Entergy

Entergy Nuclear Northeast
Entergy Nuclear Operations, Inc.
440 Hamilton Avenue
White Plains, NY 10601
Tel 914 272 3200
Fax 914 272 3205

Michael R. Kansler
President

July 29, 2004
NL-04-092

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Subject: Indian Point Nuclear Generating Unit No. 3
Docket No. 50-286
<u>Capsule X Material Surveillance Report</u>

Reference: 1. Entergy letter to NRC, NL-04-042, regarding "Reactor Vessel Material Surveillance Program: Preliminary Analysis Results for Capsule X", dated April 19, 2004.

Dear Sir:

Pursuant to Appendix H to10 CFR 50, Reference 1 provided a summary technical report, "Summary Report IPEC-RPT-04-00005 Rev. 0, Preliminary Analysis of Capsule X – Indian Point Unit 3 Reactor Vessel Surveillance Program". In Reference 1, Entergy Nuclear Operations, Inc. (ENO), also committed to provide a final report to the NRC by July 30, 2004. Attachment 1 to this letter transmits the final report WCAP-16251-NP, entitled, "Analysis of Capsule X from Entergy's Indian Point 3 Reactor Vessel Radiation Surveillance Program".

The final report differs from the preliminary report (Reference 1) in that it includes dosimetry data and tensile test results. It also revises the Surveillance Program Weld Metal temperature shift data on Table 5.10 (shown as Table 10 in Reference 1). As the Indian Point 3 reactor vessel is not weld limited, and as the revisions result in a better predicted-to-measured ratio, these revisions have no impact on the preliminary report's conclusions. Several minor typographical errors were corrected.

The results of the finalized report are consistent with those of the preliminary report. ENO concludes that no further actions are required to assure compliance with 10 CFR 50 Appendix H.

A008

There are no new commitments made in this letter. If you have any questions, please contact Ms. Charlene Faison at 914-272-3378.

Very truly yours,

Michael R. Kansler
President
Entergy Nuclear Operations, Inc.

Attachment:

I. WCAP-16251-NP, Analysis of Capsule X from Entergy's Indian Point Unit 3 Reactor Vessel Radiation Surveillance Program.

cc: Mr. Patrick D. Milano, Senior Project Manager
Project Directorate I,
Division of Licensing Project Management
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Mail Stop O-8-C2
Washington, DC 20555

Mr. Samuel J. Collins
Regional Administrator, Region I
U.S. Nuclear Regulatory Commission
475 Allendale Road
King of Prussia, PA 19406

Resident Inspector's Office
Indian Point Unit 3
U.S. Nuclear Regulatory Commission
P.O. Box 337
Buchanan, NY 10511-0337

Mr. Peter R. Smith
President
NYSERDA
17 Columbia Circle
Albany, NY 12203

Mr. Paul Eddy
New York State Dept. of Public Service
3 Empire Plaza
Albany, NY 12223

ATTACHMENT 1

WCAP-16251-NP
ANALYSIS OF CAPSULE X FROM ENTERGY'S INDIAN POINT UNIT 3 REACTOR VESSEL RADIATION SURVEILLANCE PROGRAM

Entergy Nuclear Operations, Inc.
Indian Point Nuclear Generating Unit No. 3
Docket No. 50-286

Westinghouse Non-Proprietary Class 3

WCAP-16251-NP
Revision 0

July 2004

Analysis of Capsule X from Entergy's Indian Point Unit 3 Reactor Vessel Radiation Surveillance Program

Westinghouse

WESTINGHOUSE NON-PROPRIETARY CLASS 3

WCAP-16251-NP, Revision 0

Analysis of Capsule X from Entergy's Indian Point Unit 3 Reactor Vessel Radiation Surveillance Program

T.J. Laubham
J. Conermann
S.L. Anderson

July 2004

Approved: J. Ghergurovich
J. Ghergurovich, Manager
Reactor Component Design & Analysis

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.)

PREFACE

This report has been technically reviewed and verified by:

Reviewer:

Sections 1 through 5, 7, 8, Appendices B, C and D	C.M. Burton	CuB~~t~~
Section 6 and Appendix A	G. K. Roberts	GKRoberts

EXECUTIVE SUMMARY

The purpose of this report is to document the results of the testing of surveillance Capsule X from Indian Point Unit 3. Capsule X was removed at 15.5 EFPY and post irradiation mechanical tests of the Charpy V-notch and tensile specimens were performed. A fluence evaluation utilizing the recently released neutron transport and dosimetry cross-section libraries was derived from the ENDF/B-VI data-base. Capsule X received a fluence of 0.874 x 10^{19} n/cm^2 after irradiation to 15.5 EFPY. The peak clad/base metal interface vessel fluence after 15.5 EFPY of plant operation was 5.86 x 10^{18} n/cm^2.

This evaluation lead to the following conclusions: 1) The measured 30 ft-lb shift in transition temperature values of the lower shell plate B2803-3 contained in capsule X (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. 2) The measured 30 ft-lb shift in transition temperature value of the weld metal contained in capsule X is less than the Regulatory Guide 1.99, Revision 2, prediction. 3) The measured 30 ft-lb shift in transition temperature value of the intermediate shell plate B2802-2 contained in capsule X (longitudinal) is greater than the Regulatory Guide 1.99, Revision 2, prediction. However, the shift value is less than the two sigma allowance by Regulatory Guide 1.99, Revision 2. 4) The measured percent decrease in upper shelf energy for all the surveillance materials of Capsules X contained in the Indian Point Unit 3 surveillance program are in good agreement with the Regulatory Guide 1.99, Revision 2 predictions. 5) 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 (27.1 EFPY) as required by 10CFR50, Appendix G [2]. 6) The Indian Point Unit 3 surveillance data from the lower shell plate B2803-3 was 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 Indian Point Unit 3 reactor pressure vessel, led to the following conclusions:

- The Charpy V-notch data presented in WCAP-8475[3], WCAP-9491[4], WCAP-10300[5], and WCAP-11815[6] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a re-plot of all applicable capsule data using CVGRAPH, Version 5.0.2, which is a hyperbolic tangent curve-fitting program. Appendix C presents the CVGRAPH, Version 5.02, Charpy V-notch plots and the program input data.

- Capsule X received an average fast neutron fluence (E> 1.0 MeV) of 0.874 x 10^{19} n/cm^2 after 15.5 effective full power years (EFPY) of plant operation.

- Irradiation of the reactor vessel lower shell plate B2803-3 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 191.6°F and an irradiated 50 ft-lb transition temperature of 223.8°F. This results in a 30 ft-lb transition temperature increase of 159.6°F and a 50 ft-lb transition temperature increase of 161.7°F for the longitudinal oriented specimens. See Table 5-9.

- Irradiation of the reactor vessel lower shell plate B2803-3 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 216.5°F and an irradiated 50 ft-lb transition temperature of 327.4°F. This results in a 30 ft-lb transition temperature increase of 158.2°F and a 50 ft-lb transition temperature increase of 217.9°F for the longitudinal oriented specimens. See Table 5-9.

- Irradiation of the weld metal (*heat number W5214*) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 128.5°F and an irradiated 50 ft-lb transition temperature of 196.8°F. This results in a 30 ft-lb transition temperature increase of 193.2°F and a 50 ft-lb transition temperature increase of 242.8°F. See Table 5-9.

- Irradiation of the reactor vessel intermediate shell plate B2802-2 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 98.1°F and an irradiated 50 ft-lb transition temperature of 145.0°F. This results in a 30 ft-lb transition temperature increase of 152.6°F and a 50 ft-lb transition temperature increase of 166.5°F for the longitudinal oriented specimens. See Table 5-9.

- The average upper shelf energy of the lower shell plate B2803-3 (longitudinal orientation) resulted in an average energy decrease of 24 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 lower shell plate B2803-3 (transverse orientation) resulted in an average energy decrease of 16 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 52 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 46 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 74 ft-lb for the weld metal specimens. See Table 5-9.

- The average upper shelf energy of the intermediate shell plate B2802-2 (longitudinal orientation) resulted in an average energy decrease of 20 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 105 ft-lb for the longitudinal oriented specimens. See Table 5-9.

- A comparison, as presented in Table 5-10, of the Indian Point Unit 3 reactor vessel surveillance material test results with the Regulatory Guide 1.99, Revision 2[1] predictions led to the following conclusions:

  - The measured 30 ft-lb shift in transition temperature values of the lower shell plate B2803-3 contained in capsule X (longitudinal & transverse) 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.

  - The measured 30 ft-lb shift in transition temperature value of the weld metal contained in capsule X is less than the Regulatory Guide 1.99, Revision 2, prediction.

  - The measured 30 ft-lb shift in transition temperature values of the intermediate shell plate B2802-2 contained in capsule X (longitudinal) is greater than the Regulatory Guide 1.99, Revision 2, prediction. However, the shift value is less than the two sigma allowance by Regulatory Guide 1.99, Revision 2.

  - The measured percent decrease in upper shelf energy for all the surveillance materials of Capsules X contained in the Indian Point Unit 3 surveillance program are in good agreement with the Regulatory Guide 1.99, Revision 2 predictions.

- All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are predicted to maintain an upper shelf energy greater than 50 ft-lb throughout the life of the vessel (27.1 EFPY) as required by 10CFR50, Appendix G [2].

- The calculated end-of-license (27.1 EFPY) neutron fluence (E> 1.0 MeV) at the core midplane for the Indian Point Unit 3 reactor vessel using the Regulatory Guide 1.99, Revision 2 attenuation formula (i.e., Equation #3 in the guide) are as follows:

<u>Calculated:</u> Vessel inner radius* = 9.22×10^{18} n/cm^2

Vessel 1/4 thickness = 5.50×10^{18} n/cm^2

Vessel 3/4 thickness = 1.95×10^{18} n/cm^2

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

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 Indian Point Unit 3 reactor pressure vessel materials under actual operating conditions.

The surveillance program for the Indian Point Unit 3 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-8475, "Consolidated Edison Co. of New York Indian Point Unit No. 3 Reactor Vessel Radiation Surveillance Program"[3]. The surveillance program was planned to cover the 40-year design life of the reactor pressure vessel and was based on ASTM E185-62, "Recommended Practice for Surveillance Tests on Structural Materials for Nuclear Reactors." Capsule X was removed from the reactor after 15.5 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 Indian Point Unit 3 reactor vessel and discusses the analysis of the data.

3 BACKGROUND

The ability of the large steel pressure vessel containing the reactor core and its primary coolant to resist fracture constitutes an important factor in ensuring safety in the nuclear industry. The beltline region of the reactor pressure vessel is the most critical region of the vessel because it is subjected to significant fast neutron bombardment. The overall effects of fast neutron irradiation on the mechanical properties of low alloy, ferritic pressure vessel steels such as SA302 Grade B Modified (base material of the Indian Point Unit 3 reactor pressure vessel beltline) are well documented in the literature. Generally, low alloy ferritic materials show an increase in hardness and tensile properties and a decrease in ductility and toughness during high-energy irradiation.

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

RT_{NDT} is defined as the greater of either the drop weight nil-ductility transition temperature (NDTT per ASTM E-208[7]) or the temperature 60°F less than the 50 ft-lb (and 35-mil lateral expansion) temperature as determined from Charpy specimens oriented perpendicular (transverse) to the major 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[8]. 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 Indian Point Unit 3 reactor vessel radiation surveillance program[3], in which a surveillance capsule is periodically removed from the operating nuclear reactor and the encapsulated specimens tested. The increase in the average Charpy V-notch 30 ft-lb temperature (ΔRT_{NDT}) due to irradiation is added to the initial RT_{NDT}, 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

Eight surveillance capsules for monitoring the effects of neutron exposure on the Indian Point Unit 3 reactor pressure vessel core region (beltline) materials were inserted in the reactor vessel prior to initial plant start-up. The eight capsules were positioned in the reactor vessel between the thermal shield and the vessel wall as shown in Figure 4-1. The vertical center of the capsules is opposite the vertical center of the core.

Capsule X was removed after 15.5 effective full power years (EFPY) of plant operation. This capsule contained Charpy V-notch, tensile, and Wedge Opening Loading (WOL) specimens as shown in Figure 4-2, which were made from intermediate shell plate B2802-2 (longitudinal). In addition this capsule contains Charpy V-notch and tensile specimens, also shown on Figure 4-2, made from lower shell plate B2803-3 (longitudinal & transverse) and submerged arc weld metal.

Test material obtained from the intermediate and lower shell plates (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, whereas the weld metal specimens were machined at various locations thru the weld thickness.

Charpy V-notch impact specimens from the intermediate shell plate B2802-2 and the lower shell plate B2803-3 were machined in the longitudinal orientation (longitudinal axis of the specimen parallel to the major working direction). In addition, Charpy V-notch impact specimens from the lower shell plate B2803-3 were also in the transverse orientation (longitudinal axis of the specimen perpendicular to the major working direction). The core region weld Charpy impact specimens were machined from the weldment such that the long dimension of each Charpy specimen was perpendicular to the weld direction. The notch of the weld metal Charpy specimens was machined such that the direction of crack propagation in the specimen was in the welding direction.

Tensile specimens from the intermediate shell plate B2802-2 and the lower shell plate B2803-3 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 only contained tensile specimens from the intermediate shell plate B2802-2 and lower shell plate B2803-3, both in the longitudinal orientation.

WOL test specimens from intermediate shell plate B2802-2 were machined in the longitudinal orientation so that the loading of the specimen would be in the longitudinal direction of the plate with the simulated crack propagation in the transverse direction. All specimens were fatigue pre-cracked according to ASTM E399-70T.

The chemical composition and heat treatment of the unirradiated surveillance materials are presented in Tables 4-1 and 4-2, respectively. The data in Table 4-1 and 4-2 was obtained from the surveillance capsule Z test report, WCAP-11815.

Capsule X contained dosimeter wires of pure iron, copper, nickel, and aluminum-0.15 weight percent cobalt (cadmium-shielded and unshielded).

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 Indian Point Unit 3 Reactor Vessel Surveillance Materials (Unirradiated)[a]

Element	Intermediate Shell Plate			Lower Shell Plate	Weld Metal [b]
	B2802-1	B2802-2	B2802-3	B2803-3	
C	0.22	0.19	0.20	0.22	0.08
Mn	1.41	1.33	1.32	1.30	1.18
P	0.010	0.015	0.011	0.012	0.019
S	0.023	0.019	0.025	0.024	0.016
Si	0.28	0.21	0.26	0.28	0.17
Ni	0.50	0.53	0.49	0.52	1.02 (1.21)[c]
Cr	0.08	0.09	0.08	0.08	0.04
Mo	0.46	0.48	0.50	0.45	0.53
Cu	0.18	0.20	0.19	0.24	0.15 (0.166)[c]
Al	0.036	0.027	0.042	0.03	<0.01
V	<0.01	<0.01	<0.01	<0.01	<0.01
Sn	0.014	0.017	0.014	<0.01	0.007
Cb	<0.01	<0.01	<0.01	<0.01	<0.01
Zr	<0.01	<0.01	<0.01	<0.01	<0.01
Ti	<0.01	<0.01	<0.01	<0.01	<0.01

Notes:

(a) Data obtained from WCAP-11815 and duplicated herein for completeness.

(b) Weld wire Heat Number W5214, Flux Type Linde 1092, and Flux Lot Number 3692. Surveillance weldment has the same heat and flux as the nozzle shell longitudinal weld seams 1-042A, B & C.

(c) Results of chemical analysis performed on irradiated Charpy V-notch Specimen W-15 from Capsule Y.

Table 4-2 Heat Treatment History of the Indian Point Unit 3 Reactor Vessel Surveillance Materials[a]

Material	Temperature (°F)	Time	Coolant
Shell Plates	1550 to 1650	4 hrs.	Water-Quench
	1225	4 hrs.	Air-cooled
	1125 to 1175	40 hrs.	Furnace Cooled
Weld Metal (*Heat # W5214*)	1125 to 1175	40 hrs.	Furnace Cooled

Notes:
(a) Data obtained from WCAP-11815 and duplicated herein for completeness.

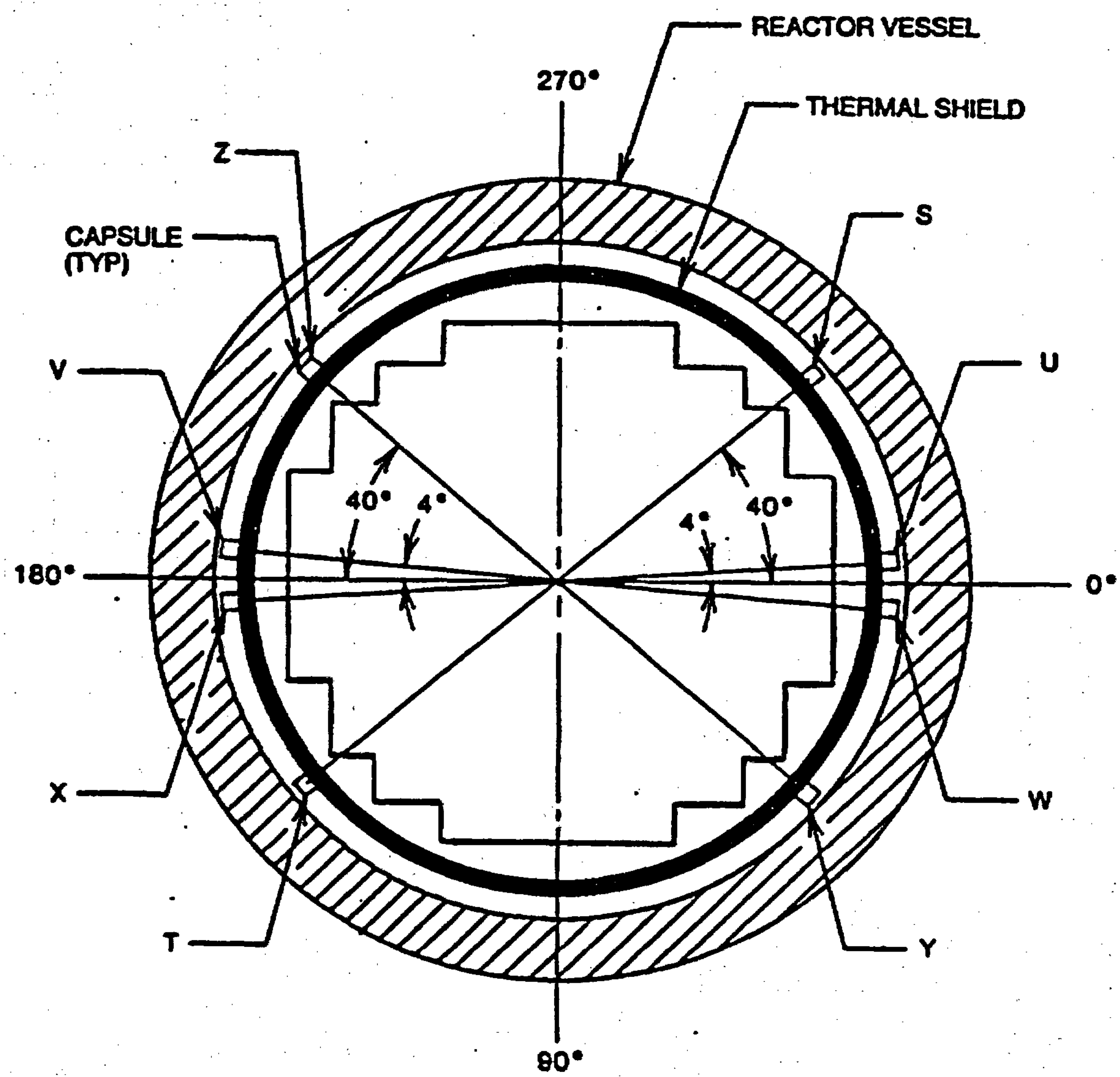


Figure 4-1 Arrangement of Surveillance Capsules in the Indian Point Unit 3 Reactor Vessel

LEGEND: A - LOWER SHELL PLATE B2803-3 (LONGITUDINAL)
AT - LOWER SHELL PLATE B2803-3 (TANGENTIAL)
W - WELD METAL (HEAT # W5214)
N - INTERMEDIATE SHELL PLATE B2802-2 (LONGITUDINAL)

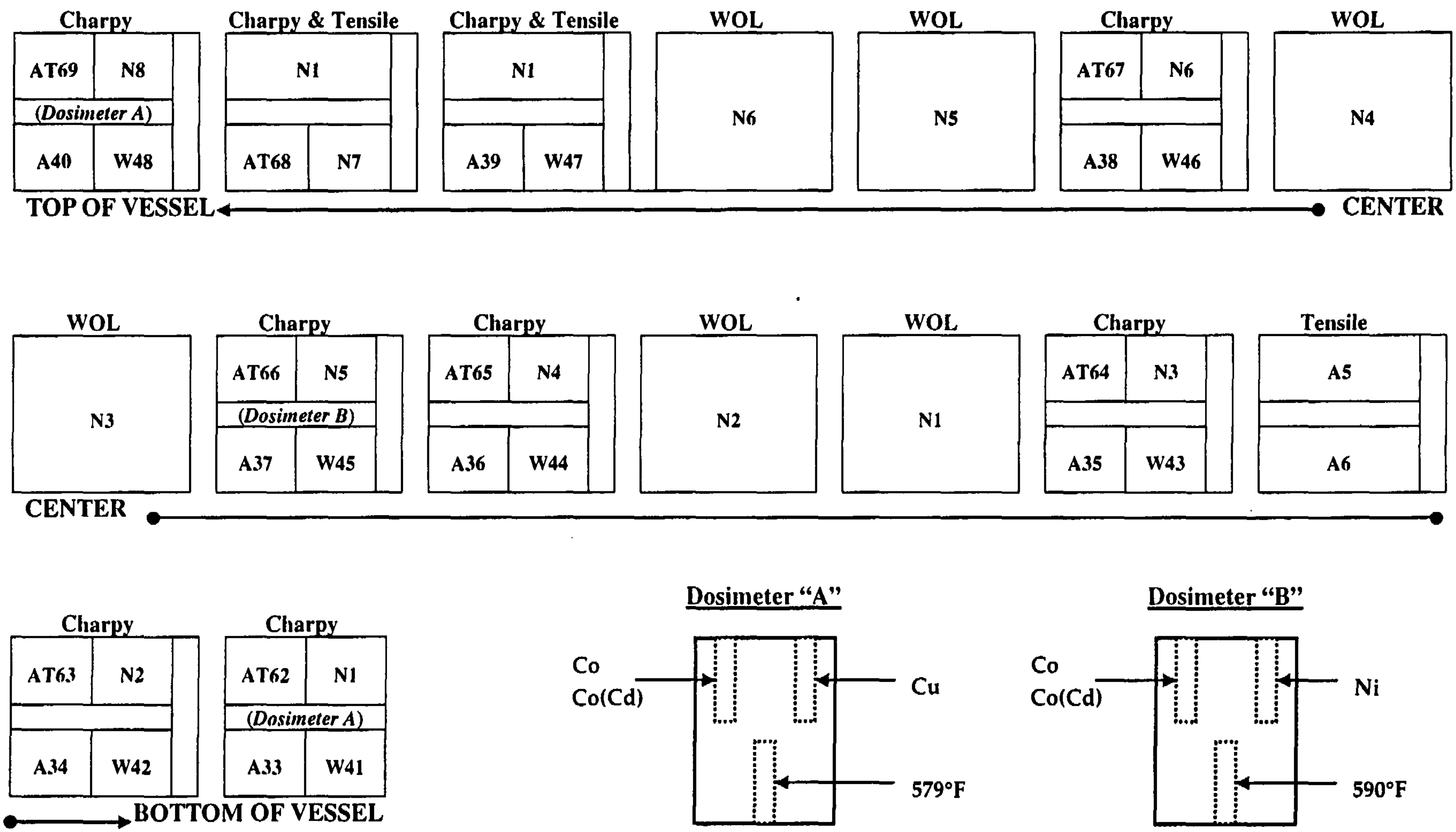


Figure 4-2 Capsule X Diagram Showing The Location of Specimens, Thermal Monitors, and Dosimeters

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[2], ASTM Specification E185-82[9], and Westinghouse Procedure RMF 8402[10], Revision 2 as modified by Westinghouse RMF Procedures 8102[11], Revision 1, and 8103[12], Revision 1.

Upon receipt of the capsule at the hot cell laboratory, the specimens and spacer blocks were carefully removed, inspected for identification number, and checked against the master list in WCAP-8475[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[13] and RMF Procedure 8103 on a Tinius-Olsen Model 74, 358J machine. The tup (striker) of the Charpy impact test machine is instrumented with a GRC 930-I instrumentation system, feeding information into an IBM compatible computer. With this system, load-time and energy-time signals can be recorded in addition to the standard measurement of Charpy energy (E_D). From the load-time curve (Appendix 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 4, 5, and 6 of Tables 5-5 through 5-8 is the cross-section area under the notch of the Charpy specimens:

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

Percent shear was determined from post-fracture photographs using the ratio-of-areas methods in compliance with ASTM Specification E23-02a[13] and A370-97a[14]. 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 E8-01 [15] and E21-92 (1998)[16], and Procedure RMF 8102. 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[17].

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

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

5.2 CHARPY V-NOTCH IMPACT TEST RESULTS

The results of the Charpy V-notch impact tests performed on the various materials contained in Capsule X, which received a fluence of 0.874 x 10^{19} n/cm^2(E> 1.0 MeV) in 15.5 EFPY of operation, are presented in Tables 5-1 through 5-11 and are compared with unirradiated results[4] 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 lower shell plate B2803-3 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 191.6°F and an irradiated 50 ft-lb transition temperature of 223.8°F. This results in a 30 ft-lb transition temperature increase of 159.6°F and a 50 ft-lb transition temperature increase of 161.7°F for the longitudinal oriented specimens. See Table 5-9.

Irradiation of the reactor vessel lower shell plate B2803-3 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 216.5°F and an irradiated 50 ft-lb transition temperature of 327.4°F. This results in a 30 ft-lb transition temperature increase of 158.2°F and a 50 ft-lb transition temperature increase of 217.9°F for the longitudinal oriented specimens. See Table 5-9.

Irradiation of the weld metal (*heat number W5214*) Charpy specimens resulted in an irradiated 30 ft-lb transition temperature of 128.5°F and an irradiated 50 ft-lb transition temperature of 196.8°F. This results in a 30 ft-lb transition temperature increase of 193.2°F and a 50 ft-lb transition temperature increase of 242.8°F. See Table 5-9.

Irradiation of the reactor vessel intermediate shell plate B2802-2 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 98.1°F and an irradiated 50 ft-lb transition temperature of 145.0°F. This results in a 30 ft-lb transition temperature increase of 152.6°F and a 50 ft-lb transition temperature increase of 166.5°F for the longitudinal oriented specimens. See Table 5-9.

The average upper shelf energy of the lower shell plate B2803-3 (longitudinal orientation) resulted in an average energy decrease of 24 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 lower shell plate B2803-3 (transverse orientation) resulted in an average energy decrease of 16 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 52 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 46 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 74 ft-lb for the weld metal specimens. See Table 5-9.

The average upper shelf energy of the intermediate shell plate B2802-2 (longitudinal orientation) resulted in an average energy decrease of 20 ft-lb after irradiation. This results in an irradiated average upper shelf energy of 105 ft-lb for the longitudinal oriented specimens. See Table 5-9.

A comparison, as presented in Table 5-10, of the Indian Point Unit 3 reactor vessel surveillance material test results with the Regulatory Guide 1.99, Revision 2[1] predictions led to the following conclusions:

- The measured 30 ft-lb shift in transition temperature values of the lower shell plate B2803-3 contained in capsule X (longitudinal & transverse) 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.

- The measured 30 ft-lb shift in transition temperature value of the weld metal contained in capsule X is less than the Regulatory Guide 1.99, Revision 2, predictions

- The measured 30 ft-lb shift in transition temperature values of the intermediate shell plate B2802-2 contained in capsule X (longitudinal) is greater than the Regulatory Guide 1.99, Revision 2, prediction. However, the shift value is less than the two sigma allowance by Regulatory Guide 1.99, Revision 2.

- The measured percent decrease in upper shelf energy for all the surveillance materials of Capsules X contained in the Indian Point Unit 3 surveillance program are in good agreement with the Regulatory Guide 1.99, Revision 2 predictions.

All beltline materials exhibit a more than adequate upper shelf energy level for continued safe plant operation and are predicted to maintain an upper shelf energy greater than 50 ft-lb throughout the extended life of the vessel (27.1 EFPY) as required by 10CFR50, Appendix G [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-8475[3], WCAP-9491[4], WCAP-10300[5], and WCAP-11815[6] were based on hand-fit Charpy curves using engineering judgment. However, the results presented in this report are based on a re-plot of all applicable capsule data using CVGRAPH, Version 5.0.2, which is a hyperbolic tangent curve-fitting program. This report also shows the composite plots that show the results from the previous capsule. Appendix C presents the CVGRAPH, Version 5.02, 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 0.874×10^{19} n/cm^2 (E> 1.0 MeV) are presented in Table 5-11 and are compared with unirradiated results[3] as shown in Figures 5-17 and 5-18.

The results of the tensile tests performed on the lower Shell Plate B2803-3 (longitudinal orientation) indicated that irradiation to 0.874×10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 21 to 23 ksi increase in the 0.2 percent offset yield strength and approximately a 18 to 23 ksi increase in the ultimate tensile strength when compared to unirradiated data[3]. See Figure 5-17.

The results of the tensile tests performed on the intermediate Shell Plate B2802-2 (longitudinal orientation) indicated that irradiation to 0.874×10^{19} n/cm^2 (E> 1.0 MeV) caused approximately a 19 ksi increase in the 0.2 percent offset yield strength and approximately a 17 ksi increase in the ultimate tensile strength when compared to unirradiated data[3]. See Figure 5-18.

The fractured tensile specimens for the lower shell plate B2803-3 and intermediate shell plate B2802-2 material are shown in Figures 5-19 and 5-20. The engineering stress-strain curves for the tensile tests are shown in Figures 5-21 and 5-22.

5.4 WEDGE OPENING LOADING SPECIMEN TESTS

Per the surveillance capsule testing contract, the Wedge Opening Loading 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 Indian Point Unit 3 Lower Shell Plate B2803-3 Irradiated to a Fluence of 0.874 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**	**%**
A37	100	38	7	9	2	0.05	10
A34	150	66	21	28	14	0.36	15
A36	175	79	22	30	15	0.38	20
A33	200	93	27	37	18	0.46	40
A40	225	107	51	69	36	0.91	70
A39	280	138	82	111	59	1.50	100
A35	350	177	78	106	57	1.45	100
A38	375	191	83	113	68	1.73	100

Table 5-2 Charpy V-notch Data for the Indian Point Unit 3 Lower Shell Plate B2803-3 Irradiated to a Fluence of 0.874 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	%
AT64	100	38	6	8	0	0.00	15
AT69	175	79	20	27	14	0.36	25
AT68	210	99	22	30	14	0.36	30
AT67	225	107	33	45	25	0.64	60
AT66	250	121	44	60	34	0.86	95
AT65	325	163	47	64	38	0.97	100
AT62	375	191	54	73	45	1.14	100
AT63	390	199	55	75	45	1.14	100

Table 5-3 Charpy V-notch Data for the Indian Point Unit 3 Surveillance Weld Metal Irradiated to a Fluence of 0.874 x 10^{19} n/cm^2 (E> 1.0 MeV)							
Sample	**Temperature**		**Impact Energy**		**Lateral Expansion**		**Shear**
Number	**°F**	**°C**	**ft-lbs**	**Joules**	**mils**	**mm**	**%**
W42	75	24	9	12	5	0.13	20
W41	125	52	49	66	36	0.91	50
W43	125	52	24	33	19	0.48	40
W48	150	66	35	47	26	0.66	45
W47	200	93	37	50	30	0.76	70
W44	250	121	67	91	52	1.32	95
W45	300	149	72	98	56	1.42	98
W46	350	177	75	102	57	1.45	100

Table 5-4 Charpy V-notch Data for the Indian Point Unit 3 Intermediate Shell Plate B2802-2 Irradiated to a Fluence of 0.874 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	%
N2	25	-4	8	11	3	0.08	5
N6	75	24	24	33	14	0.36	15
N5	125	52	59	80	40	1.02	30
N7	150	66	40	54	30	0.76	55
N4	200	93	58	79	44	1.12	65
N1	250	121	104	141	69	1.75	100
N8	300	149	105	142	71	1.80	100
N3	325	163	105	142	68	1.73	100

Table 5-5 Instrumented Charpy Impact Test Results for the Indian Point Unit 3 Lower Shell Plate B2803-3 Irradiated to a Fluence of 0.874×10^{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)
A37	100	7	56	19	37	2108	0.11	2304	0.13	2304	363	70	73
A34	150	21	169	68	101	3363	0.14	4187	0.22	4047	372	112	126
A36	175	22	177	68	110	3336	0.14	4173	0.22	4090	609	111	125
A33	200	27	218	65	152	3311	0.14	4061	0.22	3913	1082	110	123
A40	225	51	411	226	185	3331	0.14	4567	0.50	4529	2496	111	132
A39	280	82	661	236	425	3336	0.14	4671	0.51	n/a	n/a	111	133
A35	350	78	628	225	403	3176	0.14	4480	0.51	n/a	n/a	106	127
A38	375	83	669	222	447	3165	0.14	4344	0.51	n/a	n/a	105	125

Table 5-6 Instrumented Charpy Impact Test Results for the Indian Point Unit 3 Lower Shell Plate B2803-3 Irradiated to a Fluence of 0.874×10^{19} n/cm² (E>1.0 MeV) (Transverse Orientation)

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)
AT64	100	6	48	14	34	1416	0.09	1672	0.12	1659	455	47	51
AT69	175	20	161	68	93	3310	0.14	4149	0.22	4090	683	110	124
AT68	210	22	177	67	110	3407	0.15	4091	0.22	3927	987	113	125
AT67	225	33	266	66	200	3380	0.14	4113	0.21	4017	2273	113	125
AT66	250	44	355	162	193	3091	0.14	4136	0.41	3999	2397	103	120
AT65	325	47	379	143	236	3089	0.13	4027	0.37	3853	1829	103	118
AT62	375	54	435	162	274	2969	0.13	4063	0.41	n/a	n/a	99	117
AT63	390	55	443	148	295	3028	0.13	4080	0.38	n/a	n/a	101	118

Table 5-7 Instrumented Charpy Impact Test Results for the Indian Point Unit 3 Surveillance Weld Metal Irradiated to a Fluence of 0.874×10^{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)
W42	75	9	73	36	36	3426	0.14	3696	0.16	3687	0	114	119
W41	125	49	395	226	169	3411	0.15	4363	0.52	4288	617	114	129
W43	125	24	193	68	126	3341	0.14	4109	0.22	4058	1313	111	124
W48	150	35	282	184	98	3416	0.14	4449	0.42	4417	1141	114	131
W47	200	37	298	150	148	3371	0.14	4260	0.37	4222	1713	112	127
W44	250	67	540	227	313	3486	0.14	4432	0.50	4251	2819	116	132
W45	300	72	580	218	362	3329	0.14	4303	0.50	3029	2501	111	127
W46	350	75	604	221	383	3285	0.14	4309	0.51	n/a	n/a	109	126

Table 5-8 Instrumented Charpy Impact Test Results for the Indian Point Unit 3 Intermediate Shell Plate B2802-2 Irradiated to a Fluence of 0.874 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)
N2	25	8	64	35	29	3649	0.15	3761	0.16	3761	0	121	123
N6	75	24	193	146	47	3388	0.14	4306	0.36	4303	0	113	128
N5	125	59	475	327	148	3470	0.15	4594	0.68	4444	687	116	134
N7	150	40	322	185	138	3292	0.14	4338	0.44	4332	1570	110	127
N4	200	58	467	231	237	3239	0.14	4423	0.53	4369	2112	108	128
N1	250	104	838	311	527	3193	0.15	4446	0.68	n/a	n/a	106	127
N8	300	105	846	312	534	3272	0.14	4494	0.67	n/a	n/a	109	129
N3	325	105	846	302	544	3068	0.14	4374	0.67	n/a	n/a	102	124

Table 5-9 Effect of Irradiation to 0.874 x 10^{19} n/cm^2 (E>1.0 MeV) on the Capsule "X" Notch Toughness Properties of the Indian Point Unit 3 Reactor Vessel Surveillance Materials[c]

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
Lower Shell Plate B2803-3 (Long.)	32.0	191.6	159.6	48.6	225.0	176.4	62.1	223.8	161.7	105	81	-24
Lower Shell Plate B2803-3 (Trans.)	58.3	216.5	158.2	75.3	269.3	194.0	109.5	327.4	217.9	68	52	-16
Weld Metal (Heat # W5214)	-64.7	128.5	193.2	-59.3	184.6	243.9	-46.0	196.8	242.8	120	74	-46
Inter. Shell Plate B2802-2 (Long.)	-54.5	98.1	152.6	-38.6	147.3	185.9	-21.5	145.0	166.5	125	105	-20

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 Indian Point Unit 3 Surveillance Material 30 ft-lb Transition Temperature Shifts and Upper Shelf Energy Decreases with Regulatory Guide 1.99, Revision 2, Predictions

Material	Capsule	Fluence[(d)] (x 10^{19} n/cm², E > 1.0 MeV)	30 ft-lb Transition Temperature Shift		Upper Shelf Energy Decrease	
			Predicted (°F) [(a)]	Measured (°F) [(b)]	Predicted (%) [(a)]	Measured (%)[(c)]
Lower Shell Plate	T	0.263	101.9	139.4	24	12
B2803-3	Z	1.04	161.6	167.8	33.5	22
(*Longitudinal*)	X	0.874	153.9	159.6	32	23
Lower Shell Plate	T	0.263	101.9	105.9	24	16
B2803-3	Y	0.692	143.5	148.9	30	25
	Z	1.04	161.6	157.9	33.5	18
(*Transverse*)	X	0.874	153.9	158.2	32	24
Surveillance	T	0.263	131.3	151.6	22	30
Program	Y	0.692	185.0	172.0	27	43
Weld Metal	Z	1.04	208.3	229.2	31	37
	X	0.874	198.4	193.2	29	38
Intermediate Shell Plate B2802-2 (*Longitudinal*)	X	0.874	146.2	152.6	30	16

Notes:

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

(b) Calculated using measured Charpy data plotted using CVGRAPH, Version 5.0.2 (See Appendix C)

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

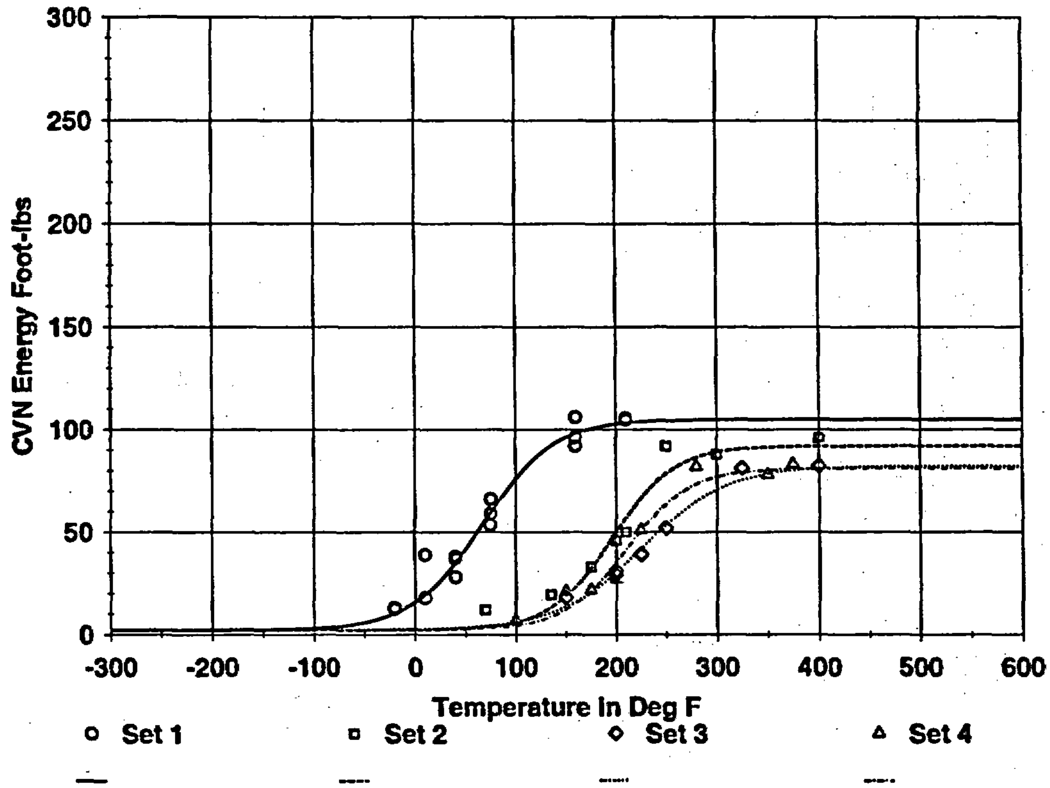
(d) The fluence values presented here are the calculated values, not the best estimate values.

