curve is a lower bound of static fracture toughness results obtained from several heats of pressure vessel steel. When a given material is indexed to the K_{Ic} curve, allowable stress intensity factors can be obtained for this material as a function of temperature. Allowable operating limits can then be determined using these allowable stress intensity factors.

RT_{NDT} and, in turn, the operating limits of nuclear power plants can be adjusted to account for the effects of radiation on the reactor vessel material properties. The changes in mechanical properties of a given reactor pressure vessel steel, due to irradiation, can be monitored by a reactor vessel surveillance program, such as the Beaver Valley Unit 2 reactor vessel radiation surveillance program [Ref. 3], in which a surveillance capsule is periodically removed from the operating nuclear reactor and the encapsulated specimens tested. The increase in the average Charpy V-notch 30 ft-lb temperature (ΔRT_{NDT}) due to irradiation is added to the initial RT_{NDT}, along with a margin (M) to cover uncertainties, to adjust the RT_{NDT} (ART) for radiation embrittlement. This ART (RT_{NDT} initial + M + ΔRT_{NDT}) is used to index the material to the K_{Ic} curve and, in turn, to set operating limits for the nuclear power plant that take into account the effects of irradiation on the reactor vessel materials.

4 DESCRIPTION OF PROGRAM

Six surveillance capsules for monitoring the effects of neutron exposure on the Beaver Valley 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 thermal shield and the vessel wall as shown in Figure 4-1. The vertical center of the capsules is opposite the vertical center of the core.

Capsule X was removed after 13.94 effective full power years (EFPY) of plant operation. This capsule contained Charpy V-notch impact and tensile specimens from Intermediate Shell Plate B9004-2, and weld metal made from sections of B9004-2 and the adjoining Lower Shell Plate B9005-2 (Heat No. C1408-1). The weld was fabricated using a submerged arc weld metal with 3/16-inch diameter weld wire type B-4, heat number 83642, with Linde 0091 flux, lot number 3536, and is identical to the wire/flux combination used in the original fabrication of the core region. There were also Charpy V-notch impact specimens for the heat-affected-zone which obtained from the weld-heat-affected zone. Additionally, bend bar and 1/2T compact tension test specimens were included in the capsule (Figure 4-2).

Test material obtained from the Intermediate Shell Plate B9004-2 (after thermal heat treatment and forming of the plate) were taken at least one plate thickness from the quenched edges of the plate. All test specimens were machined from the ¼ thickness location of the plate after performing a simulated post-weld stress-relieving treatment on the test material. Specimens were machined from weld metal and the heat-affected-zone (HAZ) metal of a stress-relieved weldment joining sections of the intermediate and lower shell plates. All HAZ specimens were obtained from the weld heat-affected-zone of intermediate shell plate B9004-2.

Charpy V-notch impact specimens from the intermediate shell plate B9004-2 were machined in the longitudinal (longitudinal axis of the specimen parallel to the major working direction) and transverse (longitudinal axis of the specimen perpendicular to the major working direction) orientations. 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 the intermediate shell plate B9004-2 were machined in both the longitudinal and transverse orientations. Tensile specimens from the weld metal were oriented with the long dimension of the specimen perpendicular to the weld direction.

Capsule X contained a bend bar specimen, machined from intermediate shell plate B9004-2 with the longitudinal axis of the specimen oriented to the working direction of the plate, such that the simulated crack in the specimen would propagate in the major working direction of the plate. All bend bar specimens were fatigue pre-cracked according to ASTM E399 [Ref. 11].

The compact tension specimens from intermediate shell plate B9004-2 were machined in the transverse and longitudinal orientations, to obtain fracture toughness data both normal and parallel to the rolling direction of the plate. Compact tension test specimens from the weld metal were machined normal to the weld direction with the notch oriented in the direction of the weld. All specimens were fatigue pre-cracked according to ASTM E399 [Ref. 11].

The chemical composition and heat treatment of the unirradiated surveillance materials are presented in Tables 4-1 and 4-2, respectively. The chemical analysis reported in Table 4-1 was obtained from unirradiated material used in the surveillance program [Ref. 3].

Capsule X contained dosimeter wires of pure iron, copper, 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 [Ref. 3].

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 X is shown in Figure 4-2.

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

Element	Intermediate Shell Plate B9004-2 [a]	Weld Metal [a,b]
C	0.24	0.10
Al	0.047	0.001
S	0.016	0.011
N_2	0.009	0.028
Co	0.009	0.007
As	0.010	0.005
Cu	0.05	0.08
W	0.01	<0.01
Si	0.24	0.14
Sn	0.008	0.005
Mo	0.59	0.49
Zr	0.002	<0.001
Ni	0.56	0.07
P	0.010	0.008
Mn	1.32	1.17
B	0.0003	<0.001
Cr	0.08	0.07
Cb	<0.01	<0.01
V	0.003	0.002
Ti	<0.01	<0.01

Notes:

a. Analysis conducted by Combustion Engineering, Inc.

b. The surveillance weldment is a submerged arc weld fabricated using 3/16-inch diameter weld wire type B-4, heat number 83642, with a Linde 0091 flux, lot number 3536. This weld wire/flux combination is identical to that used for the intermediate and lower shell vertical seams and the girth weld between the intermediate and lower shell plates.

Table 4-2 Heat Treatment History of the Beaver Valley Unit 2 Reactor Vessel Surveillance Materials [Ref. 3]			
Material	**Temperature (°F)**	**Time**	**Coolant**
Intermediate Shell Plates B9004-2	Austenitizing: 1600 ± 25	4 hrs.	Water-Quench
	Tempered: 1225 ± 25	4 hrs.	Air-cooled
	Stress Relief: 1140 ± 25	30 hrs.	Furnace Cooled
Weldment	Stress Relief: 1150 ± 25	13.5 hrs.	Furnace Cooled

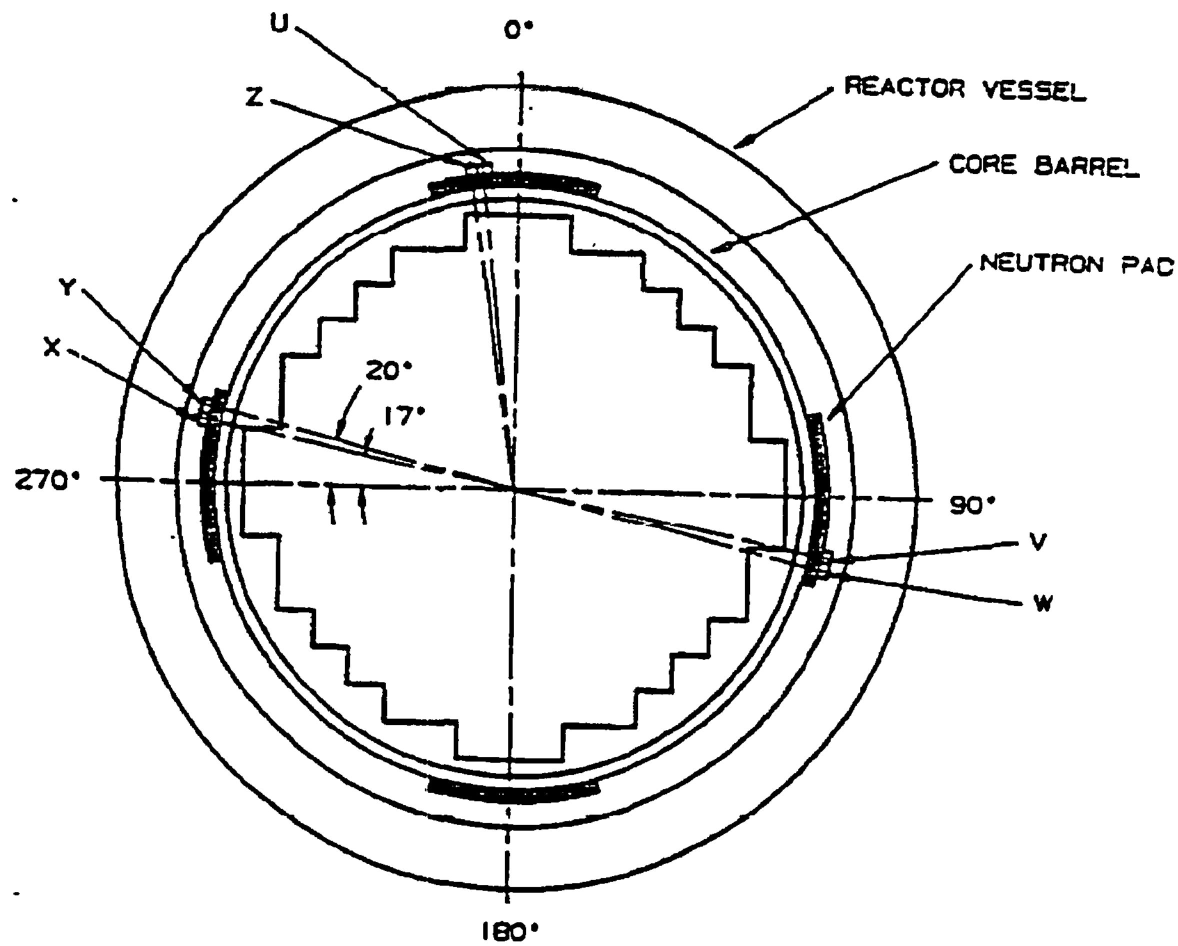


Figure 4-1 Arrangement of Surveillance Capsules in the Beaver Valley Unit 2 Reactor Vessel

LEGEND: WL – INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)
WT – INTERMEDIATE SHELL PLATE B9004-2 (TANGENTIAL)
WW– WELD METAL (HEAT # 83652)
WH – HEAT AFFECTED ZONE METAL

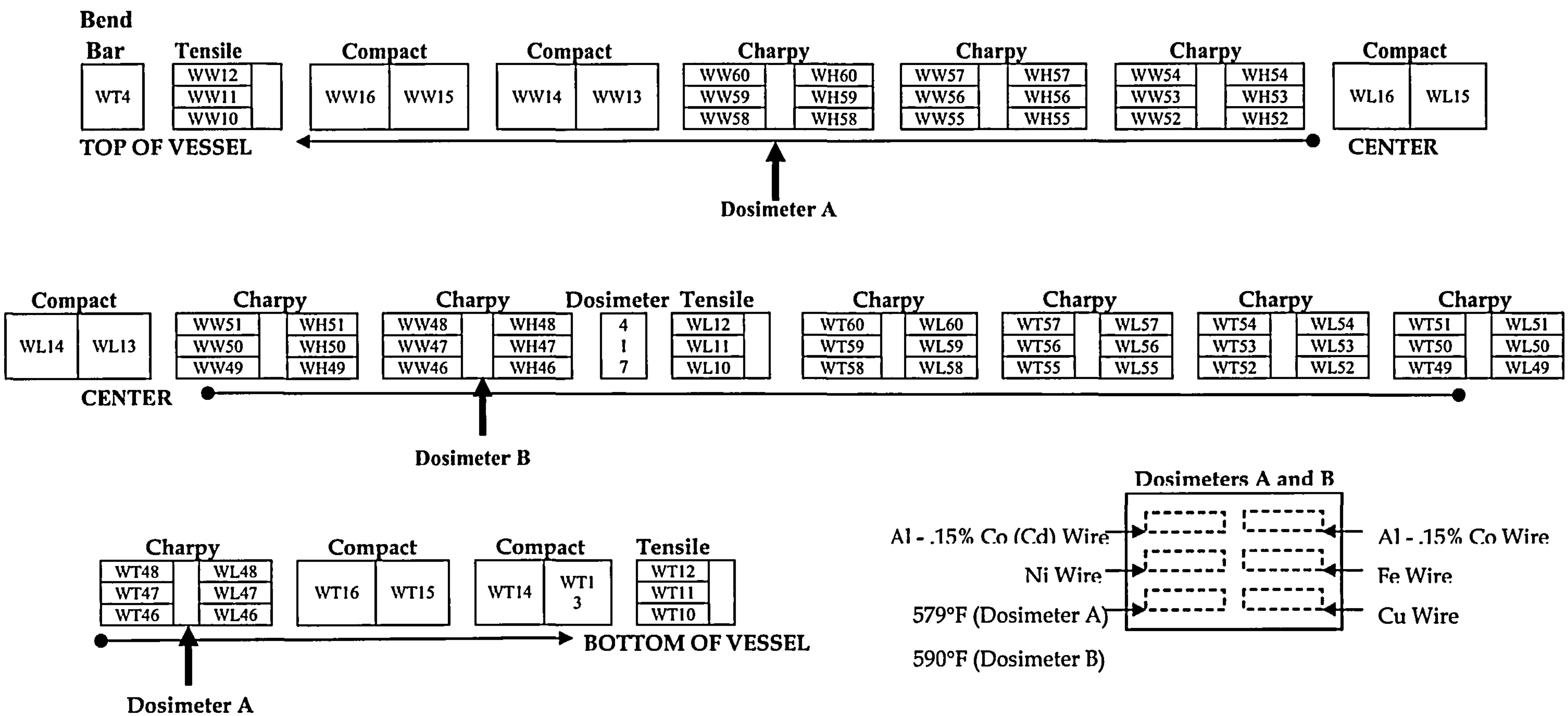


Figure 4-2 Capsule X Diagram Showing The Location of Specimens, Thermal Monitors, and Dosimeters

5 TESTING OF SPECIMENS FROM CAPSULE X

5.1 OVERVIEW

The post-irradiation mechanical testing of the Charpy V-notch impact specimens and tensile specimens was performed in the Remote Metallographic Facility (RMF) at the Westinghouse Science and Technology Department. Testing was performed in accordance with 10CFR50, Appendices G and H [Ref. 2], ASTM Specification E185-82 [Ref. 12], and Westinghouse Procedure RMF 8402, Revision 2 [Ref. 13] as detailed by Westinghouse RMF Procedures 8102, Revision 3 [Ref. 14], and 8103, Revision 2 [Ref.15].

Upon receipt of the capsule at the hot cell laboratory (located at RMF), the specimens and spacer blocks were carefully removed, inspected for identification number, and checked against the master list in WCAP-9615 [Ref. 3]. 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 E23-02a [Ref. 16] and RMF Procedure 8103 [Ref. 15] on a Tinius-Olsen Model 74, 358J machine. The tup (striker) of the Charpy impact test machine is instrumented with an Instrom Impulse 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 B), the load of general yielding (P_{GY}), the time to general yielding (T_{GY}), the maximum load (P_M), and the time to maximum load (t_M) can be determined. Under some test conditions, a sharp drop in load indicative of fast fracture was observed. The load at which fast fracture was initiated is identified as the fast fracture load (P_F), and the load at which fast fracture terminated is identified as the arrest load (P_A).

The energy at maximum load (E_M) was determined by comparing the energy-time record and the load-time record. The energy at maximum load is approximately equivalent to the energy required to initiate a crack in the specimen. Therefore, the propagation energy for the crack (E_p) is the difference between the total energy to fracture (E_D) and the energy at maximum load (E_M).

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

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

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

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

$$\sigma_Y = (P_{GY} * L) / [B * (W - a)^2 * 1.21] = (3.305 * P_{GY} * W) / [B * (W - a)^2] \quad (2)$$

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

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

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

The symbol A in columns 5, 6, and 7 of Tables 5-5 through 5-8 is the cross-section area under the notch of the Charpy specimens:

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

Percent shear was determined from post-fracture photographs using the ratio-of-areas methods in compliance with ASTM Specification E23-02a [Ref. 16] and A370-97a [Ref. 17].. 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 E8-04 [Ref. 18] and E21-03a [Ref. 19], and Procedure RMF 8102 [Ref. 14]. 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 [Ref. 20].

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

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

5.2 CHARPY V-NOTCH IMPACT TEST RESULTS

The results of the Charpy V-notch impact tests performed on the various materials contained in Capsule X, which received a fluence of 5.601 x 10^{19} n/cm^2(E> 1.0 MeV) in 13.94 EFPY of operation, are presented in Tables 5-1 through 5-12 and are compared with unirradiated results [Ref. 3] as shown in Figures 5-1 through 5-12.

The transition temperature increases and upper shelf energy decreases for the Capsule X materials are summarized in Table 5-9 and led to the following results:

Irradiation of the reactor vessel intermediate shell plate B9004-2 Charpy specimens, oriented with the longitudinal axis of the specimen parallel to the major working direction (longitudinal orientation), resulted in an irradiated 30 ft-lb transition temperature of 133.6°F and an irradiated 50 ft-lb transition temperature of 185.3°F. This results in a 30 ft-lb transition temperature increase of 98.0°F and a 50 ft-lb transition temperature increase of 105.0°F, relative to the unirradiated values, for the longitudinal oriented specimens. See Table 5-9.

Irradiation of the reactor vessel intermediate shell plate B9004-2 Charpy specimens, oriented with the longitudinal axis of the specimen perpendicular to the major working direction (transverse orientation), resulted in an irradiated 30 ft-lb transition temperature of 143.9°F and an irradiated 50 ft-lb transition temperature of 212.7°F. This results in a 30 ft-lb transition temperature increase of 104.1°F and a 50 ft-lb transition temperature increase of 121.5°F, relative to the unirradiated values, for the longitudinal oriented specimens. See Table 5-9.

Irradiation of the weld metal (*heat number 83652*) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -16.9°F and an irradiated 50 ft-lb transition temperature of 10.0°F. This results in a 30 ft-lb transition temperature increase of 22.9°F and a 50 ft-lb transition temperature increase of 31.7°F, relative to the unirradiated values. See Table 5-9.

Irradiation of the reactor vessel heat affected zone Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of -1.9°F and an irradiated 50 ft-lb transition temperature of 49.8°F. This results in a 30 ft-lb transition temperature increase of 85.3°F and a 50 ft-lb transition temperature increase of 91.6°F, relative to the unirradiated values, for the HAZ specimens. See Table 5-9.

The average upper shelf energy of the intermediate shell plate B9004-2 (longitudinal orientation) resulted in an average energy decrease of 14 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 81 ft-lb for the longitudinal oriented specimens. See Table 5-9.

The average upper shelf energy of the intermediate shell plate B9004-2 (transverse orientation) resulted in an average energy decrease of 5 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 74 ft-lb for the longitudinal oriented specimens. See Table 5-9.

The average upper shelf energy of the weld metal Charpy specimens resulted in an average energy decrease of 6 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 133 ft-lb for the weld metal specimens. See Table 5-9.

The average upper shelf energy of the heat affected zone material resulted in an average energy decrease of 0 ft-lb after irradiation. An irradiated average upper shelf energy of 114 ft-lb for the HAZ specimens was measured. See Table 5-9.

A comparison, as presented in Table 5-10, of the Beaver Valley Unit 2 reactor vessel surveillance material test results with the Regulatory Guide 1.99, Revision 2 [Ref. 1] predictions led to the following conclusions:

- Five out of the eight measured 30 ft-lb shifts in transition temperature values of the intermediate shell plate B9004-2 (longitudinal & transverse), relative to the unirradiated values, are greater than the Regulatory Guide 1.99, Revision 2, predictions. However, each shift value is less than the two sigma allowance by Regulatory Guide 1.99, Revision 2.

- All of the measured 30 ft-lb shifts in transition temperature value of the weld metal contained in Capsule X, relative to the unirradiated values, are less than the Regulatory Guide 1.99, Revision 2, predictions.

- The measured percent decrease in upper shelf energy for all the surveillance materials contained in the Beaver Valley Unit 2 surveillance program, relative to the unirradiated values, are less than 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 and are predicted to maintain an upper shelf energy greater than 50 ft-lb throughout the extended life of the vessel (36 EFPY) as required by 10CFR50, Appendix G [Ref. 2].

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

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

The Charpy V-notch data presented in WCAP-9615, Revision 1 [Ref. 3], WCAP-12406 [Ref. 4], WCAP-14484 [Ref. 5], WCAP-15675 [Ref. 6] and STC Letter Report STD-MCE-05-36 [Ref. 7] were fitted using CVGRAPH, Version 5.0.2, which is a hyperbolic tangent curve-fitting program. Appendix C presents the CVGRAPH, Version 5.0.2, Charpy V-notch plots and the program input data.

5.3 TENSILE TEST RESULTS

The results of the tensile tests performed on the various materials contained in Capsule X irradiated to 5.601 x 10^{19} n/cm^2 (E> 1.0 MeV) are presented in Table 5-11 and are compared with unirradiated results [Ref. 3] as shown in Figures 5-17 through 5-19.

The results of the tensile tests performed on the Intermediate Shell Plate B9004-2 (longitudinal orientation) indicated that irradiation to 5.601 x 10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 8 to 11 ksi increase in the 0.2 percent offset yield strength and approximately a 5 to 9 ksi increase in the ultimate tensile strength when compared to unirradiated data [Ref. 3]. See Figure 5-17.

The results of the tensile tests performed on the Intermediate Shell Plate B9004-2 (transverse orientation) indicated that irradiation to 5.601 x 10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 9 to 13 ksi increase in the 0.2 percent offset yield strength and approximately a 6 to 11 ksi increase in the ultimate tensile strength when compared to unirradiated data [Ref. 3]. See Figure 5-18.

The results of the tensile tests performed on the reactor vessel weld metal indicated that irradiation to 5.601 x 10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 3 to 10 ksi increase in the 0.2 percent offset yield strength and approximately a 3 to 10 ksi increase in the ultimate tensile strength when compared to unirradiated data [Ref. 3]. See Figure 5-19.

The fractured tensile specimens for the intermediate shell plate B9004-2 (longitudinal and transverse orientations) and the reactor vessel weld metal are shown in Figures 5-20 through 5-22. The engineering stress-strain curves for the tensile tests are shown in Figures 5-23 through 5-28.

5.4 COMPACT TENSION SPECIMEN TESTS

Per the surveillance capsule testing contract, the 1/2T compact tension and bend bar 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 Beaver Valley Unit 2 Intermediate Shell Plate B9004-2 Irradiated to a Fluence of 5.601 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	%
WL49	-50	-46	3	4	1	0.03	2
WL59	25	-4	11	15	8	0.20	5
WL60	75	24	25	34	17	0.43	10
WL58	100	38	23	31	18	0.46	20
WL47	125	52	27	37	21	0.53	25
WL46	150	66	35	47	26	0.66	35
WL48	175	79	38	52	30	0.76	40
WL55	200	93	37	50	29	0.74	50
WL56	225	107	75	102	53	1.35	95
WL51	250	121	78	106	58	1.47	100
WL52	275	135	77	104	59	1.50	98
WL57	280	138	73	99	58	1.47	98
WL50	325	163	87	118	60	1.52	100
WL54	350	177	89	121	65	1.65	100
WL53	375	191	86	117	63	1.60	100

Table 5-2 Charpy V-notch Data for the Beaver Valley Unit 2 Intermediate Shell Plate B9004-2 Irradiated to a Fluence of 5.601 x 10^{19} n/cm^2 (E> 1.0 MeV) (Transverse Orientation)

Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	°F	°C	ft-lbs	Joules	mils	mm	%
WT60	-50	-46	3	4	2	0.05	2
WT57	25	-4	9	12	7	0.18	10
WT56	50	10	9	12	9	0.23	15
WT50	75	24	19	26	15	0.38	20
WT46	100	38	20	27	16	0.41	25
WT59	125	52	28	38	25	0.64	30
WT54	150	66	32	43	28	0.71	35
WT47	175	79	33	45	28	0.71	45
WT52	200	93	45	61	39	0.99	55
WT55	250	121	55	75	50	1.27	75
WT58	275	135	65	88	53	1.35	90
WT53	300	149	65	88	57	1.45	100
WT48	325	163	77	104	55	1.40	100
WT51	350	177	78	106	55	1.40	100
WT49	375	191	74	100	51	1.30	100

Table 5-3 Charpy V-notch Data for the Beaver Valley Unit 2 Surveillance Weld Metal Irradiated to a Fluence of 5.601×10^{19} n/cm^2 (E> 1.0 MeV)							
Sample	Temperature		Impact Energy		Lateral Expansion		Shear
Number	°F	°C	ft-lbs	Joules	mils	mm	%
WW51	-75	-59	3	4	2	0.05	2
WW53	-50	-46	9	12	6	0.15	15
WW54	-25	-32	7	9	7	0.18	15
WW52	-25	-32	19	26	15	0.38	25
WW55	-10	-23	6	8	5	0.13	15
WW48	0	-18	56	76	40	1.02	50
WW46	10	-12	88	119	59	1.50	65
WW59	25	-4	97	132	63	1.60	75
WW57	50	10	41	56	37	0.94	45
WW50	50	10	79	107	48	1.22	65
WW58	75	24	113	153	80	2.03	90
WW47	100	38	117	159	82	2.08	95
WW60	150	66	129	175	87	2.21	100
WW56	175	79	130	176	85	2.16	100
WW49	225	107	139	188	80	2.03	100

Table 5-4 Charpy V-notch Data for the Beaver Valley Unit 2 Heat Affected Zone Material Irradiated to a Fluence of 5.601×10^{19} n/cm^2 (E> 1.0 MeV)							
Sample	**Temperature**		**Impact Energy**		**Lateral Expansion**		**Shear**
Number	**°F**	**°C**	**Ft-lbs**	**Joules**	**mils**	**mm**	**%**
WH48	-90	-68	15	20	7	0.18	15
WH55	-50	-46	13	18	7	0.18	15
WH50	-25	-32	25	34	19	0.48	35
WH49	0	-18	43	58	29	0.74	40
WH58	25	-4	45	61	34	0.86	60
WH53	50	10	58	79	36	0.91	70
WH51	75	24	43	58	29	0.74	40
WH54	100	38	87	118	61	1.55	95
WH47	125	52	63	85	43	1.09	90
WH52	135	57	61	83	36	0.91	90
WH46	150	66	85	115	57	1.45	98
WH59	175	79	87	118	61	1.55	100
WH60	200	93	122	165	88	2.24	100
WH57	225	107	137	186	89	2.26	100
WH56	250	121	137	186	81	2.06	100

Table 5-5 Instrumented Charpy Impact Test Results for the Beaver Valley Unit 2 Intermediate Shell Plate B9004-2 Irradiated to a Fluence of 5.601 x 10^{19} n/cm^2 (E>1.0 MeV) (Longitudinal Orientation)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2) Charpy E_D/A	Max. E_M/A	Prop. E_p/A	Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress σ_Y (ksi)	Flow Stress (ksi)
WL49	-50	3	24	15	9	1683	0.1	1794	0.12	1789	0	56	58
WL59	25	11	89	50	38	3411	0.14	4054	0.19	4054	0	114	124
WL60	75	25	201	157	45	3579	0.14	4600	0.36	4600	0	119	136
WL58	100	23	185	118	68	2906	0.13	4192	0.33	4189	113	97	118
WL47	125	27	218	139	78	3093	0.14	4280	0.36	4252	538	103	123
WL46	150	35	282	169	113	3088	0.13	4360	0.41	4274	983	103	124
WL48	175	38	306	194	112	3012	0.15	4372	0.47	4343	1306	100	123
WL55	200	37	298	134	164	2724	0.13	4174	0.36	4174	2639	91	115
WL56	225	75	604	239	365	2990	0.13	4601	0.53	3662	2602	100	126
WL51	250	78	628	216	413	2988	0.14	4430	0.50	n/a	n/a	99	123
WL52	275	77	620	229	392	2741	0.14	4409	0.53	3620	2282	91	119
WL57	280	73	588	211	377	3051	0.14	4335	0.49	2937	2182	102	123
WL50	325	87	701	251	450	1962	0.12	4337	0.61	n/a	n/a	65	105
WL54	350	89	717	276	441	1083	0.07	4383	0.66	n/a	n/a	36	91
WL53	375	86	693	216	477	2967	0.15	4247	0.52	n/a	n/a	99	120

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in²) Charpy E_D/A	Max. E_M/A	Prop. E_p/A	Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress σ_Y (ksi)	Flow Stress (ksi)
WT60	-50	3	24	12	12	1362	0.09	1499	0.11	1491	0	45	48
WT57	25	9	73	37	36	3213	0.14	3455	0.16	3437	0	107	111
WT56	50	9	73	30	42	2680	0.13	3022	0.15	3017	106	89	95
WT50	75	19	153	87	66	2842	0.13	3978	0.27	3978	289	95	114
WT46	100	20	161	65	96	3194	0.14	4008	0.22	4003	495	106	120
WT59	125	28	226	146	79	3068	0.14	4297	0.37	4284	770	102	123
WT54	150	32	258	151	107	2858	0.13	4179	0.39	4161	967	95	117
WT47	175	33	266	137	129	2856	0.14	4214	0.37	4211	1376	95	118
WT52	200	45	363	203	159	2769	0.13	4208	0.49	4131	2004	92	116
WT55	250	55	443	186	257	2964	0.14	4041	0.46	3382	2385	99	117
WT58	275	65	524	204	320	2766	0.14	4198	0.5	3361	2568	92	116
WT53	300	65	524	195	329	2785	0.14	4152	0.49	n/a	n/a	93	115
WT48	325	77	620	214	406	2689	0.14	4340	0.51	n/a	n/a	90	117
WT51	350	78	628	224	405	2883	0.14	4270	0.53	n/a	n/a	96	119
WT49	375	74	596	208	388	2742	0.14	4198	0.51	n/a	n/a	91	116

Table 5-6 Instrumented Charpy Impact Test Results for the Beaver Valley Unit 2 Intermediate Shell Plate B9004-2 Irradiated to a Fluence of 5.601 x 10^{19} n/cm² (E>1.0 MeV) (Transverse Orientation)

Table 5-7 Instrumented Charpy Impact Test Results for the Beaver Valley Unit 2 Surveillance Weld Metal Irradiated to a Fluence of 5.601 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 σ_Y (ksi)	Flow Stress (ksi)
WW51	-75	3	24	13	12	1267	0.09	1516	0.12	1516	0	42	46
WW53	-50	9	73	27	46	2756	0.13	2870	0.15	2857	126	92	94
WW54	-25	7	56	22	35	2357	0.12	2473	0.14	2470	0	78	80
WW52	-25	19	153	94	59	2695	0.15	3951	0.32	3917	0	90	111
WW55	-10	6	48	15	34	1521	0.1	1624	0.12	1622	126	51	52
WW48	0	56	451	244	207	3522	0.15	4611	0.52	4497	489	117	135
WW46	10	88	709	326	383	3154	0.14	4557	0.68	3728	1354	105	128
WW59	25	97	782	325	457	3237	0.14	4461	0.68	3616	1476	108	128
WW57	50	41	330	165	166	3203	0.14	4305	0.40	4246	1190	107	125
WW50	50	79	637	314	322	3114	0.14	4442	0.68	4290	2097	104	126
WW58	75	113	910	318	593	3053	0.14	4454	0.68	3097	2008	102	125
WW47	100	117	943	305	638	2703	0.13	4331	0.68	2587	1587	90	117
WW60	150	129	1039	302	738	2958	0.13	4291	0.67	n/a	n/a	99	121
WW56	175	130	1047	296	752	2707	0.13	4191	0.68	n/a	n/a	90	115
WW49	225	139	1120	293	827	2882	0.14	4127	0.68	n/a	n/a	96	117

Table 5-8 Instrumented Charpy Impact Test Results for the Beaver Valley Unit 2 Heat Affected Zone Material Irradiated to a Fluence of 5.601×10^{19} n/cm^2 (E>1.0 MeV)

Sample No.	Test Temp. (°F)	Charpy Energy E_D (ft-lb)	Normalized Energies (ft-lb/in^2)			Yield Load P_{GY} (lb)	Time to Yield t_{GY} (msec)	Max. Load P_M (lb)	Time to Max. t_M (msec)	Fast Fract. Load P_F (lb)	Arrest Load P_A (lb)	Yield Stress σ_Y (ksi)	Flow Stress (ksi)
			Charpy E_D/A	Max. E_M/A	Prop. E_p/A								
WH48	-90	15	121	67	54	2988	0.13	4255	0.22	4247	636	99	121
WH55	-50	13	105	55	49	4003	0.15	4601	0.19	4596	0	133	143
WH50	-25	25	201	72	129	3586	0.14	4590	0.22	4588	1195	119	136
WH49	0	43	346	193	153	3615	0.14	4764	0.42	4741	2157	120	140
WH58	25	45	363	215	147	3345	0.15	4684	0.47	4655	1235	111	134
WH53	50	58	467	171	297	3572	0.14	4547	0.39	4186	1626	119	135
WH51	75	43	346	157	190	2960	0.13	4514	0.39	4414	265	99	124
WH54	100	87	701	244	457	3618	0.15	4621	0.52	4165	1950	120	137
WH47	125	63	508	200	307	3342	0.14	4457	0.46	4261	3009	111	130
WH52	135	61	491	207	284	2967	0.13	4317	0.48	3279	1420	99	121
WH46	150	85	685	212	472	3564	0.14	4447	0.47	2745	1691	119	133
WH59	175	87	701	216	485	2766	0.13	4359	0.51	n/a	n/a	92	119
WH60	200	122	983	312	671	3368	0.14	4374	0.67	n/a	n/a	112	129
WH57	225	137	1104	324	780	3178	0.14	4576	0.68	n/a	n/a	106	129
WH56	250	137	1104	317	787	2947	0.14	4575	0.68	n/a	n/a	98	125

Table 5-9 Effect of Irradiation to 5.601 x 10^{19} n/cm^2 (E>1.0 MeV) on the Capsule X Toughness Properties of the Beaver Valley 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	ΔE
Intermediate Shell Plate B9004-2 (Long.)	35.6	133.6	98.0	82.9	180.4	97.5	80.3	185.3	105.0	95	81	14
Intermediate Shell Plate B9004-2 (Trans.)	39.8	143.9	104.1	90.8	179.7	88.9	91.2	212.7	121.5	79	74	5
Weld Metal (Heat # 83652)	-39.8	-16.9	22.9	-19.8	8.4	28.2	-21.7	10.0	31.7	139	133	6
Heat Affected Zone	-87.2	-1.9	85.3	-21.5	65.4	86.9	-41.8	49.8	91.6	91	114	0

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 Beaver Valley 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[(d)] (x 10^{19} n/cm^2, E > 1.0 MeV)	30 ft-lb Transition Temperature Shift		Upper Shelf Energy Decrease	
			Predicted (°F) [(a)]	Measured (°F) [(b)]	Predicted (%) [(a)]	Measured (%)[(c)]
Intermediate Shell Plate B9004-2 (*Longitudinal*)	U	0.6082	31.9	24.0	19	0
	V	2.629	46.6	56.0	24	11
	W	3.625	49.4	71.0	26	1
	X	5.601	52.7	98.0	29	15
Intermediate Shell Plate B9004-2 (*Transverse*)	U	0.6082	31.9	17.7	19	0
	V	2.629	46.6	46.1	24	4
	W	3.625	49.4	63.4	26	5
	X	5.601	52.7	104.1	29	6
Surveillance Program Weld Metal	U	0.6082	32.7	4.1	19	4
	V	2.629	47.8	25.7	26	2
	W	3.625	50.7	6.0	28	2
	X	5.601	54.1	22.9	31	4
Heat Affected Zone Material	U	0.6082	--	0[(d)]	---	0
	V	2.629	--	41.2	---	4
	W	3.625	--	51.3	---	0
	X	5.601	--	85.3		0

Notes:

(a) Based on Regulatory Guide 1.99, Revision 2 [Ref. 1], 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 5.0.2 (See Appendix C)

(c) Values are based on the definition of upper shelf energy given in ASTM E185-82 [Ref. 12].

(d) The fluence values presented here are the calculated values, not the best estimate values.

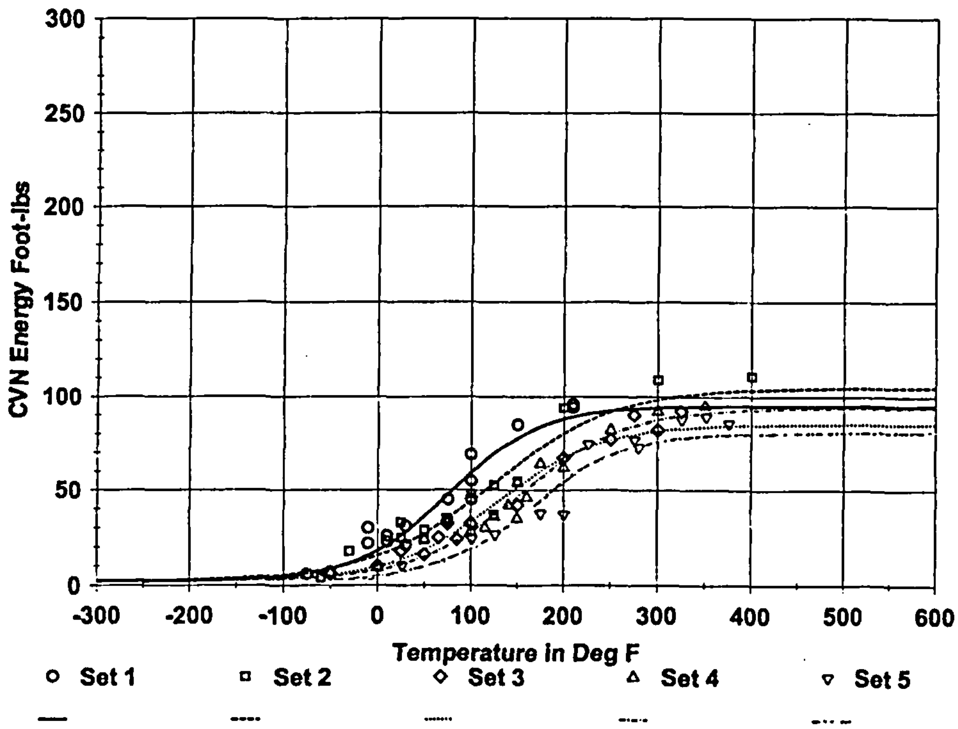
Table 5-11 Tensile Properties of the Beaver Valley Unit 2 Capsule X Reactor Vessel Surveillance Materials Irradiated to 5.601 x 10^{19} n/cm^2 (E > 1.0 MeV)

Material	Sample Number	Test Temp. (°F)	0.2% Yield Strength (ksi)	Ultimate Strength (ksi)	Fracture Load (kip)	Fracture Stress (ksi)	Fracture Strength (ksi)	Uniform Elongation (%)	Total Elongation (%)	Reduction in Area (%)
Intermediate Shell Plate B9004-2 (Longitudinal)	WL10	175	80.0	99.5	3.24	176.0	66.0	9.4	20.9	62
	WL11	275	76.4	96.4	3.08	167.0	62.6	10.1	22.1	62
	WL12	550	70.3	98.6	3.26	151.5	66.4	10.1	21.6	56
Intermediate Shell Plate B9004-2 (Transverse)	WT10	150	80.0	99.8	3.36	156.2	68.4	10.6	22.0	56
	WT11	245	77.8	96.8	3.31	157.6	67.3	9.9	20.3	57
	WT12	550	72.8	99.0	3.69	159.4	75.2	11.9	20.6	53
Surveillance Program Weld Metal	WW10	70	78.9	93.0	2.73	175.6	55.6	10.5	26.3	68
	WW11	125	77.6	90.1	2.53	183.4	51.4	9.8	25.2	72
	WW12	550	69.3	89.0	2.77	163.1	56.3	10.1	23.7	65

INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:09 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	BEAVER VALLEY 2	UNIRR	SA533B1	LT	C0544-2
2	BEAVER VALLEY 2	U	SA533B1	LT	C0544-2
3	BEAVER VALLEY 2	V	SA533B1	LT	C0544-2
4	BEAVER VALLEY 2	W	SA533B1	LT	C0544-2
5	BEAVER VALLEY 2	X	SA533B1	LT	C0544-2



Results

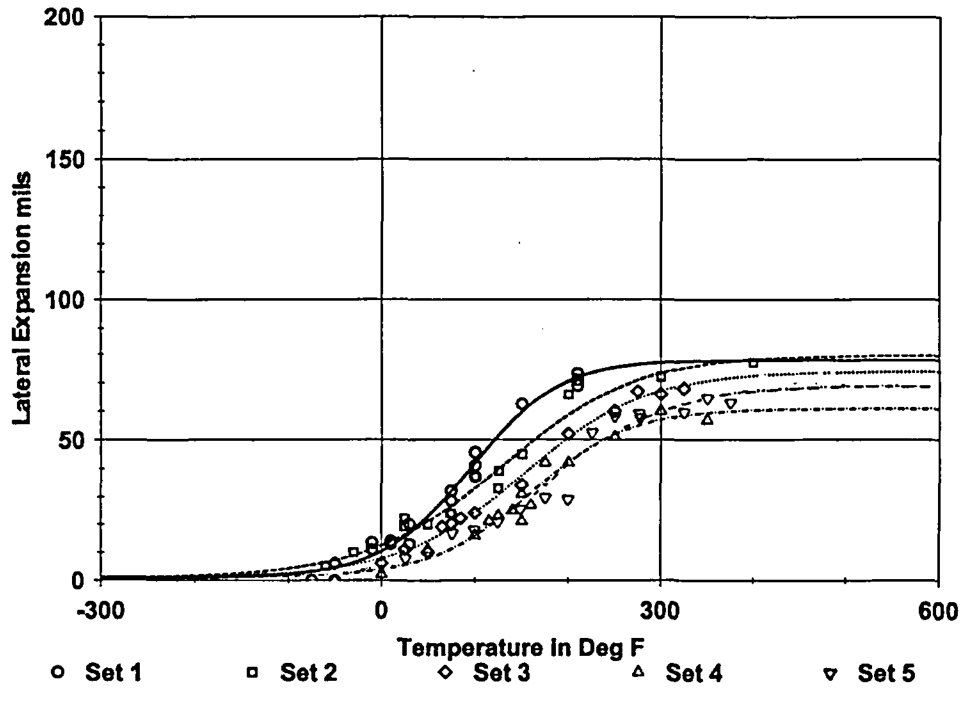
Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	95.0	.0	35.6	.0	80.3	.0
2		2.2	105.0	10.0	59.6	24.0	115.5	35.2
3		2.2	85.0	-10.0	91.6	56.0	146.6	66.3
4		2.2	94.0	-1.0	106.6	71.0	158.9	78.6
5		2.2	81.0	-14.0	133.6	98.0	185.3	105.0

Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Longitudinal Orientation)

INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 10/28/2005 11:27 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	BEAVER VALLEY 2	UNIRR	SA533B1	LT	C0544-2
2	BEAVER VALLEY 2	U	SA533B1	LT	C0544-2
3	BEAVER VALLEY 2	V	SA533B1	LT	C0544-2
4	BEAVER VALLEY 2	W	SA533B1	LT	C0544-2
5	BEAVER VALLEY 2	X	SA533B1	LT	C0544-2



Results

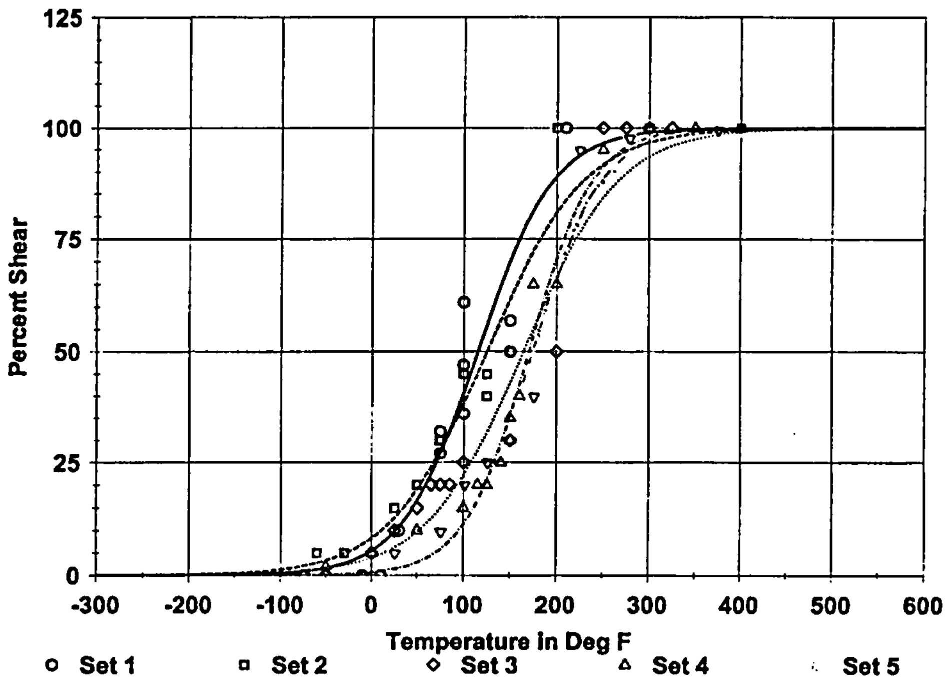
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1.0	77.9	.0	82.9	.0
2		1.0	79.8	1.9	107.9	25.0
3		1.0	73.7	-4.2	142.0	59.1
4		1.0	60.9	-17.0	173.2	90.3
5		1.0	68.9	-9.0	180.4	97.5

Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Longitudinal Orientation)

INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:23 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	BEAVER VALLEY 2	UNIRR	SA533B1	LT	C0544-2
2	BEAVER VALLEY 2	U	SA533B1	LT	C0544-2
3	BEAVER VALLEY 2	V	SA533B1	LT	C0544-2
4	BEAVER VALLEY 2	W	SA533B1	LT	C0544-2
5	BEAVER VALLEY 2	X	SA533B1	LT	C0544-2



Results

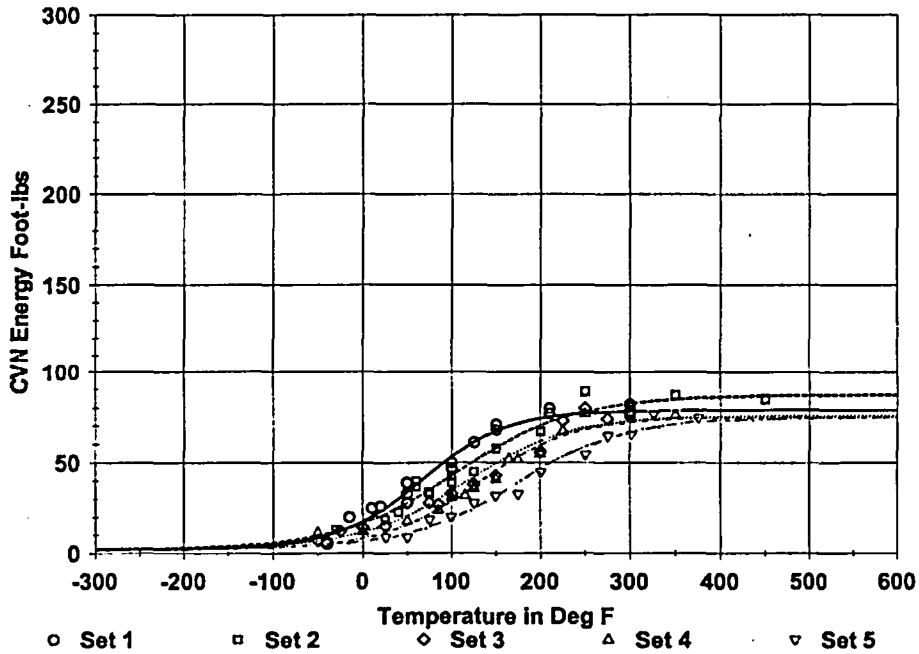
Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	115.4	.0
2		.0	100.0	.0	125.1	9.7
3		.0	100.0	.0	165.0	49.6
4		.0	100.0	.0	170.2	54.8
5		.0	100.0	.0	175.1	59.7

Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Longitudinal Orientation)

INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 10/25/2005 11:06 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	BEAVER VALLEY 2	UNIRR	SA533B1	TL	C0544-2
2	BEAVER VALLEY 2	U	SA533B1	TL	C0544-2
3	BEAVER VALLEY 2	V	SA533B1	TL	C0544-2
4	BEAVER VALLEY 2	W	SA533B1	TL	C0544-2
5	BEAVER VALLEY 2	X	SA533B1	TL	C0544-2



Results

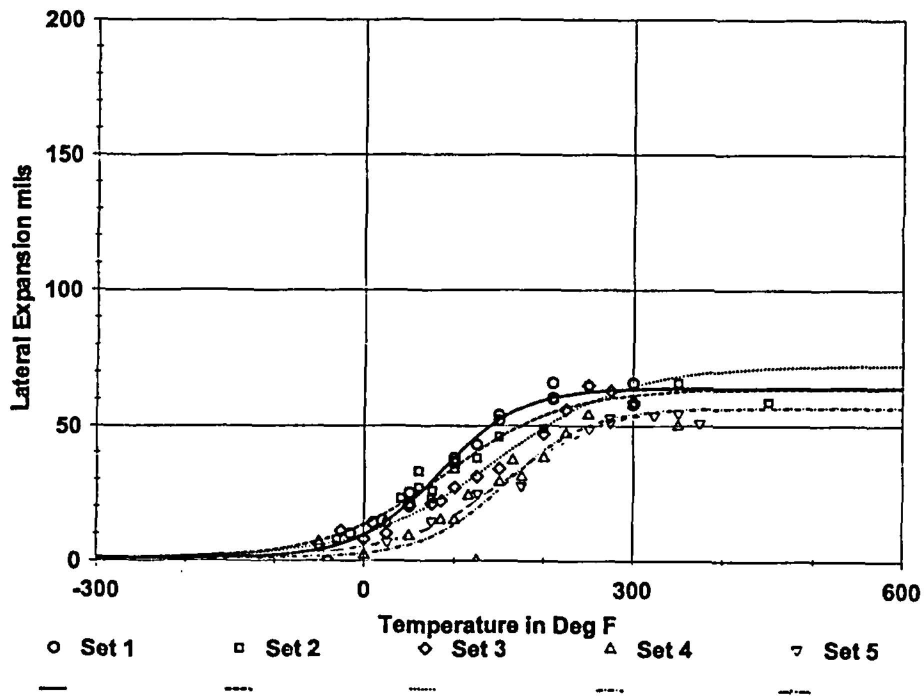
Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	79.0	.0	39.8	.0	91.2	.0
2		2.2	87.0	8.0	57.5	17.7	122.6	31.4
3		2.2	76.0	-3.0	85.9	46.1	151.9	60.7
4		2.2	75.0	-4.0	103.2	63.4	163.6	72.4
5		2.2	74.0	-5.0	143.9	104.1	212.7	121.5

Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Transverse Orientation)

INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/01/2005 03:58 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	BEAVER VALLEY 2	UNIRR	SA533B1	TL	C0544-2
2	BEAVER VALLEY 2	U	SA533B1	TL	C0544-2
3	BEAVER VALLEY 2	V	SA533B1	TL	C0544-2
4	BEAVER VALLEY 2	W	SA533B1	TL	C0544-2
5	BEAVER VALLEY 2	X	SA533B1	TL	C0544-2



Results

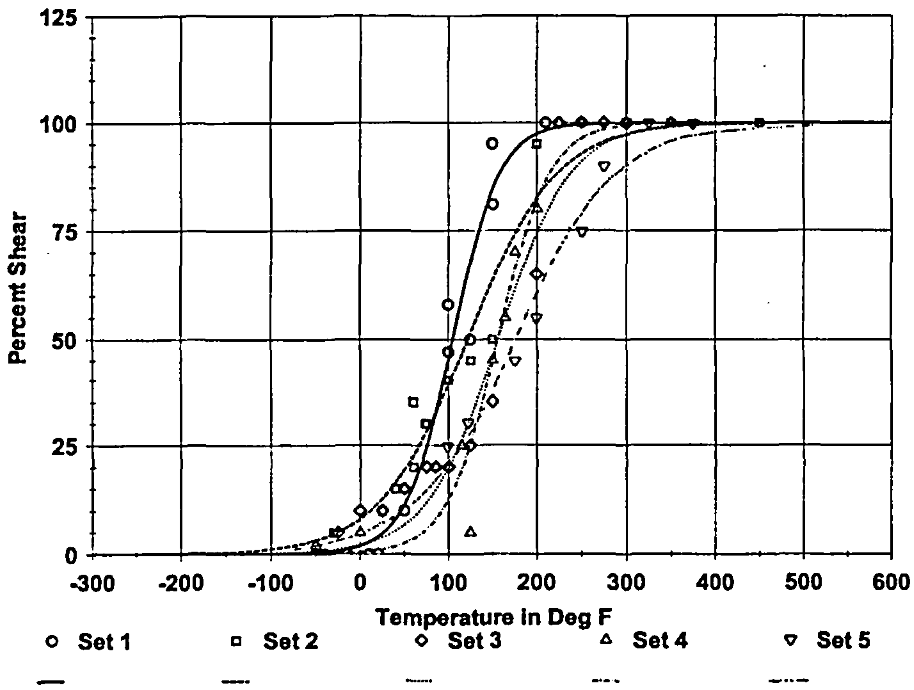
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1.0	64.3	.0	90.8	.0
2		1.0	64.0	-.3	102.3	11.5
3		1.0	72.4	8.1	139.0	48.2
4		1.0	56.8	-7.5	178.9	88.1
5		1.0	57.4	-6.9	179.7	88.9

Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Transverse Orientation)

INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 04:06 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	BEAVER VALLEY 2	UNIRR	SA533B1	TL	C0544-2
2	BEAVER VALLEY 2	U	SA533B1	TL	C0544-2
3	BEAVER VALLEY 2	V	SA533B1	TL	C0544-2
4	BEAVER VALLEY 2	W	SA533B1	TL	CO544-2
5	BEAVER VALLEY 2	X	SA533B1	TL	C0544-2



Results

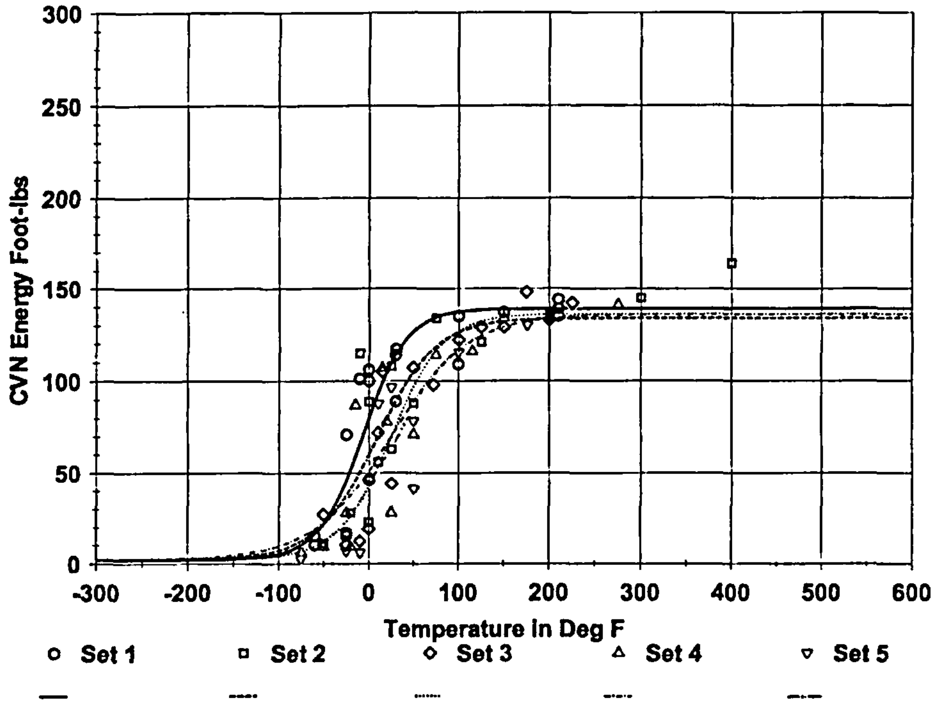
Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	105.0	.0
2		.0	100.0	.0	122.1	17.1
3		.0	100.0	.0	157.1	52.1
4		.0	100.0	.0	156.3	51.3
5		.0	100.0	.0	175.1	70.1

Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Transverse Orientation)

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 10:20 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	BEAVER VALLEY 2	UNIRR	SAW	NA	83642
2	BEAVER VALLEY 2	U	SAW	NA	83642
3	BEAVER VALLEY 2	V	SAW	NA	83642
4	BEAVER VALLEY 2	W	SAW	NA	83642
5	BEAVER VALLEY 2	X	SAW	NA	83642



Results

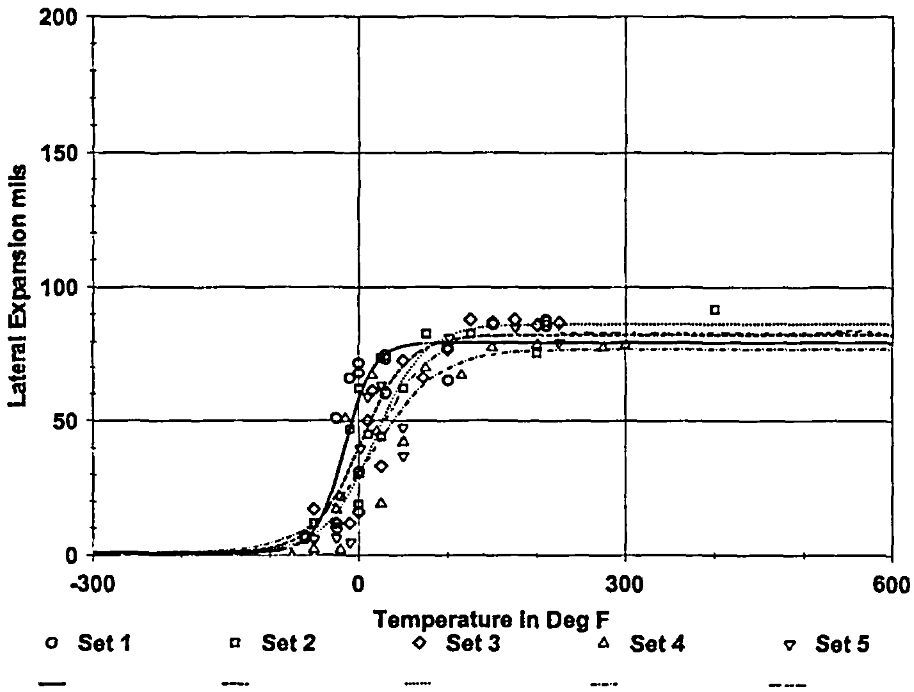
Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	139.0	.0	-39.8	.0	-21.7	.0
2		2.2	134.0	-5.0	-35.7	4.1	-10.6	11.1
3		2.2	136.0	-3.0	-14.1	25.7	7.7	29.4
4		2.2	136.0	-3.0	-33.8	6.0	-1.4	20.3
5		2.2	133.0	-6.0	-16.9	22.9	10.0	31.7

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

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/02/2005 09:27 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	BEAVER VALLEY 2	UNIRR	SAW	NA	83642
2	BEAVER VALLEY 2	U	SAW	NA	83642
3	BEAVER VALLEY 2	V	SAW	NA	83642
4	BEAVER VALLEY 2	W	SAW	NA	83642
5	BEAVER VALLEY 2	X	SAW	NA	83642



Results

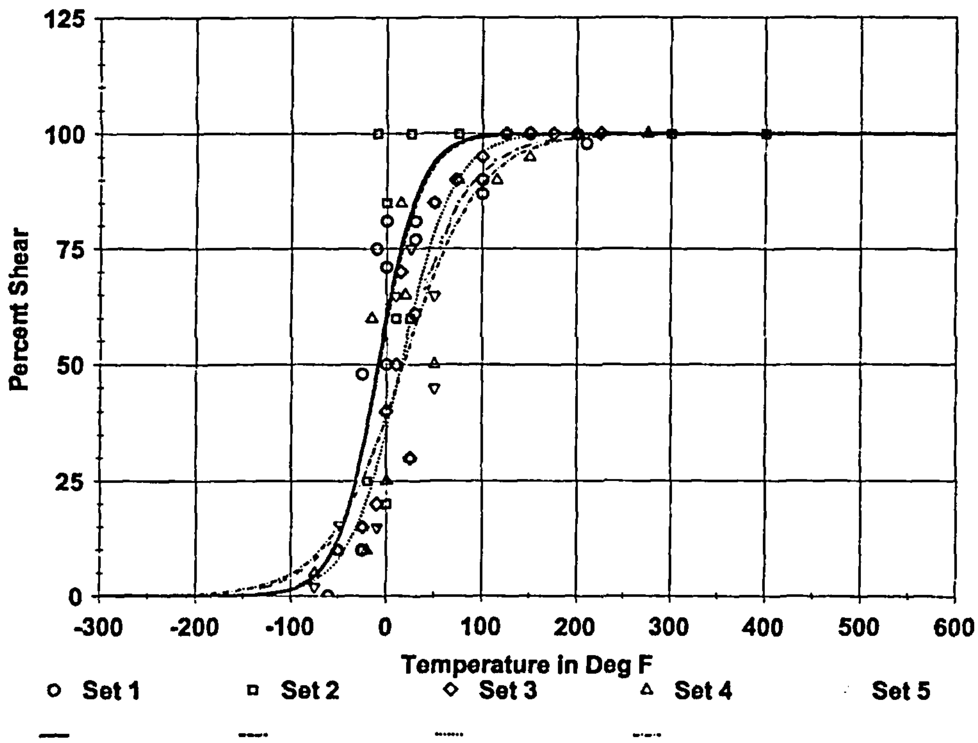
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1.0	79.8	.0	-19.8	.0
2		1.0	82.6	2.8	-6.5	13.3
3		1.0	86.3	6.5	7.9	27.7
4		1.0	77.4	-2.4	9.0	28.8
5		1.0	83.8	4.0	8.4	28.2

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

SURVEILLANCE PROGRAM WELD METAL

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 10:50 AM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	BEAVER VALLEY 2	UNIRR	SAW	NA	83642
2	BEAVER VALLEY 2	U	SAW	NA	83642
3	BEAVER VALLEY 2	V	SAW	NA	83642
4	BEAVER VALLEY 2	W	SAW	NA	83642
5	BEAVER VALLEY 2	X	SAW	NA	83642



Results

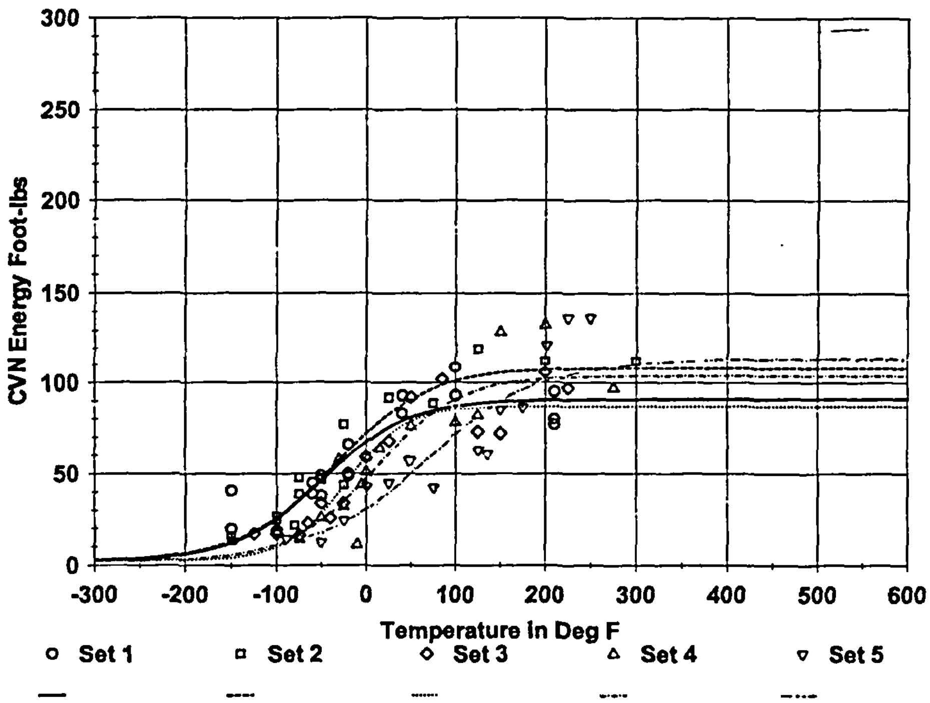
Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	-8.6	.0
2		.0	100.0	.0	-7.5	1.1
3		.0	100.0	.0	15.8	24.4
4		.0	100.0	.0	17.7	26.3
5		.0	100.0	.0	15.4	24.0

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

HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 02:32 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	BEAVER VALLEY 2	UNIRR	SA533B1	NA	C0544-2
2	BEAVER VALLEY 2	U	SA533B1	NA	C0544-2
3	BEAVER VALLEY 2	V	SA533B1	NA	C0544-2
4	BEAVER VALLEY 2	W	SA533B1	NA	C0544-2
5	BEAVER VALLEY 2	X	SA533B1	NA	C0544-2



Results

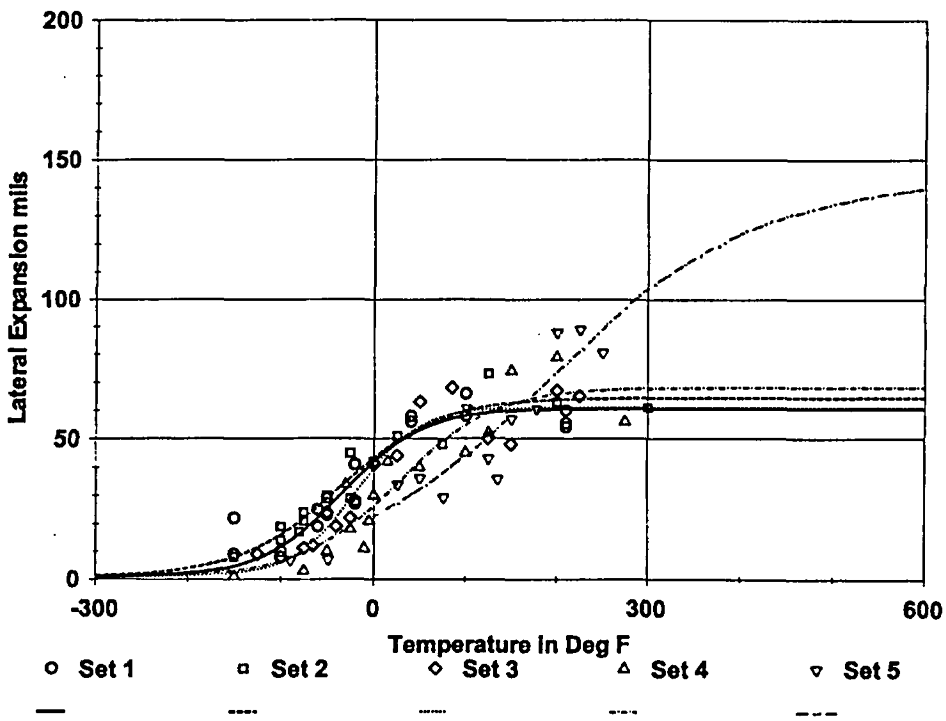
Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	91.0	.0	-87.2	.0	-41.8	.0
2		2.2	109.0	18.0	-89.2	-2.0	-45.0	-3.2
3		2.2	87.0	-4.0	-46.0	41.2	-14.1	27.7
4		2.2	104.0	13.0	-35.9	51.3	4.4	46.2
5		2.2	114.0	23.0	-1.9	85.3	49.8	91.6

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

HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/01/2005 02:44 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	BEAVER VALLEY 2	UNIRR	SA533B1	NA	C0544-2
2	BEAVER VALLEY 2	U	SA533B1	NA	C0544-2
3	BEAVER VALLEY 2	V	SA533B1	NA	C0544-2
4	BEAVER VALLEY 2	W	SA533B1	NA	C0544-2
5	BEAVER VALLEY 2	X	SA533B1	NA	C0544-2



Results

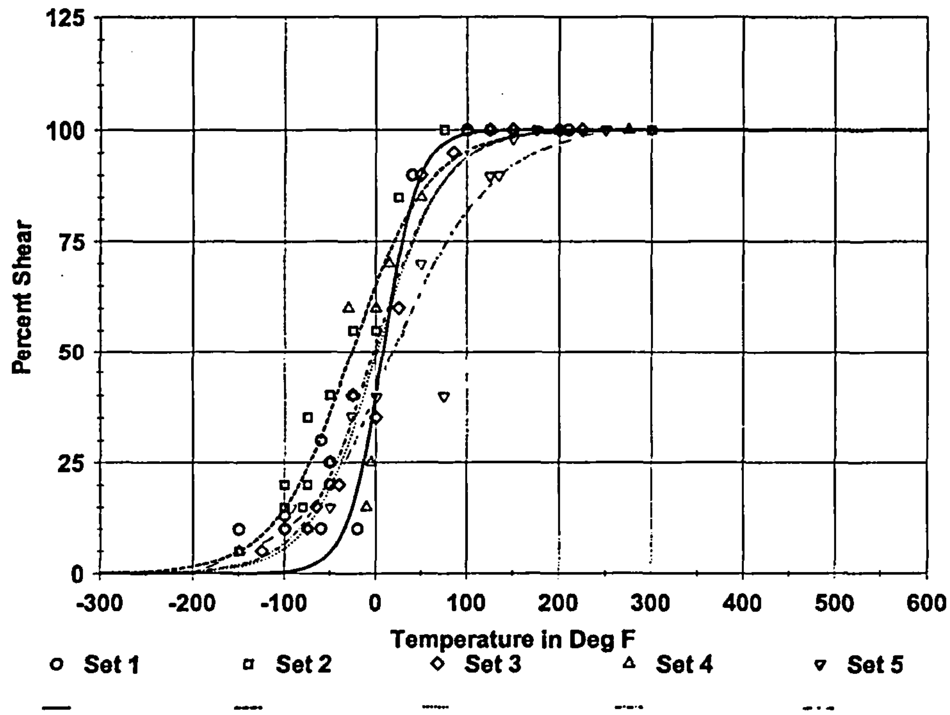
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		1.0	60.6	.0	-21.5	.0
2		1.0	64.5	3.9	-29.0	-7.5
3		1.0	61.0	.4	-10.0	11.5
4		1.0	68.1	7.5	28.2	49.7
5		1.0	143.0	82.3	65.4	86.9

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

HEAT AFFECTED ZONE

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 02:35 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	BEAVER VALLEY 2	UNIRR	SA533B1	NA	C0544-2
2	BEAVER VALLEY 2	U	SA533B1	NA	C0544-2
3	BEAVER VALLEY 2	V	SA533B1	NA	C0544-2
4	BEAVER VALLEY 2	W	SA533B1	NA	C0544-2
5	BEAVER VALLEY 2	X	SA533B1	NA	C0544-2



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	7.9	.0
2		.0	100.0	.0	-26.1	-34.0
3		.0	100.0	.0	2.0	-5.9
4		.0	100.0	.0	-2.0	-9.9
5		.0	100.0	.0	19.8	11.9

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

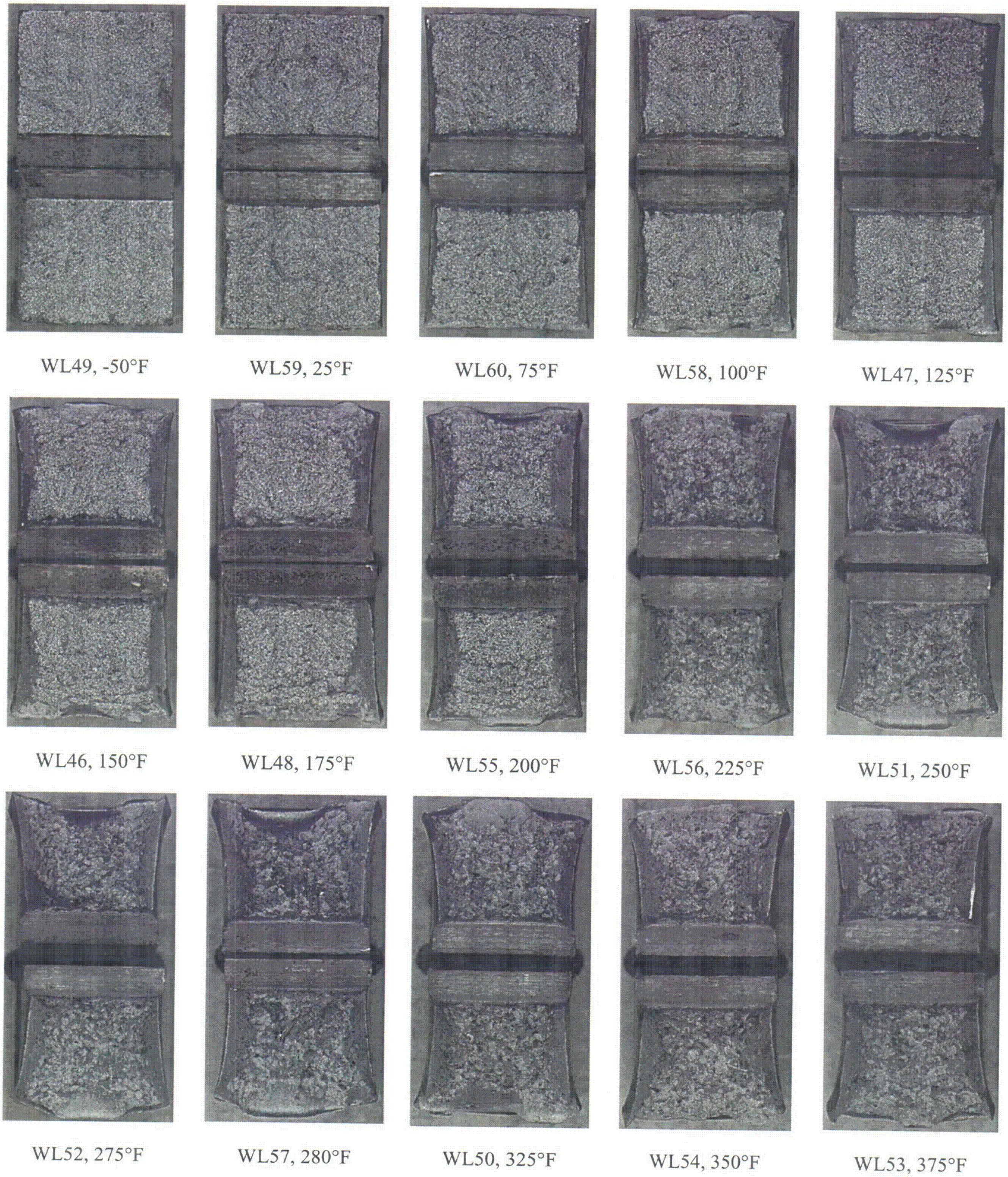


Figure 5-13 Charpy Impact Specimen Fracture Surfaces for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Longitudinal Orientation)

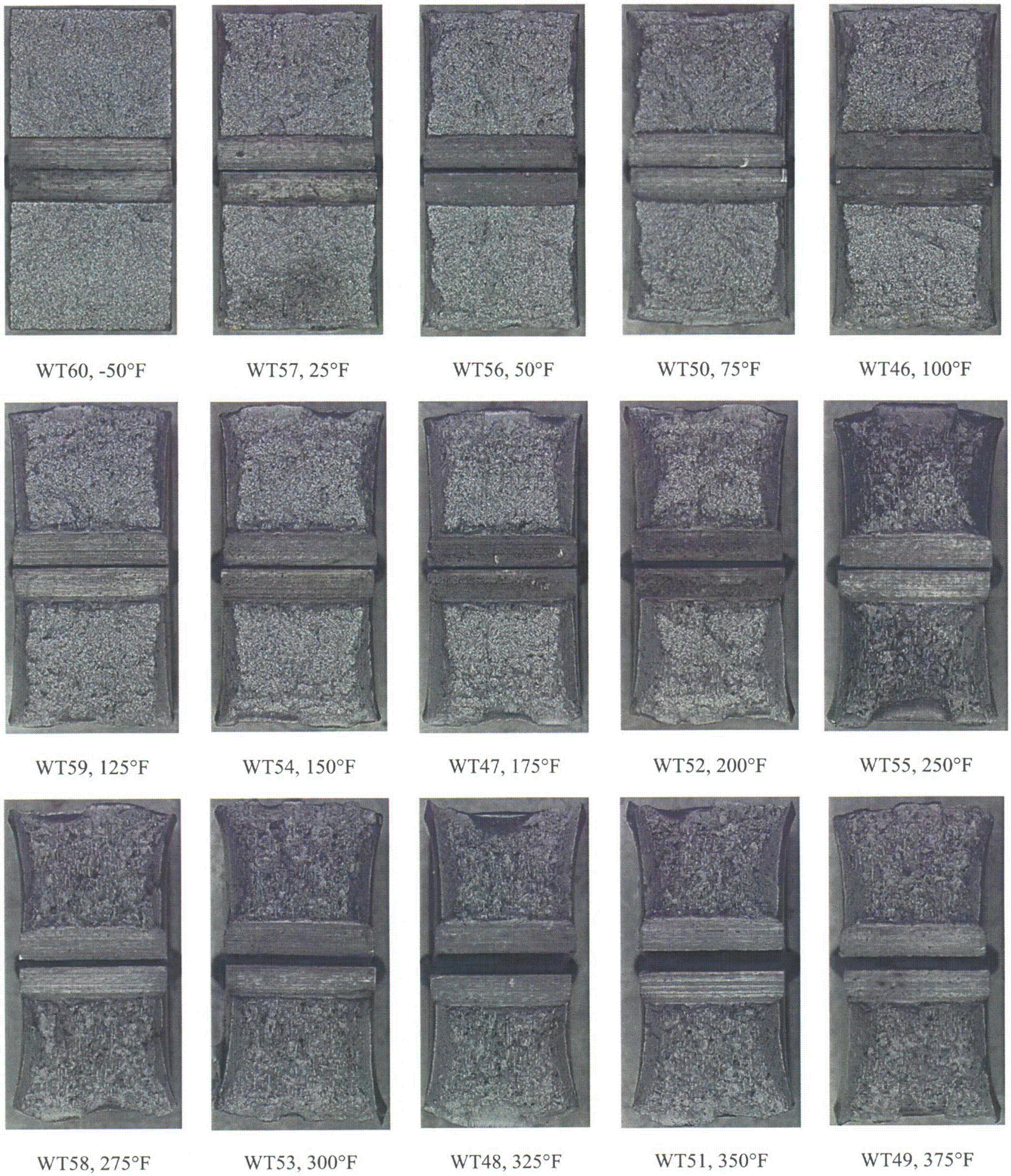


Figure 5-14 Charpy Impact Specimen Fracture Surfaces for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Transverse Orientation)

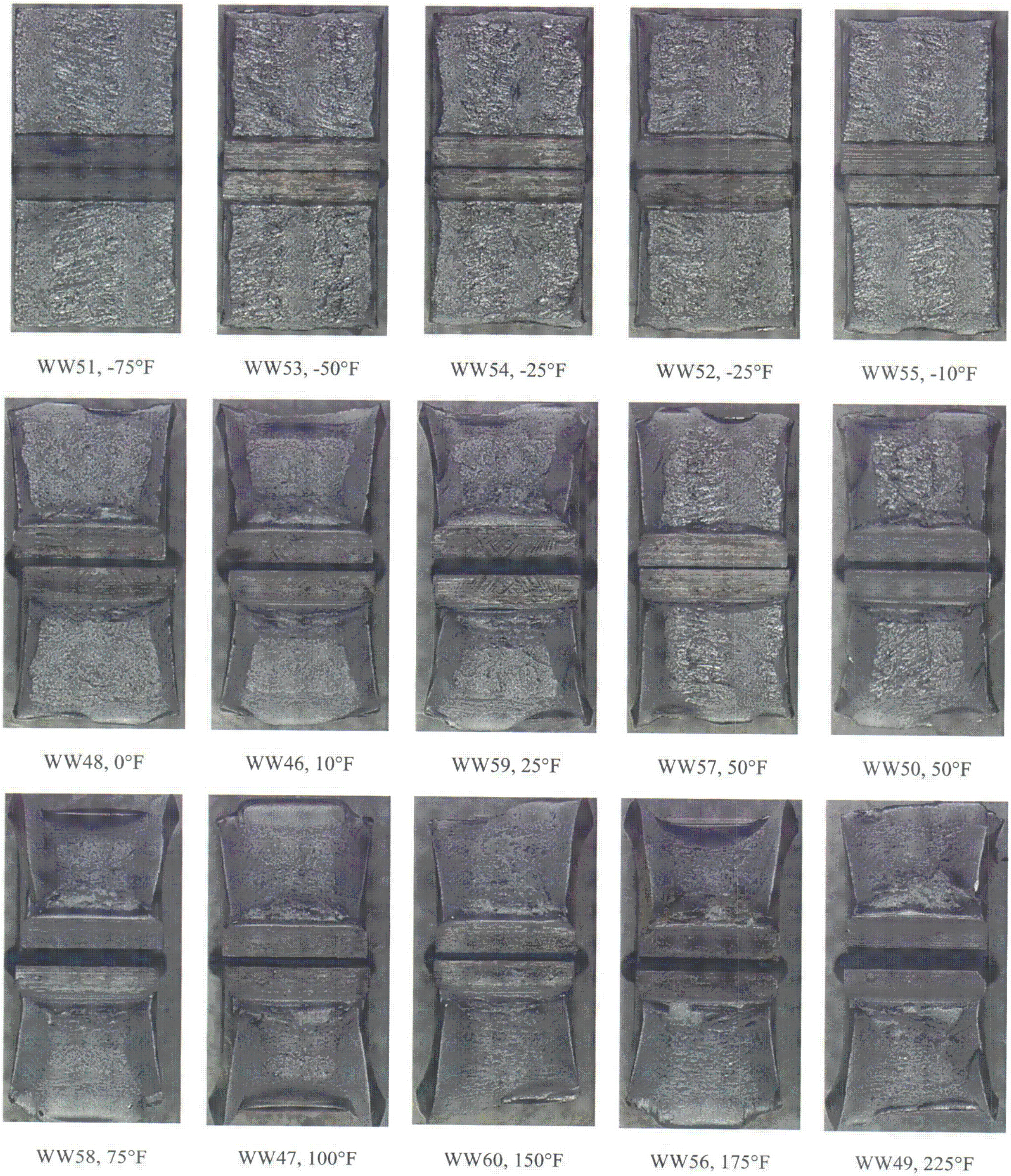


Figure 5-15 Charpy Impact Specimen Fracture Surfaces for Beaver Valley Unit 2 Reactor Vessel Weld Metal

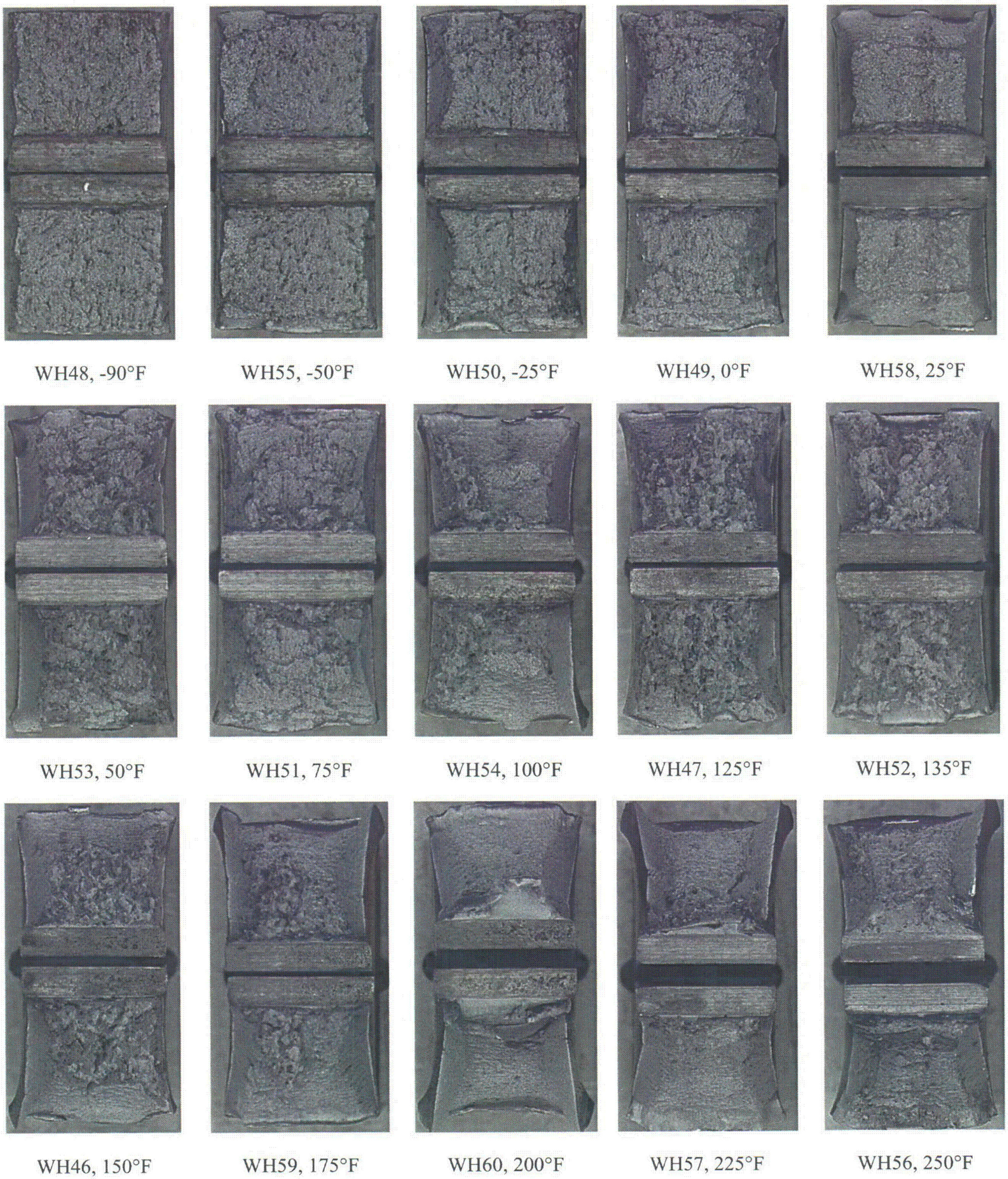
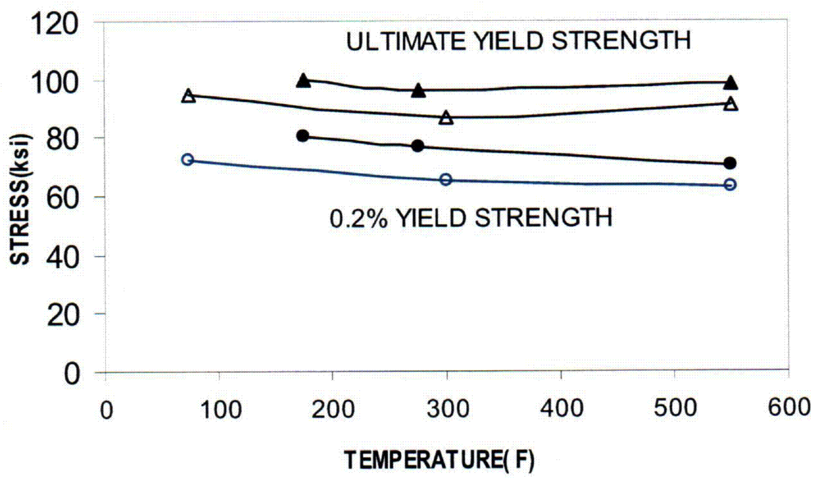


Figure 5-16 Charpy Impact Specimen Fracture Surfaces for Beaver Valley Unit 2 Reactor Vessel Heat Affected Zone Material



Legend: Δ and ○ are Unirradiated
▲and ● are Irradiated to 5.601 x 10^{19} n/cm^2 (E > 1.0 MeV)

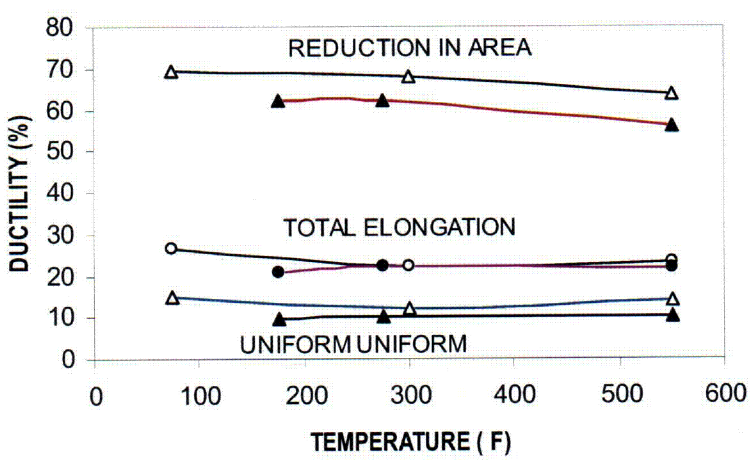
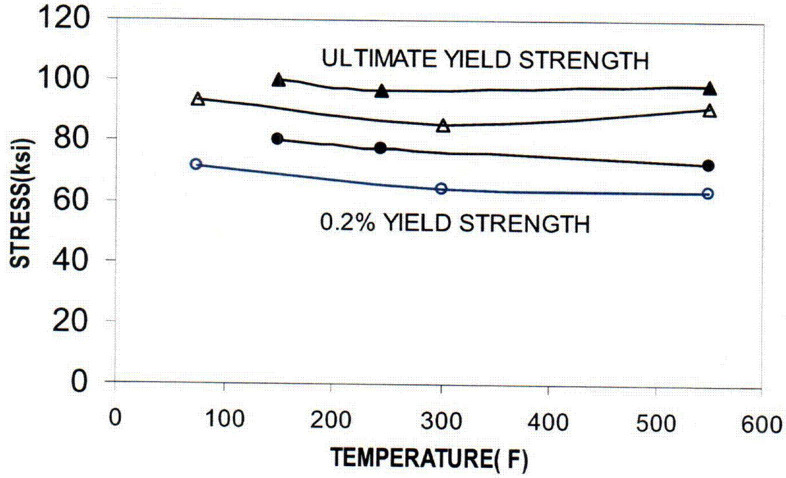


Figure 5-17 Tensile Properties for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Longitudinal Orientation)

C01



Legend: Δ and ○ are Unirradiated

▲ and ● are Irradiated to 5.601 x 10^{19} n/cm^2 (E > 1.0 MeV)

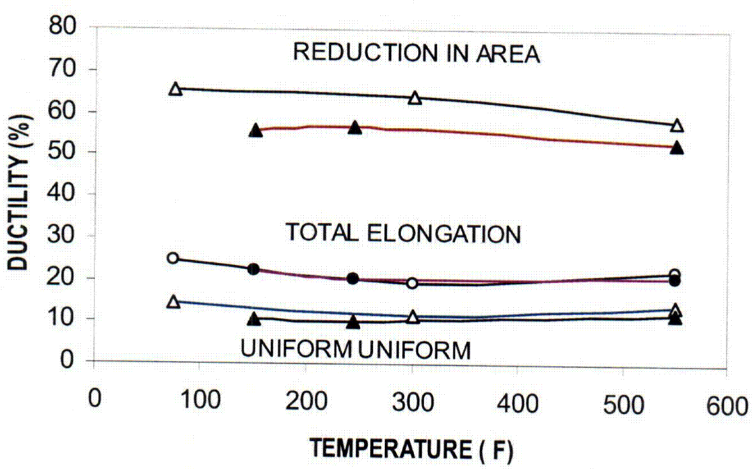
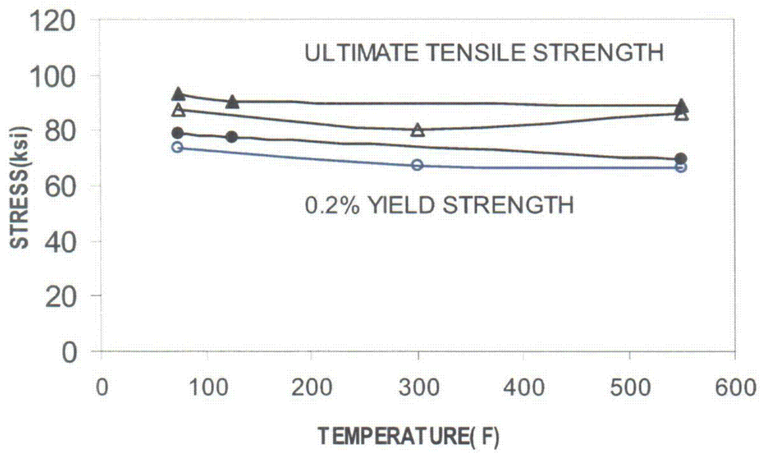


Figure 5-18 Tensile Properties for Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Transverse Orientation)

C02



Legend: Δ and ○ are Unirradiated

▲and ● are Irradiated to 5.601 x 10^{18} n/cm^2 (E > 1.0 MeV)

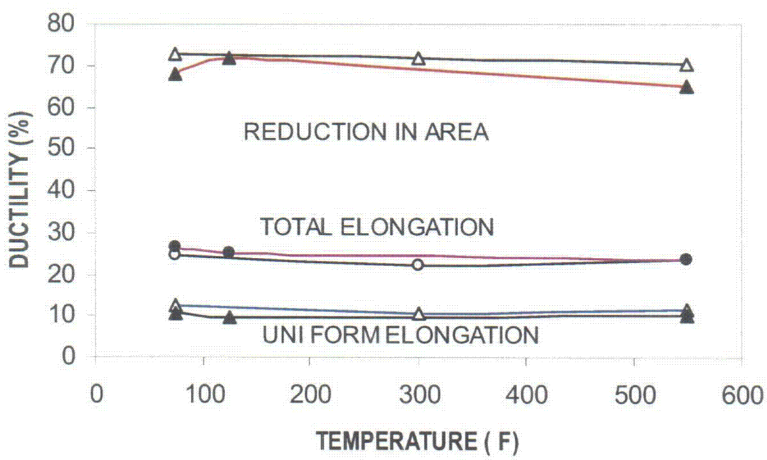
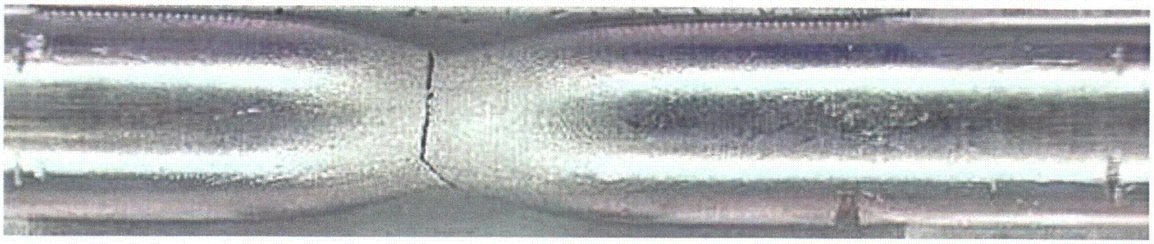
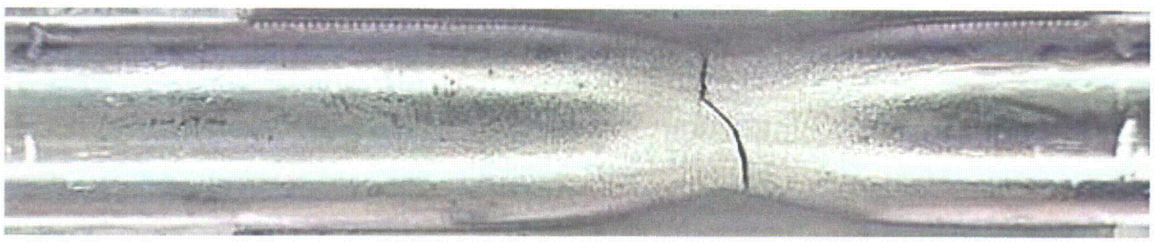


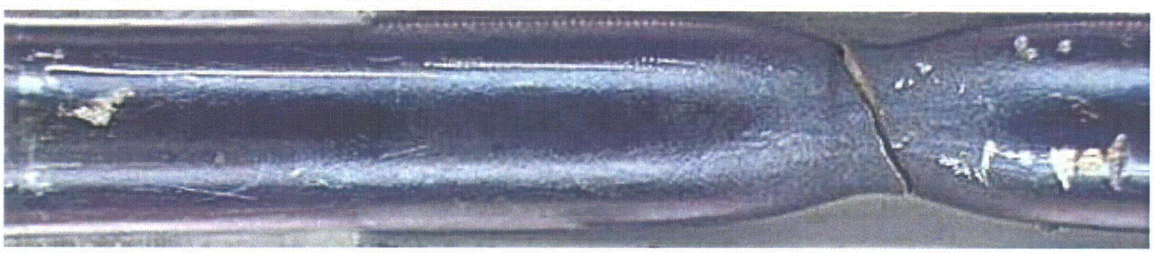
Figure 5-19 Tensile Properties for Beaver Valley Unit 2 Reactor Vessel Weld Metal



Specimen WL-10 Tested at 175°F

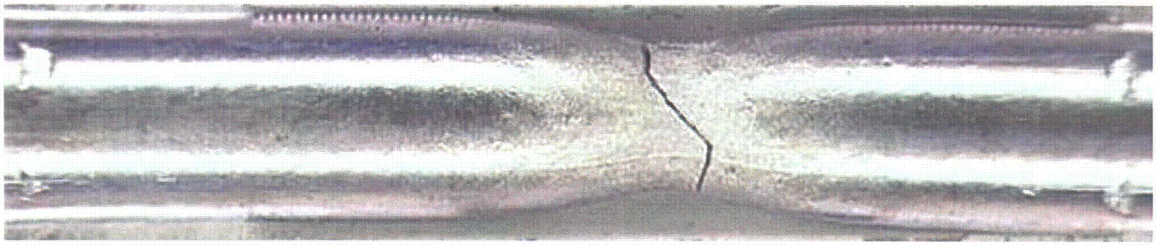


Specimen WL-11 Tested at 275°F

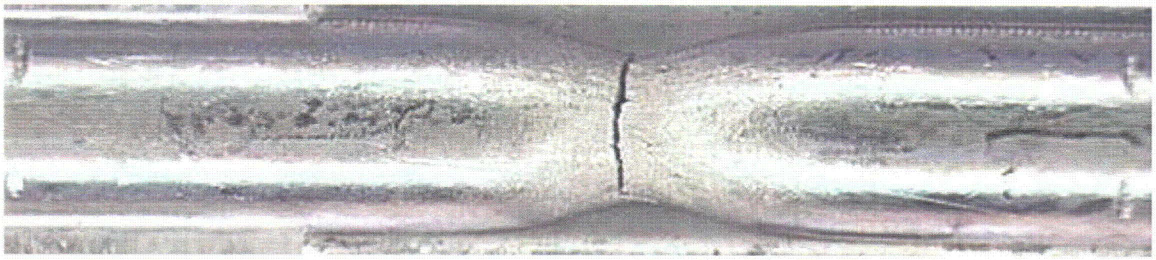


Specimen WL-12 Tested at 550°F

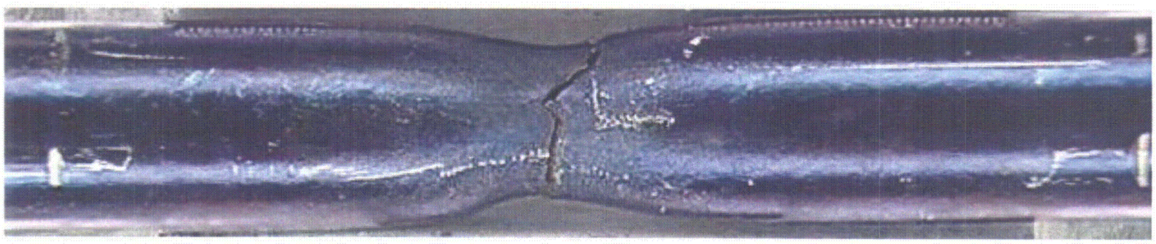
Figure 5-20 Fractured Tensile Specimens from Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Longitudinal Orientation)



Specimen WT-10 Tested at 150°F

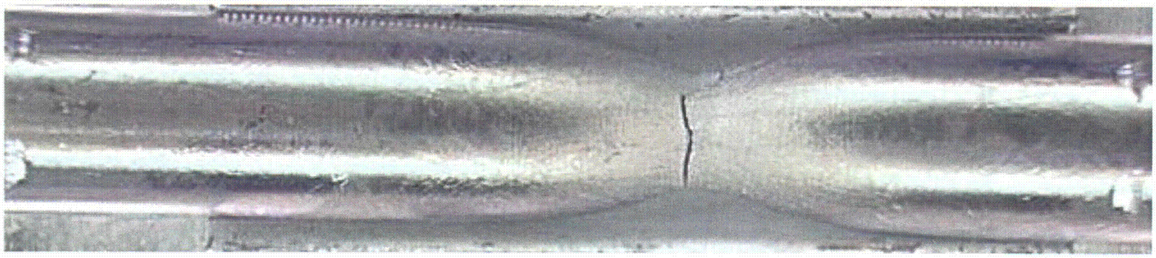


Specimen WT-11 Tested at 245°F

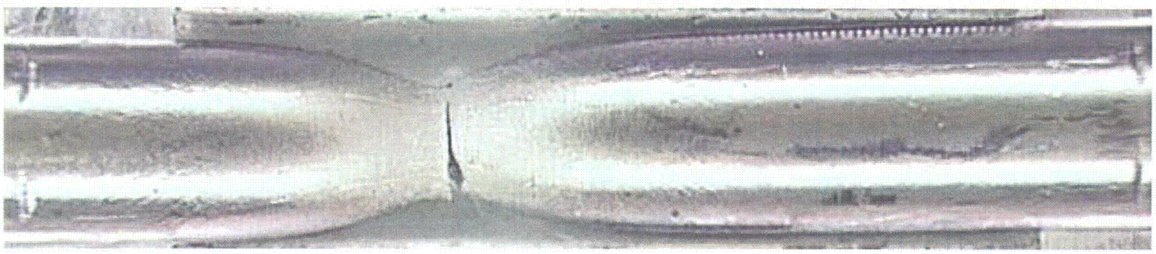


Specimen WT-12 Tested at 550°F

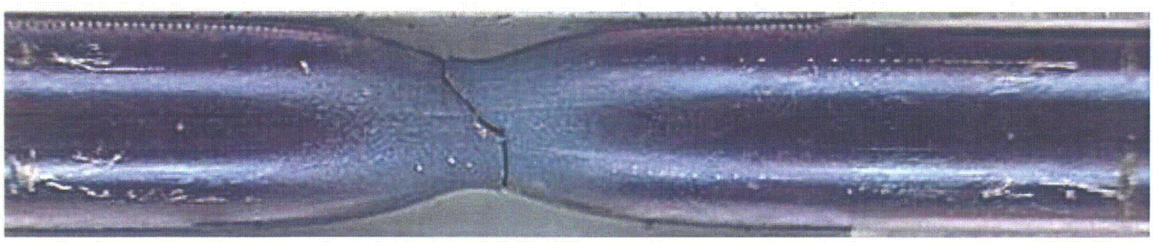
Figure 5-21 Fractured Tensile Specimen from Beaver Valley Unit 2 Reactor Vessel Intermediate Shell Plate B9004-2 (Transverse Orientation)



Specimen WW-10 Tested at 70°F

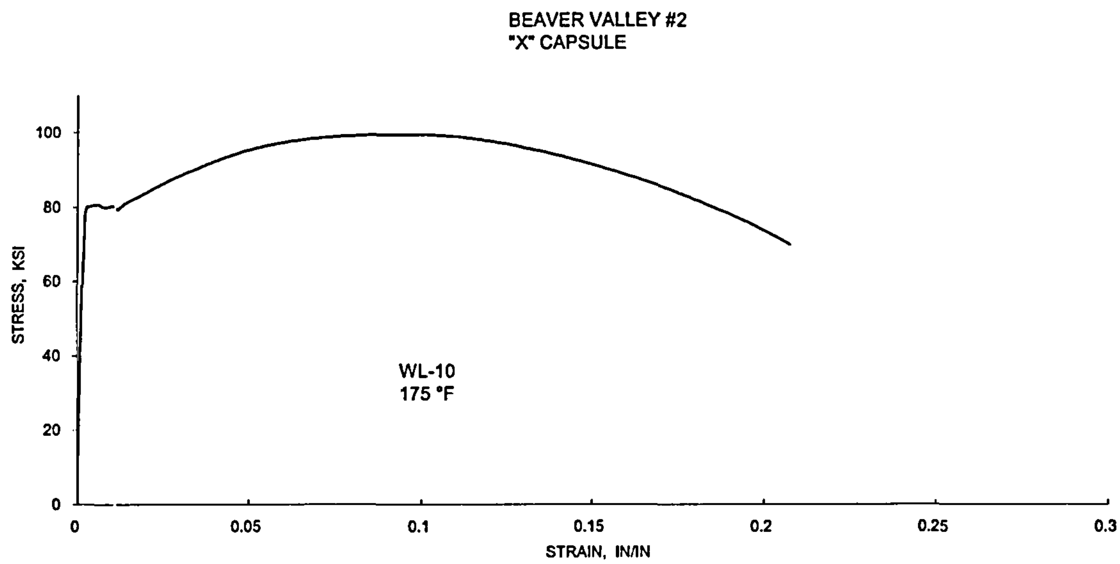


Specimen WW-11 Tested at 125°F



Specimen WW-12 Tested at 550°F

Figure 5-22 Fractured Tensile Specimen from Beaver Valley Unit 2 Reactor Vessel Weld Metal



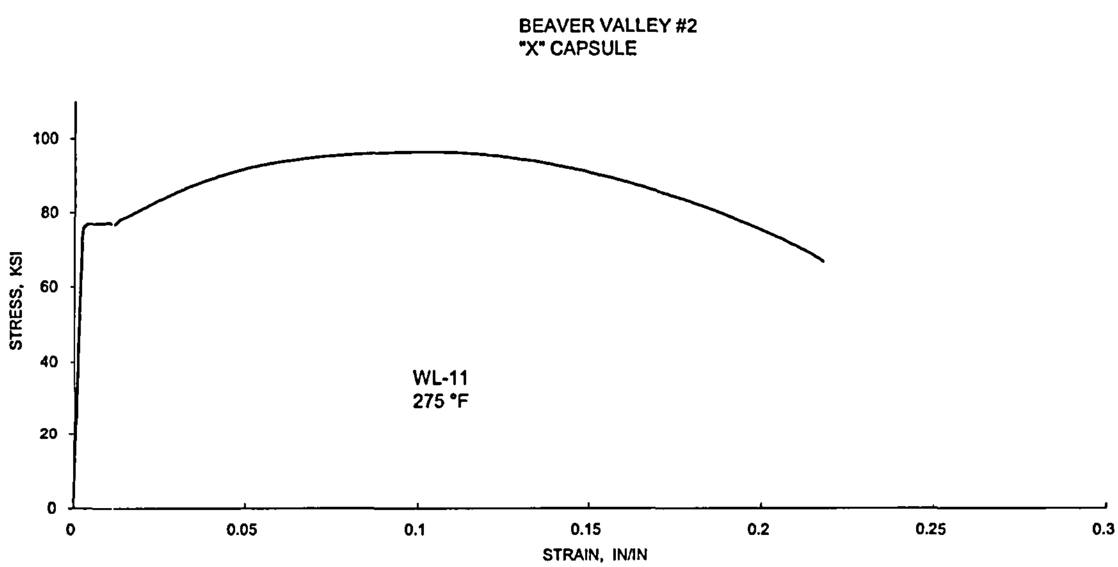


Figure 5-23 Engineering Stress-Strain Curves for Beaver Valley Unit 2 Intermediate Shell Plate B9004-2 Tensile Specimens WL-10 and WL-11 (Longitudinal Orientation)

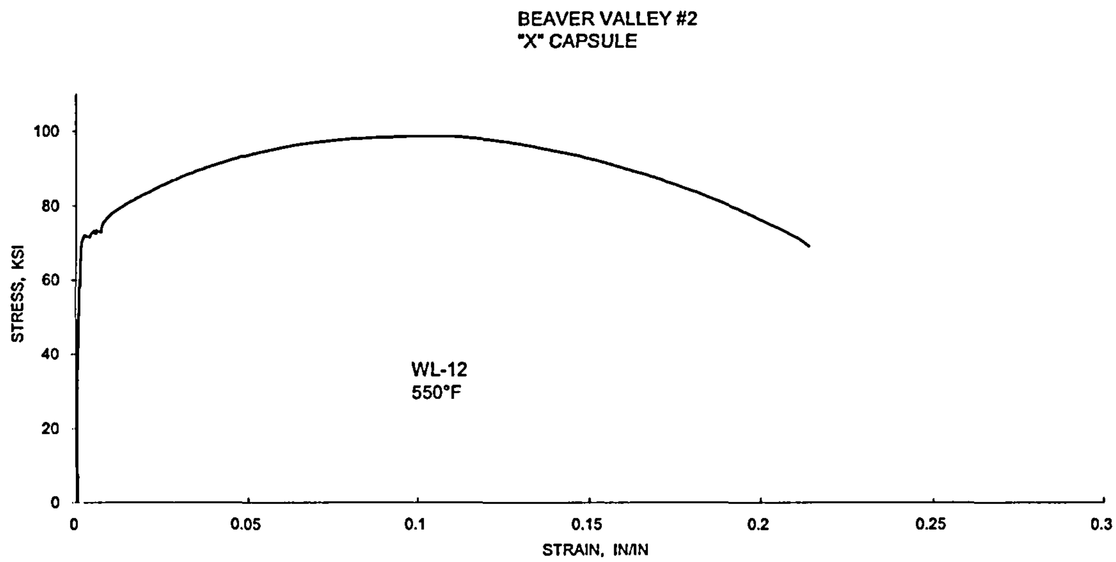
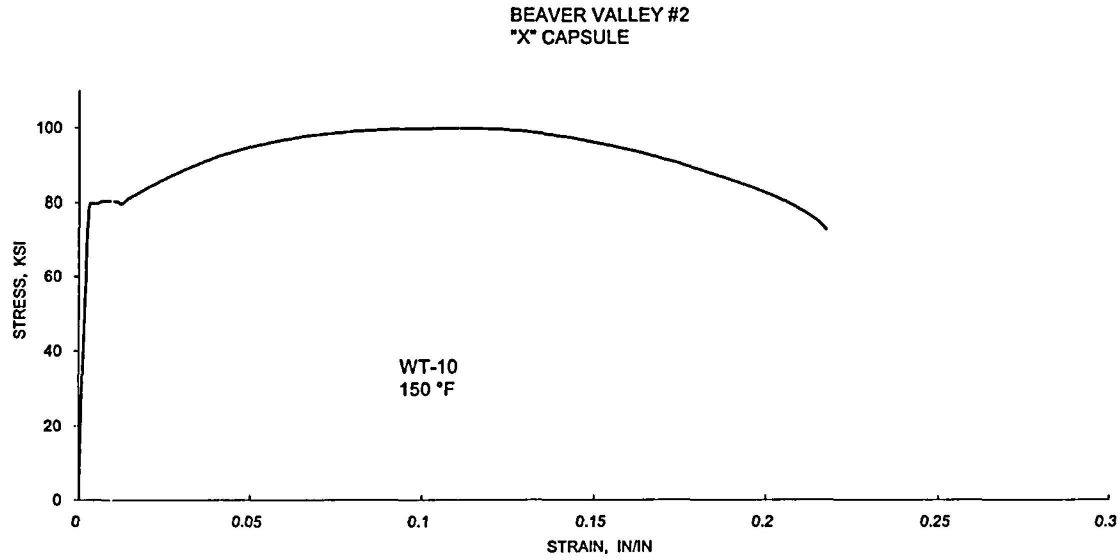


Figure 5-24 Engineering Stress-Strain Curve for Beaver Valley Unit 2 Intermediate Shell Plate B9004-2 Tensile Specimen WL-12 (Longitudinal Orientation)



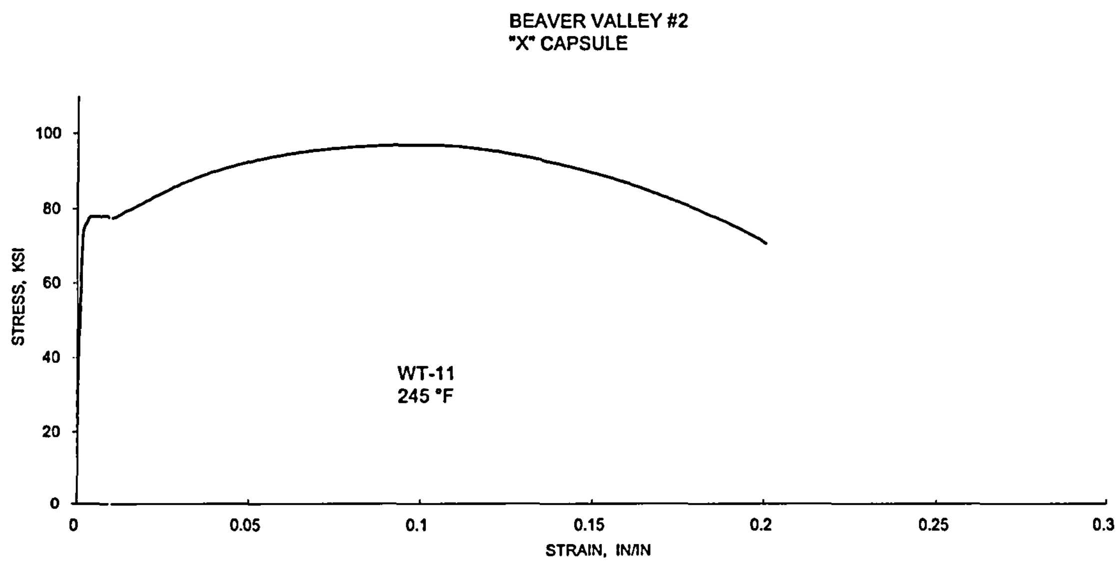


Figure 5-25 Engineering Stress-Strain Curves for Beaver Valley Unit 2 Intermediate Shell Plate B9004-2 Tensile Specimens WT-10 and WT-11 (Transverse Orientation)

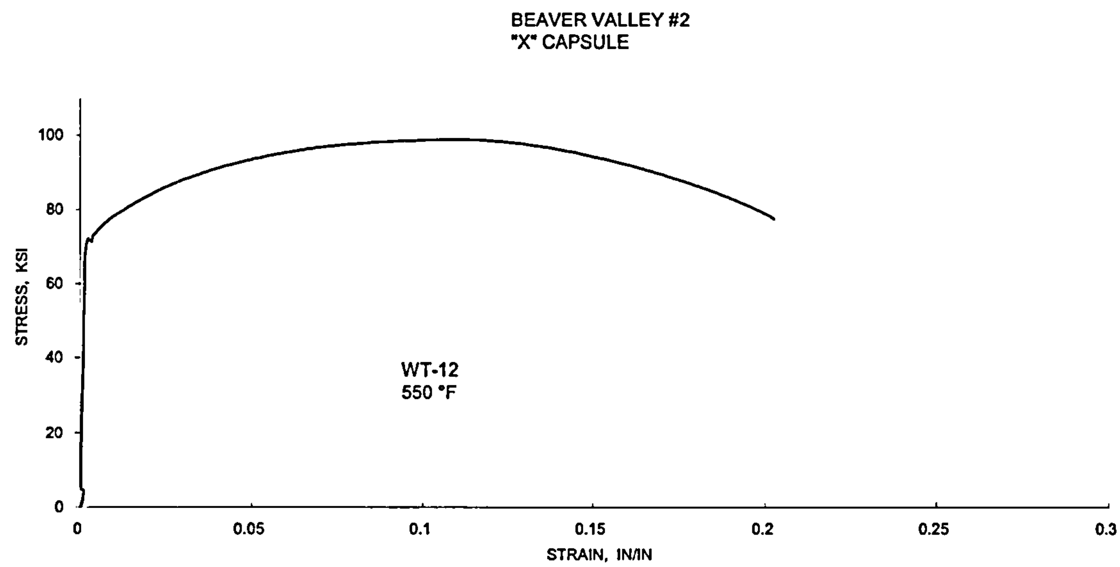
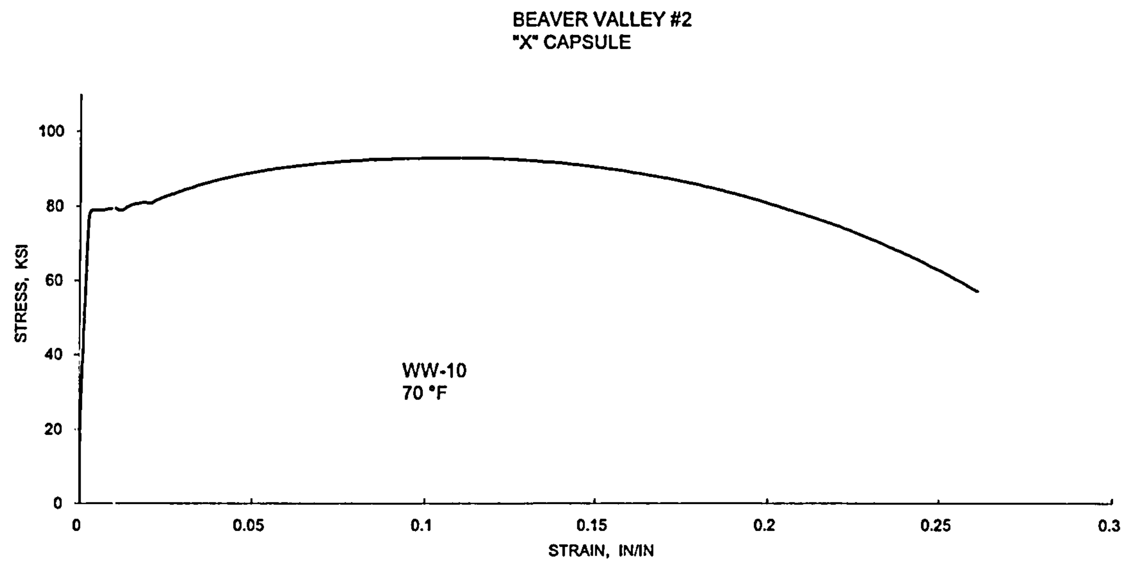


Figure 5-26 Engineering Stress-Strain Curve for Beaver Valley Unit 2 Intermediate Shell Plate B9004-2 Tensile Specimen WT-12 (Transverse Orientation)



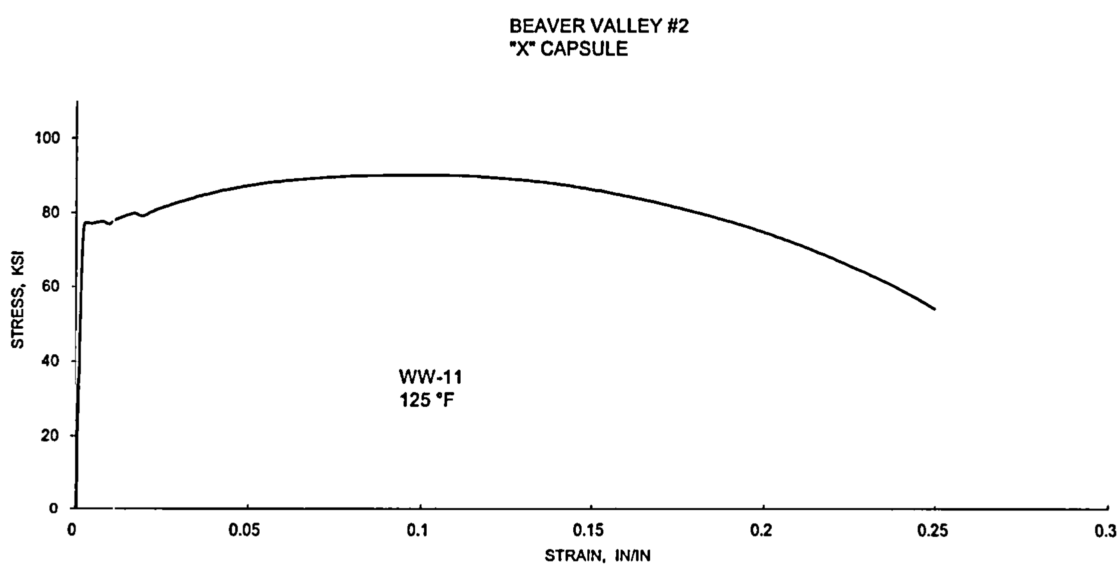


Figure 5-27 Engineering Stress-Strain Curves for Beaver Valley Unit 2 Weld Metal Tensile Specimens WW-10 and WW-11

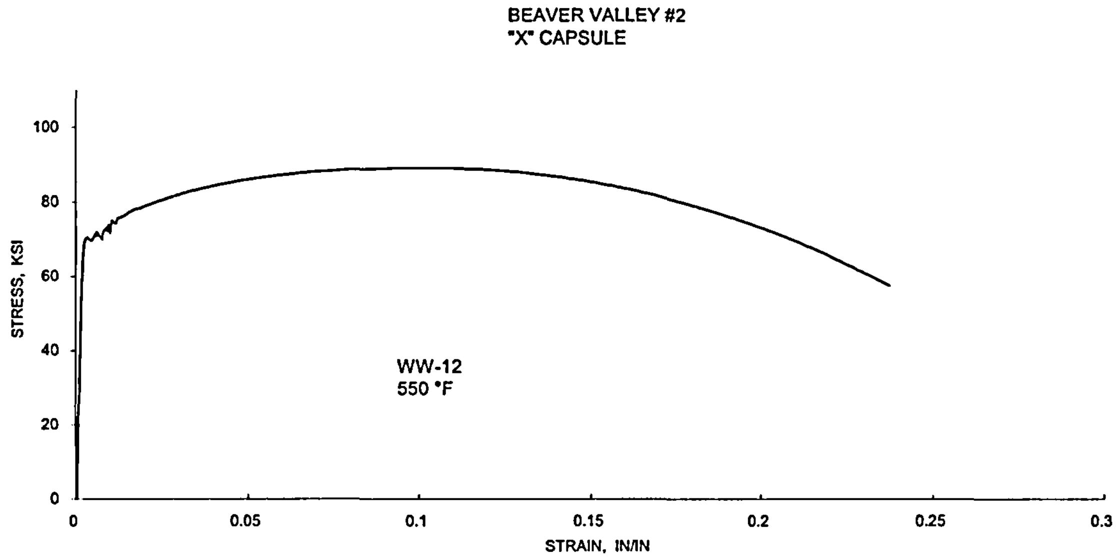


Figure 5-28 Engineering Stress-Strain Curve for Beaver Valley Unit 2 Weld Metal Tensile Specimen WW-12

6 RADIATION ANALYSIS AND NEUTRON DOSIMETRY

6.1 INTRODUCTION (REPLACED ENTIRE SECTION)

This section describes a discrete ordinates S_n transport analysis performed for the Beaver Valley Unit 2 reactor to determine the neutron radiation environment within the reactor pressure vessel and surveillance capsules. In this analysis, fast neutron exposure parameters in terms of fast neutron fluence (E > 1.0 MeV) and iron atom displacements (dpa) were established on a plant and fuel cycle specific basis. An evaluation of the most recent dosimetry sensor set from Capsule X, withdrawn at the end of the eleventh plant operating cycle, is provided. In addition, to provide an up-to-date database applicable to the Beaver Valley Unit 2 reactor, sensor sets from previously withdrawn capsules (U, V, and W) were re-analyzed using the current dosimetry evaluation methodology. These dosimetry updates are presented in Appendix A of this report. Comparisons of the results from these dosimetry evaluations with the analytical predictions served to validate the plant specific neutron transport calculations. These validated calculations subsequently formed the basis for providing projections of the neutron exposure of the reactor pressure vessel for operating periods extending to 54 Effective Full Power Years (EFPY).

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 the development of damage trend curves as well as for the implementation of trend curve data to assess the condition of the vessel. 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 and improved accuracy in the 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 E853-01, "Analysis and Interpretation of Light-Water Reactor Surveillance Results,"[Ref. 21] recommends reporting displacements per iron atom (dpa) along with fluence (E > 1.0 MeV) to provide a database for future reference. The energy dependent dpa function to be used for this evaluation is specified in ASTM Standard Practice E693-01, "Characterizing Neutron Exposures in Iron and Low Alloy Steels in Terms of Displacements per Atom." [Ref. 22] 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." [Ref. 1]

All of the calculations and dosimetry evaluations described in this section and in Appendix A were based on the latest available nuclear cross-section data derived from ENDF/B-VI and made use of the latest available calculational tools. Furthermore, the neutron transport and dosimetry evaluation methodologies follow the guidance and meet the requirements of Regulatory Guide 1.190, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence" [Ref. 23]. Additionally, the methods used to develop the calculated pressure vessel fluence follow the NRC approved methodology described in WCAP-14040-NP-A, "Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves," May 2004 [Ref. 24]. The dosimetry evaluations use the methodology described in WCAP-16083-NP, "Benchmark Testing of the FERRET Code for Least Squares Evaluation of Light Water Reactor Dosimetry," May 2004 [Ref. 25].