Table 5-11 Tensile Properties of the Indian Point Unit 3 Capsule X Reactor Vessel Surveillance Materials Irradiated to 0.874 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 (%)**
Lower Shell Plate B2803-3 (Long.)	A5	250	81.7	101.0	3.68	147.8	74.9	11.3	21.4	49
	A6	550	75.4	100.0	3.90	149.7	79.5	10.5	18.6	47
Inter. Shell Plate B2802-2 (Long.)	N1	225	73.3	90.2	2.98	165.7	60.6	11.3	22.4	63

LOWER SHELL PLATE B2803-3 (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:43 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Indian Point 3	UNIRR	SA302B	LT	A-0512-2
2	Indian Point 3	T	SA302B	LT	A-0512-2
3	Indian Point 3	Z	SA302B	LT	A-0512-2
4	Indian Point 3	X	SA302B	LT	A-0512-2



Results

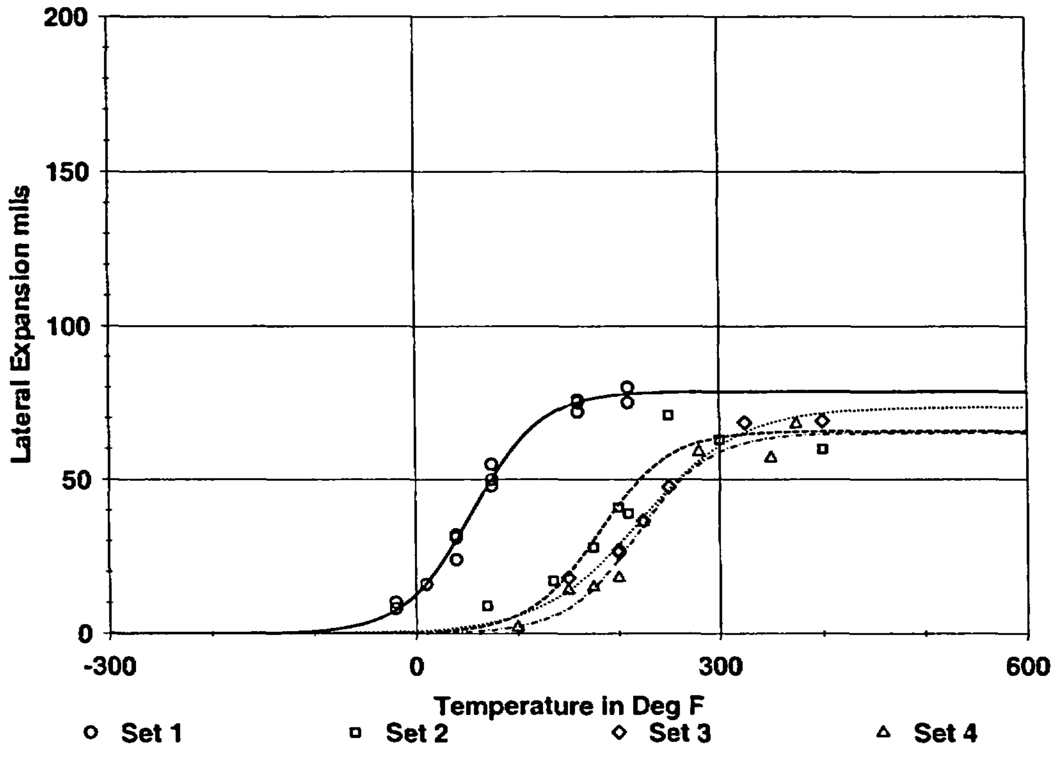
Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	105.0	.0	32.0	.0	62.1	.0
2		2.2	92.0	-13.0	171.4	139.4	200.2	138.1
3		2.2	82.0	-23.0	199.8	167.8	242.7	180.6
4		2.2	81.0	-24.0	191.6	159.6	223.8	161.7

Figure 5-1 Charpy V-Notch Impact Energy vs. Temperature for Indian Point Unit 3 Reactor Vessel Lower Shell Plate B2803-3 (Longitudinal Orientation)

LOWER SHELL PLATE B2803-3 (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:57 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Indian Point 3	UNIRR	SA302B	LT	A-0512-2
2	Indian Point 3	T	SA302B	LT	A-0512-2
3	Indian Point 3	Z	SA302B	LT	A-0512-2
4	Indian Point 3	X	SA302B	LT	A-0512-2



Results

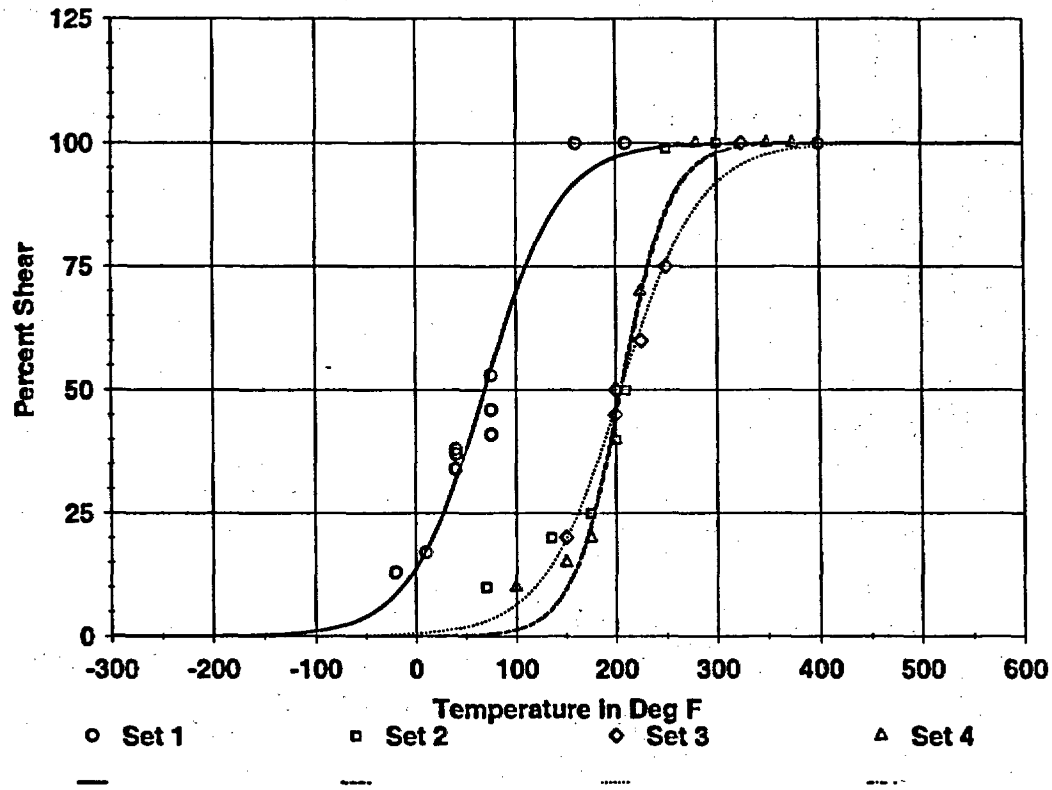
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		.0	78.7	.0	48.6	.0
2		.0	65.8	-12.9	185.4	136.8
3		.0	73.4	-5.2	218.3	169.7
4		.0	65.1	-13.5	225.0	176.4

Figure 5-2 Charpy V-Notch Lateral Expansion vs. Temperature for Indian Point Unit 3 Reactor Vessel Lower Shell Plate B2803-3 (Longitudinal Orientation)

LOWER SHELL PLATE B2803-3 (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:53 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Indian Point 3	UNIRR	SA302B	LT	A-0512-2
2	Indian Point 3	T	SA302B	LT	A-0512-2
3	Indian Point 3	Z	SA302B	LT	A-0512-2
4	Indian Point 3	X	SA302B	LT	A-0512-2



Results

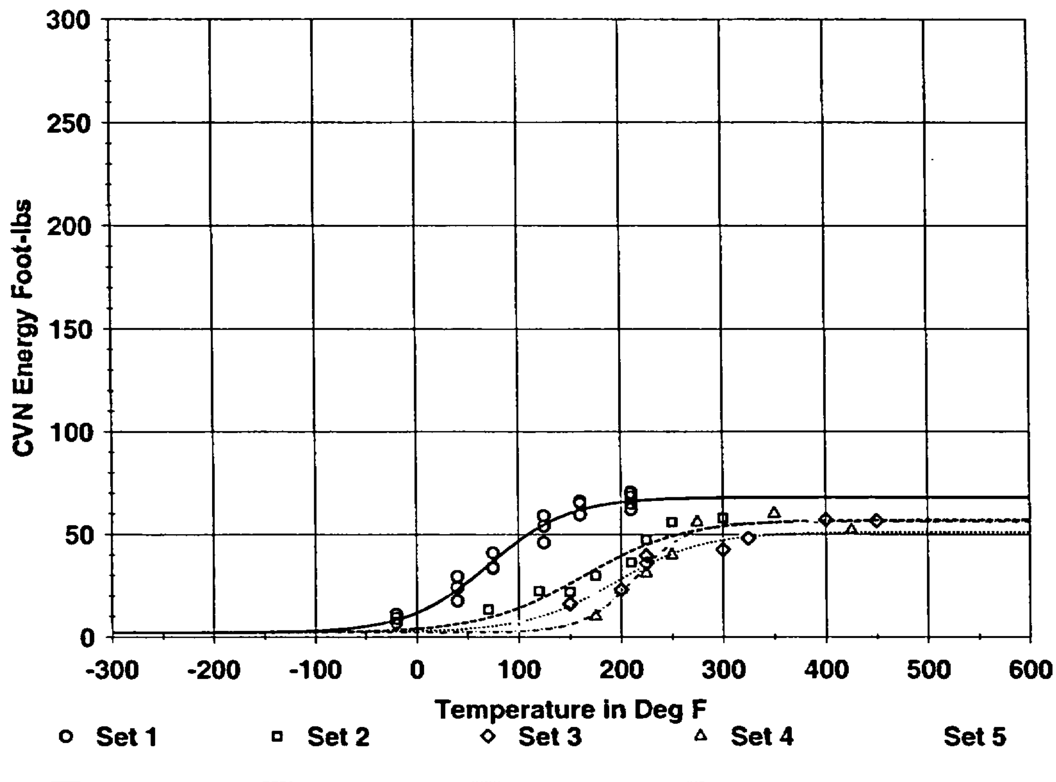
Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	68.8	.0
2		.0	100.0	.0	204.7	135.9
3		.0	100.0	.0	205.3	136.5
4		.0	100.0	.0	206.3	137.5

Figure 5-3 Charpy V-Notch Percent Shear vs. Temperature for Indian Point Unit 3 Reactor Vessel Lower Shell Plate B2803-3 (Longitudinal Orientation)

LOWER SHELL PLATE B2803-3 (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:10 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Indian Point 3	UNIRR	SA302B	TL	A-0512-2
2	Indian Point 3	T	SA302B	TL	A-0512-2
3	Indian Point 3	Y	SA302B	TL	A-0512-2
4	Indian Point 3	Z	SA302B	TL	A-0512-2
5	Indian Point 3	X	SA302B	TL	A-0512-2



Results

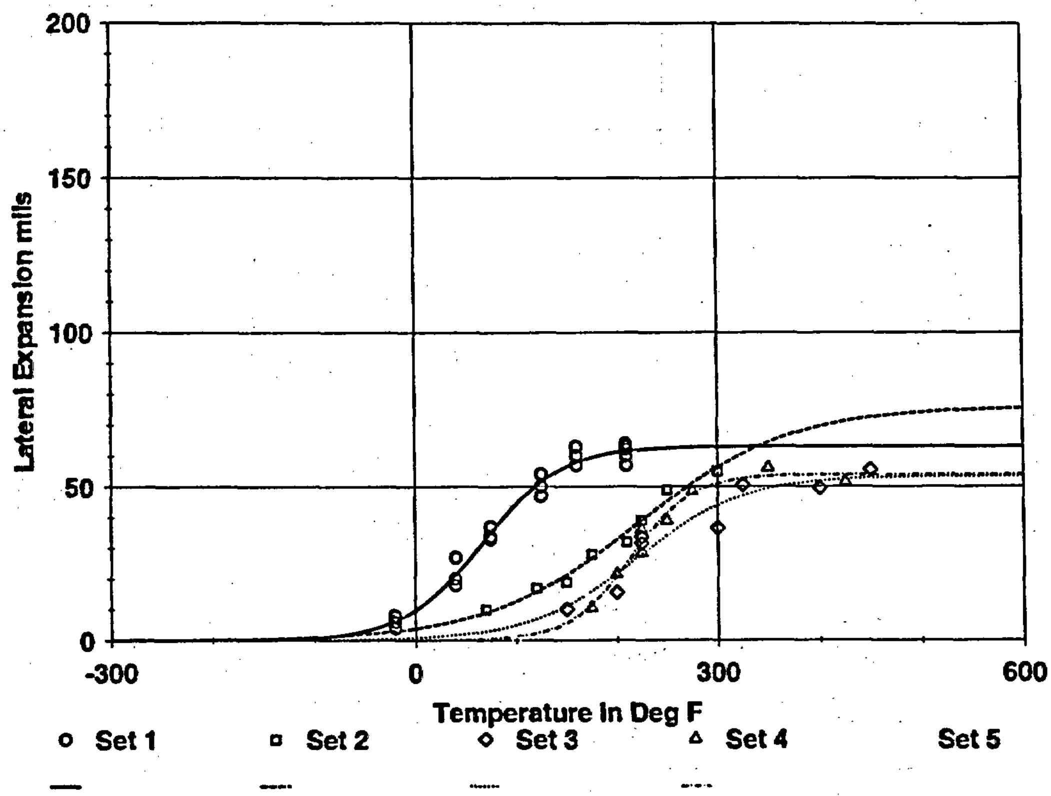
Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	68.0	.0	58.3	.0	109.5	.0
2		2.2	57.0	-11.0	164.2	105.9	256.4	146.9
3		2.2	51.0	-17.0	207.2	148.9	362.1	252.6
4		2.2	56.0	-12.0	216.2	157.9	266.7	157.2
5		2.2	52.0	-16.0	216.5	158.2	327.4	217.9

Figure 5-4 Charpy V-Notch Impact Energy vs. Temperature for Indian Point Unit 3 Reactor Vessel Lower Shell Plate B2803-3 (Transverse Orientation)

LOWER SHELL PLATE 2803-3 (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:36 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Indian Point 3	UNIRR	SA302B	TL	A-0512-2
2	Indian Point 3	T	SA302B	TL	A-0512-2
3	Indian Point 3	Y	SA302B	TL	A-0512-2
4	Indian Point 3	Z	SA302B	TL	A-0512-2
5	Indian Point 3	X	SA302B	TL	A-0512-2



Results

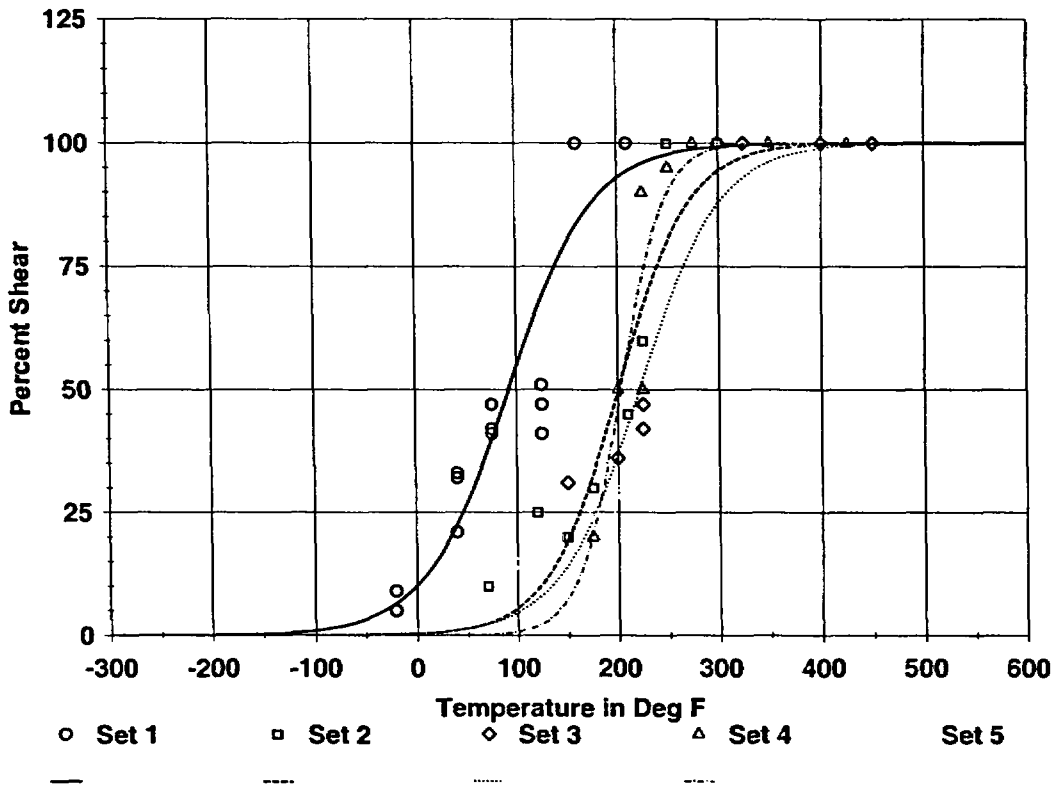
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		.0	63.1	.0	75.3	.0
2		.0	76.0	12.9	209.2	133.9
3		.0	53.3	-9.8	254.3	179.0
4		.0	53.9	-9.2	232.8	157.5
5		.0	44.4	-18.7	269.3	194.0

Figure 5-5 Charpy V-Notch Lateral Expansion vs. Temperature for Indian Point Unit 3 Reactor Vessel Lower Shell Plate B2803-3 (Transverse Orientation)

LOWER SHELL PLATE B2803-3 (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:16 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Indian Point 3	UNIRR	SA302B	TL	A-0512-2
2	Indian Point 3	T	SA302B	TL	A-0512-2
3	Indian Point 3	Y	SA302B	TL	A-0512-2
4	Indian Point 3	Z	SA302B	TL	A-0512-2
5	Indian Point 3	X	SA302B	TL	A-0512-2



Results

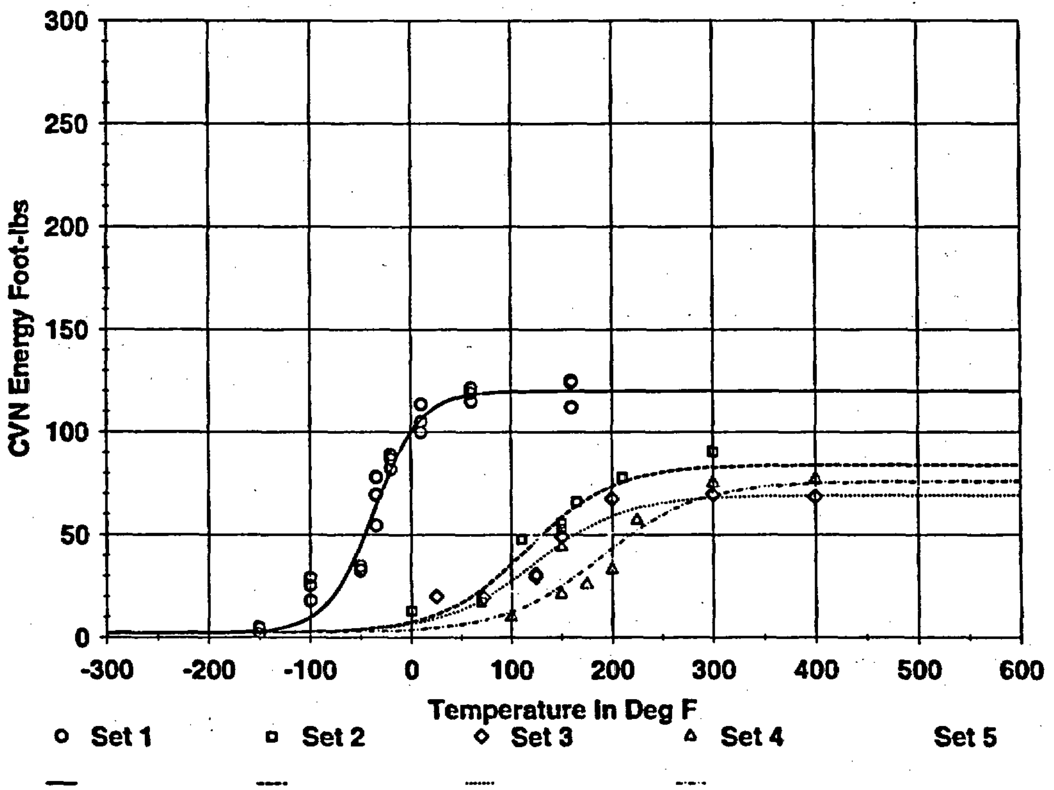
Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	92.2	.0
2		.0	100.0	.0	200.4	108.2
3		.0	100.0	.0	221.9	129.7
4		.0	100.0	.0	203.3	111.1
5		.0	100.0	.0	217.1	124.9

Figure 5-6 Charpy V-Notch Percent Shear vs. Temperature for Indian Point Unit 3 Reactor Vessel Lower Shell Plate B2803-3 (Transverse Orientation)

SURVEILLANCE WELD MATERIAL

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 02:31 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Indian Point 3	UNIRR	SAW	NA	W5214
2	Indian Point 3	T	SAW	NA	W5214
3	Indian Point 3	Y	SAW	NA	W5214
4	Indian Point 3	Z	SAW	NA	W5214
5	Indian Point 3	X	SAW	NA	W5214



Results

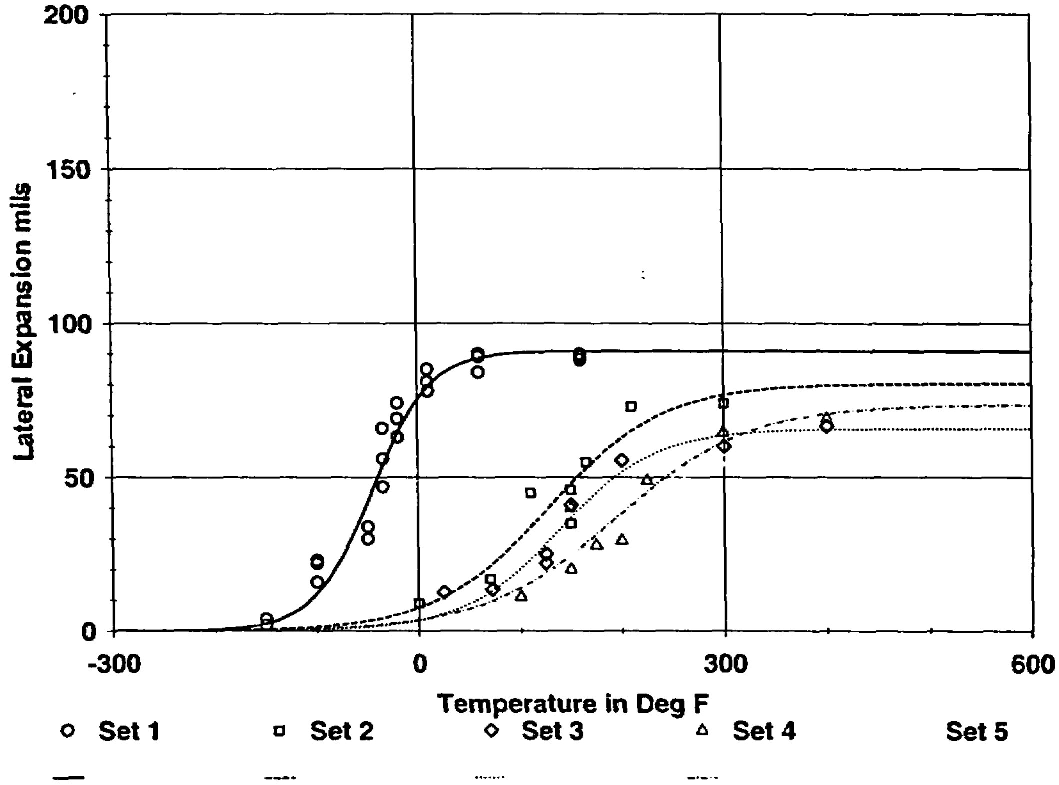
Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	120.0	.0	-64.7	.0	-46.0	.0
2		2.2	84.0	-36.0	86.9	151.6	130.6	176.6
3		2.2	69.0	-51.0	107.3	172.0	164.2	210.2
4		2.2	76.0	-44.0	164.5	229.2	218.7	264.7
5		2.2	74.0	-46.0	128.5	193.2	196.8	242.8

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

SURVEILLANCE WELD MATERIAL

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:11 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Indian Point 3	UNIRR	SAW	NA	W5214
2	Indian Point 3	T	SAW	NA	W5214
3	Indian Point 3	Y	SAW	NA	W5214
4	Indian Point 3	Z	SAW	NA	W5214
5	Indian Point 3	X	SAW	NA	W5214



Results

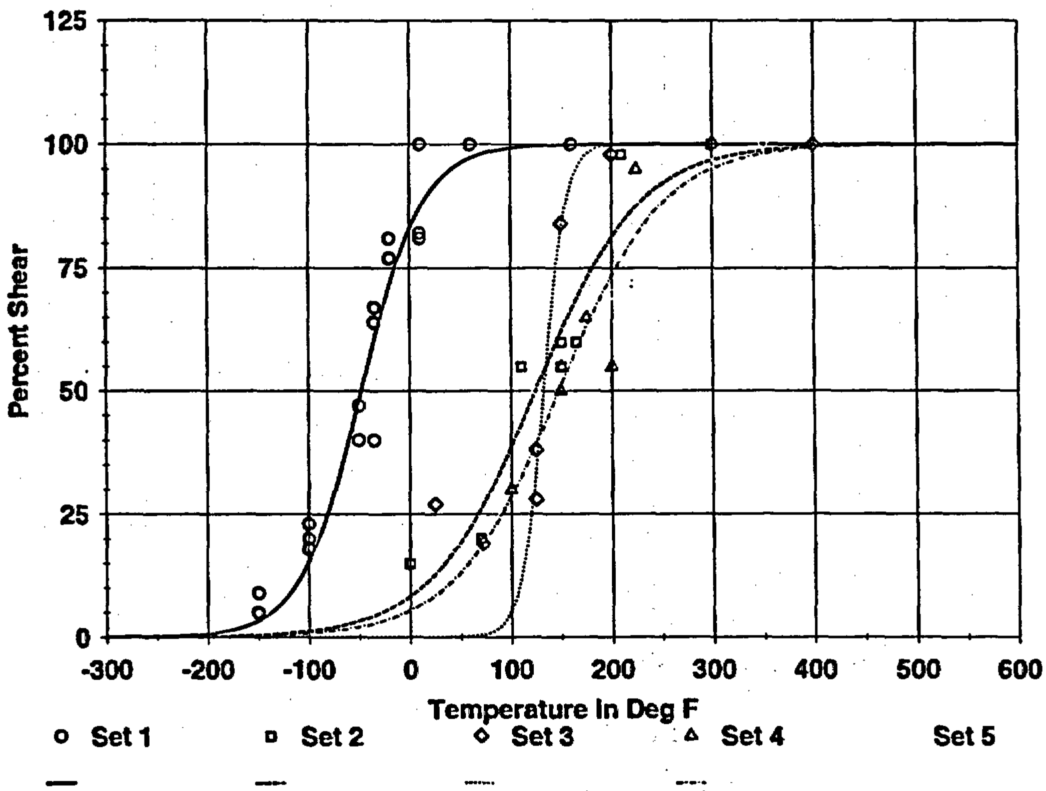
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		.0	90.8	.0	-59.3	.0
2		.0	80.3	-10.5	113.3	172.6
3		.0	65.6	-25.2	145.0	204.3
4		.0	73.5	-17.3	187.8	247.1
5		.0	62.1	-28.7	184.6	243.9

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

SURVEILLANCE WELD MATERIAL

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 03:57 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Indian Point 3	UNIRR	SAW	NA	W5214
2	Indian Point 3	T	SAW	NA	W5214
3	Indian Point 3	Y	SAW	NA	W5214
4	Indian Point 3	Z	SAW	NA	W5214
5	Indian Point 3	X	SAW	NA	W5214



Results

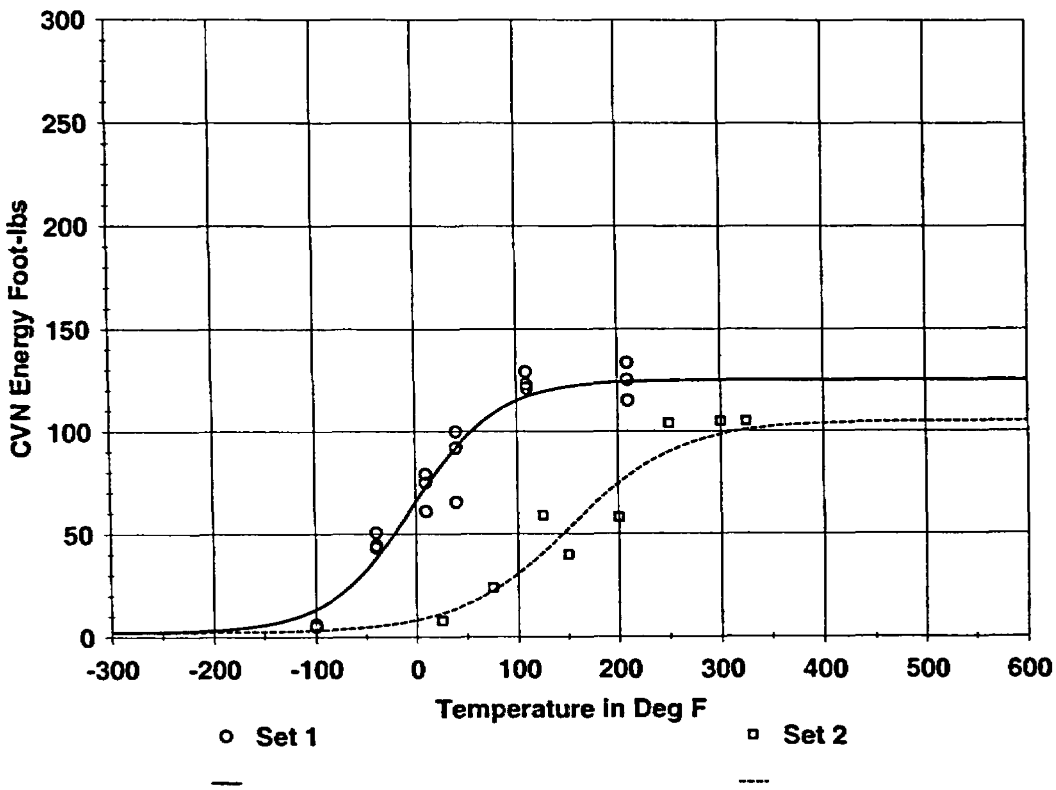
Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	-47.8	.0
2		.0	100.0	.0	124.0	171.8
3		.0	100.0	.0	132.6	180.4
4		.0	100.0	.0	147.5	195.3
5		.0	100.0	.0	144.5	192.3

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

INTERMEDIATE SHELL PLATE B2802-2 (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:42 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Indian Point 3	UNIRR	SA302B	LT	A-0516-2
2	Indian Point 3	X	SA302B	LT	A-0516-2



Results

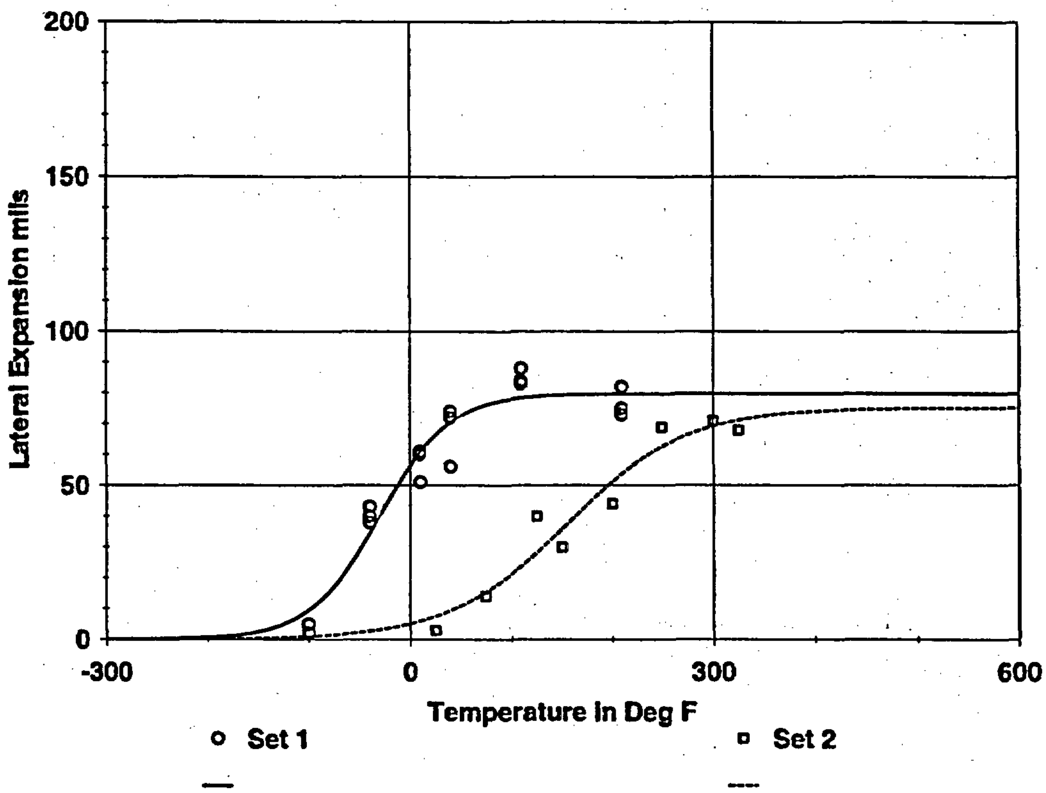
Curve	Fluence	LSE	USE	d-USE	T @30	d-T @30	T @50	d-T @50
1		2.2	125.0	.0	-54.5	.0	-21.5	.0
2		2.2	105.0	-20.0	98.1	152.6	145.0	166.5

Figure 5-10 Charpy V-Notch Impact Energy vs. Temperature for Indian Point Unit 3 Reactor Vessel Intermediate Shell Plate B2802-2 (Longitudinal)

INTERMEDIATE SHELL PLATE B2802-2 (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:48 PM
Data Set(s) Plotted

Curve	Plant	Capsule	Material	Ori.	Heat #
1	Indian Point 3	UNIRR	SA302B	LT	A-0516-2
2	Indian Point 3	X	SA302B	LT	A-0516-2



Results

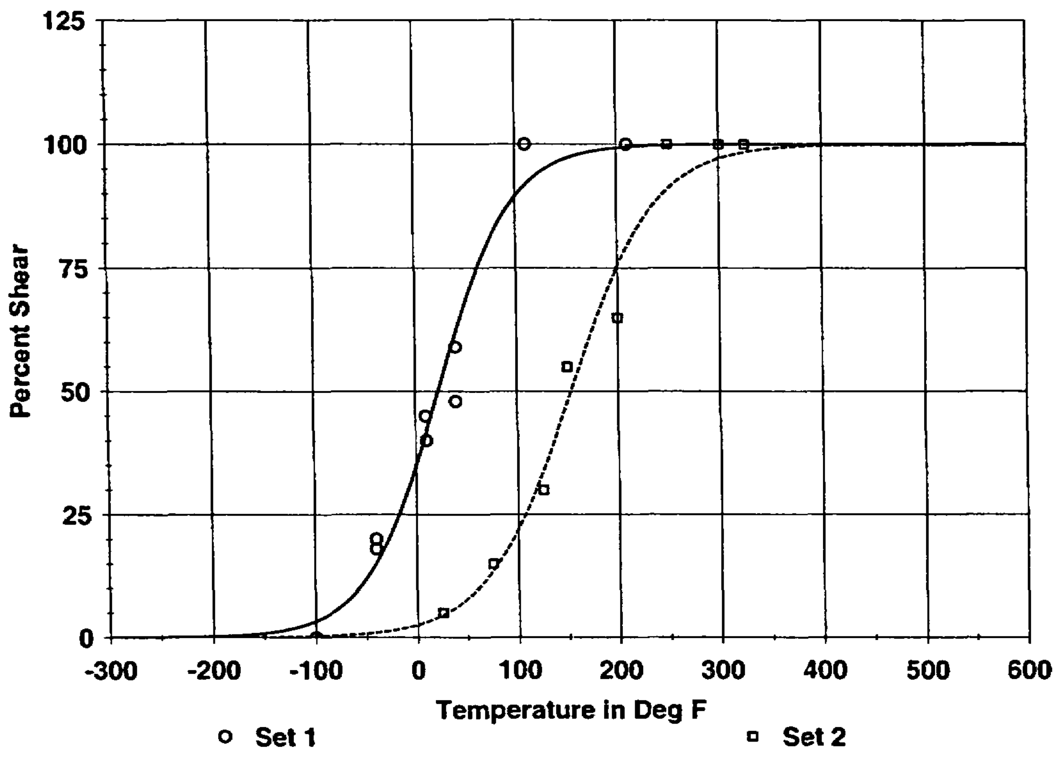
Curve	Fluence	LSE	USE	d-USE	T @35	d-T @35
1		.0	79.8	.0	-38.6	.0
2		.0	75.2	-4.6	147.3	185.9

Figure 5-11 Charpy V-Notch Lateral Expansion vs. Temperature for Indian Point Unit 3 Reactor Vessel Intermediate Shell Plate B2802-2 (Longitudinal)

INTERMEDIATE SHELL PLATE B2802-2 (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:45 PM
Data Set(s) Plotted

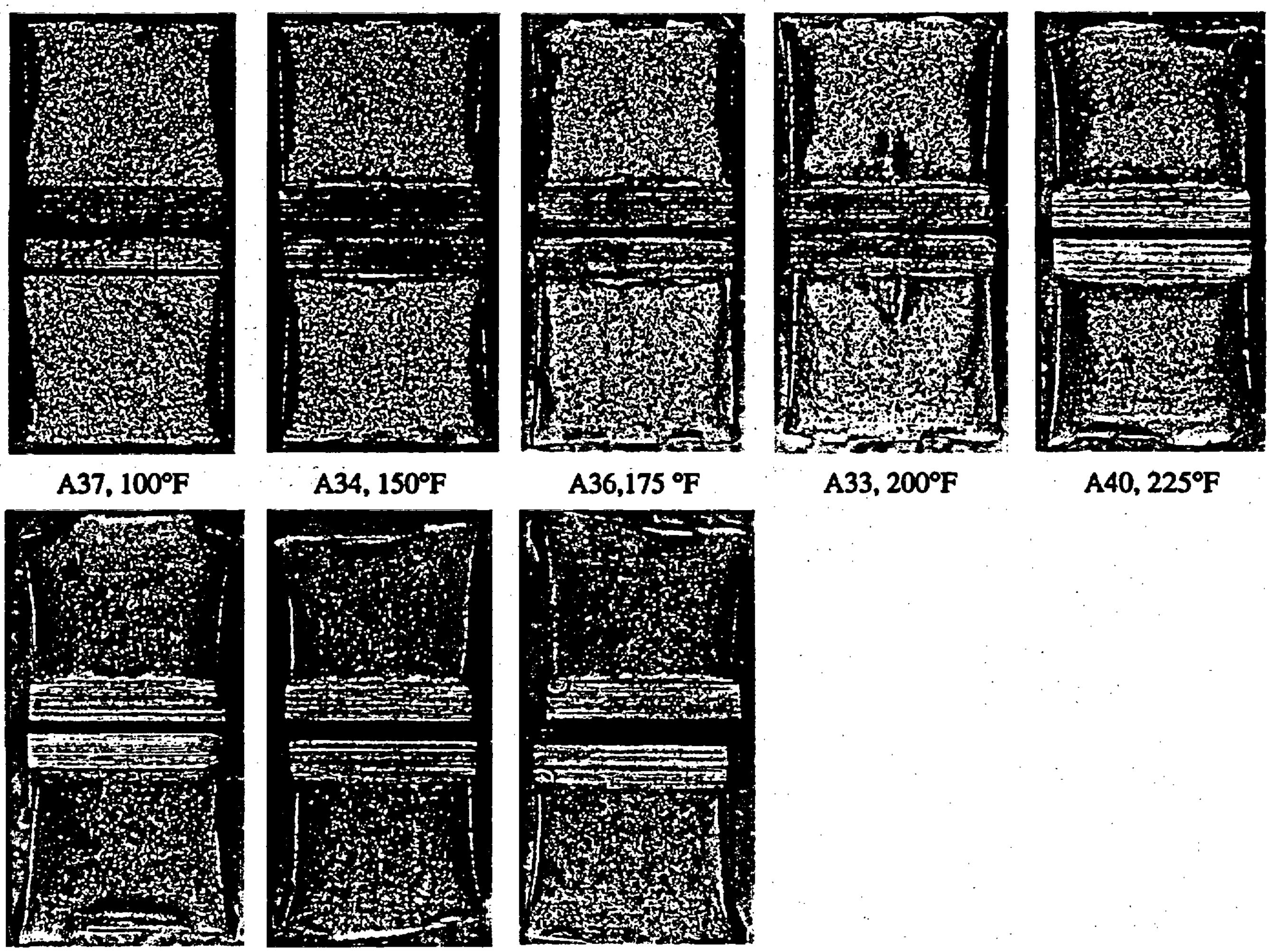
Curve	Plant	Capsule	Material	Ori.	Heat #
1	Indian Point 3	UNIRR	SA302B	LT	A-0516-2
2	Indian Point 3	X	SA302B	LT	A-0516-2



Results

Curve	Fluence	LSE	USE	d-USE	T @50	d-T @50
1		.0	100.0	.0	22.6	.0
2		.0	100.0	.0	153.2	130.6

Figure 5-12 Charpy V-Notch Percent Shear vs. Temperature for Indian Point Unit 3 Reactor Vessel Intermediate Shell Plate B2802-2 (Longitudinal)



A37, 100°F | A34, 150°F | A36,175 °F | A33, 200°F | A40, 225°F

A39, 280°F | A35, 350°F | A38, 375°F

Figure 5-13 Charpy Impact Specimen Fracture Surfaces for Indian Point Unit 3 Reactor Vessel Lower Shell Plate B2803-3 (Longitudinal Orientation)

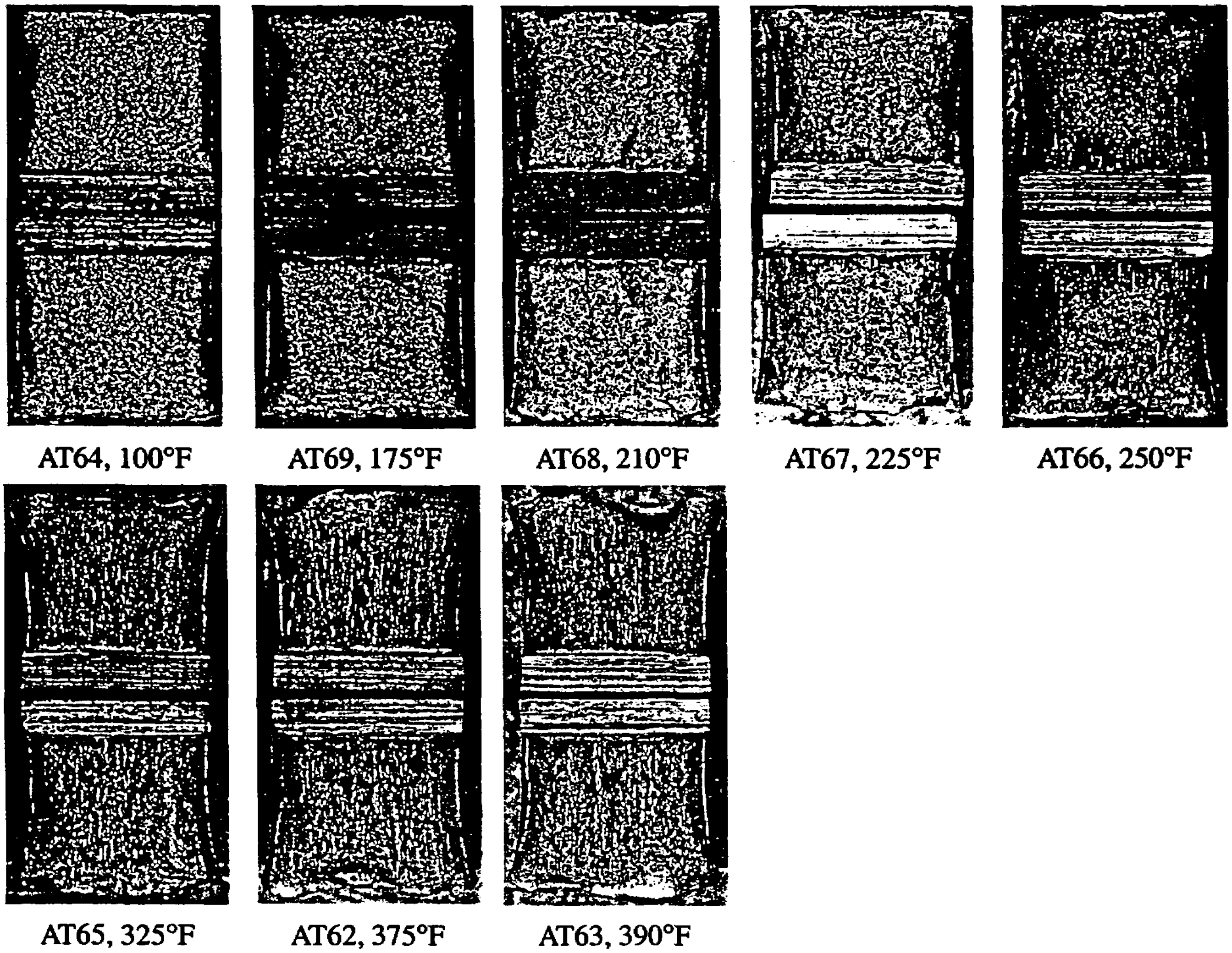


Figure 5-14 Charpy Impact Specimen Fracture Surfaces for Indian Point Unit 3 Reactor Vessel Lower Shell Plate B2803-3 (Transverse Orientation)

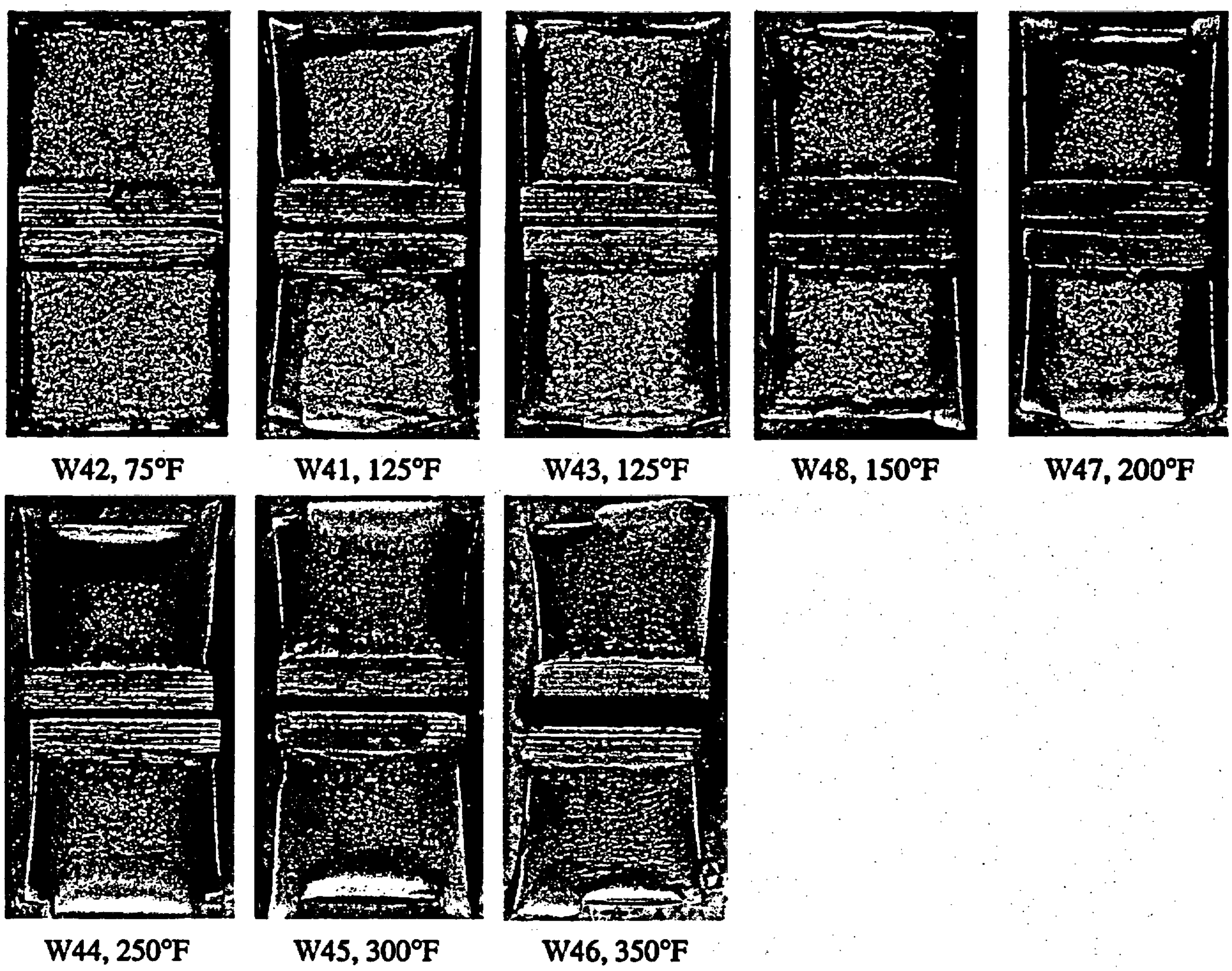
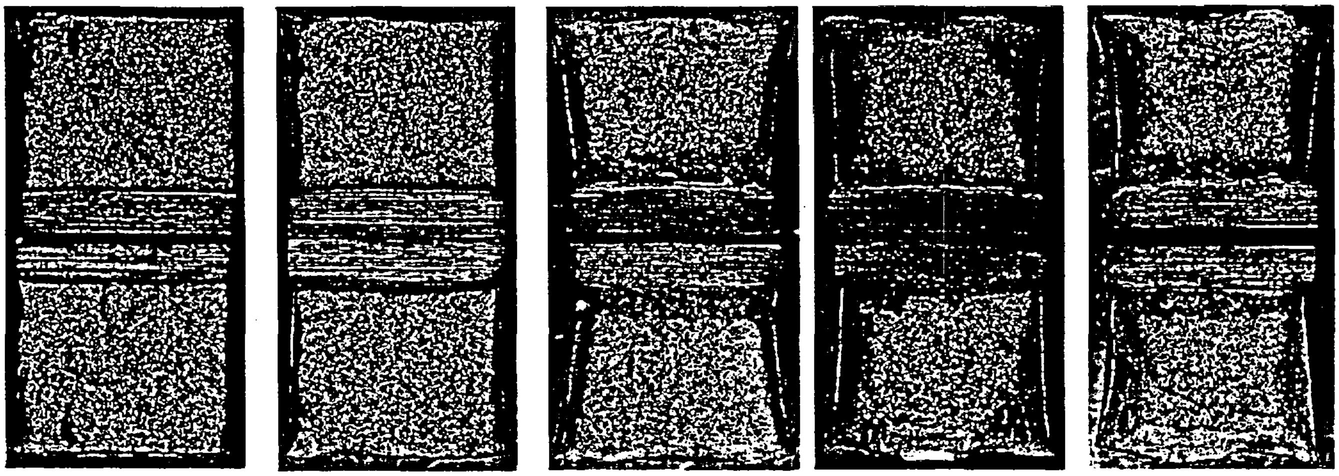
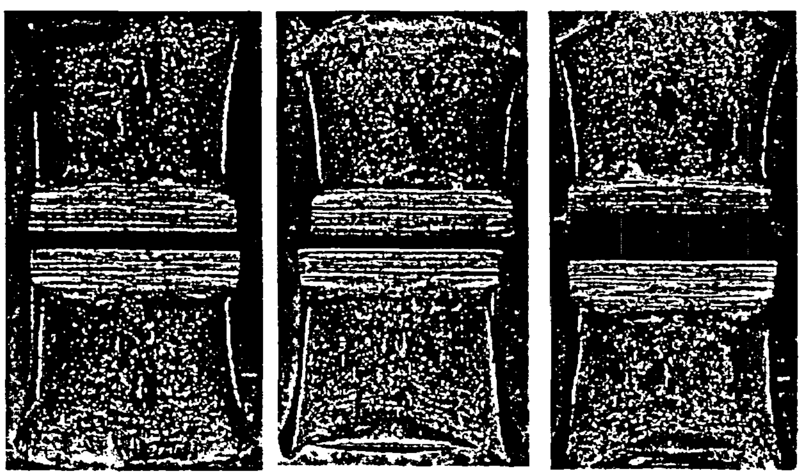