6.2 DISCRETE ORDINATES ANALYSIS

A plan view of the Beaver Valley Unit 2 reactor geometry at the core midplane is shown in Figure 4-1. Six irradiation capsules attached to the neutron pad are included in the reactor design that constitutes the reactor vessel surveillance program. The capsules are located at azimuthal angles of 107°, 287°, 343° (17° from the core cardinal axes) and 110°, 290°, 340° (20° from the core cardinal axes). The stainless steel specimen containers are 1.182-inch by 1-inch and are 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 pads 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 Beaver Valley Unit 2 reactor vessel and surveillance capsules, a series of fuel cycle specific forward transport calculations were carried out using the following three-dimensional flux synthesis technique:

$$\phi(r,\theta,z) = \phi(r,\theta) * \frac{\phi(r,z)}{\phi(r)}$$

where $\phi(r,\theta,z)$ is the synthesized three-dimensional neutron flux distribution, $\phi(r,\theta)$ is the transport solution in r,θ geometry, $\phi(r,z)$ is the two-dimensional solution for a cylindrical reactor model using the actual axial core power distribution, and $\phi(r)$ is the one-dimensional solution for a cylindrical reactor model using the same source per unit height as that used in the r,θ two-dimensional calculation. This synthesis procedure was carried out for each operating cycle at Beaver Valley Unit 2.

For the Beaver Valley Unit 2 transport calculations, two octant symmetric r,θ models were developed and are depicted in Figure 6-1. The first model contained the shortened neutron pad (15° span) with no surveillance capsules, while the second contained the extended neutron pad (26° span) including the surveillance capsules. The latter model was used to perform surveillance capsule dosimetry evaluations and subsequent comparisons with calculated results, while the former model was used to generate the maximum fluence at the pressure vessel wall. In developing these analytical models, nominal design dimensions were employed for the various structural components. Likewise, water temperatures, and hence, coolant densities in the reactor core and downcomer regions of the reactor were taken to be representative of full power operating conditions. The coolant densities were treated on a fuel cycle specific basis. The reactor core itself was treated as a homogeneous mixture of fuel, cladding, water, and miscellaneous core structures such as fuel assembly grids, guide tubes, et cetera. The geometric mesh description of the r,θ reactor models consisted of 185 radial by 92 azimuthal intervals. Mesh sizes were chosen to assure that proper convergence of the inner iterations was achieved on a pointwise basis. The pointwise inner iteration flux convergence criterion utilized in the r,θ calculations was set at a value of 0.001.

The r,z model used for the Beaver Valley Unit 2 calculations is shown in Figure 6-2 and extends radially from the centerline of the reactor core out to a location interior to the primary biological shield and over an axial span from an elevation 1-foot below the active fuel to approximately 1-foot above the active fuel. As in the case of the r,θ models, nominal design dimensions and full power coolant densities were employed in the calculations. In this case, the homogenous core region was treated as an equivalent cylinder with a volume equal to that of the active core zone. The stainless steel former plates located between the core baffle and core barrel regions were also explicitly included in the model. The r,z geometric mesh description of this reactor model consisted of 149 radial by 178 axial intervals. As in the case of the r,θ calculations, mesh sizes were chosen to assure that proper convergence of the inner iterations was achieved on a pointwise basis. The pointwise inner iteration flux convergence criterion utilized in the r,z calculations was also set at a value of 0.001.

The one-dimensional radial model used in the synthesis procedure consisted of the same 149 radial mesh intervals included in the r,z model. Thus, radial synthesis factors could be determined on a meshwise basis throughout the entire geometry.

The core power distributions used in the plant specific transport analysis were taken from the appropriate Beaver Valley Unit 2 fuel cycle design reports. The data extracted from the design reports represented cycle dependent fuel assembly enrichments, burnups, and axial power distributions. This information was used to develop spatial and energy dependent core source distributions averaged over each individual fuel cycle. Therefore, the results from the neutron transport calculations provided data in terms of fuel cycle averaged neutron flux, which when multiplied by the appropriate fuel cycle length, generated the incremental fast neutron exposure for each fuel cycle. In constructing these core source distributions, the energy distribution of the source was based on an appropriate fission split for uranium and plutonium isotopes based on the initial enrichment and burnup history of individual fuel assemblies. From these assembly dependent fission splits, composite values of energy release per fission, neutron yield per fission, and fission spectrum were determined.

All of the transport calculations supporting this analysis were carried out using the DORT discrete ordinates code Version 3.1 [Ref. 26] and the BUGLE-96 cross-section library [Ref. 27]. The BUGLE-96 library provides a 67 group coupled neutron-gamma ray cross-section data set produced specifically for light water reactor (LWR) applications. In these analyses, anisotropic scattering was treated with a P_5 legendre expansion and angular discretization was modeled with an S_{16} order of angular quadrature. Energy and space dependent core power distributions, as well as system operating temperatures, were treated on a fuel cycle specific basis.

Selected results from the neutron transport analyses are provided in Tables 6-1 through 6-6. In Table 6-1, the calculated exposure rates and integrated exposures, expressed in terms of both neutron fluence ($E > 1.0$ MeV) and dpa, are given at the radial and azimuthal center of the two azimuthally symmetric surveillance capsule positions (17° and 20°). These results, representative of the axial midplane of the active core, establish the calculated exposure of the surveillance capsules withdrawn to date as well as projected into the future. Similar information is provided in Table 6-2 for the reactor vessel inner radius. The vessel data given in Table 6-2 are representative of the axial location of the maximum neutron exposure at each of four azimuthal locations (0°, 15°, 30°, and 45°). It is also important to note that the data for the vessel inner radius were taken at the clad/base metal interface, and thus, represent the maximum calculated exposure levels of the vessel plates and welds.

Both calculated fluence (E > 1.0 MeV) and dpa data are provided in Tables 6-1 and 6-2. These data tabulations include both plant and fuel cycle specific calculated neutron exposures at the end of the eleventh operating fuel cycle as well as projections to 17, 20, 25, 32, 48, and 54 EFPY. The projections were based on the assumption that the core power distributions and associated plant operating characteristics for cycle 12 were representative of plant operation to 17 effective full power years and that the preliminary cycle 13 core power distribution was applicable beyond 17 effective full power years. The future projections listed in Tables 6-1 and 6-2 are also based on the assumption of a power uprate to 2900 MWt at 17 effective full power years.

Radial gradient information applicable to fast (E > 1.0 MeV) neutron fluence and dpa are given in Tables 6-3 and 6-4, respectively. The data, based on the cumulative integrated exposures from Cycles 1 through 11, are presented on a relative basis for each exposure parameter at several azimuthal locations. Exposure distributions through the vessel wall may be obtained by multiplying the calculated exposure at the vessel inner radius by the gradient data listed in Tables 6-3 and 6-4.

The calculated fast neutron exposures for the four surveillance capsules withdrawn from the Beaver Valley Unit 2 reactor are provided in Table 6-5. These assigned neutron exposure levels are based on the plant and fuel cycle specific neutron transport calculations performed for the Beaver Valley Unit 2 reactor.

Updated lead factors for the Beaver Valley Unit 2 surveillance capsules are provided in Table 6-6. The capsule lead factor is defined as the ratio of the calculated fluence (E > 1.0 MeV) at the geometric center of the surveillance capsule to the corresponding maximum calculated fluence at the pressure vessel clad/base metal interface. In Table 6-6, the lead factors for capsules that have been withdrawn from the reactor (U, V, W, and X) were based on the calculated fluence values for the irradiation period corresponding to the time of withdrawal for the individual capsules. For the capsules remaining in the reactor (Y and Z) the lead factor corresponds to the calculated fluence values at the end of cycle 11, the last completed operating fuel cycle for Beaver Valley Unit 2.

6.3 NEUTRON DOSIMETRY

The validity of the calculated neutron exposures previously reported in Section 6.2 is demonstrated by a direct comparison against the measured sensor reaction rates and via a least squares evaluation performed for each of the capsule dosimetry sets. However, since the neutron dosimetry measurement data merely serves to validate the calculated results, only the direct comparison of measured-to-calculated results for the most recent surveillance capsule removed from service is provided in this section of the report. For completeness, the assessment of all measured dosimetry removed to date, based on both direct and least squares evaluation comparisons, is documented in Appendix A.

The direct comparison of measured versus calculated fast neutron threshold reaction rates for the sensors from Capsule X, that was withdrawn from Beaver Valley Unit 2 at the end of the eleventh fuel cycle, is summarized below.

Reaction	Reaction Rates (rps/atom)		M/C
	Measured	Calculated	Ratio
$^{63}Cu(n,\alpha)^{60}Co$	5.96E-17	6.02E-17	0.99
$^{54}Fe(n,p)^{54}Mn$	6.21E-15	6.99E-15	0.89
$^{58}Ni(n,p)^{58}Co$	9.05E-15	9.88E-15	0.92
$^{237}Np(n,f)^{137}Cs$ (Cd)	3.64E-13	4.09E-13	0.89
		Average:	0.92
		% Standard Deviation:	5.1

The measured-to-calculated (M/C) reaction rate ratios for the Capsule X threshold reactions range from 0.89 to 0.99, and the average M/C ratio is 0.92 ± 5.1% (1σ). This direct comparison falls well within the ± 20% criterion specified in Regulatory Guide 1.190; furthermore, it is consistent with the full set of comparisons given in Appendix A for all measured dosimetry removed to date from the Beaver Valley Unit 2 reactor. These comparisons validate the current analytical results described in Section 6.2; therefore, the calculations are deemed applicable for Beaver Valley Unit 2.

6.4 CALCULATIONAL UNCERTAINTIES

The uncertainty associated with the calculated neutron exposure of the Beaver Valley Unit 2 surveillance capsule and reactor pressure vessel is based on the recommended approach provided in Regulatory Guide 1.190. In particular, the qualification of the methodology was carried out in the following four stages:

1 - Comparison of calculations with benchmark measurements from the Pool Critical Assembly (PCA) simulator at the Oak Ridge National Laboratory (ORNL).

2 - Comparisons of calculations with surveillance capsule and reactor cavity measurements from the H. B. Robinson power reactor benchmark experiment.

3 - An analytical sensitivity study addressing the uncertainty components resulting from important input parameters applicable to the plant specific transport calculations used in the neutron exposure assessments.

4 - Comparisons of the plant specific calculations with all available dosimetry results from the Beaver Valley Unit 2 surveillance program.

The first phase of the methods qualification (PCA comparisons) addressed the adequacy of basic transport calculation and dosimetry evaluation techniques and associated cross-sections. This phase, however, did not test the accuracy of commercial core neutron source calculations nor did it address uncertainties in operational or geometric variables that impact power reactor calculations. The second phase of the qualification (H. B. Robinson comparisons) addressed uncertainties in these additional areas that are primarily methods related and would tend to apply generically to all fast neutron exposure evaluations. The third phase of the qualification (analytical sensitivity study) identified the potential uncertainties introduced into the overall evaluation due to calculational methods approximations as well as to a lack of knowledge relative to various plant specific input parameters. The overall calculational uncertainty applicable to the Beaver Valley Unit 2 analysis was established from results of these three phases of the methods qualification.

The fourth phase of the uncertainty assessment (comparisons with Beaver Valley Unit 2 measurements) was used solely to demonstrate the validity of the transport calculations and to confirm the uncertainty estimates associated with the analytical results. The comparison was used only as a check and was not used in any way to modify the calculated surveillance capsule and pressure vessel neutron exposures previously described in Section 6.2. As such, the validation of the Beaver Valley Unit 2 analytical model based on the measured plant dosimetry is completely described in Appendix A.

The following summarizes the uncertainties developed from the first three phases of the methodology qualification. Additional information pertinent to these evaluations is provided in Reference 3.

	Capsule	Vessel IR
PCA Comparisons	3%	3%
H. B. Robinson Comparisons	3%	3%
Analytical Sensitivity Studies	10%	11%
Additional Uncertainty for Factors not Explicitly Evaluated	5%	5%
Net Calculational Uncertainty	12%	13%

The net calculational uncertainty was determined by combining the individual components in quadrature. Therefore, the resultant uncertainty was treated as random and no systematic bias was applied to the analytical results.

The plant specific measurement comparisons described in Appendix A support these uncertainty assessments for Beaver Valley Unit 2.

Figure 6-1
r,θ Reactor Geometry with a 15° Neutron Pad at the Core Midplane

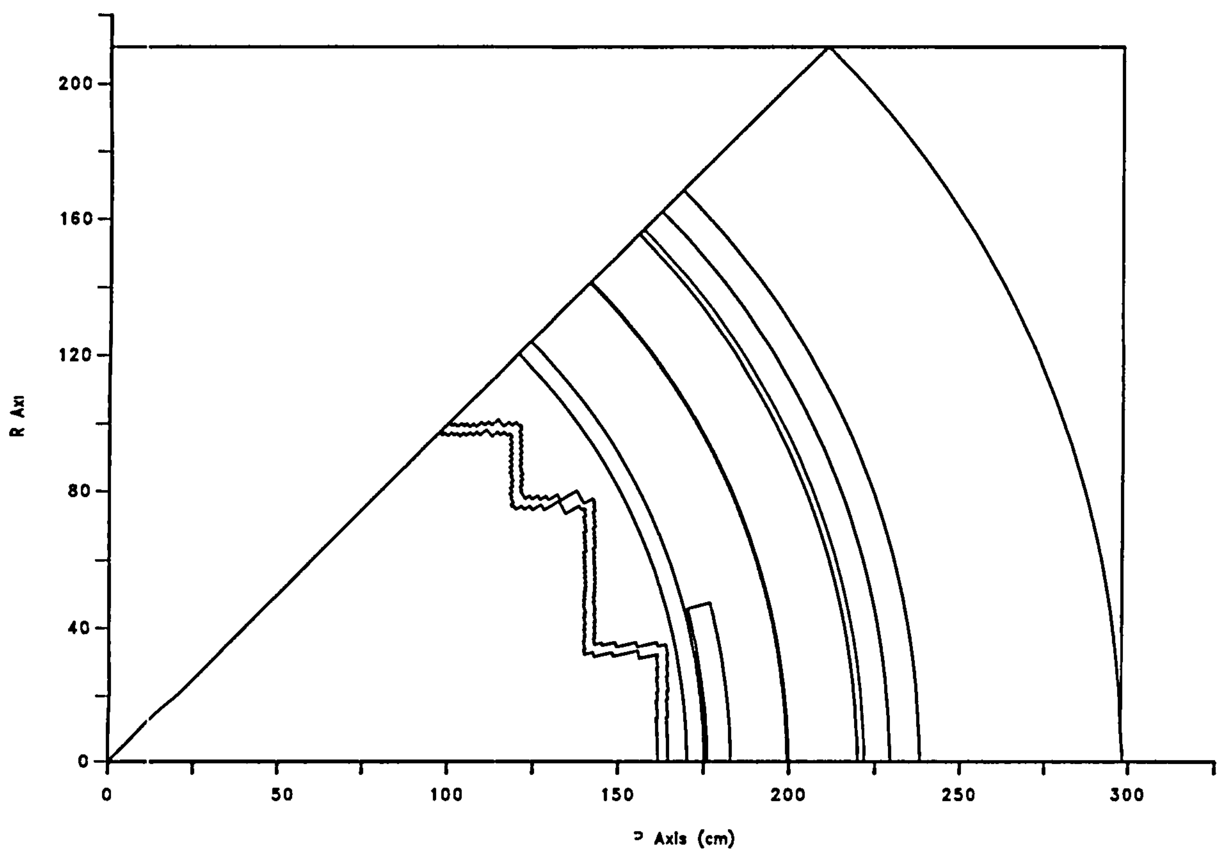


Figure 6-1 (continued)
r,θ Reactor Geometry with a 26° Neutron Pad at the Core Midplane

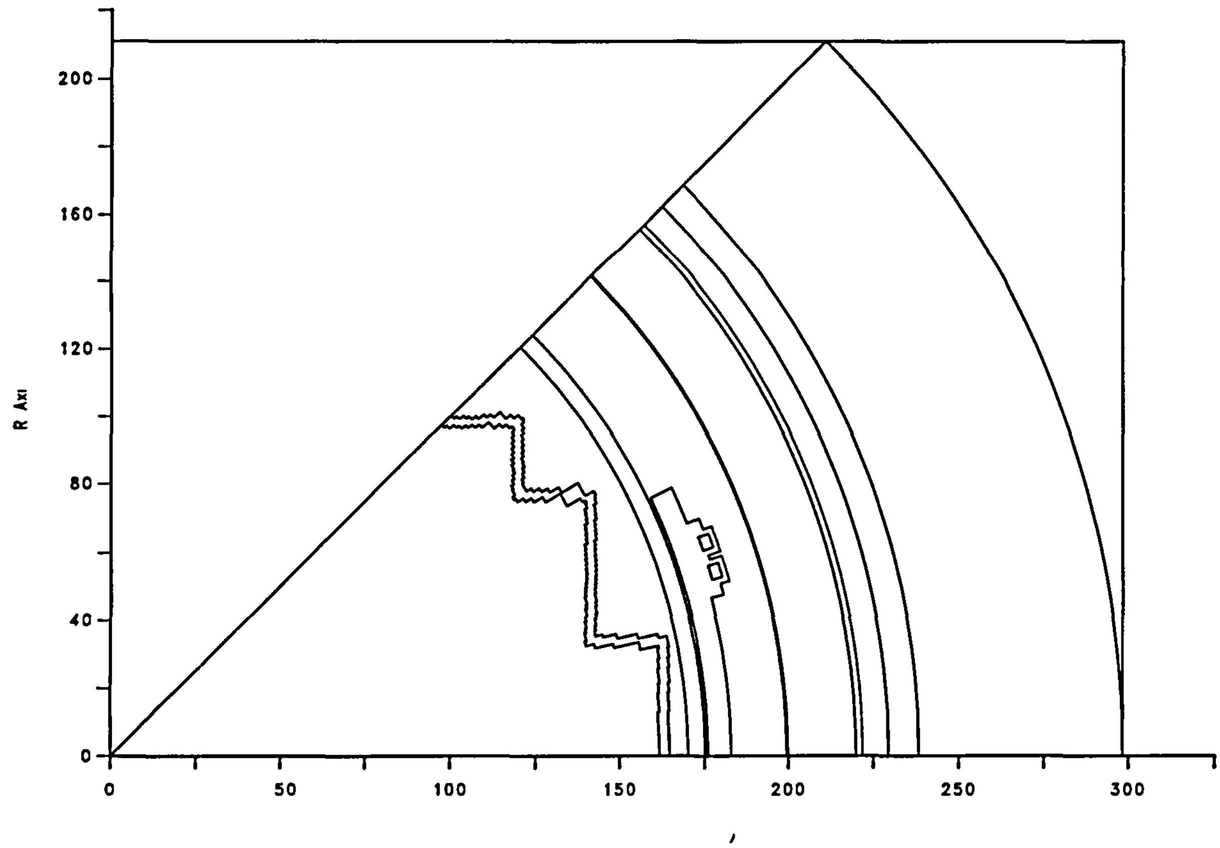


Figure 6-2
Beaver Valley Unit 2 r,z Reactor Geometry with Neutron Pad

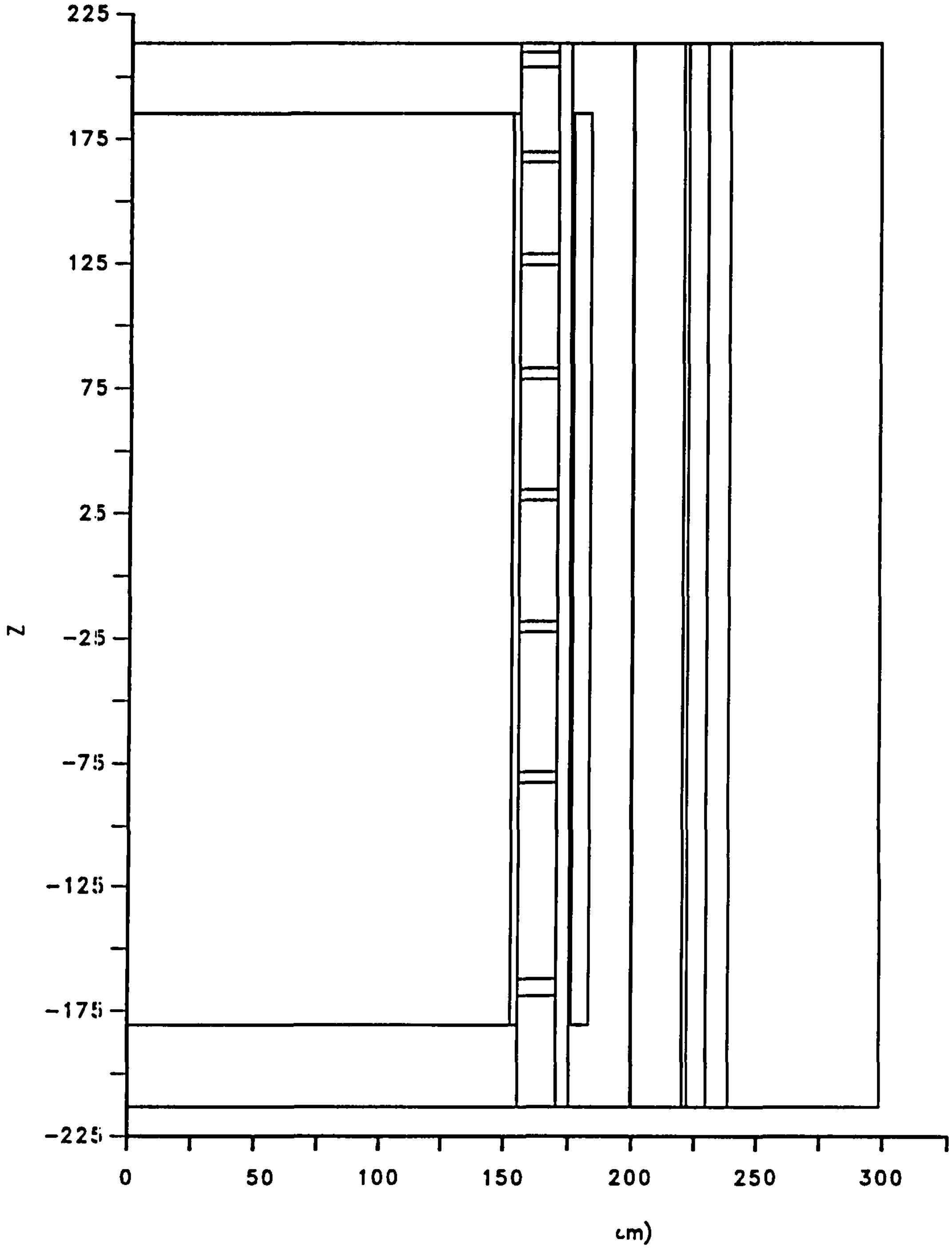


Table 6-1
Calculated Neutron Exposure Rates And Integrated Exposures
At The Surveillance Capsule Center
Neutrons (E > 1.0 MeV)

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Flux (E > 1.0 MeV) [n/cm^2-s]	
				17°	20°
1	3.92E+07	3.92E+07	1.24	1.55E+11	1.34E+11
2	3.20E+07	7.12E+07	2.26	1.26E+11	1.11E+11
3	3.90E+07	1.10E+08	3.49	1.41E+11	1.27E+11
4	3.99E+07	1.50E+08	4.76	1.38E+11	1.23E+11
5	3.87E+07	1.89E+08	5.98	1.34E+11	1.16E+11
6	3.88E+07	2.28E+08	7.21	1.25E+11	1.14E+11
7	3.93E+07	2.67E+08	8.46	1.23E+11	1.09E+11
8	4.15E+07	3.08E+08	9.77	1.20E+11	1.07E+11
9	3.86E+07	3.47E+08	11.00	1.11E+11	9.64E+10
10	4.73E+07	3.94E+08	12.49	1.14E+11	1.01E+11
11	4.56E+07	4.40E+08	13.94	1.19E+11	1.03E+11
12(Prj)	9.66E+07	5.37E+08	17.00	1.11E+11	9.57E+10
Future	9.47E+07	6.31E+08	20.00	1.21E+11	1.03E+11
Future	1.58E+08	7.89E+08	25.00	1.21E+11	1.03E+11
Future	2.21E+08	1.01E+09	32.00	1.21E+11	1.03E+11
Future	5.05E+08	1.52E+09	48.00	1.21E+11	1.03E+11
Future	1.89E+08	1.70E+09	54.00	1.21E+11	1.03E+11

Note: Neutron exposure values reported for the surveillance capsules are centered at the core midplane.

Table 6-1 cont'd
Calculated Neutron Exposure Rates And Integrated Exposures At The Surveillance Capsule Center

Neutrons (E > 1.0 MeV)

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Fluence (E > 1.0 MeV) [n/cm^2]	
				17°	20°
1	3.92E+07	3.92E+07	1.24	6.08E+18	5.26E+18
2	3.20E+07	7.12E+07	2.26	1.01E+19	8.81E+18
3	3.90E+07	1.10E+08	3.49	1.56E+19	1.38E+19
4	3.99E+07	1.50E+08	4.76	2.11E+19	1.87E+19
5	3.87E+07	1.89E+08	5.98	2.63E+19	2.31E+19
6	3.88E+07	2.28E+08	7.21	3.11E+19	2.76E+19
7	3.93E+07	2.67E+08	8.46	3.60E+19	3.19E+19
8	4.15E+07	3.08E+08	9.77	4.10E+19	3.63E+19
9	3.86E+07	3.47E+08	11.00	4.52E+19	4.00E+19
10	4.73E+07	3.94E+08	12.49	5.06E+19	4.48E+19
11	4.56E+07	4.40E+08	13.94	5.60E+19	4.95E+19
12(Prj)	9.66E+07	5.37E+08	17.00	6.67E+19	5.87E+19
Future	9.47E+07	6.31E+08	20.00	7.81E+19	6.85E+19
Future	1.58E+08	7.89E+08	25.00	9.72E+19	8.47E+19
Future	2.21E+08	1.01E+09	32.00	1.24E+20	1.07E+20
Future	5.05E+08	1.52E+09	48.00	1.85E+20	1.59E+20
Future	1.89E+08	1.70E+09	54.00	2.08E+20	1.79E+20

Note: Neutron exposure values reported for the surveillance capsules are centered at the core midplane.

Table 6-1 cont'd
Calculated Neutron Exposure Rates And Integrated Exposures
At The Surveillance Capsule Center

IRON ATOM DISPLACEMENTS

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Displacement Rate [dpa/s]	
				17°	20°
1	3.92E+07	3.92E+07	1.24	3.19E-10	2.70E-10
2	3.20E+07	7.12E+07	2.26	2.54E-10	2.20E-10
3	3.90E+07	1.10E+08	3.49	2.85E-10	2.52E-10
4	3.99E+07	1.50E+08	4.76	2.79E-10	2.43E-10
5	3.87E+07	1.89E+08	5.98	2.73E-10	2.30E-10
6	3.88E+07	2.28E+08	7.21	2.53E-10	2.26E-10
7	3.93E+07	2.67E+08	8.46	2.49E-10	2.17E-10
8	4.15E+07	3.08E+08	9.77	2.43E-10	2.12E-10
9	3.86E+07	3.47E+08	11.00	2.25E-10	1.92E-10
10	4.73E+07	3.94E+08	12.49	2.30E-10	2.00E-10
11	4.56E+07	4.40E+08	13.94	2.39E-10	2.05E-10
12(Prj)	9.66E+07	5.37E+08	17.00	2.25E-10	1.90E-10
Future	9.47E+07	6.31E+08	20.00	2.45E-10	2.05E-10
Future	1.58E+08	7.89E+08	25.00	2.45E-10	2.05E-10
Future	2.21E+08	1.01E+09	32.00	2.45E-10	2.05E-10
Future	5.05E+08	1.52E+09	48.00	2.45E-10	2.05E-10
Future	1.89E+08	1.70E+09	54.00	2.45E-10	2.05E-10

Note: Neutron exposure values reported for the surveillance capsules are centered at the core midplane.

Table 6-1 cont'd
Calculated Neutron Exposure Rates And Integrated Exposures
At The Surveillance Capsule Center

IRON ATOM DISPLACEMENTS

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Displacements [dpa]	
				17°	20°
1	3.92E+07	3.92E+07	1.24	1.25E-02	1.06E-02
2	3.20E+07	7.12E+07	2.26	2.06E-02	1.76E-02
3	3.90E+07	1.10E+08	3.49	3.18E-02	2.74E-02
4	3.99E+07	1.50E+08	4.76	4.29E-02	3.71E-02
5	3.87E+07	1.89E+08	5.98	5.34E-02	4.60E-02
6	3.88E+07	2.28E+08	7.21	6.32E-02	5.48E-02
7	3.93E+07	2.67E+08	8.46	7.30E-02	6.33E-02
8	4.15E+07	3.08E+08	9.77	8.31E-02	7.21E-02
9	3.86E+07	3.47E+08	11.00	9.18E-02	7.95E-02
10	4.73E+07	3.94E+08	12.49	1.03E-01	8.90E-02
11	4.56E+07	4.40E+08	13.94	1.14E-01	9.83E-02
12(Prj)	9.66E+07	5.37E+08	17.00	1.35E-01	1.17E-01
Future	9.47E+07	6.31E+08	20.00	1.59E-01	1.36E-01
Future	1.58E+08	7.89E+08	25.00	1.97E-01	1.68E-01
Future	2.21E+08	1.01E+09	32.00	2.51E-01	2.14E-01
Future	5.05E+08	1.52E+09	48.00	3.75E-01	3.17E-01
Future	1.89E+08	1.70E+09	54.00	4.22E-01	3.56E-01

Note: Neutron exposure values reported for the surveillance capsules are centered at the core midplane.

Table 6-2
Calculated Azimuthal Variation Of Maximum Exposure Rates
And Integrated Exposures At The Reactor Vessel
Clad/Base Metal Interface
With Uprate to 2900 MWt at the Start of Cycle 13

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Flux (E > 1.0 MeV) [n/cm^2-s]			
				0°	15°	30°	45°
1	3.92E+07	3.92E+07	1.24	4.89E+10	2.73E+10	2.02E+10	1.38E+10
2	3.20E+07	7.12E+07	2.26	3.34E+10	2.09E+10	1.56E+10	1.07E+10
3	3.90E+07	1.10E+08	3.49	3.39E+10	2.29E+10	1.80E+10	1.29E+10
4	3.99E+07	1.50E+08	4.76	3.68E+10	2.29E+10	1.67E+10	1.07E+10
5	3.87E+07	1.89E+08	5.98	3.75E+10	2.27E+10	1.56E+10	1.06E+10
6	3.88E+07	2.28E+08	7.21	3.18E+10	2.11E+10	1.79E+10	1.29E+10
7	3.93E+07	2.67E+08	8.46	3.32E+10	2.08E+10	1.71E+10	1.30E+10
8	4.15E+07	3.08E+08	9.77	3.11E+10	1.99E+10	1.58E+10	1.15E+10
9	3.86E+07	3.47E+08	11.00	3.31E+10	1.900+10	1.46E+10	1.11E+10
10	4.73E+07	3.94E+08	12.49	2.96E+10	1.89E+10	1.46E+10	1.07E+10
11	4.56E+07	4.40E+08	13.94	3.25E+10	1.97E+10	1.43E+10	9.50E+09
12(Prj)	9.66E+07	5.37E+08	17.00	3.12E+10	1.86E+10	1.38E+10	9.98E+09
Future	9.47E+07	6.31E+08	20.00	3.82E+10	2.04E+10	1.44E+10	1.01E+10
Future	1.58E+08	7.89E+08	25.00	3.82E+10	2.04E+10	1.44E+10	1.01E+10
Future	2.21E+08	1.01E+09	32.00	3.82E+10	2.04E+10	1.44E+10	1.01E+10
Future	5.05E+08	1.52E+09	48.00	3.82E+10	2.04E+10	1.44E+10	1.01E+10
Future	1.89E+08	1.70E+09	54.00	3.82E+10	2.04E+10	1.44E+10	1.01E+10

Table 6-2 cont'd
Calculated Azimuthal Variation Of Maximum Exposure Rates
And Integrated Exposures At The Reactor Vessel
Clad/Base Metal Interface
With Uprate to 2900 MWt at the Start of Cycle 13

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Fluence (E > 1.0 MeV) [n/cm²]			
				0°	15°	30°	45°
1	3.92E+07	3.92E+07	1.24	1.92E+18	1.07E+18	7.91E+17	5.41E+17
2	3.20E+07	7.12E+07	2.26	2.98E+18	1.74E+18	1.29E+18	8.82E+17
3	3.90E+07	1.10E+08	3.49	4.31E+18	2.63E+18	1.99E+18	1.38E+18
4	3.99E+07	1.50E+08	4.76	5.77E+18	3.55E+18	2.66E+18	1.81E+18
5	3.87E+07	1.89E+08	5.98	7.22E+18	4.42E+18	3.26E+18	2.22E+18
6	3.88E+07	2.28E+08	7.21	8.46E+18	5.24E+18	3.96E+18	2.72E+18
7	3.93E+07	2.67E+08	8.46	9.76E+18	6.06E+18	4.63E+18	3.23E+18
8	4.15E+07	3.08E+08	9.77	1.11E+19	6.88E+18	5.29E+18	3.70E+18
9	3.86E+07	3.47E+08	11.00	1.23E+19	7.62E+18	5.85E+18	4.13E+18
10	4.73E+07	3.94E+08	12.49	1.37E+19	8.51E+18	6.54E+18	4.64E+18
11	4.56E+07	4.40E+08	13.94	1.52E+19	9.41E+18	7.20E+18	5.07E+18
12(Prj)	9.66E+07	5.37E+08	17.00	1.82E+19	1.12E+19	8.53E+18	6.04E+18
Future	9.47E+07	6.31E+08	20.00	2.18E+19	1.31E+18	9.89E+18	6.99E+18
Future	1.58E+08	7.89E+08	25.00	2.79E+19	1.63E+19	1.22E+19	8.58E+18
Future	2.21E+08	1.01E+09	32.00	3.63E+19	2.09E+19	1.53E+19	1.08E+19
Future	5.05E+08	1.52E+09	48.00	5.56E+19	3.11E+19	2.26E+19	1.59E+19
Future	1.89E+08	1.70E+09	54.00	6.29E+19	3.50E+19	2.53E+19	1.78E+19

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 With Uprate to 2900 MWt at the Start of Cycle 13

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Iron Atom Displacement Rate [dpa/s]			
				0°	15°	30°	45°
1	3.92E+07	3.92E+07	1.24	7.76E-11	4.29E-11	3.09E-11	2.13E-11
2	3.20E+07	7.12E+07	2.26	5.32E-11	3.29E-11	2.41E-11	1.66E-11
3	3.90E+07	1.10E+08	3.49	5.39E-11	3.60E-11	2.77E-11	1.99E-11
4	3.99E+07	1.50E+08	4.76	5.84E-11	3.60E-11	2.57E-11	1.66E-11
5	3.87E+07	1.89E+08	5.98	5.96E-11	3.57E-11	2.40E-11	1.64E-11
6	3.88E+07	2.28E+08	7.21	5.05E-11	3.31E-11	2.75E-11	1.99E-11
7	3.93E+07	2.67E+08	8.46	5.27E-11	3.27E-11	2.63E-11	2.00E-11
8	4.15E+07	3.08E+08	9.77	4.94E-11	3.13E-11	2.43E-11	1.78E-11
9	3.86E+07	3.47E+08	11.00	5.28E-11	3.00E-11	2.24E-11	1.71E-11
10	4.73E+07	3.94E+08	12.49	4.69E-11	2.96E-11	2.25E-11	1.66E-11
11	4.56E+07	4.40E+08	13.94	5.15E-11	3.09E-11	2.22E-11	1.47E-11
12(Prj)	9.66E+07	5.37E+08	17.00	4.95E-11	2.92E-11	2.11E-11	1.55E-11
Future	9.47E+07	6.31E+08	20.00	6.07E-11	3.21E-11	2.22E-11	1.56E-11
Future	1.58E+08	7.89E+08	25.00	6.07E-11	3.21E-11	2.22E-11	1.56E-11
Future	2.21E+08	1.01E+09	32.00	6.07E-11	3.21E-11	2.22E-11	1.56E-11
Future	5.05E+08	1.52E+09	48.00	6.07E-11	3.21E-11	2.22E-11	1.56E-11
Future	1.89E+08	1.70E+09	54.00	6.07E-11	3.21E-11	2.22E-11	1.56E-11

Table 6-2 cont'd
Calculated Azimuthal Variation Of Maximum Exposure Rates
And Integrated Exposures At The Reactor Vessel
Clad/Base Metal Interface
With Uprate to 2900 MWt

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Iron Atom Displacements [dpa]			
				0°	15°	30°	45°
1	3.92E+07	3.92E+07	1.24	3.04E-03	1.68E-03	1.21E-03	8.35E-04
2	3.20E+07	7.12E+07	2.26	4.75E-03	2.73E-03	1.98E-03	1.37E-03
3	3.90E+07	1.10E+08	3.49	6.85E-03	4.14E-03	3.06E-03	2.14E-03
4	3.99E+07	1.50E+08	4.76	9.18E-03	5.57E-03	4.09E-03	2.80E-03
5	3.87E+07	1.89E+08	5.98	1.15E-02	6.95E-03	5.02E-03	3.44E-03
6	3.88E+07	2.28E+08	7.21	1.34E-02	8.24E-03	6.09E-03	4.21E-03
7	3.93E+07	2.67E+08	8.46	1.55E-02	9.52E-03	7.12E-03	5.00E-03
8	4.15E+07	3.08E+08	9.77	1.76E-02	1.08E-02	8.13E-03	5.73E-03
9	3.86E+07	3.47E+08	11.00	1.96E-02	1.20E-02	8.99E-03	6.40E-03
10	4.73E+07	3.94E+08	12.49	2.18E-02	1.34E-02	1.01E-02	7.18E-03
11	4.56E+07	4.40E+08	13.94	2.42E-02	1.48E-02	1.11E-02	7.85E-03
12(Prj)	9.66E+07	5.37E+08	17.00	2.90E-02	1.76E-02	1.31E-02	9.35E-03
Future	9.47E+07	6.31E+08	20.00	3.47E-02	2.07E-02	1.52E-02	1.08E-02
Future	1.58E+08	7.89E+08	25.00	4.43E-02	2.57E-02	1.87E-02	1.33E-02
Future	2.21E+08	1.01E+09	32.00	5.77E-02	3.28E-02	2.36E-02	1.67E-02
Future	5.05E+08	1.52E+09	48.00	8.83E-02	4.91E-02	3.48E-02	2.46E-02
Future	1.89E+08	1.70E+09	54.00	9.98E-02	5.51E-02	3.90E-02	2.76E-02

Table 6-3
Relative Radial Distribution Of Neutron Fluence (E > 1.0 MeV)
Within The Reactor Vessel Wall

RADIUS (cm)	AZIMUTHAL ANGLE			
	0°	15°	30°	45°
199.79	1.000	1.000	1.000	1.000
204.79	0.587	0.601	0.600	0.603
209.79	0.301	0.316	0.314	0.318
214.79	0.148	0.159	0.158	0.161
219.79	0.068	0.078	0.078	0.082

Note:
Base Metal Inner Radius = 199.79 cm
Base Metal 1/4T = 204.79 cm
Base Metal 1/2T = 209.79 cm
Base Metal 3/4T = 214.79 cm
Base Metal Outer Radius = 219.79 cm

Table 6-4
Relative Radial Distribution Of Iron Atom Displacements (dpa)
Within The Reactor Vessel Wall

RADIUS (cm)	AZIMUTHAL ANGLE			
	0°	15°	30°	45°
199.79	1.000	1.000	1.000	1.000
204.79	0.666	0.681	0.665	0.668
209.79	0.417	0.436	0.416	0.420
214.79	0.254	0.274	0.256	0.262
219.79	0.140	0.163	0.154	0.164

Note:
Base Metal Inner Radius = 199.79 cm
Base Metal 1/4T = 204.79 cm
Base Metal 1/2T = 209.79 cm
Base Metal 3/4T = 214.79 cm
Base Metal Outer Radius = 219.79 cm

Table 6-5
Calculated Fast Neutron Exposure of Surveillance Capsules Withdrawn from Beaver Valley Unit 2

Capsule	Irradiation Time [EFPY]	Fluence (E > 1.0 MeV) [n/cm^2]	Iron Displacements [dpa]
U	1.24	6.08E+18	1.25E-02
V	5.98	2.63E+19	5.34E-02
W	9.77	3.63E+19	7.20E-02
X	13.94	5.60E+19	1.14E-01

Table 6-6
Calculated Surveillance Capsule Lead Factors

Capsule ID And Location	Status	Lead Factor
U (17°)	Withdrawn EOC 1	3.17
V (17°)	Withdrawn EOC 5	3.64
W (20°)	Withdrawn EOC 8	3.29
X (17°)	Withdrawn EOC 11	3.68
Y (20°)	In Reactor	3.25
Z (20°)	In Reactor	3.25

Note: Lead factors for capsules remaining in the reactor are based on cycle specific exposure calculations through the current operating fuel reload, i.e., Cycle 11

7 SURVEILLANCE CAPSULE REMOVAL SCHEDULE

The following surveillance capsule removal schedule meets the requirements of ASTM E185-82 [Ref. 12] and is recommended for future capsules to be removed from the Beaver Valley Unit 2 reactor vessel.

Table 7-1 Recommended Surveillance Capsule Withdrawal Schedule

Capsule	Capsule Location	Lead Factor (a)	Withdrawal EFPY (b)	Fluence (n/cm^2) (a)
U	343°	3.17	1.24	6.082×10^{18} (c)
V	107°	3.64	5.98	2.629×10^{19} (c)
W	110°	3.29	9.77	3.625×10^{19} (c)
X	287°	3.68	13.94	5.601×10^{19} (c)
Y	290°	3.25	Standby (d)	(d)
Z	340°	3.25	Standby (d)	(d)

Notes:

(a) Updated in Capsule X dosimetry analysis.
(b) Effective Full Power Years (EFPY) from plant startup.
(c) Actual plant evaluation calculated fluence.
(d) These capsules will reach a fluence of approximately 6.29×10^{19} (54 EFPY Peak Fluence) which occurs at 17.33 EFPY. It is recommended that these standby capsules are withdrawn between 17 and 18 EFPY and placed in storage. Future testing of one of the standby capsules is prudent if license extension for the plant is implemented.

8 REFERENCES

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

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

3. WCAP-9615, Revision 1, *Duquesne Light Company Beaver Valley Unit 2 Reactor Vessel Radiation Surveillance Program*, P.A. Peters, dated June 1995.

4. WCAP-12406, *Analysis of Capsule U from the Duquesne Light Company Beaver Valley Unit 2 Reactor Vessel Radiation Surveillance Program*, S.E. Yanichko, et. al., September 1989.

5. WCAP-14484, *Analysis of Capsule V from the Duquesne Light Company Beaver Valley Unit 2 Reactor Vessel Radiation Surveillance Program*, P.A. Grendys, et. al., February 1996.

6. WCAP-15675, *Analysis of Capsule W from FirstEnergy Nuclear Operating Company Beaver Valley Unit 2 Reactor Vessel Radiation Surveillance Program*, J.H. Ledger, et. al., August 2001.

7. STD Letter Report STD-MCE-05-36, *Beaver Valley Unit 2, Capsule X Test Report*, J. Conermann, et al., July 11, 2005.

8. ASTM E185-73, *Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels,* American Society for Testing and Materials.

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

10. ASTM E208, *Standard Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels*, American Society for Testing and Materials.

11. ASTM E399, *Test Method for Plane-Strain Fracture Toughness of Metallic Materials,* American Society for Testing and Materials.

12. ASTM E185-82, *Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels*, American Society for Testing and Materials.

13. Westinghouse Science and Technology Department Procedure RMF 8402, *Surveillance Capsule Testing Program*, Revision 2, dated 1/6/2005.

14. Westinghouse Science and Technology Procedure RMF 8102, *Tensile Testing*, Revision 3, dated 3/1/1999.

15. Westinghouse Science and Technology Procedure RMF 8103, *Charpy Impact Testing*, Revision 2, dated 8/1/1998.

16. ASTM E23-02a, *Standard Test Method for Notched Bar Impact Testing of Metallic Materials*, American Society for Testing and Materials.

17. ASTM A370-97a, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*, American Society for Testing and Materials.

18. ASTM E8-04, *Standard Test Methods for Tension Testing of Metallic Materials,* American Society for Testing and Materials.

19. ASTM E21-03a, *Standard Test Methods for Elevated Temperature Tension Tests of Metallic Materials,* American Society for Testing and Materials.

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

21. ASTM E853-01, *Standard Practice for Analysis and Interpretation of Light Water Reactor Surveillance Results, E706(1A),* Volume 12.02, American Society for Testing and Materials.

22. ASTM E693-01, *Standard Practice for Characterizing Neutron Exposures in Iron and Low Alloy Steels in Terms of Displacements Per Atom (DPA), E706(ID),* Volume 12.02, American Society for Testing and Materials.

23. Regulatory Guide RG-1.190, *Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence*, U. S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, March 2001.

24. WCAP-14040-NP-A, Revision 4, *Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves*, May 2004.

25. WCAP-16083-NP, *Benchmark Testing of the FERRET Code for the Least Squares Evaluation of Light Water Reactor Dosimetry,* S.L. Anderson, May 2004.

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

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

APPENDIX A

VALIDATION OF THE RADIATION TRANSPORT MODELS BASED ON NEUTRON DOSIMETRY MEASUREMENTS CREDIBILITY

A.1 Neutron Dosimetry

Comparisons of measured dosimetry results to both the calculated and least squares adjusted values for all surveillance capsules withdrawn from service to date at Beaver Valley Unit 2 are described herein. The sensor sets from these capsules have been analyzed in accordance with the current dosimetry evaluation methodology described in Regulatory Guide 1.190, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence."[Ref. A-1] One of the main purposes for presenting this material is to demonstrate that the overall measurements agree with the calculated and least squares adjusted values to within ± 20% as specified by Regulatory Guide 1.190, thus serving to validate the calculated neutron exposures previously reported in Section 6.2 of this report.

A.1.1 Sensor Reaction Rate Determinations

In this section, the results of the evaluations of the four neutron sensor sets withdrawn to date as part of the Beaver Valley Unit 2 Reactor Vessel Materials Surveillance Program are presented. The capsule designation, location within the reactor, and time of withdrawal of each of these dosimetry sets were as follows:

Capsule ID	Azimuthal Location	Withdrawal Time	Irradiation Time [EFPY]
U	17°	End of Cycle 1	1.24
V	17°	End of Cycle 5	5.98
W	20°	End of Cycle 8	9.77
X	17°	End of Cycle 11	13.94

The azimuthal locations included in the above tabulation represent the first octant equivalent azimuthal angle of the geometric center of the respective surveillance capsules. The passive neutron sensors included in the evaluations of Surveillance Capsules U, V, W and X are summarized as follows:

Sensor Material	Reaction Of Interest	Capsule U	Capsule V	Capsule W	Capsule X
Copper	$^{63}Cu(n,\alpha)^{60}Co$	X	X	X	X
Iron	$^{54}Fe(n,p)^{54}Mn$	X	X	X	X
Nickel	$^{58}Ni(n,p)^{58}Co$	X	X	X	X
Uranium-238	$^{238}U(n,f)^{137}Cs$	X	X	X**	X**
Neptunium-237	$^{237}Np(n,f)^{137}Cs$	X	X	X	X
Cobalt-Aluminum*	$^{59}Co(n,\gamma)^{60}Co$	X	X	X	X

* The cobalt-aluminum measurements for this plant include both bare wire and cadmium-covered sensors.

** The U-238 sensors from these capsules yielded erroneous results and were, therefore, rejected.

Since all of the dosimetry monitors were accommodated within the dosimeter block centered at the radial center of the material test specimen array, gradient corrections were not required for these reaction rates. Pertinent physical and nuclear characteristics of the passive neutron sensors are listed in Table A-1.

The use of passive monitors such as those listed above 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.

Results from the radiometric counting of the neutron sensors from Capsules U, V, W, and X are provided in Table A-4. In all cases, the radiometric counting followed established ASTM procedures. Following sample preparation and weighing, the specific activity of each sensor was determined by means of a high-resolution gamma spectrometer. For the copper, iron, nickel, and cobalt-aluminum sensors, these analyses were performed by direct counting of each of the individual samples. In the case of the uranium and neptunium fission sensors, the analyses were carried out by direct counting preceded by dissolution and chemical separation of cesium from the sensor material.

The irradiation history of the reactor over the irradiation periods experienced by Capsules U, V, W, and X was based on the reported monthly power generation of Beaver Valley Unit 2 from initial reactor criticality through the end of the dosimetry evaluation period. For the sensor sets utilized in the surveillance capsules, the half-lives of the product isotopes are long enough that a monthly histogram describing reactor operation has proven to be an adequate representation for use in radioactive decay corrections for the reactions of interest in the exposure evaluations. The irradiation history applicable to Capsules U, V, W, and X is given in Table A-2.

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 $\phi(E > 1.0 \text{ MeV})$ during irradiation period j to the time weighted average $\phi(E > 1.0 \text{ MeV})$ over the entire irradiation period.
λ	=	Decay constant of the product isotope (1/sec).
t_j	=	Length of irradiation period j (sec).
t_d	=	Decay time following irradiation period j (sec).

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

In the equation describing the reaction rate calculation, the ratio $[P_j]/[P_{ref}]$ accounts for month-by-month variation of reactor core power level within any given fuel cycle as well as over multiple fuel cycles. The ratio C_j, which was calculated for each fuel cycle using the transport methodology 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. The fuel cycle specific neutron flux values along with the computed values for C_j are listed in Table A-3. These flux values represent the cycle dependent results at the radial and azimuthal center of the respective capsules at the axial elevation of the active fuel midplane.

Prior to using the measured reaction rates in the least-squares evaluations of the dosimetry sensor sets, additional corrections were made to the ^{238}U measurements to account for the presence of ^{235}U impurities in the sensors as well as to adjust for the build-in of plutonium isotopes over the course of the irradiation. Corrections were also made to the ^{238}U and ^{237}Np sensor reaction rates to account for gamma ray induced fission reactions that occurred over the course of the capsule irradiations. The correction factors applied to the Beaver Valley Unit 2 fission sensor reaction rates are summarized as follows:

Correction	Capsule U	Capsule V	Capsule W	Capsule X
^{235}U Impurity/Pu Build-in	0.861	0.789		
^{238}U(γ,f)	0.976	0.976		
Net ^{238}U Correction	0.840	0.770	n/a	n/a
^{237}Np(γ,f)	0.994	0.994	0.994	0.994

These factors were applied in a multiplicative fashion to the decay corrected uranium and neptunium fission sensor reaction rates.

Results of the sensor reaction rate determinations for Capsules U, V, W, and X are given in Table A-4. In Table A-4, the measured specific activities, decay corrected saturated specific activities, and computed reaction rates for each sensor indexed to the radial center of the capsule are listed. The fission sensor reaction rates are listed both with and without the applied corrections for ^{238}U impurities, plutonium build-in, and gamma ray induced fission effects.

A.1.2 Least Squares Evaluation of Sensor Sets

Least squares adjustment methods provide the capability of combining the measurement data with the corresponding neutron transport calculations resulting in a Best Estimate neutron energy spectrum with associated uncertainties. Best Estimates for key exposure parameters such as $\phi(E > 1.0\ MeV)$ or dpa/s along with their uncertainties are then easily obtained from the adjusted spectrum. In general, the least squares methods, as applied to surveillance capsule dosimetry evaluations, act to reconcile the measured sensor reaction rate data, dosimetry reaction cross-sections, and the calculated neutron energy spectrum within their respective uncertainties. For example,

$$R_i \pm \delta_{R_i} = \sum_g (\sigma_{ig} \pm \delta_{\sigma_{ig}})(\phi_g \pm \delta_{\phi_g})$$

relates a set of measured reaction rates, R_i, to a single neutron spectrum, ϕ_g, through the multigroup dosimeter reaction cross-section, σ_{ig}, each with an uncertainty δ. The primary objective of the least squares evaluation is to produce unbiased estimates of the neutron exposure parameters at the location of the measurement.

For the least squares evaluation of the Beaver Valley Unit 2 surveillance capsule dosimetry, the FERRET code [Ref. A-2] was employed to combine the results of the plant specific neutron transport calculations and sensor set reaction rate measurements to determine best-estimate values of exposure parameters ($\phi(E > 1.0\ MeV)$ and dpa) along with associated uncertainties for the four in-vessel capsules withdrawn to date.

The application of the least squares methodology requires the following input:

1 - The calculated neutron energy spectrum and associated uncertainties at the measurement location.

2 - The measured reaction rates and associated uncertainty for each sensor contained in the multiple foil set.

3 - The energy dependent dosimetry reaction cross-sections and associated uncertainties for each sensor contained in the multiple foil sensor set.

For the Beaver Valley Unit 2 application, the calculated neutron spectrum was obtained from the results of plant specific neutron transport calculations described in Section 6.2 of this report. The sensor reaction rates were derived from the measured specific activities using the procedures described in Section A.1.1. The dosimetry reaction cross-sections and uncertainties were obtained from the SNLRML dosimetry cross-section library [Ref. A-3]. The SNLRML library is an evaluated dosimetry reaction cross-section compilation recommended for use in LWR evaluations by ASTM Standard E1018, "Application of ASTM Evaluated Cross-Section Data File, Matrix E 706 (IIB)".

The uncertainties associated with the measured reaction rates, dosimetry cross-sections, and calculated neutron spectrum were input to the least squares procedure in the form of variances and covariances. The assignment of the input uncertainties followed the guidance provided in ASTM Standard E 944, "Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance."

The following provides a summary of the uncertainties associated with the least squares evaluation of the Beaver Valley Unit 2 surveillance capsule sensor sets.

Reaction Rate Uncertainties

The overall uncertainty associated with the measured reaction rates includes components due to the basic measurement process, irradiation history corrections, and corrections for competing reactions. A high level of accuracy in the reaction rate determinations is assured by utilizing laboratory procedures that conform to the ASTM National Consensus Standards for reaction rate determinations for each sensor type.

After combining all of these uncertainty components, the sensor reaction rates derived from the counting and data evaluation procedures were assigned the following net uncertainties for input to the least squares evaluation:

Reaction	Uncertainty
$^{63}Cu(n,\alpha)^{60}Co$	5%
$^{54}Fe(n,p)^{54}Mn$	5%
$^{58}Ni(n,p)^{58}Co$	5%
$^{238}U(n,f)^{137}Cs$	10%
$^{237}Np(n,f)^{137}Cs$	10%
$^{59}Co(n,\gamma)^{60}Co$	5%

These uncertainties are given at the 1σ level.

Dosimetry Cross-Section Uncertainties

The reaction rate cross-sections used in the least squares evaluations were taken from the SNLRML library. This data library provides reaction cross-sections and associated uncertainties, including covariances, for 66 dosimetry sensors in common use. Both cross-sections and uncertainties are provided in a fine multigroup structure for use in least squares adjustment applications. These cross-sections were compiled from the most recent cross-section evaluations and they have been tested with respect to their accuracy and consistency for least squares evaluations. Further, the library has been empirically tested for use in fission spectra determination as well as in the fluence and energy characterization of 14 MeV neutron sources.

For sensors included in the Beaver Valley Unit 2 surveillance program, the following uncertainties in the fission spectrum averaged cross-sections are provided in the SNLRML documentation package.

Reaction	Uncertainty
$^{63}Cu(n,\alpha)^{60}Co$	4.08-4.16%
$^{54}Fe(n,p)^{54}Mn$	3.05-3.11%
$^{58}Ni(n,p)^{58}Co$	4.49-4.56%
$^{238}U(n,f)^{137}Cs$	0.54-0.64%
$^{237}Np(n,f)^{137}Cs$	10.32-10.97%
$^{59}Co(n,\gamma)^{60}Co$	0.79-3.59%

These tabulated ranges provide an indication of the dosimetry cross-section uncertainties associated with the sensor sets used in LWR irradiations.

Calculated Neutron Spectrum

The neutron spectra input to the least squares adjustment procedure were obtained directly from the results of plant specific transport calculations for each surveillance capsule irradiation period and location. The spectrum for each capsule was input in an absolute sense (rather than as simply a relative spectral shape). Therefore, within the constraints of the assigned uncertainties, the calculated data were treated equally with the measurements.

While the uncertainties associated with the reaction rates were obtained from the measurement procedures and counting benchmarks and the dosimetry cross-section uncertainties were supplied directly with the SNLRML library, the uncertainty matrix for the calculated spectrum was constructed from the following relationship:

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

where R_n specifies an overall fractional normalization uncertainty and the fractional uncertainties R_g and $R_{g'}$ specify additional random groupwise uncertainties 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 the short-range correlations over a group range γ (θ specifies the strength of the latter term). The value of δ is 1.0 when g = g', and is 0.0 otherwise.

The set of parameters defining the input covariance matrix for the Beaver Valley Unit 2 calculated spectra was as follows:

Flux Normalization Uncertainty (R_n)	15%
Flux Group Uncertainties (R_g, $R_{g'}$)	
(E > 0.0055 MeV)	15%
(0.68 eV < E < 0.0055 MeV)	29%
(E < 0.68 eV)	52%
Short Range Correlation (θ)	
(E > 0.0055 MeV)	0.9
(0.68 eV < E < 0.0055 MeV)	0.5
(E < 0.68 eV)	0.5
Flux Group Correlation Range (γ)	
(E > 0.0055 MeV)	6
(0.68 eV < E < 0.0055 MeV)	3
(E < 0.68 eV)	2

A.1.3 Comparisons of Measurements and Calculations

Results of the least squares evaluations of the dosimetry from the Beaver Valley Unit 2 surveillance capsules withdrawn to date are provided in Tables A-5 and A-6. In Table A-5, measured, calculated, and best-estimate values for sensor reaction rates are given for each capsule. Also provided in this tabulation are ratios of the measured reaction rates to both the calculated and least squares adjusted reaction rates.

These ratios of M/C and M/BE illustrate the consistency of the fit of the calculated neutron energy spectra to the measured reaction rates both before and after adjustment. In Table A-6, comparison of the calculated and best estimate values of neutron flux (E > 1.0 MeV) and iron atom displacement rate are tabulated along with the BE/C ratios observed for each of the capsules.

The data comparisons provided in Tables A-5 and A-6 show that the adjustments to the calculated spectra are relatively small and well within the assigned uncertainties for the calculated spectra, measured sensor reaction rates, and dosimetry reaction cross-sections. Further, these results indicate that the use of the least squares evaluation results in a reduction in the uncertainties associated with the exposure of the surveillance capsules. From Section 6.4 of this report, it may be noted that the uncertainty associated with the unadjusted calculation of neutron fluence (E > 1.0 MeV) and iron atom displacements at the surveillance capsule locations is specified as 12% at the 1σ level. From Table A-6, it is noted that the corresponding uncertainties associated with the least squares adjusted exposure parameters have been reduced to 6%-7% for neutron flux (E > 1.0 MeV) and 8%-9% for iron atom displacement rate. Again, the uncertainties from the least squares evaluation are at the 1σ level.

Further comparisons of the measurement results with calculations are given in Tables A-7 and A-8. These comparisons are given on two levels. In Table A-7, calculations of individual threshold sensor reaction rates are compared directly with the corresponding measurements. These threshold reaction rate comparisons provide a good evaluation of the accuracy of the fast neutron portion of the calculated energy spectra. In Table A-8, calculations of fast neutron exposure rates in terms of ϕ(E > 1.0 MeV) and dpa/s are compared with the best estimate results obtained from the least squares evaluation of the capsule dosimetry results. These two levels of comparison yield consistent and similar results with all measurement-to-calculation comparisons falling well within the 20% limits specified as the acceptance criteria in Regulatory Guide 1.190.

In the case of the direct comparison of measured and calculated sensor reaction rates, the M/C comparisons for fast neutron reactions range from 0.89–1.11 for the 18 samples included in the data set. The overall average M/C ratio for the entire set of Beaver Valley Unit 2 data is 0.98 with an associated standard deviation of 7.5%.

In the comparisons of best estimate and calculated fast neutron exposure parameters, the corresponding BE/C comparisons for the capsule data sets range from 0.90–0.98 for neutron flux (E > 1.0 MeV) and from 0.91 to 0.99 for iron atom displacement rate. The overall average BE/C ratios for neutron flux (E > 1.0 MeV) and iron atom displacement rate are 0.95 with a standard deviation of 3.6% and 0.96 with a standard deviation of 3.6%, respectively.

Based on these comparisons, it is concluded that the calculated fast neutron exposures provided in Section 6.2 of this report are validated for use in the assessment of the condition of the materials comprising the beltline region of the Beaver Valley Unit 2 reactor pressure vessel.

Table A-1
Nuclear Parameters Used In The Evaluation Of Neutron Sensors

Monitor Material	Reaction of Interest	Target Atom Fraction	90% Response RANGE (MEV)	Product Half-life	Fission Yield (%)
Copper	^{63}Cu (n,α)	0.6917	4.9 – 11.8	5.271 y	
Iron	^{54}Fe (n,p)	0.0585	2.1 – 8.4	312.3 d	
Nickel	^{58}Ni (n,p)	0.6808	1.5 – 8.2	70.82 d	
Uranium-238	^{238}U (n,f)	1.0000	1.2 – 6.8	30.07 y	6.02
Neptunium-237	^{237}Np (n,f)	1.0000	0.4 – 3.6	30.07 y	6.17
Cobalt-Aluminum	^{59}Co (n,γ)	0.0015	non-threshold	5.271 y	

Note: The 90% response range is defined such that, in the neutron spectrum characteristic of the Beaver Valley Unit 2 surveillance capsules, approximately 90% of the sensor response is due to neutrons in the energy range specified with approximately 5% of the total response due to neutrons with energies below the lower limit and 5% of the total response due to neutrons with energies above the upper limit.

Table A-2
Monthly Thermal Generation During The First Eleven Fuel Cycles Of The Beaver Valley Unit 2 Reactor (Reactor Power of 2652 MWt for Cycles 1 through 9, and 2689MW for Cycles 10 and 11)

Year	Month	Thermal Generation (MWt-hr)	Year	Month	Thermal Generation (MWt-hr)	Year	Month	Thermal Generation (MWt-hr)
1987	8	188655	1990	8	1664072	1993	8	1951094
1987	9	309627	1990	9	74406	1993	9	782113
1987	10	1138592	1990	10	0	1993	10	0
1987	11	517531	1990	11	375293	1993	11	0
1987	12	1868106	1990	12	1962999	1993	12	1318343
1988	1	1647518	1991	1	1966105	1994	1	1957437
1988	2	948305	1991	2	1772383	1994	2	1767624
1988	3	1961547	1991	3	1920061	1994	3	1957207
1988	4	1816453	1991	4	1899670	1994	4	1895053
1988	5	1963013	1991	5	1959596	1994	5	1960148
1988	6	1795032	1991	6	1764771	1994	6	1121998
1988	7	1881079	1991	7	1941503	1994	7	1954090
1988	8	1783059	1991	8	1954146	1994	8	1958831
1988	9	1802754	1991	9	1881952	1994	9	1897976
1988	10	1882405	1991	10	1861135	1994	10	1962873
1988	11	1900844	1991	11	1674762	1994	11	1894630
1988	12	1963294	1991	12	1636047	1994	12	1950889
1989	1	1863158	1992	1	1870700	1995	1	1917701
1989	2	1018798	1992	2	1796307	1995	2	1754716
1989	3	612808	1992	3	509755	1995	3	1200818
1989	4	0	1992	4	0	1995	4	0
1989	5	12973	1992	5	1023309	1995	5	1147307
1989	6	1009593	1992	6	1809717	1995	6	1864365
1989	7	1033532	1992	7	1934799	1995	7	1916207
1989	8	1948907	1992	8	1959446	1995	8	1773194
1989	9	1900600	1992	9	1859358	1995	9	1880865
1989	10	1966839	1992	10	1960015	1995	10	1957436
1989	11	1899581	1992	11	1752279	1995	11	1754746
1989	12	1814015	1992	12	1708578	1995	12	1891015
1990	1	1686721	1993	1	1635667	1996	1	1810014
1990	2	1194673	1993	2	1702839	1996	2	1742890
1990	3	1476919	1993	3	1947152	1996	3	1915329
1990	4	1380856	1993	4	1786447	1996	4	1777999
1990	5	1489609	1993	5	1839535	1996	5	1934637
1990	6	1431870	1993	6	1888001	1996	6	1857380
1990	7	1577454	1993	7	1834053	1996	7	1918340

Table A-2 cont'd
Monthly Thermal Generation During The First Eleven Fuel Cycles Of The Beaver Valley Unit 2 Reactor (Reactor Power of 2652 MWt for Cycles 1 through 9, and 2689MW for Cycles 10 and 11)

Year	Month	Thermal Generation (MWt-hr)	Year	Month	Thermal Generation (MWt-hr)	Year	Month	Thermal Generation (MWt-hr)
1996	8	1469931	1999	8	1928918	2002	8	1997895
1996	9	0	1999	9	1874313	2002	9	1823374
1996	10	0	1999	10	1323291	2002	10	2000043
1996	11	0	1999	11	1682987	2002	11	1933715
1996	12	694343	1999	12	1775505	2002	12	1962537
1997	1	1210605	2000	1	1903763	2003	1	1997888
1997	2	1776258	2000	2	1677554	2003	2	1804094
1997	3	1178064	2000	3	1681774	2003	3	1997749
1997	4	1768747	2000	4	1873178	2003	4	1930985
1997	5	1942927	2000	5	1944510	2003	5	1953657
1997	6	1853679	2000	6	1857436	2003	6	1894875
1997	7	1082321	2000	7	1931752	2003	7	1997943
1997	8	1914272	2000	8	1925633	2003	8	1998043
1997	9	1572152	2000	9	1207003	2003	9	733841
1997	10	1944012	2000	10	286752	2003	10	1019110
1997	11	1895487	2000	11	1901991	2003	11	1931584
1997	12	990665	2000	12	1435864	2003	12	1998849
1998	1	0	2001	1	1950715	2004	1	1997347
1998	2	0	2001	2	1778926	2004	2	1869774
1998	3	0	2001	3	1724097	2004	3	1998361
1998	4	0	2001	4	1748718	2004	4	1869427
1998	5	0	2001	5	1944298	2004	5	1949549
1998	6	0	2001	6	1904103	2004	6	1933646
1998	7	0	2001	7	1938365	2004	7	1965028
1998	8	0	2001	8	1928137	2004	8	1997512
1998	9	25385	2001	9	1873345	2004	9	1928322
1998	10	1935467	2001	10	1968825	2004	10	2001362
1998	11	1624078	2001	11	1932741	2004	11	1934478
1998	12	1955838	2001	12	1997249	2004	12	1997979
1999	1	1954784	2002	1	1997170	2005	1	1999031
1999	2	1626617	2002	2	157181	2005	2	1675452
1999	3	0	2002	3	1730020	2005	3	1831750
1999	4	964605	2002	4	1842917	2005	4	154254
1999	5	1943731	2002	5	1816591			
1999	6	1859034	2002	6	1932910			
1999	7	1226305	2002	7	1997512			

Table A-3
Calculated C_j Factors at the Surveillance Capsule Center
Core Midplane Elevation

Fuel Cycle	Capsule U	Capsule V	Capsule W	Capsule X
1	1.55E+11	1.55E+11	1.34E+11	1.55E+11
2		1.26E+11	1.11E+11	1.26E+11
3		1.41E+11	1.27E+11	1.41E+11
4		1.38E+11	1.23E+11	1.38E+11
5		1.34E+11	1.16E+11	1.34E+11
6			1.14E+11	1.25E+11
7			1.09E+11	1.23E+11
8			1.07E+11	1.20E+11
9				1.11E+11
10				1.14E+11
11				1.18E+11
Average	1.55E+11	1.39E+11	1.18E+11	1.27E+11

Fuel Cycle	Capsule U	Capsule V	Capsule W	Capsule X
1	1.000	1.115	1.136	1.220
2		0.906	0.941	0.992
3		1.014	1.076	1.110
4		0.993	1.042	1.087
5		0.964	0.983	1.055
6			0.966	0.984
7			0.924	0.969
8			0.907	0.945
9				0.874
10				0.898
11				0.929
Average	1.000	1.000	1.000	1.000

Table A-4
Measured Sensor Activities And Reaction Rates
Surveillance Capsule U

Reaction	Location	Measured Activity (dps/g)	Saturated Activity (dps/g)	Radially Adjusted Saturated Activity (dps/g)	Radially Adjusted Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	Top	7.54E+04	5.18E+05	5.18E+05	7.90E-17
	Middle	7.17E+04	4.92E+05	4.92E+05	7.51E-17
	Bottom	6.70E+04	4.60E+05	4.60E+05	7.02E-17
	Average				**7.48E-17**
$^{54}Fe\ (n,p)\ ^{54}Mn$	Top	2.77E+06	5.33E+06	5.33E+06	8.44E-15
	Middle	2.53E+06	4.87E+06	4.87E+06	7.71E-15
	Bottom	2.44E+06	4.69E+06	4.69E+06	7.44E-15
	Average				**7.86E-15**
$^{58}Ni\ (n,p)\ ^{58}Co$	Middle	3.49E+07	7.80E+07	7.80E+07	1.12E-14
	Bottom	3.37E+07	7.54E+07	7.54E+07	1.08E-14
	Average				**1.10E-14**
$^{238}U\ (n,f)\ ^{137}Cs$ (Cd)	Middle	2.66E+05	9.48E+06	9.48E+06	6.23E-14
$^{238}U\ (n,f)\ ^{137}Cs$ (Cd)		Including ^{235}U, ^{239}Pu, and γ,fission corrections:			**5.23E-14**
$^{237}Np\ (n,f)\ ^{137}Cs$ (Cd)	Middle	1.99E+06	7.10E+07	7.10E+07	4.53E-13
$^{237}Np\ (n,f)\ ^{137}Cs$ (Cd)			Including γ,fission correction:		**4.50E-13**
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Top	1.50E+07	1.03E+08	1.03E+08	6.72E-12
	Top	1.28E+07	8.79E+07	8.79E+07	5.73E-12
	Middle	1.36E+07	9.34E+07	9.34E+07	6.09E-12
	Middle	1.58E+07	1.09E+08	1.09E+08	7.08E-12
	Bottom	1.43E+07	9.82E+07	9.82E+07	6.41E-12
	Average				**6.41E-12**
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)	Top	8.57E+06	5.88E+07	5.88E+07	3.84E-12
	Middle	8.69E+06	5.97E+07	5.97E+07	3.89E-12
	Bottom	9.17E+06	6.30E+07	6.30E+07	4.11E-12
	Average				**3.95E-12**

Notes: 1) Measured specific activities are indexed to a counting date of May 17, 1989.
2) The average ^{238}U (n,f) reaction rate of 5.23E-14 includes a correction factor of 0.861 to account for plutonium build-in and an additional factor of 0.976 to account for photo-fission effects in the sensor.
3) The average ^{237}Np (n,f) reaction rate of 4.50E-13 includes a correction factor of 0.994 to account for photo-fission effects in the sensor.

Table A-4 cont'd
Measured Sensor Activities And Reaction Rates
Surveillance Capsule V

Reaction	Location	Measured Activity (dps/g)	Saturated Activity (dps/g)	Radially Adjusted Saturated Activity (dps/g)	Radially Adjusted Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	Top	2.41E+05	4.99E+05	4.99E+05	7.56E-17
	Middle	2.27E+05	4.67E+05	4.67E+05	7.13E-17
	Bottom	2.16E+05	4.44E+05	4.44E+05	6.78E-17
	Average				**7.16E-17**
^{54}Fe (n,p) ^{54}Mn	Top	3.25E+06	4.80E+06	4.80E+06	7.61E-15
	Middle	3.08E+06	4.55E+06	4.55E+06	7.21E-15
	Bottom	2.94E+06	4.34E+06	4.34E+06	6.88E-15
	Average				**7.23E-15**
^{58}Ni (n,p) ^{58}Co	Top	2.56E+07	7.45E+07	7.45E+07	1.07E-14
	Middle	2.41E+07	7.01E+07	7.01E+07	1.00E-14
	Bottom	2.34E+07	6.81E+07	6.81E+07	9.75E-15
	Average				**1.02E-14**
^{238}U (n,f) ^{137}Cs (Cd)	Middle	1.13E+06	8.97E+06	8.97E+06	5.89E-14
^{238}U (n,f) ^{137}Cs (Cd)		Including ^{235}U, ^{239}Pu, and γ,fission corrections:			**4.53E-14**
^{237}Np (n,f) ^{137}Cs (Cd)	Middle	8.83E+06	7.01E+07	7.01E+07	4.47E-13
^{237}Np (n,f) ^{137}Cs (Cd)			Including γ,fission correction:		**4.45E-13**
^{59}Co (n,γ) ^{60}Co	Top	4.07E+07	8.37E+07	8.37E+07	5.46E-12
	Top	3.63E+07	7.47E+07	7.47E+07	4.87E-12
	Middle	3.67E+07	7.55E+07	7.55E+07	4.93E-12
	Middle	4.36E+07	8.97E+07	8.97E+07	5.85E-12
	Bottom	3.71E+07	7.63E+07	7.63E+07	4.98E-12
	Bottom	4.40E+07	9.05E+07	9.05E+07	5.91E-12
	Average				**5.33E-12**
^{59}Co (n,γ) ^{60}Co (Cd)	Top	2.41E+07	4.96E+07	4.96E+07	3.24E-12
	Middle	2.48E+07	5.10E+07	5.10E+07	3.33E-12
	Bottom	2.51E+07	5.16E+07	5.16E+07	3.37E-12
	Average				**3.31E-12**

Notes: 1) Measured specific activities are indexed to a counting date of June 30, 1995.
2) The average ^{238}U (n,f) reaction rate of 4.53E-14 includes a correction factor of 0.789 to account for plutonium build-in and an additional factor of 0.976 to account for photo-fission effects in the sensor.
3) The average ^{237}Np (n,f) reaction rate of 4.45E-13 includes a correction factor of 0.994 to account for photo-fission effects in the sensor.

Table A-4 cont'd
Measured Sensor Activities And Reaction Rates
Surveillance Capsule W

Reaction	Location	Measured Activity (dps/g)	Saturated Activity (dps/g)	Radially Adjusted Saturated Activity (dps/g)	Radially Adjusted Reaction Rate (rps/atom)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	Top	2.39E+05	4.11E+05	4.11E+05	6.27E-17
	Middle	2.17E+05	3.73E+05	3.73E+05	5.69E-17
	Bottom	2.11E+05	3.63E+05	3.63E+05	5.54E-17
	Average				**5.83E-17**
$^{54}Fe\ (n,p)\ ^{54}Mn$	Top	2.91E+06	4.29E+06	4.29E+06	6.80E-15
	Middle	2.65E+06	3.90E+06	3.90E+06	6.19E-15
	Bottom	2.44E+06	3.60E+06	3.60E+06	5.70E-15
	Average				**6.23E-15**
$^{58}Ni\ (n,p)\ ^{58}Co$	Top	4.39E+06	6.88E+07	6.88E+07	9.85E-15
	Middle	3.94E+06	6.17E+07	6.17E+07	8.84E-15
	Bottom	3.85E+06	6.03E+07	6.03E+07	8.63E-15
	Average				**9.11E-15**
$^{237}Np\ (n,f)\ ^{137}Cs$ (Cd)	Middle	1.06E+07	5.50E+07	5.50E+07	3.51E-13
$^{237}Np\ (n,f)\ ^{137}Cs$ (Cd)		Including γ,fission correction:			**3.49E-13**
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Top	3.24E+07	5.57E+07	5.57E+07	3.64E-12
	Top	3.73E+07	6.42E+07	6.42E+07	4.19E-12
	Middle	3.33E+07	5.73E+07	5.73E+07	3.74E-12
	Middle	3.98E+07	6.85E+07	6.85E+07	4.47E-12
	Bottom	3.40E+07	5.85E+07	5.85E+07	3.82E-12
	Bottom	3.89E+07	6.69E+07	6.69E+07	4.37E-12
	Average				**4.03E-12**
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)	Top	2.22E+07	3.82E+07	3.82E+07	2.49E-12
	Middle	2.27E+07	3.90E+07	3.90E+07	2.55E-12
	Bottom	2.31E+07	3.97E+07	3.97E+07	2.59E-12
	Average				**2.54E-12**

Notes: 1) Measured specific activities are indexed to a counting date of October 20, 2000.
2) The average ^{237}Np (n,f) reaction rate of 4.97E-13 includes a correction factor of 0.994 to account for photo-fission effects in the sensor.

Table A-4 cont'd
Measured Sensor Activities And Reaction Rates
Surveillance Capsule X

Reaction	Location	Measured Activity (dps/g)	Saturated Activity (dps/g)	Radially Adjusted Saturated Activity (dps/g)	Radially Adjusted Reaction Rate (rps/atom)
^{63}Cu (n,α) ^{60}Co	Top	2.97E+05	4.09E+05	4.09E+05	6.24E-17
	Middle	2.83E+05	3.90E+05	3.90E+05	5.94E-17
	Bottom	2.71E+05	3.73E+05	3.73E+05	5.69E-17
	Average				**5.96E-17**
^{54}Fe (n,p) ^{54}Mn	Top	3.33E+06	4.08E+06	4.08E+06	6.46E-15
	Bottom	3.07E+06	3.76E+06	3.76E+06	5.96E-15
	Average				**6.21E-15**
^{58}Ni (n,p) ^{58}Co	Top	3.59E+07	6.54E+07	6.54E+07	9.36E-15
	Top	3.58E+07	6.52E+07	6.52E+07	9.33E-15
	Middle	3.40E+06	6.19E+07	6.19E+07	8.86E-15
	Bottom	3.31E+06	6.03E+07	6.03E+07	8.63E-15
	Average				**9.05E-15**
^{237}Np (n,f) ^{137}Cs (Cd)	Middle	1.54E+07	5.74E+07	5.74E+07	3.66E-13
^{237}Np (n,f) ^{137}Cs (Cd)		Including γ,fission correction:			**3.64E-13**
^{59}Co (n,γ) ^{60}Co	Top	4.73E+07	6.51E+07	6.51E+07	4.25E-12
	Top	5.19E+07	7.15E+07	7.15E+07	4.66E-12
	Middle	5.54E+07	7.63E+07	7.63E+07	4.98E-12
	Middle	4.58E+07	6.31E+07	6.31E+07	4.11E-12
	Bottom	5.37E+07	7.39E+07	7.39E+07	4.82E-12
	Bottom	4.66E+07	6.42E+07	6.42E+07	4.19E-12
	Average				**4.50E-12**
^{59}Co (n,γ) ^{60}Co (Cd)	Top	3.04E+07	4.19E+07	4.19E+07	2.73E-12
	Middle	2.97E+07	5.74E+07	5.74E+07	2.67E-12
	Average				**2.70E-12**

Notes: 1) Measured specific activities are indexed to a counting date of May 27, 2005.
2) The average ^{237}Np (n,f) reaction rate of 3.64E-13 includes a correction factor of 0.994 to account for photo-fission effects in the sensor.

Table A-5
Comparison of Measured, Calculated, and Best Estimate Reaction Rates At The Surveillance Capsule Center

Capsule U

	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	7.47E-17	6.82E-17	7.22E-17	1.10	0.97
$^{54}Fe(n,p)^{54}Mn$	7.86E-15	8.22E-15	8.09E-15	0.96	1.03
$^{58}Ni(n,p)^{58}Co$	1.10E-14	1.17E-14	1.14E-14	0.94	1.04
$^{238}U(n,f)^{137}Cs$ (Cd)	5.23E-14	4.71E-14	4.59E-14	1.11	0.88
$^{237}Np(n,f)^{137}Cs$ (Cd)	4.50E-13	5.05E-13	4.71E-13	0.89	1.05
$^{59}Co(n,\gamma)^{60}Co$	6.41E-12	4.92E-12	6.24E-12	1.30	0.97
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	3.95E-12	3.77E-12	4.02E-12	1.05	1.02

Capsule V

	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	7.16E-17	6.47E-17	6.88E-17	1.11	0.96
$^{54}Fe(n,p)^{54}Mn$	7.23E-15	7.59E-15	7.47E-15	0.95	1.03
$^{58}Ni(n,p)^{58}Co$	1.01E-14	1.07E-14	1.05E-14	0.94	1.03
$^{238}U(n,f)^{137}Cs$ (Cd)	4.53E-14	4.27E-14	4.18E-14	1.06	0.92
$^{237}Np(n,f)^{137}Cs$ (Cd)	4.44E-13	4.49E-13	4.43E-13	0.99	1.00
$^{59}Co(n,\gamma)^{60}Co$	5.33E-12	4.26E-12	5.20E-12	1.25	0.98
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	3.31E-12	3.27E-12	3.37E-12	1.01	1.02

Capsule W

	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	5.83E-17	5.90E-17	5.78E-17	0.99	0.99
$^{54}Fe(n,p)^{54}Mn$	6.23E-15	6.70E-15	6.37E-15	0.93	1.02
$^{58}Ni(n,p)^{58}Co$	9.10E-15	9.44E-15	9.04E-15	0.96	0.99
$^{237}Np(n,f)^{137}Cs$ (Cd)	3.49E-13	3.70E-13	3.52E-13	0.94	1.01
$^{59}Co(n,\gamma)^{60}Co$	4.03E-12	3.28E-12	3.93E-12	1.23	1.02
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	2.54E-12	2.53E-12	2.59E-12	1.00	1.00

Table A-5 cont'd
Comparison of Measured, Calculated, and Best Estimate Reaction Rates At The Surveillance Capsule Center

Capsule X

	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	5.96E-17	6.02E-17	5.83E-17	0.99	1.02
$^{54}Fe(n,p)^{54}Mn$	6.21E-15	6.99E-15	6.38E-15	0.89	0.97
$^{58}Ni(n,p)^{58}Co$	9.05E-15	9.88E-15	9.05E-15	0.92	1.00
$^{237}Np(n,f)^{137}Cs$ (Cd)	3.64E-13	4.09E-13	3.68E-13	0.89	0.99
$^{59}Co(n,\gamma)^{60}Co$	4.50E-12	3.87E-12	4.39E-12	1.16	1.03
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	2.70E-12	2.97E-12	2.75E-12	0.91	0.98

Table A-6
Comparison of Calculated and Best Estimate Exposure Rates
At The Surveillance Capsule Center

Capsule ID	ϕ(E > 1.0 MeV) [n/cm^2-s]			
	Calculated	Best Estimate	Uncertainty (1σ)	BE/C
U	1.55E+11	1.51E+11	6%	0.972
V	1.39E+11	1.37E+11	6%	0.981
W	1.18E+11	1.12E+11	7%	0.954
X	1.27E+11	1.15E+11	7%	0.903

Note: Calculated results are based on the synthesized transport calculations taken at the core midplane following the completion of each respective capsules irradiation period.

Capsule ID	Iron Atom Displacement Rate [dpa/s]			
	Calculated	Best Estimate	Uncertainty (1σ)	BE/C
U	3.19E-10	3.10E-10	8%	0.971
V	2.83E-10	2.80E-10	8%	0.988
W	2.34E-10	2.23E-10	8%	0.956
X	2.58E-10	2.35E-10	9%	0.909

Note: Calculated results are based on the synthesized transport calculations taken at the core midplane following the completion of each respective capsules irradiation period.

Table A-7
Comparison of Measured/Calculated (M/C) Sensor Reaction Rate Ratios Including all Fast Neutron Threshold Reactions

Reaction	Capsule U	Capsule V	Capsule W	Capsule X
$^{63}Cu(n,\alpha)^{60}Co$	1.10	1.11	0.99	0.99
$^{54}Fe(n,p)^{54}Mn$	0.96	0.95	0.93	0.89
$^{58}Ni(n,p)^{58}Co$	0.94	0.94	0.96	0.92
$^{238}U(n,p)^{137}Cs$ (Cd)	1.11	1.06		
$^{237}Np(n,f)^{137}Cs$ (Cd)	0.89	0.99	0.94	0.89
Average	1.00	1.01	0.96	0.92
% Standard Deviation	9.9	7.2	2.8	5.1

Note: The overall average M/C ratio for the set of 18 sensor measurements is 0.98 with an associated standard deviation of 7.5%.

Table A-8
Comparison of Best Estimate/Calculated (BE/C) Exposure Rate Ratios

Capsule ID	BE/C Ratio	
	$\phi(E > 1.0$ MeV)	dpa/s
U	0.97	0.97
V	0.98	0.99
W	0.95	0.96
X	0.90	0.91
Average	0.95	0.96
% Standard Deviation	3.6	3.6

Appendix A References:

A-1. Regulatory Guide RG-1.190, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence," U. S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, March 2001.

A-2. A. Schmittroth, *FERRET Data Analysis Core*, HEDL-TME 79-40, Hanford Engineering Development Laboratory, Richland, WA, September 1979.

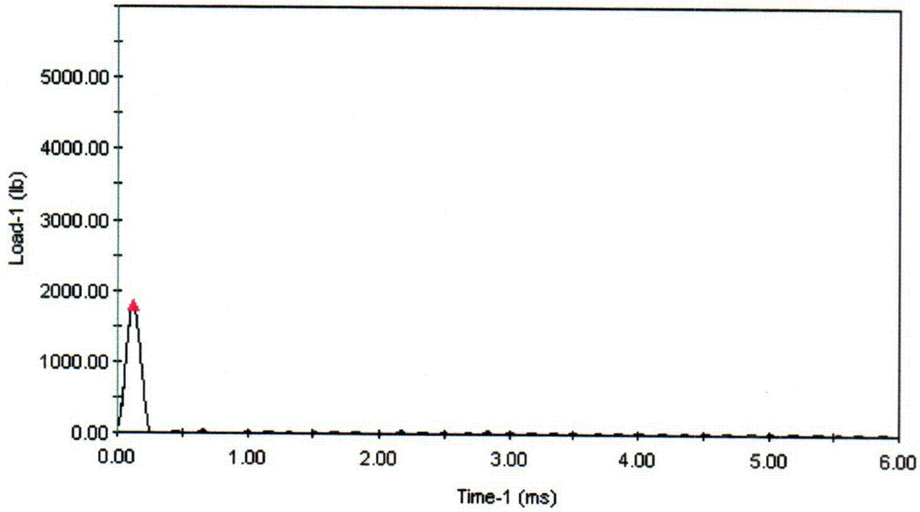
A-3. RSIC Data Library Collection DLC-178, "SNLRML Recommended Dosimetry Cross-Section Compendium", July 1994.

APPENDIX B

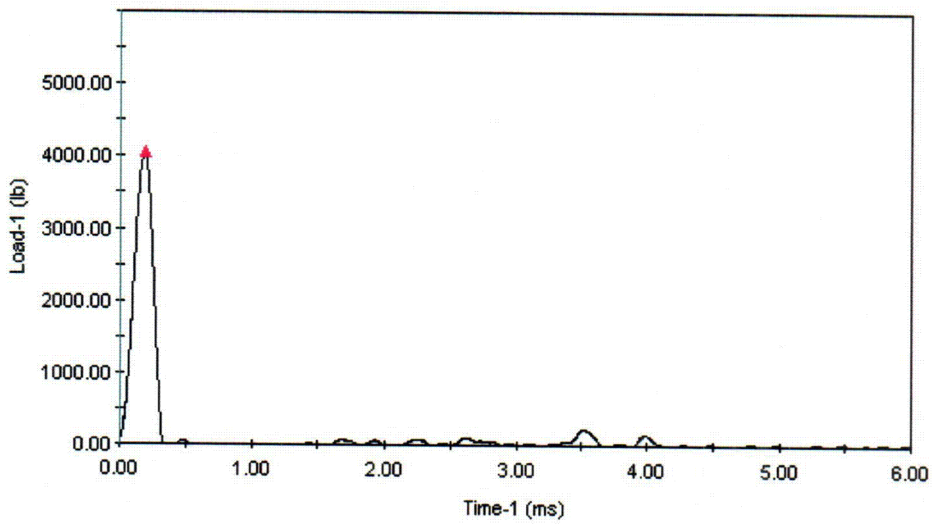
LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS

INSTRUMENTED CHARPY IMPACT TEST CURVES

- Specimen prefix "WL" denotes Intermediate Plate, Longitudinal Orientation
- Specimen prefix "WT" denotes Intermediate Plate, Transverse Orientation
- Specimen prefix "WW" denotes Weld Material
- Specimen prefix "WH" denotes Heat-Affected Zone material