Figure 5-15 Charpy Impact Specimen Fracture Surfaces for Indian Point Unit 3 Reactor Vessel Weld Metal

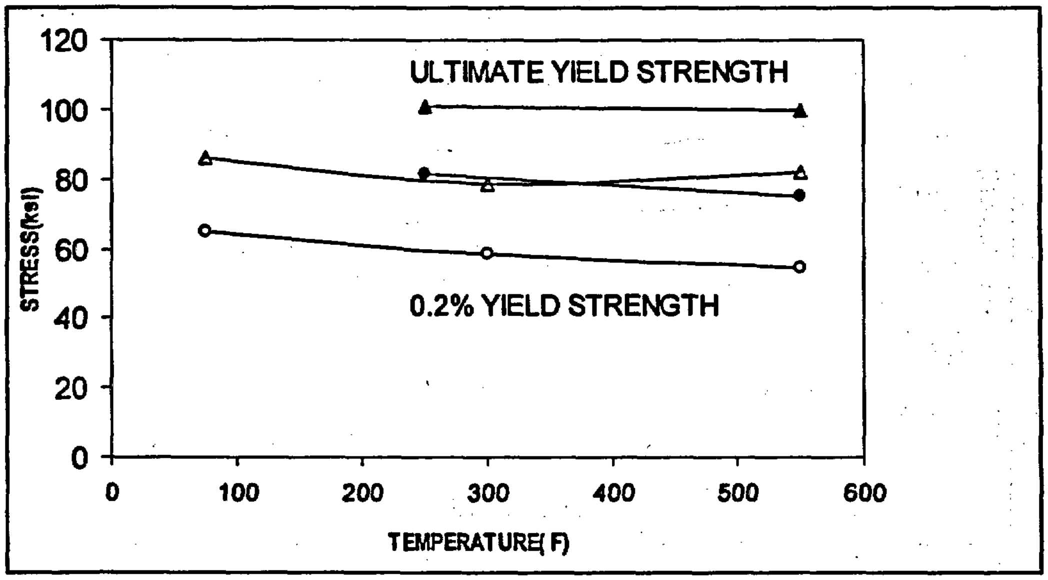


N2, 25°F N6, 75°F N5, 125°F N7, 150°F N4, 200°F



N1, 250°F N8, 300°F N3, 325°F

Figure 5-16 Charpy Impact Specimen Fracture Surfaces for Indian Point Unit 3 Reactor Vessel Intermediate Shell Plate B2802-2 (Longitudinal Orientation)



Legend: Δ and o are Unirradiated

▲ and • are Irradiated to 8.74 x 10^{18} n/cm^2 (E > 1.0 MeV)

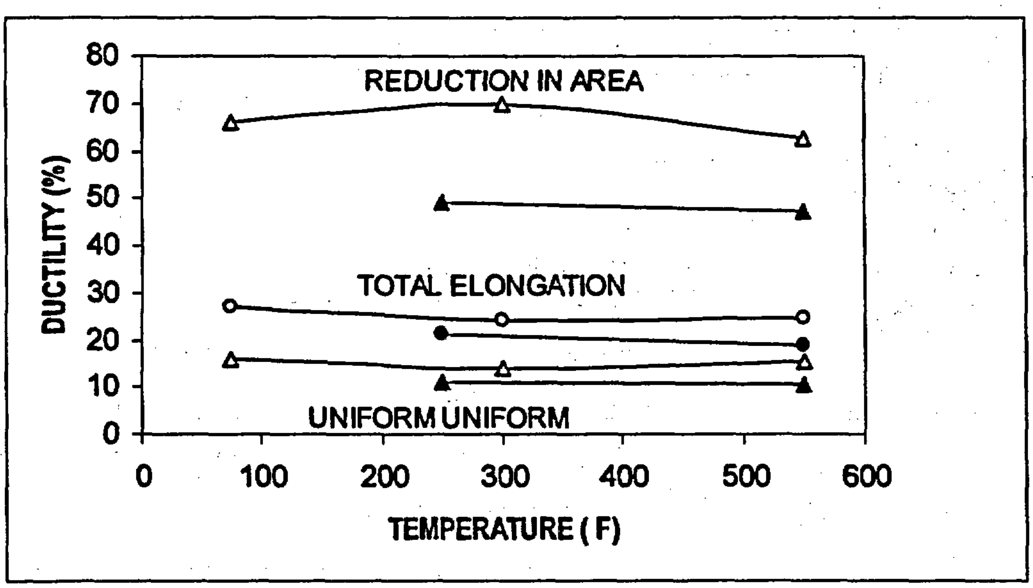
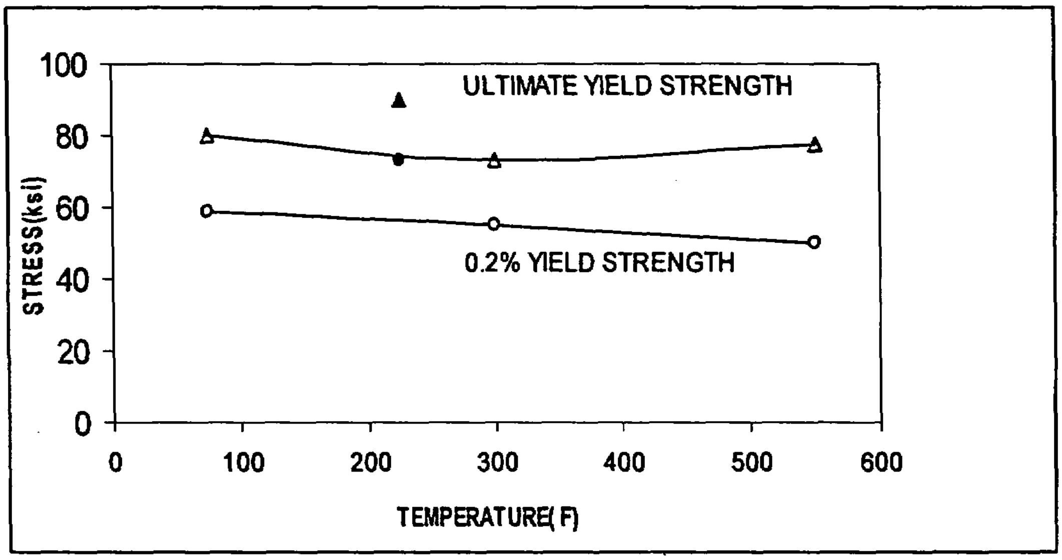


Figure 5-17 Tensile Properties for Indian Point Unit 3 Reactor Vessel Lower Shell Plate B2803-3 (Longitudinal Orientation)



Legend: Δ and ○ are Unirradiated
▲and ● are Irradiated to 8.74 x 10^{18} n/cm^2 (E > 1.0 MeV)

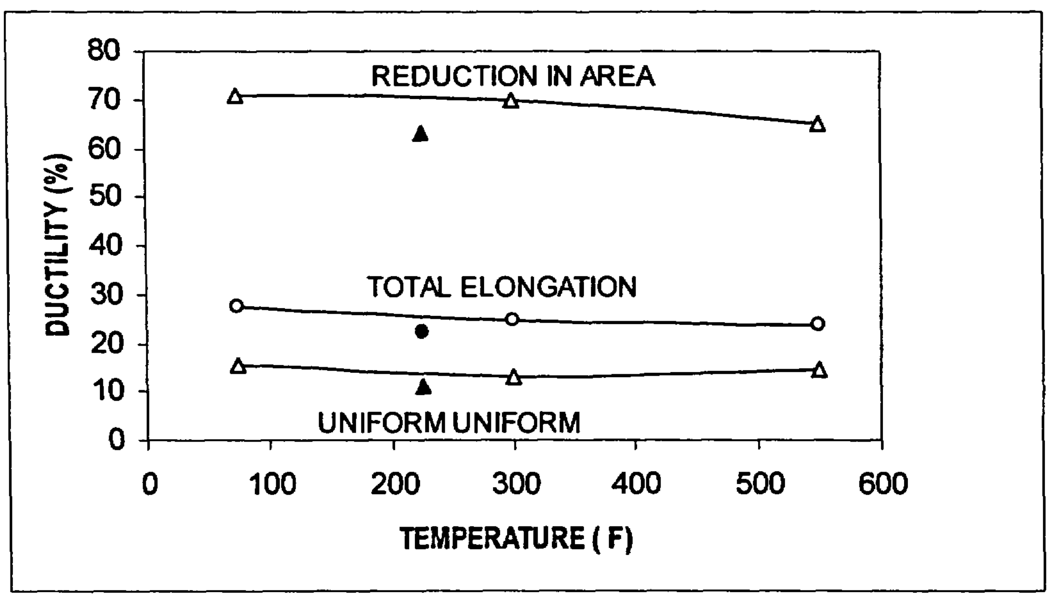
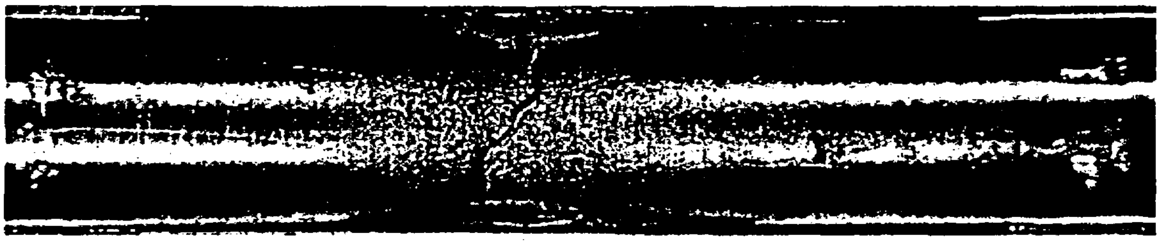


Figure 5-18 Tensile Properties for Indian Point Unit 3 Reactor Vessel Intermediate Shell Plate B2802-2 (Longitudinal Orientation)



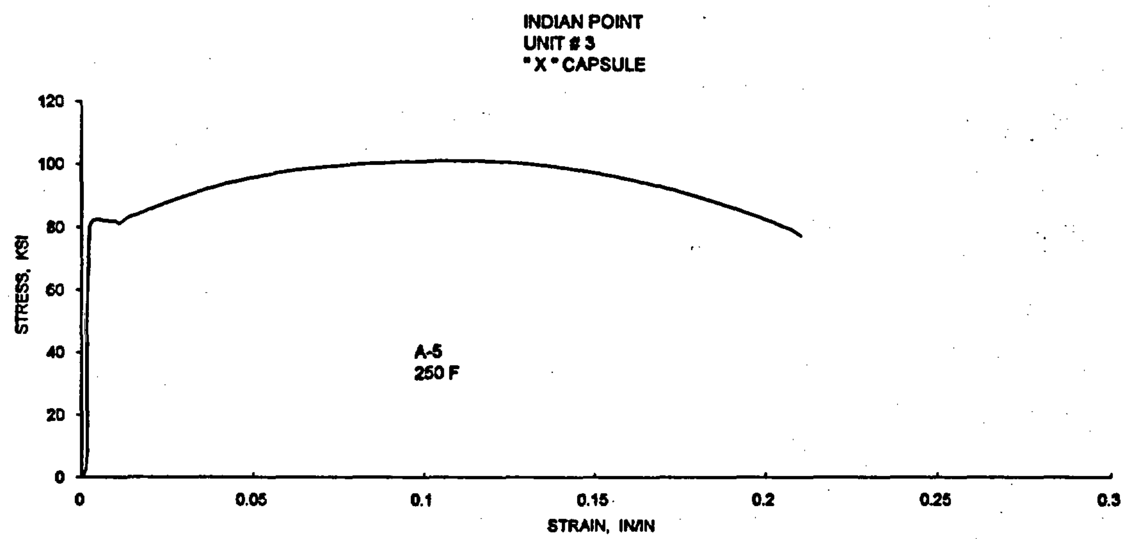
Specimen A5 Tested at 250°F

Specimen A6 Tested at 550°F

Figure 5-19 Fractured Tensile Specimens from Indian Point Unit 3 Reactor Vessel Lower Shell Plate B2803-3 (Longitudinal Orientation)

Specimen N1 Tested at 225°F

Figure 5-20 Fractured Tensile Specimen from Indian Point Unit 3 Reactor Vessel Intermediate Shell Plate B2802-2 (Longitudinal Orientation)



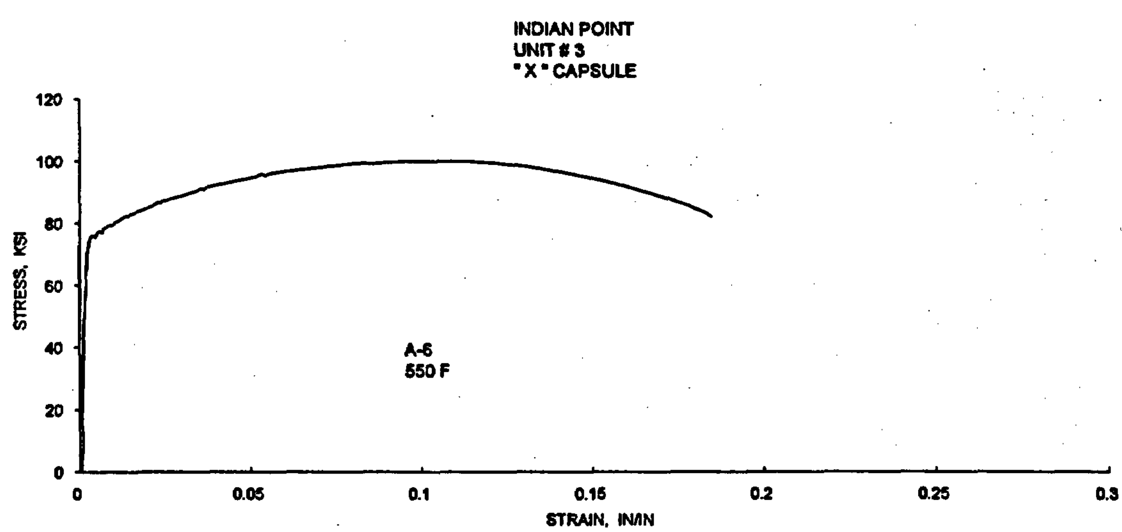


Figure 5-21 Engineering Stress-Strain Curves for Indian Point Unit 3 Lower Shell Plate B2803-3 Tensile Specimens A5 and A6 (Longitudinal Orientation)

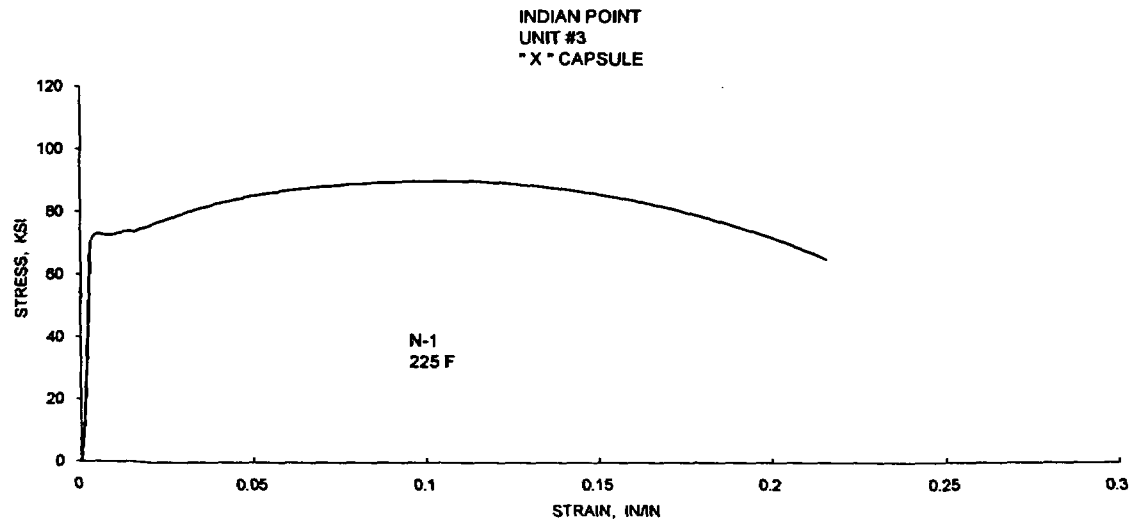


Figure 5-22 Engineering Stress-Strain Curve for Indian Point Unit 3 Intermediate Shell Plate B2802-2 Tensile Specimen N1 (Longitudinal Orientation)

6 RADIATION ANALYSIS AND NEUTRON DOSIMETRY

6.1 INTRODUCTION

This section describes a discrete ordinates S_n transport analysis performed for the Indian Point Unit 3 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 twelfth plant operating cycle, is provided. In addition, to provide an up-to-date data base applicable to the Indian point Unit 3 reactor, the sensor sets from the previously withdrawn capsules (T, Y, and Z) 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, "Analysis and Interpretation of Light-Water Reactor Surveillance Results," recommends reporting displacements per iron atom (dpa) along with fluence (E > 1.0 MeV) to provide a database for future reference. The energy dependent dpa function to be used for this evaluation is specified in ASTM Standard Practice E693, "Characterizing Neutron Exposures in Iron and Low Alloy Steels in Terms of Displacements per Atom." The application of the dpa parameter to the assessment of embrittlement gradients through the thickness of the reactor vessel wall has already been promulgated in Revision 2 to Regulatory Guide 1.99, "Radiation Embrittlement of Reactor Vessel Materials."

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 of Regulatory Guide 1.190, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence."[20] Additionally, the methods used to develop the calculated pressure vessel fluence are consistent with the NRC approved methodology described in WCAP-14040-NP-A, Revision 4, "Methodology Used to Develop Cold Overpressure Mitigating System Setpoints and RCS Heatup and Cooldown Limit Curves," May 2004.[21]

6.2 DISCRETE ORDINATES ANALYSIS

A plan view of the Indian Point Unit 3 reactor geometry at the core midplane is shown in Figure 4-1. Eight irradiation capsules attached to the thermal shield are included in the reactor design that constitutes the reactor vessel surveillance program. The capsules are located at azimuthal angles of 4°, 176°, 184°, and 356° (4° from the core cardinal axes) and 40°, 140°, 220°, and 320° (40° from the core cardinal axes) as shown in Figure 4-1. The stainless steel specimen containers are 1-inch square and are approximately 38 inches in height. The containers are positioned axially such that the test specimens are centered on the core midplane, thus spanning the central 3 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 Indian Point Unit 3 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 Indian Point Unit 3.

For the Indian Point Unit 3 transport calculations, the r,θ model depicted in Figure 6-1 was utilized since the reactor geometry is octant symmetric. This r,θ model included the core, the reactor internals, the thermal shield – including explicit representations of the surveillance capsules at 4° and 40°, the pressure vessel cladding and vessel wall, the insulation external to the pressure vessel, and the primary biological shield wall. This model formed the basis for the calculated results and enabled making comparisons to the surveillance capsule dosimetry evaluations. In developing the analytical model, 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 model consisted of 170 radial by 67 azimuthal intervals. Mesh sizes were chosen to assure that proper convergence of the inner iterations was achieved on a point-wise basis. The point-wise 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 Indian Point Unit 3 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 one foot below the active fuel to one foot above the active fuel. As in the case of the r,θ model, 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 the reactor model consisted of 153 radial by 90 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 point-wise basis. The point-wise 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 153 radial mesh intervals included in the r,z models. Thus, radial synthesis factors could be determined on a mesh-wise basis throughout the entire geometry.

The core power distributions used in the plant specific transport analysis were provided by the Nuclear Fuels Division of Westinghouse. Specifically, the data utilized included cycle dependent fuel assembly initial enrichments, burn-ups, and axial power distributions. This power distribution information was provided on a fuel cycle specific basis for the first 13 reactor operating cycles at Indian Point Unit 3. Each of these fuel cycle designs has been implemented at the plant. Also included in this fluence evaluation are the analyses for three preliminary future cycle designs (14, 15, and 16) that were created as a part of a power uprate study. 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 burn-up 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[22] and the BUGLE-96 cross-section library.[23] 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.

The results of the cycle specific transport calculations were also used to provide projections of the neutron exposure of the reactor pressure vessel for operating periods extending to 54 Effective Full Power Years (EFPY). These projections accounted for a power uprate from 3025.0 MWt to 3067.4 MWt occurring during fuel cycle 12 followed by an additional power uprate to 3216 MWt at the onset of cycle 14.

The projections beyond the end of cycle 16 assumed continued operation at the uprated core power level of 3216 MWt with a spatial core power distribution identical to the preliminary equilibrium cycle design intended for implementation in cycle 16.

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 octant symmetric surveillance capsule positions, i.e., for the 4° and 40° locations. 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 at four azimuthal locations. The vessel data given in Table 6-2 were taken at the clad/base metal interface, and thus, represent maximum calculated exposure levels on the vessel.

Both calculated fluence (E > 1.0 MeV) and dpa data are provided in Table 6-1 and Table 6-2. These data tabulations include both plant and fuel cycle specific calculated neutron exposures at the end of the twelfth fuel cycle as well as future projections to 17.4, 19.3, 21.2, 23, 32, 34, 48, and 54 EFPY. The calculations for Cycle 13 account for an uprate from 3025.0 MWt to 3067.4 MWt. The projections beyond 17.4 EFPY are based on an additional power uprate to 3216 MWt.

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 16, 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 Indian Point Unit 3 reactor are provided in Table 6-5. These assigned neutron exposure levels are based on the plant and fuel cycle specific neutron transport calculations.

Updated lead factors for the Indian Point Unit 3 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 (T, Y, Z 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 (S, U, V and W), the lead factor corresponds to the calculated fluence values at the end of Cycle 16, the last projected fuel cycle for Indian Point Unit 3.

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 Indian Point Unit 3 at the end of the twelfth fuel cycle, is summarized below.

Reaction	Reaction Rates (rps/atom)		M/C Ratio
	Measured	Calculated	
$^{63}Cu(n,\alpha)^{60}Co$	1.97E-17	1.81E-17	1.09
$^{54}Fe(n,p)^{54}Mn$	1.44E-15	1.60E-15	0.90
$^{58}Ni(n,p)^{58}Co$	2.01E-15	2.14E-15	0.94
		Average:	0.98
		% Standard Deviation:	10.2

The measured-to-calculated (M/C) reaction rate ratios for the Capsule X threshold reactions range from 0.90 to 1.09, and the average M/C ratio is 0.98 ± 10.2% (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 Indian Point Unit 3 reactor. These comparisons validate the current analytical results described in Section 6.2; therefore, the calculations are deemed applicable for Indian Point Unit 3.

6.4 CALCULATIONAL UNCERTAINTIES

The uncertainty associated with the calculated neutron exposure of the Indian Point Unit 3 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 as described in Reference 2:

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 Indian Point Unit 3 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 Indian Point Unit 3 analysis was established from results of these three phases of the methods qualification.

The fourth phase of the uncertainty assessment (comparisons with Indian Point Unit 3 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 Indian Point Unit 3 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 21.

	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 Indian Point Unit 3.

Figure 6-1

Indian Point Unit 3 r,θ Reactor Geometry

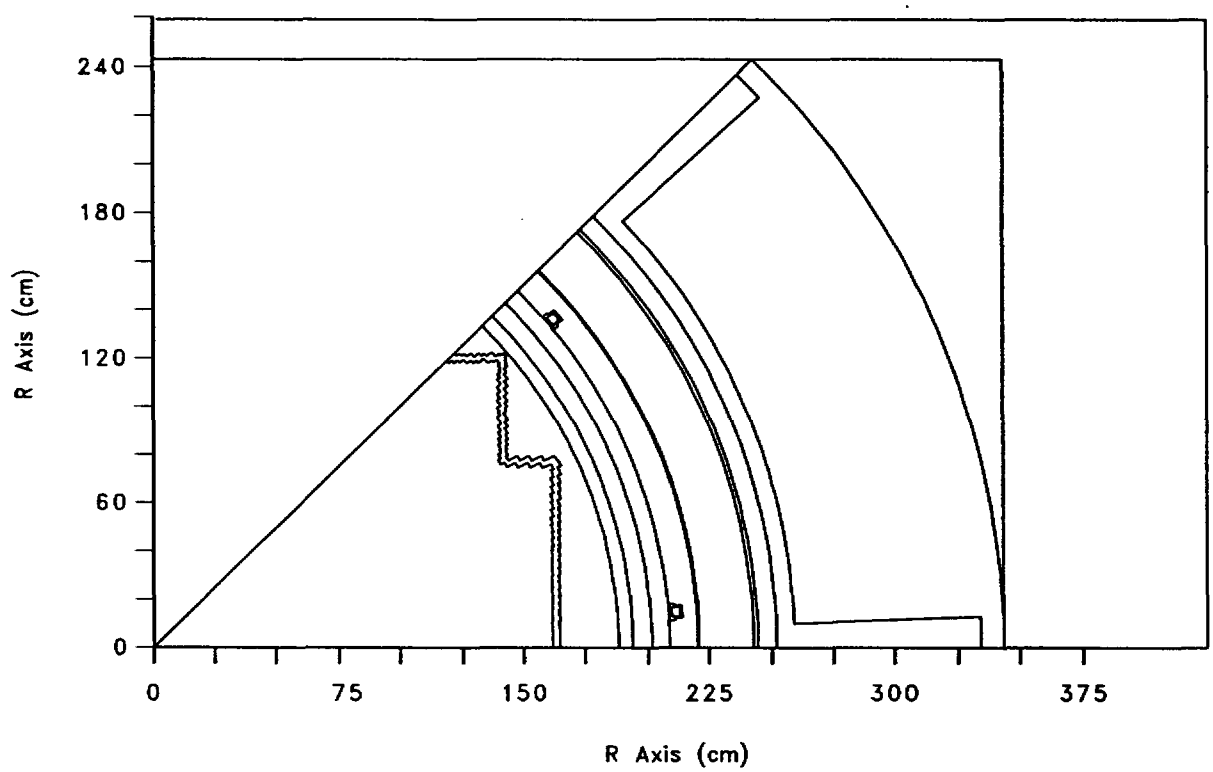


Figure 6-2

Indian Point Unit 3 r,z Reactor Geometry

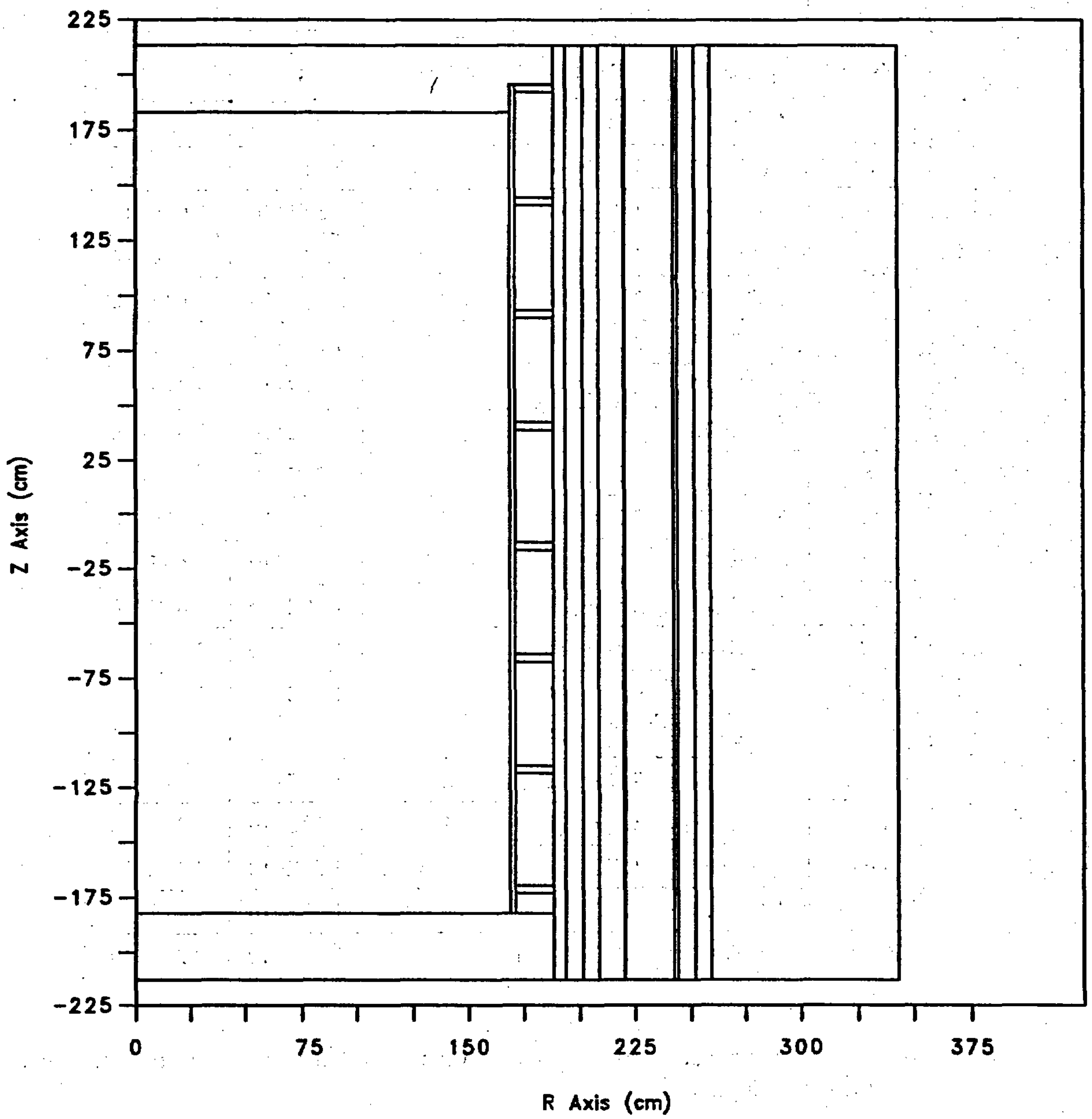


Table 6-1

Calculated Neutron Exposure Rates And Integrated Exposures
At The Surveillance Capsule Center

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Flux [n/cm^2-s]	
				4°	40°
1	4.30E+07	4.30E+07	1.4	1.97E+10	6.13E+10
2	2.89E+07	7.19E+07	2.3	2.21E+10	7.50E+10
3	3.02E+07	1.02E+08	3.2	2.57E+10	7.03E+10
4	3.59E+07	1.38E+08	4.4	2.30E+10	5.11E+10
5	3.60E+07	1.74E+08	5.5	2.06E+10	4.62E+10
6	3.77E+07	2.12E+08	6.7	1.85E+10	4.07E+10
7	3.41E+07	2.46E+08	7.8	1.71E+10	3.31E+10
8	3.57E+07	2.82E+08	8.9	2.03E+10	3.32E+10
9	4.88E+07	3.30E+08	10.5	1.80E+10	3.00E+10
10	5.65E+07	3.87E+08	12.3	1.34E+10	2.92E+10
11	4.66E+07	4.33E+08	13.7	1.20E+10	2.60E+10
12	5.71E+07	4.91E+08	15.5	1.25E+10	3.01E+10
13	5.98E+07	5.50E+08	17.4	1.29E+10	2.53E+10
14	5.83E+07	6.09E+08	19.3	1.48E+10	3.26E+10
15	5.92E+07	6.68E+08	21.2	1.44E+10	3.23E+10
16	5.92E+07	7.27E+08	23.0	1.50E+10	3.27E+10
Future	2.84E+08	1.01E+09	32.0	1.50E+10	3.27E+10
Future	6.31E+07	1.07E+09	34.0	1.50E+10	3.27E+10
Future	4.42E+08	1.52E+09	48.0	1.50E+10	3.27E+10
Future	1.89E+08	1.71E+09	54.0	1.50E+10	3.27E+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

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Fluence [n/cm²]	
				4°	40°
1	4.30E+07	4.30E+07	1.4	8.47E+17	2.63E+18
2	2.89E+07	7.19E+07	2.3	1.49E+18	4.80E+18
3	3.02E+07	1.02E+08	3.2	2.26E+18	6.92E+18
4	3.59E+07	1.38E+08	4.4	3.09E+18	8.76E+18
5	3.60E+07	1.74E+08	5.5	3.83E+18	1.04E+19
6	3.77E+07	2.12E+08	6.7	4.53E+18	1.20E+19
7	3.41E+07	2.46E+08	7.8	5.11E+18	1.31E+19
8	3.57E+07	2.82E+08	8.9	5.83E+18	1.43E+19
9	4.88E+07	3.30E+08	10.5	6.71E+18	1.57E+19
10	5.65E+07	3.87E+08	12.3	7.47E+18	1.74E+19
11	4.66E+07	4.33E+08	13.7	8.03E+18	1.86E+19
12	5.71E+07	4.91E+08	15.5	8.74E+18	2.03E+19
13	5.98E+07	5.50E+08	17.4	9.51E+18	2.18E+19
14	5.83E+07	6.09E+08	19.3	1.04E+19	2.37E+19
15	5.92E+07	6.68E+08	21.2	1.12E+19	2.56E+19
16	5.92E+07	7.27E+08	23.0	1.21E+19	2.76E+19
Future	2.84E+08	1.01E+09	32.0	1.64E+19	3.69E+19
Future	6.31E+07	1.07E+09	34.0	1.73E+19	3.89E+19
Future	4.42E+08	1.52E+09	48.0	2.40E+19	5.34E+19
Future	1.89E+08	1.71E+09	54.0	2.68E+19	5.96E+19

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

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Iron Atom Displacement Rate [dpa/s]	
				4°	40°
1	4.30E+07	4.30E+07	1.4	3.18E-11	1.03E-10
2	2.89E+07	7.19E+07	2.3	3.57E-11	1.27E-10
3	3.02E+07	1.02E+08	3.2	4.15E-11	1.19E-10
4	3.59E+07	1.38E+08	4.4	3.71E-11	8.60E-11
5	3.60E+07	1.74E+08	5.5	3.31E-11	7.76E-11
6	3.77E+07	2.12E+08	6.7	2.98E-11	6.84E-11
7	3.41E+07	2.46E+08	7.8	2.75E-11	5.54E-11
8	3.57E+07	2.82E+08	8.9	3.27E-11	5.58E-11
9	4.88E+07	3.30E+08	10.5	2.90E-11	5.02E-11
10	5.65E+07	3.87E+08	12.3	2.17E-11	4.90E-11
11	4.66E+07	4.33E+08	13.7	1.93E-11	4.36E-11
12	5.71E+07	4.91E+08	15.5	2.00E-11	5.04E-11
13	5.98E+07	5.50E+08	17.4	2.08E-11	4.23E-11
14	5.83E+07	6.09E+08	19.3	2.38E-11	5.47E-11
15	5.92E+07	6.68E+08	21.2	2.32E-11	5.41E-11
16	5.92E+07	7.27E+08	23.0	2.42E-11	5.49E-11
Future	2.84E+08	1.01E+09	32.0	2.42E-11	5.49E-11
Future	6.31E+07	1.07E+09	34.0	2.42E-11	5.49E-11
Future	4.42E+08	1.52E+09	48.0	2.42E-11	5.49E-11
Future	1.89E+08	1.71E+09	54.0	2.42E-11	5.49E-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

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Iron Atom Displacements [dpa]	
				4°	40°
1	4.30E+07	4.30E+07	1.4	1.37E-03	4.45E-03
2	2.89E+07	7.19E+07	2.3	2.40E-03	8.11E-03
3	3.02E+07	1.02E+08	3.2	3.65E-03	1.17E-02
4	3.59E+07	1.38E+08	4.4	4.98E-03	1.48E-02
5	3.60E+07	1.74E+08	5.5	6.17E-03	1.76E-02
6	3.77E+07	2.12E+08	6.7	7.30E-03	2.02E-02
7	3.41E+07	2.46E+08	7.8	8.23E-03	2.20E-02
8	3.57E+07	2.82E+08	8.9	9.40E-03	2.40E-02
9	4.88E+07	3.30E+08	10.5	1.08E-02	2.65E-02
10	5.65E+07	3.87E+08	12.3	1.20E-02	2.93E-02
11	4.66E+07	4.33E+08	13.7	1.29E-02	3.13E-02
12	5.71E+07	4.91E+08	15.5	1.41E-02	3.42E-02
13	5.98E+07	5.50E+08	17.4	1.53E-02	3.67E-02
14	5.83E+07	6.09E+08	19.3	1.67E-02	3.99E-02
15	5.92E+07	6.68E+08	21.2	1.81E-02	4.31E-02
16	5.92E+07	7.27E+08	23.0	1.95E-02	4.63E-02
Future	2.84E+08	1.01E+09	32.0	2.64E-02	6.19E-02
Future	6.31E+07	1.07E+09	34.0	2.79E-02	6.54E-02
Future	4.42E+08	1.52E+09	48.0	3.86E-02	8.96E-02
Future	1.89E+08	1.71E+09	54.0	4.32E-02	1.00E-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

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	4.30E+07	4.30E+07	1.4	6.01E+09	9.56E+09	1.20E+10	1.79E+10
2	2.89E+07	7.19E+07	2.3	7.37E+09	1.17E+10	1.49E+10	2.39E+10
3	3.02E+07	1.02E+08	3.2	7.71E+09	1.21E+10	1.41E+10	1.99E+10
4	3.59E+07	1.38E+08	4.4	6.97E+09	1.02E+10	1.09E+10	1.47E+10
5	3.60E+07	1.74E+08	5.5	6.17E+09	8.93E+09	9.49E+09	1.33E+10
6	3.77E+07	2.12E+08	6.7	5.56E+09	8.34E+09	8.97E+09	1.18E+10
7	3.41E+07	2.46E+08	7.8	5.09E+09	8.78E+09	8.71E+09	9.48E+09
8	3.57E+07	2.82E+08	8.9	6.02E+09	9.50E+09	8.08E+09	9.59E+09
9	4.88E+07	3.30E+08	10.5	5.47E+09	7.39E+09	7.22E+09	8.74E+09
10	5.65E+07	3.87E+08	12.3	4.27E+09	6.37E+09	7.05E+09	8.87E+09
11	4.66E+07	4.33E+08	13.7	3.68E+09	5.78E+09	6.78E+09	7.60E+09
12	5.71E+07	4.91E+08	15.5	3.81E+09	5.67E+09	6.96E+09	8.85E+09
13	5.98E+07	5.50E+08	17.4	3.96E+09	6.09E+09	6.66E+09	7.35E+09
14	5.83E+07	6.09E+08	19.3	4.55E+09	6.84E+09	7.62E+09	9.69E+09
15	5.92E+07	6.68E+08	21.2	4.45E+09	6.87E+09	7.78E+09	9.63E+09
16	5.92E+07	7.27E+08	23.0	4.65E+09	7.16E+09	7.96E+09	9.78E+09
Future	2.84E+08	1.01E+09	32.0	4.65E+09	7.16E+09	7.96E+09	9.78E+09
Future	6.31E+07	1.07E+09	34.0	4.65E+09	7.16E+09	7.96E+09	9.78E+09
Future	4.42E+08	1.52E+09	48.0	4.65E+09	7.16E+09	7.96E+09	9.78E+09
Future	1.89E+08	1.71E+09	54.0	4.65E+09	7.16E+09	7.96E+09	9.78E+09

Table 6-2 cont'd

Calculated Azimuthal Variation Of Maximum Exposure Rates
And Integrated Exposures At The Reactor Vessel
Clad/Base Metal Interface

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Neutron Fluence (E > 1.0 MeV) [n/cm^2]			
				0°	15°	30°	45°
1	4.30E+07	4.30E+07	1.4	2.58E+17	4.11E+17	5.15E+17	7.69E+17
2	2.89E+07	7.19E+07	2.3	4.47E+17	7.12E+17	8.97E+17	1.38E+18
3	3.02E+07	1.02E+08	3.2	6.80E+17	1.08E+18	1.32E+18	1.98E+18
4	3.59E+07	1.38E+08	4.4	9.30E+17	1.44E+18	1.71E+18	2.51E+18
5	3.60E+07	1.74E+08	5.5	1.15E+18	1.76E+18	2.06E+18	2.99E+18
6	3.77E+07	2.12E+08	6.7	1.36E+18	2.08E+18	2.39E+18	3.44E+18
7	3.41E+07	2.46E+08	7.8	1.54E+18	2.38E+18	2.69E+18	3.76E+18
8	3.57E+07	2.82E+08	8.9	1.75E+18	2.72E+18	2.98E+18	4.10E+18
9	4.88E+07	3.30E+08	10.5	2.02E+18	3.08E+18	3.33E+18	4.53E+18
10	5.65E+07	3.87E+08	12.3	2.25E+18	3.42E+18	3.71E+18	5.01E+18
11	4.66E+07	4.33E+08	13.7	2.42E+18	3.69E+18	4.03E+18	5.36E+18
12	5.71E+07	4.91E+08	15.5	2.64E+18	4.01E+18	4.42E+18	5.86E+18
13	5.98E+07	5.50E+08	17.4	2.87E+18	4.38E+18	4.82E+18	6.30E+18
14	5.83E+07	6.09E+08	19.3	3.13E+18	4.77E+18	5.26E+18	6.86E+18
15	5.92E+07	6.68E+08	21.2	3.39E+18	5.17E+18	5.71E+18	7.42E+18
16	5.92E+07	7.27E+08	23.0	3.66E+18	5.58E+18	6.17E+18	7.98E+18
Future	2.84E+08	1.01E+09	32.0	4.95E+18	7.57E+18	8.38E+18	1.07E+19
Future	6.31E+07	1.07E+09	34.0	5.24E+18	8.01E+18	8.87E+18	1.13E+19
Future	4.42E+08	1.52E+09	48.0	7.27E+18	1.11E+19	1.24E+19	1.56E+19
Future	1.89E+08	1.71E+09	54.0	8.15E+18	1.25E+19	1.39E+19	1.74E+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

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Iron Atom Displacement Rate [dpa/s]			
				0°	15°	30°	45°
1	4.30E+07	4.30E+07	1.4	9.74E-12	1.53E-11	1.93E-11	2.89E-11
2	2.89E+07	7.19E+07	2.3	1.19E-11	1.88E-11	2.40E-11	3.85E-11
3	3.02E+07	1.02E+08	3.2	1.25E-11	1.94E-11	2.27E-11	3.22E-11
4	3.59E+07	1.38E+08	4.4	1.13E-11	1.63E-11	1.76E-11	2.38E-11
5	3.60E+07	1.74E+08	5.5	9.98E-12	1.43E-11	1.53E-11	2.15E-11
6	3.77E+07	2.12E+08	6.7	9.00E-12	1.33E-11	1.45E-11	1.90E-11
7	3.41E+07	2.46E+08	7.8	8.26E-12	1.40E-11	1.40E-11	1.53E-11
8	3.57E+07	2.82E+08	8.9	9.76E-12	1.52E-11	1.30E-11	1.55E-11
9	4.88E+07	3.30E+08	10.5	8.84E-12	1.18E-11	1.16E-11	1.41E-11
10	5.65E+07	3.87E+08	12.3	6.92E-12	1.02E-11	1.14E-11	1.43E-11
11	4.66E+07	4.33E+08	13.7	5.96E-12	9.25E-12	1.09E-11	1.23E-11
12	5.71E+07	4.91E+08	15.5	6.17E-12	9.08E-12	1.12E-11	1.43E-11
13	5.98E+07	5.50E+08	17.4	6.41E-12	9.74E-12	1.07E-11	1.19E-11
14	5.83E+07	6.09E+08	19.3	7.37E-12	1.09E-11	1.23E-11	1.56E-11
15	5.92E+07	6.68E+08	21.2	7.21E-12	1.10E-11	1.25E-11	1.55E-11
16	5.92E+07	7.27E+08	23.0	7.53E-12	1.15E-11	1.28E-11	1.58E-11
Future	2.84E+08	1.01E+09	32.0	7.53E-12	1.15E-11	1.28E-11	1.58E-11
Future	6.31E+07	1.07E+09	34.0	7.53E-12	1.15E-11	1.28E-11	1.58E-11
Future	4.42E+08	1.52E+09	48.0	7.53E-12	1.15E-11	1.28E-11	1.58E-11
Future	1.89E+08	1.71E+09	54.0	7.53E-12	1.15E-11	1.28E-11	1.58E-11

Table 6-2 cont'd

Calculated Azimuthal Variation Of Maximum Exposure Rates
And Integrated Exposures At The Reactor Vessel
Clad/Base Metal Interface

Cycle	Cycle Length [EFPS]	Cumulative Irradiation Time [EFPS]	Cumulative Irradiation Time [EFPY]	Iron Atom Displacements [dpa]			
				0°	15°	30°	45°
1	4.30E+07	4.30E+07	1.4	4.19E-04	6.59E-04	8.31E-04	1.24E-03
2	2.89E+07	7.19E+07	2.3	7.25E-04	1.14E-03	1.45E-03	2.24E-03
3	3.02E+07	1.02E+08	3.2	1.10E-03	1.73E-03	2.13E-03	3.21E-03
4	3.59E+07	1.38E+08	4.4	1.51E-03	2.31E-03	2.76E-03	4.06E-03
5	3.60E+07	1.74E+08	5.5	1.87E-03	2.82E-03	3.31E-03	4.84E-03
6	3.77E+07	2.12E+08	6.7	2.21E-03	3.33E-03	3.86E-03	5.55E-03
7	3.41E+07	2.46E+08	7.8	2.49E-03	3.81E-03	4.34E-03	6.07E-03
8	3.57E+07	2.82E+08	8.9	2.84E-03	4.35E-03	4.80E-03	6.63E-03
9	4.88E+07	3.30E+08	10.5	3.27E-03	4.92E-03	5.37E-03	7.32E-03
10	5.65E+07	3.87E+08	12.3	3.64E-03	5.47E-03	5.98E-03	8.09E-03
11	4.66E+07	4.33E+08	13.7	3.92E-03	5.90E-03	6.49E-03	8.66E-03
12	5.71E+07	4.91E+08	15.5	4.27E-03	6.42E-03	7.13E-03	9.48E-03
13	5.98E+07	5.50E+08	17.4	4.65E-03	7.00E-03	7.76E-03	1.02E-02
14	5.83E+07	6.09E+08	19.3	5.08E-03	7.63E-03	8.47E-03	1.11E-02
15	5.92E+07	6.68E+08	21.2	5.49E-03	8.27E-03	9.19E-03	1.20E-02
16	5.92E+07	7.27E+08	23.0	5.93E-03	8.93E-03	9.93E-03	1.29E-02
Future	2.84E+08	1.01E+09	32.0	8.02E-03	1.21E-02	1.35E-02	1.73E-02
Future	6.31E+07	1.07E+09	34.0	8.49E-03	1.28E-02	1.43E-02	1.83E-02
Future	4.42E+08	1.52E+09	48.0	1.18E-02	1.78E-02	1.99E-02	2.51E-02
Future	1.89E+08	1.71E+09	54.0	1.32E-02	2.00E-02	2.23E-02	2.81E-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°
220.35	1.000	1.000	1.000	1.000
225.87	0.544	0.546	0.550	0.540
231.39	0.262	0.262	0.266	0.256
236.90	0.121	0.121	0.124	0.116
242.42	0.055	0.054	0.056	0.050

Note:
Base Metal Inner Radius = 220.35 cm
Base Metal 1/4T = 225.87 cm
Base Metal 1/2T = 231.39 cm
Base Metal 3/4T = 236.90 cm
Base Metal Outer Radius = 242.42 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°
220.35	1.000	1.000	1.000	1.000
225.87	0.641	0.638	0.649	0.639
231.39	0.394	0.390	0.403	0.388
236.90	0.238	0.235	0.246	0.228
242.42	0.135	0.132	0.140	0.119

Note:
Base Metal Inner Radius = 220.35 cm
Base Metal 1/4T = 225.87 cm
Base Metal 1/2T = 231.39 cm
Base Metal 3/4T = 236.90 cm
Base Metal Outer Radius = 242.42 cm

Table 6-5

Calculated Fast Neutron Exposure of Surveillance Capsules
Withdrawn from Indian Point Unit 3

Capsule	Irradiation Time [EFPY]	Fluence (E > 1.0 MeV) [n/cm^2]	Iron Displacements [dpa]
T	1.4	2.63E+18	4.45E-03
Y	3.2	6.92E+18	1.17E-02
Z	5.5	1.04E+19	1.76E-02
X	15.5	8.74E+18	1.41E-02

Table 6-6

Calculated Surveillance Capsule Lead Factors

Capsule ID And Location	Status	Lead Factor
T (40°)	Withdrawn EOC 1	3.43
Y (40°)	Withdrawn EOC 3	3.49
Z (40°)	Withdrawn EOC 5	3.48
X (4°)	Withdrawn EOC 12	1.49
S(40°)	In Reactor	3.46
U (4°)	In Reactor	1.52
V (4°)	In Reactor	1.52
W(4°)	In Reactor	1.52

Note: Lead factors for capsules remaining in the reactor are based on cycle specific exposure calculations through the last analyzed fuel cycle, i.e., Cycle 16.