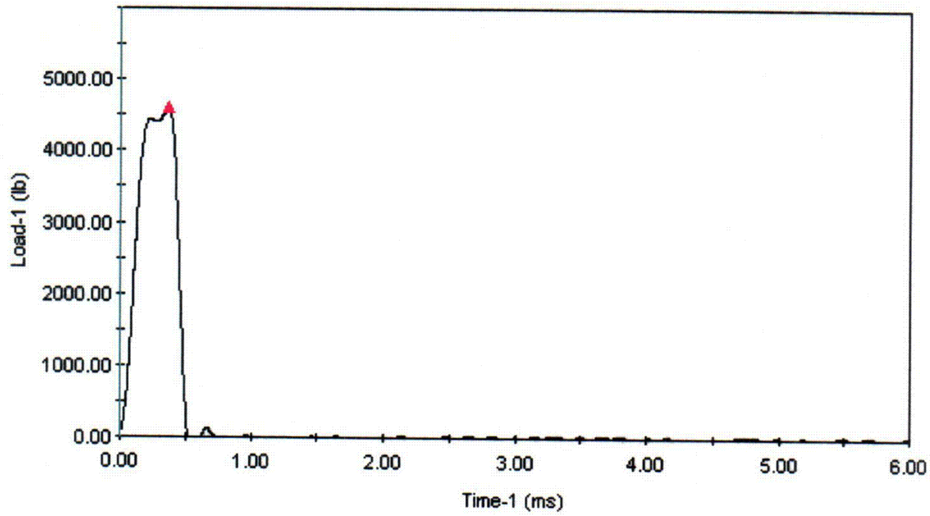


WL49, -50°F

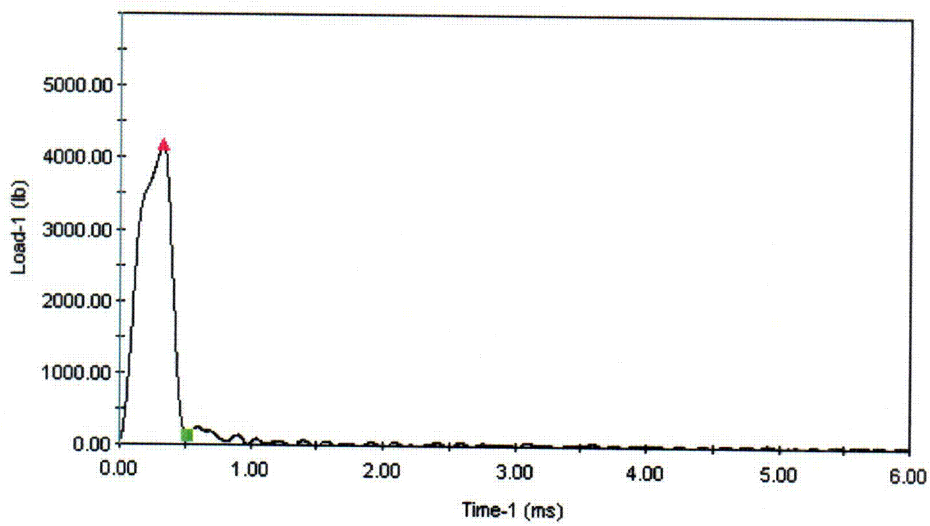


WL59, 25°F

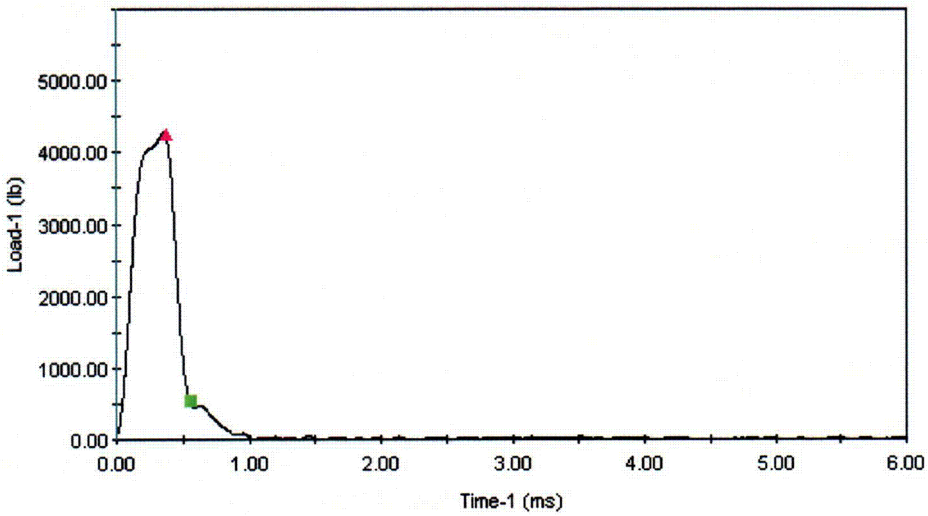
C04



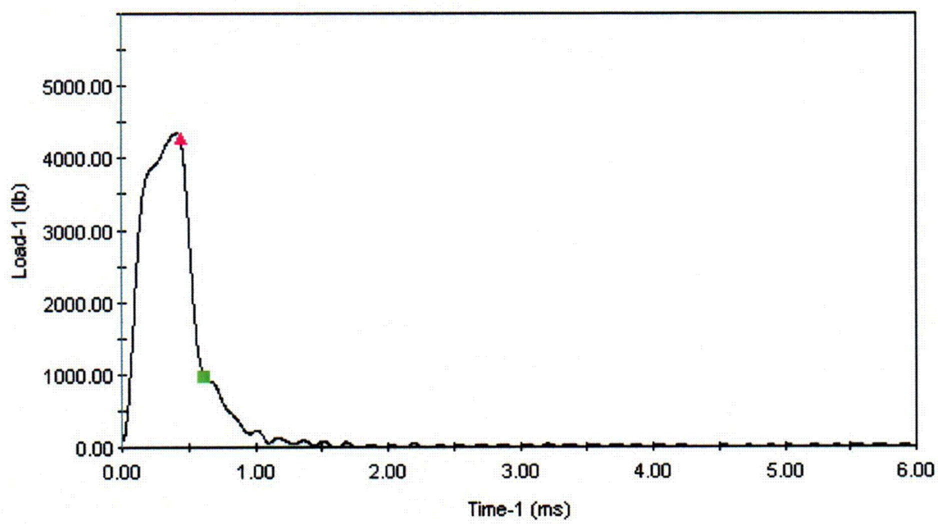
WL60, 75°F



WL58, 100°F

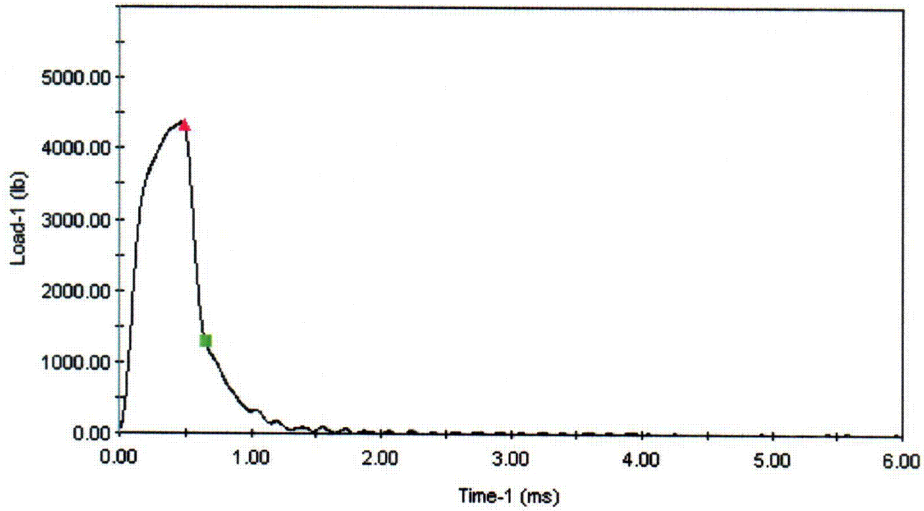


WL47, 125°F

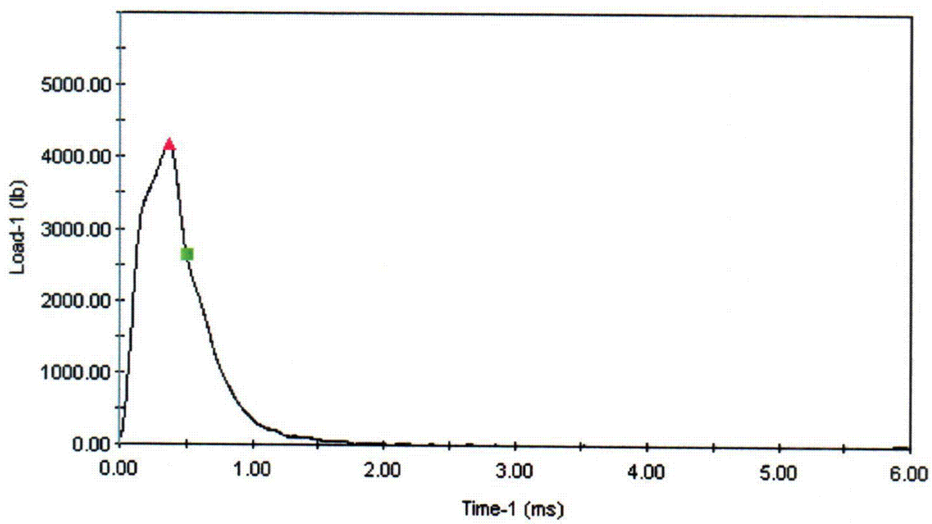


WL46, 150°F

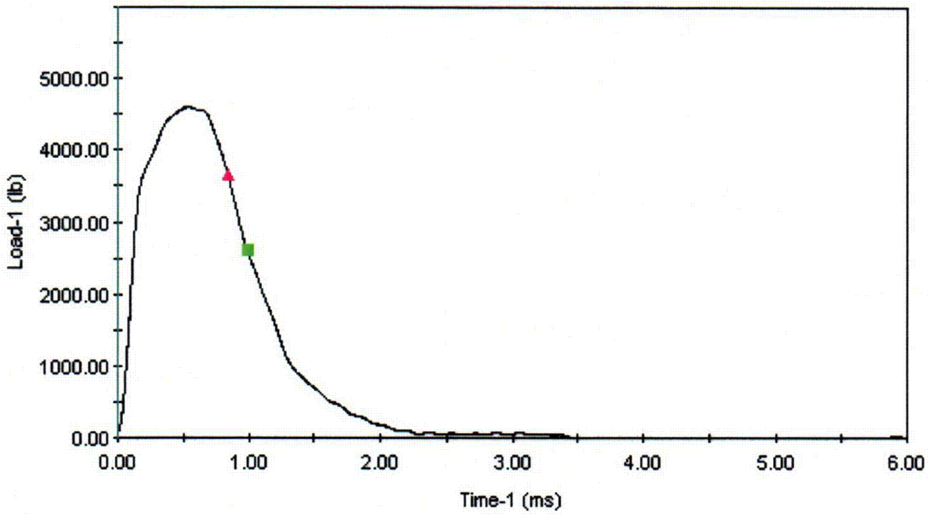
COC



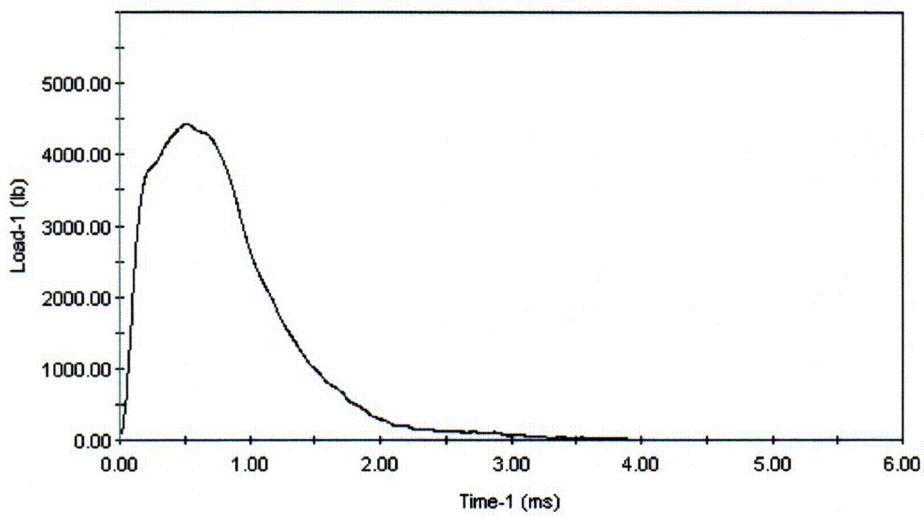
WL48, 175°F



WL55, 200°F

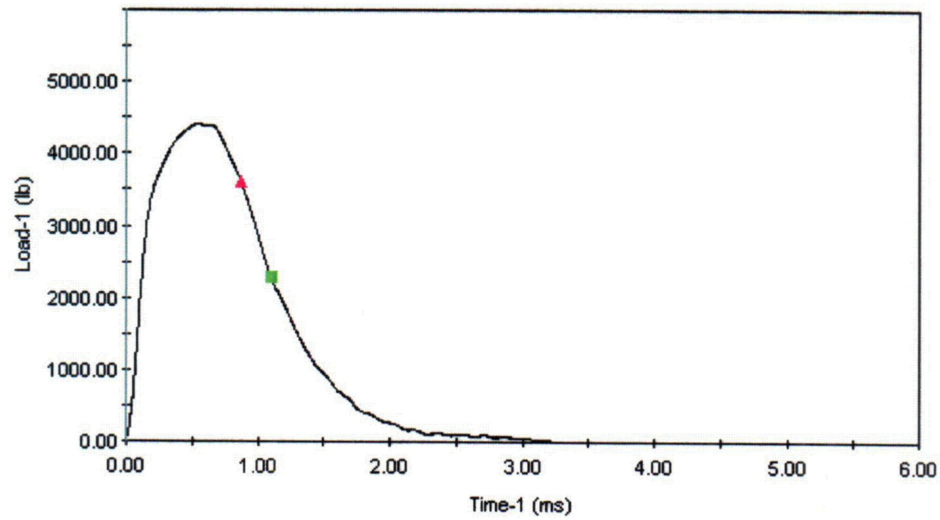


WL56, 225°F

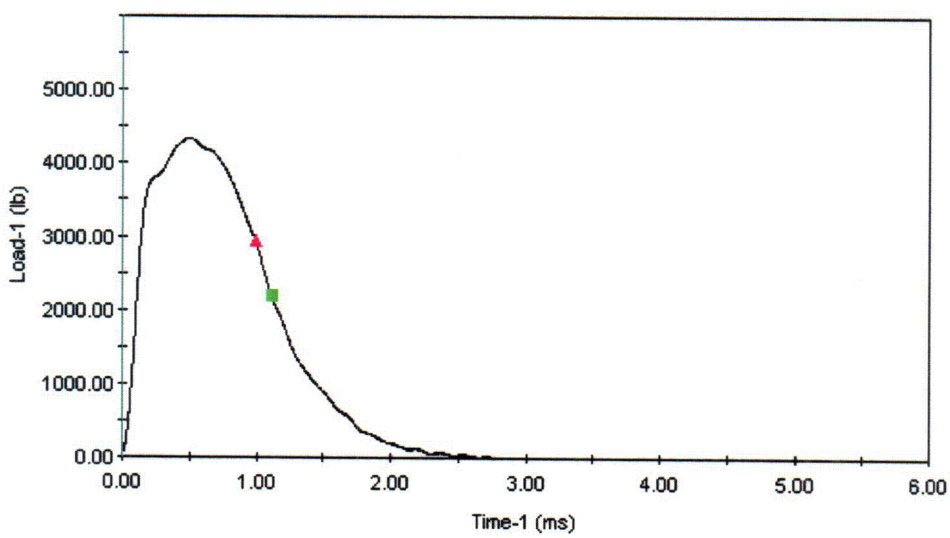


WL51, 250°F

C08

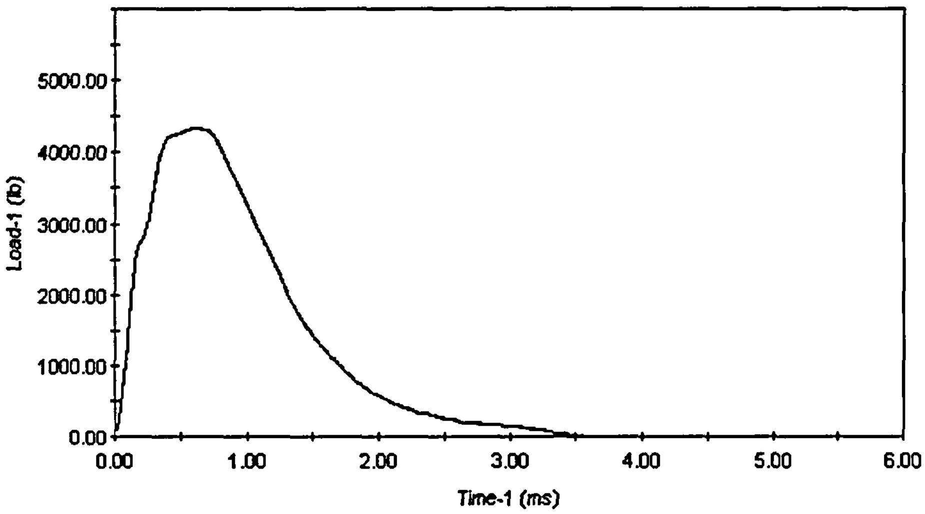


WL52, 275°F

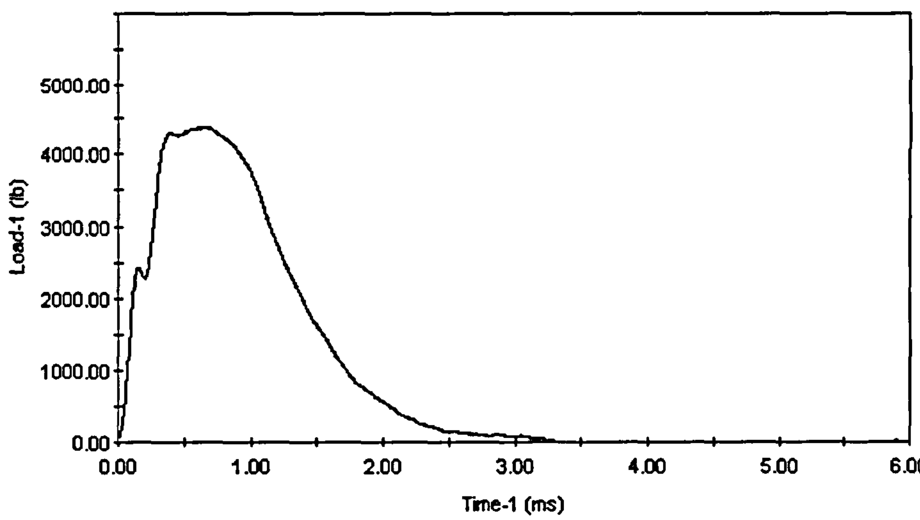


WL57, 280°F

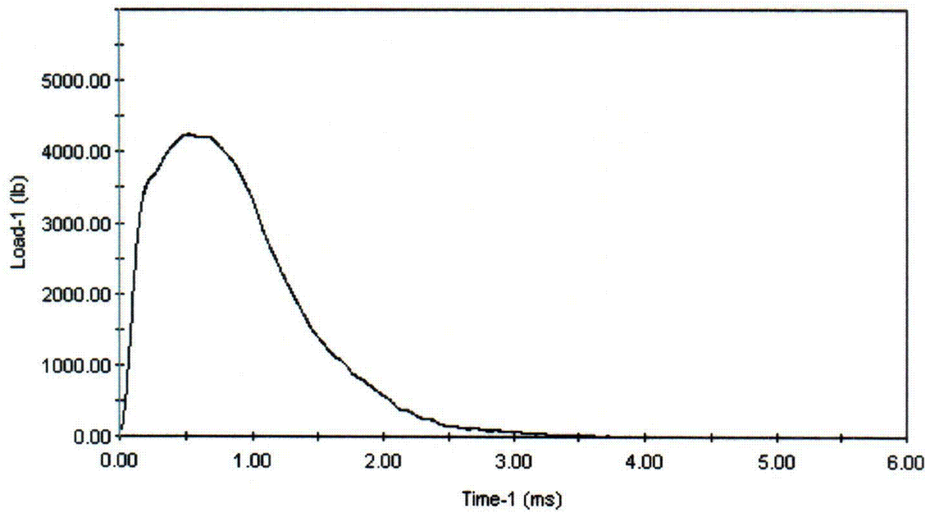
C09



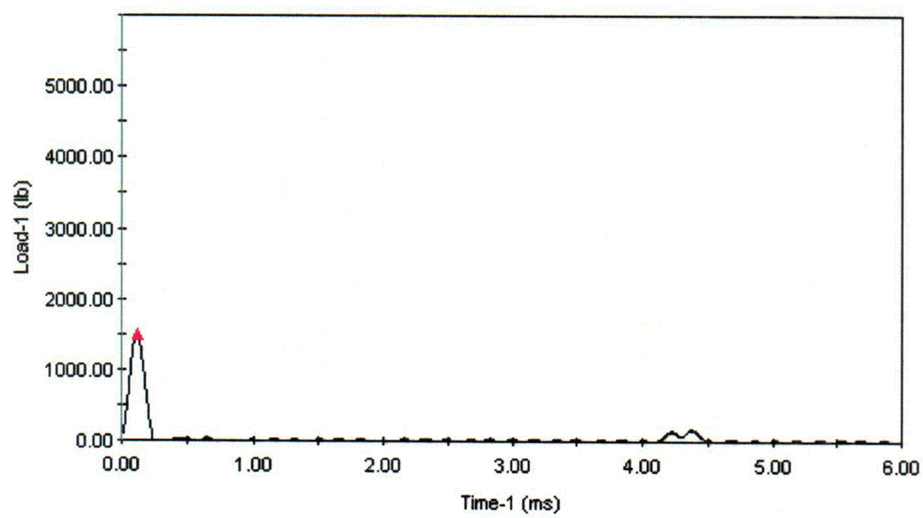
WL50, 325°F



WL54, 350°F

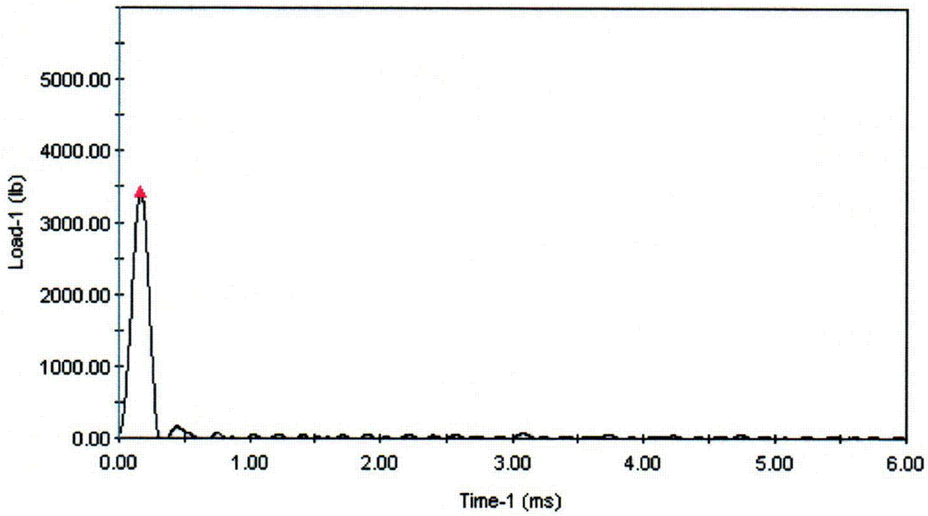


WL53, 375°F

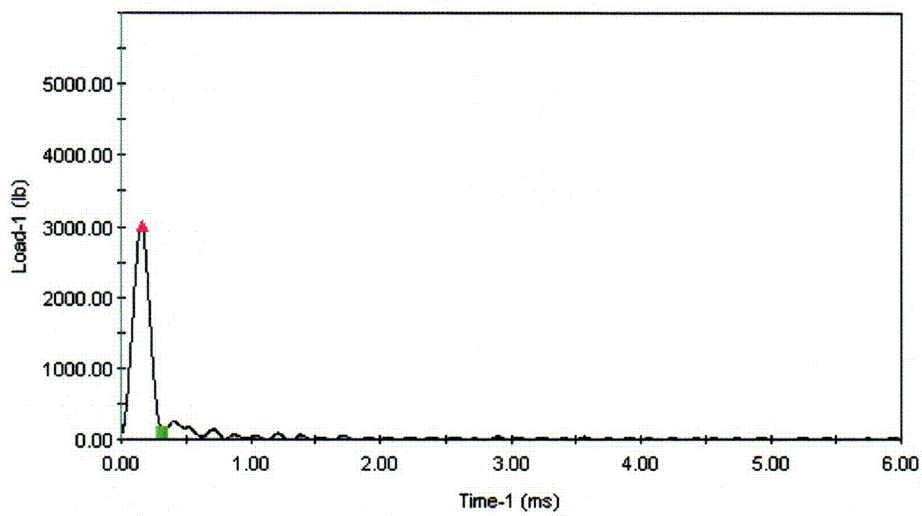


WT60, -50°F

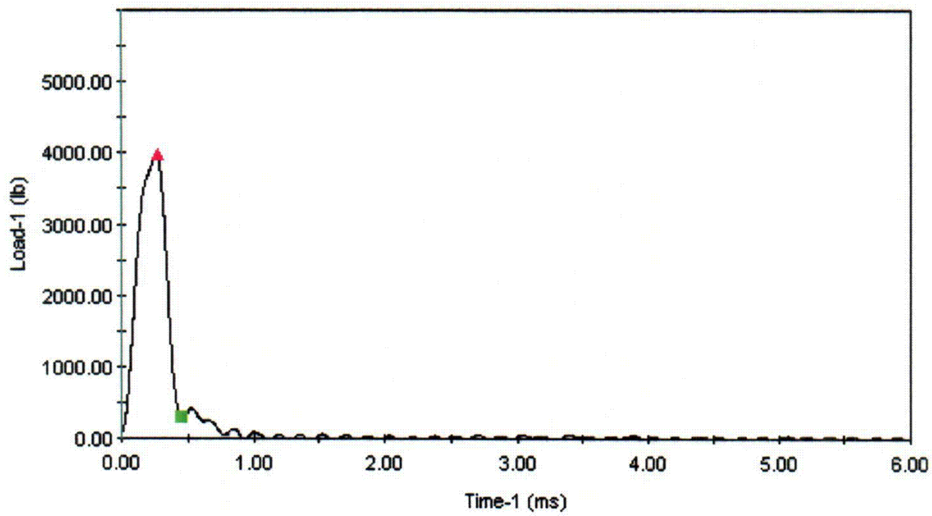
C10



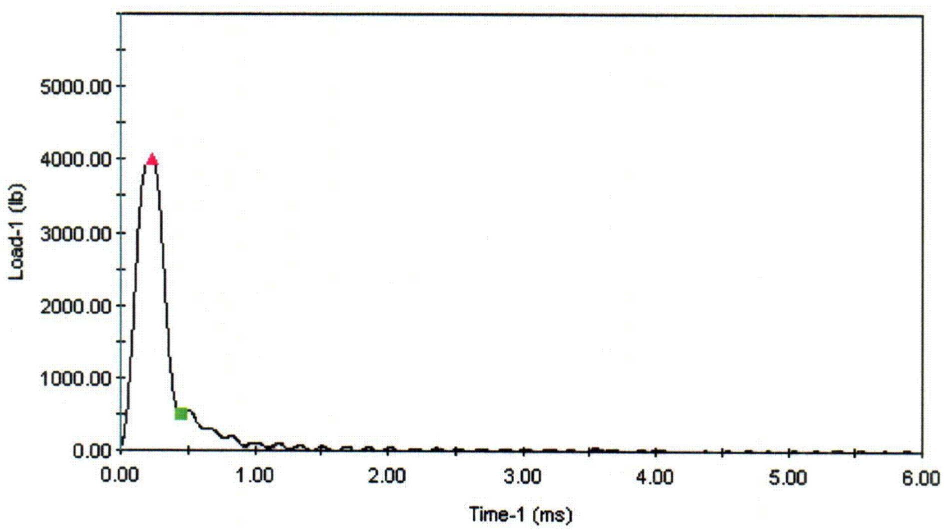
WT57, 25°F



WT56, 50°F

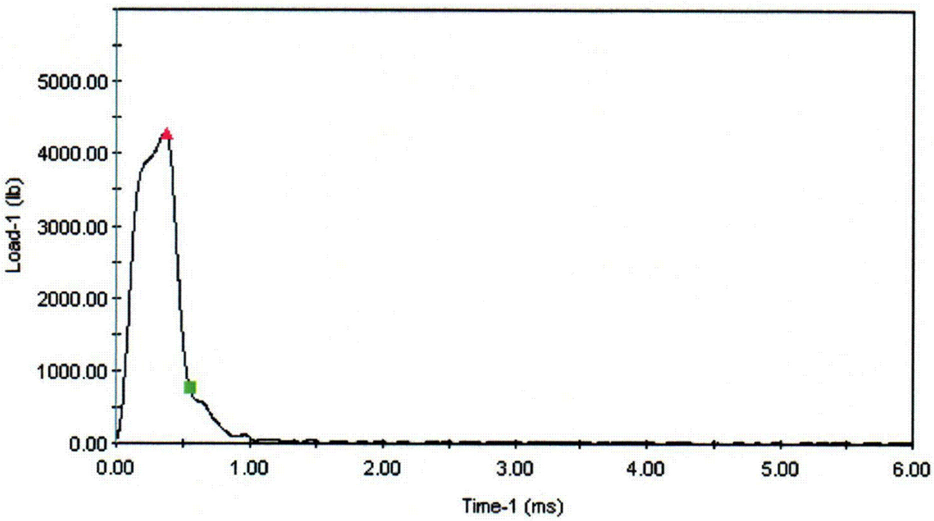


WT50, 75°F

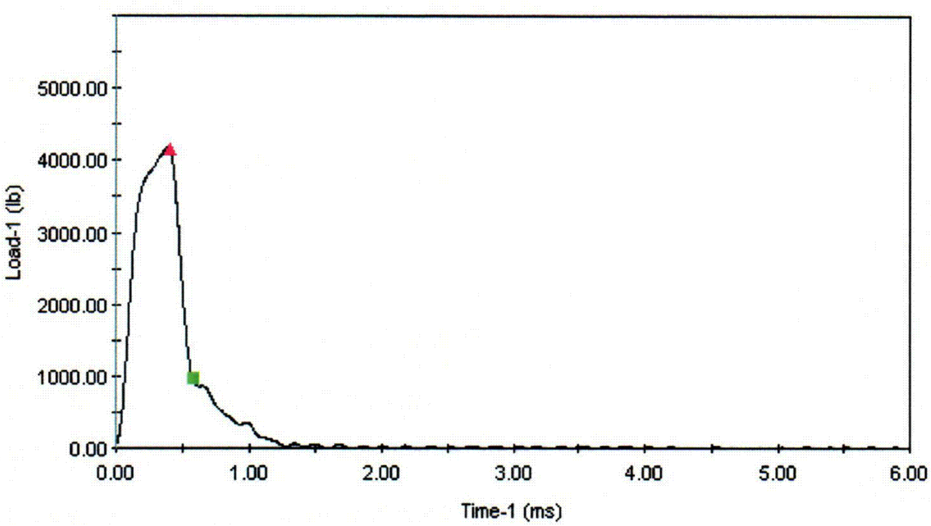


WT46, 100°F

C12

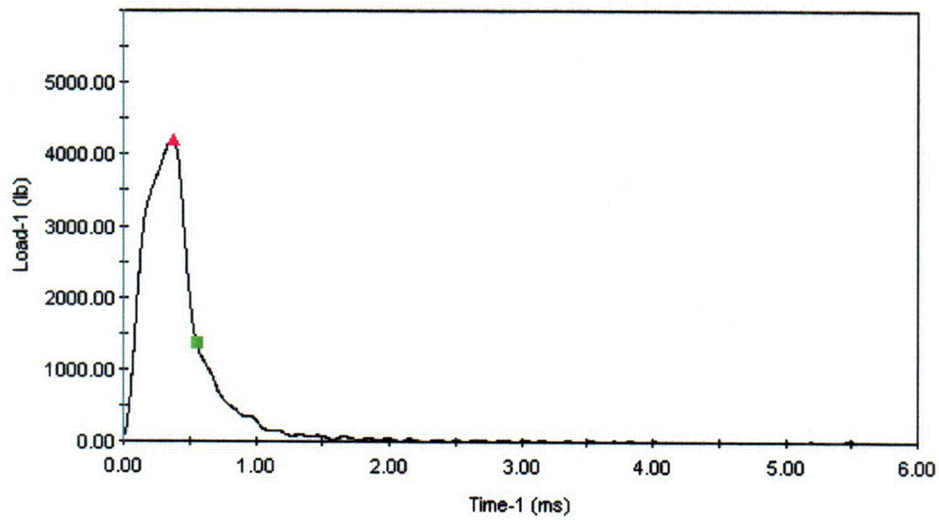


WT59, 125°F

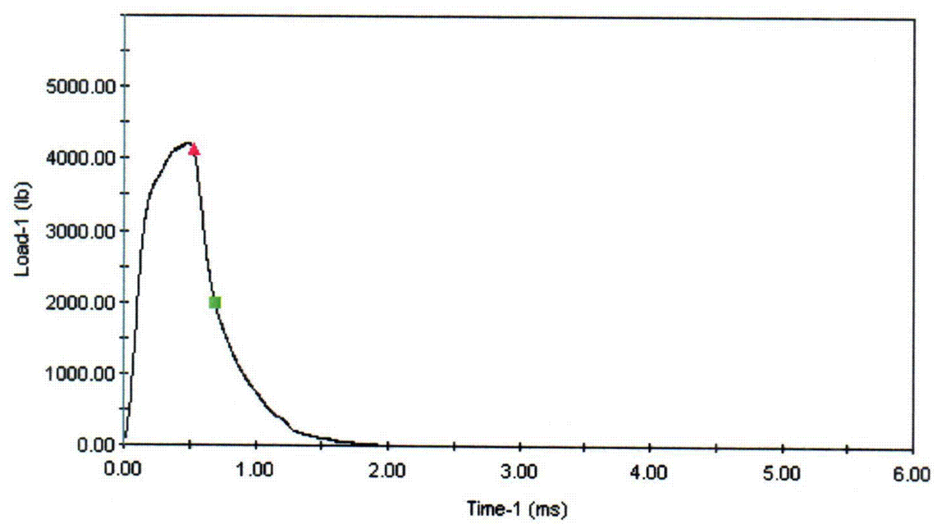


WT54, 150°F

C13

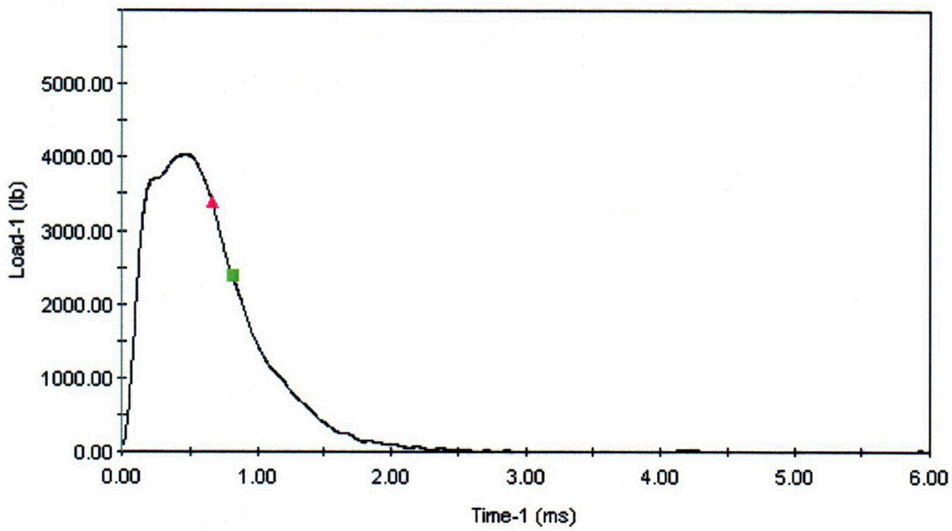


WT47, 175°F

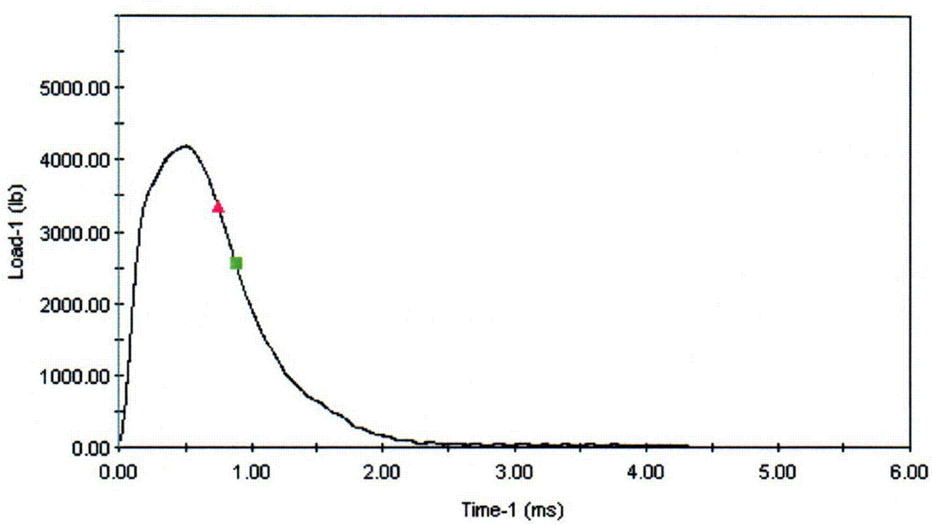


WT52, 200°F

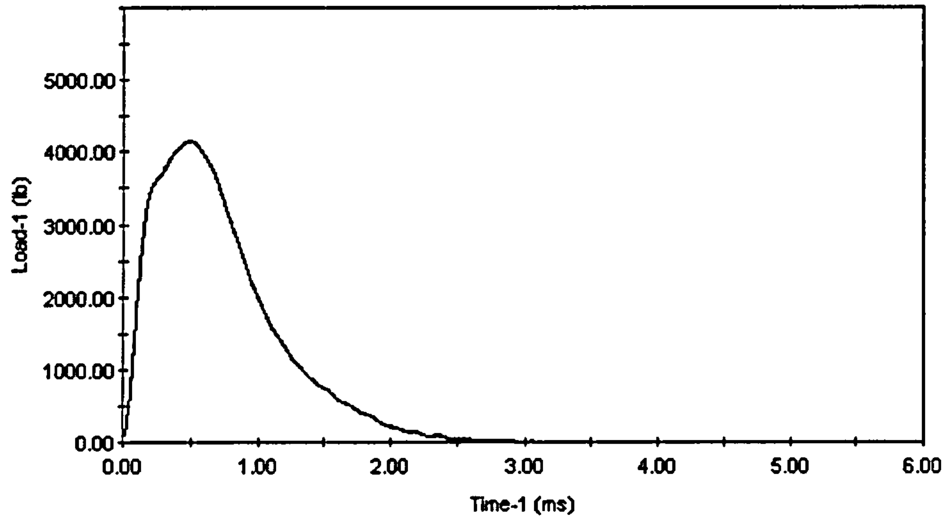
C14



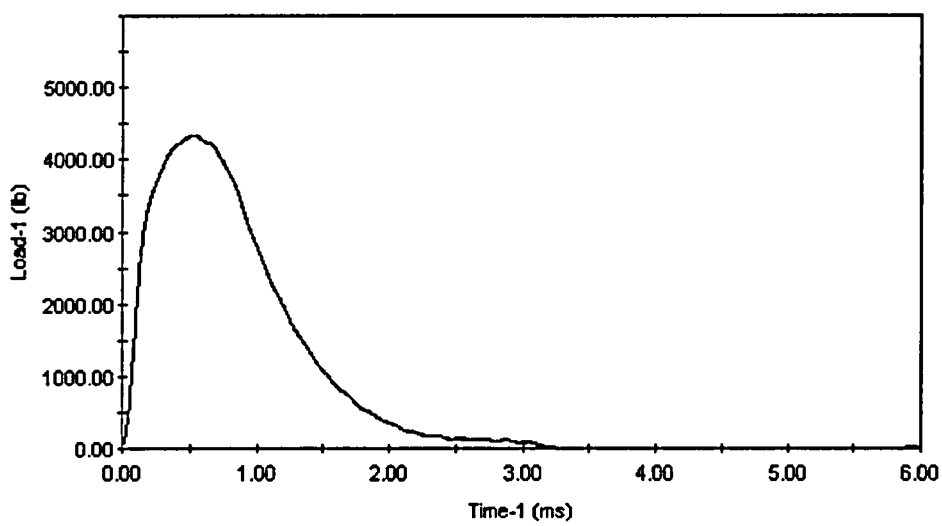
WT55, 250°F



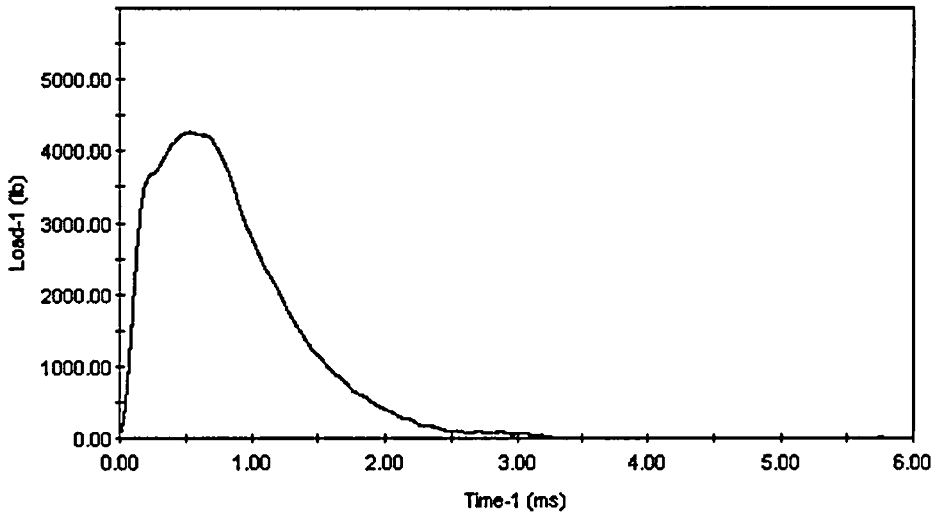
WT58, 275°F



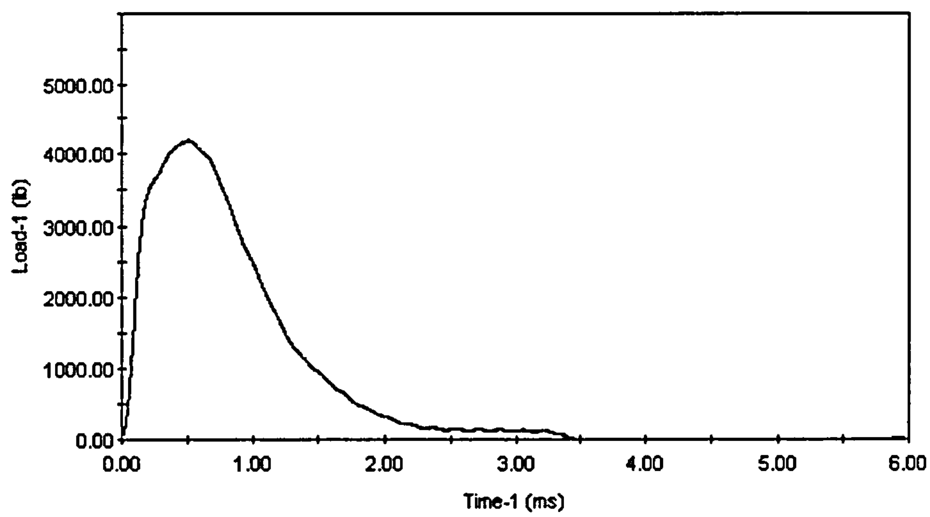
WT53, 300°F



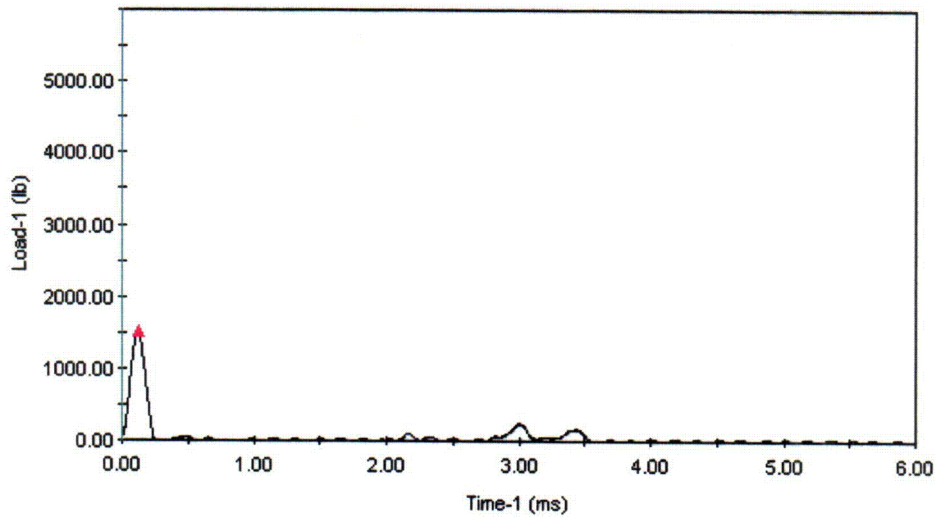
WT48, 325°F



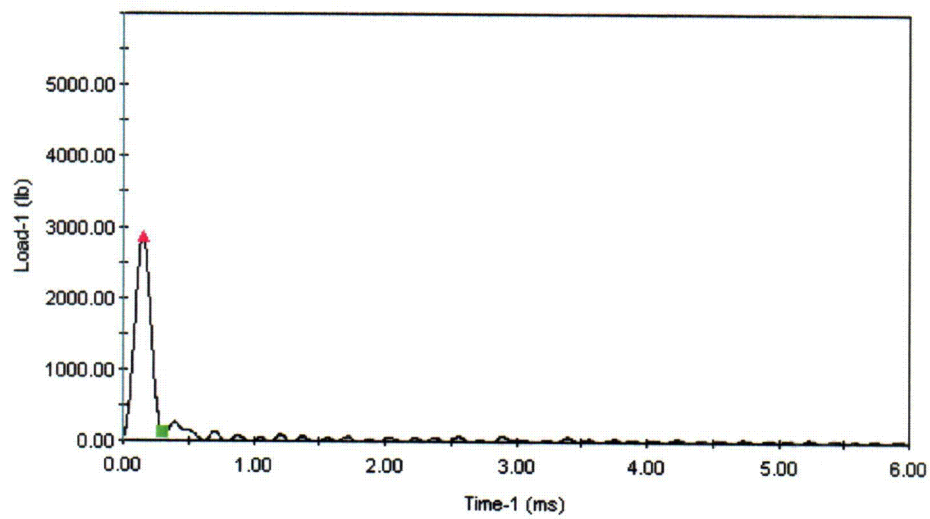
WT51, 350°F



WT49, 375°F

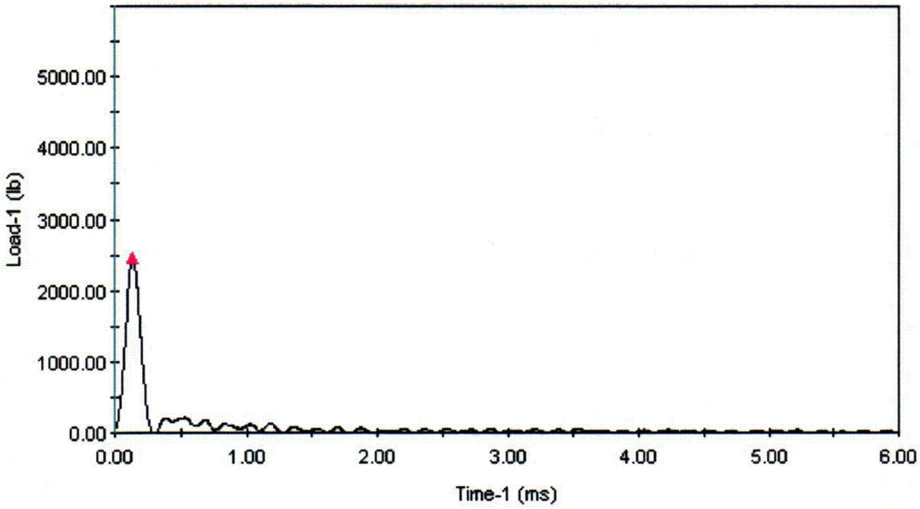


WW51, -75°F

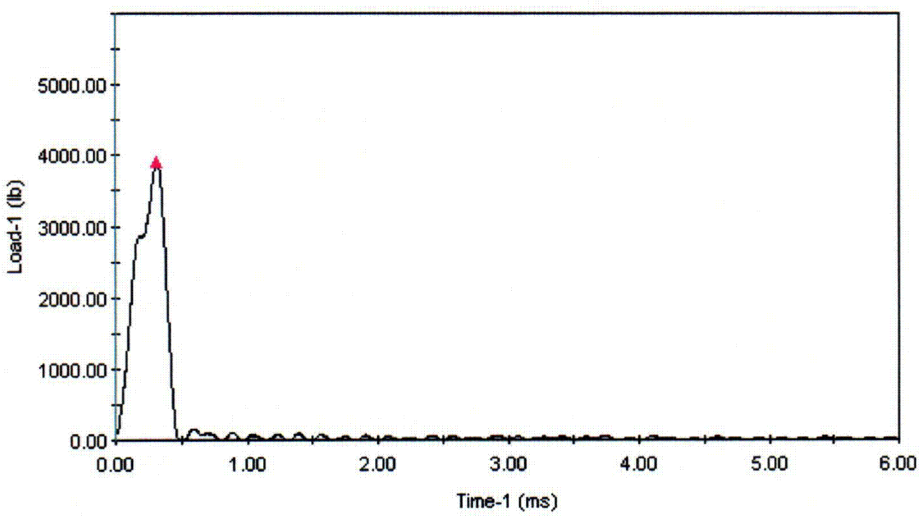


WW53, -50°F

C16

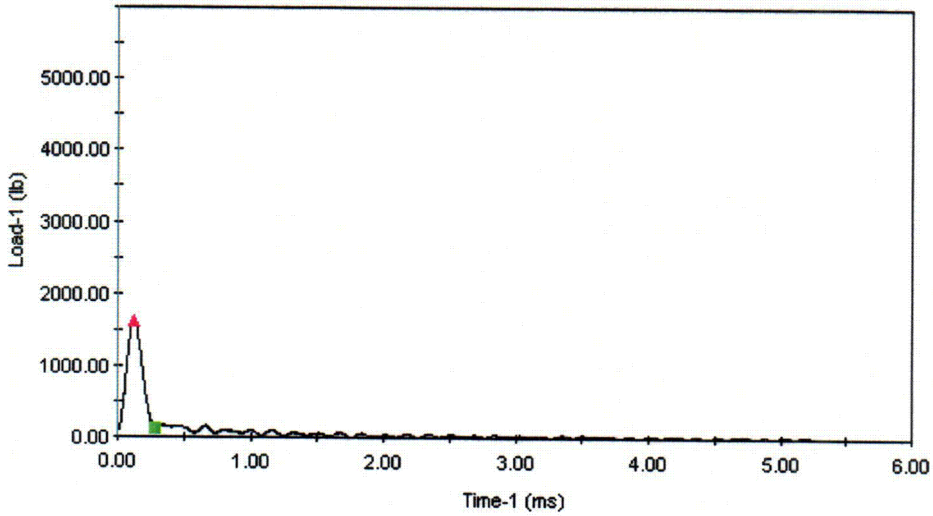


WW54, -25°F

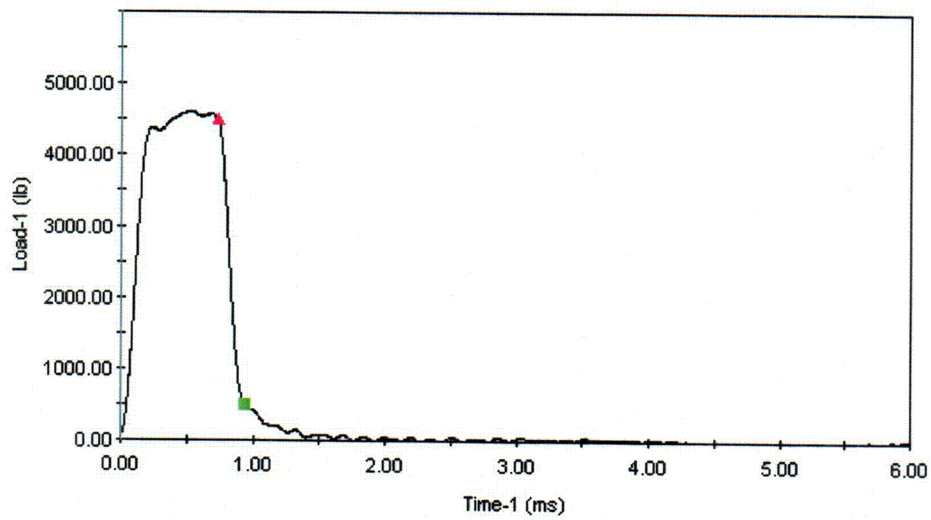


WW52, -25°F

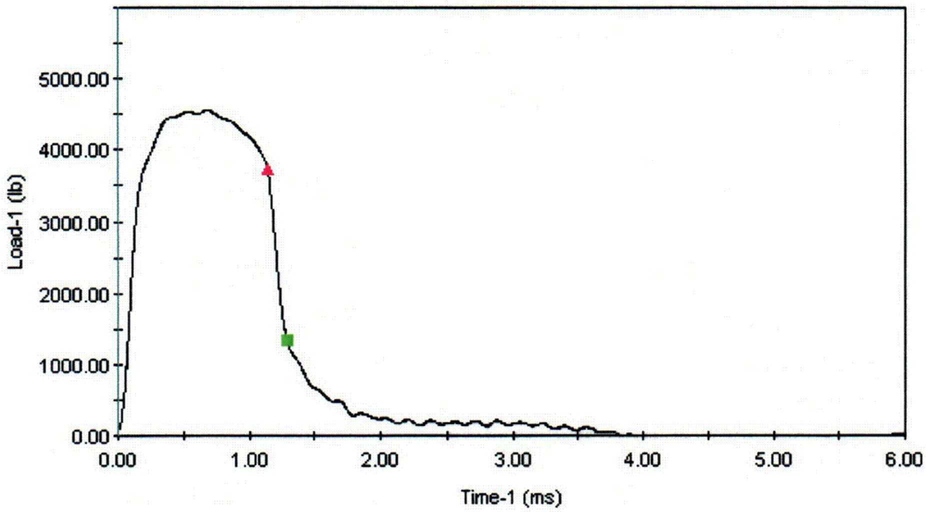
C17



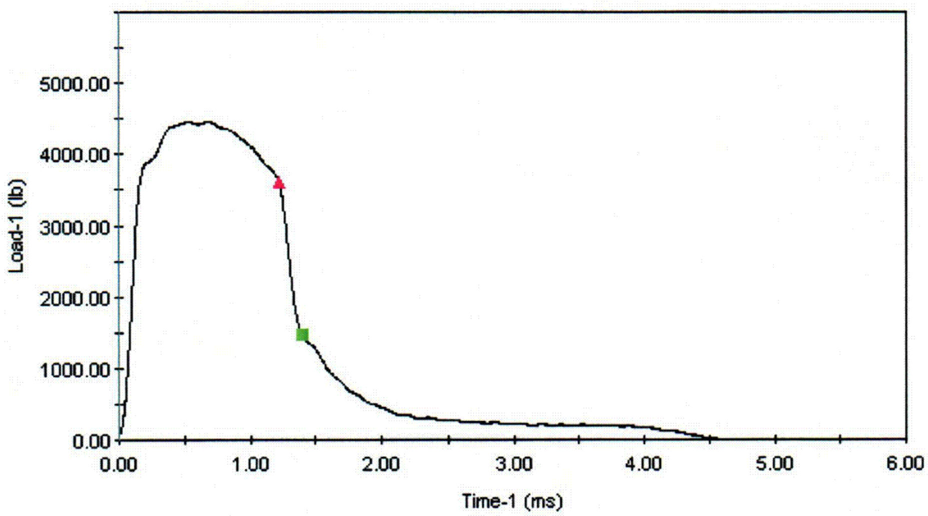
WW55, -10°F



WW48, 0°F

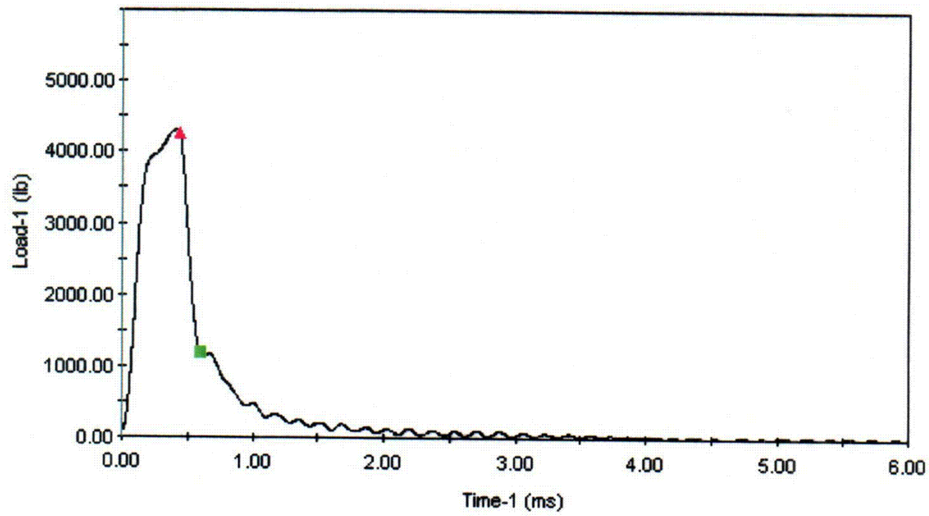


WW46, 10°F

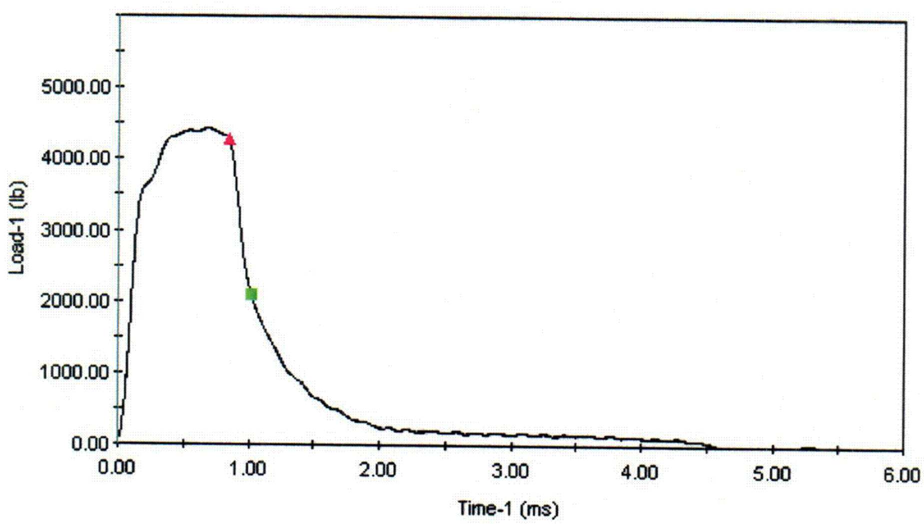


WW59, 25°F

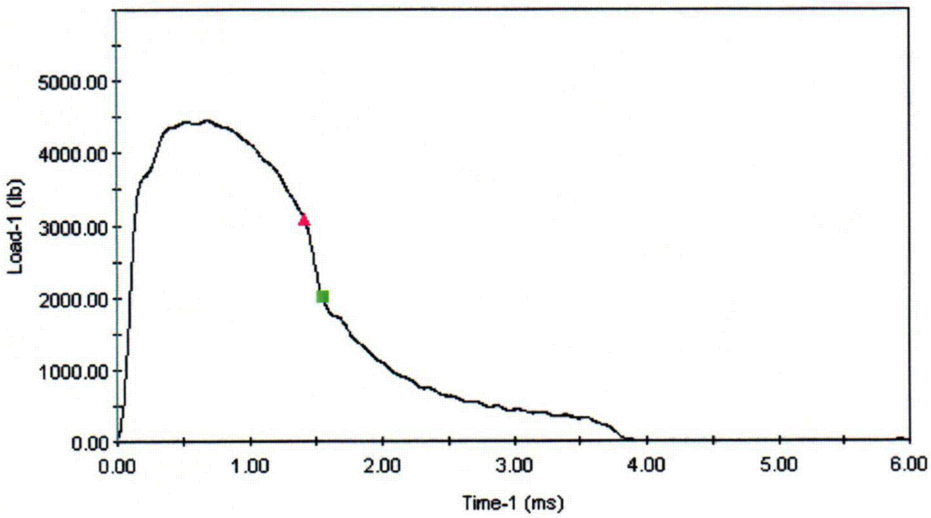
C19



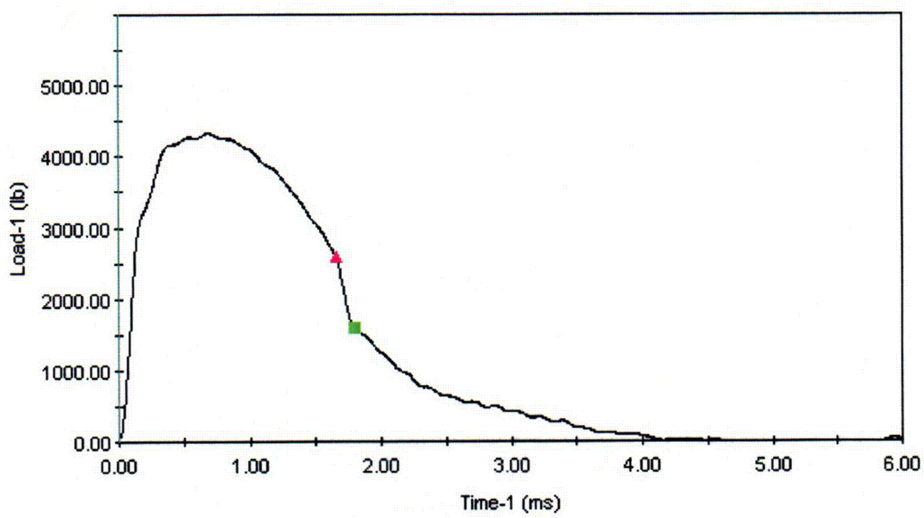
WW57, 50°F



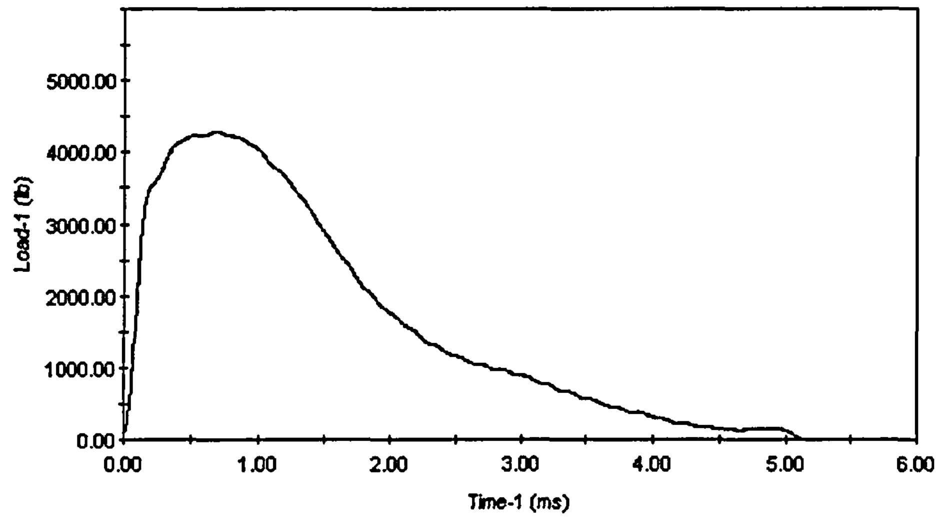
WW50, 50°F



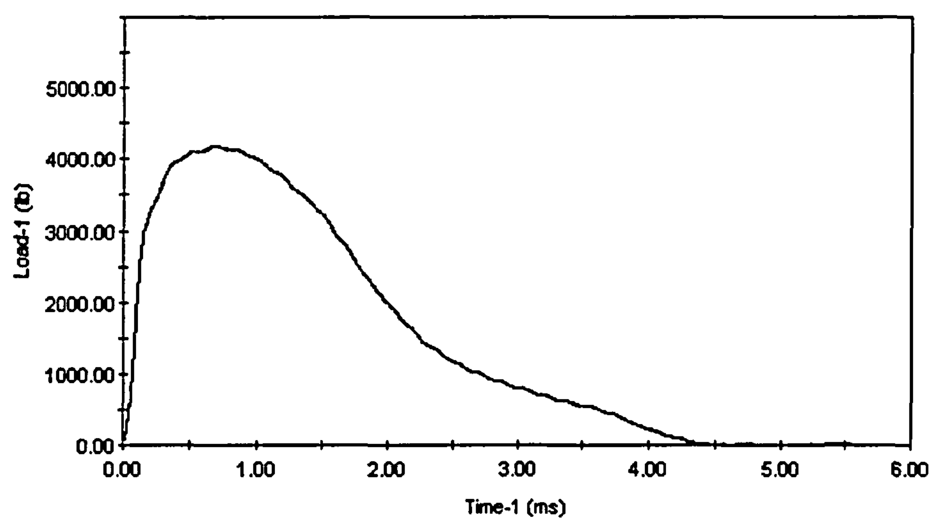
WW58, 75°F



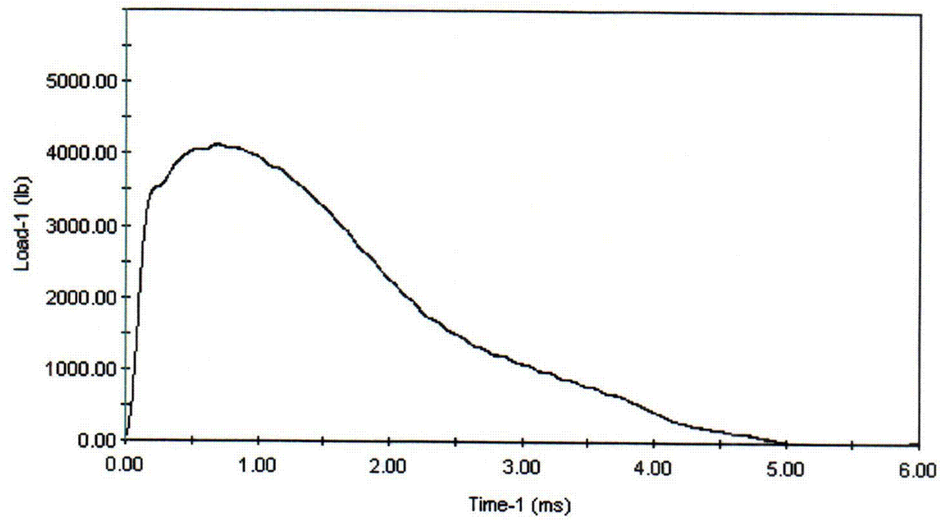
WW47, 100°F



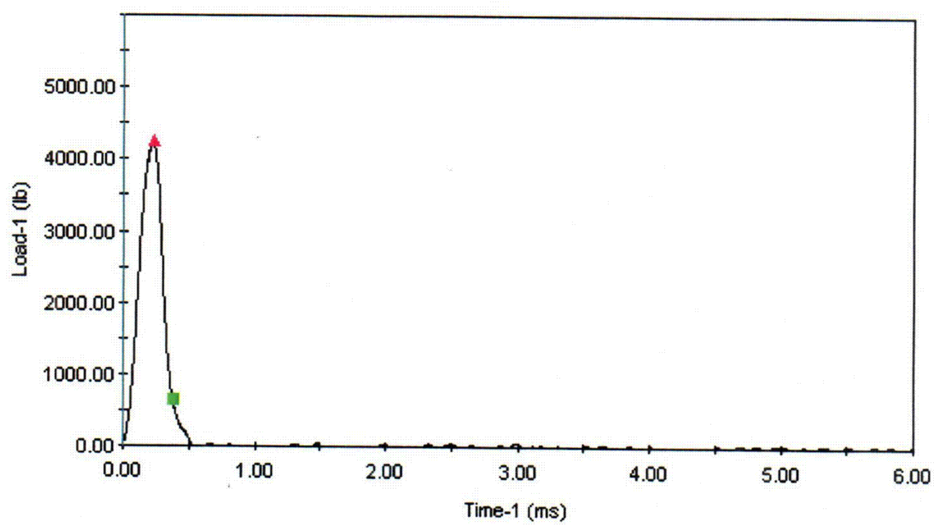
WW60, 150°F



WW56, 175°F

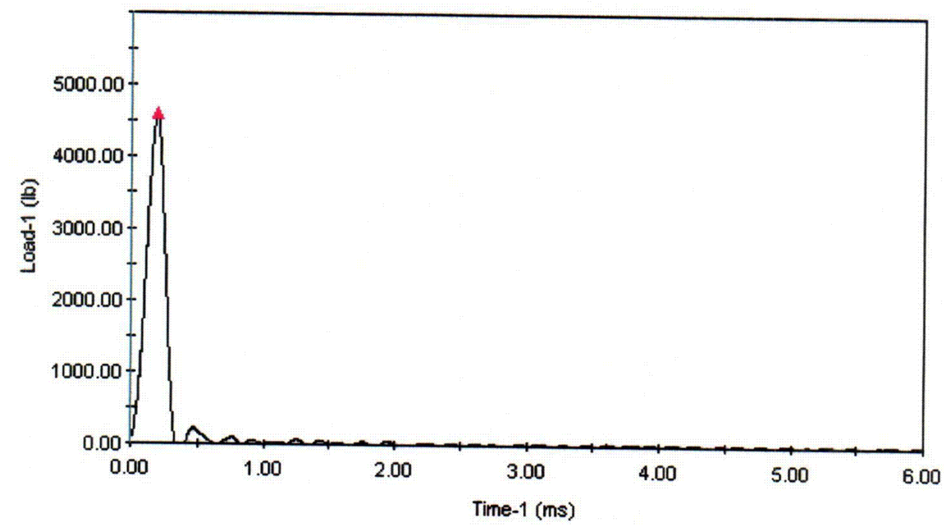


WW49, 225°F

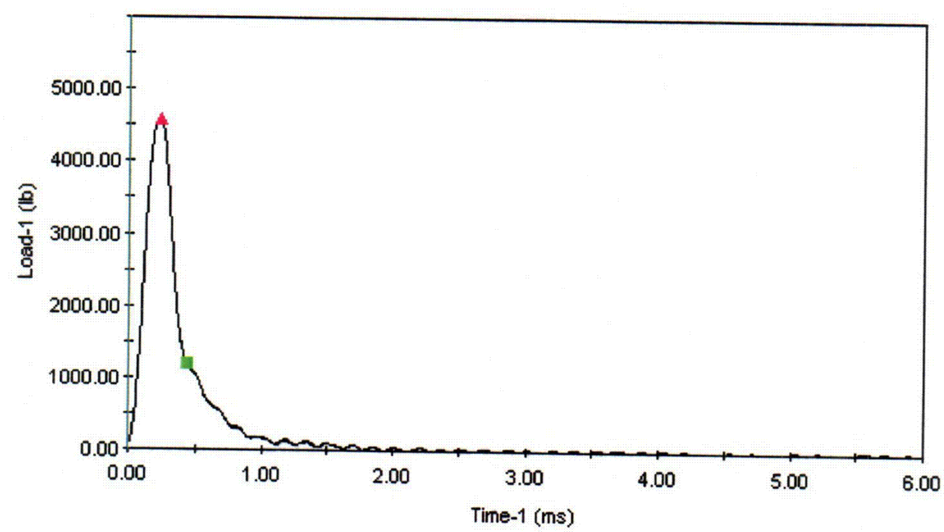


WH48, -90°F

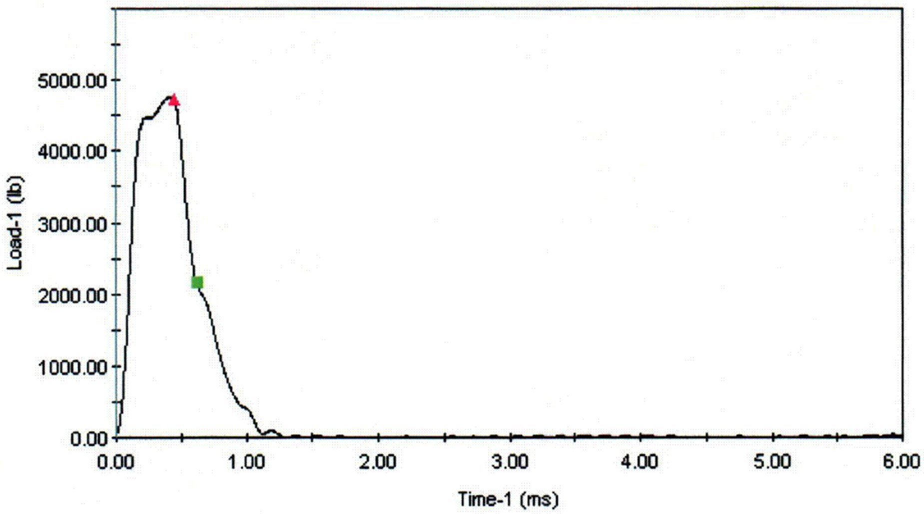
C22



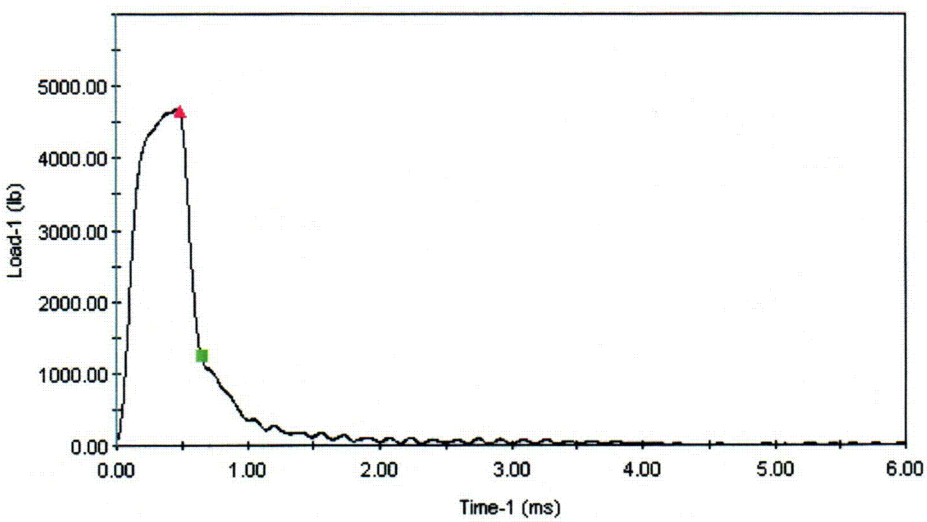
WH55, -50°F



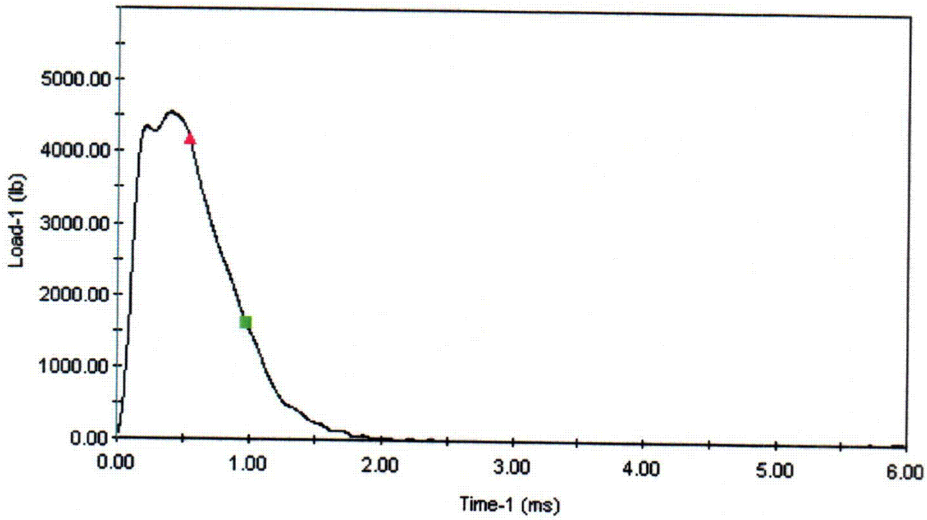
WH50, -25°F



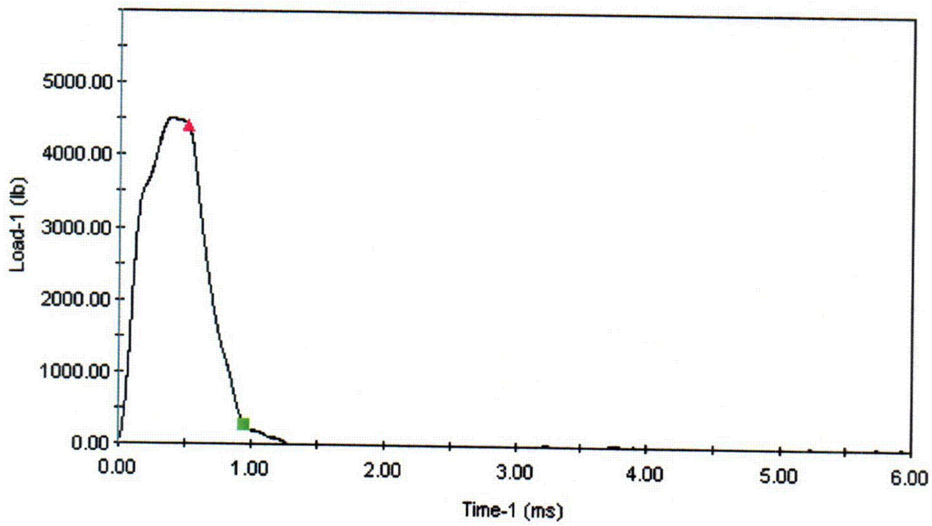
WH49, 0°F



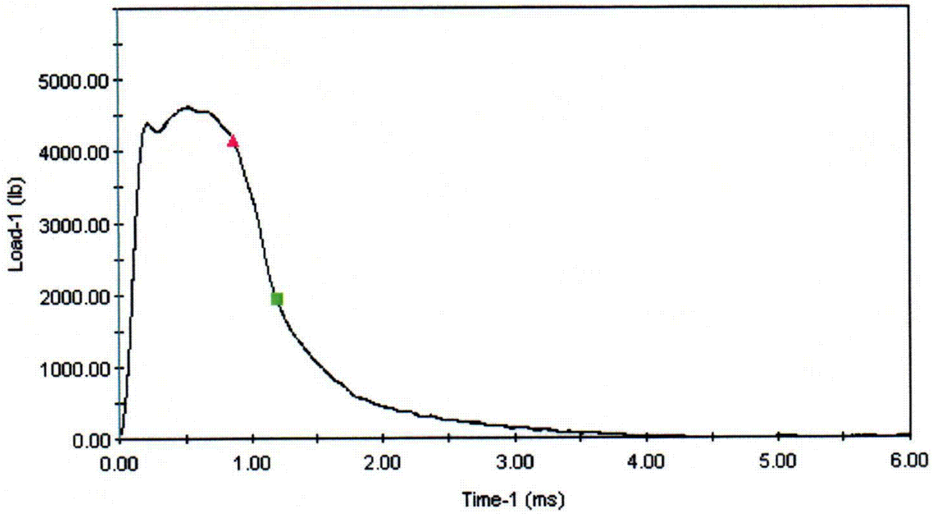
WH58, 25°F



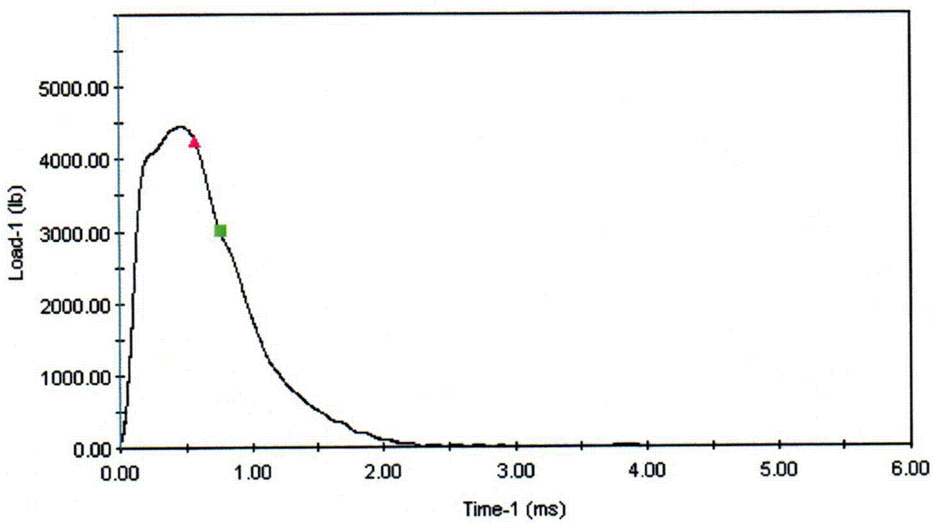
WH53, 50°F



WH51, 75°F

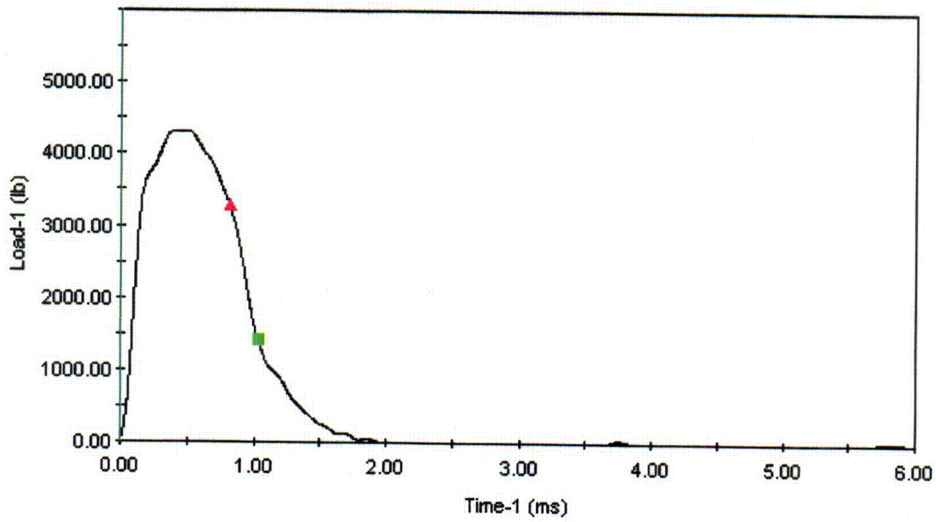


WH54, 100°F

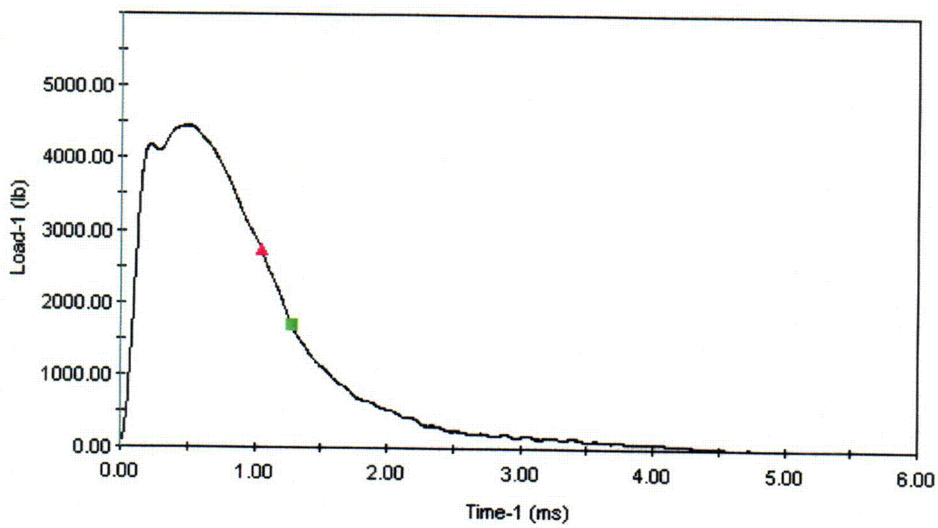


WH47, 125°F

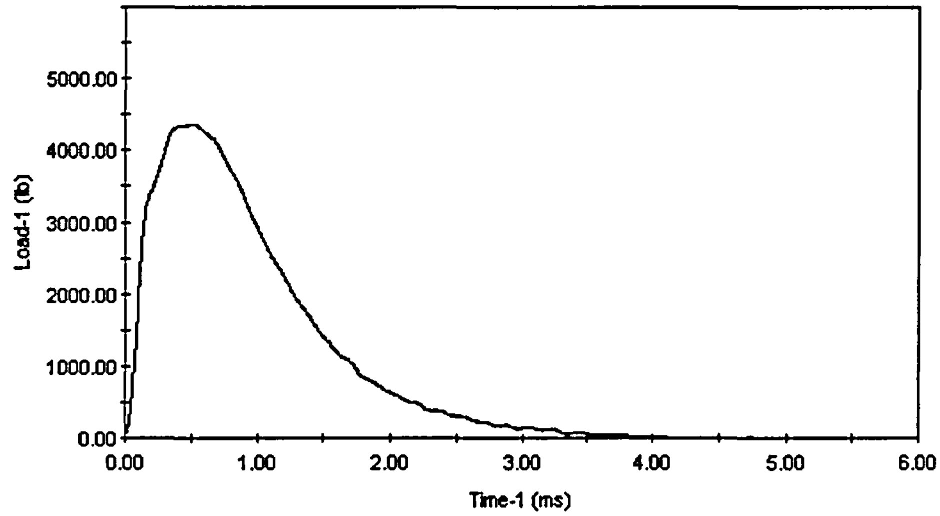
C26



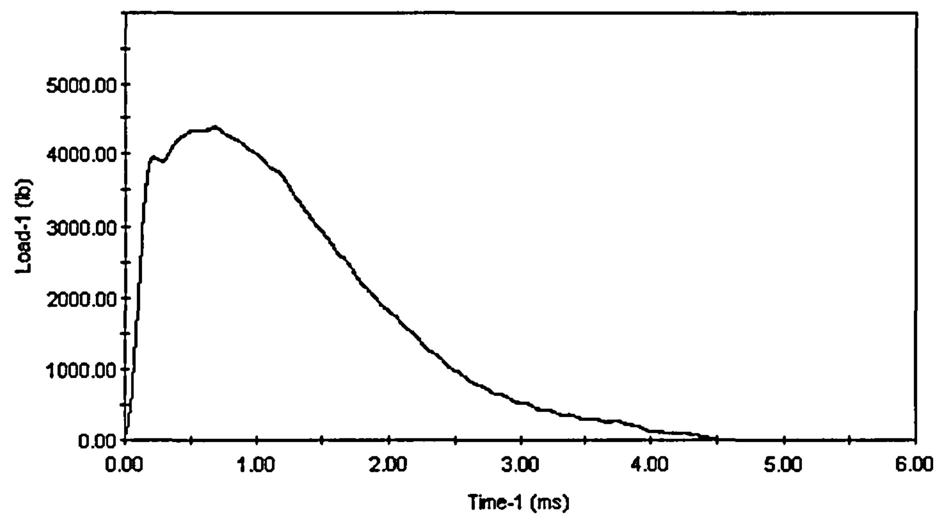
WH52, 135°F



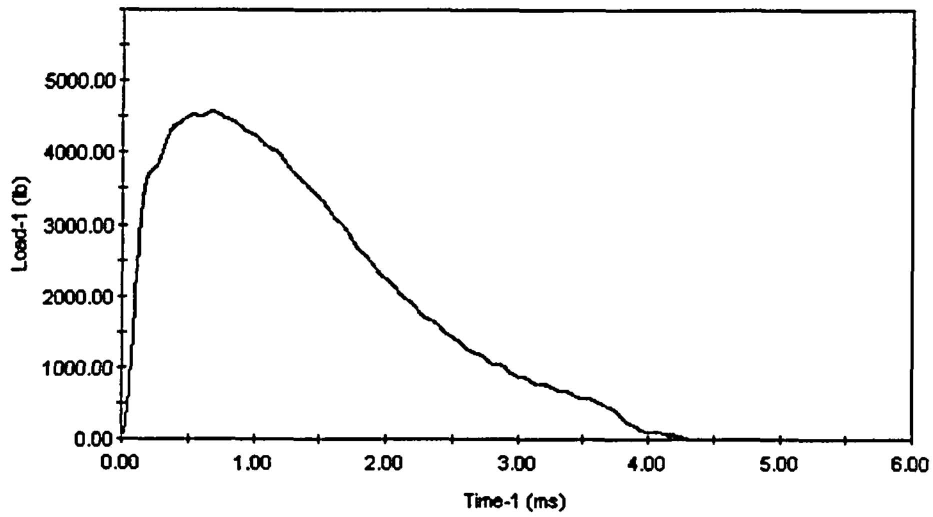
WH46, 150°F



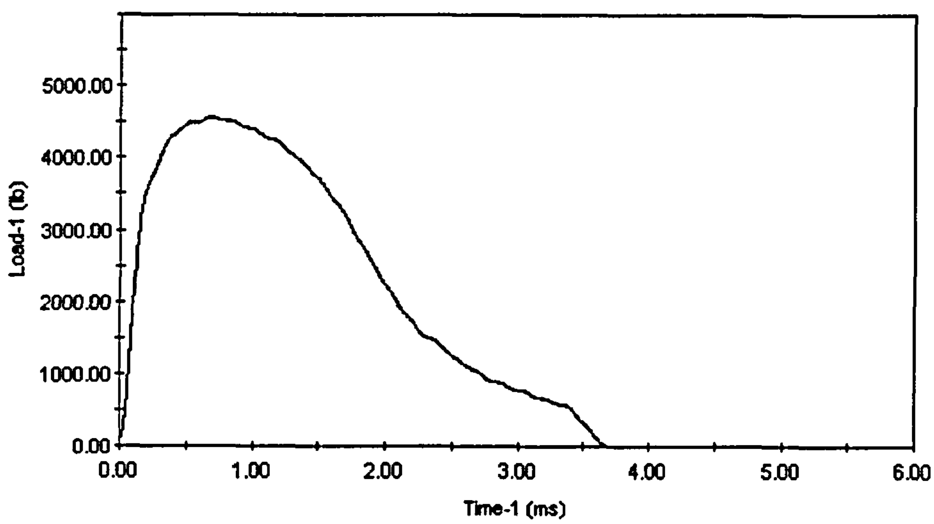
WH59, 175°F



WH60, 200°F



WH57, 225°F



WH56, 250°F

APPENDIX C

CHARPY V-NOTCH PLOTS FOR EACH CAPSULE USING SYMMETRIC 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 5.0.2. The definition for Upper Shelf Energy (USE) is given in ASTM E185-82, Section 4.18, and reads as follows:

> "*upper shelf energy level* – 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."

Westinghouse typically reports the average of all Charpy data ≥ 95% shear as the USE. In some instances, there may be data deemed 'out of family' and are removed from the determination of the USE based on engineering judgement. The USE values reported in Table C-1 and used to generate the Charpy V-notch curves were determined utilizing this methodology.

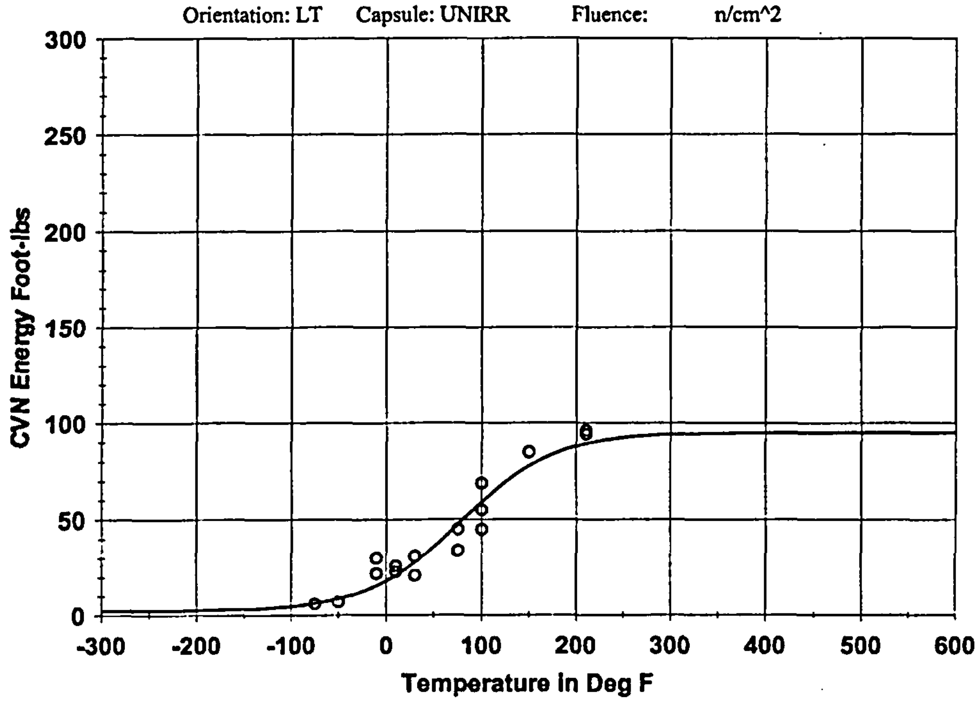
The lower shelf energy values were fixed at 2.2 ft-lb for all cases.