7 SURVEILLANCE CAPSULE REMOVAL SCHEDULE

The following surveillance capsule removal schedule meets the requirements of ASTM E185-82 and is recommended for future capsules to be removed from the Indian Point Unit 3 reactor vessel. This recommended removal schedule is applicable to 27.1 EFPY of operation.

Table 7-1 Recommended Surveillance Capsule Withdrawal Schedule

Capsule	Capsule Location	Lead Factor (a)	Withdrawal EFPY (b)	Fluence (n/cm^2) (a)
T	40°	3.43	1.4	2.63×10^{18} (c)
Y	40°	3.49	3.2	6.92×10^{18} (c)
Z	40°	3.48	5.5	1.04×10^{19} (c)
S	40°	3.46	(d)	(d)
X	4°	1.49	15.5	8.74×10^{18} (c)
V	4°	1.52	EOL (e, f)	(e, f)
W	4°	1.52	EOL (e, f)	(e, f)
U	4°	1.52	EOL (e, f)	(e, f)

Notes:

(a) Updated in Capsule X dosimetry analysis.

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

(c) Plant specific evaluation.

(d) Indian Point Unit 3 tried to remove Capsule S in May of 2001; however, the Capsule was not retrievable. Therefore, the Capsule Removal Schedule was revised to exclude Capsule S and make use of a spare capsule in its place. Due to the presence of spare capsules, the RV surveillance program is not degraded by the elimination of Capsule S

(e) If Indian Point Unit 3 is following a withdrawal schedule for the standard EOL (27.1 EFPY), then it is recommended to remove the 5th & standby capsules any time after 16.1 EFPY, but not to exceed 27.1 EFPY (EOL). This would satisfy the ASTM E 185-82 requirement to withdrawal @ EOL, not less than once or greater than twice the peak EOL vessel fluence. The projected fluence on the capsules will be between 9.22×10^{18} n/cm^2 (One times the EOL peak vessel) and 1.844×10^{19} n/cm^2 (Two times the peak EOL vessel fluence), depending on the exact withdrawal time. The standby capsules should also be withdrawn and placed in storage. Alternative fluence measuring techniques must be applied.

(f) If Indian Point Unit 3 is following a withdrawal schedule for License Extension (45.3 EFPY), then it is recommended to remove the 5th and standby capsules any time after 28.2 EFPY, but not to exceed 45.3 EFPY (EOLE). This would satisfy the ASTM E 185-82 requirement to withdrawal @ EOL, not less than once or greater than twice the peak EOL vessel fluence. The projected fluence on the capsules will be between 1.48×10^{19} n/cm^2 (One times the EOLE peak vessel) and 2.96×10^{19} n/cm^2 (Two times the peak EOLE vessel fluence), depending on the exact withdrawal time. The standby capsules should also be withdrawn and placed in storage. Alternative fluence measuring techniques must be applied.

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-8475, *Consolidated Edison Co. of New York Indian Point Unit No. 3 Reactor Vessel Radiation Surveillance Program*, S.E. Yanichko, et. al., dated January 1975.

4. WCAP-9491, *Analysis of Capsule T from the Indian Point Unit No. 3 Unit 1 Reactor Vessel Radiation Surveillance Program*, J. A. Davidson, et. al., April 1979.

5. WCAP-10300, *Analysis of Capsule Y from the Power Authority of the State of New York Indian Point Unit No. 3 Unit 1 Reactor Vessel Radiation Surveillance Program*, S.E. Yanichko, et. al., March 1983.

6. WCAP-11815, *Analysis of Capsule Z from the New York Power Authority Indian Point Unit No. 3 Unit 1 Reactor Vessel Radiation Surveillance Program*, S.E. Yanichko, et. al., March 1988.

7. ASTM E208, *Standard Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels*, in ASTM Standards, Section 3, American Society for Testing and Materials, Philadelphia, PA.

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

9. ASTM E185-82, *Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels.*

10. Procedure RMF 8402, *Surveillance Capsule Testing Program*, Revision 2.

11. Procedure RMF 8102, *Tensile Testing*, Revision 1.

12. Procedure RMF 8103, *Charpy Impact Testing*, Revision 1.

13. ASTM E23-02a, *Standard Test Method for Notched Bar Impact Testing of Metallic Materials*, ASTM, 2002.

14. ASTM A370-97a, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*, ASTM, 1997.

15. ASTM E8-01, *Standard Test Methods for Tension Testing of Metallic Materials*, ASTM, 2001.

16. ASTM E21-92 (1998), *Standard Test Methods for Elevated Temperature Tension Tests of Metallic Materials*, ASTM, 1998.

17. ASTM E83-93, *Standard Practice for Verification and Classification of Extensometers*, in ASTM Standards, Section 3, American Society for Testing and Materials, Philadelphia, PA, 1993.

18. ASTM E185-79, *Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels*

19. WCAP-14370, *Use of the Hyperbolic Tangent Function for Fitting Transition Temperature Toughness Data*, T. R. Mager, et al, May 1995.

20. 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.

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

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

23. 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

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 Indian Point Unit 3 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."[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. This information may also be useful in the future, in particular, as least squares adjustment techniques become accepted in the regulatory environment.

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 Indian Point Unit 3 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]
T	40°	End of Cycle 1	1.4
Y	40°	End of Cycle 3	3.2
Z	40°	End of Cycle 5	5.5
X	4°	End of Cycle 12	15.5

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 T, Y, Z, and X are summarized as follows:

Sensor Material	Reaction Of Interest	Capsule T	Capsule Y	Capsule Z	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		
Neptunium-237	$^{237}Np(n,f)^{137}Cs$		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.

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.

The radiometric counting of the neutron sensors from Capsules T, Y, and Z was completed by the Westinghouse Analytical Services Laboratory located at the Waltz Mill site[A-2, A-3, A-4]. The radiometric counting of the sensors from Capsule X was carried out by Pace Analytical Services, Inc., also located at the Westinghouse Waltz Mill Site. 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 T, Y, Z, and X was based on the monthly power generation of Indian Point Unit 3 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 T, Y, Z, 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 (MWt).
P_{ref}	=	Maximum or reference power level of the reactor (MWt).
C_j	=	Calculated ratio of $\phi(E > 1.0$ MeV) during irradiation period j to the time weighted average $\phi(E > 1.0$ MeV) over the entire irradiation period.
λ	=	Decay constant of the product isotope (1/sec).
t_j	=	Length of irradiation period j (sec).
t_d	=	Decay time following irradiation period j (sec).

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

In the equation describing the reaction rate calculation, the ratio $[P_j]/[P_{ref}]$ accounts for month-by-month variation of reactor core power level within any given fuel cycle as well as over multiple fuel cycles. The ratio C_j, which 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.

Since the construction of the surveillance capsules used in the Indian Point Unit 3 reactor design places individual sensors at several radial locations within the test specimen array, gradient corrections were applied to the measured reaction rates to index all of the sensor measurements to a common geometric location within the capsule. In the case of Indian Point Unit 3, the following radii apply to the locations of the various sensors:

Sensor Type	Radius (cm)
Copper	211.18
Iron From Core Side Charpy	211.18
Nickel	211.18
Uranium 238	211.41
Neptunium 237	211.41
Iron From Vessel Side Charpy	212.18
Bare Cobalt-Aluminum	212.18
Cd Covered Cobalt-Aluminum	212.18

Gradient correction Factors used in indexing the measured results to the geometric center of the surveillance capsules (211.41 cm) were based on the transport calculations completed for Indian Point Unit 3 and were as follows:

Sensor Type	Radius (cm)	40° Capsule Correction	4° Capsule Correction
Copper	211.18	0.955	0.956
Iron From Core Side Charpy	211.18	0.953	0.954
Nickel	211.18	0.953	0.955
Uranium 238	211.41	1.000	1.000
Neptunium 237	211.41	1.000	1.000
Iron From Vessel Side Charpy	212.18	1.156	1.149
Bare Cobalt-Aluminum	212.18	0.974	0.950
Cd Covered Cobalt-Aluminum	212.18	1.152	1.124

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 Indian Point Unit 3 fission sensor reaction rates are summarized as follows:

Correction	Capsule T	Capsule Y	Capsule Z	Capsule X
^{235}U Impurity/Pu Build-in	N/A	0.858	N/A	N/A
$^{238}U(\gamma,f)$	N/A	0.958	N/A	N/A
Net ^{238}U Correction	N/A	0.822	N/A	N/A
$^{237}Np(\gamma,f)$	N/A	0.985	N/A	N/A

These factors were applied in a multiplicative fashion to the decay corrected uranium and neptunium fission sensor reaction rates. Note that the ^{238}U and ^{237}Np sensors were included only in Capsule Y.

Results of the sensor reaction rate determinations for Capsules T, Y, Z, 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 ^{235}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 $\phi(E > 1.0\text{ MeV})$ 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 Indian Point Unit 3 application, the FERRET code[A-5] 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 ($\phi(E > 1.0\text{ MeV})$ 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 Indian Point Unit 3 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[A-6]. 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 Indian point Unit 3 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 Indian Point Unit 3 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 group-wise 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 Indian Point Unit 3 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 <u>Comparisons of Measurements and Calculations</u>

Results of the least squares evaluations of the dosimetry from the Indian Point Unit 3 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 7% - 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 0.90 to 1.23 for the 14 samples included in the data set. The overall average M/C ratio for the entire set of Indian Point Unit 3 data is 1.06 with an associated standard deviation of 10.1%.

In the comparisons of best estimate and calculated fast neutron exposure parameters, the corresponding BE/C comparisons for the capsule data sets range from 0.91 to 1.18 for neutron flux (E > 1.0 MeV) and from 0.91 to 1.15 for iron atom displacement rate. The overall average BE/C ratios for neutron flux (E > 1.0 MeV) and iron atom displacement rate are 1.02 with a standard deviation of 11.9% and 1.01 with a standard deviation of 10.9%, 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 Indian Point Unit 3 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 – 12.1	5.271 y	
Iron	^{54}Fe (n,p)	0.0585	2.1 – 8.9	312.1 d	
Nickel	^{58}Ni (n,p)	0.6808	1.5 – 8.8	70.82 d	
Uranium-238	^{238}U (n,f)	1.0000	1.3 – 7.0	30.07 y	6.02
Neptunium-237	^{237}Np (n,f)	1.0000	0.4 – 4.4	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 Indian Point Unit 3 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 Twelve Fuel Cycles
Of The Indian Point Unit 3 Reactor

Year	Month	Thermal Generation (MWt-hr)	Year	Month	Thermal Generation (MWt-hr)	Year	Month	Thermal Generation (MWt-hr)
1976	4	7394	1979	4	1803659	1983	4	0
1976	5	570059	1979	5	2236503	1983	5	0
1976	6	1074795	1979	6	2056010	1983	6	0
1976	7	1109470	1979	7	1601186	1983	7	0
1976	8	1375290	1979	8	1618305	1983	8	0
1976	9	605492	1979	9	564515	1983	9	0
1976	10	1613060	1979	10	0	1983	10	0
1976	11	1859918	1979	11	0	1983	11	0
1976	12	1687081	1979	12	0	1983	12	0
1977	1	1158756	1980	1	0	1984	1	0
1977	2	1805507	1980	2	298849	1984	2	0
1977	3	1964160	1980	3	991653	1984	3	0
1977	4	1479229	1980	4	695552	1984	4	0
1977	5	2018472	1980	5	1824582	1984	5	0
1977	6	1935000	1980	6	1996621	1984	6	282244
1977	7	1941232	1980	7	1088451	1984	7	0
1977	8	1996896	1980	8	1999791	1984	8	0
1977	9	1897557	1980	9	1905318	1984	9	0
1977	10	371890	1980	10	0	1984	10	0
1977	11	0	1980	11	0	1984	11	0
1977	12	833079	1980	12	725986	1984	12	0
1978	1	1951512	1981	1	2074821	1985	1	423
1978	2	1161885	1981	2	0	1985	2	1542818
1978	3	1955510	1981	3	0	1985	3	2058008
1978	4	1616402	1981	4	1088240	1985	4	2144331
1978	5	1885029	1981	5	1394908	1985	5	2041716
1978	6	440030	1981	6	1393640	1985	6	2105400
1978	7	0	1981	7	1458736	1985	7	0
1978	8	283997	1981	8	1441828	1985	8	0
1978	9	1823475	1981	9	196767	1985	9	0
1978	10	2135478	1981	10	0	1985	10	788038
1978	11	2119504	1981	11	386680	1985	11	2046223
1978	12	1603787	1981	12	1960672	1985	12	2002904
1979	1	2114526	1982	1	2055809	1986	1	2254965
1979	2	2021349	1982	2	1563844	1986	2	1981394
1979	3	1647683	1982	3	1440377	1986	3	2163376

Table A-2 cont'd

Monthly Thermal Generation During The First Twelve Fuel Cycles Of The Indian Point Unit 3 Reactor

Year	Month	Thermal Generation (MWt-hr)	Year	Month	Thermal Generation (MWt-hr)	Year	Month	Thermal Generation (MWt-hr)
1986	4	1801432	1989	4	0	1992	4	1243176
1986	5	261216	1989	5	0	1992	5	0
1986	6	1179256	1989	6	186875	1992	6	0
1986	7	181463	1989	7	2168026	1992	7	0
1986	8	0	1989	8	2202457	1992	8	1455404
1986	9	1469788	1989	9	2136821	1992	9	658303
1986	10	2177363	1989	10	1883145	1992	10	1138362
1986	11	2010045	1989	11	1883145	1992	11	1740734
1986	12	2247782	1989	12	2251639	1992	12	2249459
1987	1	2217919	1990	1	2228855	1993	1	1827512
1987	2	1680057	1990	2	2033379	1993	2	1857911
1987	3	1930676	1990	3	135483	1993	3	0
1987	4	1809631	1990	4	1547737	1993	4	0
1987	5	57335	1990	5	2241934	1993	5	0
1987	6	0	1990	6	2058672	1993	6	0
1987	7	0	1990	7	2175820	1993	7	0
1987	8	0	1990	8	2034186	1993	8	0
1987	9	1400877	1990	9	926462	1993	9	0
1987	10	2160202	1990	10	0	1993	10	0
1987	11	2143211	1990	11	0	1993	11	0
1987	12	2035559	1990	12	189055	1993	12	0
1988	1	2224853	1991	1	2072170	1994	1	0
1988	2	1979688	1991	2	2060225	1994	2	0
1988	3	2194305	1991	3	1440264	1994	3	0
1988	4	1979091	1991	4	1425214	1994	4	0
1988	5	761416	1991	5	1247238	1994	5	0
1988	6	1759009	1991	6	2197470	1994	6	0
1988	7	2155305	1991	7	2256537	1994	7	0
1988	8	2084174	1991	8	2168594	1994	8	0
1988	9	2092028	1991	9	2186839	1994	9	0
1988	10	831920	1991	10	1325804	1994	10	0
1988	11	521805	1991	11	1910528	1994	11	0
1988	12	2203860	1991	12	2278127	1994	12	0
1989	1	2192602	1992	1	2275140	1995	1	0
1989	2	180873	1992	2	2133566	1995	2	0
1989	3	0	1992	3	2133566	1995	3	0

Table A-2 cont'd

Monthly Thermal Generation During The First Twelve Fuel Cycles
Of The Indian Point Unit 3 Reactor

Year	Month	Thermal Generation (MWt-hr)	Year	Month	Thermal Generation (MWt-hr)	Year	Month	Thermal Generation (MWt-hr)
1995	4	0	1998	4	2177403	2001	4	1959848
1995	5	0	1998	5	2224644	2001	5	416282
1995	6	149	1998	6	2030124	2001	6	2156571
1995	7	1360205	1998	7	2119531	2001	7	2245664
1995	8	2219597	1998	8	1295166	2001	8	2243771
1995	9	992785	1998	9	2025197	2001	9	2216498
1995	10	0	1998	10	2251102	2001	10	2216498
1995	11	0	1998	11	1314785	2001	11	2216498
1995	12	0	1998	12	1904078	2001	12	2264345
1996	1	0	1999	1	2244323	2002	1	2267346
1996	2	0	1999	2	2030095	2002	2	2047713
1996	3	0	1999	3	1851999	2002	3	2265719
1996	4	1610268	1999	4	2172953	2002	4	2190676
1996	5	1970640	1999	5	2225331	2002	5	2269544
1996	6	2157246	1999	6	2170027	2002	6	2192665
1996	7	2095611	1999	7	2198814	2002	7	2247948
1996	8	2174775	1999	8	2011341	2002	8	2213933
1996	9	2120695	1999	9	613391	2002	9	2181936
1996	10	2002741	1999	10	594041	2002	10	2265746
1996	11	1955649	1999	11	2082383	2002	11	1711030
1996	12	2099613	1999	12	2268422	2002	12	2175283
1997	1	1210149	2000	1	2266690	2003	1	2177101
1997	2	603387	2000	2	2118635	2003	2	2067096
1997	3	2242233	2000	3	2265943	2003	3	2056477
1997	4	2166533	2000	4	2188810	2003	4	121323
1997	5	959250	2000	5	2264330			
1997	6	0	2000	6	1877829			
1997	7	0	2000	7	2256059			
1997	8	0	2000	8	2250086			
1997	9	686135	2000	9	2179194			
1997	10	2087877	2000	10	2115678			
1997	11	2177701	2000	11	2190661			
1997	12	1273755	2000	12	2056591			
1998	1	2079247	2001	1	2268374			
1998	2	2031050	2001	2	2050102			
1998	3	2234917	2001	3	2269861			

Table A-3

Calculated C_j Factors at the Surveillance Capsule Center
Core Midplane Elevation

Fuel Cycle	ϕ(E > 1.0 MeV) [n/cm2-s]			
	Capsule T	Capsule Y	Capsule Z	Capsule X
1	6.13E+10	6.13E+10	6.13E+10	1.97E+10
2		7.50E+10	7.50E+10	2.21E+10
3		7.03E+10	7.03E+10	2.57E+10
4			5.11E+10	2.30E+10
5			4.62E+10	2.06E+10
6				1.85E+10
7				1.71E+10
8				2.03E+10
9				1.80E+10
10				1.34E+10
11				1.20E+10
12				1.25E+10
Average	6.13E+10	6.78E+10	5.99E+10	1.78E+10

Fuel Cycle	C_j			
	Capsule T	**Capsule Y**	**Capsule Z**	**Capsule X**
1	1.00	0.90	1.02	1.11
2		1.11	1.25	1.24
3		1.04	1.17	1.44
4			0.85	1.29
5			0.77	1.16
6				1.04
7				0.96
8				1.14
9				1.01
10				0.75
11				0.67
12				0.70
Average	1.00	1.00	1.00	1.00

Table A-4

Measured Sensor Activities And Reaction Rates
Surveillance Capsule T

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	4.87E+04	3.25E+05	3.10E+05	4.74E-17
	Bottom	4.59E+04	3.06E+05	2.93E+05	4.46E-17
	Average				**4.60E-17**
^{54}Fe (n,p) ^{54}Mn	W-40	1.37E+06	3.50E+06	3.34E+06	5.29E-15
	W-37	1.25E+06	3.19E+06	3.04E+06	4.83E-15
	B-9	1.34E+06	3.42E+06	3.26E+06	5.17E-15
	A-32	1.17E+06	2.99E+06	3.46E+06	5.48E-15
	AT-58	1.09E+06	2.79E+06	3.22E+06	5.10E-15
	AT-54	1.18E+06	3.02E+06	3.49E+06	5.53E-15
	Average				**5.23E-15**
^{58}Ni (n,p) ^{58}Co	Middle	8.11E+06	5.00E+07	4.77E+07	6.82E-15
	Average				**6.82E-15**
^{59}Co (n,γ) ^{60}Co	Top	7.63E+06	5.09E+07	4.96E+07	3.24E-12
	Middle	6.84E+06	4.57E+07	4.45E+07	2.90E-12
	Bottom	7.68E+06	5.13E+07	4.99E+07	3.26E-12
	Average				**3.13E-12**
^{59}Co (n,γ) ^{60}Co (Cd)	Top	3.08E+06	2.06E+07	2.37E+07	1.55E-12
	Middle	3.03E+06	2.02E+07	2.33E+07	1.52E-12
	Bottom	3.02E+06	2.02E+07	2.32E+07	1.52E-12
	Average				**1.53E-12**

Notes:

1) Measured specific activities are indexed to a counting date of November 7, 1978.
2) The location of the iron sensors corresponds to individual Charpy specimens from which the iron samples were extracted.

Table A-4 cont'd

Measured Sensor Activities And Reaction Rates
Surveillance Capsule Y

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	8.58E+04	3.09E+05	2.95E+05	4.50E-17
	Bottom	8.93E+04	3.21E+05	3.07E+05	4.68E-17
	Average				**4.59E-17**
$^{54}Fe\ (n,p)\ ^{54}Mn$	W-16	1.05E+06	3.13E+06	2.98E+06	4.73E-15
	W-12	1.04E+06	3.10E+06	2.96E+06	4.68E-15
	W-9	1.06E+06	3.16E+06	3.01E+06	4.77E-15
	AT-37	8.98E+05	2.68E+06	3.10E+06	4.91E-15
	AT-33	8.70E+05	2.59E+06	3.00E+06	4.75E-15
	AT-30	8.14E+05	2.43E+06	2.81E+06	4.45E-15
	Average				**4.72E-15**
$^{58}Ni\ (n,p)\ ^{58}Co$	Middle	4.05E+06	4.64E+07	4.42E+07	6.33E-15
	Average				**6.33E-15**
$^{238}U\ (n,f)\ ^{137}Cs$ (Cd)	Middle	3.32E+05	4.71E+06	4.71E+06	3.10E-14
$^{238}U\ (n,f)\ ^{137}Cs$ (Cd)		Including ^{235}U, ^{239}Pu, and γ,fission corrections:			**2.54E-14**
$^{237}Np\ (n,f)\ ^{137}Cs$ (Cd)	Middle	2.34E+06	3.32E+07	3.32E+07	2.12E-13
$^{237}Np\ (n,f)\ ^{137}Cs$ (Cd)			Including γ,fission correction:		**2.09E-13**
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Top	1.52E+07	5.47E+07	5.33E+07	3.48E-12
	Middle	1.42E+07	5.11E+07	4.98E+07	3.25E-12
	Bottom	1.52E+07	5.47E+07	5.33E+07	3.48E-12
	Average				**3.40E-12**
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)	Top	5.56E+06	2.00E+07	2.31E+07	1.50E-12
	Middle	5.36E+06	1.93E+07	2.22E+07	1.45E-12
	Bottom	5.79E+06	2.08E+07	2.40E+07	1.57E-12
	Average				**1.51E-12**

Notes:

1) Measured specific activities are indexed to a counting date of October 20, 1982.
2) The average ^{238}U (n,f) reaction rate of 2.54E-14 includes a correction factor of 0.858 to account for ^{235}U impurities & plutonium build-in & an additional factor of 0.958 to account for photo-fission effects in the sensor.
3) The average ^{237}Np (n,f) reaction rate of 2.09E-13 includes a correction factor of 0.985 to account for photo-fission effects in the sensor.
4) The location of the iron sensors corresponds to individual Charpy specimens from which the iron samples were extracted.

Table A-4 cont'd

Measured Sensor Activities And Reaction Rates
Surveillance Capsule Z

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	1.01E+05	2.93E+05	2.80E+05	4.27E-17
	Bottom	9.92E+04	2.88E+05	2.75E+05	4.20E-17
	Average				4.23E-17
$^{54}Fe\ (n,p)\ ^{54}Mn$	W-64	9.92E+05	2.85E+06	2.71E+06	4.30E-15
	W-61	9.93E+05	2.85E+06	2.72E+06	4.31E-15
	TI	9.66E+05	2.77E+06	2.64E+06	4.19E-15
	AT-82	7.94E+05	2.28E+06	2.64E+06	4.18E-15
	AT-78	8.25E+05	2.37E+06	2.74E+06	4.34E-15
	A-56	7.65E+05	2.20E+06	2.54E+06	4.02E-15
	Average				4.22E-15
$^{58}Ni\ (n,p)\ ^{58}Co$	Middle	4.03E+06	3.83E+07	3.65E+07	5.22E-15
	Average				5.22E-15
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Top	1.47E+07	4.27E+07	4.16E+07	2.71E-12
	Middle	1.36E+07	3.95E+07	3.85E+07	2.51E-12
	Bottom	1.49E+07	4.33E+07	4.21E+07	2.75E-12
	Average				2.66E-12
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)	Top	5.90E+06	1.71E+07	1.97E+07	1.29E-12
	Middle	5.82E+06	1.69E+07	1.95E+07	1.27E-12
	Bottom	5.92E+06	1.72E+07	1.98E+07	1.29E-12
	Average				1.28E-12

Notes:
1) Measured specific activities are indexed to a counting date of November 1, 1987.
2) The location of the iron sensors corresponds to individual Charpy specimens from which the iron samples were extracted.

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)
$^{63}Cu\ (n,\alpha)\ ^{60}Co$	Top	6.94E+04	1.38E+05	1.32E+05	2.01E-17
	Bottom	6.65E+04	1.32E+05	1.26E+05	1.92E-17
	Average				**1.97E-17**
$^{54}Fe\ (n,p)\ ^{54}Mn$	AT-67	2.78E+05	8.08E+05	9.28E+05	1.47E-15
	AT-64	2.56E+05	7.44E+05	8.55E+05	1.36E-15
	AT-69	2.83E+05	8.22E+05	9.45E+05	1.50E-15
	Average				**1.44E-15**
$^{58}Ni\ (n,p)\ ^{58}Co$	Middle	5.31E+05	1.47E+07	1.40E+07	2.01E-15
$^{59}Co\ (n,\gamma)\ ^{60}Co$	Top	4.09E+06	8.12E+06	7.71E+06	5.03E-13
	Middle	4.42E+06	8.77E+06	8.33E+06	5.44E-13
	Bottom	4.68E+06	9.29E+06	8.82E+06	5.76E-13
	Average				**5.41E-13**
$^{59}Co\ (n,\gamma)\ ^{60}Co$ (Cd)	Top	1.67E+06	3.31E+06	3.72E+06	2.43E-13
	Middle	1.71E+06	3.39E+06	3.81E+06	2.49E-13
	Bottom	1.75E+06	3.47E+06	3.90E+06	2.55E-13
	Average				**2.49E-13**

Notes:
1) Measured specific activities are indexed to a counting date of January 23, 2004.
2) The location of the iron sensors corresponds to individual charpy specimens from which the iron samples were extracted.

Table A-5

Comparison of Measured, Calculated, and Best Estimate
Reaction Rates At The Surveillance Capsule Center

Capsule T

	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	4.60E-17	3.80E-17	4.58E-17	1.21	1.00
$^{54}Fe(n,p)^{54}Mn$	5.23E-15	4.25E-15	5.12E-15	1.23	1.02
$^{58}Ni(n,p)^{58}Co$	6.82E-15	5.87E-15	6.95E-15	1.16	0.98
$^{238}U(n,f)^{137}Cs$ (Cd)					
$^{237}Np(n,f)^{137}Cs$ (Cd)					
$^{59}Co(n,\gamma)^{60}Co$	3.13E-12	2.48E-12	3.11E-12	1.26	1.01
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	1.53E-12	1.29E-12	1.53E-12	1.19	1.00

Capsule Y

	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	4.59E-17	4.16E-17	4.46E-17	1.10	1.03
$^{54}Fe(n,p)^{54}Mn$	4.72E-15	4.69E-15	4.80E-15	1.01	0.98
$^{58}Ni(n,p)^{58}Co$	6.33E-15	6.47E-15	6.56E-15	0.98	0.96
$^{238}U(n,f)^{137}Cs$ (Cd)	2.54E-14	2.34E-14	2.41E-14	1.09	1.05
$^{237}Np(n,f)^{137}Cs$ (Cd)	2.09E-13	1.85E-13	2.00E-13	1.13	1.05
$^{59}Co(n,\gamma)^{60}Co$	3.40E-12	2.75E-12	3.37E-12	1.24	1.01
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	1.51E-12	1.44E-12	1.52E-12	1.05	0.99

Table A-5

Comparison of Measured, Calculated, and Best Estimate
Reaction Rates At The Surveillance Capsule Center

Capsule Z

	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	4.23E-17	3.76E-17	4.06E-17	1.13	1.04
$^{54}Fe(n,p)^{54}Mn$	4.22E-15	4.18E-15	4.16E-15	1.01	1.01
$^{58}Ni(n,p)^{58}Co$	5.22E-15	5.76E-15	5.54E-15	0.91	0.94
$^{238}U(n,f)^{137}Cs$ (Cd)					
$^{237}Np(n,f)^{137}Cs$ (Cd)					
$^{59}Co(n,\gamma)^{60}Co$	2.66E-12	2.41E-12	2.65E-12	1.10	1.00
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	1.28E-12	1.26E-12	1.28E-12	1.02	1.00

Capsule X

	Reaction Rate [rps/atom]				
Reaction	Measured	Calculated	Best Estimate	M/C	M/BE
$^{63}Cu(n,\alpha)^{60}Co$	1.97E-17	1.81E-17	1.88E-17	1.09	1.05
$^{54}Fe(n,p)^{54}Mn$	1.44E-15	1.60E-15	1.50E-15	0.90	0.96
$^{58}Ni(n,p)^{58}Co$	2.01E-15	2.14E-15	2.03E-15	0.94	0.99
$^{238}U(n,f)^{137}Cs$ (Cd)					
$^{237}Np(n,f)^{137}Cs$ (Cd)					
$^{59}Co(n,\gamma)^{60}Co$	5.41E-13	5.49E-13	5.40E-13	0.99	1.00
$^{59}Co(n,\gamma)^{60}Co$ (Cd)	2.49E-13	2.79E-13	2.50E-13	0.89	1.00

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
T	6.13E+10	7.21E+10	7%	1.18
Y	6.78E+10	7.03E+10	6%	1.04
Z	5.99E+10	5.63E+10	7%	0.94
X	1.78E+10	1.62E+10	7%	0.91

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
T	1.03E-10	1.19E-10	9%	1.15
Y	1.14E-10	1.19E-10	7%	1.03
Z	1.01E-10	9.46E-11	9%	0.94
X	2.87E-11	2.60E-11	8%	0.91

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	M/C Ratio			
	Capsule T	**Capsule Y**	**Capsule Z**	**Capsule X**
$^{63}Cu(n,\alpha)^{60}Co$	1.21	1.10	1.13	1.09
$^{54}Fe(n,p)^{54}Mn$	1.23	1.01	1.01	0.90
$^{58}Ni(n,p)^{58}Co$	1.16	0.98	0.91	0.94
$^{238}U(n,p)^{137}Cs$ (Cd)		1.09		
$^{237}Np(n,f)^{137}Cs$ (Cd)		1.13		
Average	1.20	1.06	1.01	0.98
% Standard Deviation	2.9	6.1	10.8	10.2

Note: The overall average M/C ratio for the set of 14 sensor measurements is 1.06 with an associated standard deviation of 10.1%.

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
T	1.18	1.15
Y	1.04	1.03
Z	0.94	0.94
X	0.91	0.91
Average	1.02	1.01
% Standard Deviation	11.9	10.9

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 1995.

A-2. WCAP-9491, "Analysis of Capsule T from the Indian Point Unit No. 3 Unit 1 Reactor Vessel Radiation Surveillance Program," J. A. Davidson, et. al., April 1979.

A-3 WCAP-10300, "Analysis of Capsule Y from the Power Authority of the State of New York Indian Point Unit No. 3 Unit 1 Reactor Vessel Radiation Surveillance Program," S.E. Yanichko, et. al., March 1983.

A-4 WCAP-11815, "Analysis of Capsule Z from the New York Power Authority Indian Point Unit No. 3 Unit 1 Reactor Vessel Radiation Surveillance Program," S.E. Yanichko, et. al., March 1988.

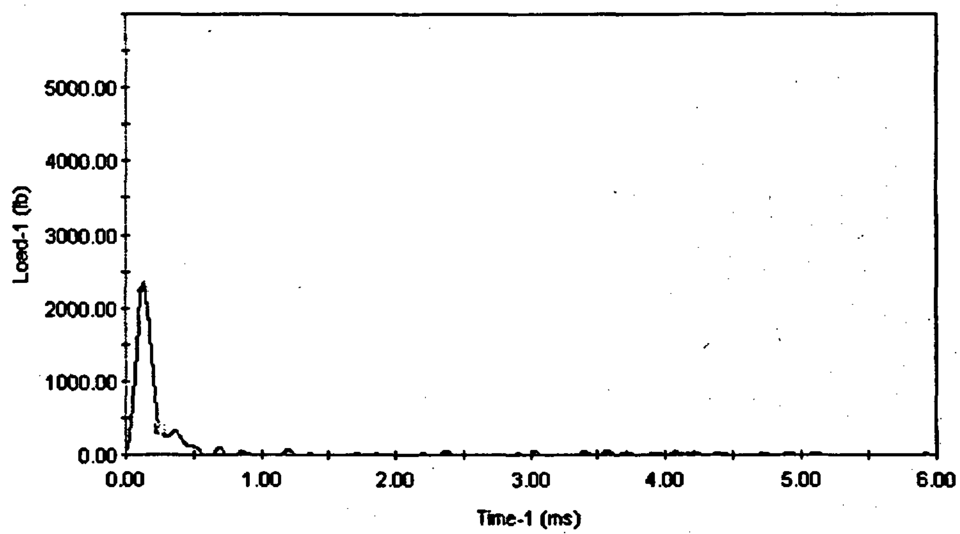
A-5 A. Schmittroth, *FERRET Data Analysis Core*, HEDL-TME 79-40, Hanford Engineering Development Laboratory, Richland, WA, September 1979.

A-6. RSIC Data Library Collection DLC-178, "SNLRML Recommended Dosimetry Cross-Section Compendium", July 1994.

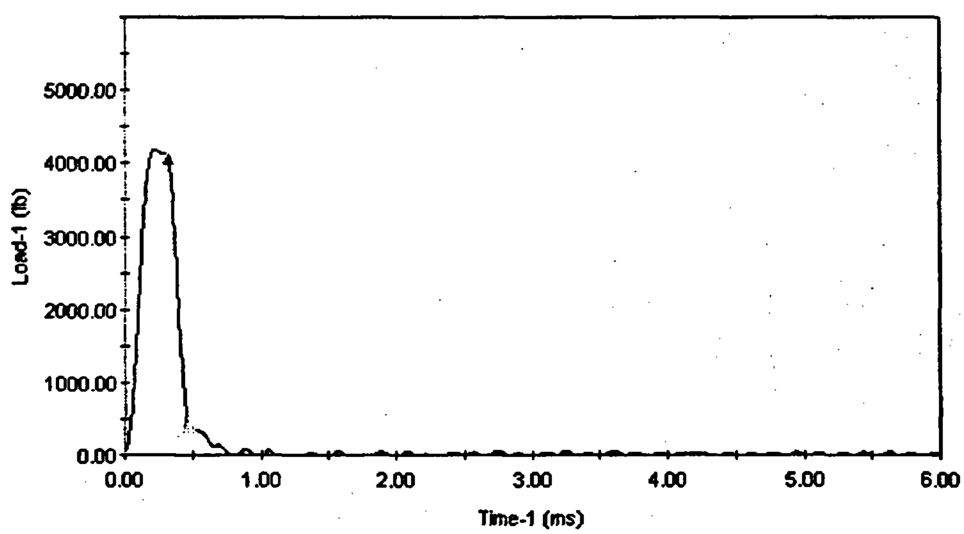
APPENDIX B

LOAD-TIME RECORDS FOR CHARPY SPECIMEN TESTS

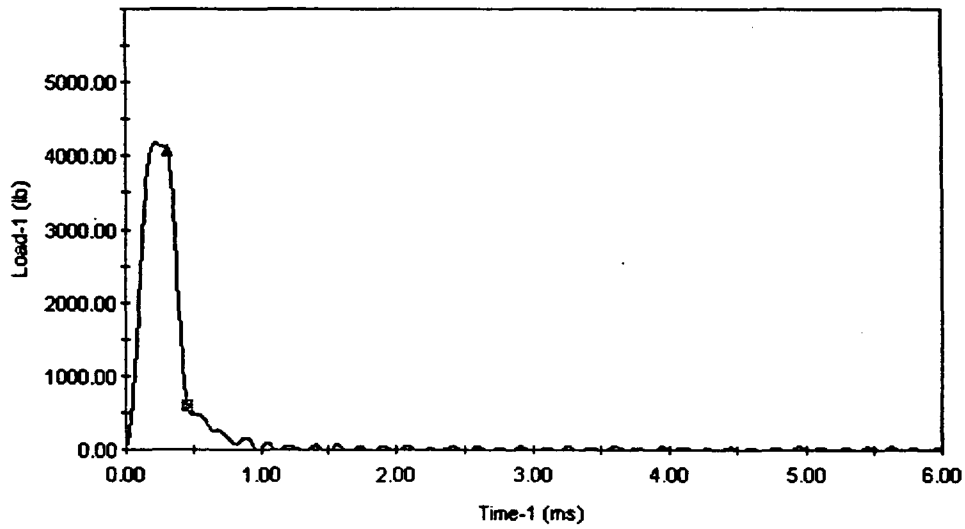
- Specimen prefix "A" denotes Lower Shell Plate B2803-3, Longitudinal Orientation
- Specimen prefix "AT" denotes Lower Shell Plate B2803-3, Transverse Orientation
- Specimen prefix "W" denotes Weld Material
- Specimen prefix "N" denotes Intermediate Shell Plate B2802-2, Long. Orientation
- Load (1) is in units of lbs
- Time (1) is in units of milli seconds