Table C-1 Upper Shelf Energy Values Fixed in CVGraph

Material	Unirradiated	Capsule U	Capsule V	Capsule W	Capsule X
Intermediate Shell Plate B9004-2 (*Long.*)	95 ft-lbs	105 ft-lbs	85 ft-lbs	94 ft-lbs	81 ft-lbs
Intermediate Shell Plate B9004-2 (*Trans.*)	79 ft-lbs	87 ft-lbs	76 ft-lbs	75 ft-lbs	74 ft-lbs
Weld Metal (*Heat # 83652*)	139 ft-lbs	134 ft-lbs	136 ft-lbs	136 ft-lbs	133 ft-lbs
Heat Affected Zone Material	91 ft-lbs	109 ft-lbs	87 ft-lbs	104 ft-lbs	114 ft-lbs

UNIRRADIATED INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:05 PM
Page 1
Coefficients of Curve 1
A = 48.6 B = 46.4 C = 98.21 T0 = 77.3 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=95.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=35.6 Deg F Temp@50 ft-lbs=80.3 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-75.00	6.00	6.19	-.19
-50.00	7.00	8.66	-1.66
-10.00	22.00	15.62	6.38
-10.00	30.00	15.62	14.38
10.00	26.00	20.99	5.01
10.00	23.00	20.99	2.01
30.00	31.00	27.83	3.17
30.00	21.00	27.83	-6.83
75.00	45.00	47.51	-2.51

UNIRRADIATED INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

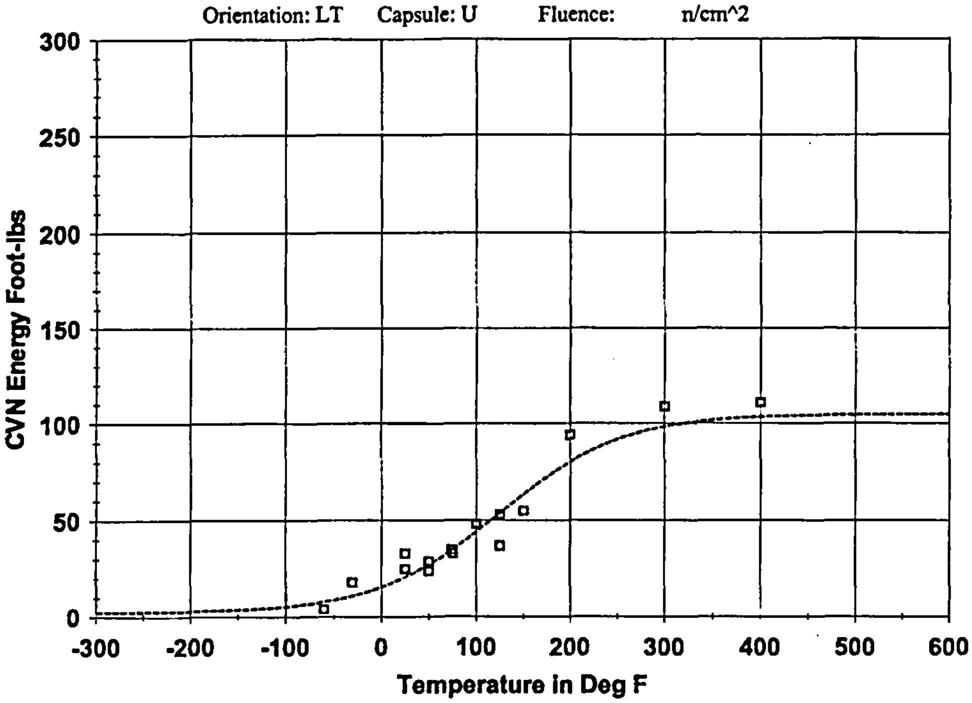
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
75.00	34.00	47.51	-13.51
100.00	69.00	59.14	9.86
100.00	55.00	59.14	-4.14
100.00	45.00	59.14	-14.14
150.00	85.00	77.80	7.20
150.00	85.00	77.80	7.20
210.00	94.00	89.17	4.83
210.00	96.00	89.17	6.83
210.00	94.00	89.17	4.83

Correlation Coefficient = .970

CAPSULE U INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:05 PM
Page 1
Coefficients of Curve 2
A = 53.6 B = 51.4 C = 131.08 T0 = 124.63 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=105.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=59.6 Deg F Temp@50 ft-lbs=115.5 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-60.00	4.00	8.00	-4.00
-30.00	18.00	11.07	6.93
25.00	25.00	20.65	4.35
25.00	33.00	20.65	12.35
50.00	24.00	27.13	-3.13
50.00	29.00	27.13	1.87
74.00	35.00	34.68	.32
75.00	33.00	35.02	-2.02
100.00	48.00	44.05	3.95

CAPSULE U INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: U Fluence: n/cm^2

Charpy V-Notch Data

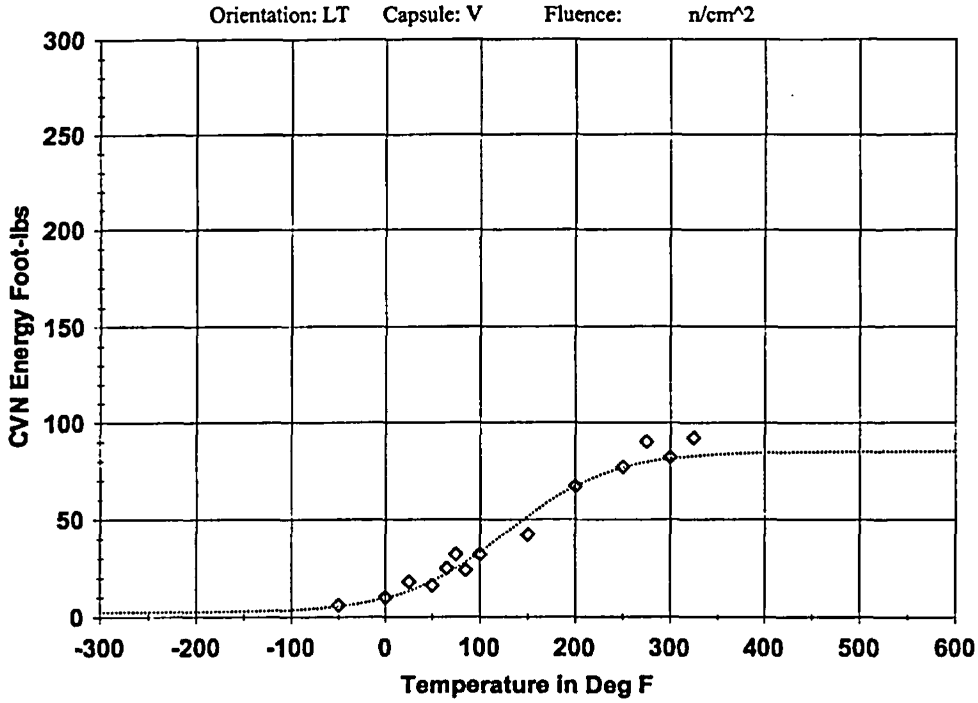
Temperature	Input CVN	Computed CVN	Differential
125.00	37.00	53.74	-16.74
125.00	53.00	53.74	-.74
150.00	55.00	63.42	-8.42
200.00	94.00	80.28	13.72
300.00	109.00	98.38	10.62
400.00	111.00	103.48	7.52

Correlation Coefficient = .970

CAPSULE V INTERMEDIATE SHELL PLATE 9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:06 PM

Coefficients of Curve 3
A = 43.6 B = 41.4 C = 110.82 T0 = 129.32 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=85.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=91.6 Deg F Temp@50 ft-lbs=146.6 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: V Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	6.00	5.33	.67
.00	10.00	9.52	.48
25.00	18.00	13.14	4.86
50.00	16.00	18.17	-2.17
65.00	25.00	21.95	3.05
75.00	32.00	24.79	7.21
85.00	24.00	27.87	-3.87
100.00	32.00	32.90	-.90
150.00	42.00	51.24	-9.24

CAPSULE V INTERMEDIATE SHELL PLATE 9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: V Fluence: n/cm^2

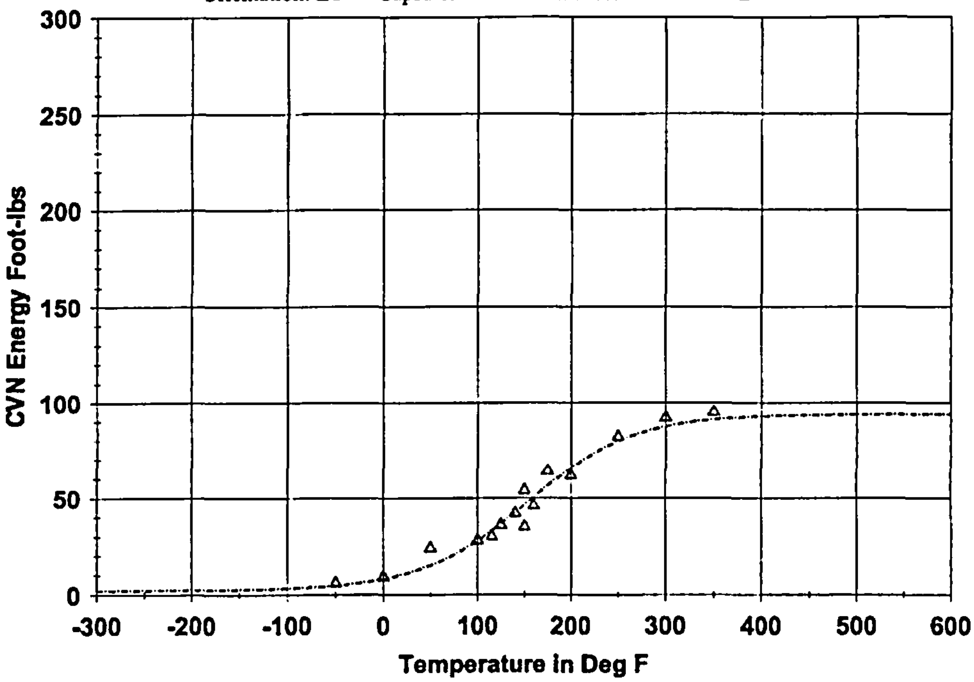
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
200.00	67.00	66.92	.08
250.00	77.00	76.57	.43
275.00	90.00	79.43	10.57
300.00	82.00	81.36	.64
325.00	92.00	82.65	9.35

Correlation Coefficient = .986

CAPSULE W INTERMEDIATE SHELL PLATE 9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:06 PM
Page 1
Coefficients of Curve 4
A = 48.1 B = 45.9 C = 114.14 T0 = 154.1 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=94.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=106.6 Deg F Temp@50 ft-lbs=158.9 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	6.00	4.70	1.30
.00	9.00	7.98	1.02
50.00	24.00	14.96	9.04
100.00	28.00	27.84	.16
115.00	30.00	32.96	-2.96
125.00	36.00	36.65	-.65
140.00	42.00	42.46	-.46
150.00	54.00	46.45	7.55
150.00	35.00	46.45	-11.45

CAPSULE W INTERMEDIATE SHELL PLATE 9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: W Fluence: n/cm^2

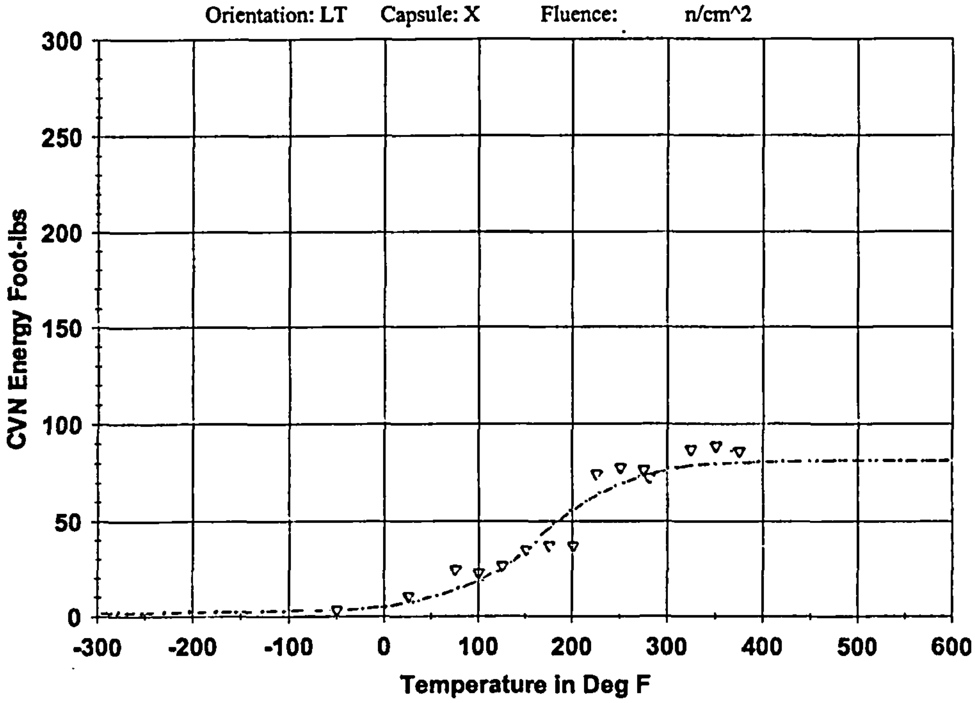
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
160.00	46.00	50.47	-4.47
175.00	64.00	56.41	7.59
200.00	62.00	65.62	-3.62
250.00	82.00	79.58	2.42
300.00	92.00	87.39	4.61
350.00	95.00	91.13	3.87

Correlation Coefficient = .981

CAPSULE X INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:06 PM
Page 1
Coefficients of Curve 5
A = 41.6 B = 39.4 C = 99.55 T0 = 163.71 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=81.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=133.6 Deg F Temp@50 ft-lbs=185.3 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	3.00	3.26	-.26
25.00	11.00	6.77	4.23
75.00	25.00	13.55	11.45
100.00	23.00	19.34	3.66
125.00	27.00	27.01	-.01
150.00	35.00	36.21	-1.21
175.00	38.00	46.05	-8.05
200.00	37.00	55.36	-18.36
225.00	75.00	63.20	11.80

CAPSULE X INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: X Fluence: n/cm^2

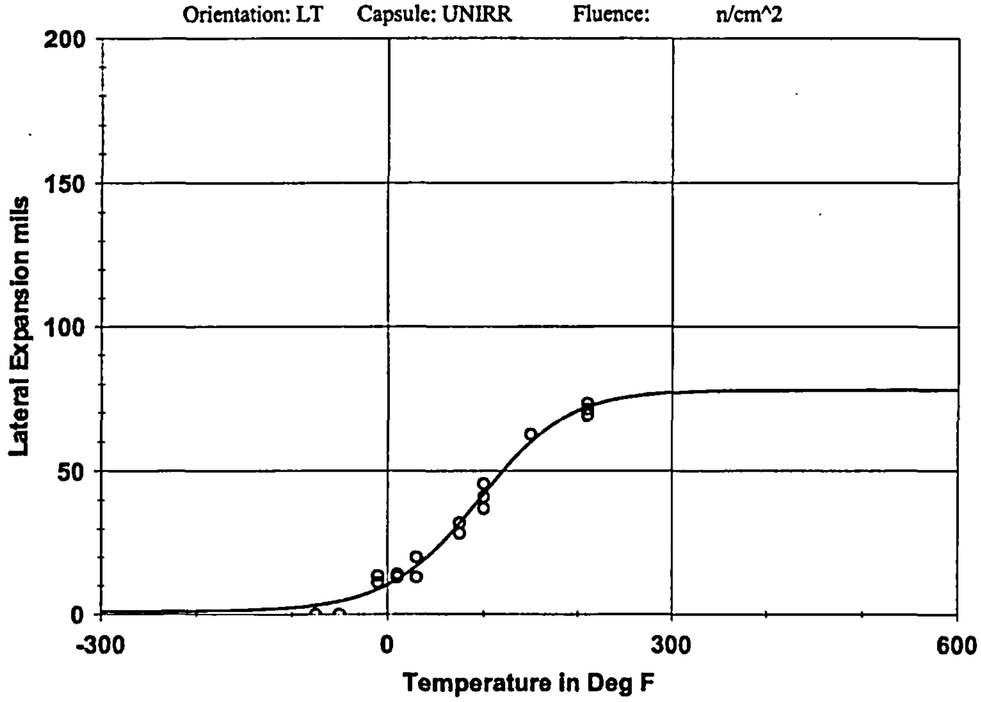
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
250.00	78.00	69.17	8.83
275.00	77.00	73.39	3.61
280.00	73.00	74.05	-1.05
325.00	87.00	78.03	8.97
350.00	89.00	79.18	9.82
375.00	86.00	79.89	6.11

Correlation Coefficient = .965

UNIRRADIATED INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 10/28/2005 11:41 AM
Page 1
Coefficients of Curve 1
A = 39.45 B = 38.45 C = 94.75 T0 = 93.9 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=77.9 *Lower Shelf L.E.=1.0(Fixed)*
Temp.@L.E. 35 mils=82.9 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-75.00	.00	3.12	-3.12
-50.00	.00	4.52	-4.52
-10.00	11.00	8.72	2.28
-10.00	13.50	8.72	4.78
10.00	14.00	12.18	1.82
10.00	13.00	12.18	.82
30.00	20.00	16.84	3.16
30.00	13.00	16.84	-3.84
75.00	32.00	31.88	.12

UNIRRADIATED INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

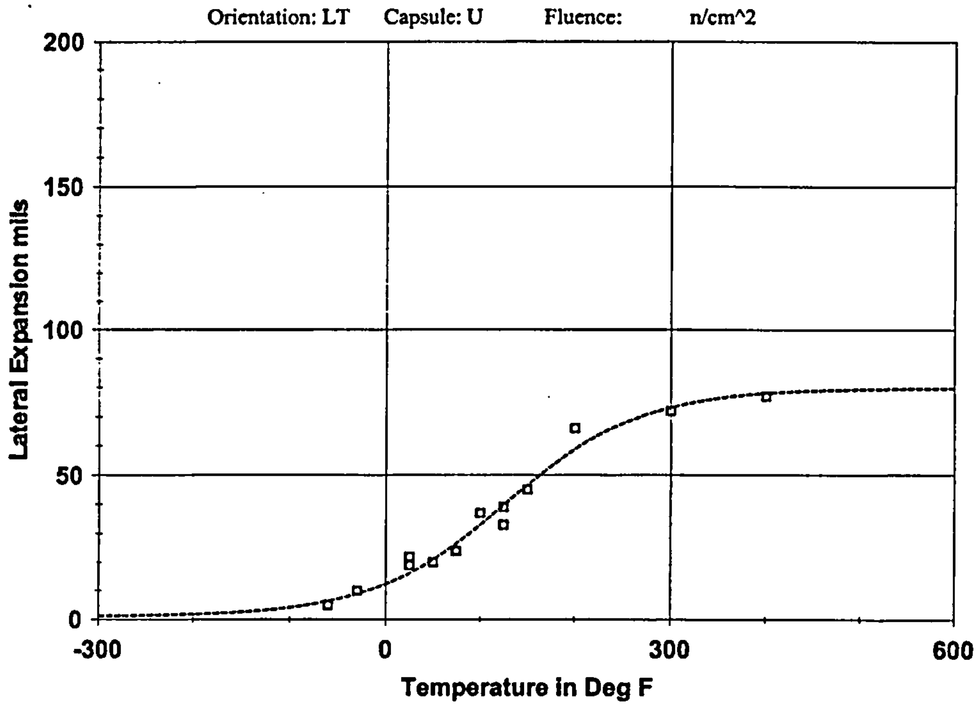
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
75.00	28.50	31.88	-3.38
100.00	45.50	41.92	3.58
100.00	37.00	41.92	-4.92
100.00	41.00	41.92	-.92
150.00	62.50	59.88	2.62
150.00	62.50	59.88	2.62
210.00	69.00	71.79	-2.79
210.00	73.00	71.79	1.21
210.00	71.00	71.79	-.79

Correlation Coefficient = .993

CAPSULE U INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 10/28/2005 11:17 AM
Page 1
Coefficients of Curve 2
A = 40.38 B = 39.38 C = 143.58 T0 = 127.55 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=79.8 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=107.9 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-60.00	5.00	6.38	-1.38
-30.00	10.00	8.89	1.11
25.00	19.00	16.23	2.77
25.00	22.00	16.23	5.77
50.00	20.00	20.96	-.96
50.00	20.00	20.96	-.96
74.00	24.00	26.34	-2.34
75.00	24.00	26.58	-2.58
100.00	37.00	32.91	4.09

CAPSULE U INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: U Fluence: n/cm^2

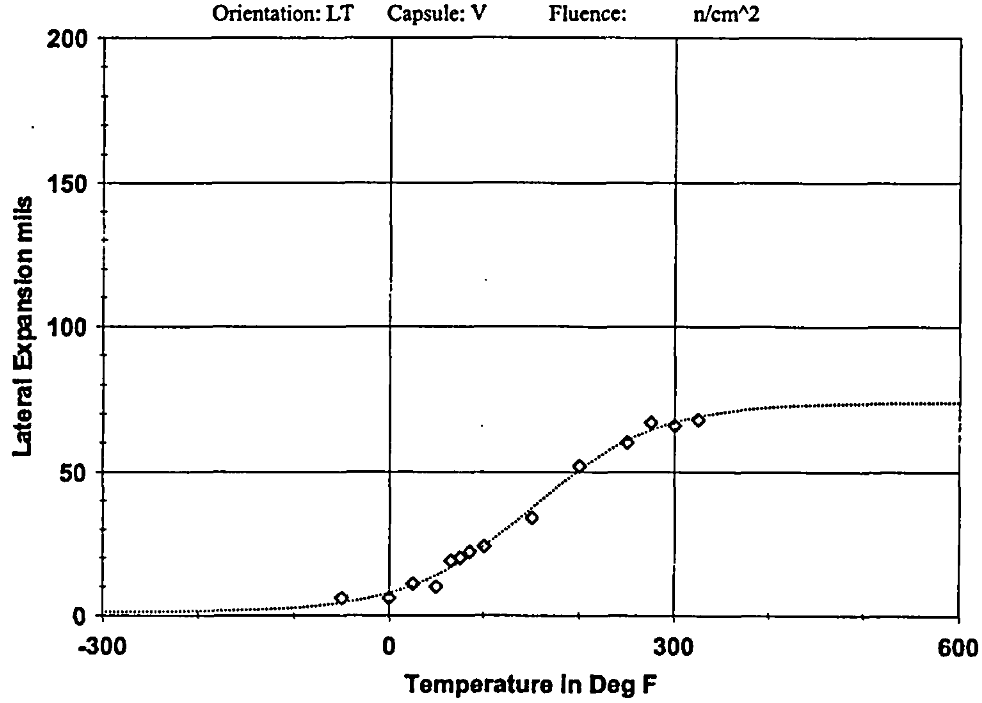
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
125.00	33.00	39.68	-6.68
125.00	39.00	39.68	-.68
150.00	45.00	46.48	-1.48
200.00	66.00	58.72	7.28
300.00	72.00	73.22	-1.22
400.00	77.00	78.02	-1.02

Correlation Coefficient = .987

CAPSULE V INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 10/28/2005 11:17 AM
Page 1
Coefficients of Curve 3
A = 37.35 B = 36.35 C = 130.93 T0 = 150.4 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=73.7 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=142.0 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: V Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	6.00	4.25	1.75
.00	6.00	7.64	-1.64
25.00	11.00	10.33	.67
50.00	10.00	13.90	-3.90
65.00	19.00	16.52	2.48
75.00	20.00	18.46	1.54
85.00	22.00	20.57	1.43
100.00	24.00	24.01	-.01
150.00	34.00	37.24	-3.24

CAPSULE V INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: V Fluence: n/cm^2

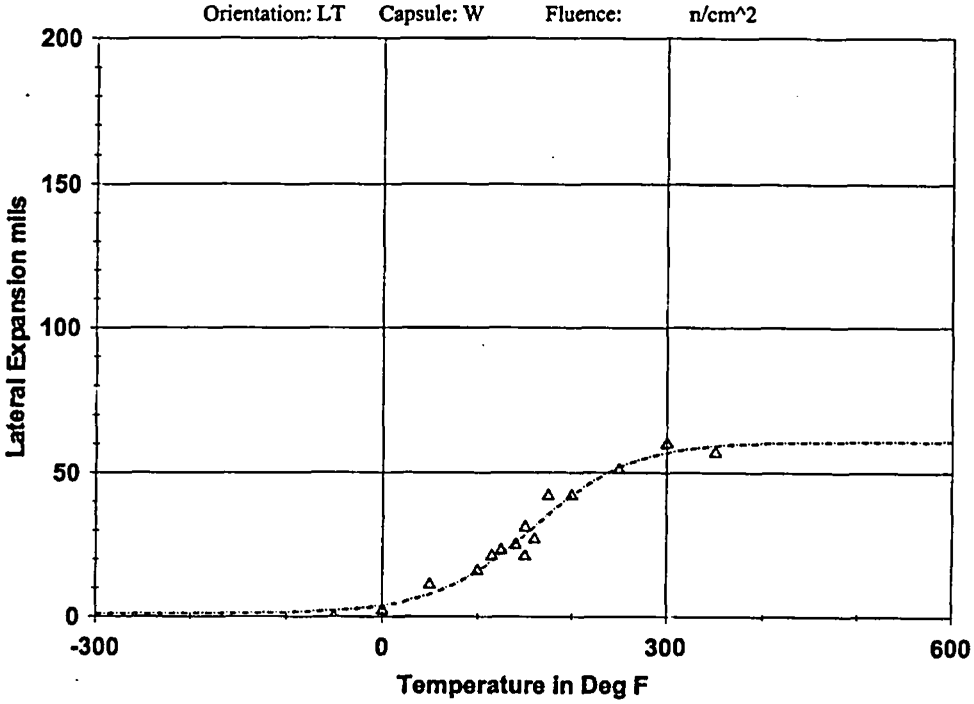
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
200.00	52.00	50.50	1.50
250.00	60.00	60.67	-.67
275.00	67.00	64.27	2.73
300.00	66.00	66.99	-.99
325.00	68.00	68.98	-.98

Correlation Coefficient = .996

CAPSULE W INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 10/28/2005 11:17 AM
Page 1
Coefficients of Curve 4
A = 30.95 B = 29.95 C = 105.74 T0 = 158.73 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=60.9 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=173.2 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	.00	2.13	-2.13
.00	2.00	3.83	-1.83
50.00	11.00	7.79	3.21
100.00	16.00	15.84	.16
115.00	21.00	19.22	1.78
125.00	23.00	21.71	1.29
140.00	25.00	25.70	-.70
150.00	31.00	28.48	2.52
150.00	21.00	28.48	-7.48

CAPSULE W INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: W Fluence: n/cm^2

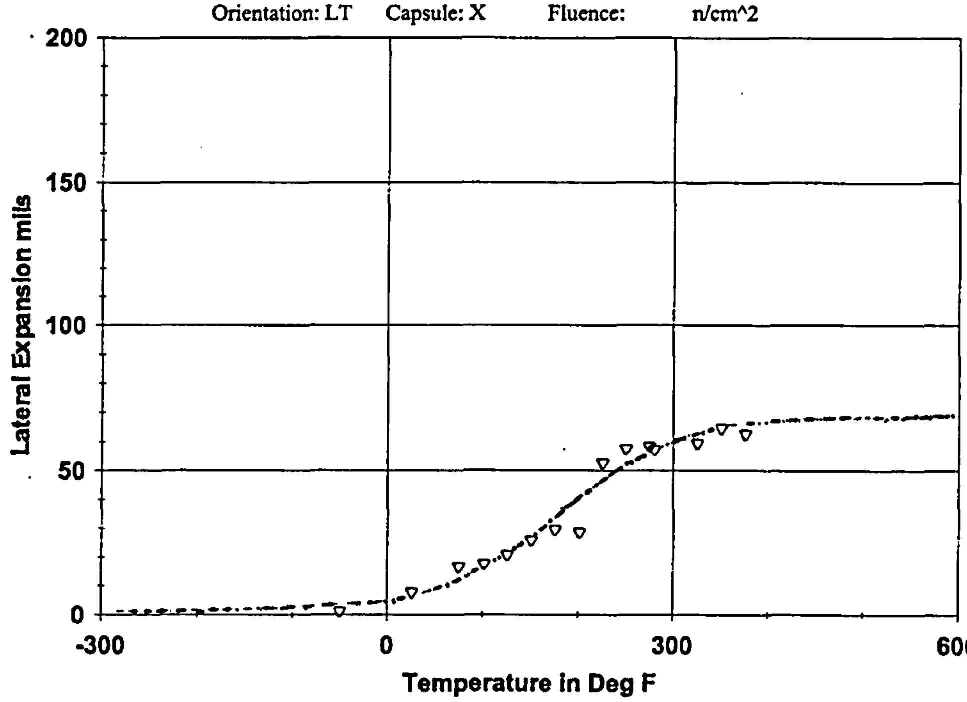
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
160.00	27.00	31.31	-4.31
175.00	42.00	35.52	6.48
200.00	42.00	42.08	-.08
250.00	51.00	51.85	-.85
300.00	60.00	57.02	2.98
350.00	57.00	59.33	-2.33

Correlation Coefficient = .983

CAPSULE X INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 10/28/2005 11:17 AM
Page 1
Coefficients of Curve 5
A = 34.96 B = 33.96 C = 127.68 T0 = 180.18 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=68.9 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=180.4 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	1.00	2.80	-1.80
25.00	8.00	6.49	1.51
75.00	17.00	11.96	5.04
100.00	18.00	16.05	1.95
125.00	21.00	21.13	-.13
150.00	26.00	27.08	-1.08
175.00	30.00	33.58	-3.58
200.00	29.00	40.19	-11.19
225.00	53.00	46.41	6.59

CAPSULE X INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: X Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
250.00	58.00	51.87	6.13
275.00	59.00	56.37	2.63
280.00	58.00	57.15	.85
325.00	60.00	62.55	-2.55
350.00	65.00	64.47	.53
375.00	63.00	65.85	-2.85

Correlation Coefficient = .980

UNIRRADIATED INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:22 PM

Coefficients of Curve 1

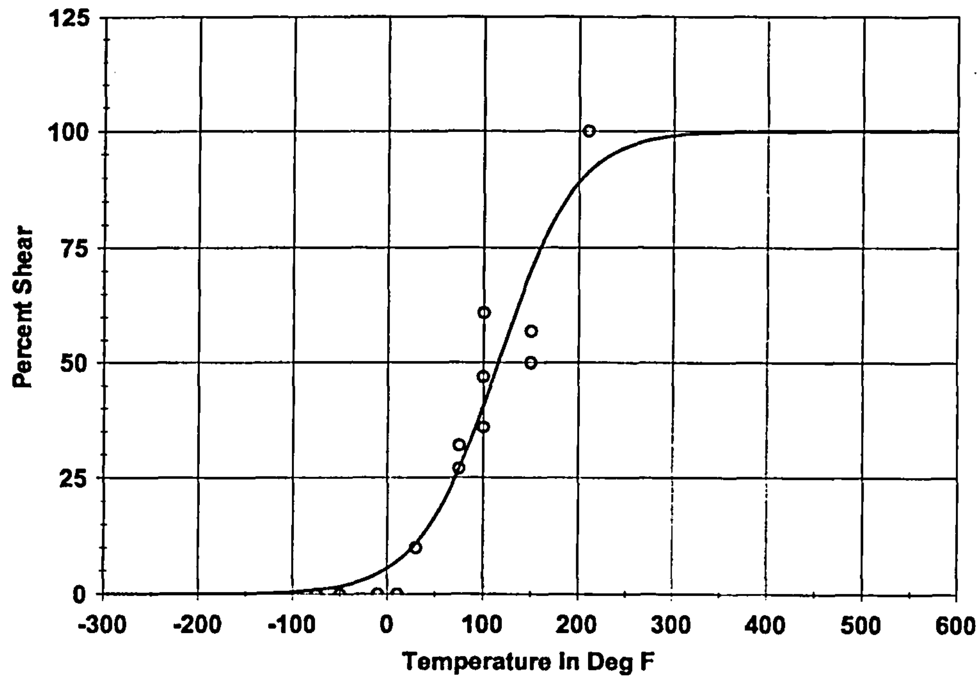
A = 50. B = 50. C = 81.15 T0 = 115.34 D = 0.00E+00

Equation is A + B * [Tanh((T-To)/(C+DT))]

Temperature at 50% Shear = 115.4

Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2

Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75.00	.00	.91	-.91
-50.00	.00	1.67	-1.67
-10.00	.00	4.36	-4.36
-10.00	.00	4.36	-4.36
10.00	.00	6.94	-6.94
10.00	.00	6.94	-6.94
30.00	10.00	10.88	-.88
30.00	10.00	10.88	-.88
75.00	27.00	27.01	-.01

UNIRRADIATED INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

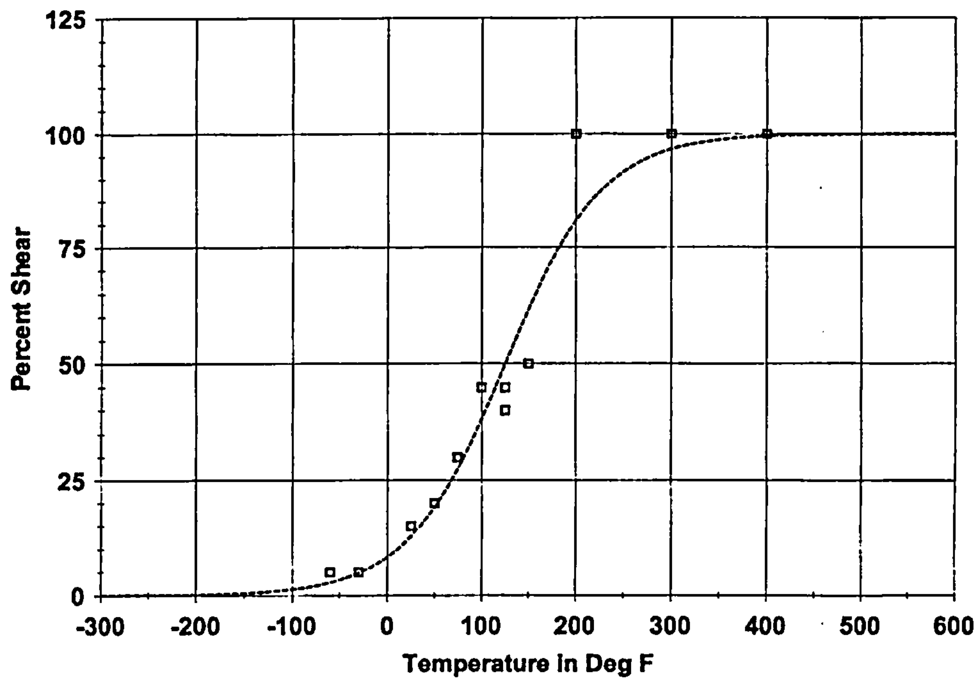
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
75.00	32.00	27.01	4.99
100.00	61.00	40.66	20.34
100.00	47.00	40.66	6.34
100.00	36.00	40.66	-4.66
150.00	50.00	70.14	-20.14
150.00	57.00	70.14	-13.14
210.00	100.00	91.16	8.84
210.00	100.00	91.16	8.84
210.00	100.00	91.16	8.84

Correlation Coefficient = .969

CAPSULE U INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:22 PM
Page 1
Coefficients of Curve 2
A = 50. B = 50. C = 104.13 T0 = 125.04 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 125.1
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-60.00	5.00	2.78	2.22
-30.00	5.00	4.84	.16
25.00	15.00	12.77	2.23
25.00	15.00	12.77	2.23
50.00	20.00	19.14	.86
50.00	20.00	19.14	.86
74.00	30.00	27.28	2.72
75.00	30.00	27.67	2.33
100.00	45.00	38.21	6.79

CAPSULE U INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: U Fluence: n/cm^2

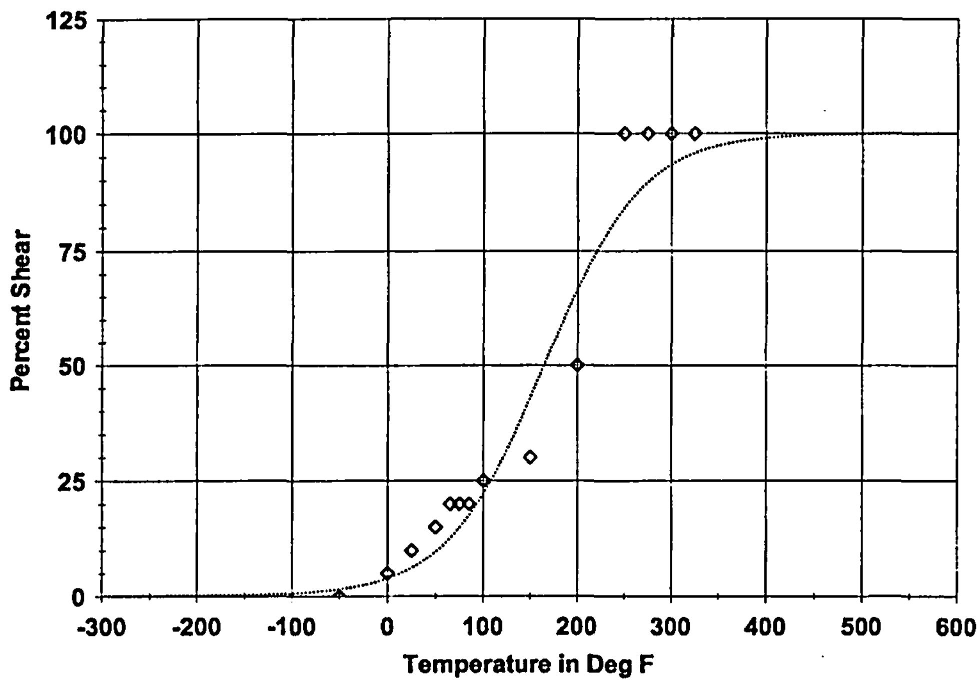
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
125.00	40.00	49.98	-9.98
125.00	45.00	49.98	-4.98
150.00	50.00	61.76	-11.76
200.00	100.00	80.84	19.16
300.00	100.00	96.64	3.36
400.00	100.00	99.49	.51

Correlation Coefficient = .978

CAPSULE V INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:22 PM
Page 1
Coefficients of Curve 3
A = 50. B = 50. C = 102.55 T0 = 164.92 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 165.0
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: V Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	.00	1.49	-1.49
.00	5.00	3.86	1.14
25.00	10.00	6.13	3.87
50.00	15.00	9.61	5.39
65.00	20.00	12.47	7.53
75.00	20.00	14.76	5.24
85.00	20.00	17.38	2.62
100.00	25.00	21.99	3.01
150.00	30.00	42.78	-12.78

CAPSULE V INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: V Fluence: n/cm^2

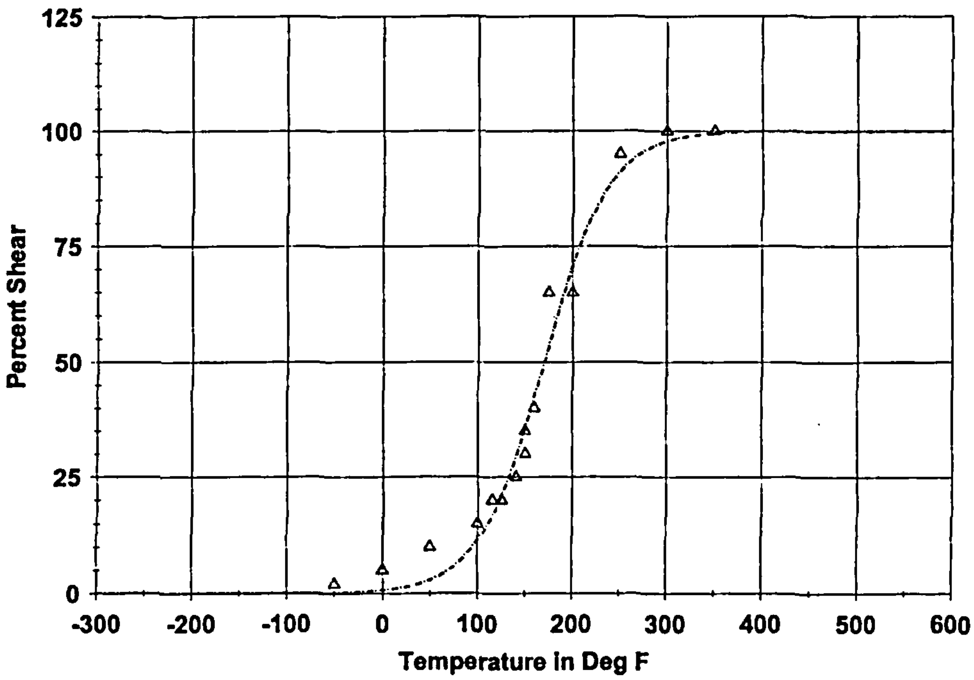
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
200.00	50.00	66.47	-16.47
250.00	100.00	84.02	15.98
275.00	100.00	89.54	10.46
300.00	100.00	93.31	6.69
325.00	100.00	95.78	4.22

Correlation Coefficient = .978

CAPSULE W INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:22 PM
Page 1
Coefficients of Curve 4
A = 50. B = 50. C = 68.4 T0 = 170.19 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 170.2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	2.00	.16	1.84
.00	5.00	.69	4.31
50.00	10.00	2.89	7.11
100.00	15.00	11.38	3.62
115.00	20.00	16.61	3.39
125.00	20.00	21.06	-1.06
140.00	25.00	29.26	-4.26
150.00	35.00	35.65	-.65
150.00	30.00	35.65	-5.65

CAPSULE W INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: W Fluence: n/cm^2

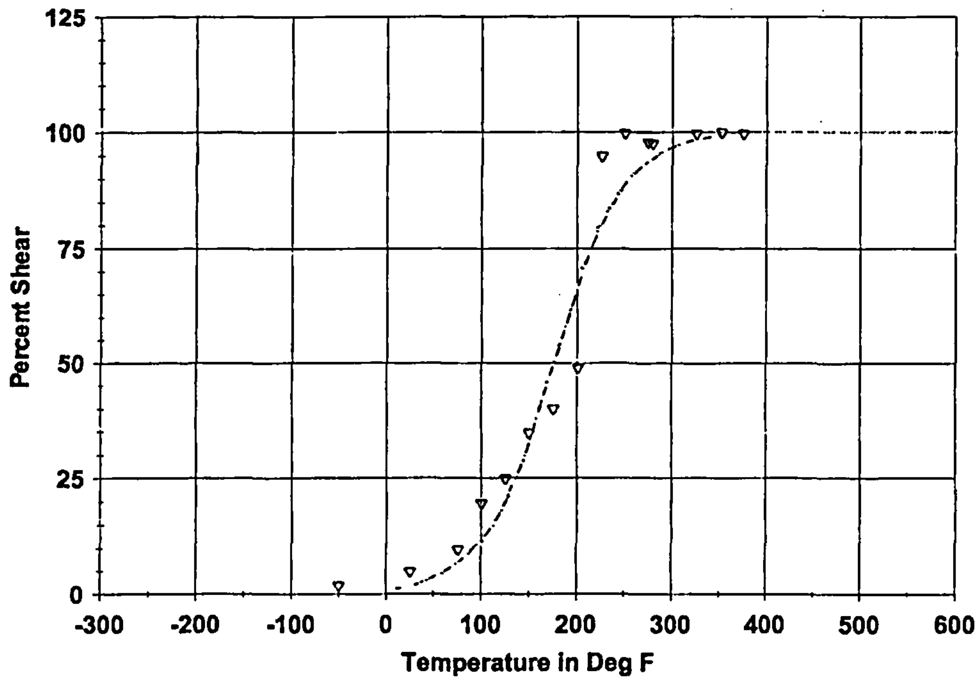
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
160.00	40.00	42.60	-2.60
175.00	65.00	53.51	11.49
200.00	65.00	70.50	-5.50
250.00	95.00	91.16	3.84
300.00	100.00	97.80	2.20
350.00	100.00	99.48	.52

Correlation Coefficient = .991

CAPSULE X INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:22 PM
Page 1
Coefficients of Curve 5
A = 50. B = 50. C = 71.78 T0 = 175.02 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 175.1
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	2.00	.19	1.81
25.00	5.00	1.51	3.49
75.00	10.00	5.80	4.20
100.00	20.00	11.01	8.99
125.00	25.00	19.88	5.12
150.00	35.00	33.25	1.75
175.00	40.00	49.99	-9.99
200.00	50.00	66.73	-16.73
225.00	95.00	80.10	14.90

CAPSULE X INTERMEDIATE SHELL PLATE B9004-2 (LONGITUDINAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: LT Capsule: X Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
250.00	100.00	88.98	11.02
275.00	98.00	94.19	3.81
280.00	98.00	94.91	3.09
325.00	100.00	98.49	1.51
350.00	100.00	99.24	.76
375.00	100.00	99.62	.38

Correlation Coefficient = .982

UNIRRADIATED INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:50 PM

Coefficients of Curve 1

A = 40.6 B = 38.4 C = 96.46 T0 = 67.07 D = 0.00E+00

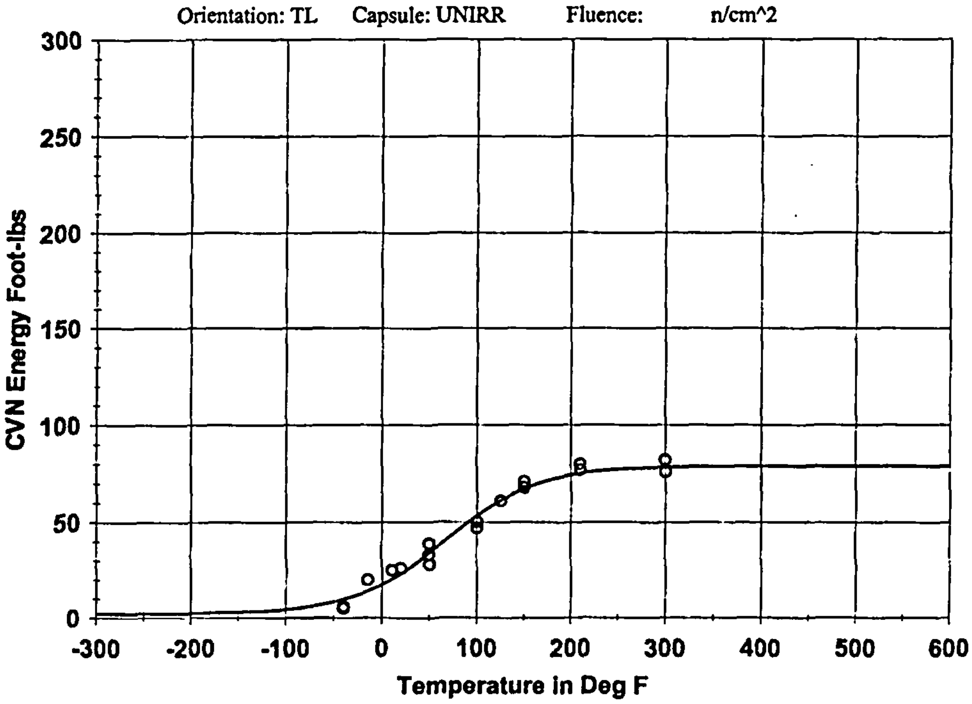
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=79.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=39.8 Deg F Temp@50 ft-lbs=91.2 Deg F

Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2

Orientation: TL Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-40.00	6.00	9.72	-3.72
-40.00	5.00	9.72	-4.72
-15.00	20.00	14.05	5.95
10.00	25.00	20.21	4.79
20.00	26.00	23.22	2.78
50.00	39.00	33.87	5.13
50.00	28.00	33.87	-5.87
50.00	33.00	33.87	-.87
100.00	50.00	53.22	-3.22

UNIRRADIATED INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

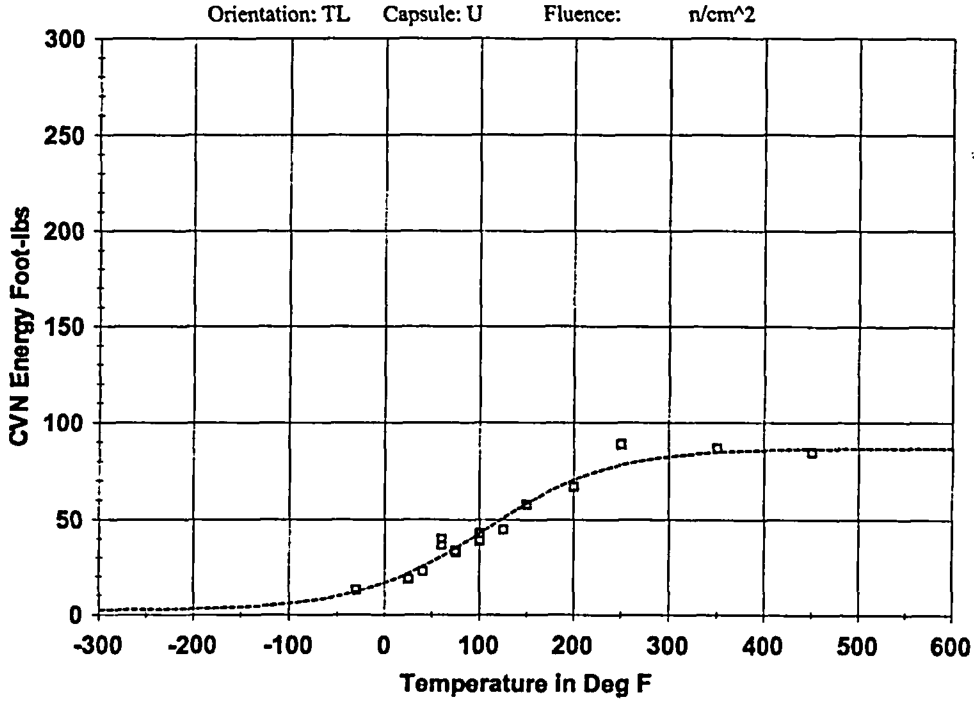
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
100.00	47.00	53.22	-6.22
125.00	61.00	61.24	-.24
150.00	68.00	67.33	.67
150.00	71.00	67.33	3.67
210.00	77.00	75.23	1.77
210.00	80.00	75.23	4.77
210.00	80.00	75.23	4.77
300.00	82.00	78.39	3.61
300.00	76.00	78.39	-2.39

Correlation Coefficient = .988

CAPSULE U INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:51 PM
Page 1
Coefficients of Curve 2
A = 44.6 B = 42.4 C = 133.76 T0 = 105.42 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=87.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=57.5 Deg F Temp@50 ft-lbs=122.6 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-30.00	13.00	12.09	.91
25.00	19.00	21.79	-2.79
40.00	23.00	25.37	-2.37
60.00	37.00	30.73	6.27
60.00	40.00	30.73	9.27
74.00	34.00	34.82	-.82
75.00	33.00	35.12	-2.12
100.00	43.00	42.88	.12
100.00	39.00	42.88	-3.88

CAPSULE U INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: U Fluence: n/cm^2

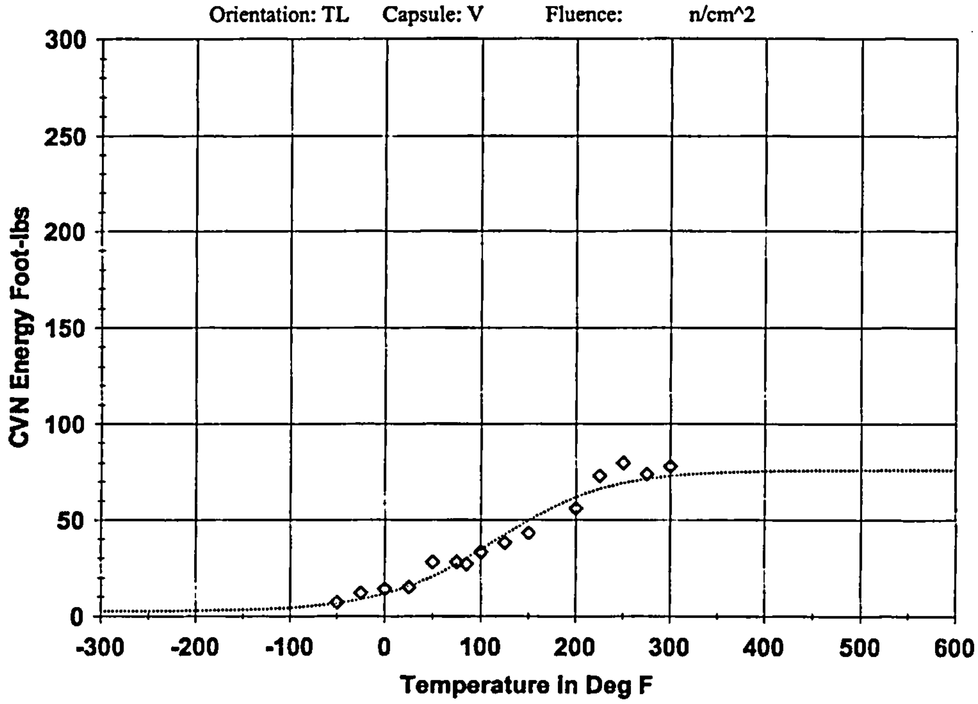
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
125.00	45.00	50.76	-5.76
150.00	58.00	58.23	-.23
200.00	67.00	70.41	-3.41
250.00	89.00	78.24	10.76
350.00	87.00	84.87	2.13
450.00	85.00	86.51	-1.51

Correlation Coefficient = .981

CAPSULE V INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:51 PM
Page 1
Coefficients of Curve 3
A = 39.1 B = 36.9 C = 118.74 T0 = 115.7 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=76.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=85.9 Deg F Temp@50 ft-lbs=151.9 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: V Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	7.00	6.47	.53
-25.00	12.00	8.51	3.49
.00	14.00	11.40	2.60
25.00	15.00	15.36	-.36
50.00	28.00	20.54	7.46
75.00	28.00	26.92	1.08
85.00	27.00	29.77	-2.77
100.00	33.00	34.25	-1.25
125.00	38.00	41.98	-3.98

CAPSULE V INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: V Fluence: n/cm^2

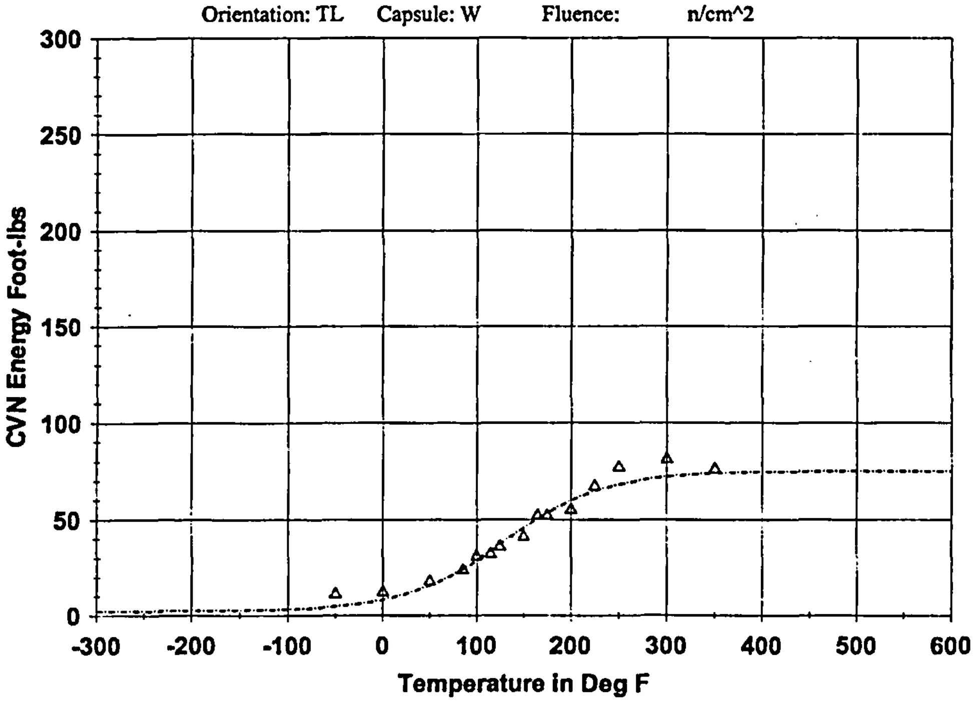
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
150.00	43.00	49.47	-6.47
200.00	56.00	61.63	-5.63
225.00	73.00	65.89	7.11
250.00	80.00	69.04	10.96
275.00	74.00	71.28	2.72
300.00	78.00	72.83	5.17

Correlation Coefficient = .981

CAPSULE W INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:51 PM
Page 1
Coefficients of Curve 4
A = 38.6 B = 36.4 C = 106.94 T0 = 128.94 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=75.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=103.2 Deg F Temp@50 ft-lbs=163.6 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	11.00	4.68	6.32
.00	12.00	8.19	3.81
50.00	18.00	15.74	2.26
85.00	24.00	24.43	-.43
100.00	31.00	28.98	2.02
115.00	32.00	33.88	-1.88
125.00	36.00	37.26	-1.26
150.00	41.00	45.68	-4.68
165.00	52.00	50.43	1.57

CAPSULE W INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: CO544-2
Orientation: TL Capsule: W Fluence: n/cm^2

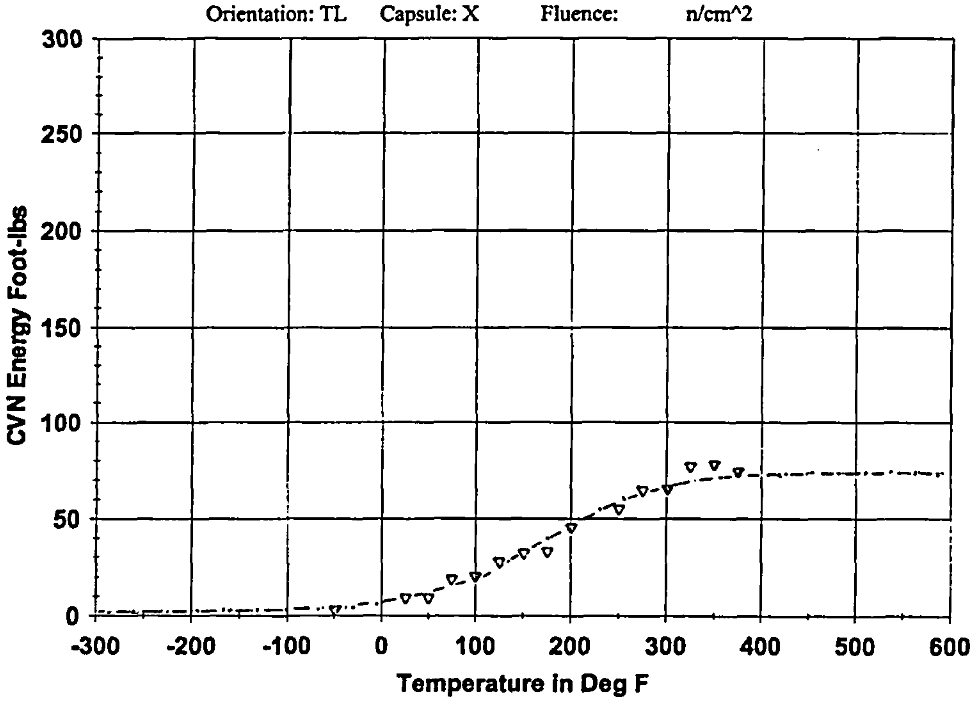
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
175.00	52.00	53.37	-1.37
200.00	55.00	59.76	-4.76
225.00	67.00	64.64	2.36
250.00	77.00	68.15	8.85
300.00	81.00	72.15	8.85
350.00	76.00	73.85	2.15

Correlation Coefficient = .984

CAPSULE X INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 03:51 PM
Page 1
Coefficients of Curve 5
A = 38.1 B = 35.9 C = 119.72 T0 = 171.36 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=74.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=143.9 Deg F Temp@50 ft-lbs=212.7 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	3.00	3.94	-.94
25.00	9.00	7.93	1.07
50.00	9.00	10.55	-1.55
75.00	19.00	14.16	4.84
100.00	20.00	18.92	1.08
125.00	28.00	24.85	3.15
150.00	32.00	31.76	.24
175.00	33.00	39.19	-6.19
200.00	45.00	46.53	-1.53

CAPSULE X INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: X Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
250.00	55.00	58.79	-3.79
275.00	65.00	63.20	1.80
300.00	65.00	66.50	-1.50
325.00	77.00	68.88	8.12
350.00	78.00	70.54	7.46
375.00	74.00	71.69	2.31

Correlation Coefficient = .990

UNIRRADIATED INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/01/2005 03:56 PM

Page 1

Coefficients of Curve 1

A = 32.63 B = 31.63 C = 91.03 T0 = 83.96 D = 0.00E+00

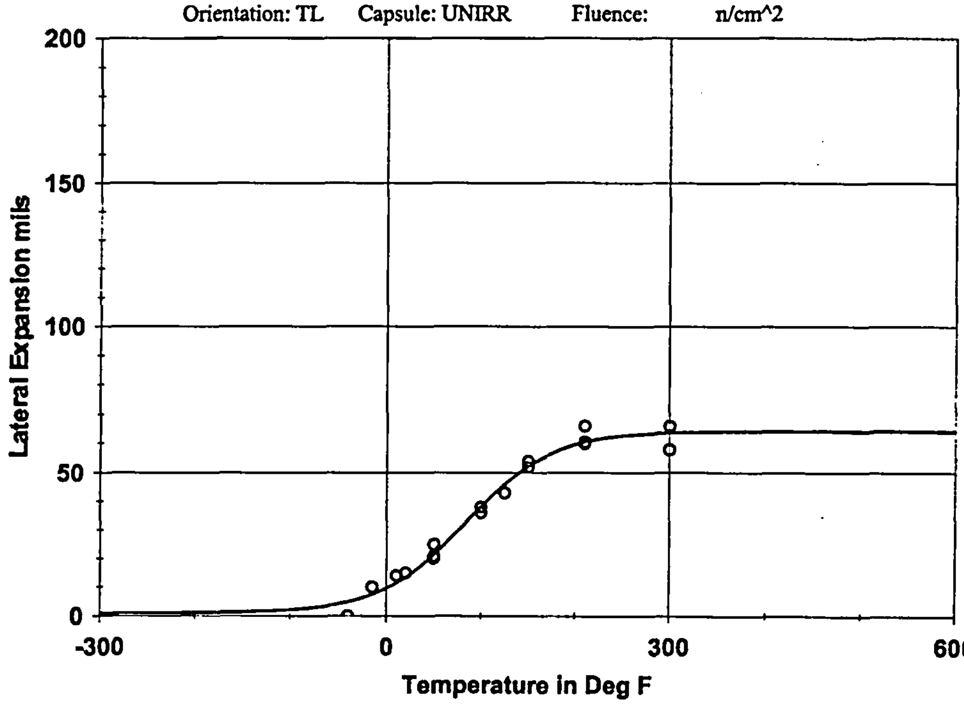
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=64.3 Lower Shelf L.E.=1.0(Fixed)

Temp.@L.E. 35 mils=90.8 Deg F

Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2

Orientation: TL Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-40.00	.00	4.90	-4.90
-40.00	.00	4.90	-4.90
-15.00	10.00	7.46	2.54
10.00	14.00	11.41	2.59
20.00	15.00	13.46	1.54
50.00	25.00	21.35	3.65
50.00	20.00	21.35	-1.35
50.00	21.00	21.35	-.35
100.00	38.00	38.14	-.14

UNIRRADIATED INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

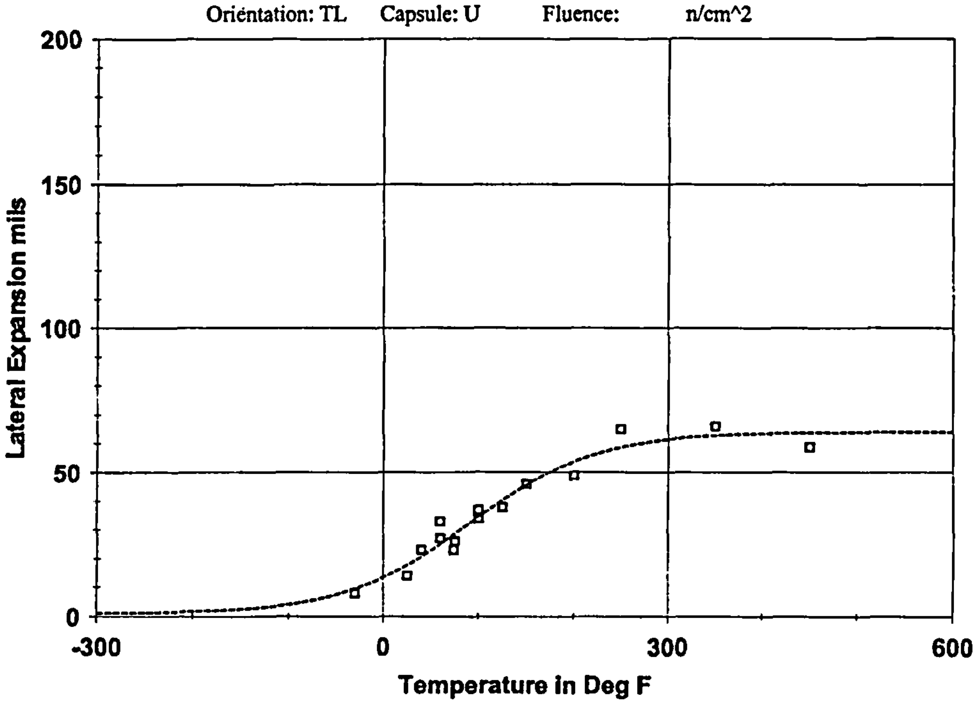
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
100.00	36.00	38.14	-2.14
125.00	43.00	45.99	-2.99
150.00	54.00	52.25	1.75
150.00	52.00	52.25	-.25
210.00	60.50	60.52	-.02
210.00	66.00	60.52	5.48
210.00	60.00	60.52	-.52
300.00	66.00	63.71	2.29
300.00	58.00	63.71	-5.71

Correlation Coefficient = .991

CAPSULE U INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/01/2005 03:57 PM
Page 1
Coefficients of Curve 2
A = 32.48 B = 31.48 C = 130.65 T0 = 91.78 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=64.0 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=102.3 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-30.00	8.00	9.45	-1.45
25.00	14.00	17.66	-3.66
40.00	23.00	20.62	2.38
60.00	27.00	24.97	2.03
60.00	33.00	24.97	8.03
74.00	23.00	28.23	-5.23
75.00	26.00	28.46	-2.46
100.00	37.00	34.46	2.54
100.00	34.00	34.46	-.46

CAPSULE U INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: U Fluence: n/cm^2

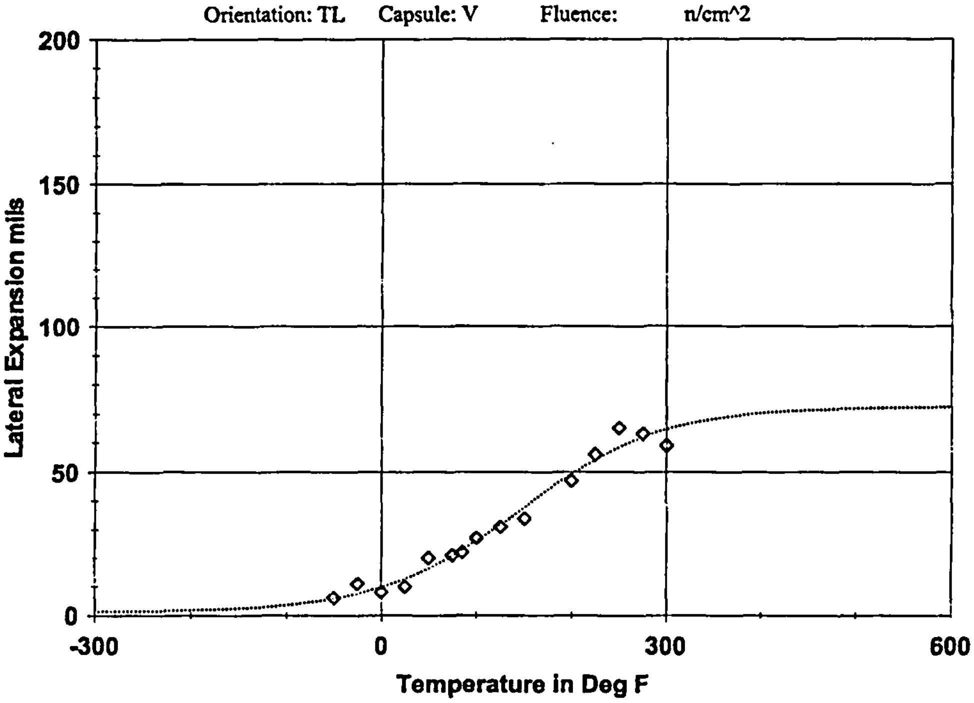
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
125.00	38.00	40.32	-2.32
150.00	46.00	45.65	.35
200.00	49.00	53.88	-4.88
250.00	65.00	58.84	6.16
350.00	66.00	62.78	3.22
450.00	59.00	63.71	-4.71

Correlation Coefficient = .973

CAPSULE V INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/01/2005 03:57 PM
Page 1
Coefficients of Curve 3
A = 36.69 B = 35.69 C = 147.86 T0 = 146.02 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=72.4 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=139.0 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: V Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	6.00	5.70	.30
-25.00	11.00	7.43	3.57
.00	8.00	9.70	-1.70
25.00	10.00	12.63	-2.63
50.00	20.00	16.30	3.70
75.00	21.00	20.76	.24
85.00	22.00	22.75	-.75
100.00	27.00	25.93	1.07
125.00	31.00	31.65	-.65

CAPSULE V INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: V Fluence: n/cm^2

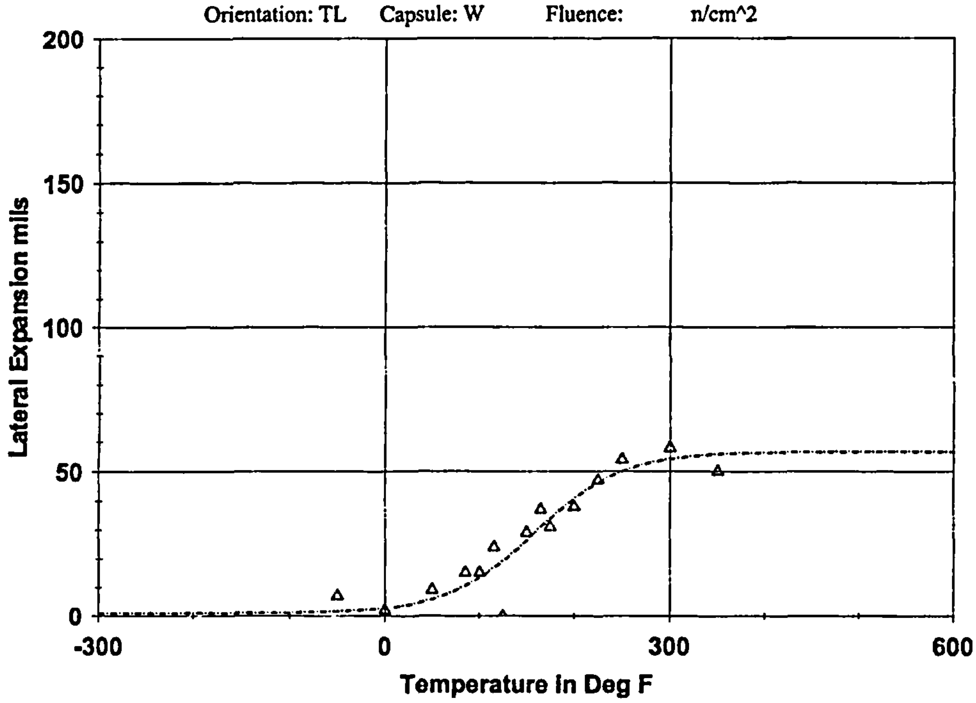
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
150.00	34.00	37.65	-3.65
200.00	47.00	49.18	-2.18
225.00	56.00	54.13	1.87
250.00	65.00	58.34	6.66
275.00	63.00	61.77	1.23
300.00	59.00	64.48	-5.48

Correlation Coefficient = .989

CAPSULE W INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/01/2005 03:57 PM
Page 1
Coefficients of Curve 4
A = 28.88 B = 27.88 C = 92.25 T0 = 158.27 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=56.8   Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=178.9 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	7.00	1.60	5.40
.00	2.00	2.75	-.75
50.00	9.00	5.87	3.13
85.00	15.00	10.46	4.54
100.00	15.00	13.29	1.71
115.00	24.00	16.68	7.32
125.00	.00	19.24	-19.24
150.00	29.00	26.38	2.62
165.00	37.00	30.91	6.09

CAPSULE W INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: W Fluence: n/cm^2

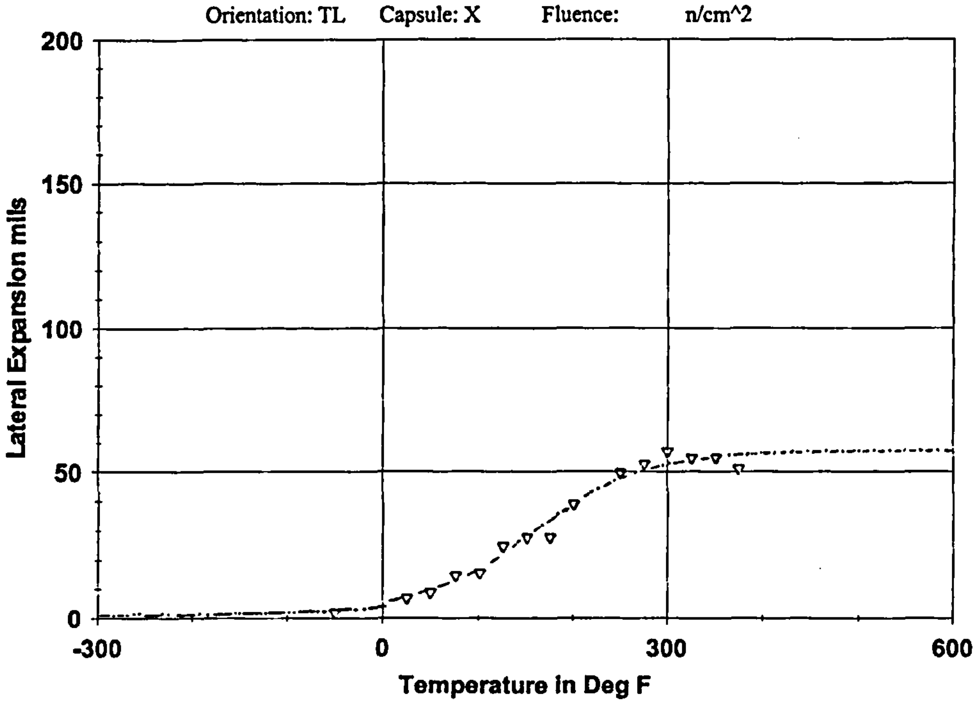
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
175.00	31.00	33.88	-2.88
200.00	38.00	40.69	-2.69
225.00	47.00	46.13	.87
250.00	54.00	50.04	3.96
300.00	58.00	54.29	3.71
350.00	50.00	55.89	-5.89

Correlation Coefficient = .941

CAPSULE X INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/01/2005 03:57 PM
Page 1
Coefficients of Curve 5
A = 29.2 B = 28.2 C = 118.13 T0 = 154.97 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=57.4 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=179.7 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	2.00	2.70	-.70
25.00	7.00	6.62	.38
50.00	9.00	9.16	-.16
75.00	15.00	12.58	2.42
100.00	16.00	16.95	-.95
125.00	25.00	22.20	2.80
150.00	28.00	28.01	-.01
175.00	28.00	33.94	-5.94
200.00	39.00	39.46	-.46

CAPSULE X INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: X Fluence: n/cm^2

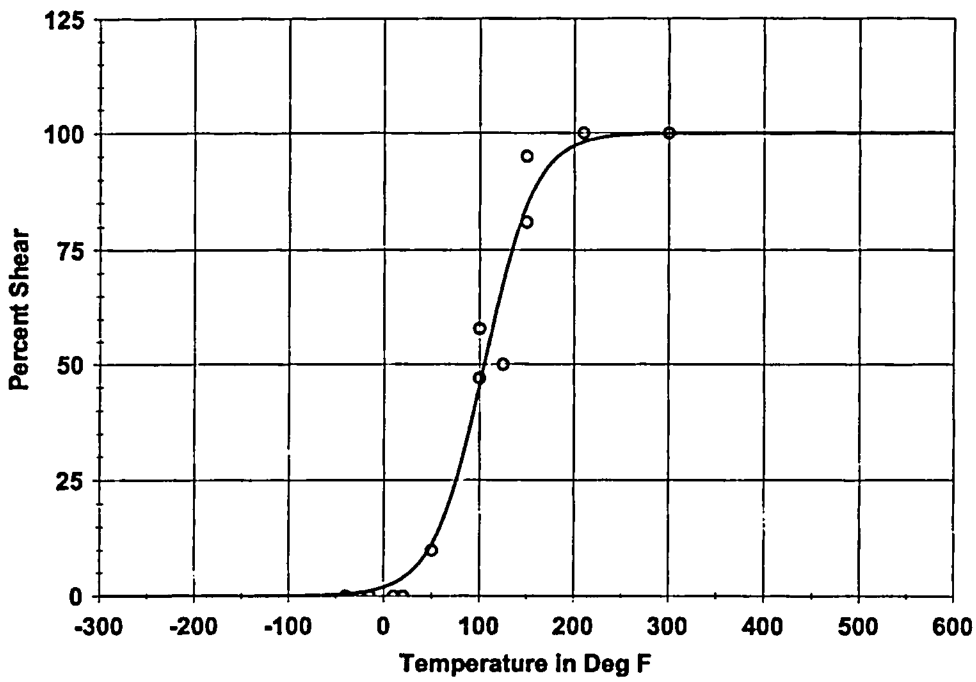
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
250.00	50.00	48.00	2.00
275.00	53.00	50.87	2.13
300.00	57.00	52.94	4.06
325.00	55.00	54.40	.60
350.00	55.00	55.40	-.40
375.00	51.00	56.08	-5.08

Correlation Coefficient = .991

UNIRRADIATED INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 04:02 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 53.26 T0 = 104.9 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 105.0
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-40.00	.00	.43	-.43
-40.00	.00	.43	-.43
-15.00	.00	1.10	-1.10
10.00	.00	2.76	-2.76
20.00	.00	3.96	-3.96
50.00	10.00	11.29	-1.29
50.00	10.00	11.29	-1.29
50.00	10.00	11.29	-1.29
100.00	58.00	45.41	12.59

UNIRRADIATED INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

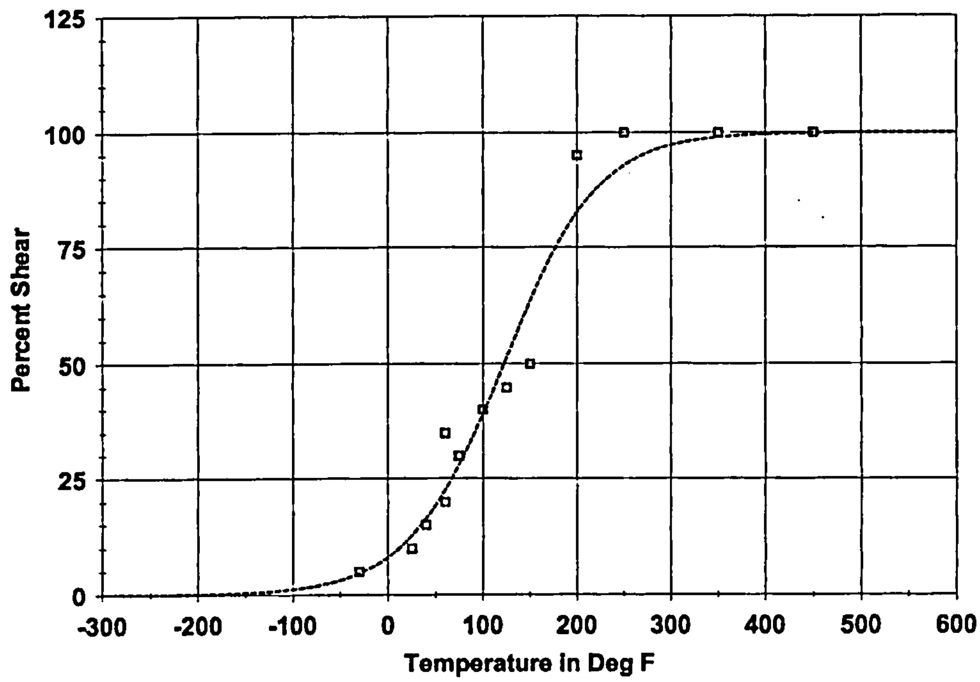
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100.00	47.00	45.41	1.59
125.00	50.00	68.02	-18.02
150.00	95.00	84.47	10.53
150.00	81.00	84.47	-3.47
210.00	100.00	98.10	1.90
210.00	100.00	98.10	1.90
210.00	100.00	98.10	1.90
300.00	100.00	99.93	.07
300.00	100.00	99.93	.07

Correlation Coefficient = .990

CAPSULE U INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 04:02 PM
Page 1
Coefficients of Curve 2
A = 50. B = 50. C = 100.52 T0 = 122.03 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 122.1
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-30.00	5.00	4.63	.37
25.00	10.00	12.67	-2.67
40.00	15.00	16.35	-1.35
60.00	20.00	22.54	-2.54
60.00	35.00	22.54	12.46
74.00	30.00	27.78	2.22
75.00	30.00	28.18	1.82
100.00	40.00	39.21	.79
100.00	40.00	39.21	.79

CAPSULE U INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: U Fluence: n/cm^2

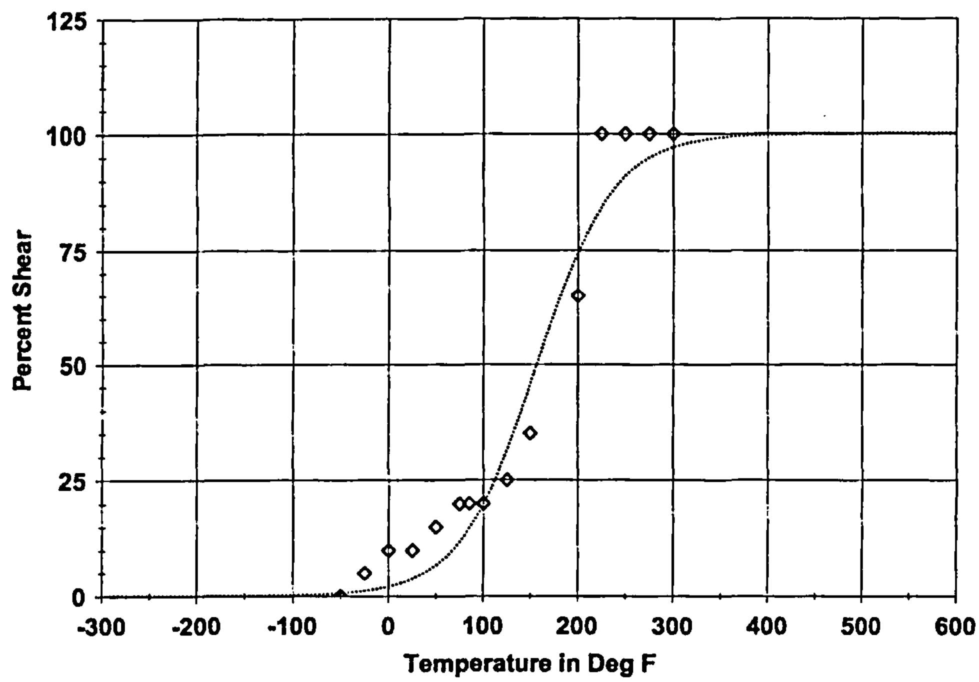
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
125.00	45.00	51.48	-6.48
150.00	50.00	63.57	-13.57
200.00	95.00	82.51	12.49
250.00	100.00	92.73	7.27
350.00	100.00	98.94	1.06
450.00	100.00	99.85	.15

Correlation Coefficient = .982

CAPSULE V INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 04:02 PM
Page 1
Coefficients of Curve 3
A = 50. B = 50. C = 81.08 T0 = 157.09 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 157.1
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: V Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	.00	.60	-.60
-25.00	5.00	1.11	3.89
.00	10.00	2.03	7.97
25.00	10.00	3.70	6.30
50.00	15.00	6.65	8.35
75.00	20.00	11.66	8.34
85.00	20.00	14.45	5.55
100.00	20.00	19.65	.35
125.00	25.00	31.19	-6.19

CAPSULE V INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: V Fluence: n/cm^2

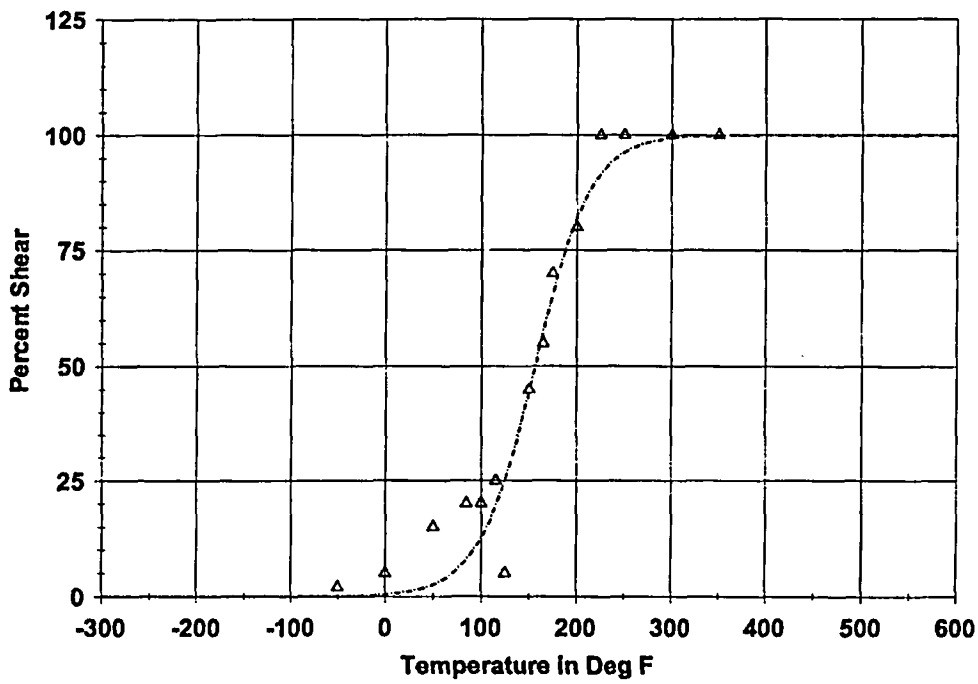
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
150.00	35.00	45.64	-10.64
200.00	65.00	74.24	-9.24
225.00	100.00	84.23	15.77
250.00	100.00	90.82	9.18
275.00	100.00	94.83	5.17
300.00	100.00	97.14	2.86

Correlation Coefficient = .983

CAPSULE W INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 04:03 PM
Page 1
Coefficients of Curve 4
A = 50. B = 50. C = 57.99 T0 = 156.22 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 156.3
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	2.00	.08	1.92
.00	5.00	.46	4.54
50.00	15.00	2.50	12.50
85.00	20.00	7.90	12.10
100.00	20.00	12.58	7.42
115.00	25.00	19.44	5.56
125.00	5.00	25.41	-20.41
150.00	45.00	44.66	.34
165.00	55.00	57.52	-2.52

CAPSULE W INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: W Fluence: n/cm^2

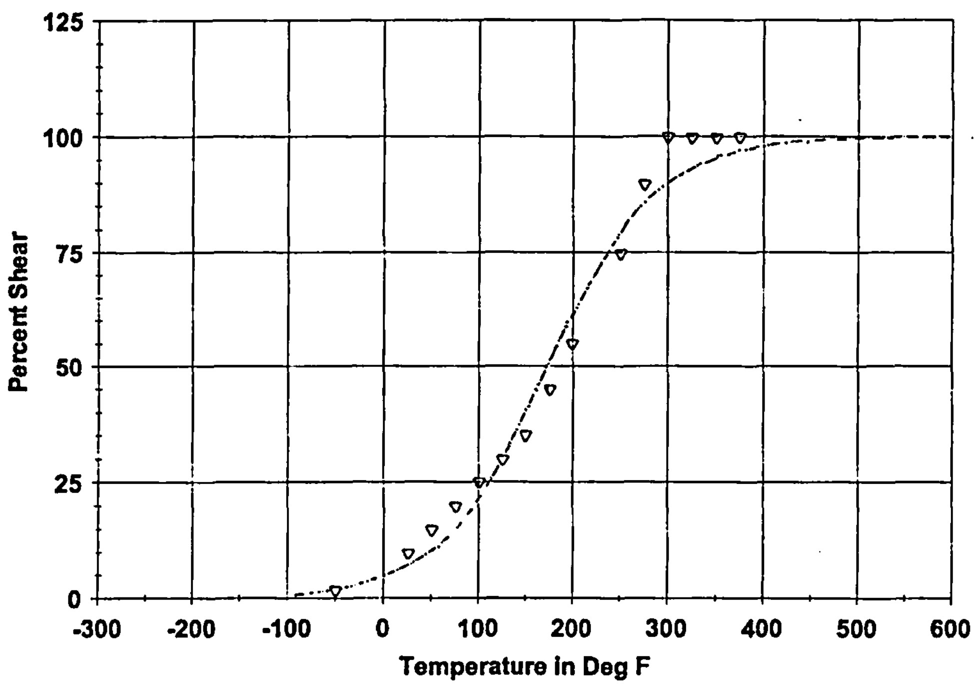
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
175.00	70.00	65.65	4.35
200.00	80.00	81.91	-1.91
225.00	100.00	91.47	8.53
250.00	100.00	96.21	3.79
300.00	100.00	99.30	.70
350.00	100.00	99.88	.12

Correlation Coefficient = .980

CAPSULE X INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/29/2005 04:03 PM
Page 1
Coefficients of Curve 5
A = 50. B = 50. C = 113.12 T0 = 175.03 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 175.1
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	2.00	1.84	.16
25.00	10.00	6.58	3.42
50.00	15.00	9.88	5.12
75.00	20.00	14.57	5.43
100.00	25.00	20.97	4.03
125.00	30.00	29.22	.78
150.00	35.00	39.11	-4.11
175.00	45.00	49.99	-4.99
200.00	55.00	60.86	-5.86

CAPSULE X INTERMEDIATE SHELL PLATE B9004-2 (TRANSVERSE)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: TL Capsule: X Fluence: n/cm^2

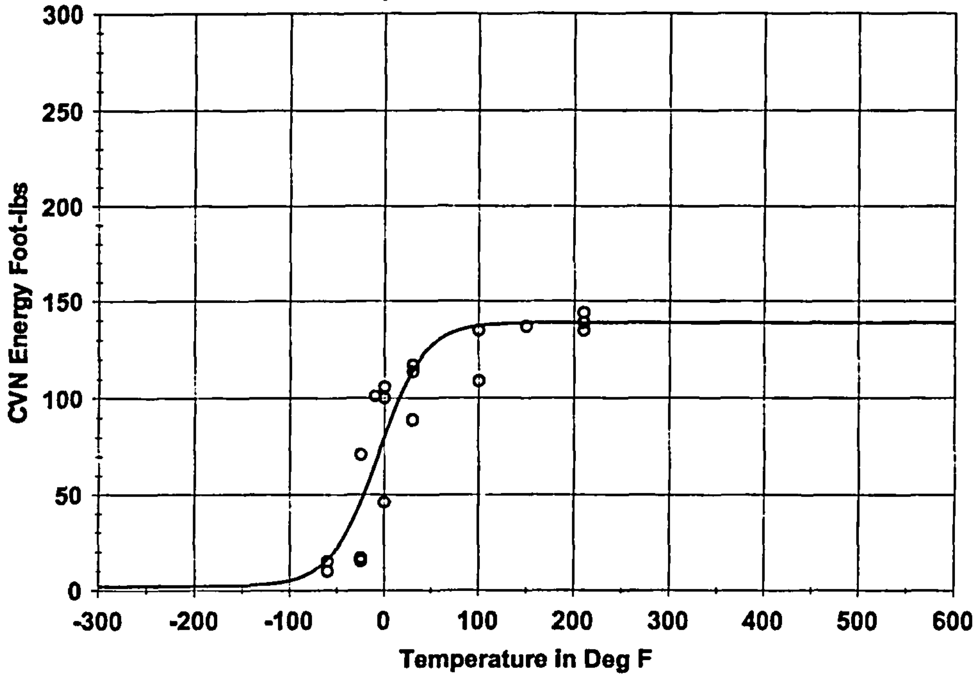
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
250.00	75.00	79.01	-4.01
275.00	90.00	85.42	4.58
300.00	100.00	90.11	9.89
325.00	100.00	93.41	6.59
350.00	100.00	95.66	4.34
375.00	100.00	97.17	2.83

Correlation Coefficient = .992

UNIRRADIATED (WELD METAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 10:18 AM
Page 1
Coefficients of Curve 1
A = 70.6 B = 68.4 C = 48.66 T0 = -6.58 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=139.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-39.8 Deg F Temp@50 ft-lbs=-21.7 Deg F
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-60.00	10.00	15.90	-5.90
-60.00	15.00	15.90	-.90
-25.00	17.00	45.88	-28.88
-25.00	15.00	45.88	-30.88
-25.00	71.00	45.88	25.12
-10.00	101.00	65.81	35.19
.00	46.00	79.80	-33.80
.00	106.00	79.80	26.20
.00	100.00	79.80	20.20

UNIRRADIATED (WELD METAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

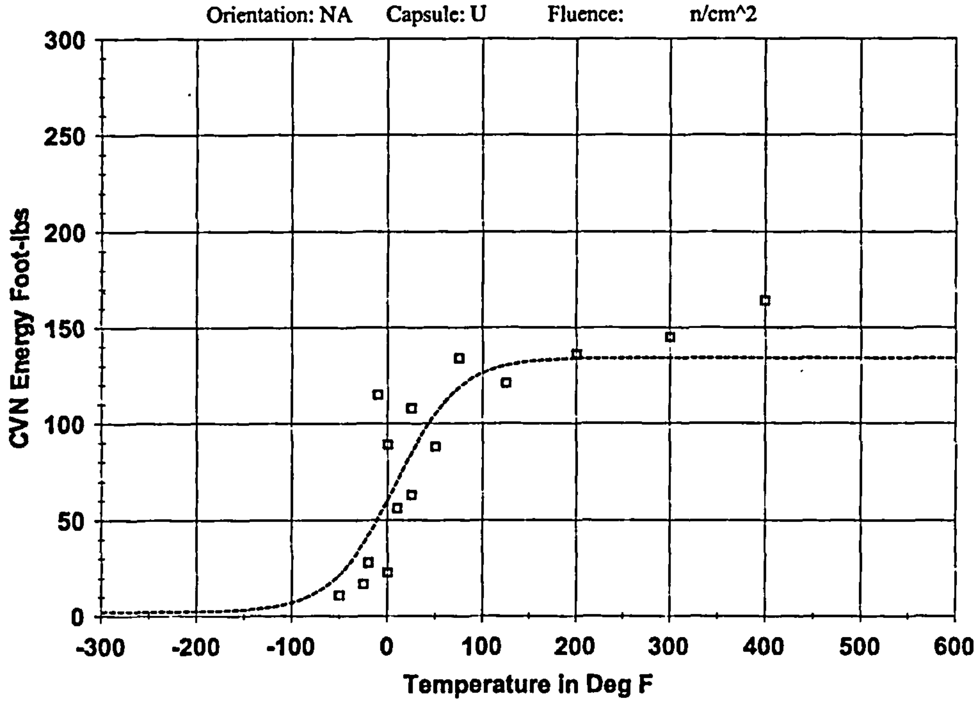
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
30.00	114.00	114.12	-.12
30.00	117.00	114.12	2.88
30.00	89.00	114.12	-25.12
100.00	135.00	137.31	-2.31
100.00	109.00	137.31	-28.31
150.00	137.00	138.78	-1.78
210.00	135.00	138.98	-3.98
210.00	139.00	138.98	.02
210.00	144.00	138.98	5.02

Correlation Coefficient = .902

CAPSULE U (WELD METAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 10:18 AM
Page 1
Coefficients of Curve 2
A = 68.1 B = 65.9 C = 66.44 T0 = 8.08 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=134.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-35.7 Deg F Temp@50 ft-lbs=-10.6 Deg F
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	11.00	21.74	-10.74
-25.00	17.00	37.76	-20.76
-20.00	28.00	41.80	-13.80
-10.00	115.00	50.60	64.40
.00	23.00	60.12	-37.12
.00	89.00	60.12	28.88
10.00	56.00	70.00	-14.00
25.00	108.00	84.53	23.47
25.00	63.00	84.53	-21.53

CAPSULE U (WELD METAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: U Fluence: n/cm^2

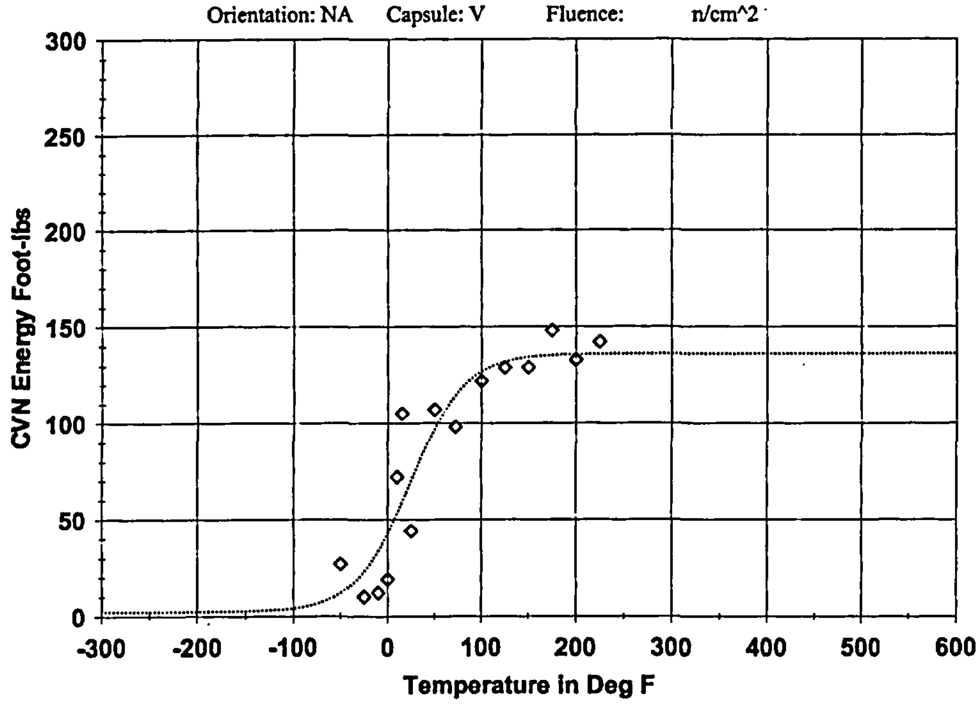
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
50.00	88.00	104.92	-16.92
75.00	134.00	118.49	15.51
125.00	121.00	130.21	-9.21
200.00	136.00	133.59	2.41
300.00	145.00	133.98	11.02
400.00	164.00	134.00	30.00

Correlation Coefficient = .856

CAPSULE V (WELD METAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 10:18 AM
Page 1
Coefficients of Curve 3
A = 69.1 B = 66.9 C = 58.12 T0 = 24.76 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=136.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-14.1 Deg F Temp@50 ft-lbs=7.7 Deg F
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: V Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-50.00	27.00	11.69	15.31
-25.00	10.00	22.65	-12.65
-10.00	12.00	33.26	-21.26
.00	19.00	42.20	-23.20
10.00	72.00	52.46	19.54
15.00	105.00	57.97	47.03
25.00	44.00	69.38	-25.38
50.00	107.00	96.46	10.54
72.00	98.00	114.00	-16.00

CAPSULE V (WELD METAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: V Fluence: n/cm^2

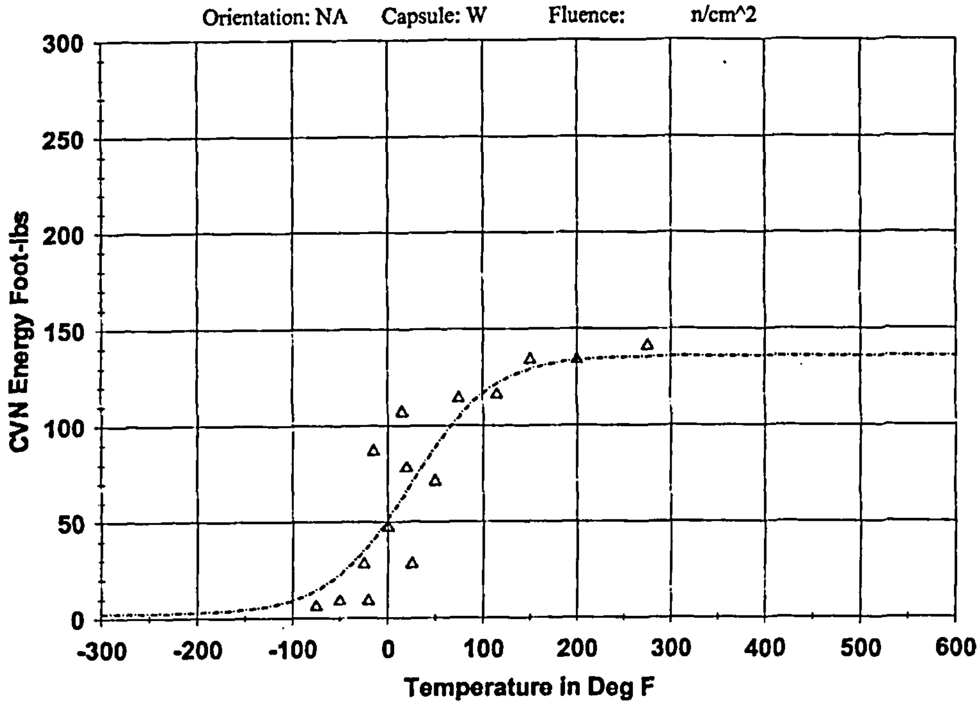
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
100.00	122.00	126.66	-4.66
125.00	129.00	131.88	-2.88
150.00	129.00	134.23	-5.23
175.00	148.00	135.24	12.76
200.00	133.00	135.68	-2.68
225.00	142.00	135.86	6.14

Correlation Coefficient = .925

CAPSULE W (WELD METAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 10:18 AM
Page 1
Coefficients of Curve 4
A = 69.1 B = 66.9 C = 86.05 T0 = 23.78 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=136.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-33.8 Deg F Temp@50 ft-lbs=-1.4 Deg F
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-75.00	6.00	14.44	-8.44
-50.00	9.00	22.61	-13.61
-25.00	28.00	34.78	-6.78
-20.00	9.00	37.73	-28.73
-15.00	87.00	40.84	46.16
.00	47.00	51.07	-4.07
15.00	107.00	62.30	44.70
20.00	78.00	66.16	11.84
25.00	28.00	70.05	-42.05

CAPSULE W (WELD METAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: W Fluence: n/cm^2

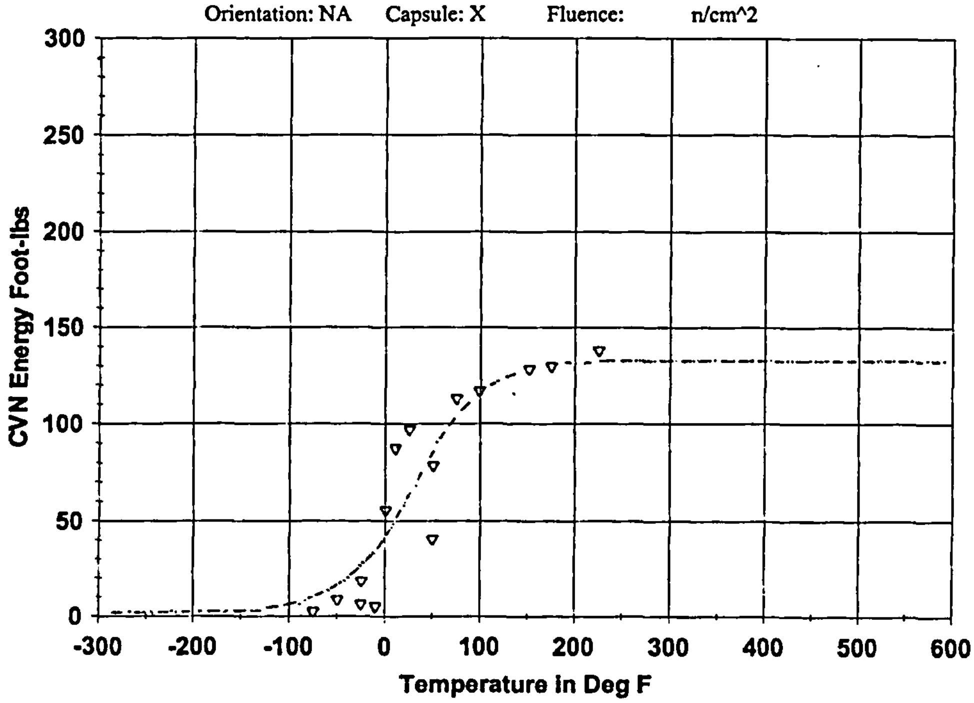
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
50.00	71.00	88.88	-17.88
75.00	114.00	104.80	9.20
115.00	116.00	121.66	-5.66
150.00	134.00	129.24	4.76
200.00	134.00	133.81	.19
275.00	141.00	135.61	5.39

Correlation Coefficient = .882

CAPSULE X (WELD METAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 10:18 AM
Page 1
Coefficients of Curve 5
A = 67.6 B = 65.4 C = 71.02 T0 = 29.58 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=133.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-16.9 Deg F Temp@50 ft-lbs=10.0 Deg F
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-75.00	3.00	8.74	-5.74
-50.00	9.00	14.78	-5.78
-25.00	7.00	25.35	-18.35
-25.00	19.00	25.35	-6.35
-10.00	6.00	34.51	-28.51
.00	56.00	41.84	14.16
10.00	88.00	50.02	37.98
25.00	97.00	63.39	33.61
50.00	41.00	85.91	-44.91

CAPSULE X (WELD METAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: X Fluence: n/cm^2

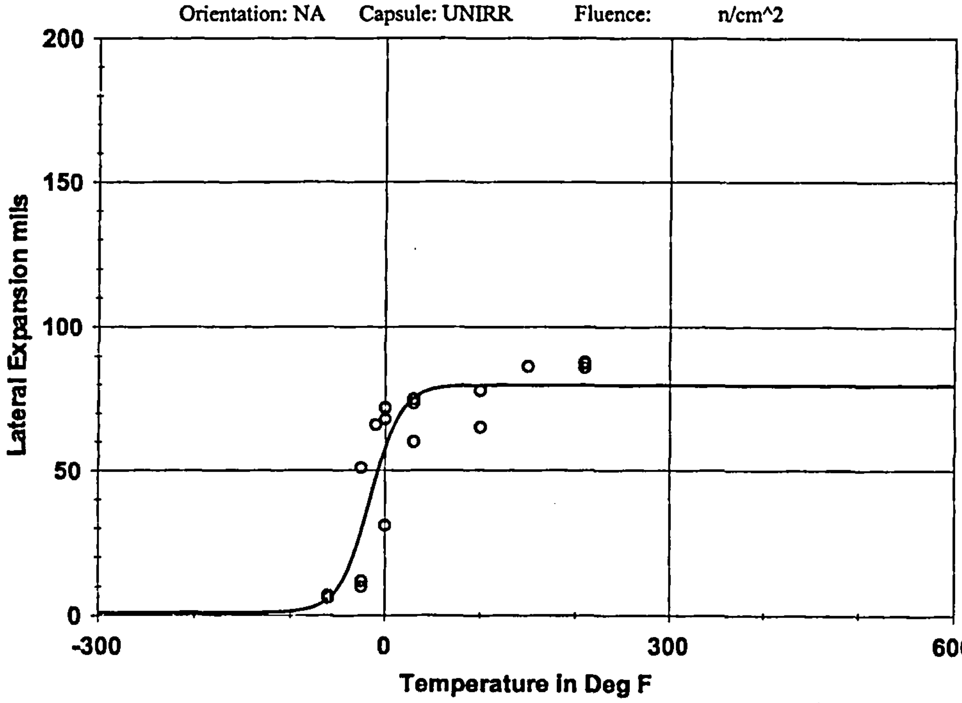
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
50.00	79.00	85.91	-6.91
75.00	113.00	104.53	8.47
100.00	117.00	117.18	-.18
150.00	129.00	128.74	.26
175.00	130.00	130.86	-.86
225.00	139.00	132.47	6.53

Correlation Coefficient = .913

UNIRRADIATED (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/02/2005 09:25 AM
Page 1
Coefficients of Curve 1
A = 40.41 B = 39.41 C = 32.36 T0 = -15.4 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=79.8 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=-19.8 Deg F
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-60.00	6.00	5.71	.29
-60.00	7.00	5.71	1.29
-25.00	12.00	29.06	-17.06
-25.00	10.00	29.06	-19.06
-25.00	51.00	29.06	21.94
-10.00	66.00	46.93	19.07
.00	31.00	57.87	-26.87
.00	72.00	57.87	14.13
.00	68.00	57.87	10.13

UNIRRADIATED (WELD)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

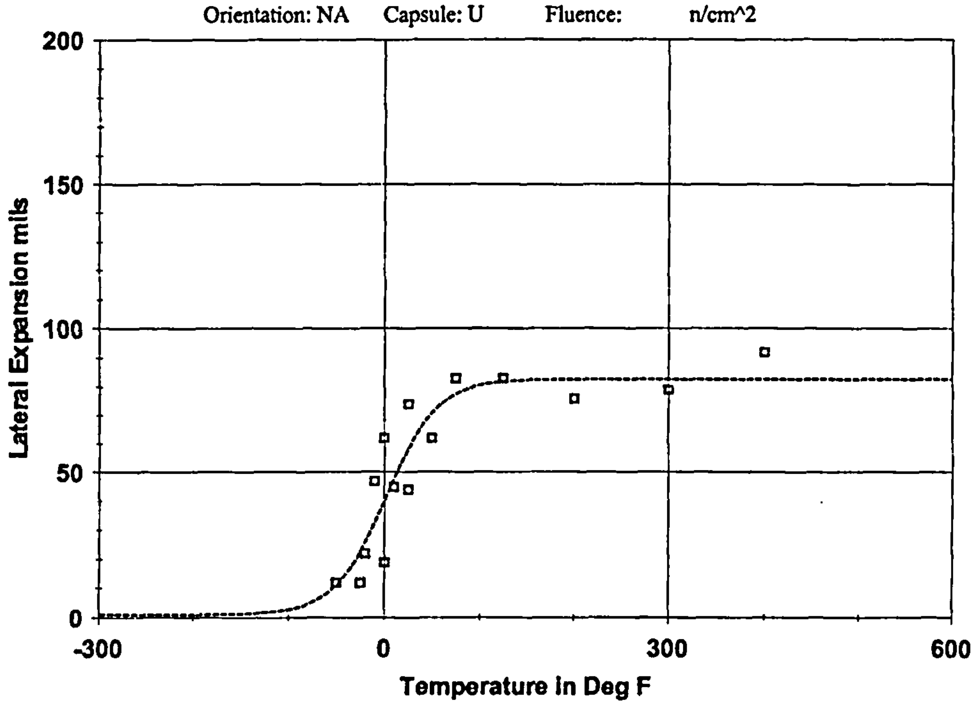
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
30.00	73.50	75.33	-1.83
30.00	75.00	75.33	-.33
30.00	60.00	75.33	-15.33
100.00	78.00	79.76	-1.76
100.00	65.00	79.76	-14.76
150.00	86.50	79.82	6.68
210.00	87.50	79.82	7.68
210.00	86.00	79.82	6.18
210.00	88.00	79.82	8.18

Correlation Coefficient = .889

CAPSULE U (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/02/2005 09:25 AM
Page 1
Coefficients of Curve 2
A = 41.82 B = 40.82 C = 53.47 T0 = 2.46 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=82.6 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=-6.5 Deg F
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	12.00	11.06	.94
-25.00	12.00	22.53	-10.53
-20.00	22.00	25.62	-3.62
-10.00	47.00	32.48	14.52
.00	19.00	39.95	-20.95
.00	62.00	39.95	22.05
10.00	45.00	47.55	-2.55
25.00	74.00	58.08	15.92
25.00	44.00	58.08	-14.08

CAPSULE U (WELD)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: U Fluence: n/cm^2

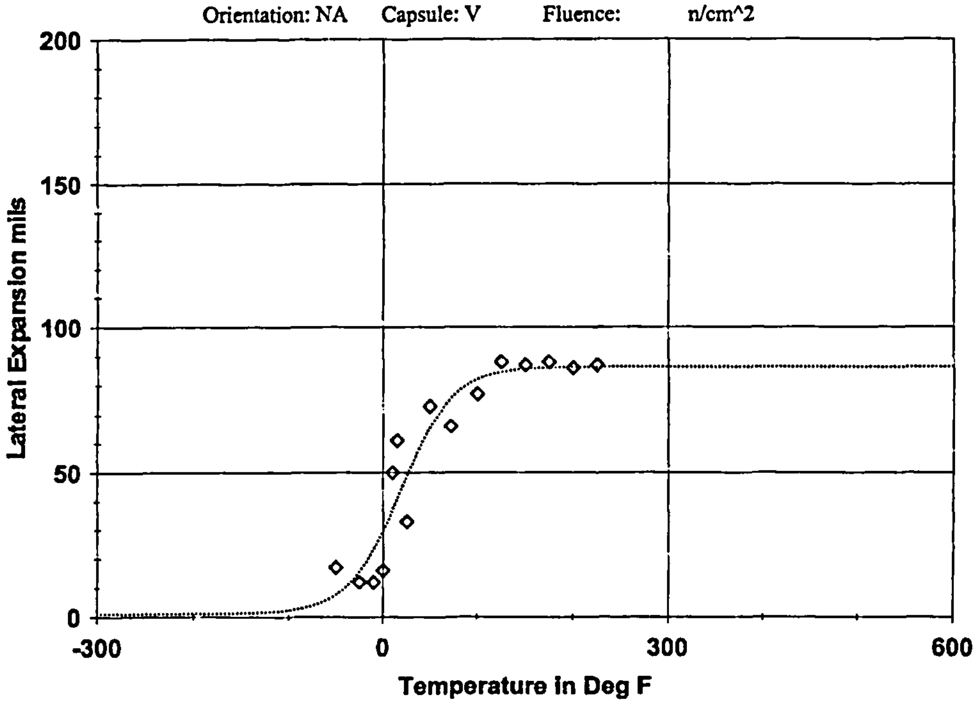
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
50.00	62.00	70.85	-8.85
75.00	83.00	77.57	5.43
125.00	83.00	81.82	1.18
200.00	76.00	82.60	-6.60
300.00	79.00	82.65	-3.65
400.00	92.00	82.65	9.35

Correlation Coefficient = .904

CAPSULE V (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/02/2005 09:25 AM
Page 1
Coefficients of Curve 3
A = 43.65 B = 42.65 C = 55.22 T0 = 19.19 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=86.3 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=7.9 Deg F
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: V Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-50.00	17.00	7.44	9.56
-25.00	12.00	15.32	-3.32
-10.00	12.00	23.00	-11.00
.00	16.00	29.40	-13.40
10.00	50.00	36.62	13.38
15.00	61.00	40.42	20.58
25.00	33.00	48.12	-15.12
50.00	73.00	65.25	7.75
72.00	66.00	75.33	-9.33

CAPSULE V (WELD)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: V Fluence: n/cm^2

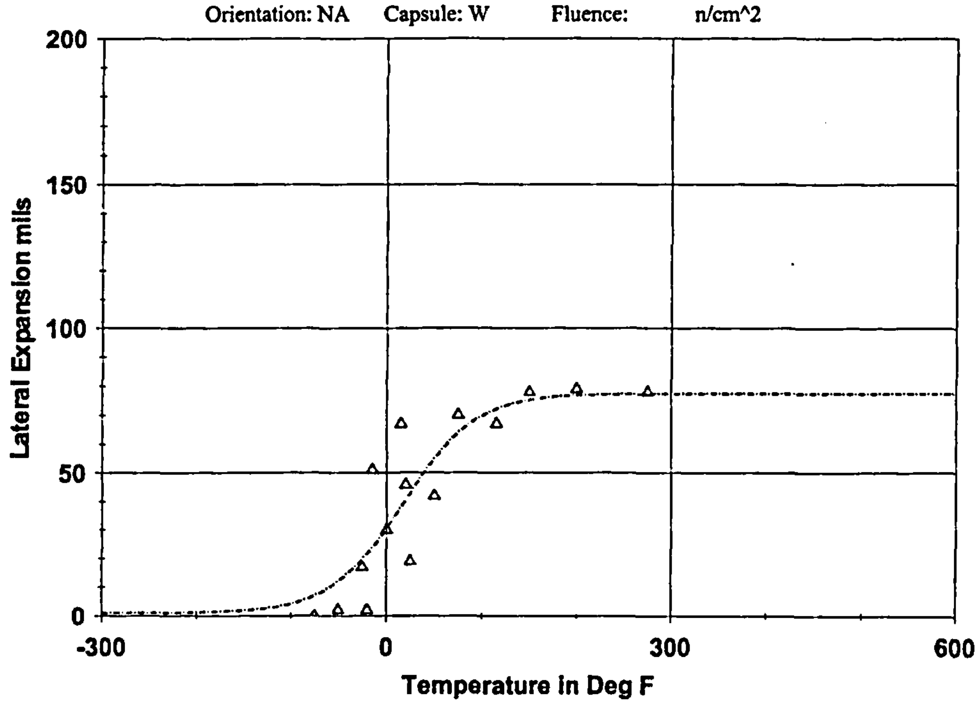
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
100.00	77.00	81.97	-4.97
125.00	88.00	84.50	3.50
150.00	87.00	85.57	1.43
175.00	88.00	86.01	1.99
200.00	86.00	86.18	-.18
225.00	87.00	86.26	.74

Correlation Coefficient = .945

CAPSULE W (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/02/2005 09:26 AM
Page 1
Coefficients of Curve 4
A = 39.22 B = 38.22 C = 75.19 T0 = 17.27 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=77.4 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=9.0 Deg F
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-75.00	.00	7.05	-7.05
-50.00	2.00	11.94	-9.94
-25.00	17.00	19.75	-2.75
-20.00	2.00	21.69	-19.69
-15.00	51.00	23.76	27.24
.00	30.00	30.59	-.59
15.00	67.00	38.07	28.93
20.00	46.00	40.61	5.39
25.00	19.00	43.14	-24.14

CAPSULE W (WELD)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: W Fluence: n/cm^2

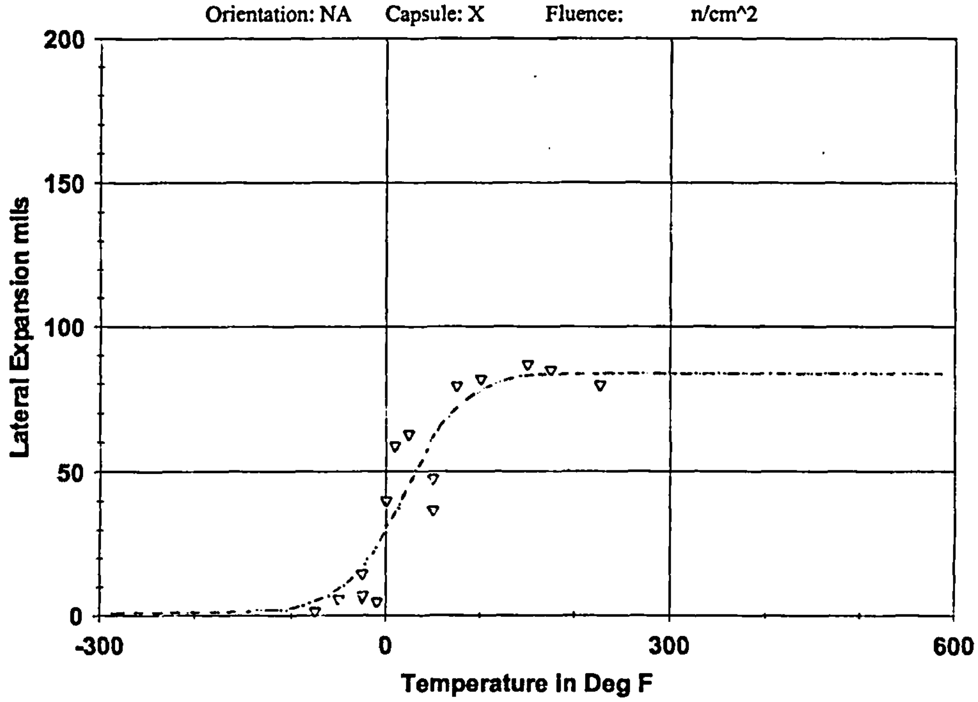
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
50.00	42.00	54.88	-12.88
75.00	70.00	63.90	6.10
115.00	67.00	72.15	-5.15
150.00	78.00	75.26	2.74
200.00	79.00	76.85	2.15
275.00	78.00	77.36	.64

Correlation Coefficient = .872

CAPSULE X (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/02/2005 09:26 AM
Page 1
Coefficients of Curve 5
A = 42.39 B = 41.39 C = 61.65 T0 = 19.49 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=83.8 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=8.4 Deg F
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-75.00	2.00	4.69	-2.69
-50.00	6.00	8.86	-2.86
-25.00	7.00	16.81	-9.81
-25.00	15.00	16.81	-1.81
-10.00	5.00	23.98	-18.98
.00	40.00	29.72	10.28
10.00	59.00	36.07	22.93
25.00	63.00	46.08	16.92
50.00	37.00	61.35	-24.35

CAPSULE X (WELD)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: X Fluence: n/cm^2

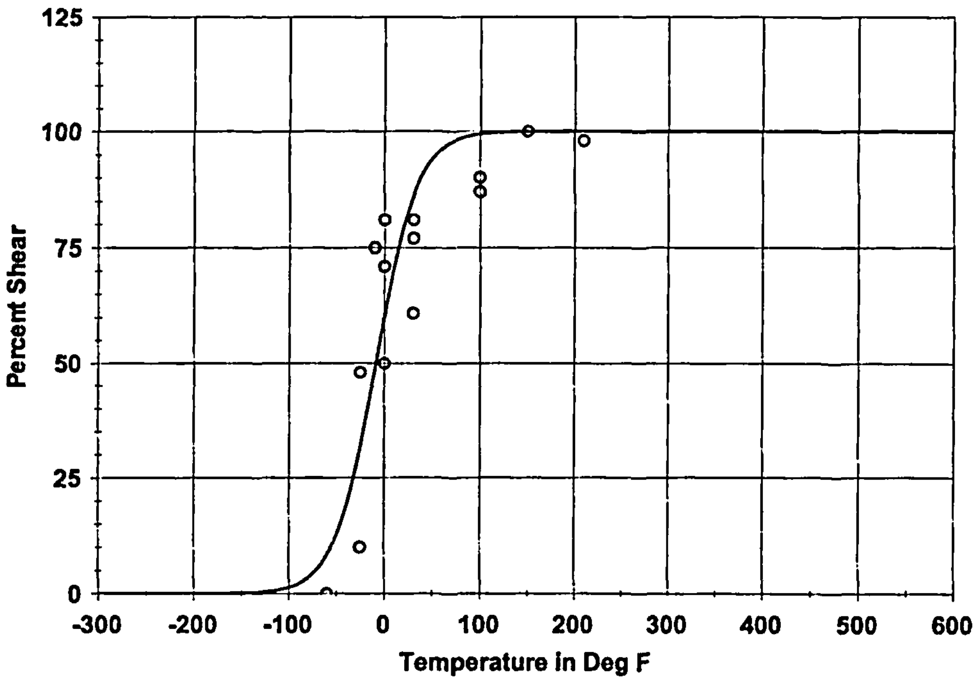
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
50.00	48.00	61.35	-13.35
75.00	80.00	72.04	7.96
100.00	82.00	78.12	3.88
150.00	87.00	82.59	4.41
175.00	85.00	83.25	1.75
225.00	80.00	83.67	-3.67

Correlation Coefficient = .922

UNIRRADIATED (WELD METAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 10:28 AM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 42.55 T0 = -8.64 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = -8.6
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-60.00	.00	8.21	-8.21
-60.00	.00	8.21	-8.21
-25.00	10.00	31.67	-21.67
-25.00	10.00	31.67	-21.67
-25.00	48.00	31.67	16.33
-10.00	75.00	48.40	26.60
.00	50.00	60.02	-10.02
.00	81.00	60.02	20.98
.00	71.00	60.02	10.98

UNIRRADIATED (WELD METAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

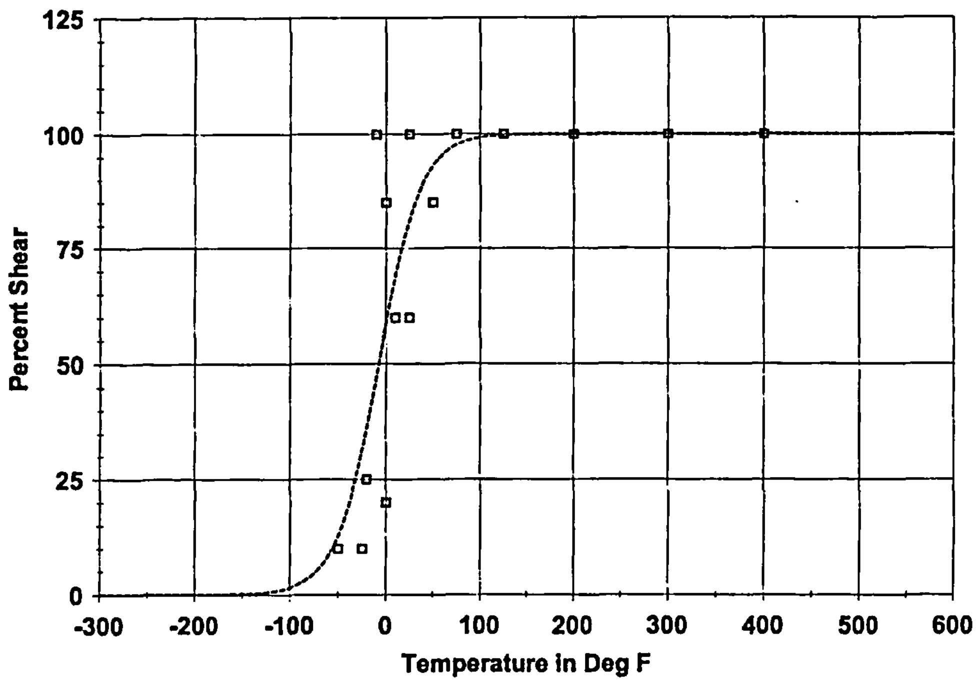
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
30.00	77.00	86.01	-9.01
30.00	81.00	86.01	-5.01
30.00	61.00	86.01	-25.01
100.00	90.00	99.40	-9.40
100.00	87.00	99.40	-12.40
150.00	100.00	99.94	.06
210.00	98.00	100.00	-2.00
210.00	98.00	100.00	-2.00
210.00	98.00	100.00	-2.00

Correlation Coefficient = .915

CAPSULE U (WELD METAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 10:29 AM
Page 1
Coefficients of Curve 2
A = 50. B = 50. C = 44.29 T0 = -7.55 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = -7.5
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	10.00	12.82	-2.82
-25.00	10.00	31.26	-21.26
-20.00	25.00	36.31	-11.31
-10.00	100.00	47.24	52.76
.00	20.00	58.45	-38.45
.00	85.00	58.45	26.55
10.00	60.00	68.84	-8.84
25.00	100.00	81.31	18.69
25.00	60.00	81.31	-21.31

CAPSULE U (WELD METAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: U Fluence: n/cm^2

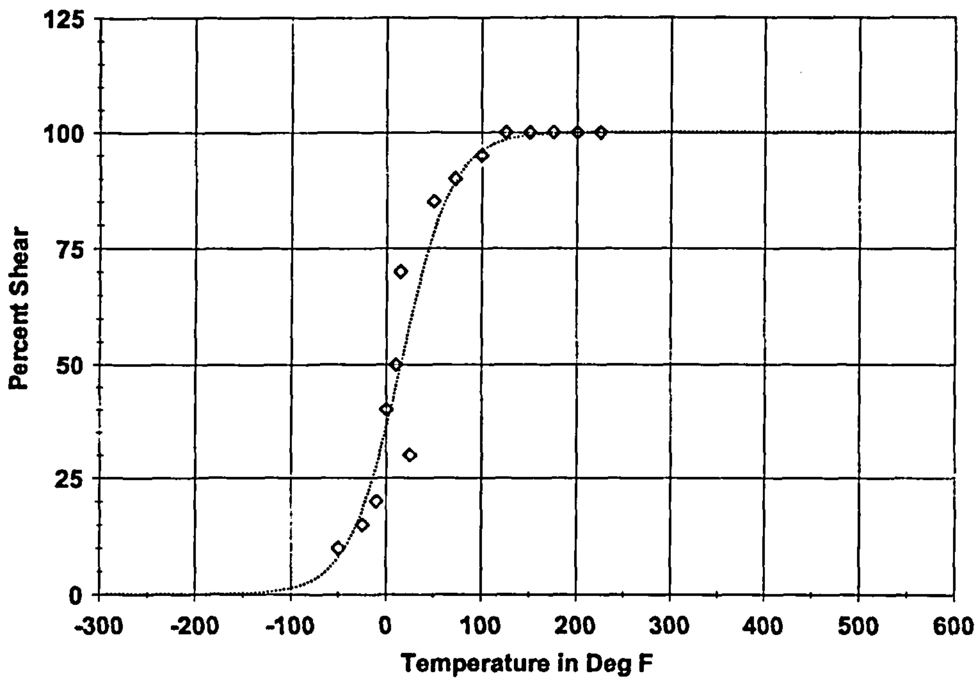
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50.00	85.00	93.08	-8.08
75.00	100.00	97.65	2.35
125.00	100.00	99.75	.25
200.00	100.00	99.99	.01
300.00	100.00	100.00	.00
400.00	100.00	100.00	.00