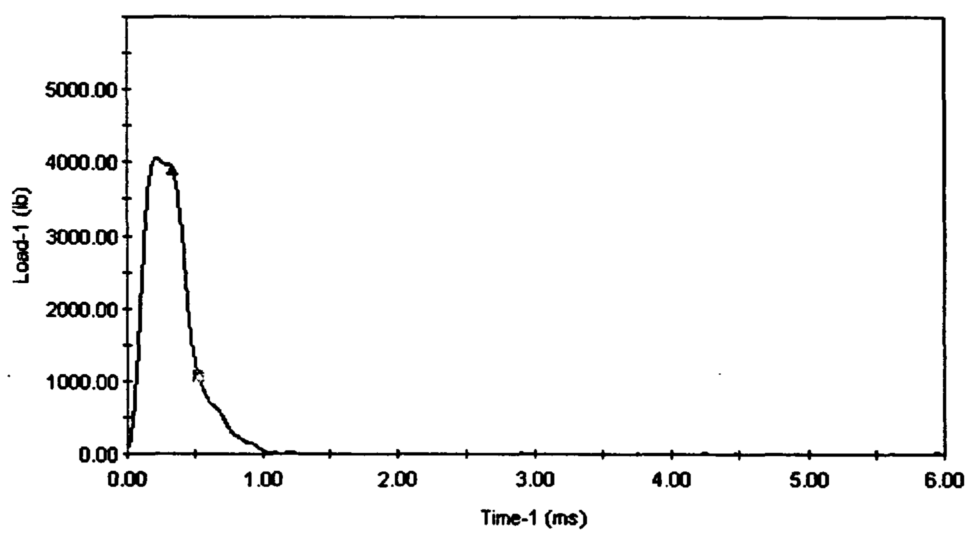
A37, 100°F



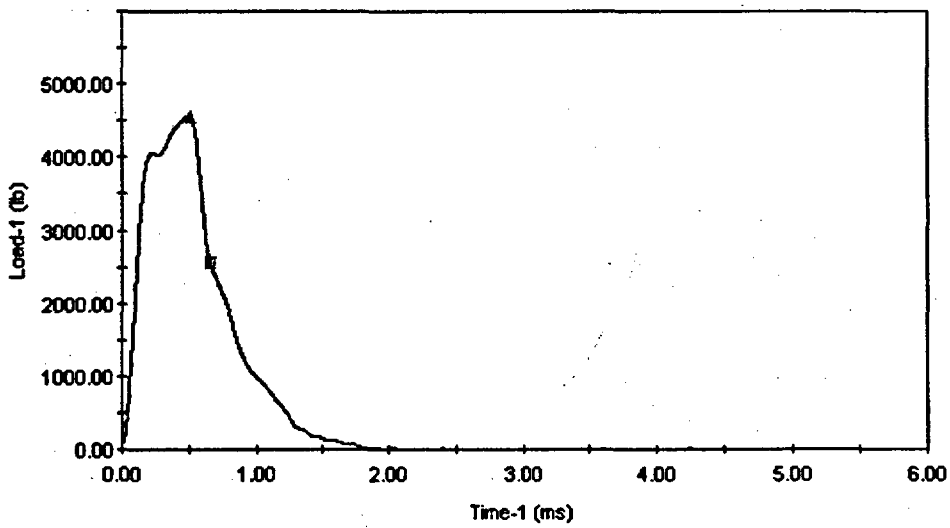
A34, 150°F



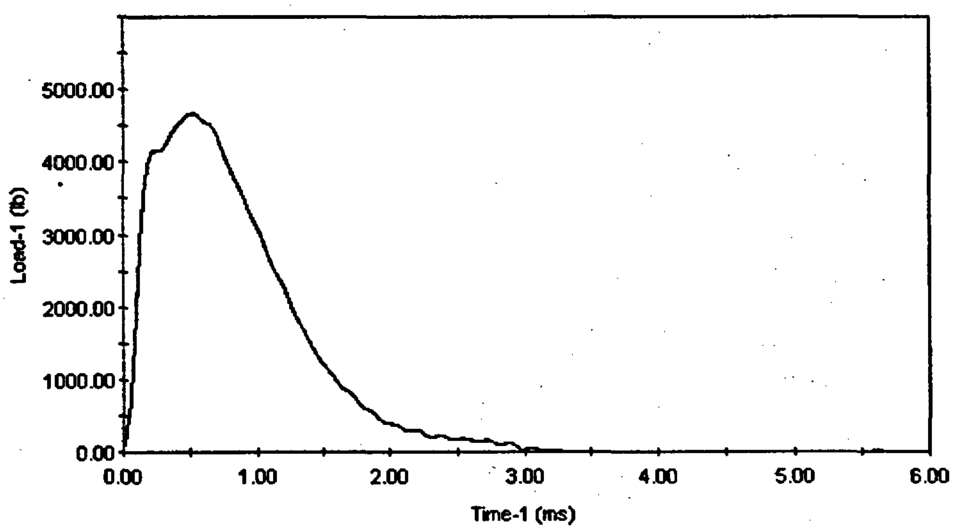
A36, 175°F



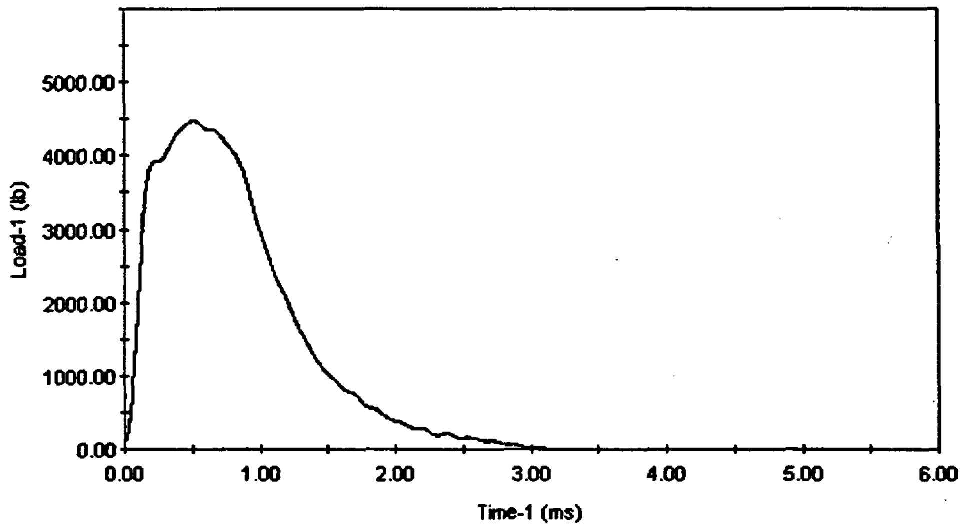
A33, 200°F



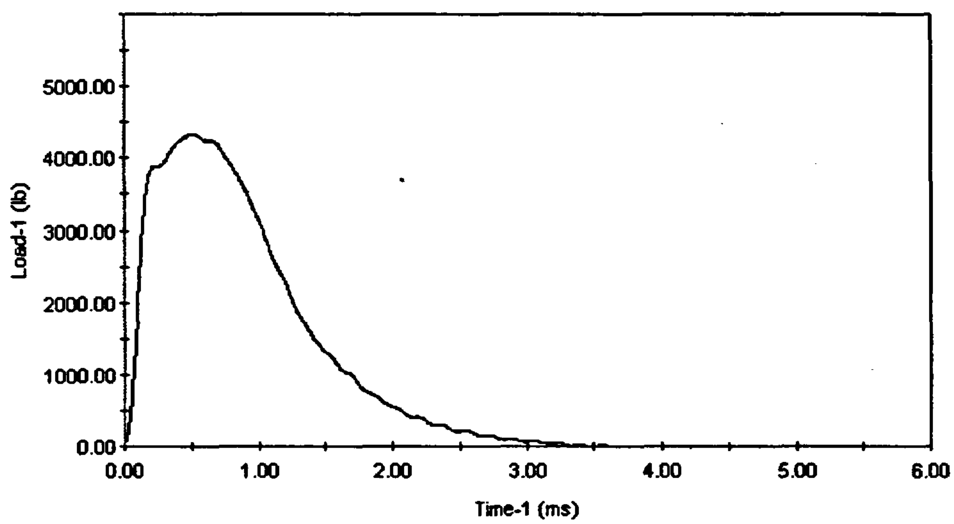
A40, 225°F



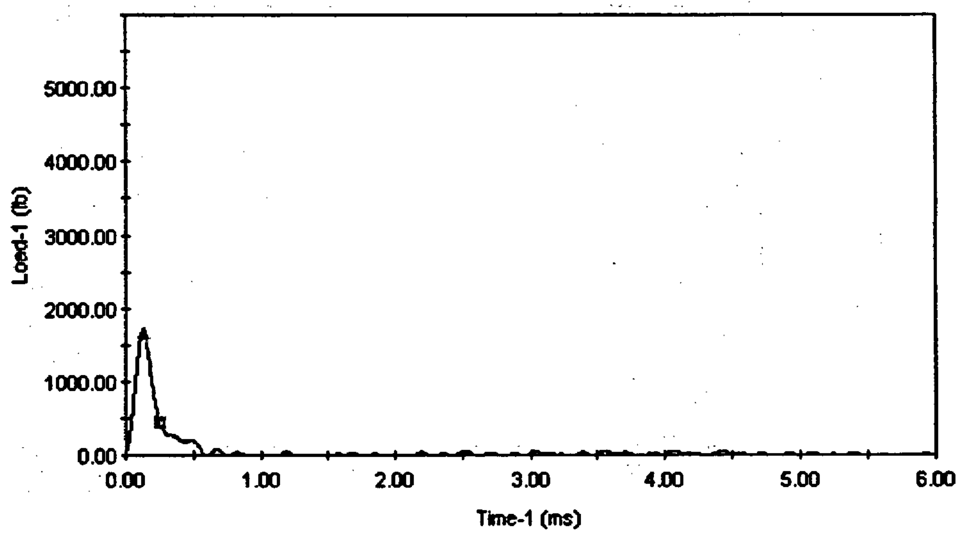
A39, 280°F



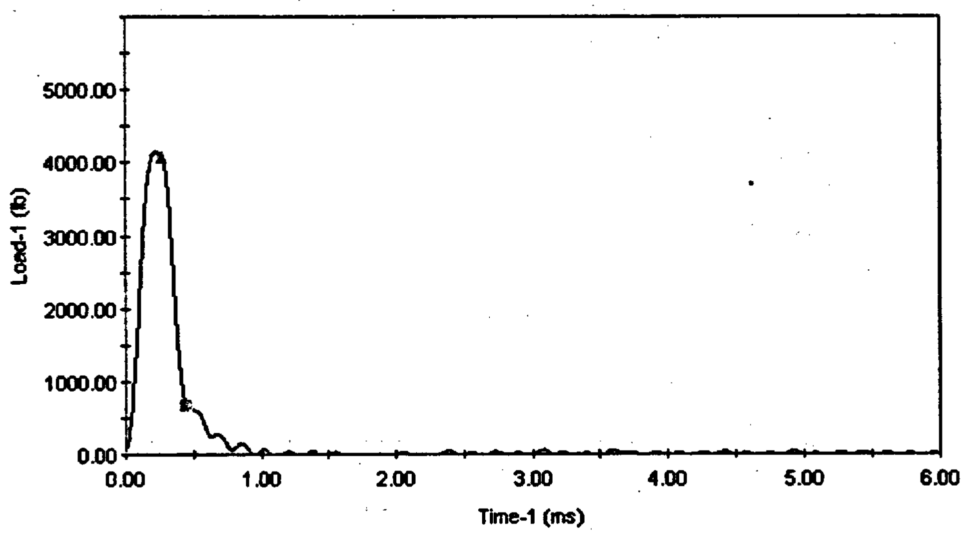
A35, 350°F



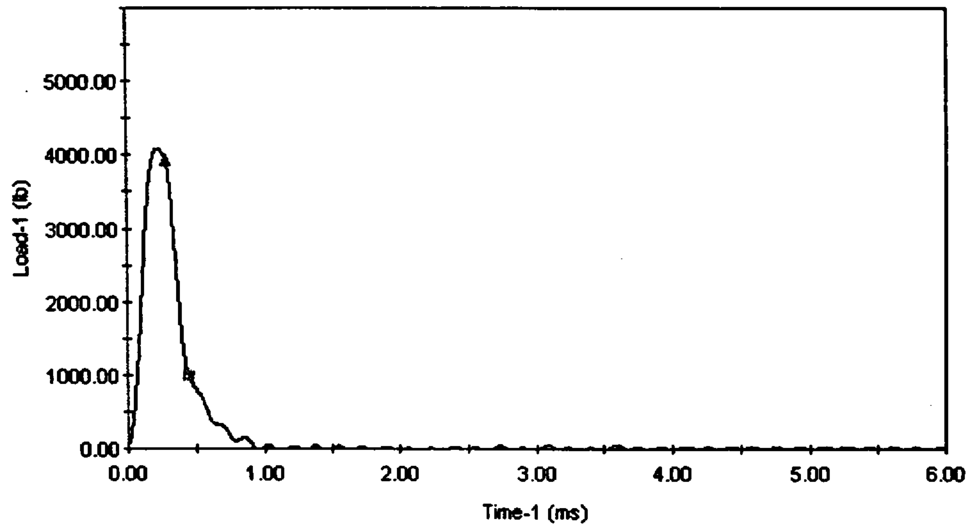
A38, 375°F



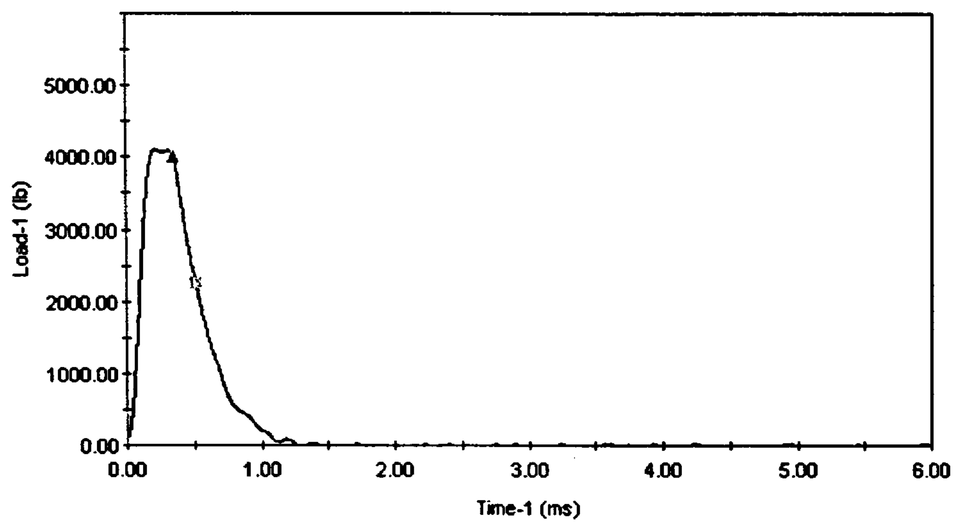
AT64, 100°F



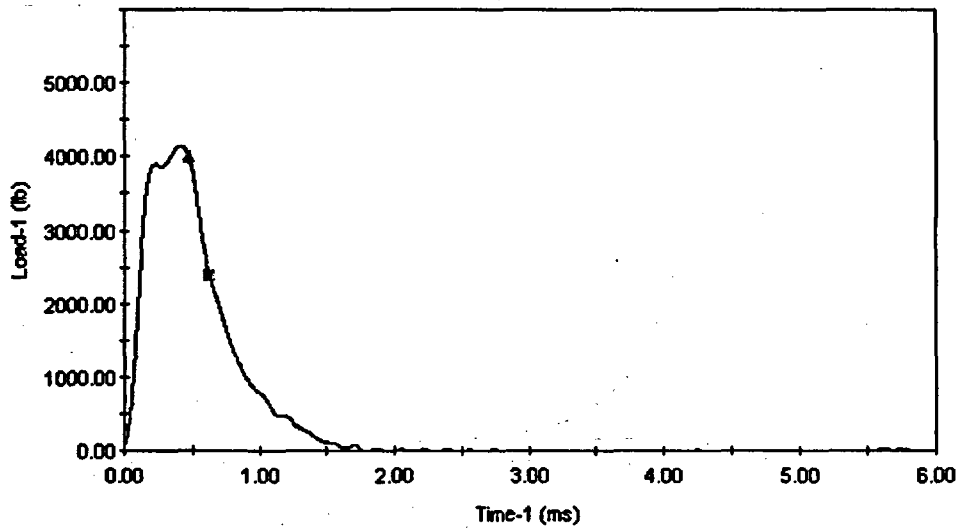
AT69, 175°F



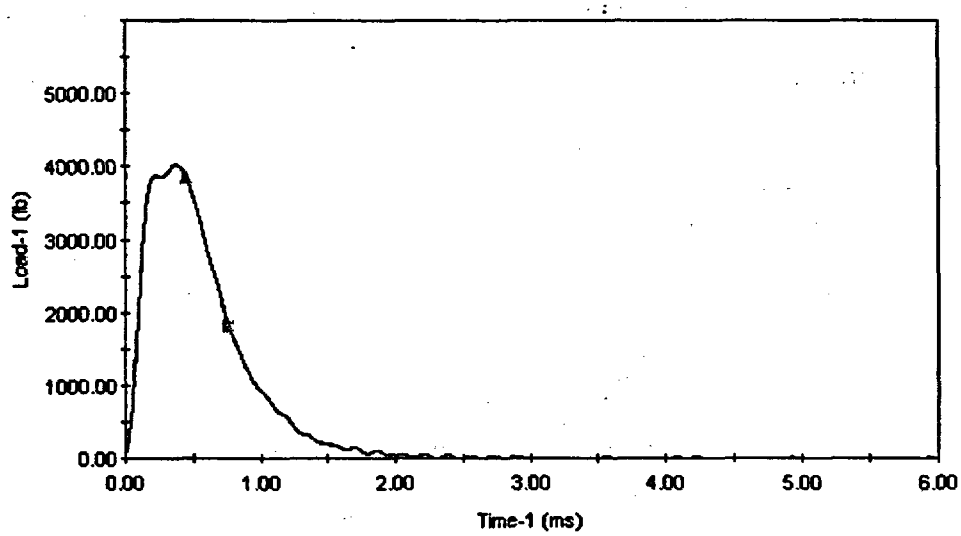
AT68, 210°F



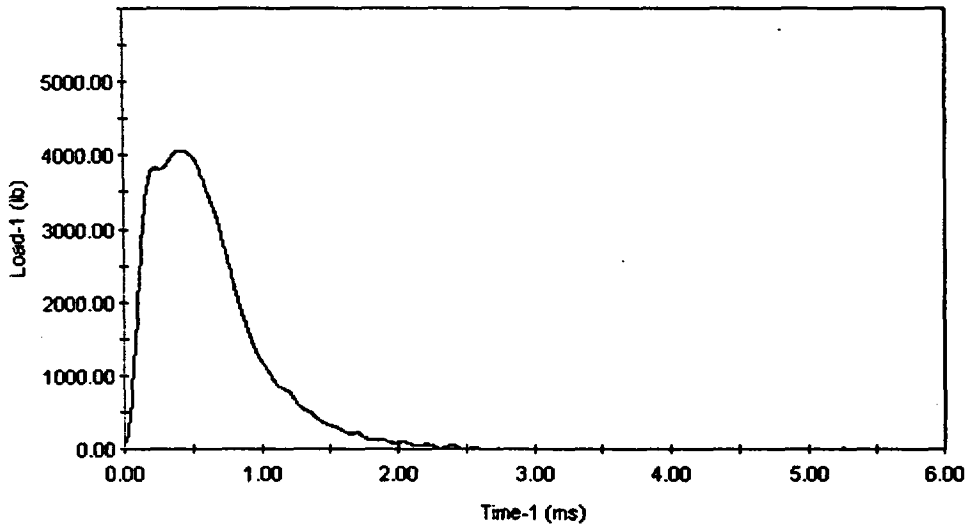
AT67, 225°F



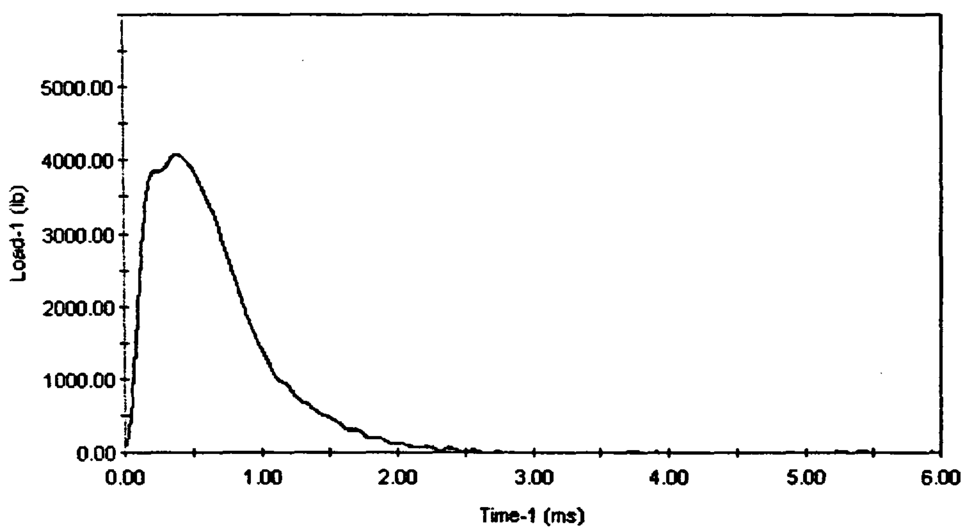
AT66, 250°F



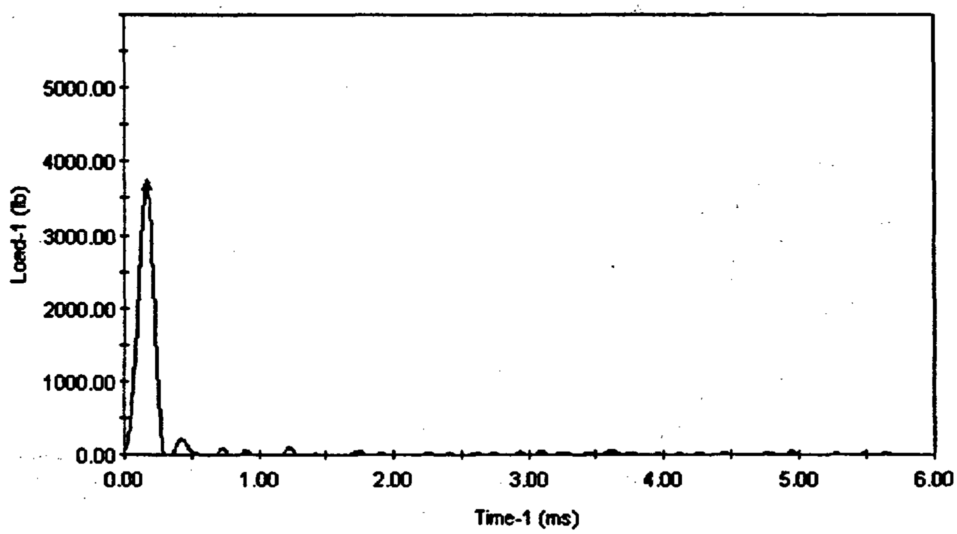
AT65, 325°F



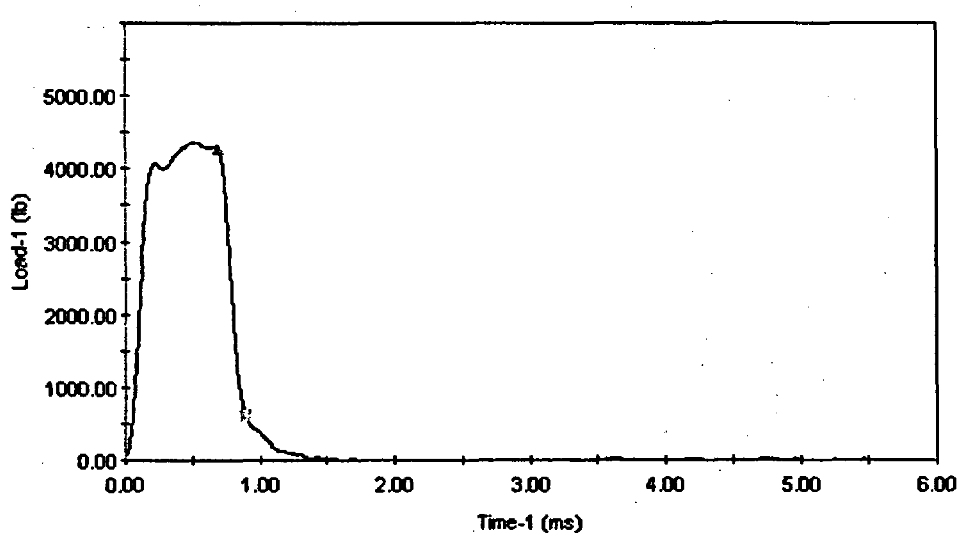
AT62, 375°F



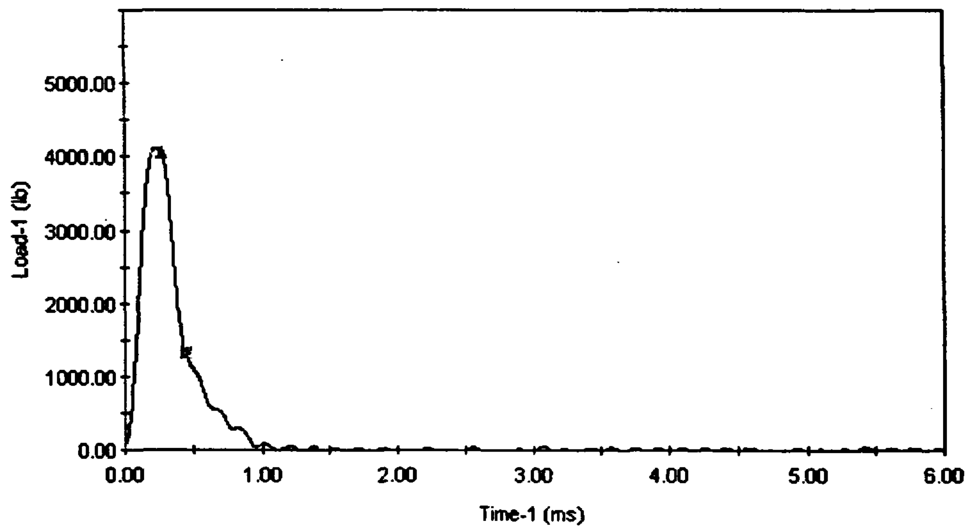
AT63, 390°F



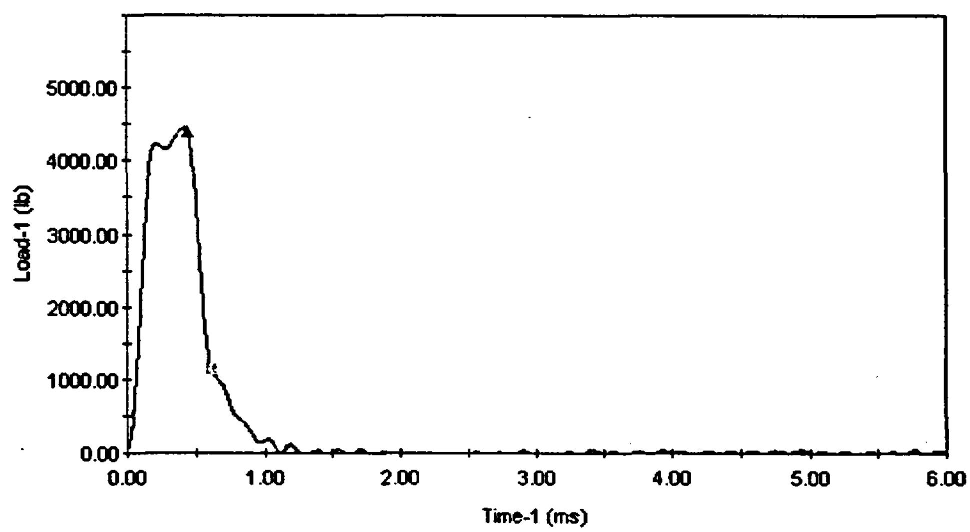
W42, 75°F



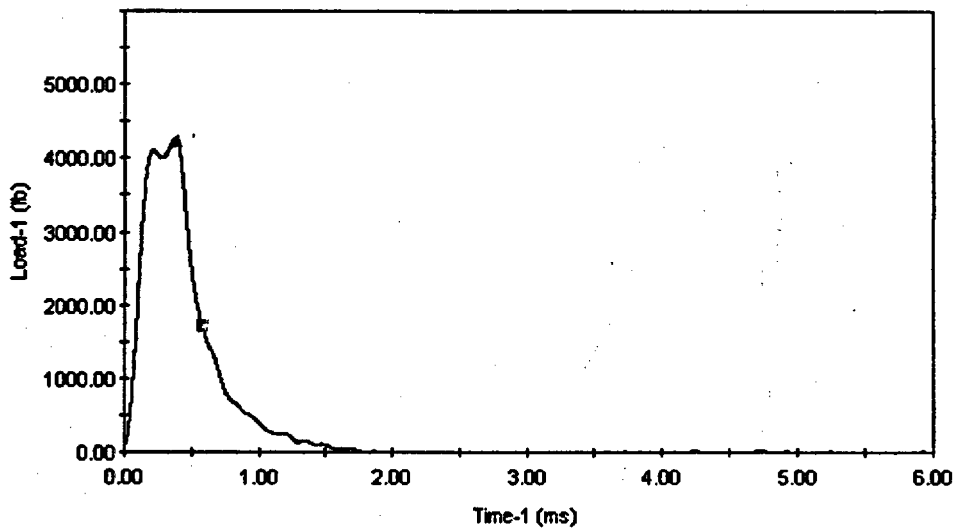
W41, 125°F



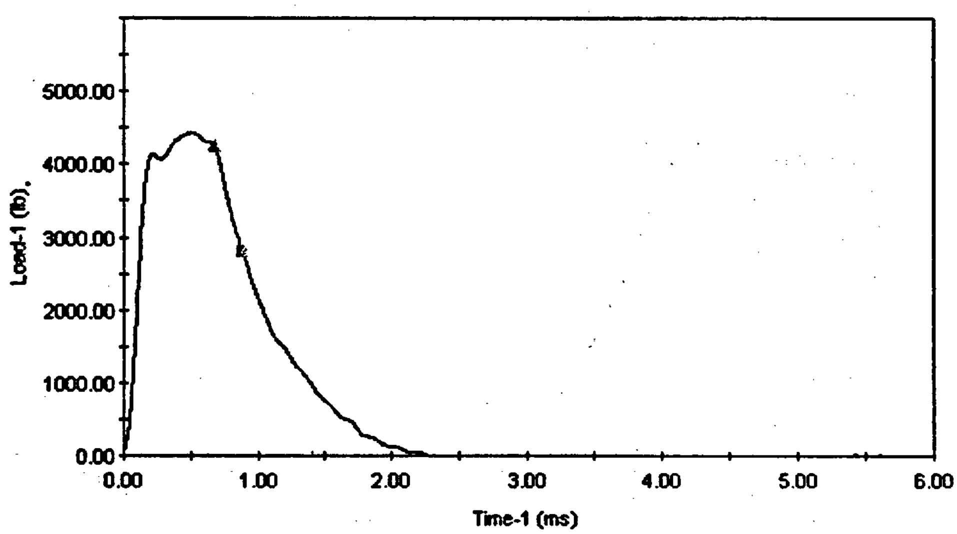
W43, 125°F



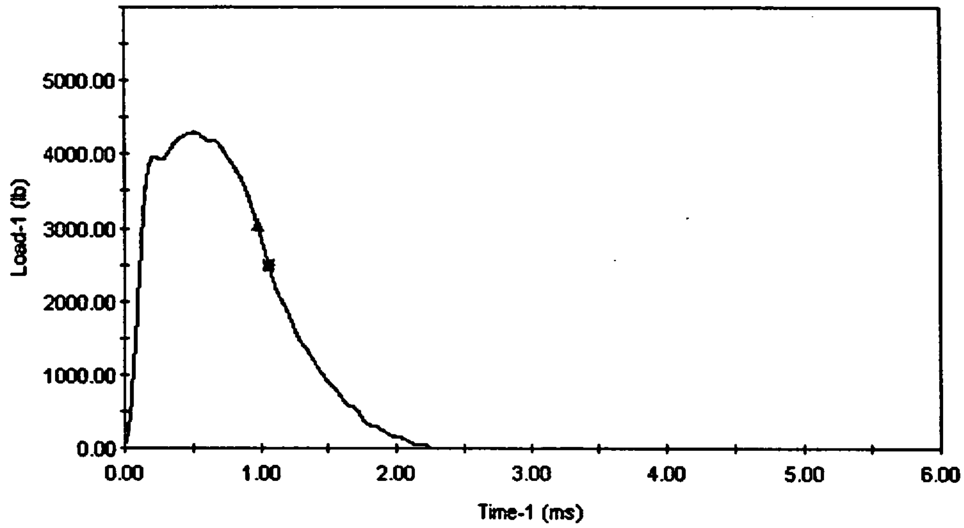
W48, 150°F



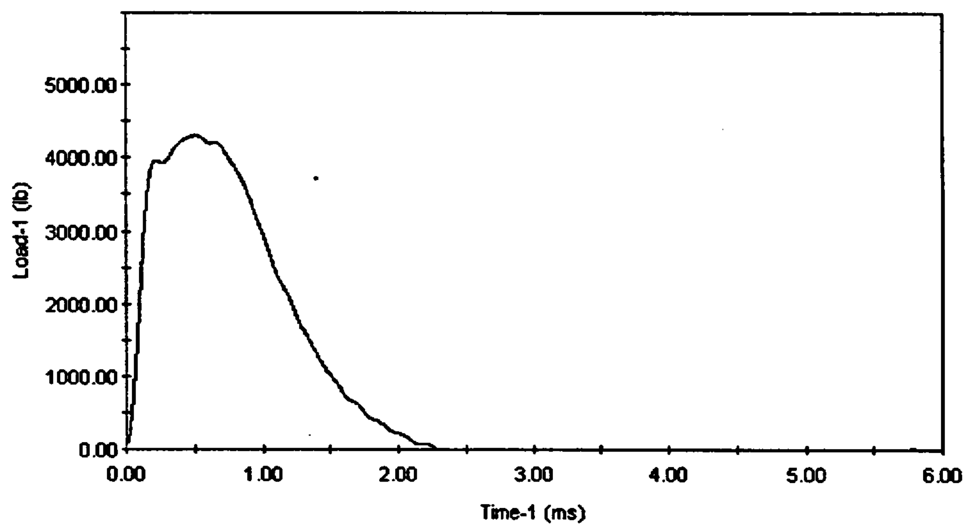
W47, 200°F



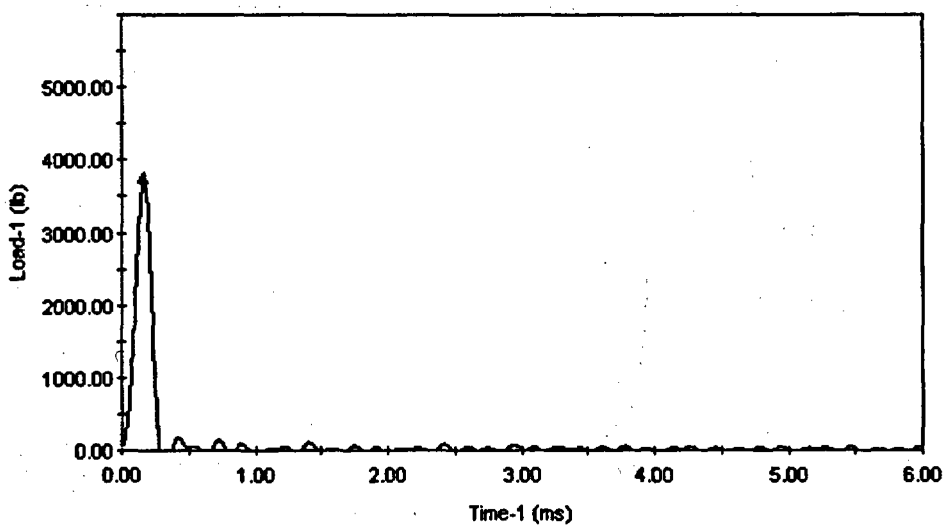
W44, 250°F



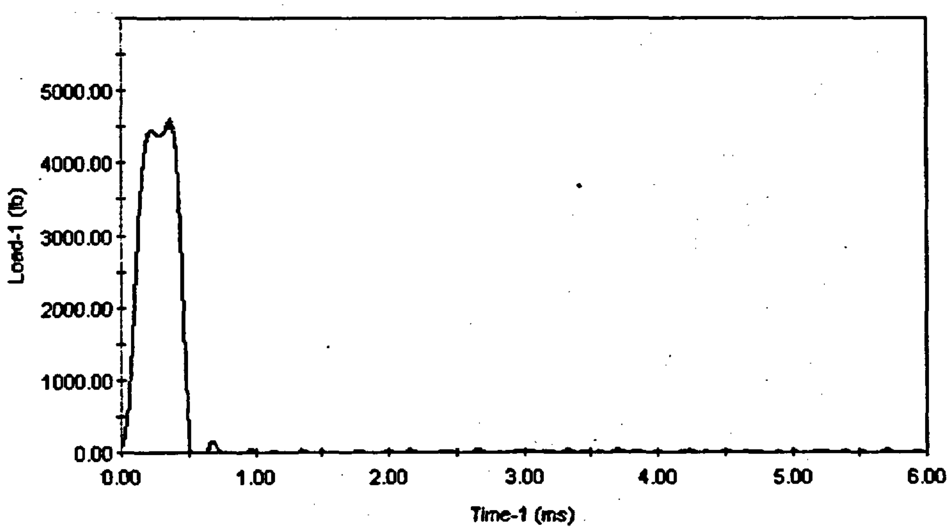
W45, 300°F



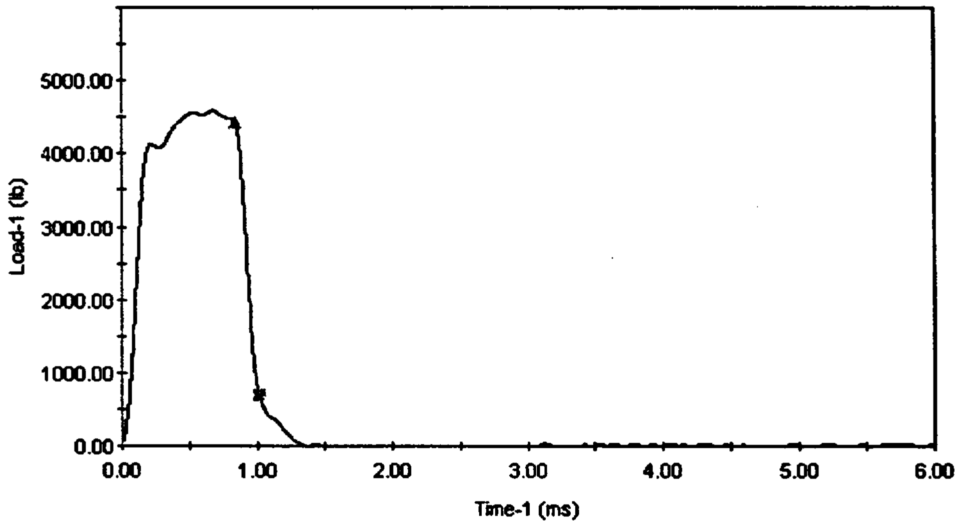
W46, 350°F


5000.00
4000.00
3000.00
2000.00
1000.00
0.00
Load-1 (lb)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Time-1 (ms)

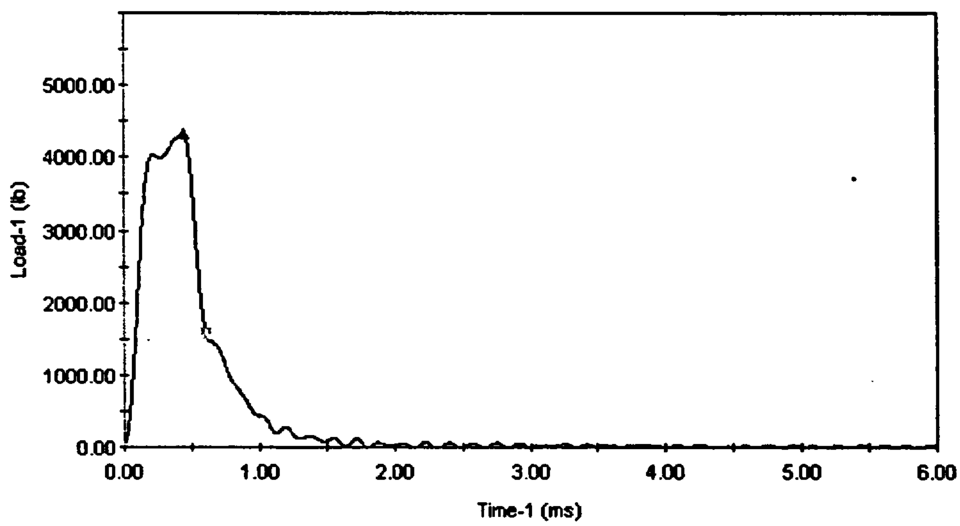
N2, 25°F


5000.00
4000.00
3000.00
2000.00
1000.00
0.00
Load-1 (lb)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Time-1 (ms)

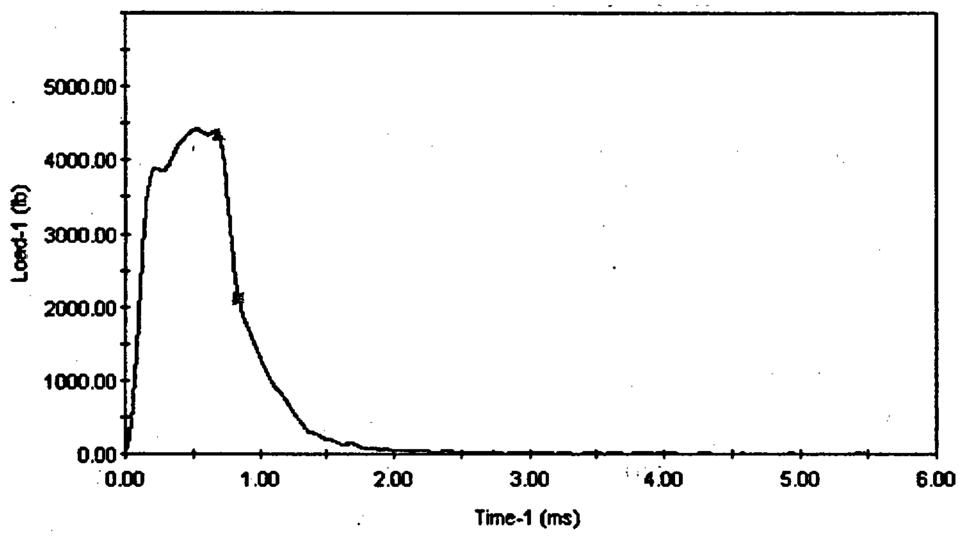
N6, 75°F



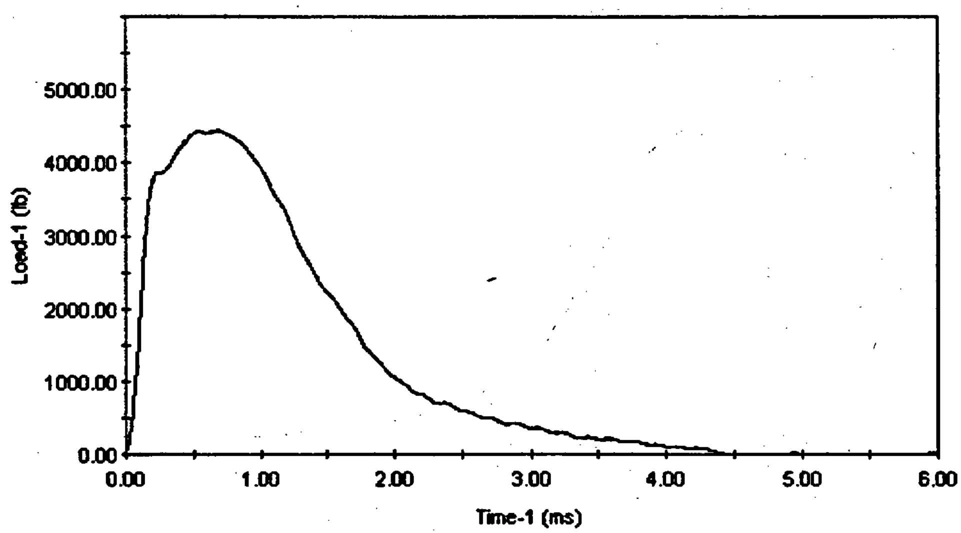
N5, 125°F



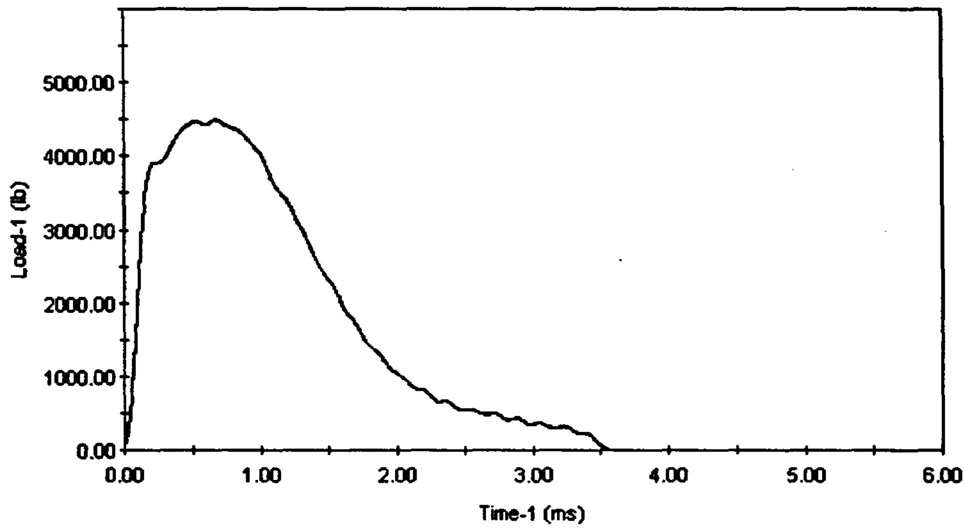
N7, 150°F



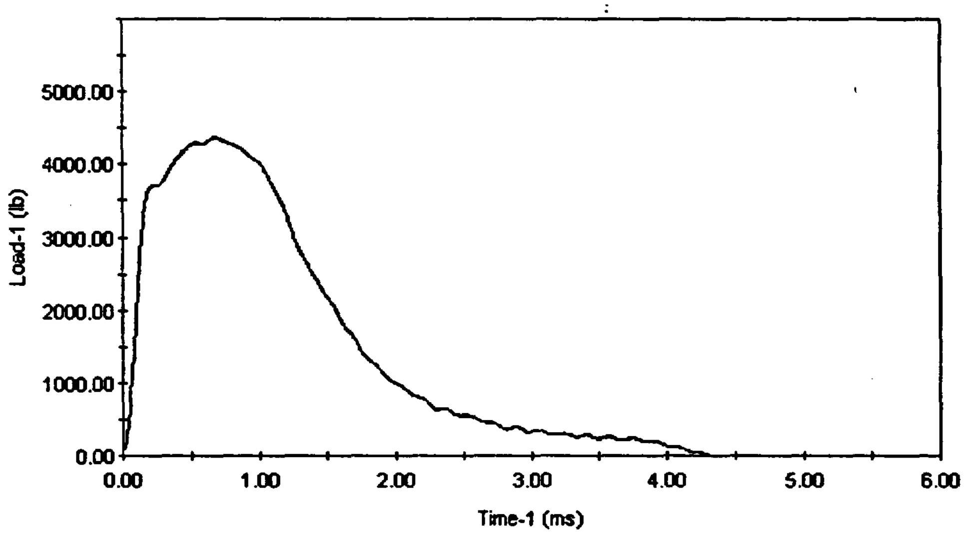
N4, 200°F



N1, 250°F



N8, 300°F



N3, 325°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."

If there are specimens tested in set of three at each temperature Westinghouse reports the set having the highest average energy as the USE (usually unirradiated material). If the specimens were not tested in sets of three at each temperature Westinghouse reports the average of all 100% shear Charpy data as the USE. Hence, 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 [ft-lb]

Material	Unirradiated	Capsule T	Capsule Y	Capsule Z	Capsule X
Lower Shell Plate B2803-3 (*Long.*)	105 ft-lbs	92 ft-lbs	---	82 ft-lbs	81 ft-lbs
Lower Shell Plate B2803-3 (*Trans.*)	68 ft-lbs	57 ft-lbs	51 ft-lbs	56 ft-lbs	52 ft-lbs
Weld Metal (*Heat # W5214*)	120 ft-lbs	84 ft-lbs	69 ft-lbs	76 ft-lbs	74 ft-lbs
Inter. Shell Plate B2802-2 (*Long.*)	125 ft-lbs	---	---	---	105 ft-lbs

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:39 PM

Page 1

Coefficients of Curve 1

A = 53.6 B = 51.4 C = 70.68 T0 = 67.02 D = 0.00E+00

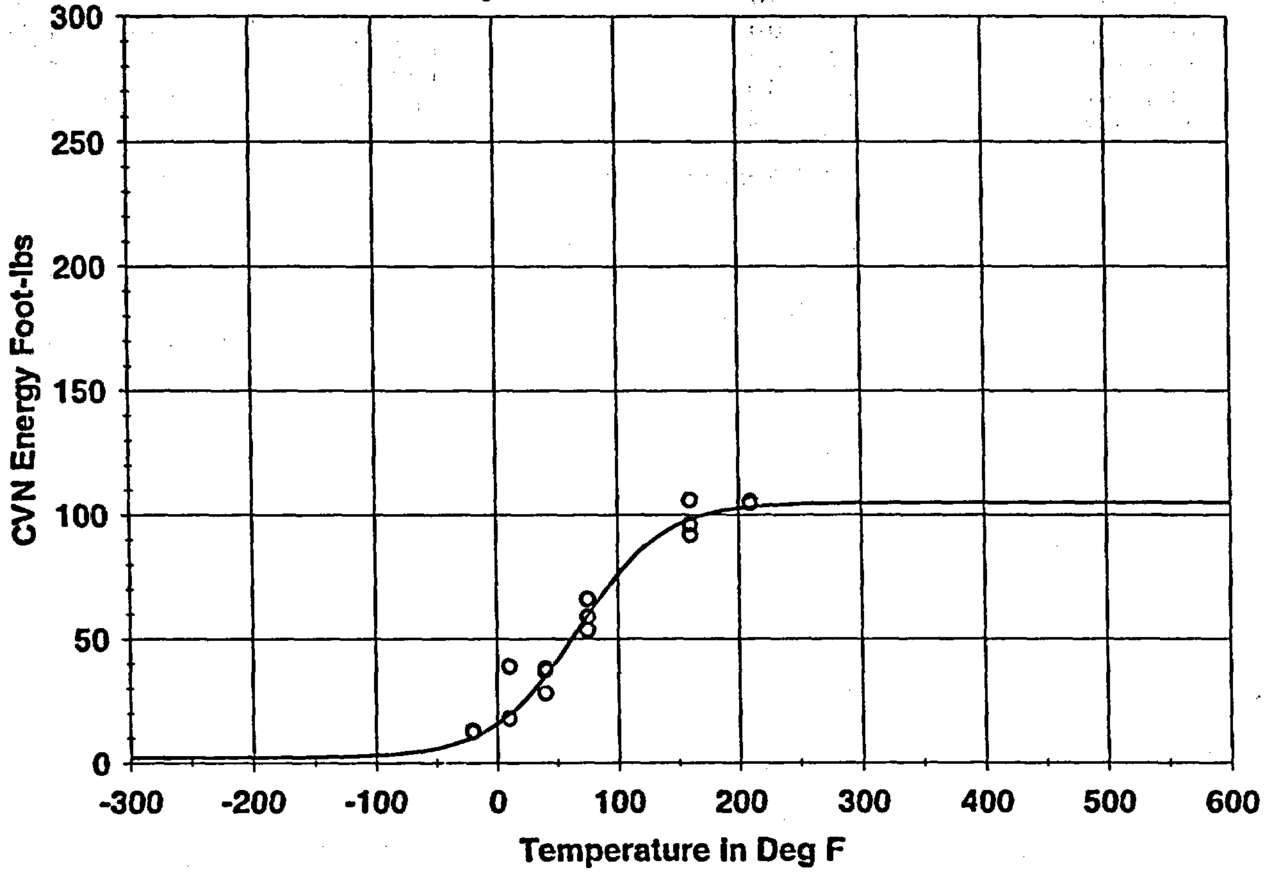
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=105.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=32.0 Deg F Temp@50 ft-lbs=62.1 Deg F

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2

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



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-20.00	12.50	10.28	2.22
-20.00	13.00	10.28	2.72
10.00	18.00	19.28	-1.28
40.00	28.00	34.86	-6.86
40.00	38.00	34.86	3.14
40.00	37.00	34.86	2.14
75.00	59.00	59.38	-.38
75.00	66.00	59.38	6.62
75.00	53.50	59.38	-5.88

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

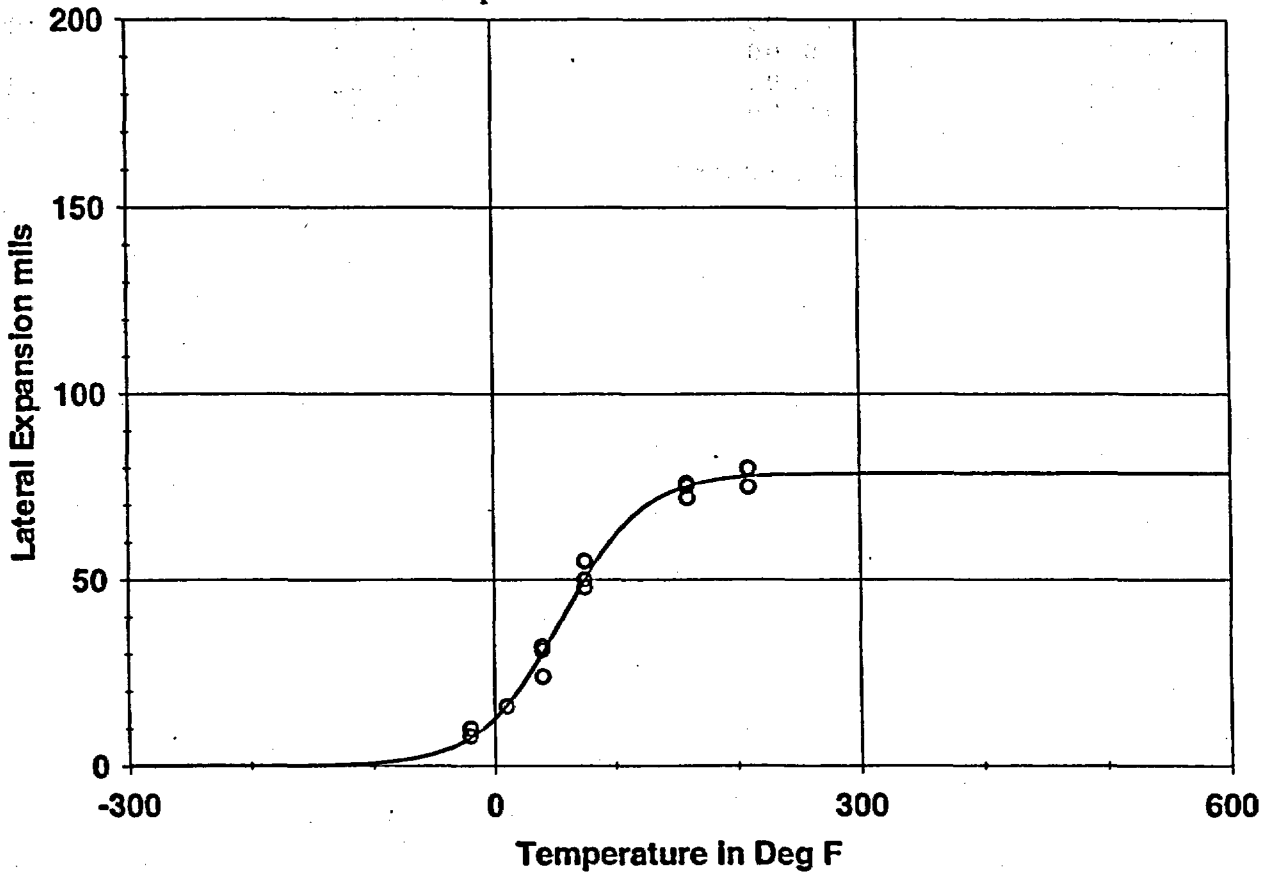
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
160.00	96.00	98.09	-2.09
160.00	106.00	98.09	7.91
160.00	92.00	98.09	-6.09
210.00	104.50	103.23	1.27
210.00	105.50	103.23	2.27
210.00	105.00	103.23	1.77

Correlation Coefficient = .993

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:56 PM
Page 1
Coefficients of Curve 1
A = 39.33 B = 39.33 C = 67.91 T0 = 56.09 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=78.7 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=48.6 Deg F
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-20.00	8.00	7.56	.44
-20.00	10.00	7.56	2.44
10.00	16.00	16.10	-.10
40.00	24.00	30.18	-6.18
40.00	32.00	30.18	1.82
40.00	31.00	30.18	.82
75.00	50.00	50.01	-.01
75.00	55.00	50.01	4.99
75.00	48.00	50.01	-2.01

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
160.00	76.00	75.14	.86
160.00	75.00	75.14	-.14
160.00	72.00	75.14	-3.14
210.00	80.00	77.82	2.18
210.00	80.00	77.82	2.18
210.00	75.00	77.82	-2.82

Correlation Coefficient = .995

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:52 PM

Page 1

Coefficients of Curve 1

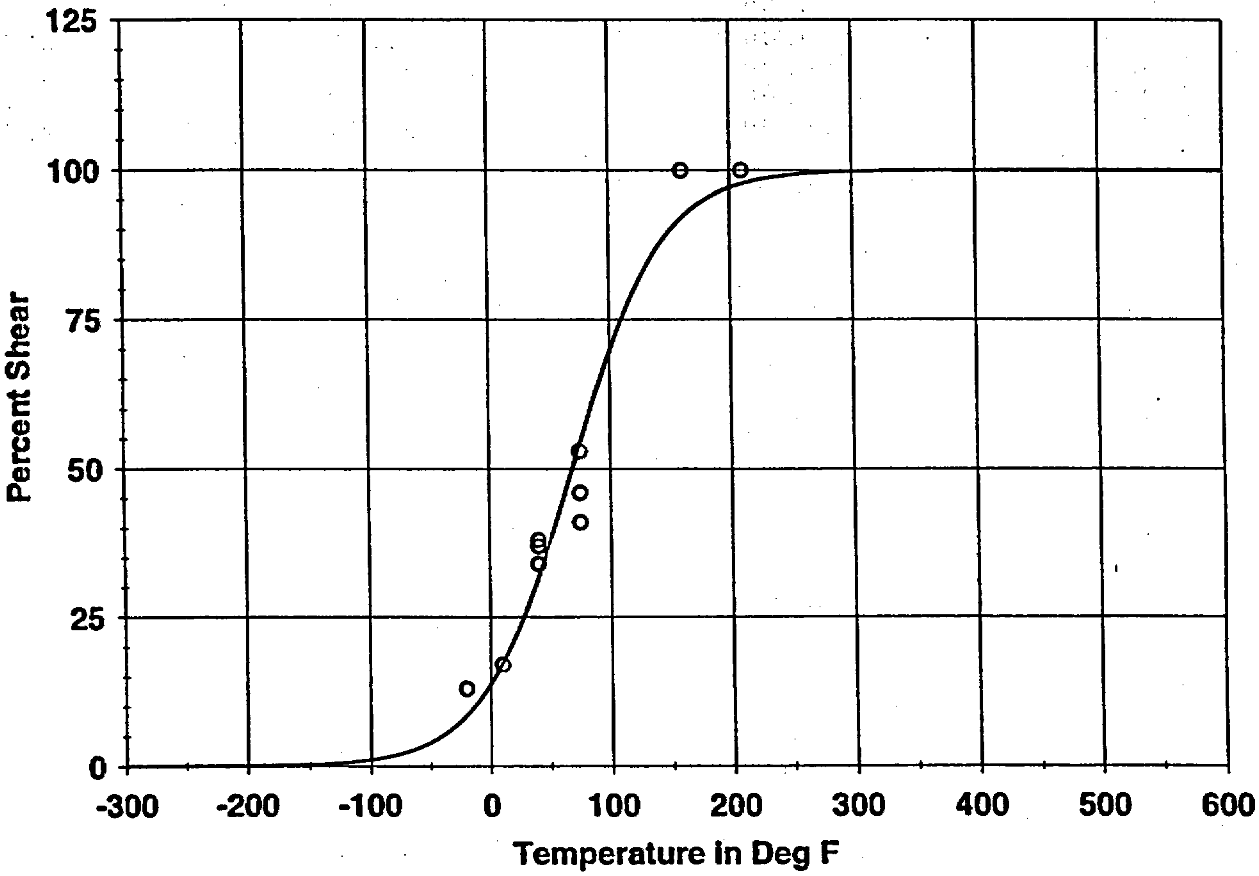
A = 50. B = 50. C = 74.77 T0 = 68.72 D = 0.00E+00

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

Temperature at 50% Shear = 68.8

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-20.00	13.00	8.52	4.48
-20.00	13.00	8.52	4.48
10.00	17.00	17.21	-.21
40.00	34.00	31.68	2.32
40.00	38.00	31.68	6.32
40.00	37.00	31.68	5.32
75.00	41.00	54.19	-13.19
75.00	53.00	54.19	-1.19
75.00	46.00	54.19	-8.19

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
160.00	100.00	91.99	8.01
160.00	100.00	91.99	8.01
160.00	100.00	91.99	8.01
210.00	100.00	97.77	2.23
210.00	100.00	97.77	2.23
210.00	100.00	97.77	2.23

Correlation Coefficient = .986

CAPSULE T (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:39 PM

Page 1

Coefficients of Curve 2

A = 47.1 B = 44.9 C = 61.77 T0 = 196.14 D = 0.00E+00

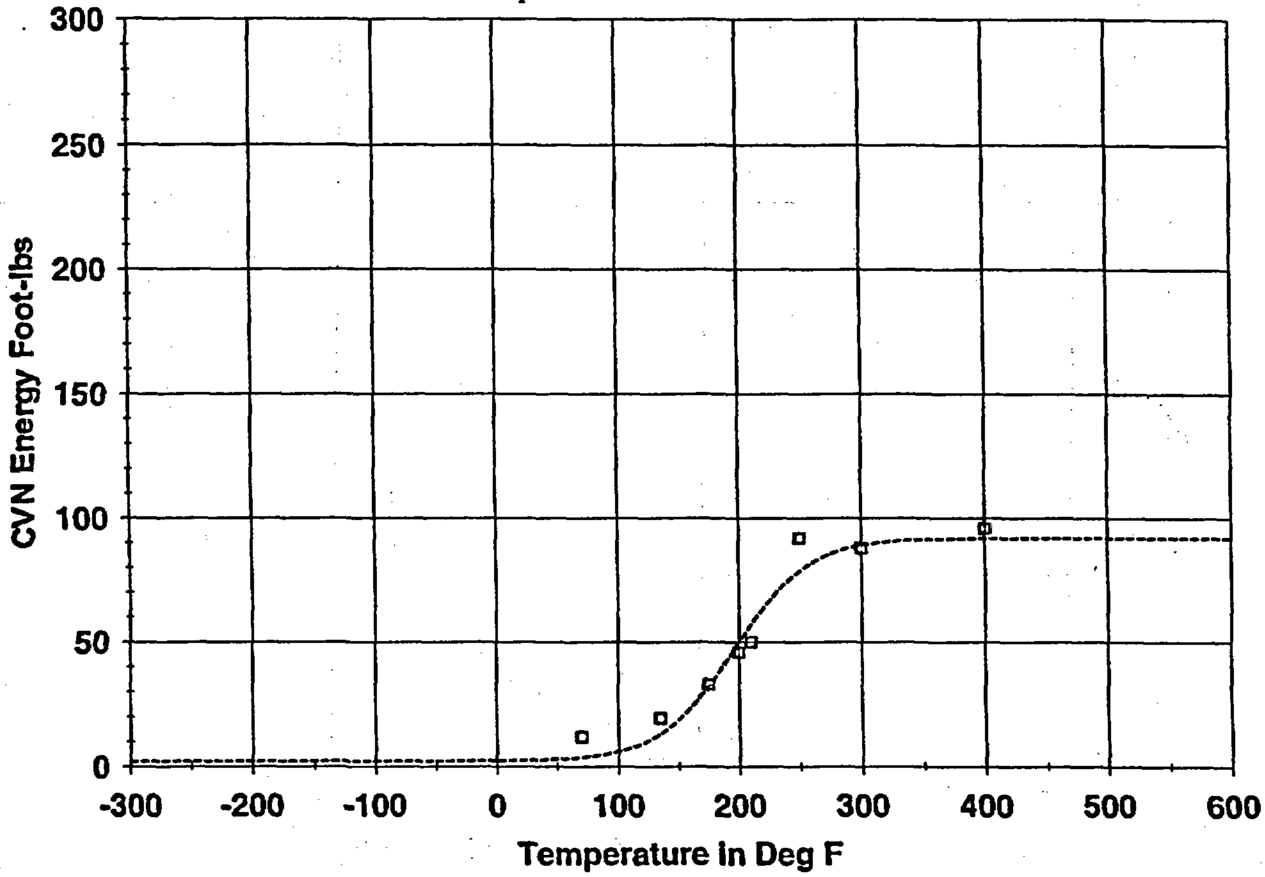
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=92.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=171.4 Deg F Temp@50 ft-lbs=200.2 Deg F

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2

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



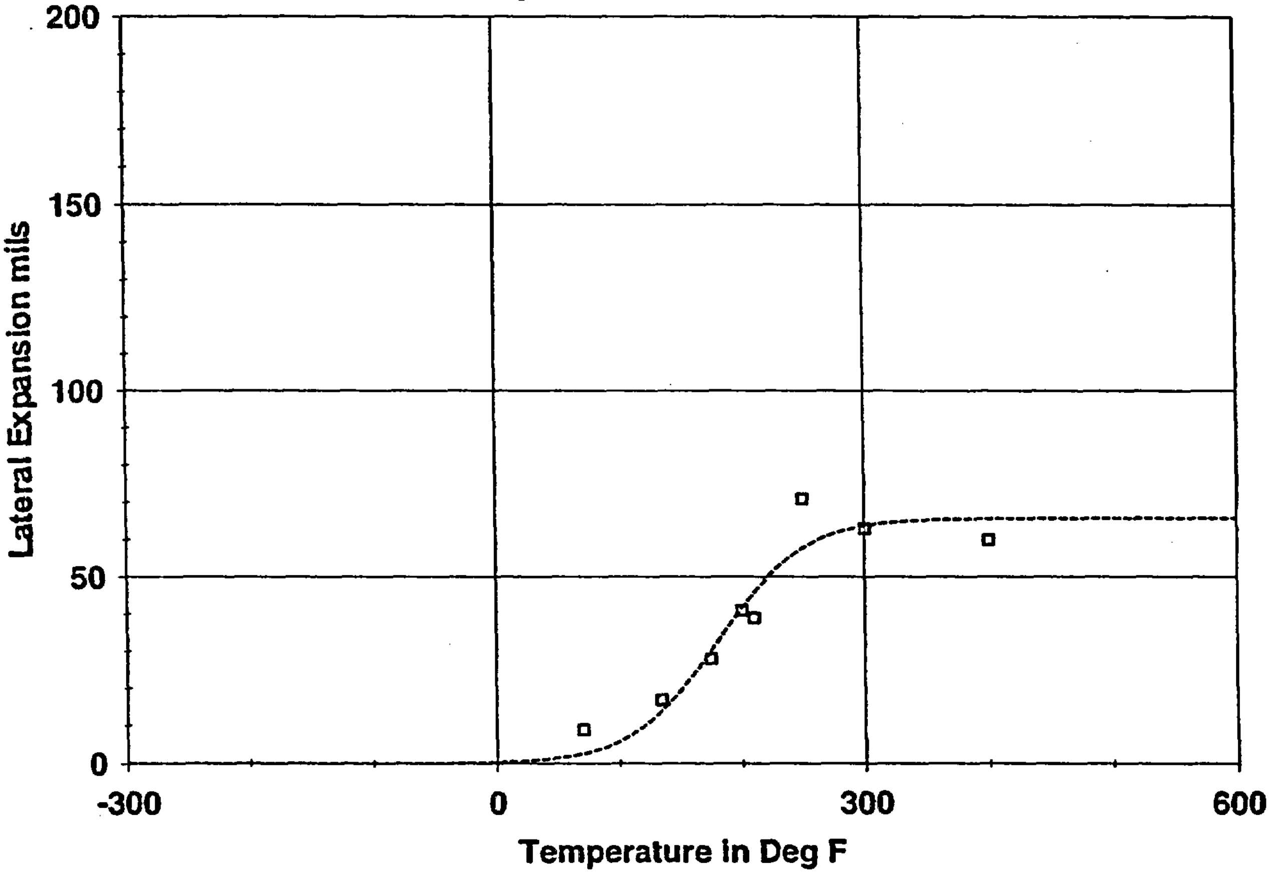
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
70.00	12.00	3.69	8.31
135.00	19.50	13.10	6.40
175.00	33.00	32.31	.69
200.00	46.00	49.90	-3.90
210.00	50.00	57.01	-7.01
250.00	92.00	78.64	13.36
300.00	88.00	88.99	-.99
400.00	96.00	91.88	4.12

Correlation Coefficient = .980

CAPSULE T (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:56 PM
Page 1
Coefficients of Curve 2
A = 32.9 B = 32.9 C = 69.91 T0 = 180.88 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=65.8 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=185.4 Deg F
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: T Fluence: n/cm^2



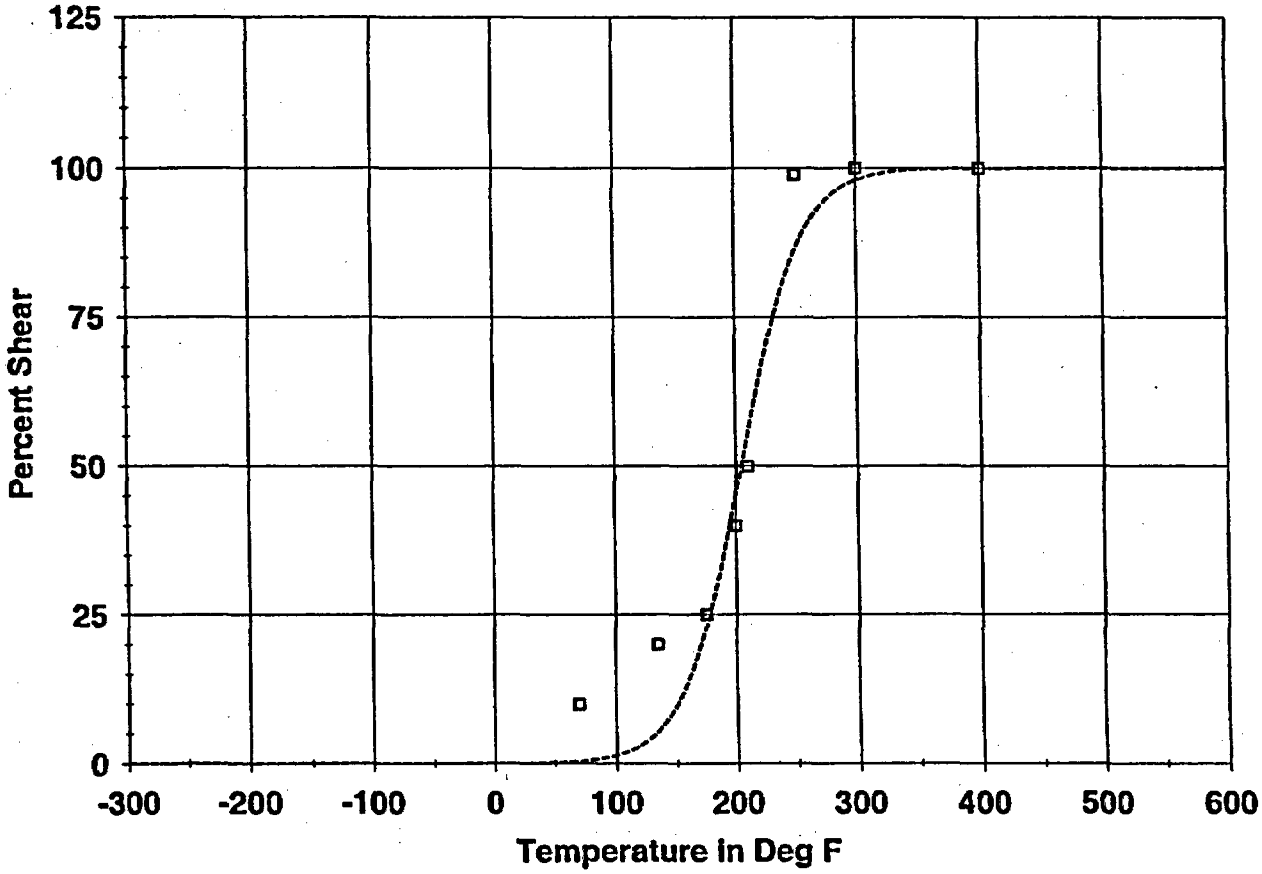
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
70.00	9.00	2.65	6.35
135.00	17.00	13.95	3.05
175.00	28.00	30.13	-2.13
200.00	41.00	41.67	-.67
210.00	39.00	45.86	-6.86
250.00	71.00	57.79	13.21
300.00	63.00	63.68	-.68
400.00	60.00	65.67	-5.67

Correlation Coefficient = .959

CAPSULE T (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:52 PM
Page 1
Coefficients of Curve 2
A = 50. B = 50. C = 48.79 T0 = 204.64 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 204.7
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: T Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
70.00	10.00	.40	9.60
135.00	20.00	5.44	14.56
175.00	25.00	22.88	2.12
200.00	40.00	45.26	-5.26
210.00	50.00	55.47	-5.47
250.00	99.00	86.52	12.48
300.00	100.00	98.03	1.97
400.00	100.00	99.97	.03

Correlation Coefficient = .982

CAPSULE Z (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:39 PM

Page 1

Coefficients of Curve 3

A = 42.1 B = 39.9 C = 83.48 T0 = 225.87 D = 0.00E+00

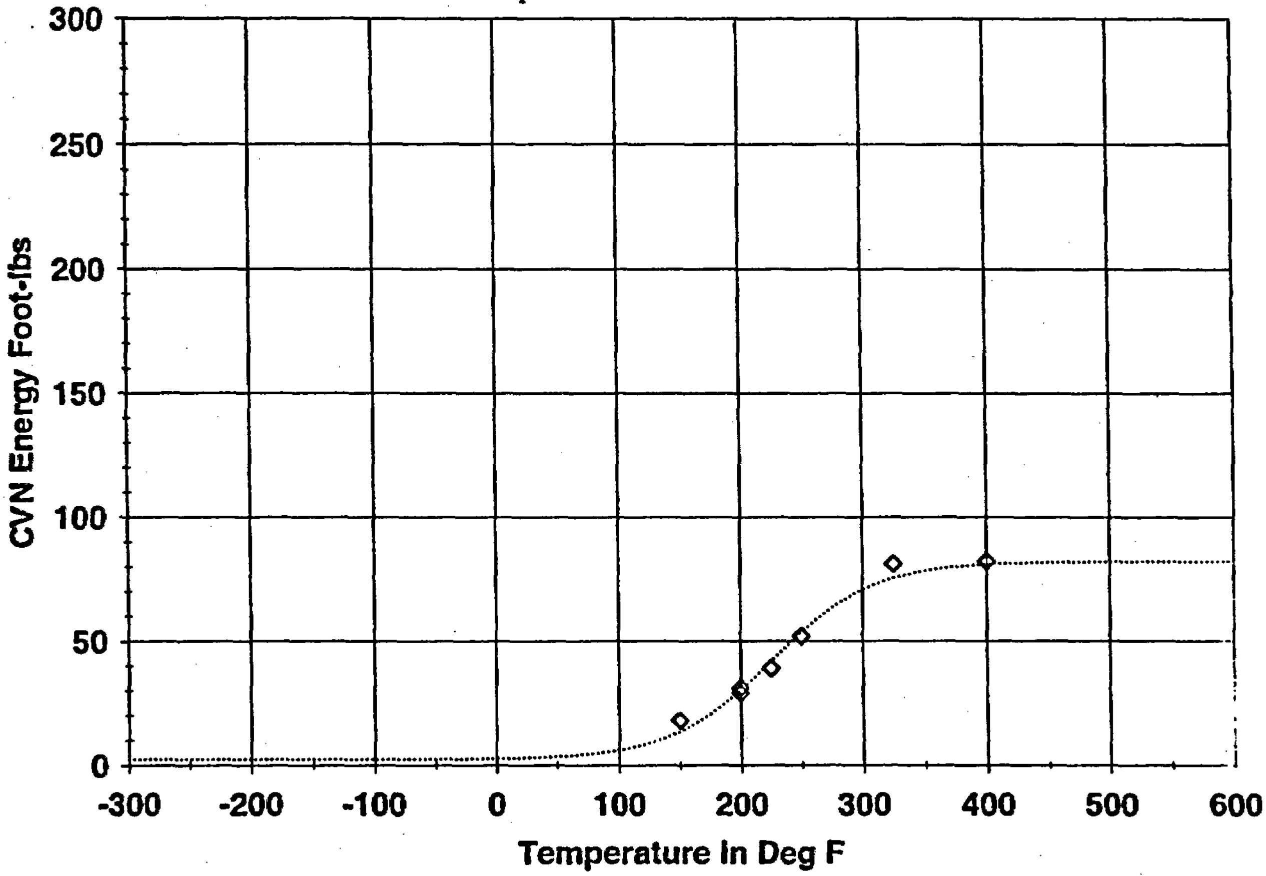
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=82.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=199.8 Deg F Temp@50 ft-lbs=242.7 Deg F

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2

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



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
150.00	18.00	13.35	4.65
200.00	29.00	30.12	-1.12
200.00	31.00	30.12	.88
225.00	39.00	41.68	-2.68
250.00	52.00	53.32	-1.32
325.00	81.00	75.21	5.79
400.00	82.00	80.79	1.21

Correlation Coefficient = .992

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:39 PM

Page 1

Coefficients of Curve 1

A = 53.6 B = 51.4 C = 70.68 T0 = 67.02 D = 0.00E+00

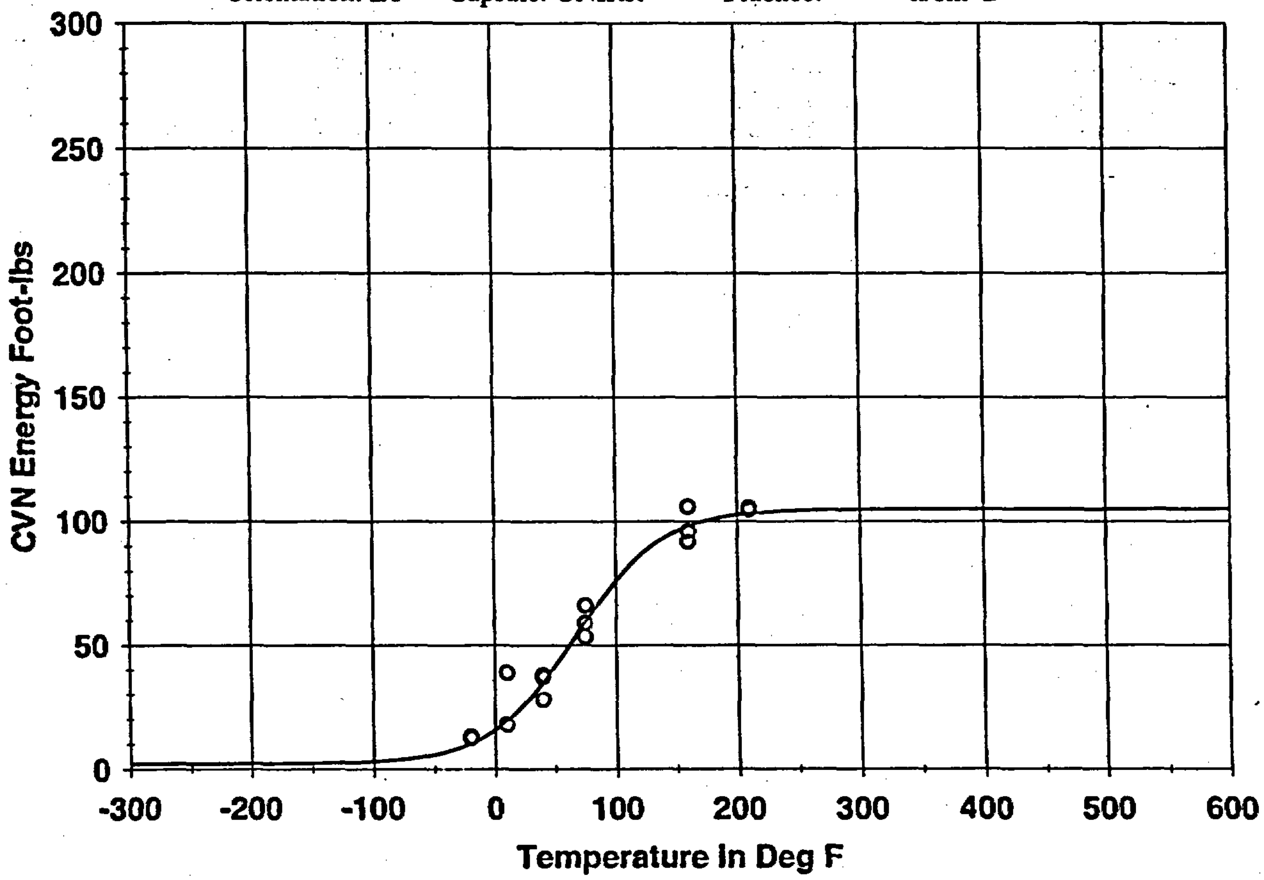
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=105.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=32.0 Deg F Temp@50 ft-lbs=62.1 Deg F

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2

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



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-20.00	12.50	10.28	2.22
-20.00	13.00	10.28	2.72
10.00	18.00	19.28	-1.28
40.00	28.00	34.86	-6.86
40.00	38.00	34.86	3.14
40.00	37.00	34.86	2.14
75.00	59.00	59.38	-.38
75.00	66.00	59.38	6.62
75.00	53.50	59.38	-5.88

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
160.00	96.00	98.09	-2.09
160.00	106.00	98.09	7.91
160.00	92.00	98.09	-6.09
210.00	104.50	103.23	1.27
210.00	105.50	103.23	2.27
210.00	105.00	103.23	1.77

Correlation Coefficient = .993

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:56 PM

Page 1

Coefficients of Curve 1

A = 39.33 B = 39.33 C = 67.91 T0 = 56.09 D = 0.00E+00

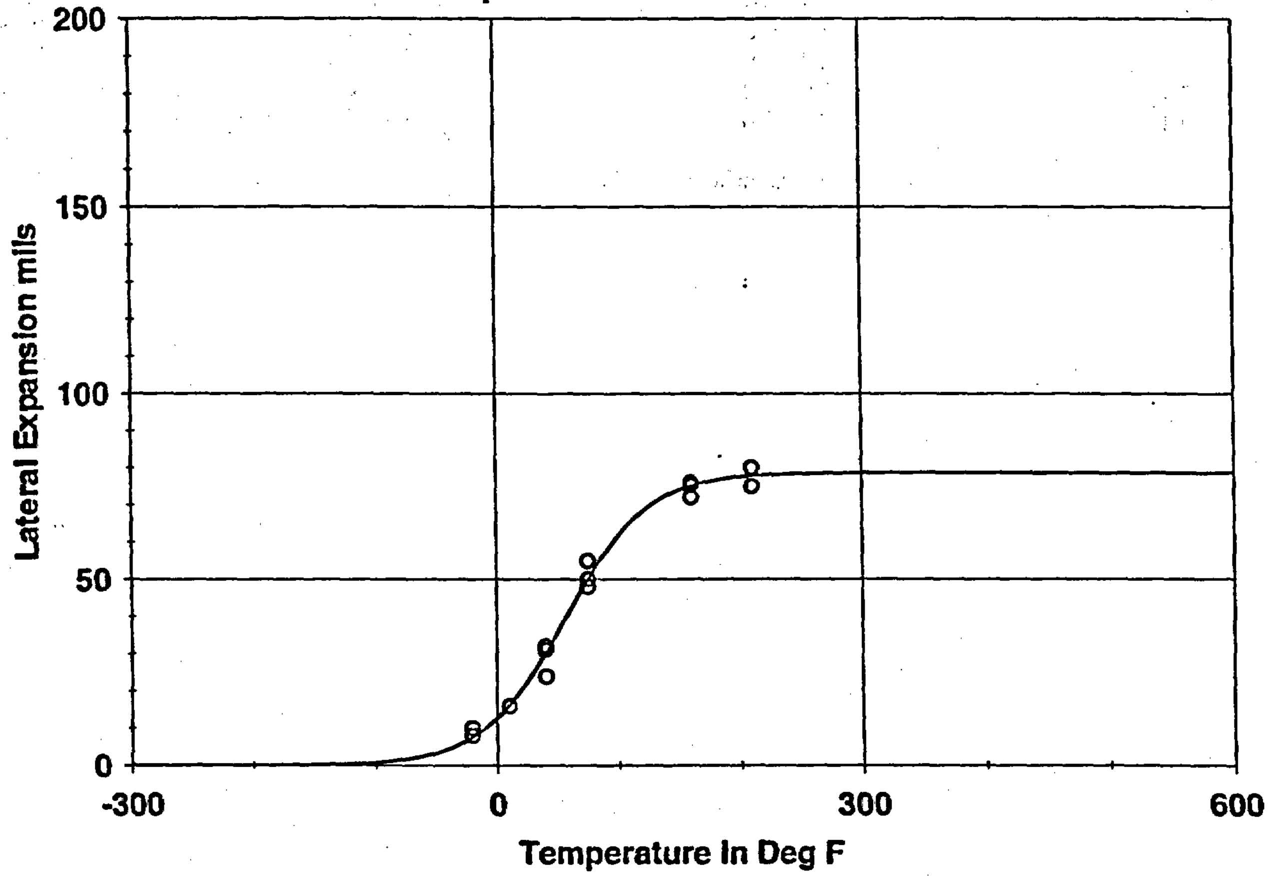
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=78.7 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=48.6 Deg F

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-20.00	8.00	7.56	.44
-20.00	10.00	7.56	2.44
10.00	16.00	16.10	-.10
40.00	24.00	30.18	-6.18
40.00	32.00	30.18	1.82
40.00	31.00	30.18	.82
75.00	50.00	50.01	-.01
75.00	55.00	50.01	4.99
75.00	48.00	50.01	-2.01

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
160.00	76.00	75.14	.86
160.00	75.00	75.14	-.14
160.00	72.00	75.14	-3.14
210.00	80.00	77.82	2.18
210.00	80.00	77.82	2.18
210.00	75.00	77.82	-2.82

Correlation Coefficient = .995

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:52 PM

Page 1

Coefficients of Curve 1

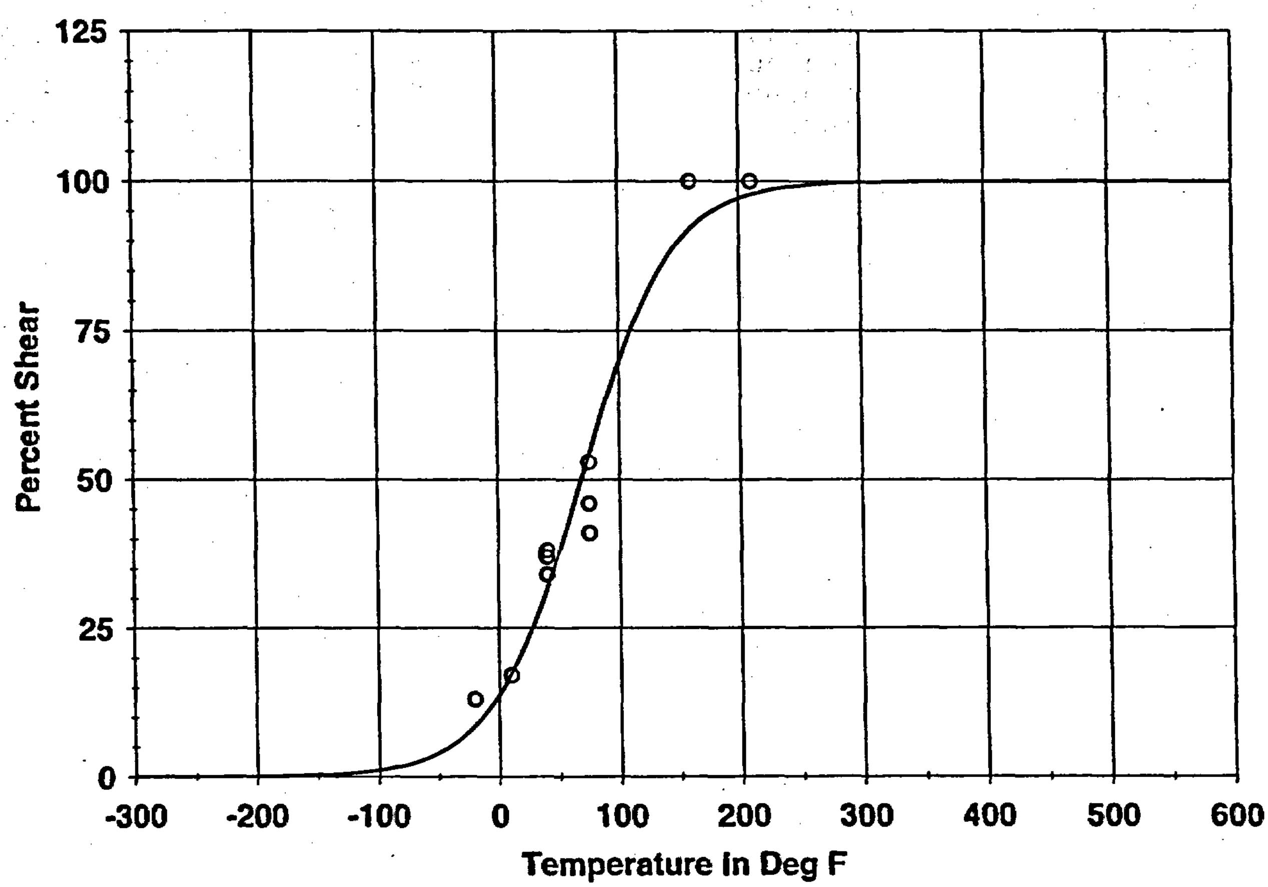
A = 50. B = 50. C = 74.77 T0 = 68.72 D = 0.00E+00

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

Temperature at 50% Shear = 68.8

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-20.00	13.00	8.52	4.48
-20.00	13.00	8.52	4.48
10.00	17.00	17.21	-.21
40.00	34.00	31.68	2.32
40.00	38.00	31.68	6.32
40.00	37.00	31.68	5.32
75.00	41.00	54.19	-13.19
75.00	53.00	54.19	-1.19
75.00	46.00	54.19	-8.19

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
160.00	100.00	91.99	8.01
160.00	100.00	91.99	8.01
160.00	100.00	91.99	8.01
210.00	100.00	97.77	2.23
210.00	100.00	97.77	2.23
210.00	100.00	97.77	2.23

Correlation Coefficient = .986

CAPSULE T (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:39 PM

Page 1

Coefficients of Curve 2

A = 47.1 B = 44.9 C = 61.77 T0 = 196.14 D = 0.00E+00

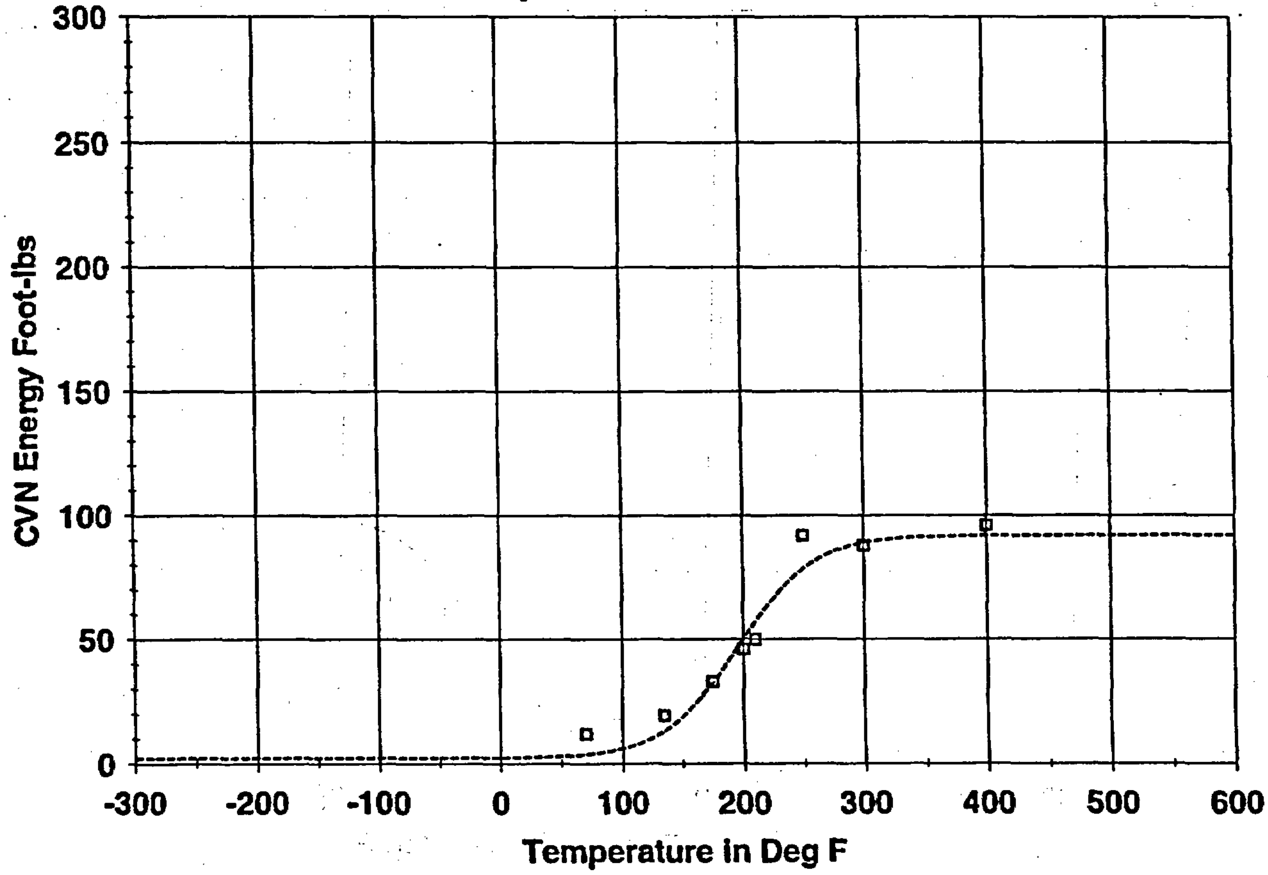
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=92.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=171.4 Deg F Temp@50 ft-lbs=200.2 Deg F