Correlation Coefficient = .808

CAPSULE V (WELD METAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 10:29 AM
Page 1
Coefficients of Curve 3
A = 50. B = 50. C = 53.49 T0 = 15.76 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 15.8
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: V Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-50.00	10.00	7.88	2.12
-25.00	15.00	17.89	-2.89
-10.00	20.00	27.62	-7.62
.00	40.00	35.68	4.32
10.00	50.00	44.64	5.36
15.00	70.00	49.29	20.71
25.00	30.00	58.55	-28.55
50.00	85.00	78.25	6.75
72.00	90.00	89.12	.88

CAPSULE V (WELD METAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: V Fluence: n/cm^2

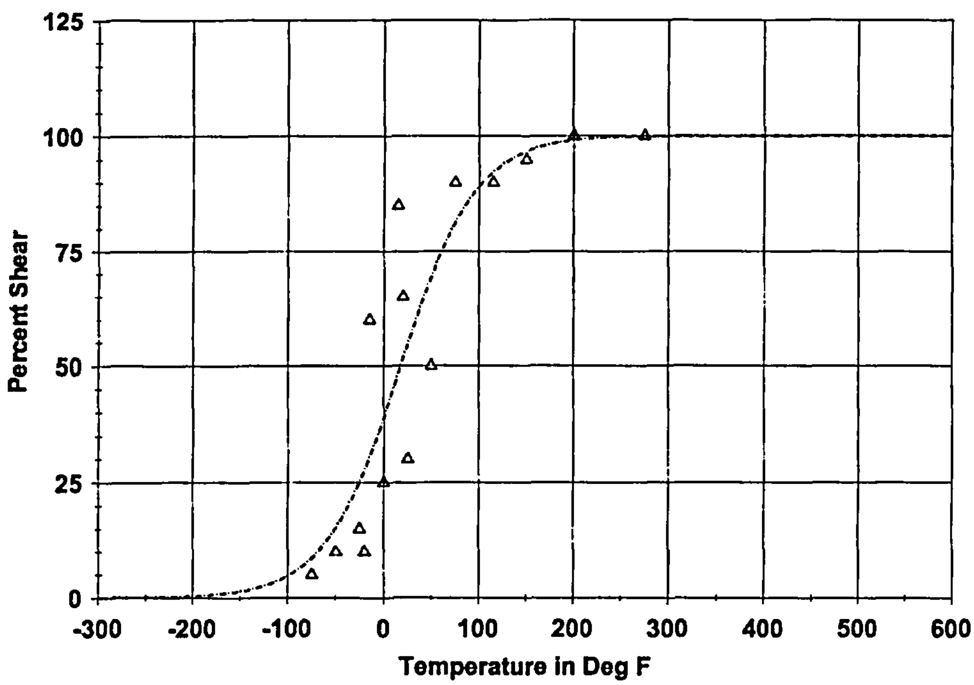
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100.00	95.00	95.89	-.89
125.00	100.00	98.35	1.65
150.00	100.00	99.34	.66
175.00	100.00	99.74	.26
200.00	100.00	99.90	.10
225.00	100.00	99.96	.04

Correlation Coefficient = .959

CAPSULE W (WELD METAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 10:29 AM
Page 1
Coefficients of Curve 4
A = 50. B = 50. C = 78.42 T0 = 17.67 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 17.7
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75.00	5.00	8.60	-3.60
-50.00	10.00	15.11	-5.11
-25.00	15.00	25.19	-10.19
-20.00	10.00	27.67	-17.67
-15.00	60.00	30.29	29.71
.00	25.00	38.92	-13.92
15.00	85.00	48.30	36.70
20.00	65.00	51.48	13.52
25.00	30.00	54.66	-24.66

CAPSULE W (WELD METAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: W Fluence: n/cm^2

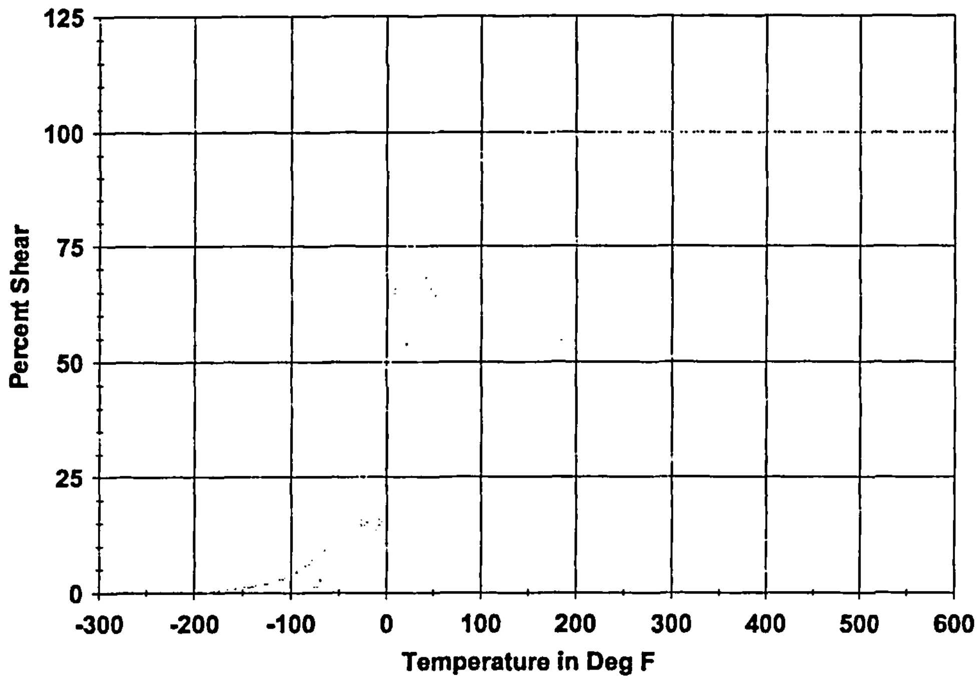
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50.00	50.00	69.52	-19.52
75.00	90.00	81.19	8.81
115.00	90.00	92.29	-2.29
150.00	95.00	96.69	-1.69
200.00	100.00	99.05	.95
275.00	100.00	99.86	.14

Correlation Coefficient = .884

CAPSULE X (WELD METAL)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 10:29 AM
Page 1
Coefficients of Curve 5
A = 50. B = 50. C = 71.09 T0 = 15.33 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 15.4
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-75.00	2.00	7.30	-5.30
-50.00	15.00	13.73	1.27
-25.00	15.00	24.33	-9.33
-25.00	25.00	24.33	.67
-10.00	15.00	32.90	-17.90
.00	50.00	39.38	10.62
10.00	65.00	46.26	18.74
25.00	75.00	56.76	18.24
50.00	45.00	72.62	-27.62

CAPSULE X (WELD METAL)

Page 2
Plant: BEAVER VALLEY 2 Material: SAW Heat: 83642
Orientation: NA Capsule: X Fluence: n/cm^2

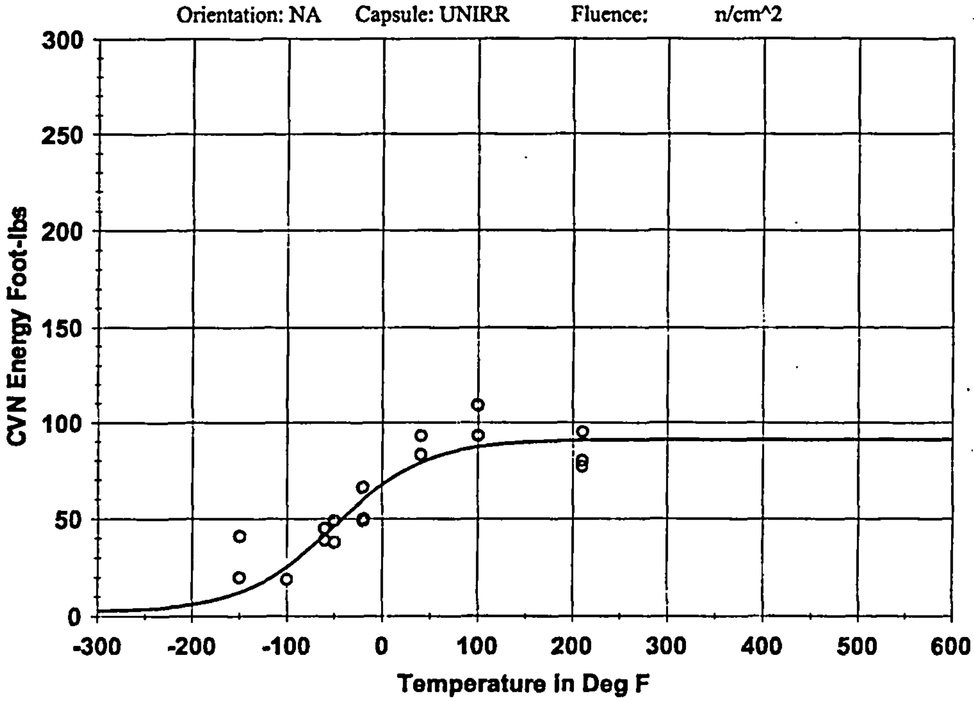
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50.00	65.00	72.62	-7.62
75.00	90.00	84.27	5.73
100.00	95.00	91.55	3.45
150.00	100.00	97.79	2.21
175.00	100.00	98.89	1.11
225.00	100.00	99.73	.27

Correlation Coefficient = .940

UNIRRADIATED (HAZ)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 02:30 PM
Page 1
Coefficients of Curve 1
A = 46.6 B = 44.4 C = 96.61 T0 = -49.3 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=91.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-87.2 Deg F Temp@50 ft-lbs=-41.8 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-150.00	41.00	12.02	28.98
-150.00	20.00	12.02	7.98
-100.00	19.00	25.23	-6.23
-100.00	19.00	25.23	-6.23
-60.00	45.00	41.70	3.30
-60.00	39.00	41.70	-2.70
-50.00	38.00	46.28	-8.28
-50.00	49.00	46.28	2.72
-20.00	49.00	59.67	-10.67

UNIRRADIATED (HAZ)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

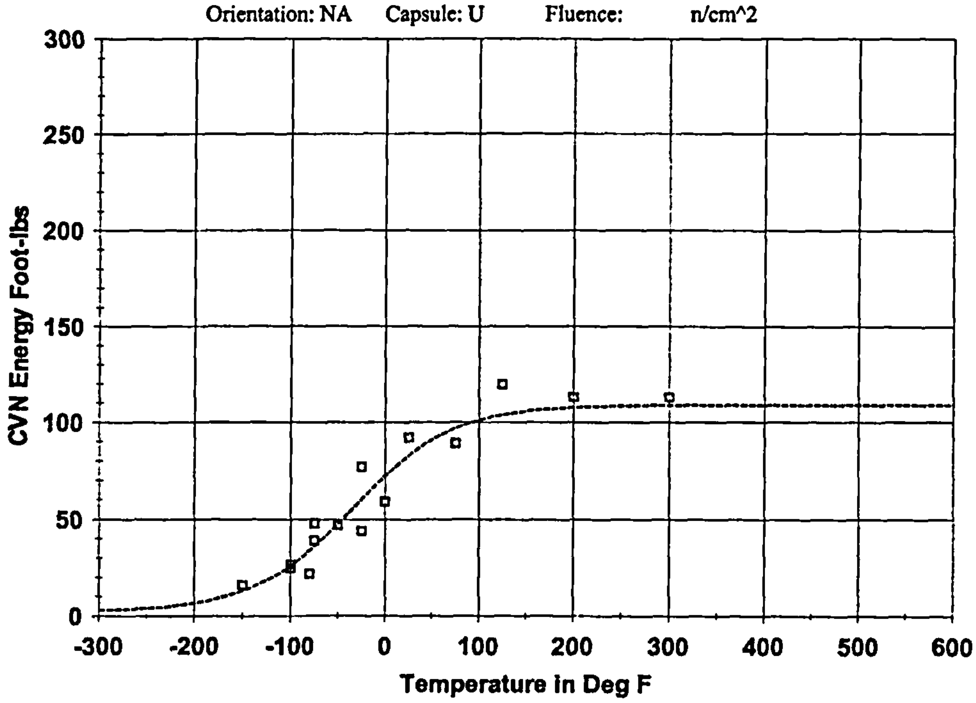
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-20.00	50.00	59.67	-9.67
-20.00	66.00	59.67	6.33
40.00	93.00	78.92	14.08
40.00	83.00	78.92	4.08
100.00	109.00	87.14	21.86
100.00	93.00	87.14	5.86
210.00	77.00	90.59	-13.59
210.00	80.00	90.59	-10.59
210.00	95.00	90.59	4.41

Correlation Coefficient = .914

CAPSULE U (HAZ)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 02:30 PM
Page 1
Coefficients of Curve 2
A = 55.6 B = 53.4 C = 106.03 T0 = -33.89 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=109.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-89.2 Deg F Temp@50 ft-lbs=-45.0 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-150.00	16.00	12.95	3.05
-100.00	25.00	26.04	-1.04
-100.00	27.00	26.04	.96
-80.00	22.00	33.74	-11.74
-75.00	39.00	35.87	3.13
-75.00	48.00	35.87	12.13
-50.00	47.00	47.55	-.55
-25.00	77.00	60.07	16.93
-25.00	44.00	60.07	-16.07

CAPSULE U (HAZ)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: U Fluence: n/cm^2

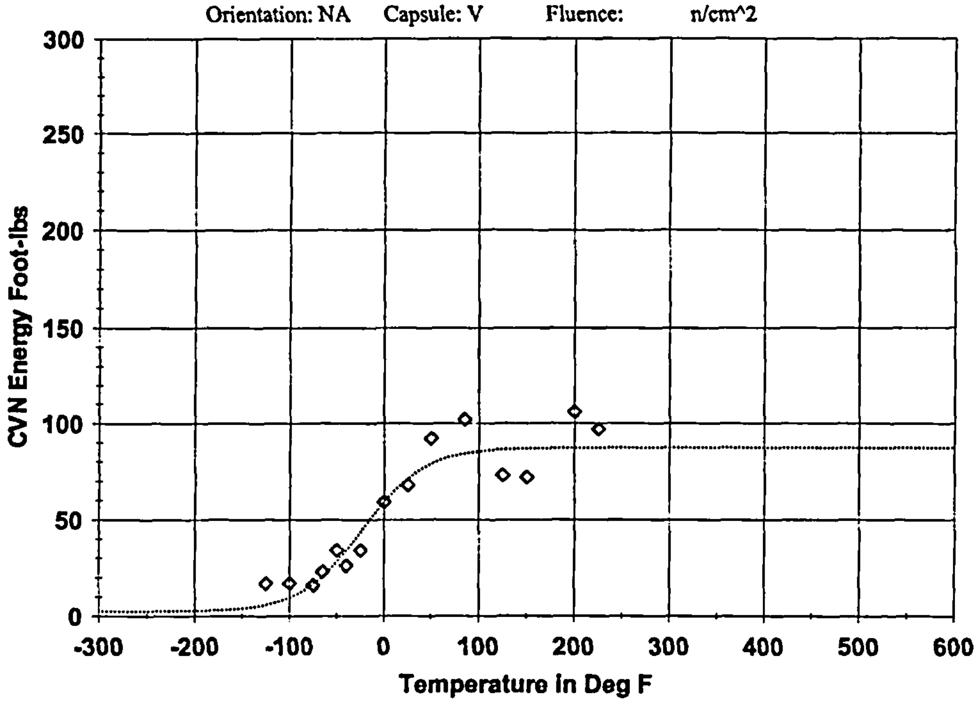
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
.00	59.00	72.11	-13.11
25.00	92.00	82.54	9.46
75.00	89.00	96.86	-7.86
125.00	120.00	103.92	16.08
200.00	113.00	107.72	5.28
300.00	113.00	108.80	4.20

Correlation Coefficient = .960

CAPSULE V (HAZ)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 02:30 PM
Page 1
Coefficients of Curve 3
A = 44.6 B = 42.4 C = 65.54 T0 = -22.51 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=87.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-46.0 Deg F Temp@50 ft-lbs=-14.1 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: V Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-125.00	17.00	5.76	11.24
-100.00	17.00	9.48	7.52
-75.00	16.00	16.42	-.42
-65.00	23.00	20.41	2.59
-50.00	34.00	27.79	6.21
-40.00	26.00	33.54	-7.54
-25.00	34.00	42.99	-8.99
.00	59.00	58.61	.39
25.00	68.00	70.88	-2.88

CAPSULE V (HAZ)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: V Fluence: n/cm^2

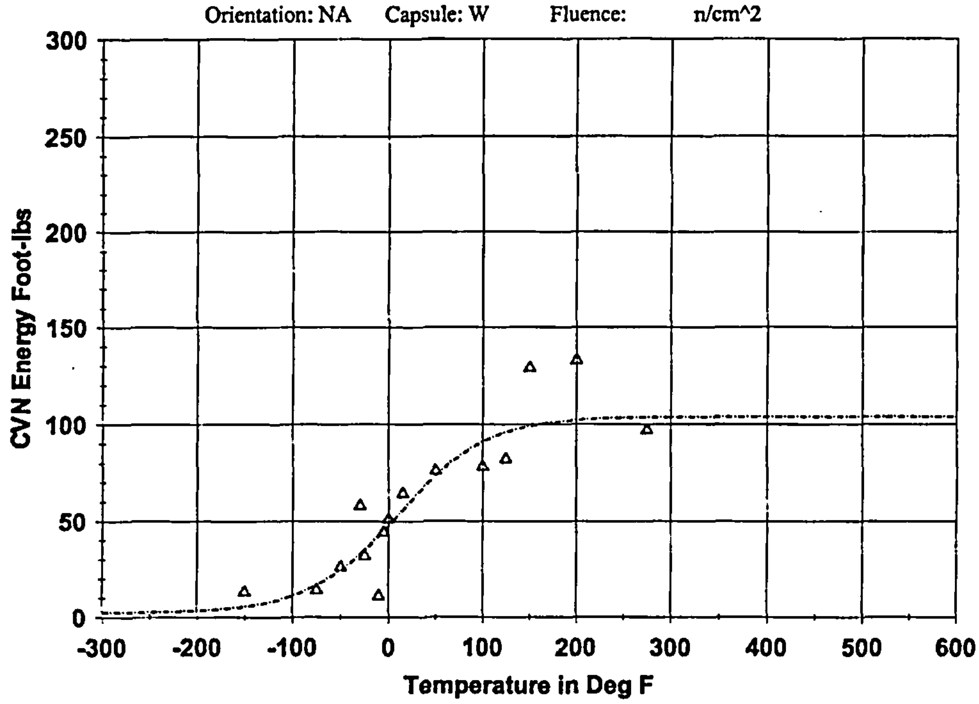
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
50.00	92.00	78.64	13.36
85.00	102.00	83.93	18.07
125.00	73.00	86.07	-13.07
150.00	72.00	86.56	-14.56
200.00	106.00	86.90	19.10
225.00	97.00	86.96	10.04

Correlation Coefficient = .948

CAPSULE W (HAZ)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 02:30 PM
Page 1
Coefficients of Curve 4
A = 53.1 B = 50.9 C = 94.17 T0 = 10.14 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=104.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-35.9 Deg F Temp@50 ft-lbs=4.4 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-150.00	13.00	5.48	7.52
-75.00	14.00	16.54	-2.54
-50.00	26.00	24.39	1.61
-30.00	58.00	32.63	25.37
-25.00	32.00	34.94	-2.94
-5.00	44.00	44.99	-.99
.00	51.00	47.64	3.36
15.00	64.00	55.72	8.28
50.00	76.00	73.44	2.56

CAPSULE W (HAZ)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: W Fluence: n/cm^2

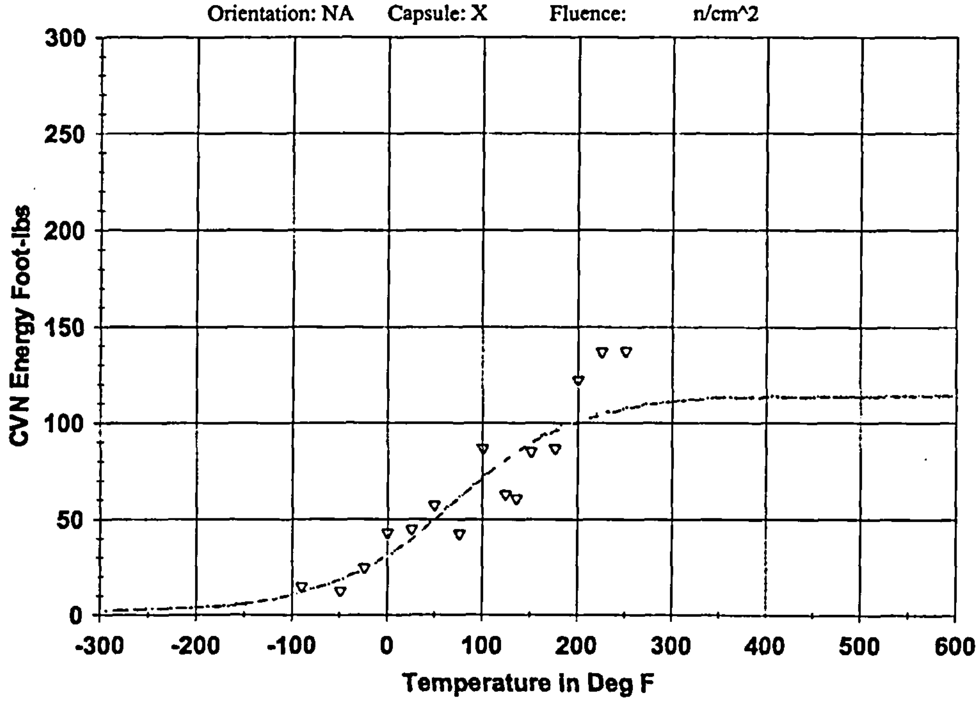
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
100.00	78.00	90.85	-12.85
125.00	82.00	95.83	-13.83
150.00	129.00	99.03	29.97
200.00	133.00	102.23	30.77
275.00	97.00	103.63	-6.63
-10.00	11.00	42.38	-31.38

Correlation Coefficient = .905

CAPSULE X (HAZ)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 02:30 PM
Page 1
Coefficients of Curve 5
A = 58.1 B = 55.9 C = 127.18 T0 = 68.35 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=114.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=-1.9 Deg F Temp@50 ft-lbs=49.8 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-90.00	15.00	10.76	4.24
-50.00	13.00	17.24	-4.24
-25.00	25.00	23.13	1.87
.00	43.00	30.65	12.35
25.00	45.00	39.75	5.25
50.00	58.00	50.09	7.91
75.00	43.00	61.02	-18.02
100.00	87.00	71.73	15.27
125.00	63.00	81.47	-18.47

CAPSULE X (HAZ)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: X Fluence: n/cm^2

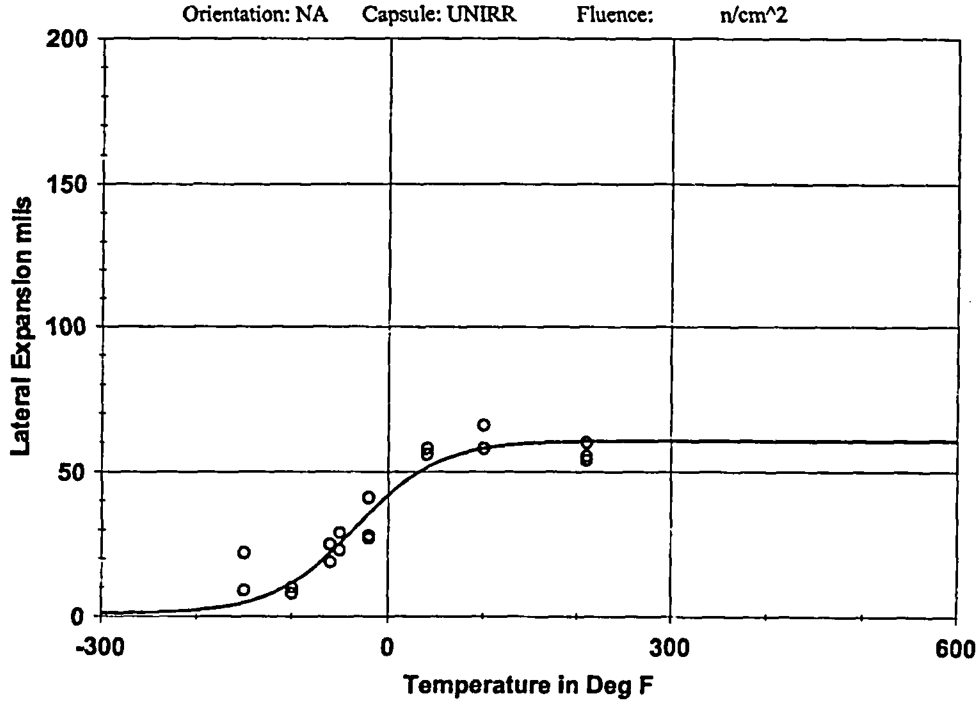
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
135.00	61.00	84.98	-23.98
150.00	85.00	89.75	-4.75
175.00	87.00	96.39	-9.39
200.00	122.00	101.48	20.52
225.00	137.00	105.23	31.77
250.00	137.00	107.92	29.08

Correlation Coefficient = .913

UNIRRADIATED (HAZ)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/01/2005 02:33 PM
Page 1
Coefficients of Curve 1
A = 30.82 B = 29.82 C = 86.37 T0 = -33.74 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=60.6 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=-21.5 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-150.00	9.00	4.78	4.22
-150.00	22.00	4.78	17.22
-100.00	8.00	11.58	-3.58
-100.00	10.00	11.58	-1.58
-60.00	25.00	22.02	2.98
-60.00	19.00	22.02	-3.02
-50.00	23.00	25.27	-2.27
-50.00	29.00	25.27	3.73
-20.00	27.00	35.53	-8.53

UNIRRADIATED (HAZ)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

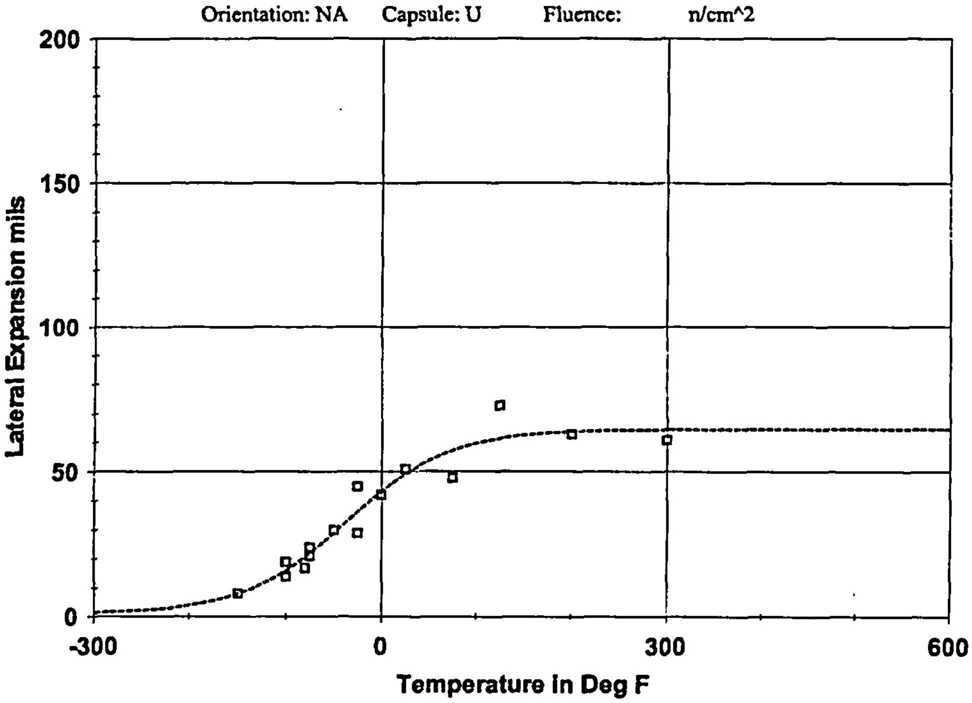
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-20.00	28.00	35.53	-7.53
-20.00	41.00	35.53	5.47
40.00	56.00	51.49	4.51
40.00	58.00	51.49	6.51
100.00	66.00	58.06	7.94
100.00	58.00	58.06	-.06
210.00	54.00	60.43	-6.43
210.00	55.50	60.43	-4.93
210.00	60.00	60.43	-.43

Correlation Coefficient = .949

CAPSULE U (HAZ)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/01/2005 02:34 PM
Page 1
Coefficients of Curve 2
A = 32.77 B = 31.77 C = 107.99 T0 = -36.62 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=64.5 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=-29.0 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-150.00	8.00	7.93	.07
-100.00	19.00	16.01	2.99
-100.00	14.00	16.01	-2.01
-80.00	17.00	20.65	-3.65
-75.00	21.00	21.93	-.93
-75.00	24.00	21.93	2.07
-50.00	30.00	28.85	1.15
-25.00	45.00	36.17	8.83
-25.00	29.00	36.17	-7.17

CAPSULE U (HAZ)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: U Fluence: n/cm^2

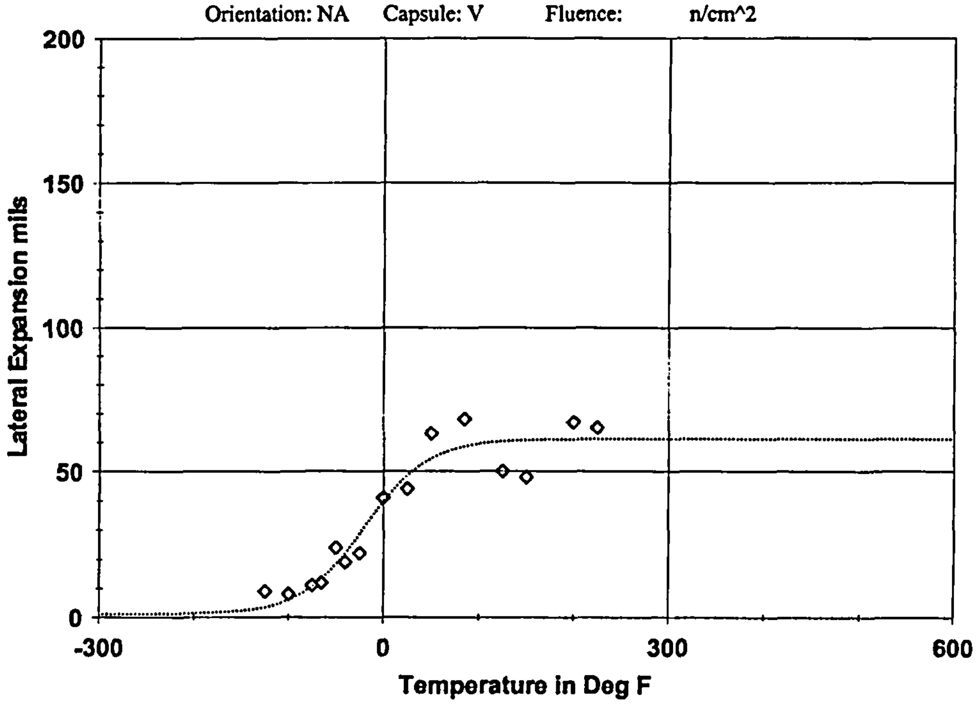
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
.00	42.00	43.15	-1.15
25.00	51.00	49.15	1.85
75.00	48.00	57.40	-9.40
125.00	73.00	61.50	11.50
200.00	63.00	63.75	-.75
300.00	61.00	64.41	-3.41

Correlation Coefficient = .964

CAPSULE V (HAZ)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/01/2005 02:34 PM
Page 1
Coefficients of Curve 3
A = 31.02 B = 30.02 C = 66.87 T0 = -18.96 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=61.0 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=-10.0 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: V Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-125.00	9.00	3.42	5.58
-100.00	8.00	5.89	2.11
-75.00	11.00	10.46	.54
-65.00	12.00	13.10	-1.10
-50.00	24.00	18.00	6.00
-40.00	19.00	21.87	-2.87
-25.00	22.00	28.31	-6.31
.00	41.00	39.31	1.69
25.00	44.00	48.33	-4.33

CAPSULE V (HAZ)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: V Fluence: n/cm^2

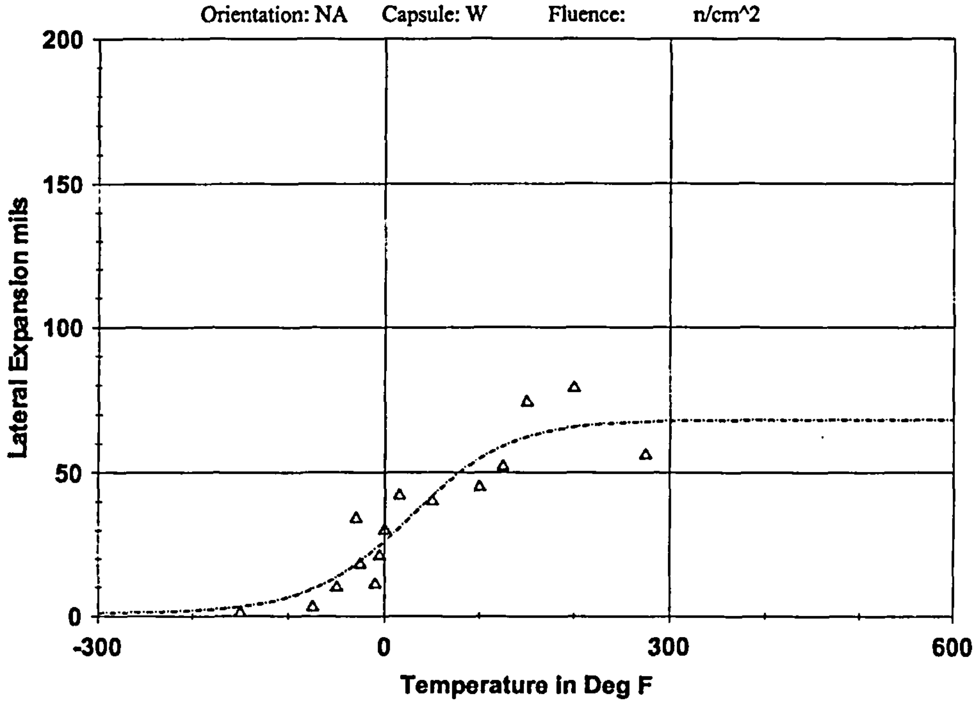
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
50.00	63.00	54.26	8.74
85.00	68.00	58.47	9.53
125.00	50.00	60.24	-10.24
150.00	48.00	60.66	-12.66
200.00	67.00	60.95	6.05
225.00	65.00	61.00	4.00

Correlation Coefficient = .957

CAPSULE W (HAZ)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/01/2005 02:34 PM
Page 1
Coefficients of Curve 4
A = 34.56 B = 33.56 C = 104.86 T0 = 26.75 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=68.1 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=28.2 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-150.00	1.00	3.23	-2.23
-75.00	3.00	9.43	-6.43
-50.00	10.00	13.61	-3.61
-30.00	34.00	17.98	16.02
-25.00	18.00	19.22	-1.22
-5.00	21.00	24.70	-3.70
.00	30.00	26.18	3.82
15.00	42.00	30.82	11.18
50.00	40.00	41.88	-1.88

CAPSULE W (HAZ)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: W Fluence: n/cm^2

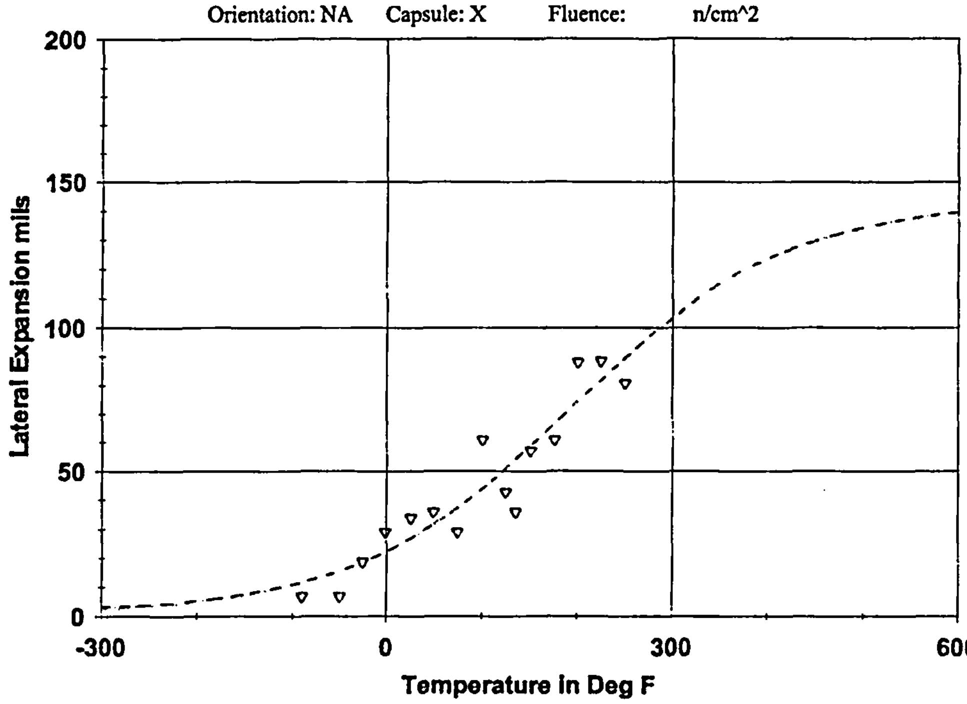
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
100.00	45.00	54.81	-9.81
125.00	52.00	59.19	-7.19
150.00	74.00	62.28	11.72
200.00	79.00	65.74	13.26
275.00	56.00	67.54	-11.54
-10.00	11.00	23.26	-12.26

Correlation Coefficient = .923

CAPSULE X (HAZ)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 09/01/2005 02:34 PM
Page 1
Coefficients of Curve 5
A = 71.99 B = 70.99 C = 223.65 T0 = 194.57 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=143.0 Lower Shelf L.E.=1.0(Fixed)
Temp.@L.E. 35 mils=65.4 Deg F
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-90.00	7.00	11.33	-4.33
-50.00	7.00	15.33	-8.33
-25.00	19.00	18.48	.52
.00	29.00	22.20	6.80
25.00	34.00	26.56	7.44
50.00	36.00	31.58	4.42
75.00	29.00	37.28	-8.28
100.00	61.00	43.64	17.36
125.00	43.00	50.59	-7.59

CAPSULE X (HAZ)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: X Fluence: n/cm^2

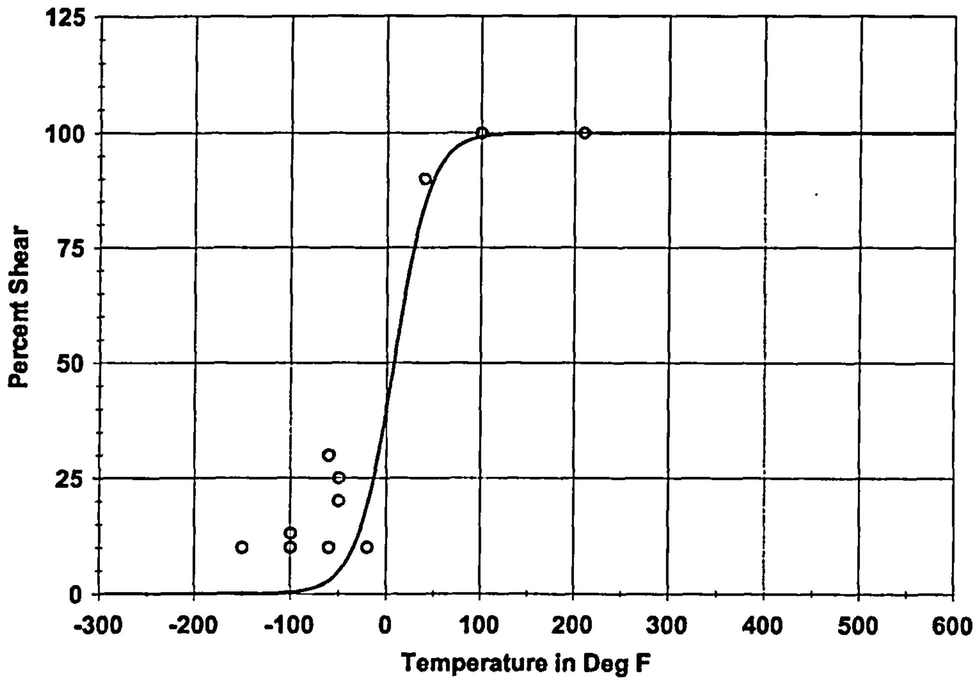
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
135.00	36.00	53.52	-17.52
150.00	57.00	58.03	-1.03
175.00	61.00	65.79	-4.79
200.00	88.00	73.71	14.29
225.00	89.00	81.59	7.41
250.00	81.00	89.23	-8.23

Correlation Coefficient = .934

UNIRRADIATED (HAZ)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 03:10 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 38.32 T0 = 7.81 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 7.9
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-150.00	10.00	.03	9.97
-150.00	10.00	.03	9.97
-100.00	10.00	.36	9.64
-100.00	13.00	.36	12.64
-60.00	30.00	2.82	27.18
-60.00	10.00	2.82	7.18
-50.00	20.00	4.66	15.34
-50.00	25.00	4.66	20.34
-20.00	10.00	18.97	-8.97

UNIRRADIATED (HAZ)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

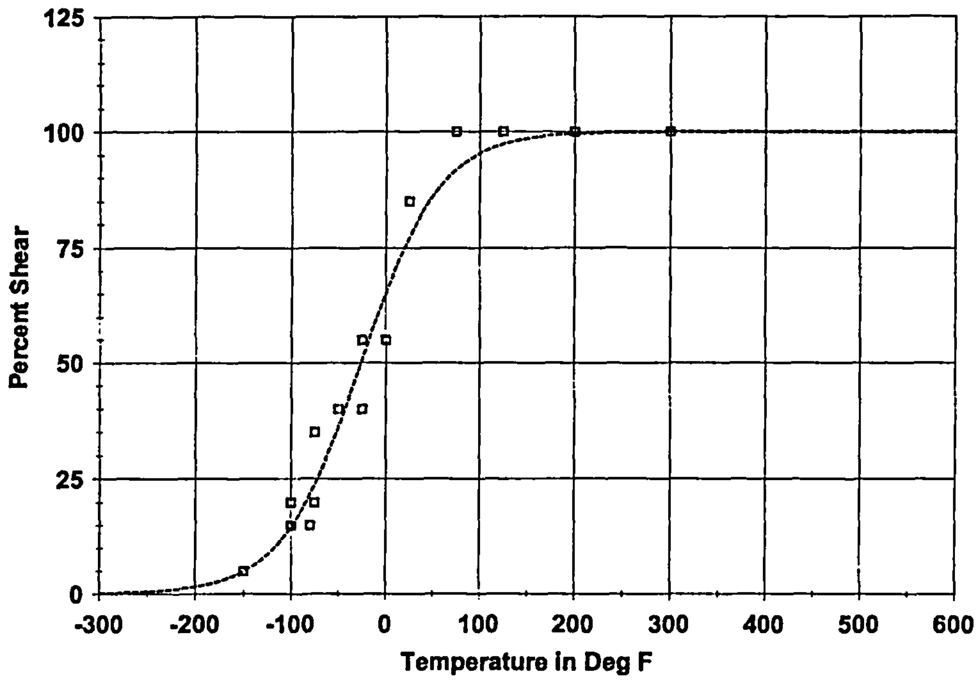
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-20.00	10.00	18.97	-8.97
-20.00	10.00	18.97	-8.97
40.00	90.00	84.29	5.71
40.00	90.00	84.29	5.71
100.00	100.00	99.19	.81
100.00	100.00	99.19	.81
210.00	100.00	100.00	.00
210.00	100.00	100.00	.00
210.00	100.00	100.00	.00

Correlation Coefficient = .977

CAPSULE U (HAZ)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 02:34 PM
Page 1
Coefficients of Curve 2
A = 50. B = 50. C = 83.7 T0 = -26.16 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = -26.1
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: U Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-150.00	5.00	4.93	.07
-100.00	15.00	14.62	.38
-100.00	20.00	14.62	5.38
-80.00	15.00	21.64	-6.64
-75.00	20.00	23.74	-3.74
-75.00	35.00	23.74	11.26
-50.00	40.00	36.13	3.87
-25.00	55.00	50.69	4.31
-25.00	40.00	50.69	-10.69

CAPSULE U (HAZ)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: U Fluence: n/cm^2

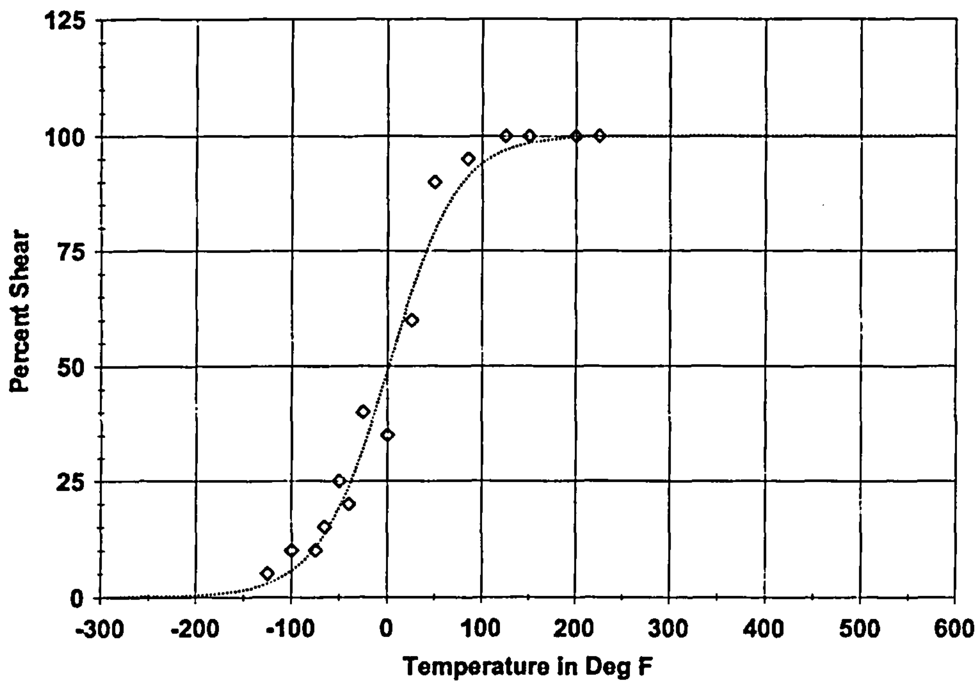
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
.00	55.00	65.13	-10.13
25.00	85.00	77.25	7.75
75.00	100.00	91.81	8.19
125.00	100.00	97.37	2.63
200.00	100.00	99.55	.45
300.00	100.00	99.96	.04

Correlation Coefficient = .984

CAPSULE V (HAZ)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 02:34 PM
Page 1
Coefficients of Curve 3
A = 50. B = 50. C = 71.81 T0 = 1.98 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 2.0
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: V Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-125.00	5.00	2.83	2.17
-100.00	10.00	5.52	4.48
-75.00	10.00	10.49	-.49
-65.00	15.00	13.41	1.59
-50.00	25.00	19.03	5.97
-40.00	20.00	23.70	-3.70
-25.00	40.00	32.05	7.95
.00	35.00	48.62	-13.62
25.00	60.00	65.50	-5.50

CAPSULE V (HAZ)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: V Fluence: n/cm^2

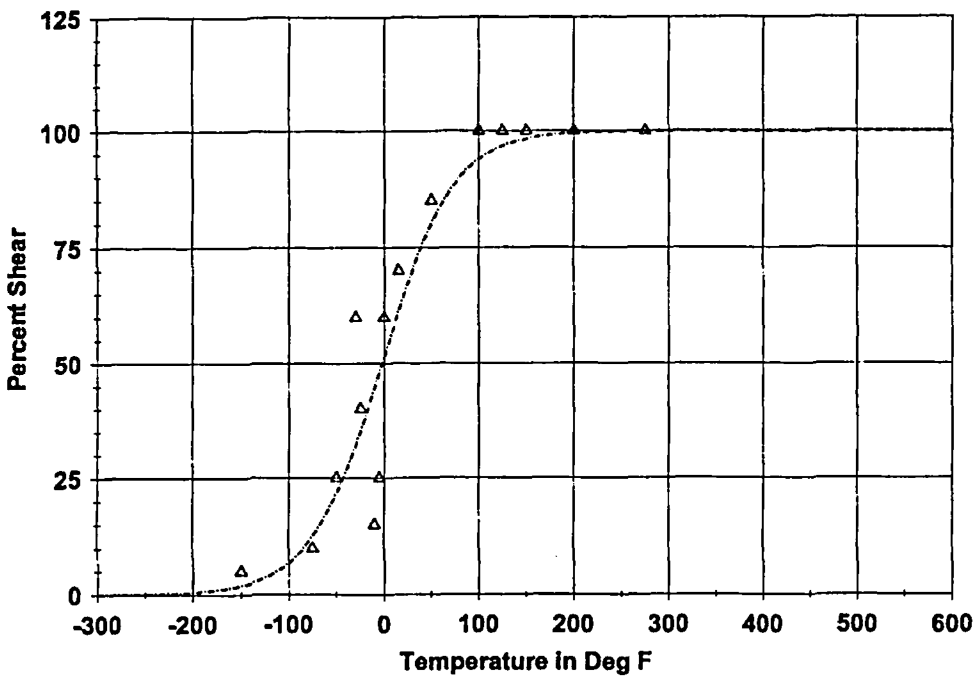
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
50.00	90.00	79.21	10.79
85.00	95.00	90.99	4.01
125.00	100.00	96.85	3.15
150.00	100.00	98.41	1.59
200.00	100.00	99.60	.40
225.00	100.00	99.80	.20

Correlation Coefficient = .989

CAPSULE W (HAZ)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 02:34 PM
Page 1
Coefficients of Curve 4
A = 50. B = 50. C = 74.91 T0 = -2.01 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = -2.0
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: W Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-150.00	5.00	1.89	3.11
-75.00	10.00	12.47	-2.47
-50.00	25.00	21.73	3.27
-30.00	60.00	32.14	27.86
-25.00	40.00	35.12	4.88
-5.00	25.00	48.00	-23.00
.00	60.00	51.34	8.66
15.00	70.00	61.16	8.84
50.00	85.00	80.04	4.96

CAPSULE W (HAZ)

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: W Fluence: n/cm^2

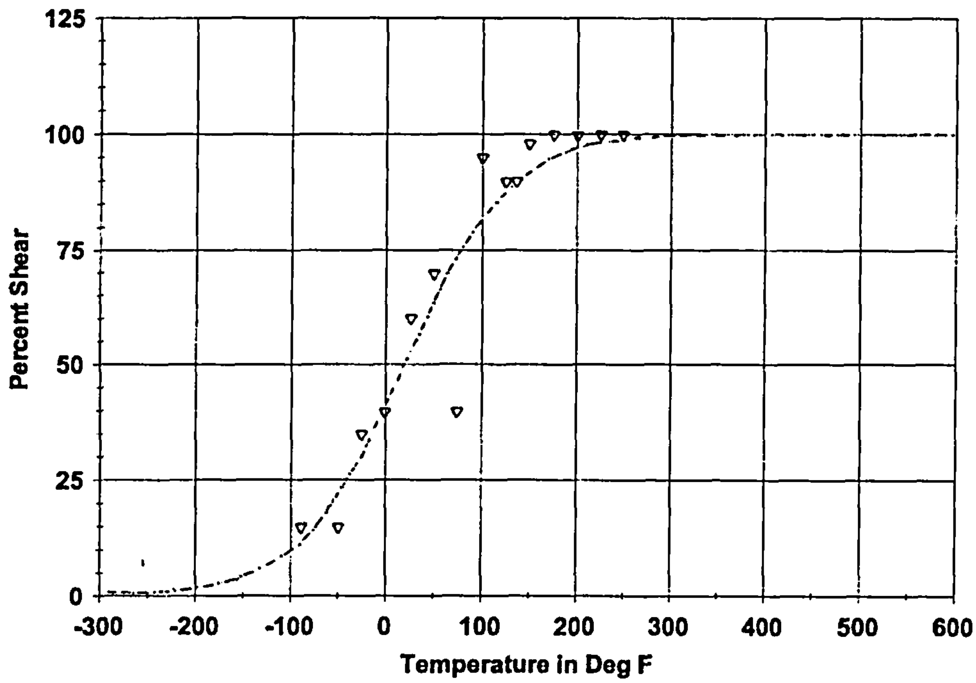
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100.00	100.00	93.84	6.16
125.00	100.00	96.74	3.26
150.00	100.00	98.30	1.70
200.00	100.00	99.55	.45
275.00	100.00	99.94	.06
-10.00	15.00	44.69	-29.69

Correlation Coefficient = .934

CAPSULE X

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 08/30/2005 02:34 PM
Page 1
Coefficients of Curve 5
A = 50. B = 50. C = 106.78 T0 = 19.76 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 19.8
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-90.00	15.00	11.35	3.65
-50.00	15.00	21.31	-6.31
-25.00	35.00	30.19	4.81
.00	40.00	40.85	-.85
25.00	60.00	52.45	7.55
50.00	70.00	63.79	6.21
75.00	40.00	73.78	-33.78
100.00	95.00	81.80	13.20
125.00	90.00	87.77	2.23

CAPSULE X

Page 2
Plant: BEAVER VALLEY 2 Material: SA533B1 Heat: C0544-2
Orientation: NA Capsule: X Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
135.00	90.00	89.65	.35
150.00	98.00	91.98	6.02
175.00	100.00	94.82	5.18
200.00	100.00	96.69	3.31
225.00	100.00	97.90	2.10
250.00	100.00	98.68	1.32

Correlation Coefficient = .947

APPENDIX D

BEAVER VALLEY UNIT 2 SURVEILLANCE PROGRAM CREDIBILITY EVALUATION

INTRODUCTION:

Regulatory Guide 1.99, Revision 2 describes general procedures acceptable to the NRC staff for calculating the effects of neutron radiation embrittlement of the low-alloy steels currently used for light-water-cooled reactor vessels. Position C.2 of Regulatory Guide 1.99, Revision 2 describes the 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 have been four surveillance capsules removed from the Beaver Valley Unit 2 reactor vessel. To use these surveillance data sets, they must be shown to be credible. In accordance with the discussion of Regulatory Guide 1.99, Revision 2, there are five requirements that must be met for the surveillance data to be judged credible. Each of these five requirements is presented, along with an evaluation of each, in the following section.

The purpose of this evaluation is to apply the credibility requirements of Regulatory Guide 1.99, Revision 2 to the Beaver Valley Unit 2 reactor vessel surveillance data and determine if the Beaver Valley Unit 2 surveillance data are 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 Beaver Valley Unit 2 reactor vessel consists of the following beltline region materials:

- Intermediate shell plates B9004-1 and -2
- Lower shell plates B9005-1 and -2
- Intermediate shell longitudinal (axial) weld seams 101-142 A & B
- Lower shell longitudinal (axial) weld seams 101-142 A & B
- Intermediate to lower shell circumferential (girth) weld seam 101-171

From WCAP-9615, Revision 1, selection of the surveillance material was based on an evaluation of initial toughness (characterized by the reference temperature, RT_{NDT} and C_v upper shelf energies), and the predicted effect of chemical composition (residual copper and phosphorus) and neutron fluence on the toughness (RT_{NDT} shift) during reactor operation. Lower shell plate numbered B9004-2 (Heat C0544-1) was selected as the surveillance base metal since it had the highest adjusted EOL RT_{NDT} of the four beltline region plates. Weld Heat 83642 was selected because it is the same heat used in fabrication of all of the axial and circumferential welds.

Based on this discussion, Criterion 1 is met for the Beaver Valley Unit 2 reactor vessel.

Criterion 2: Scatter in the plots of Charpy energy versus temperature for the irradiated and unirradiated conditions should be small enough to permit the determination of the 30 ft-lb temperature and upper shelf energy unambiguously.

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 USE of the Beaver Valley Unit 2 surveillance materials unambiguously. Hence, the Beaver Valley Unit 2 surveillance program meets this criterion.

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

The functional form of the least squares method as described in Regulatory Position 2.1 will be utilized to determine a best-fit line for these data and to determine if the scatter of ΔRT_{NDT} values about this line is less than 28°F for welds and less than 17°F for the plate.

The Beaver Valley Unit 2 lower shell plate B9004-2 and surveillance weld will be evaluated for credibility. The surveillance weld is made from weld wire Heat 83642. Since there are now four data points available that are specific to the Beaver Valley surveillance program, only that data will be evaluated to determine credibility. Note that there are two magnitudes of fluence, therefore a wider scatter band is permitted if needed.

Table D-1 contains the calculation of chemistry factors for the Beaver Valley Unit 2 reactor vessel beltline materials contained in the surveillance program. These chemistry factors are calculated per Regulatory Guide 1.99, Revision 2, Position 2.1.

Table D-1
Calculation of Chemistry Factors using Beaver Valley Unit 2 Surveillance Capsule Data

Material	Capsule	Capsule f[a]	FF[b]	ΔRT_{NDT}[c]	FF*ΔRT_{NDT}	FF^2
Intermediate Shell Plate B9004-2 (Longitudinal)	U	0.6082	0.861	24.0	20.66	0.741
	V	2.629	1.259	56.0	70.50	1.585
	W	3.625	1.335	71.0	94.79	1.782
	X	5.601	1.424	98.0	139.55	2.028
Intermediate Shell Plate B9004-2 (Transverse)	U	0.6082	0.861	17.7	15.24	0.741
	V	2.629	1.259	46.1	58.04	1.585
	W	3.625	1.335	63.4	84.64	1.782
	X	5.601	1.424	104.1	148.24	2.028
				SUM:	**631.66**	**12.272**
$CF = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (631.66) \div (12.272) =$ **51.5°F**						
Beaver Valley Surveillance Weld Metal 83642	U	0.6082	0.861	4.1	3.53	0.741
	V	2.629	1.259	25.7	32.36	1.585
	W	3.625	1.335	6.0	8.01	1.782
	X	5.601	1.424	22.9	32.61	2.028
				SUM:	**76.51**	**6.136**
$CF = \Sigma(FF * RT_{NDT}) \div \Sigma(FF^2) = (76.51) \div (6.136) =$ **12.5°F**						

Notes:
(a) f = Calculated fluence from the Beaver Valley Unit 2 capsule X dosimetry analysis results, (x 10^{19} n/cm^2, E > 1.0 MeV).
(b) FF = fluence factor = $f^{(0.28 - 0.1*\log f)}$.
(c) ΔRT_{NDT} values are the measured 30 ft-lb. shift values for Beaver Valley Unit 2 taken from Appendix C.

The scatter of ΔRT_{NDT} values about the functional form of a best-fit line drawn as described in Regulatory Position 2.1 is presented in Table D-2.

Table D-2
Beaver Valley Unit 2 Surveillance Capsule Data Scatter about the Best-Fit Line for Surveillance Materials

Material	Capsule	CF ($Slope_{best fit}$)	FF	Measured ΔRT_{NDT}	Predicted ΔRT_{NDT}	Scatter ΔRT_{NDT}	<17°F (Base Metals) <28°F (Weld)
Intermediate Shell Plate B9004-2 *(Longitudinal)*	U	51.5°F	0.861	24.0°F	44.3°F	-20.3°F	No [(a)]
	V	51.5°F	1.259	56.0°F	64.8°F	-8.8°F	Yes
	W	51.5°F	1.335	71.0°F	68.8°F	2.2°F	Yes
	X	51.5°F	1.424	98.0°F	73.3°F	24.7°F	No [(a)]
Intermediate Shell Plate B9004-2 *(Transverse)*	U	51.5°F	0.861	17.7°F	44.3°F	-26.6°F	No [(a)]
	V	51.5°F	1.259	46.1°F	64.8°F	-18.7°F	No [(a)]
	W	51.5°F	1.335	63.4°F	68.8°F	-5.4°F	Yes
	X	51.5°F	1.424	104.1°F	73.3°F	30.8°F	No [(a)]
Surveillance Weld Material (Heat # 83642)	U	12.5°F	0.861	4.1°F	10.8°F	-6.7°F	Yes
	V	12.5°F	1.259	25.7°F	15.7°F	10.0°F	Yes
	W	12.5°F	1.335	6.0°F	16.7°F	-10.7°F	Yes
	X	12.5°F	1.424	22.9°F	17.8°F	5.1°F	Yes

Note:
(a) Based on guidelines from Regulatory guide 1.99, Revision 2, and guidance from 10 CFR 50.61, if there are two or more orders of magnitude of the fluence, you are permitted to double the scatter acceptability criteria. In this case, there are two magnitudes of fluence, therefore, these data scatter can be considered acceptable.

Table D-2 indicates that 5 out of the 8 data points fall outside the $\pm 1\sigma$ of 17°F scatter band for the lower shell plate B9004-2 surveillance data. Per guidelines provided in Regulatory Guide 1.99 and 10 CFR 50.61, if there are two or more magnitudes in fluence, the scatter bands are allowed to be doubled. For Beaver Valley Unit 2, there are two orders of magnitude for the fluence. Therefore, the plate data meet this criterion since the scatter is < 34°F for all of the plate materials. No weld data points fall outside the $\pm 1\sigma$ of 28°F scatter band for the surveillance weld data; therefore, the weld data meet this criterion.

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 fuel and the vessel wall opposite the center of the core. The test capsules are in baskets attached to the vessel wall. The location of the specimens with respect to the reactor vessel beltline provides assurance that the reactor vessel wall and the specimens are subjected to equivalent operating conditions such that the temperatures will not differ by more than 25°F. Hence, this criterion is met.

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

The Beaver Valley Unit 2 surveillance program does not contain correlation monitor material. Therefore, this criterion is not applicable to the Beaver Valley Unit 2 surveillance program and exemption to its requirements is implemented.

CONCLUSION:

Based on the preceding responses to all five criteria of Regulatory Guide 1.99, Revision 2 and guidance from 10 CFR 50.61, the Beaver Valley Unit 2 surveillance plate and weld data are deemed credible. For future evaluations of ART and RT_{PTS} values, reduced margin terms for the plate and weld material is permitted per Regulatory Guide 1.99, Revision 2.