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2

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



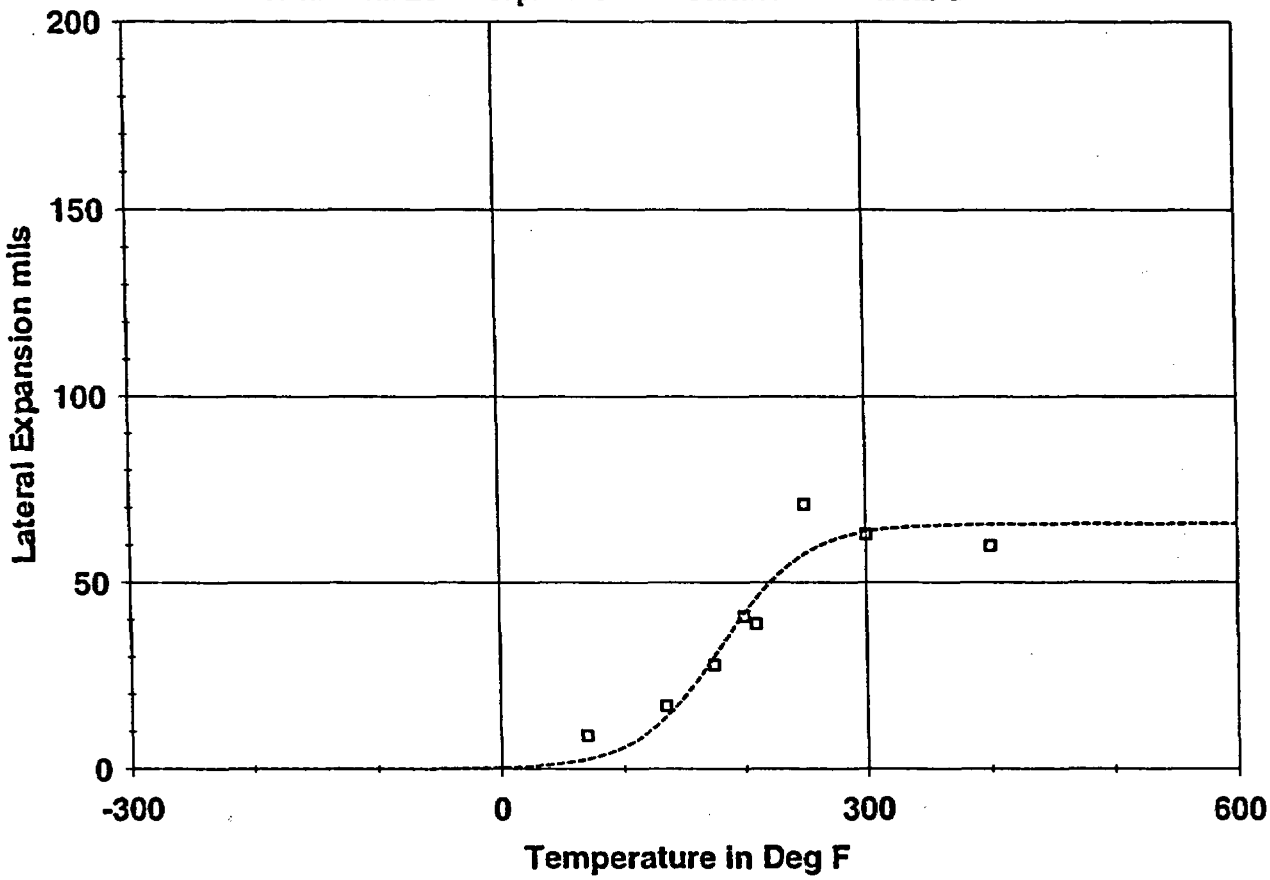
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
70.00	12.00	3.69	8.31
135.00	19.50	13.10	6.40
175.00	33.00	32.31	.69
200.00	46.00	49.90	-3.90
210.00	50.00	57.01	-7.01
250.00	92.00	78.64	13.36
300.00	88.00	88.99	-.99
400.00	96.00	91.88	4.12

Correlation Coefficient = .980

CAPSULE T (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:56 PM
Page 1
Coefficients of Curve 2
A = 32.9 B = 32.9 C = 69.91 T0 = 180.88 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=65.8 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=185.4 Deg F
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: T Fluence: n/cm^2



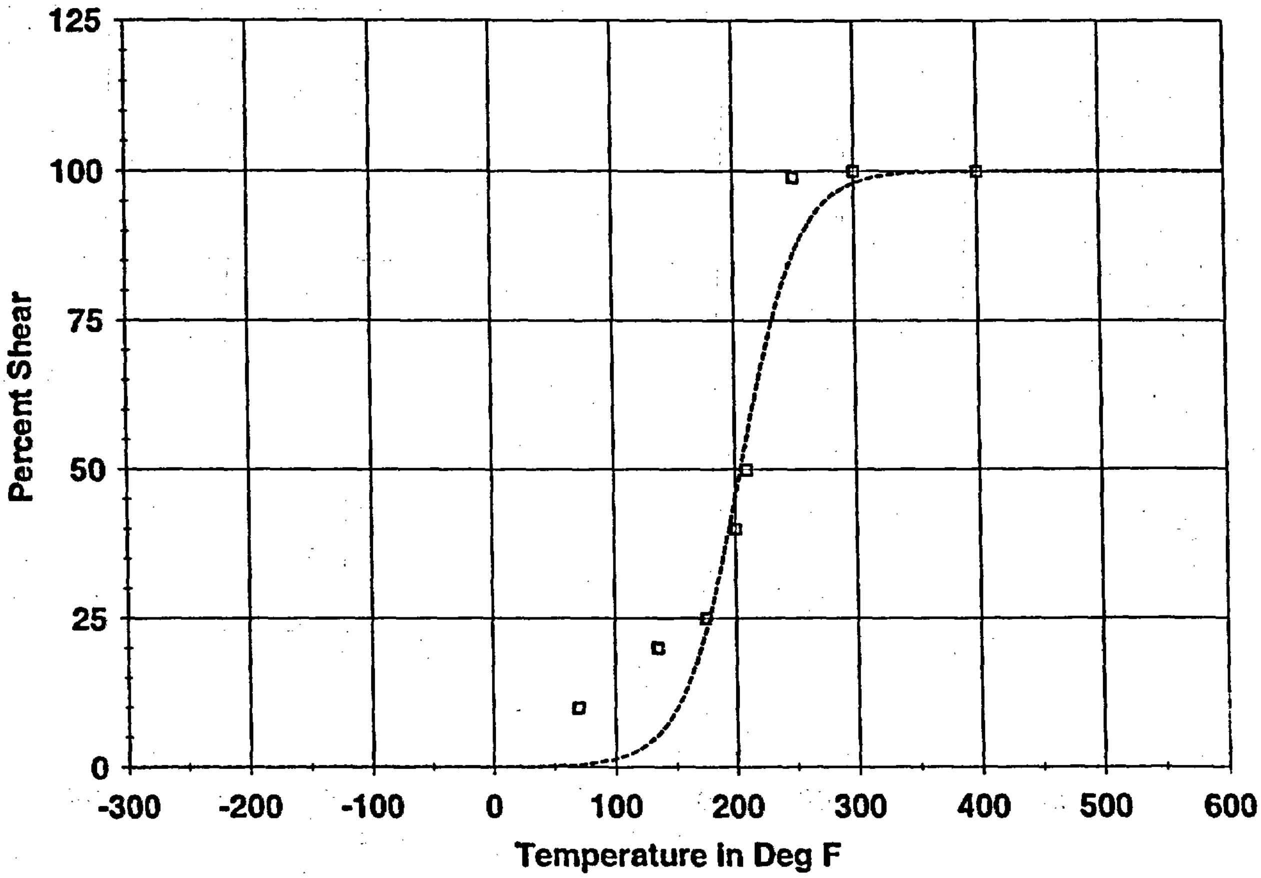
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
70.00	9.00	2.65	6.35
135.00	17.00	13.95	3.05
175.00	28.00	30.13	-2.13
200.00	41.00	41.67	-.67
210.00	39.00	45.86	-6.86
250.00	71.00	57.79	13.21
300.00	63.00	63.68	-.68
400.00	60.00	65.67	-5.67

Correlation Coefficient = .959

CAPSULE T (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:52 PM
Page 1
Coefficients of Curve 2
A = 50. B = 50. C = 48.79 T0 = 204.64 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 204.7
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: T Fluence: n/cm^2



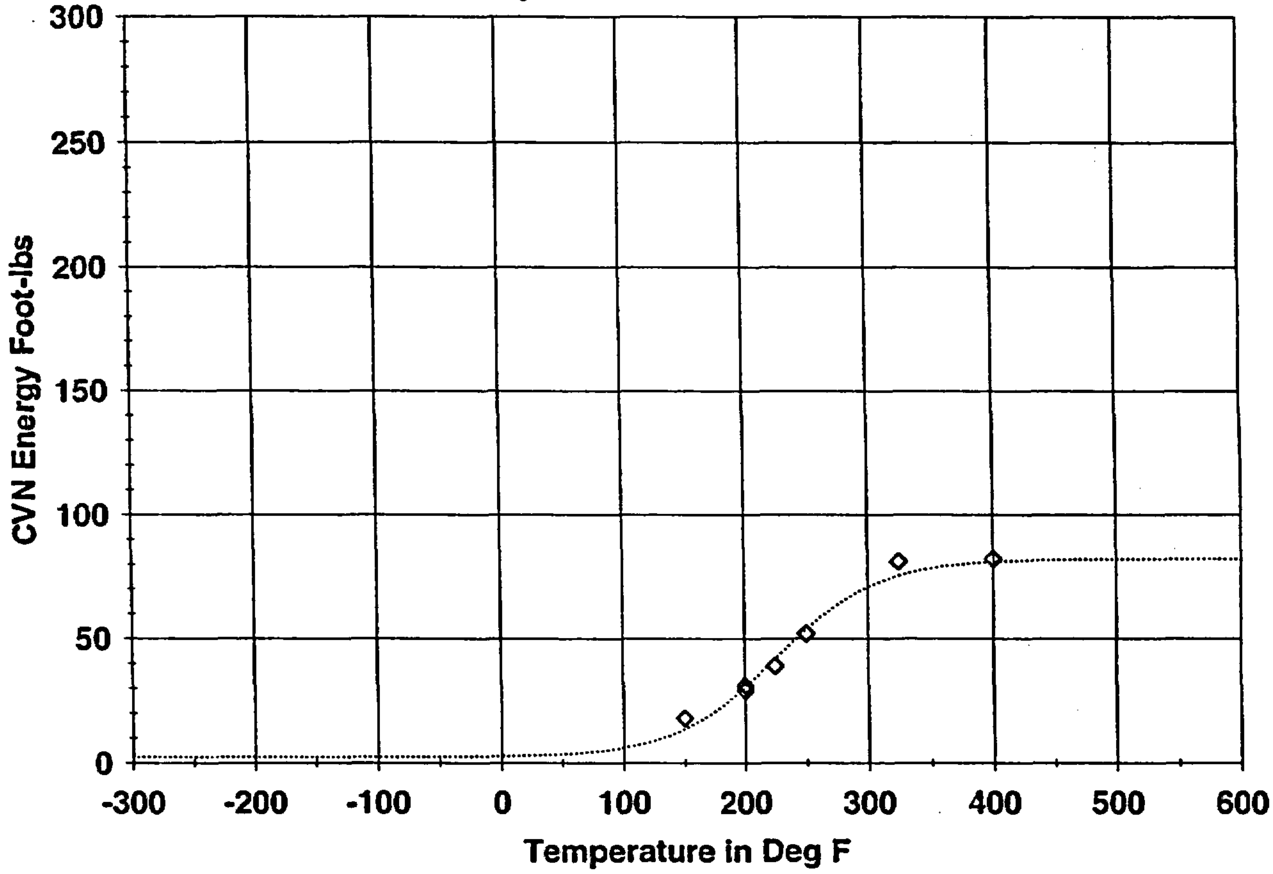
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
70.00	10.00	.40	9.60
135.00	20.00	5.44	14.56
175.00	25.00	22.88	2.12
200.00	40.00	45.26	-5.26
210.00	50.00	55.47	-5.47
250.00	99.00	86.52	12.48
300.00	100.00	98.03	1.97
400.00	100.00	99.97	.03

Correlation Coefficient = .982

CAPSULE Z (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:39 PM
Page 1
Coefficients of Curve 3
A = 42.1 B = 39.9 C = 83.48 T0 = 225.87 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=82.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=199.8 Deg F Temp@50 ft-lbs=242.7 Deg F
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: Z Fluence: n/cm^2



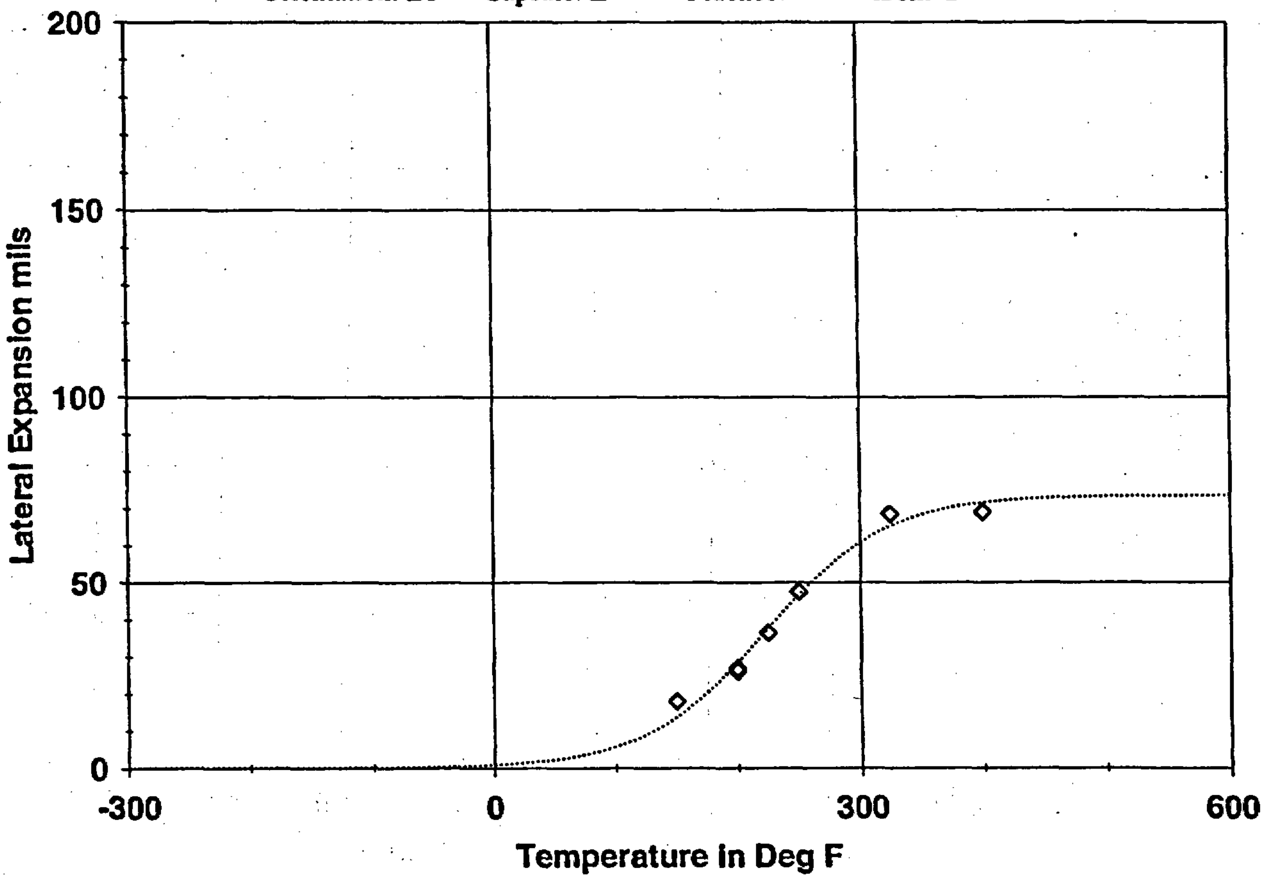
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
150.00	18.00	13.35	4.65
200.00	29.00	30.12	-1.12
200.00	31.00	30.12	.88
225.00	39.00	41.68	-2.68
250.00	52.00	53.32	-1.32
325.00	81.00	75.21	5.79
400.00	82.00	80.79	1.21

Correlation Coefficient = .992

CAPSULE Z (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:56 PM
Page 1
Coefficients of Curve 3
A = 36.71 B = 36.71 C = 98.7 T0 = 222.82 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=73.4 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=218.3 Deg F
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: Z Fluence: n/cm^2



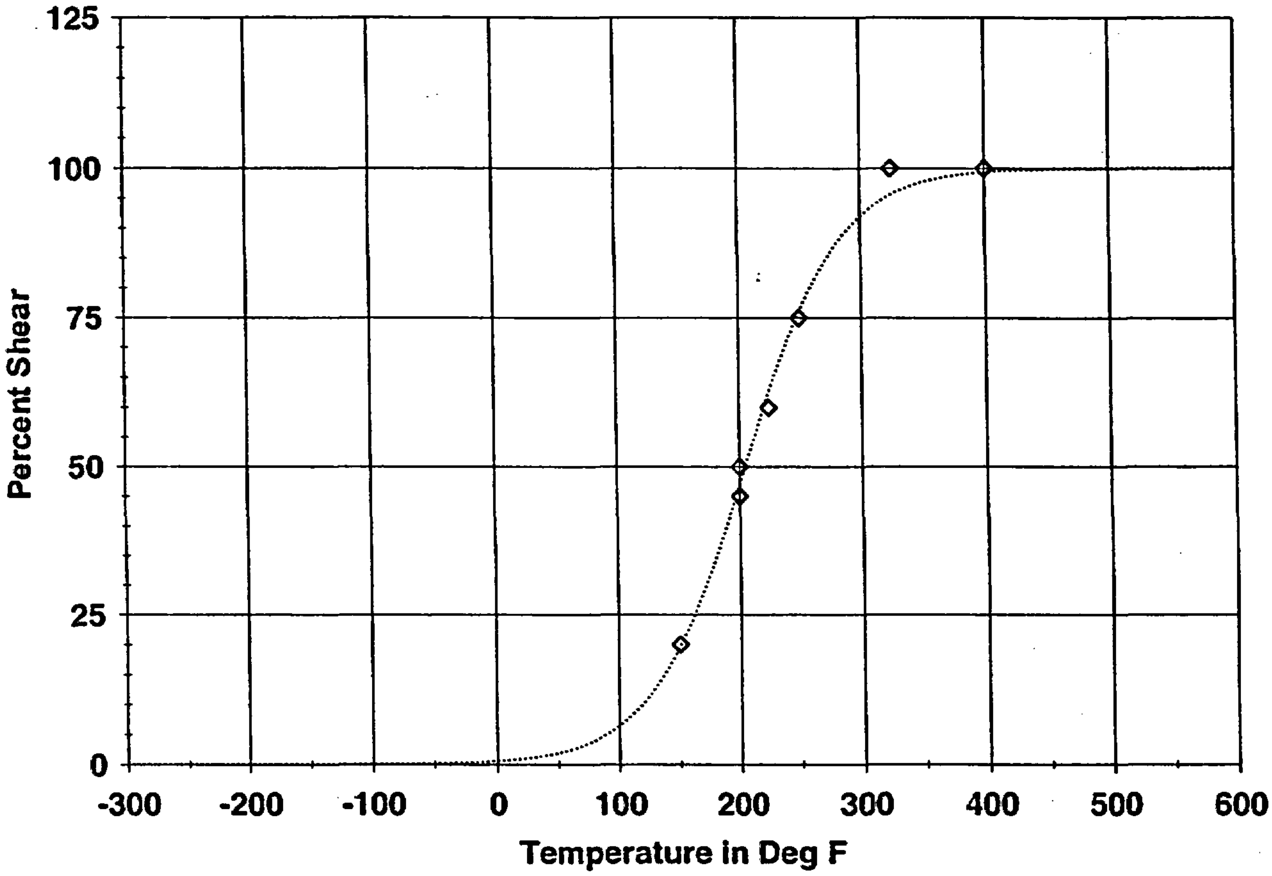
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
150.00	18.00	13.66	4.34
200.00	26.00	28.37	-2.37
200.00	27.00	28.37	-1.37
225.00	36.50	37.52	-1.02
250.00	47.50	46.57	.93
325.00	68.50	65.19	3.31
400.00	69.00	71.44	-2.44

Correlation Coefficient = .991

CAPSULE Z (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:52 PM
Page 1
Coefficients of Curve 3
A = 50. B = 50. C = 78.21 T0 = 205.29 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 205.3
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: Z Fluence: n/cm^2



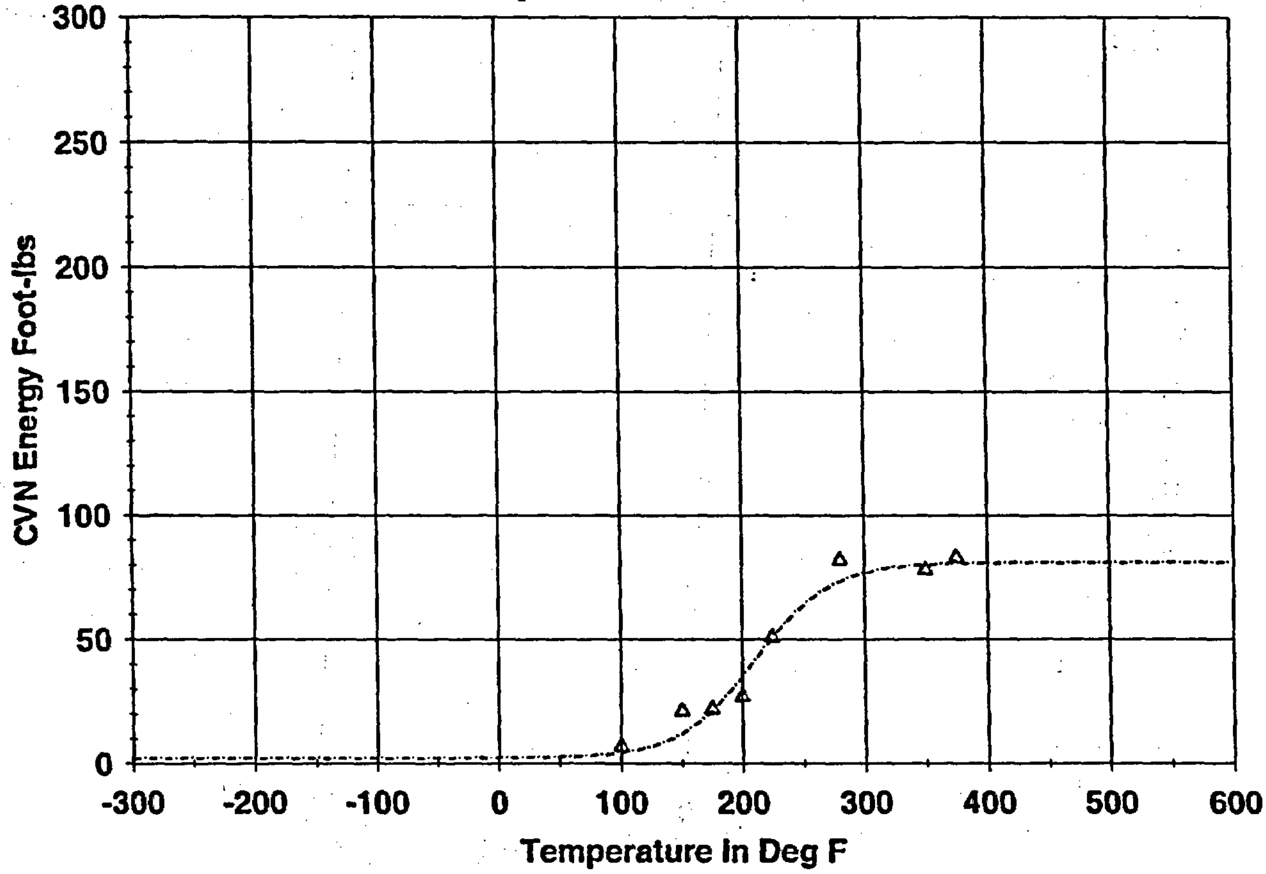
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
150.00	20.00	19.56	.44
200.00	45.00	46.62	-1.62
200.00	50.00	46.62	3.38
225.00	60.00	62.34	-2.34
250.00	75.00	75.83	-.83
325.00	100.00	95.53	4.47
400.00	100.00	99.32	.68

Correlation Coefficient = .997

CAPSULE X (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:39 PM
Page 1
Coefficients of Curve 4
A = 41.6 B = 39.4 C = 62.02 T0 = 210.35 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=191.6 Deg F Temp@50 ft-lbs=223.8 Deg F
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: X Fluence: n/cm^2



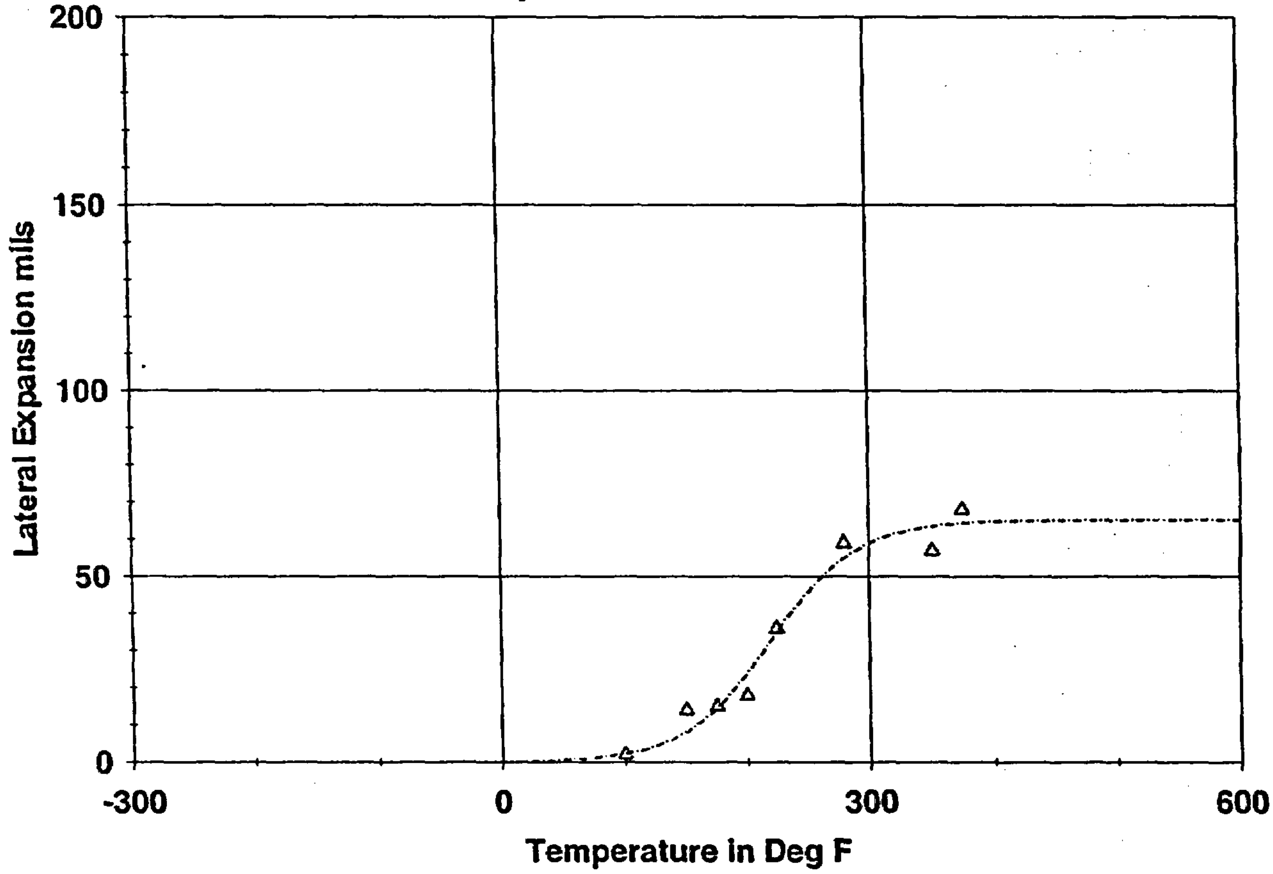
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
100.00	7.00	4.38	2.62
150.00	21.00	12.05	8.95
175.00	22.00	21.30	.70
200.00	27.00	35.09	-8.09
225.00	51.00	50.74	.26
280.00	82.00	73.46	8.54
350.00	78.00	80.14	-2.14
375.00	83.00	80.61	2.39

Correlation Coefficient = .984

CAPSULE X (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:56 PM
Page 1
Coefficients of Curve 4
A = 32.56 B = 32.56 C = 71.68 T0 = 219.55 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=65.1 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=225.0 Deg F
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: LT Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
100.00	2.00	2.24	-.24
150.00	14.00	8.18	5.82
175.00	15.00	14.58	.42
200.00	18.00	23.89	-5.89
225.00	36.00	35.03	.97
280.00	59.00	54.94	4.06
350.00	57.00	63.45	-6.45
375.00	68.00	64.27	3.73

Correlation Coefficient = .984

CAPSULE X (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:52 PM

Page 1

Coefficients of Curve 4

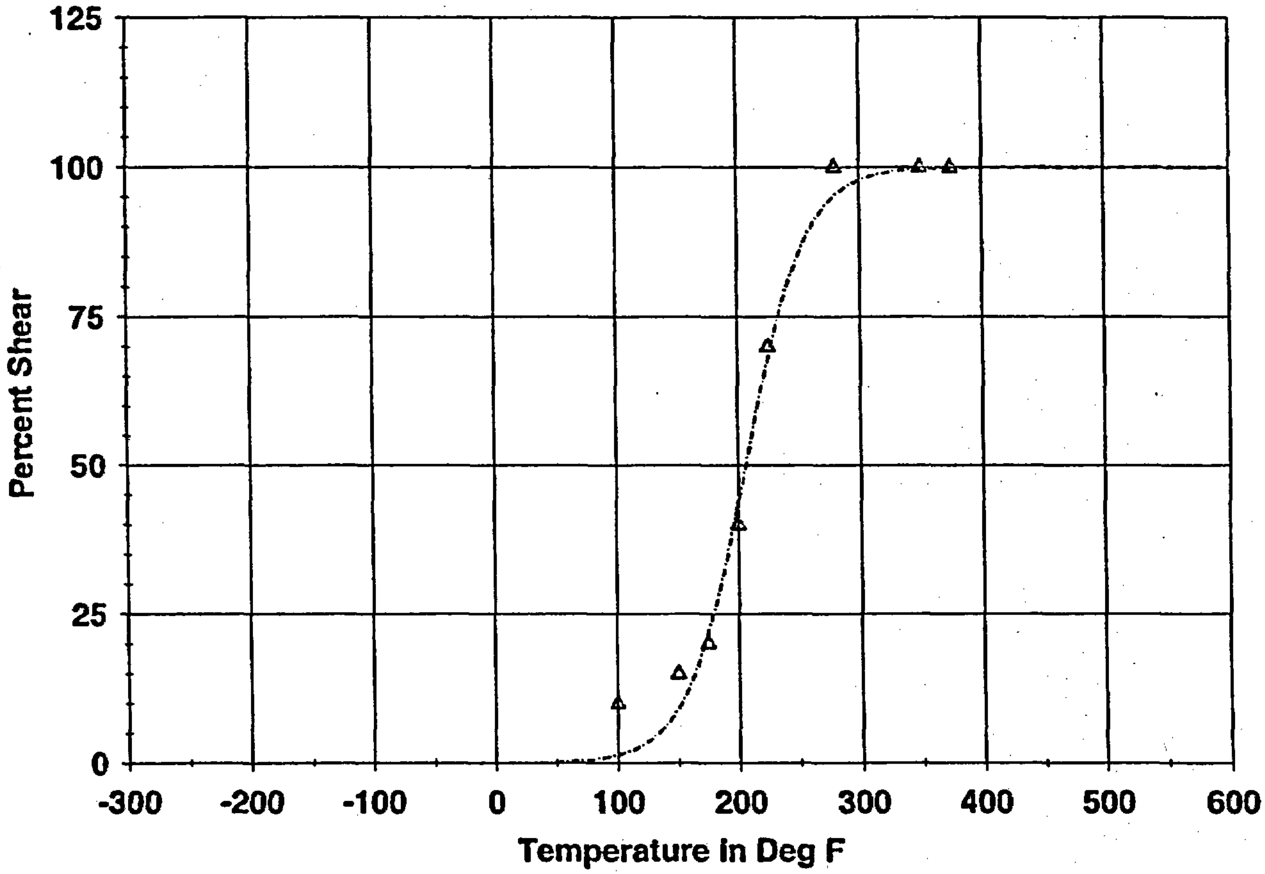
A = 50. B = 50. C = 49.18 T0 = 206.3 D = 0.00E+00

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

Temperature at 50% Shear = 206.3

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100.00	10.00	1.31	8.69
150.00	15.00	9.20	5.80
175.00	20.00	21.88	-1.88
200.00	40.00	43.63	-3.63
225.00	70.00	68.15	1.85
280.00	100.00	95.25	4.75
350.00	100.00	99.71	.29
375.00	100.00	99.90	.10

Correlation Coefficient = .995

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:07 PM

Page 1

Coefficients of Curve 1

A = 35.1 B = 32.9 C = 79.37 T0 = 70.69 D = 0.00E+00

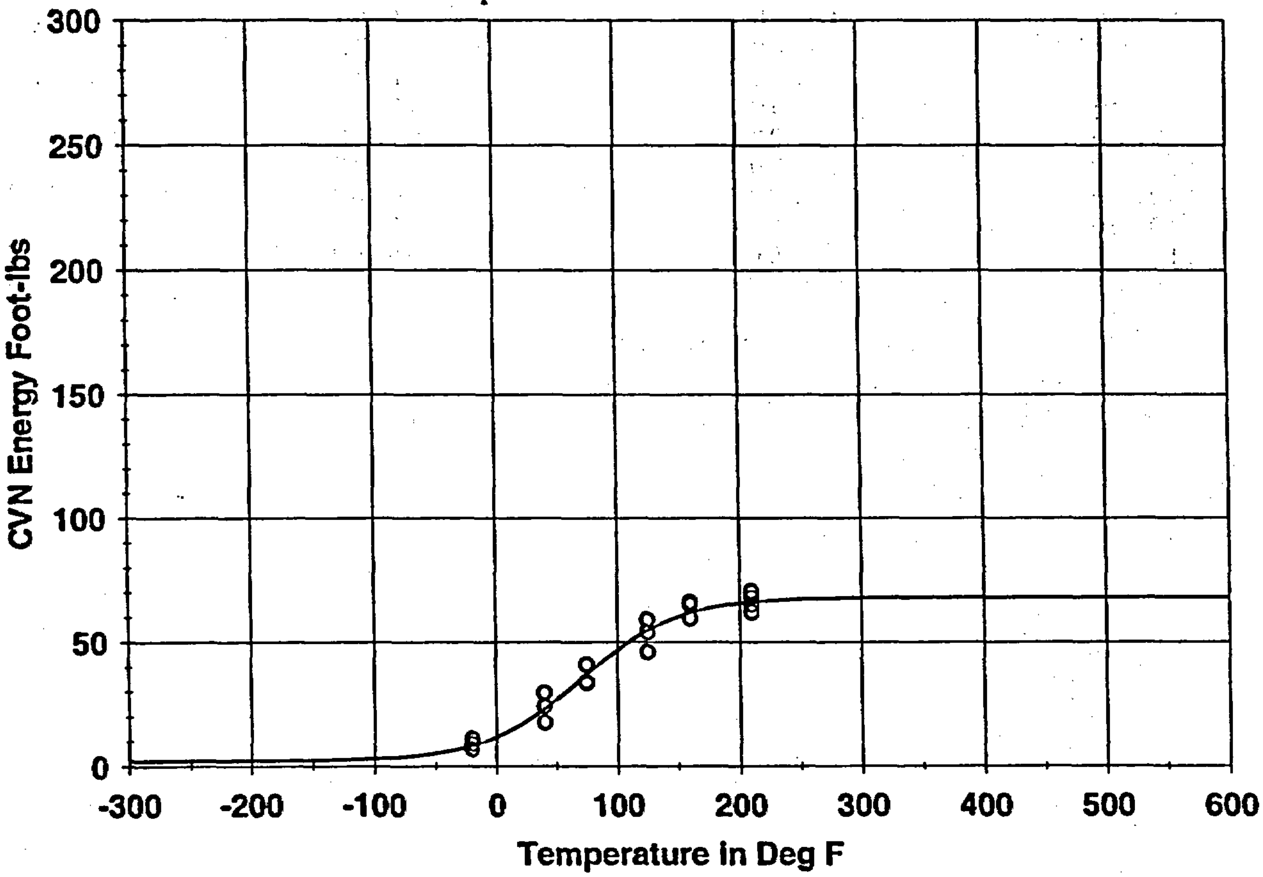
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=68.0(Fixed)   Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=58.3 Deg F   Temp@50 ft-lbs=109.5 Deg F

Plant: Indian Point 3   Material: SA302B   Heat: A-0512-2

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



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-20.00	9.00	8.28	.72
-20.00	7.00	8.28	-1.28
-20.00	11.00	8.28	2.72
40.00	29.50	22.98	6.52
40.00	24.00	22.98	1.02
40.00	17.50	22.98	-5.48
75.00	34.00	36.89	-2.89
75.00	41.00	36.89	4.11
75.00	33.50	36.89	-3.39

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
125.00	54.00	54.65	-.65
125.00	59.00	54.65	4.35
125.00	46.00	54.65	-8.65
160.00	65.00	61.73	3.27
160.00	66.00	61.73	4.27
160.00	59.50	61.73	-2.23
210.00	62.00	66.09	-4.09
210.00	70.00	66.09	3.91
210.00	65.00	66.09	-1.09
210.00	70.50	66.09	4.41
210.00	68.00	66.09	1.91
210.00	70.00	66.09	3.91

Correlation Coefficient = .984

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:34 PM

Page 1

Coefficients of Curve 1

A = 31.57 B = 31.57 C = 78.27 T0 = 66.73 D = 0.00E+00

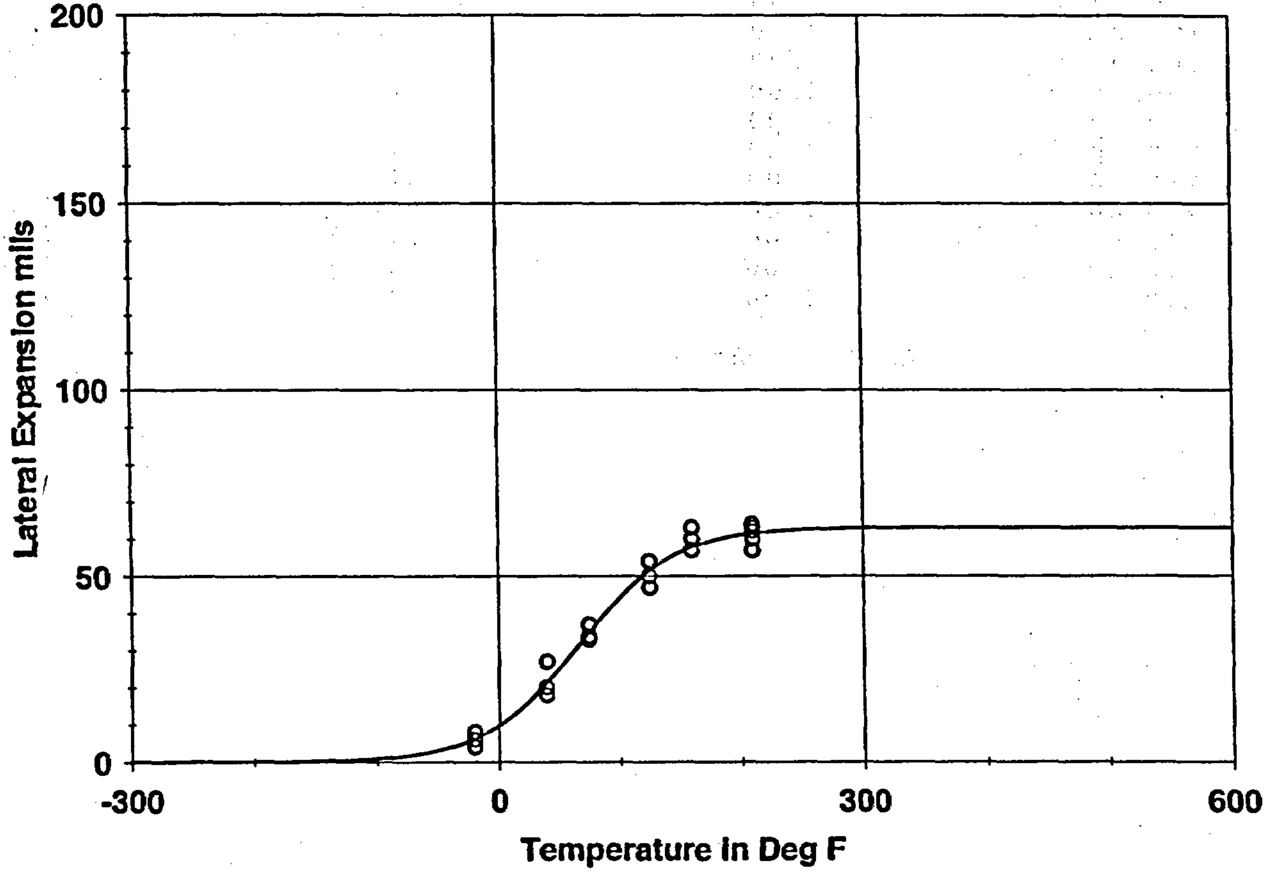
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=63.1 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=75.3 Deg F

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-20.00	6.00	6.21	-.21
-20.00	4.00	6.21	-2.21
-20.00	8.00	6.21	1.79
40.00	27.00	21.19	5.81
40.00	20.00	21.19	-1.19
40.00	18.00	21.19	-3.19
75.00	33.00	34.89	-1.89
75.00	37.00	34.89	2.11
75.00	34.00	34.89	-.89

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

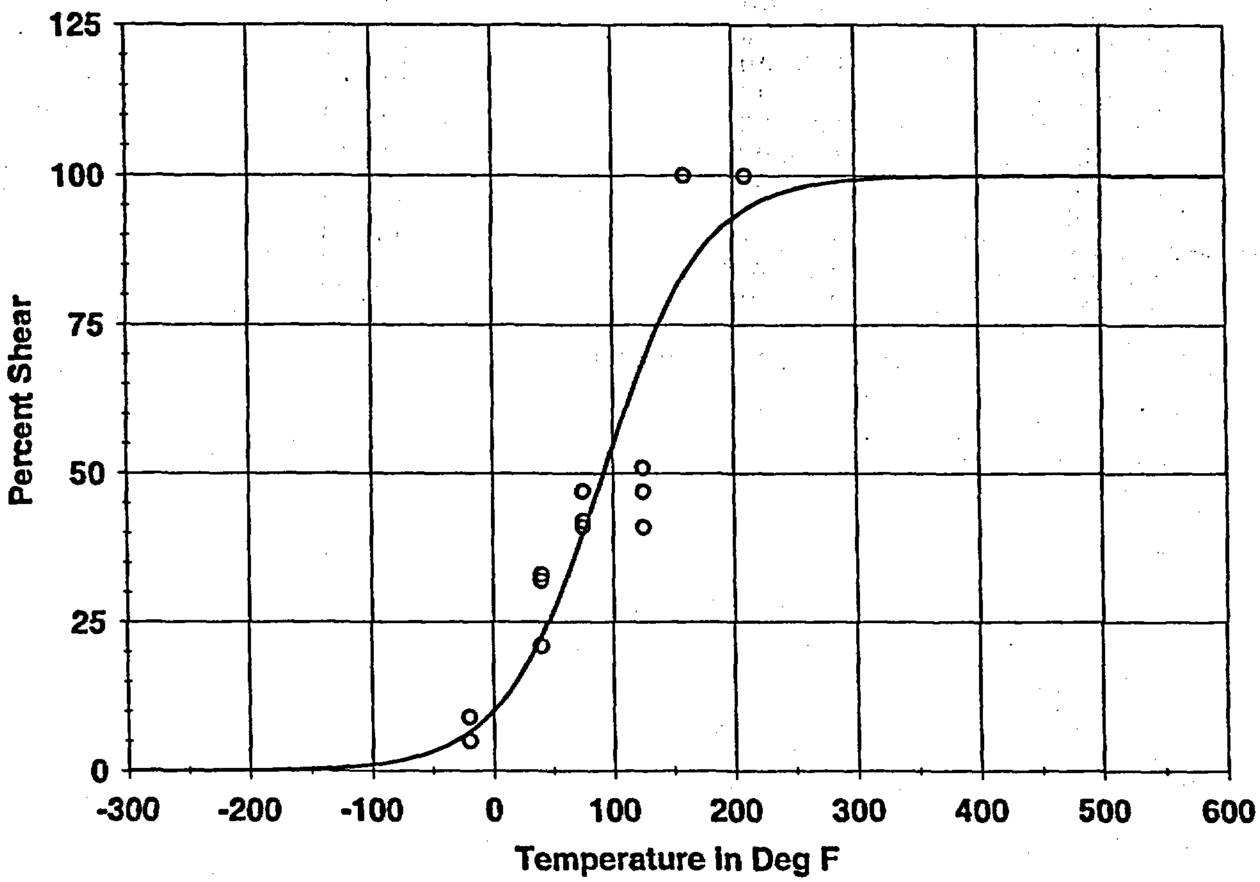
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
125.00	50.00	51.51	-1.51
125.00	54.00	51.51	2.49
125.00	47.00	51.51	-4.51
160.00	63.00	57.80	5.20
160.00	60.00	57.80	2.20
160.00	57.00	57.80	-.80
210.00	62.00	61.55	.45
210.00	60.00	61.55	-1.55
210.00	57.00	61.55	-4.55
210.00	64.00	61.55	2.45
210.00	60.00	61.55	-1.55
210.00	63.00	61.55	1.45

Correlation Coefficient = .991

UNIRRADIATED (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:14 PM
Page 1
Coefficients of Curve 1
A = 50. B = 50. C = 83.96 T0 = 92.15 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 92.2
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: TL Capsule: UNIRR Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-20.00	5.00	6.47	-1.47
-20.00	5.00	6.47	-1.47
-20.00	9.00	6.47	2.53
40.00	32.00	22.41	9.59
40.00	33.00	22.41	10.59
40.00	21.00	22.41	-1.41
75.00	41.00	39.93	1.07
75.00	47.00	39.93	7.07
75.00	42.00	39.93	2.07

UNIRRADIATED (TRANSVERSE ORIENTATION)

Page 2
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: TL Capsule: UNIRR Fluence: n/cm^2

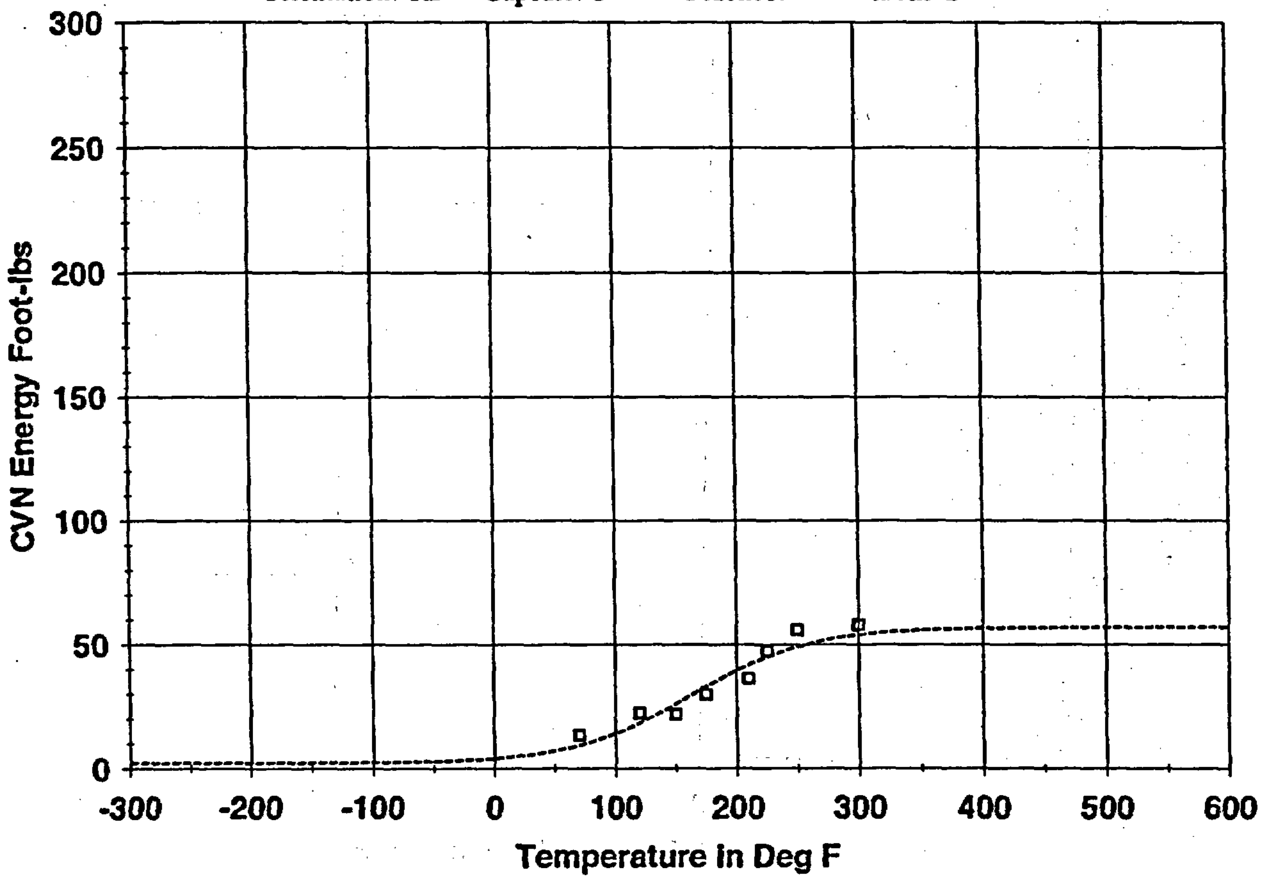
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
125.00	47.00	68.62	-21.62
125.00	51.00	68.62	-17.62
125.00	41.00	68.62	-27.62
160.00	100.00	83.43	16.57
160.00	100.00	83.43	16.57
160.00	100.00	83.43	16.57
210.00	100.00	94.31	5.69
210.00	100.00	94.31	5.69
210.00	100.00	94.31	5.69
210.00	100.00	94.31	5.69
210.00	100.00	94.31	5.69
210.00	100.00	94.31	5.69

Correlation Coefficient = .950

CAPSULE T (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:07 PM
Page 1
Coefficients of Curve 2
A = 29.6 B = 27.4 C = 97.43 T0 = 162.76 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=57.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=164.2 Deg F Temp@50 ft-lbs=256.4 Deg F
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: TL Capsule: T Fluence: n/cm^2



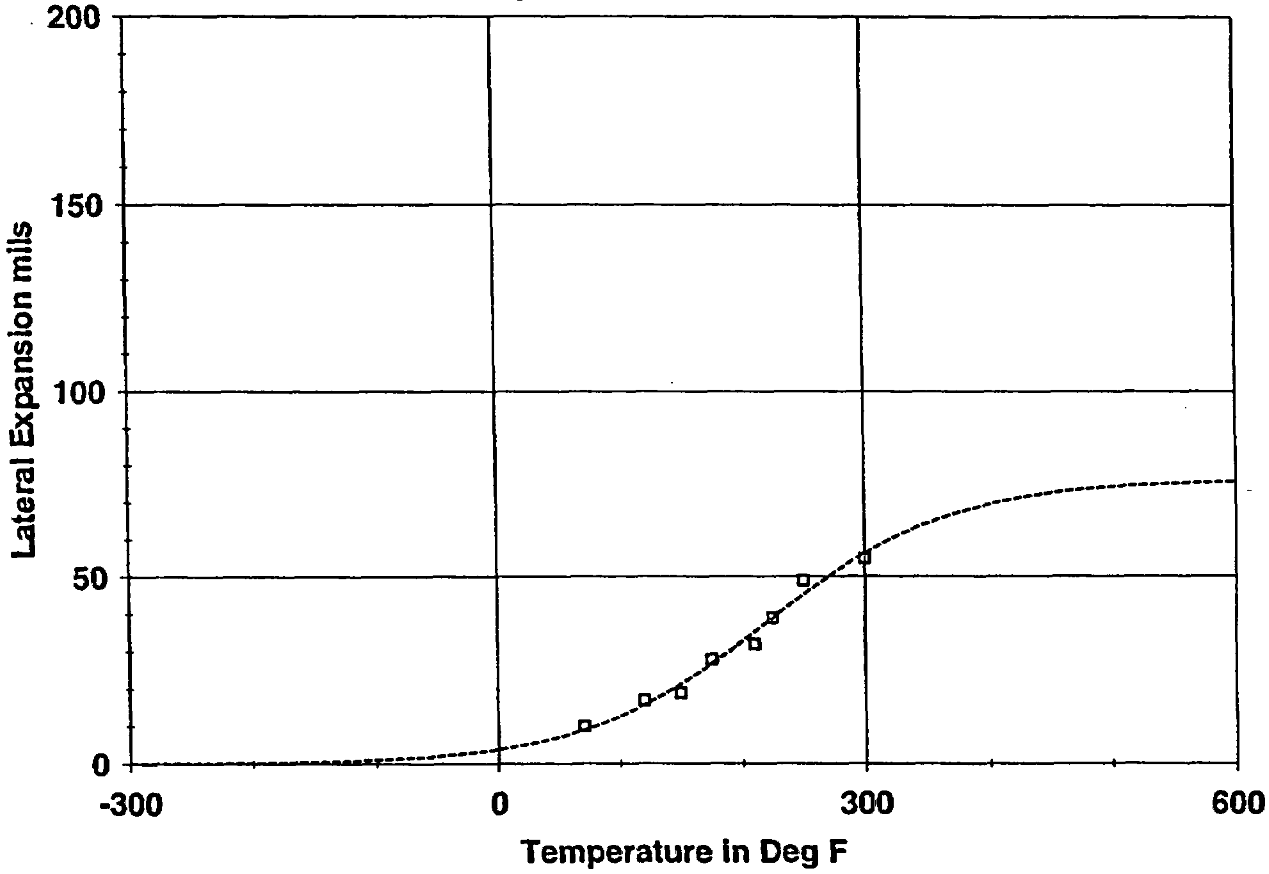
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
70.00	13.50	9.30	4.20
120.00	22.50	18.29	4.21
150.00	22.00	26.03	-4.03
175.00	30.00	33.02	-3.02
210.00	36.50	41.93	-5.43
225.00	47.50	45.06	2.44
250.00	56.00	49.16	6.84
300.00	58.00	53.91	4.09

Correlation Coefficient = .961

CAPSULE T (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:34 PM
Page 1
Coefficients of Curve 2
A = 38.02 B = 38.02 C = 150.8 T0 = 221.15 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=76.0 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=209.2 Deg F
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: TL Capsule: T Fluence: n/cm^2



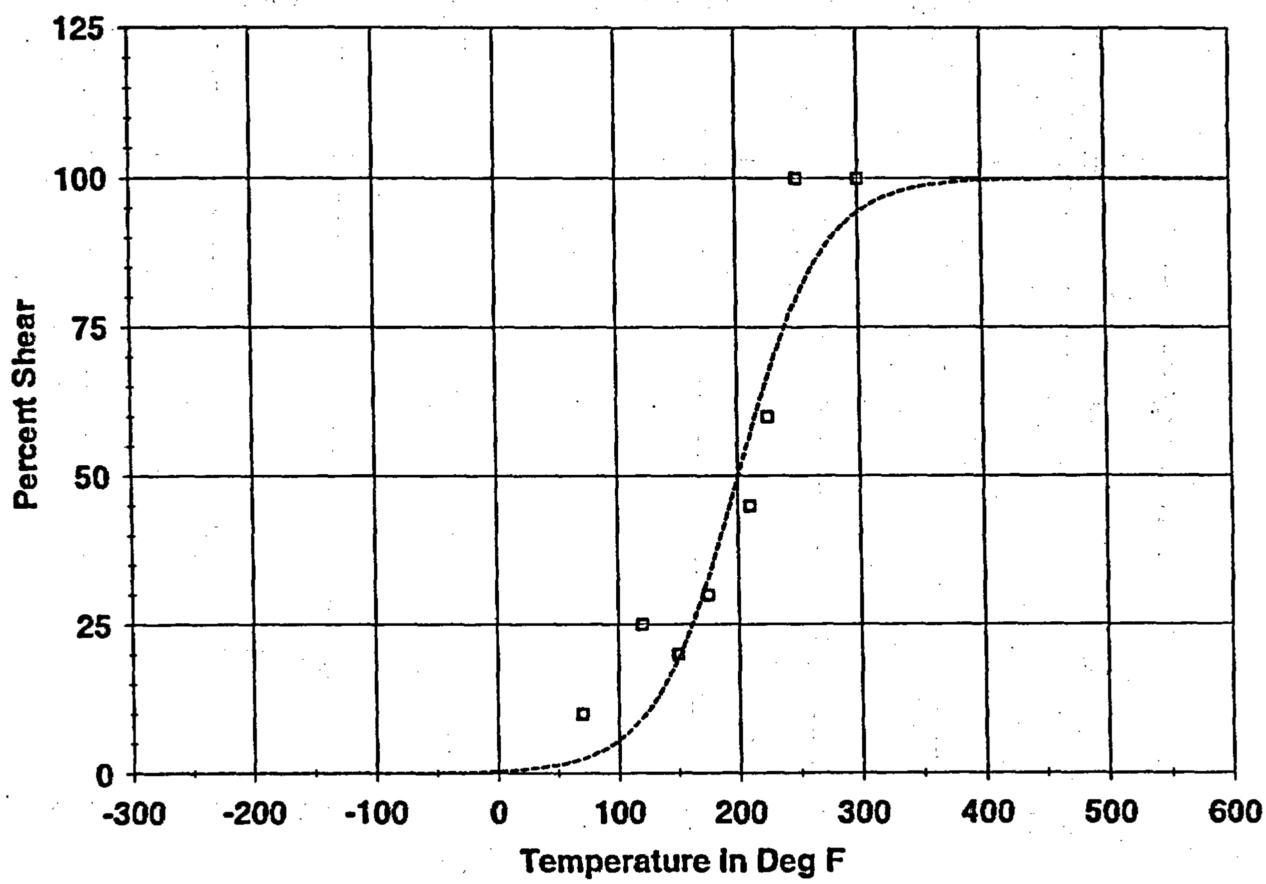
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
70.00	10.00	9.03	.97
120.00	17.00	15.76	1.24
150.00	19.00	21.31	-2.31
175.00	28.00	26.74	1.26
210.00	32.00	35.22	-3.22
225.00	39.00	38.99	.01
250.00	49.00	45.21	3.79
300.00	55.00	56.27	-1.27

Correlation Coefficient = .990

CAPSULE T (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:14 PM
Page 1
Coefficients of Curve 2
A = 50. B = 50. C = 70.63 T0 = 200.34 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 200.4
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: TL Capsule: T Fluence: n/cm^2



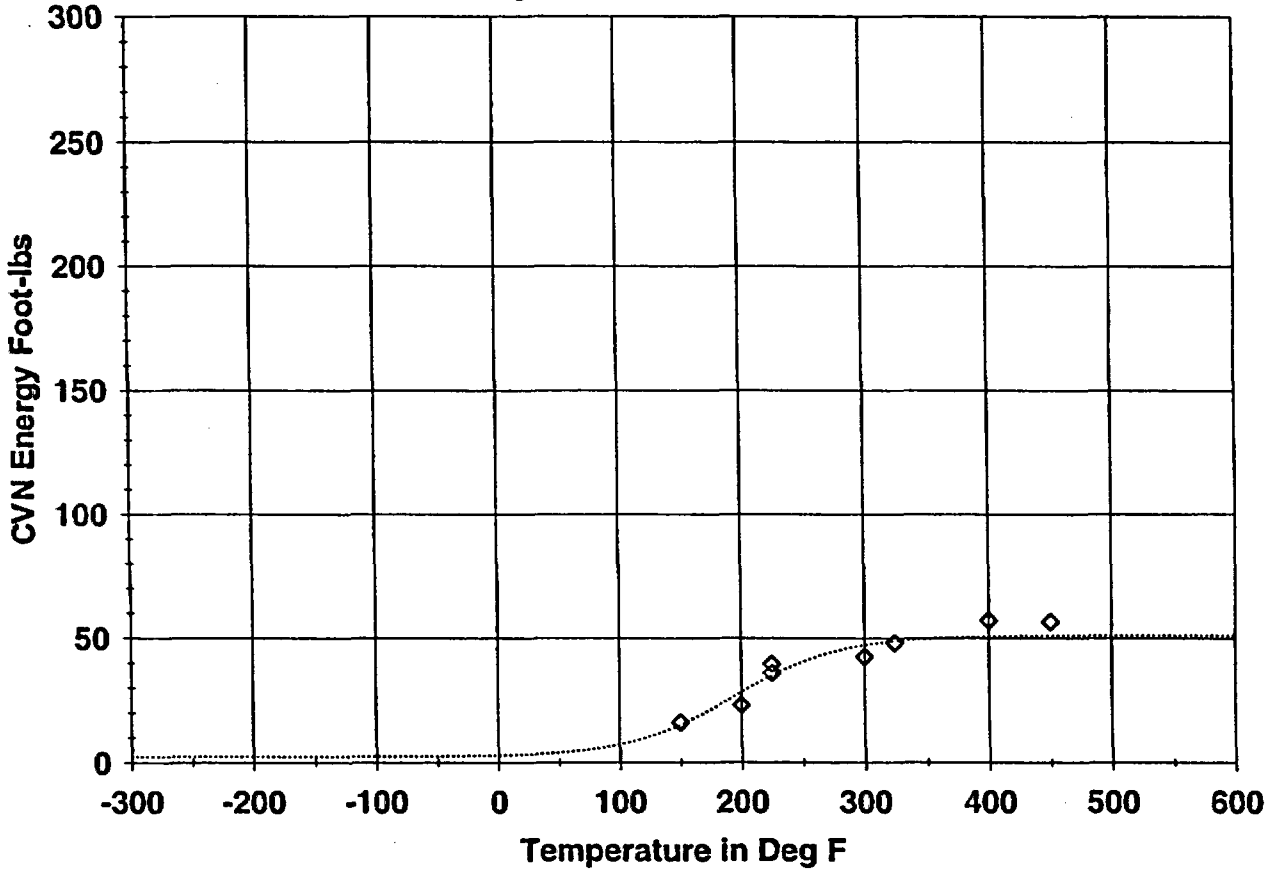
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
70.00	10.00	2.43	7.57
120.00	25.00	9.32	15.68
150.00	20.00	19.38	.62
175.00	30.00	32.79	-2.79
210.00	45.00	56.79	-11.79
225.00	60.00	66.78	-6.78
250.00	100.00	80.32	19.68
300.00	100.00	94.39	5.61

Correlation Coefficient = .952

CAPSULE Y (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:07 PM
Page 1
Coefficients of Curve 3
A = 26.6 B = 24.4 C = 86.38 T0 = 195.04 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=51.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=207.2 Deg F Temp@50 ft-lbs=362.1 Deg F
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: TL Capsule: Y Fluence: n/cm^2



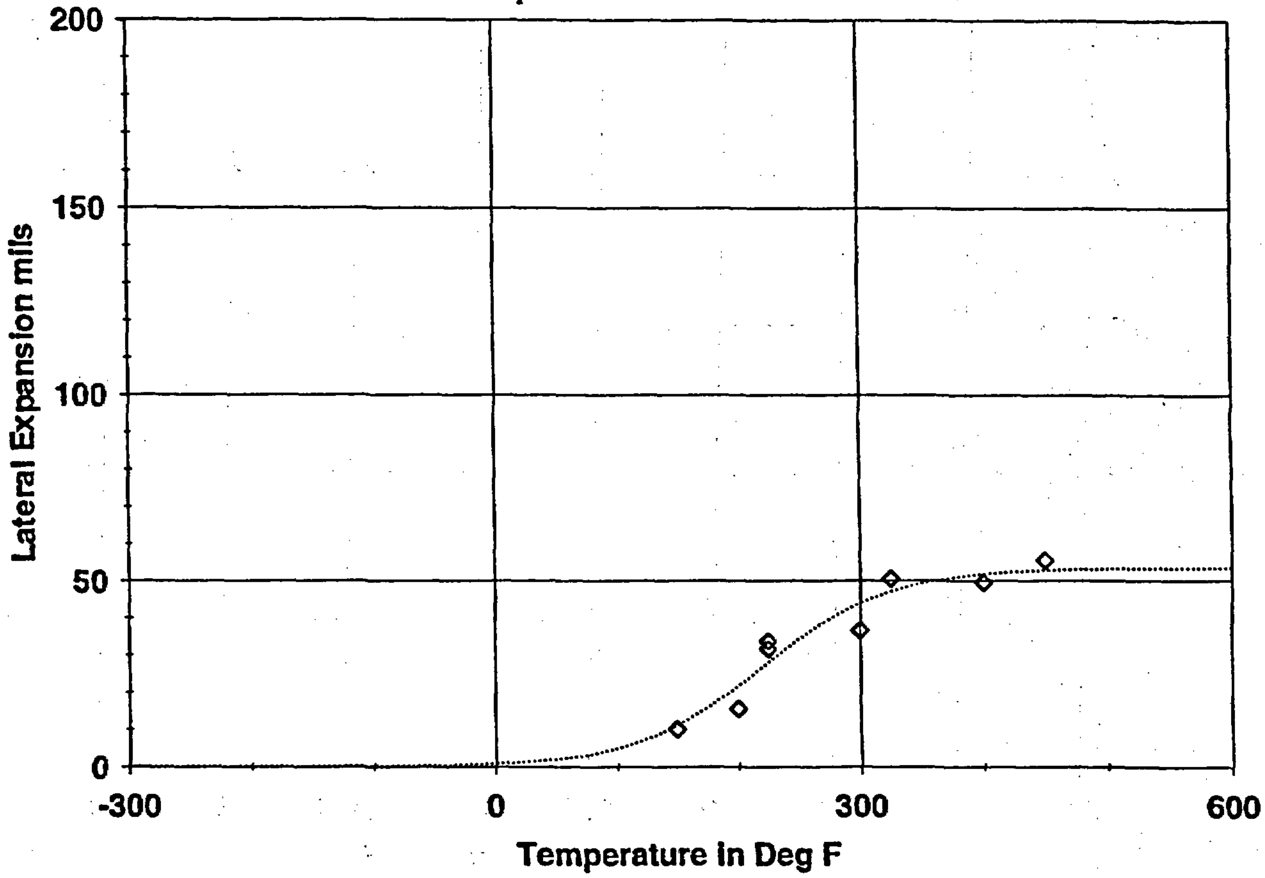
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
150.00	16.00	14.92	1.08
200.00	23.00	28.00	-5.00
225.00	39.50	34.74	4.76
225.00	36.00	34.74	1.26
300.00	42.50	47.05	-4.55
325.00	48.00	48.71	-.71
400.00	57.00	50.58	6.42
450.00	56.50	50.87	5.63

Correlation Coefficient = .958

CAPSULE Y (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:34 PM
Page 1
Coefficients of Curve 3
A = 26.67 B = 26.67 C = 104.32 T0 = 220.53 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=53.3 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=254.3 Deg F
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: TL Capsule: Y Fluence: n/cm^2



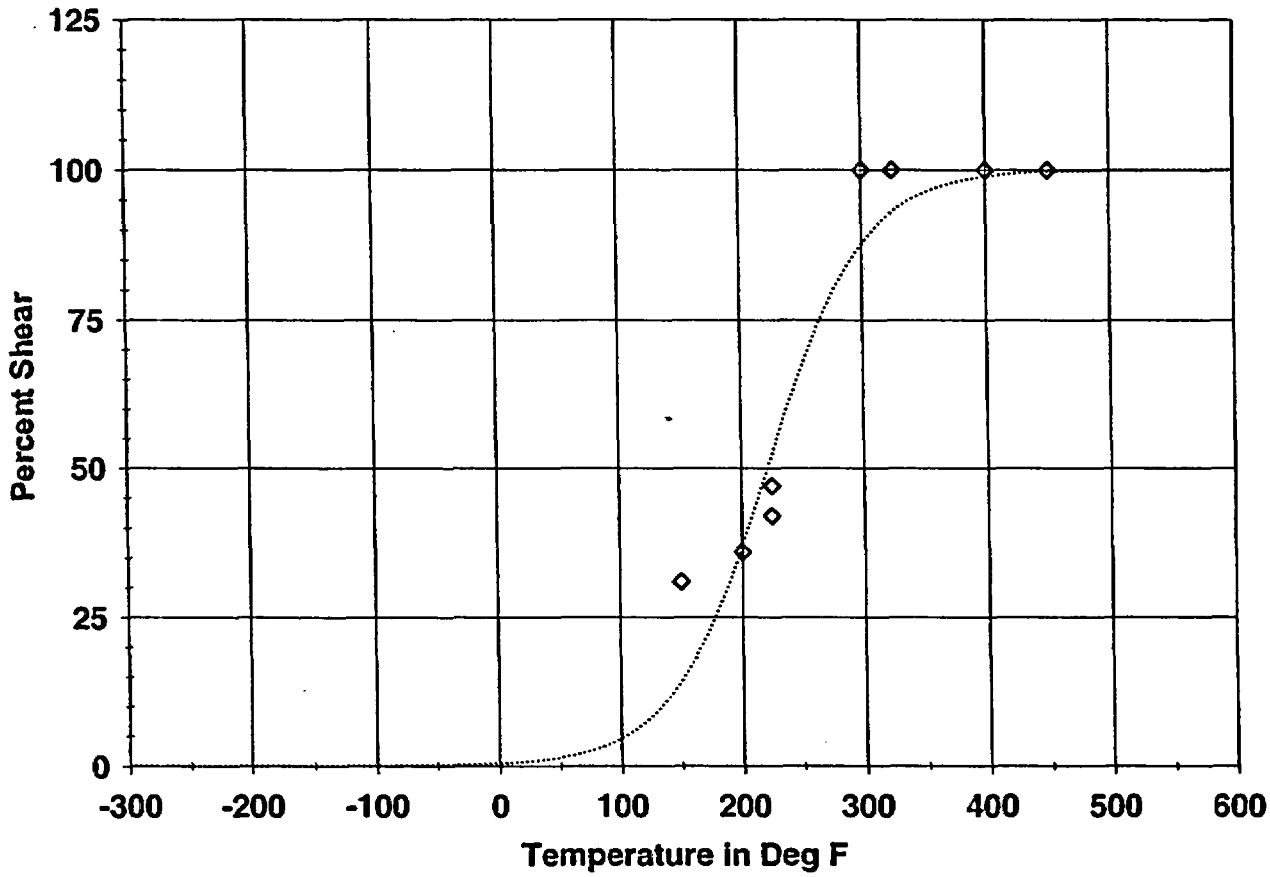
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
150.00	10.00	10.96	-.96
200.00	15.50	21.49	-5.99
225.00	31.50	27.82	3.68
225.00	33.50	27.82	5.68
300.00	36.50	43.80	-7.30
325.00	50.50	47.00	3.50
400.00	49.50	51.69	-2.19
450.00	55.50	52.70	2.80

Correlation Coefficient = .957

CAPSULE Y (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:14 PM
Page 1
Coefficients of Curve 3
A = 50. B = 50. C = 79.94 T0 = 221.88 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 221.9
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: TL Capsule: Y Fluence: n/cm^2



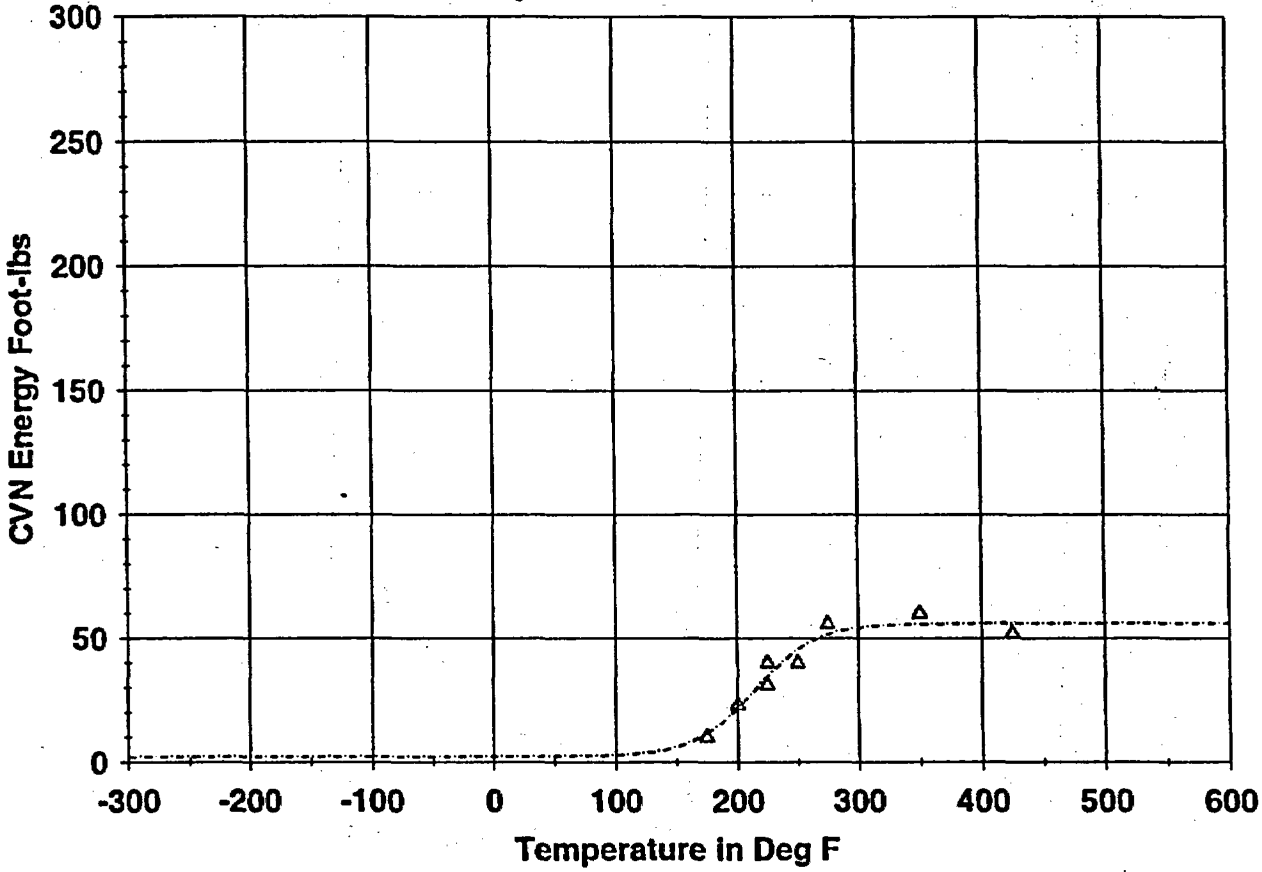
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
150.00	31.00	14.21	16.79
200.00	36.00	36.65	-.65
225.00	47.00	51.95	-4.95
225.00	42.00	51.95	-9.95
300.00	100.00	87.59	12.41
325.00	100.00	92.96	7.04
400.00	100.00	98.85	1.15
450.00	100.00	99.67	.33

Correlation Coefficient = .963

CAPSULE Z (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:07 PM
Page 1
Coefficients of Curve 4
A = 29.1 B = 26.9 C = 50.31 T0 = 214.42 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf Energy=56.0(Fixed) Lower Shelf Energy=2.2(Fixed)
Temp@30 ft-lbs=216.2 Deg F Temp@50 ft-lbs=266.7 Deg F
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: TL Capsule: Z Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
175.00	10.00	11.49	-1.49
200.00	23.00	21.59	1.41
225.00	40.00	34.67	5.33
225.00	31.00	34.67	-3.67
250.00	40.00	45.48	-5.48
275.00	56.00	51.56	4.44
350.00	60.00	55.76	4.24
425.00	52.00	55.99	-3.99

Correlation Coefficient = .968

CAPSULE Z (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:34 PM

Page 1

Coefficients of Curve 4

A = 26.96 B = 26.96 C = 59.95 T0 = 214.3 D = 0.00E+00

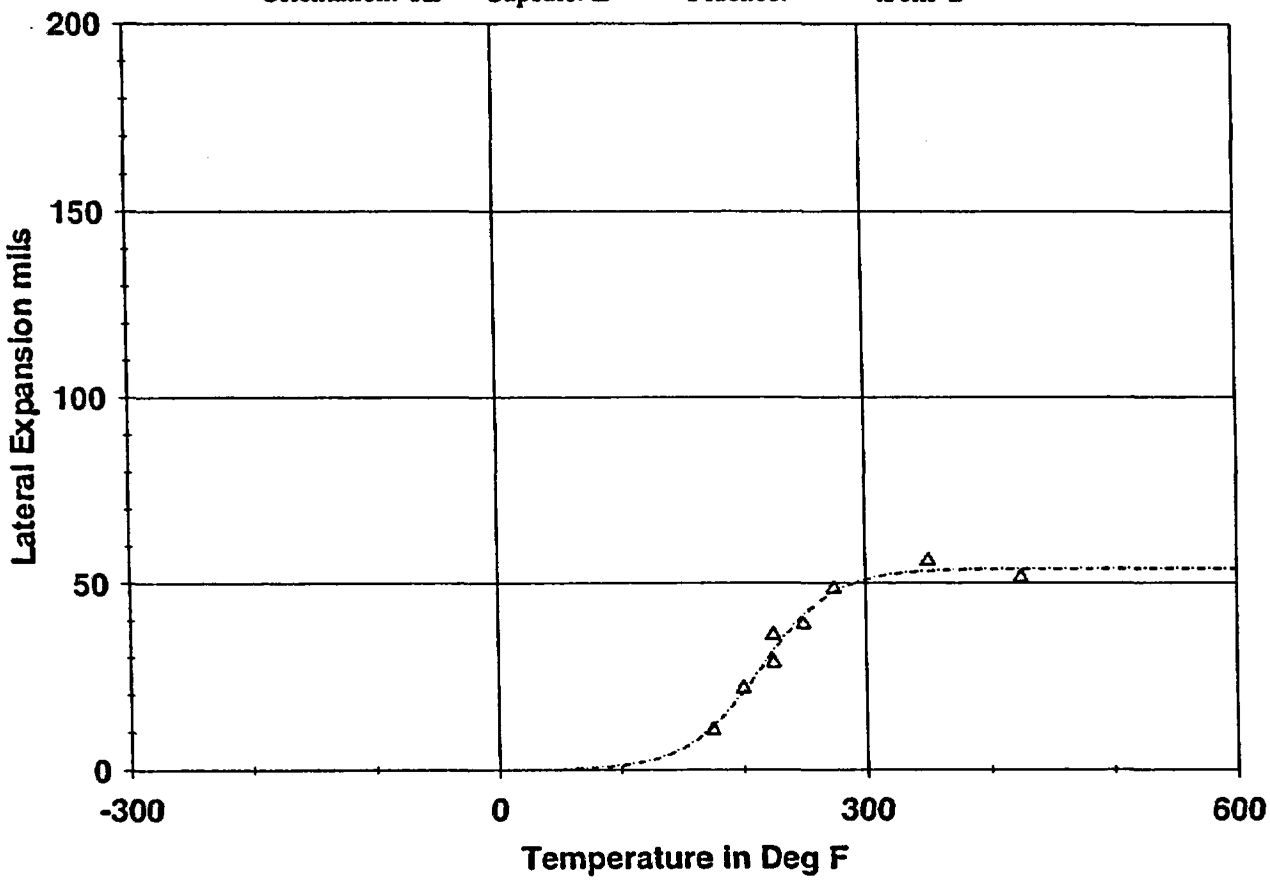
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=53.9 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=232.8 Deg F

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
175.00	10.50	11.44	-.94
200.00	21.50	20.64	.86
225.00	36.00	31.72	4.28
225.00	28.50	31.72	-3.22
250.00	39.00	41.35	-2.35
275.00	48.50	47.63	.87
350.00	56.00	53.34	2.66
425.00	51.50	53.86	-2.36

Correlation Coefficient = .986

CAPSULE Z (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:14 PM

Page 1

Coefficients of Curve 4

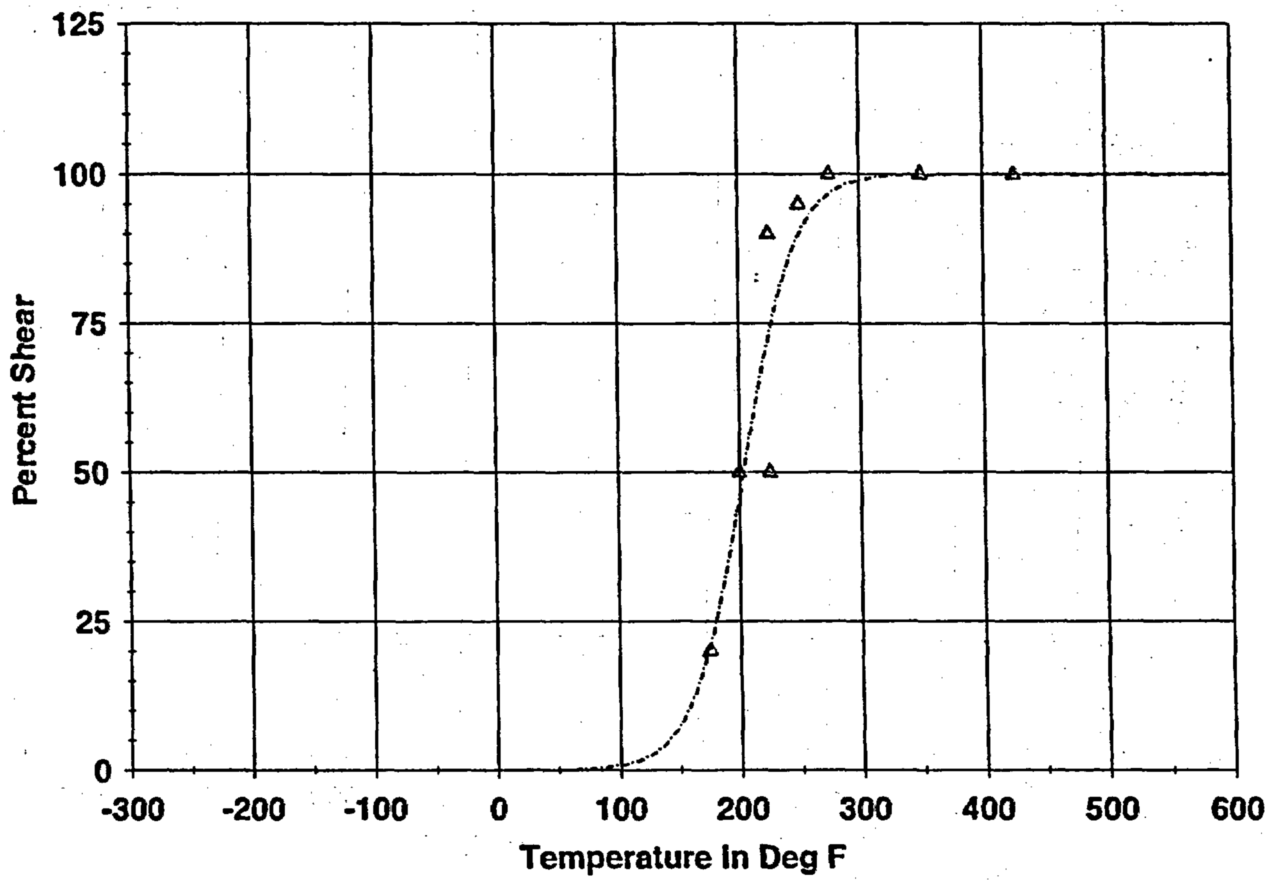
A = 50. B = 50. C = 42.51 T0 = 203.29 D = 0.00E+00

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

Temperature at 50% Shear = 203.3

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
175.00	20.00	20.90	-.90
200.00	50.00	46.13	3.87
225.00	90.00	73.52	16.48
225.00	50.00	73.52	-23.52
250.00	95.00	90.00	5.00
275.00	100.00	96.69	3.31
350.00	100.00	99.90	.10
425.00	100.00	100.00	.00

Correlation Coefficient = .933

CAPSULE X (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:07 PM

Page 1

Coefficients of Curve 5

A = 27.1 B = 24.9 C = 75.44 T0 = 207.61 D = 0.00E+00

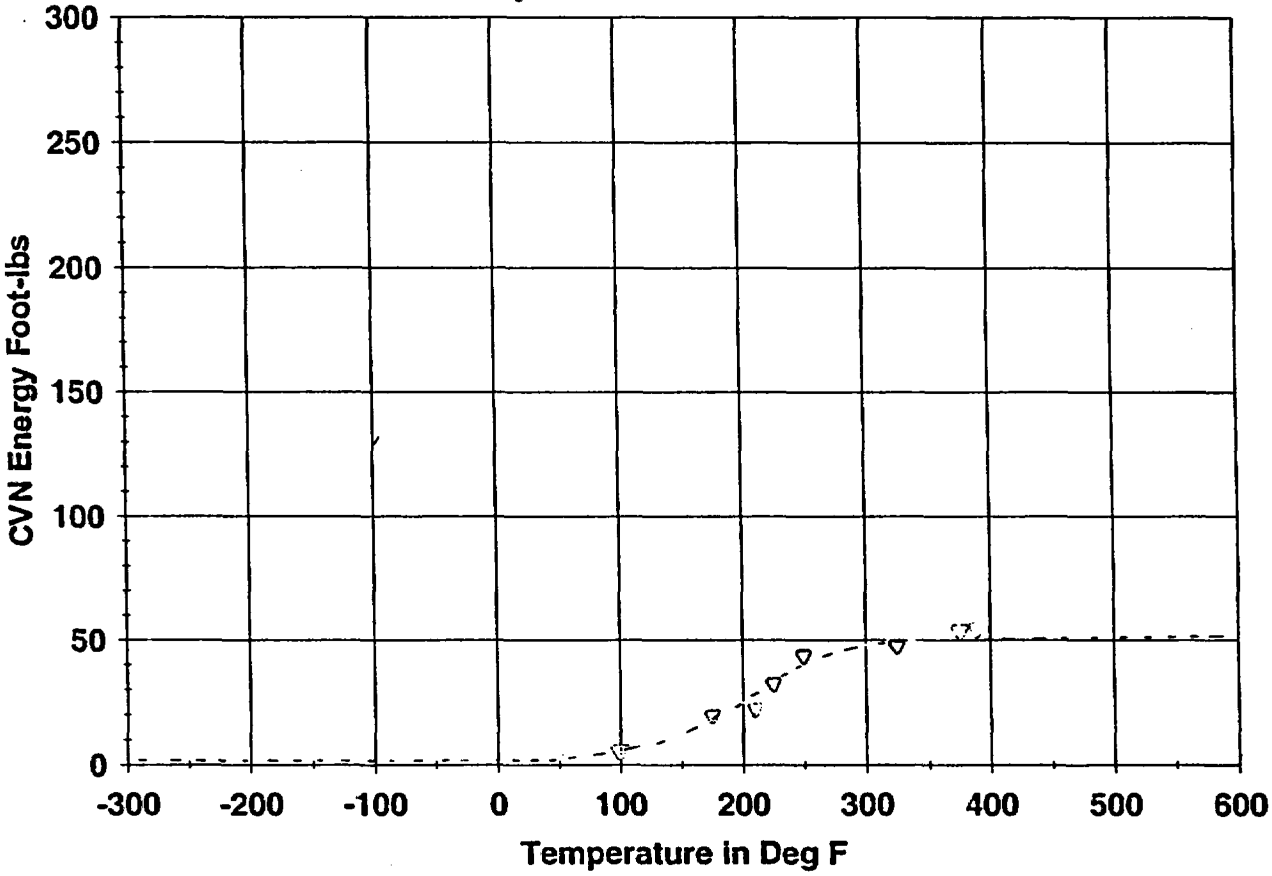
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=52.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=216.5 Deg F Temp@50 ft-lbs=327.4 Deg F

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2

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



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
100.00	6.00	4.92	1.08
175.00	20.00	16.96	3.04
210.00	22.00	27.89	-5.89
225.00	33.00	32.74	.26
250.00	44.00	39.78	4.22
325.00	47.00	49.88	-2.88
375.00	54.00	51.42	2.58
390.00	55.00	51.61	3.39

Correlation Coefficient = .981

CAPSULE X (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:34 PM

Page 1

Coefficients of Curve 5

A = 22.2 B = 22.2 C = 75.96 T0 = 219.26 D = 0.00E+00

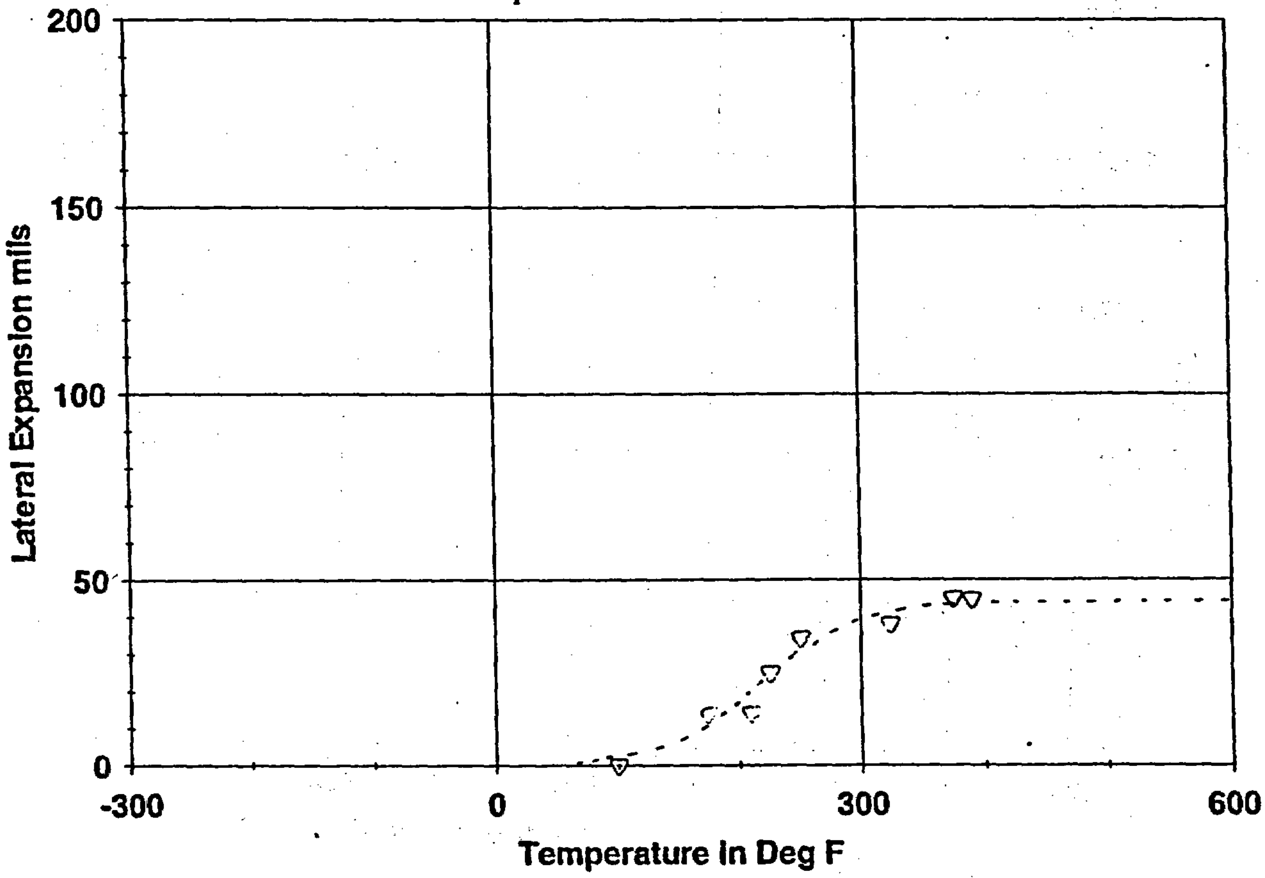
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=44.4 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=269.3 Deg F

Plant: Indian Point 3 Material: SA302B Heat: A-0512-2

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



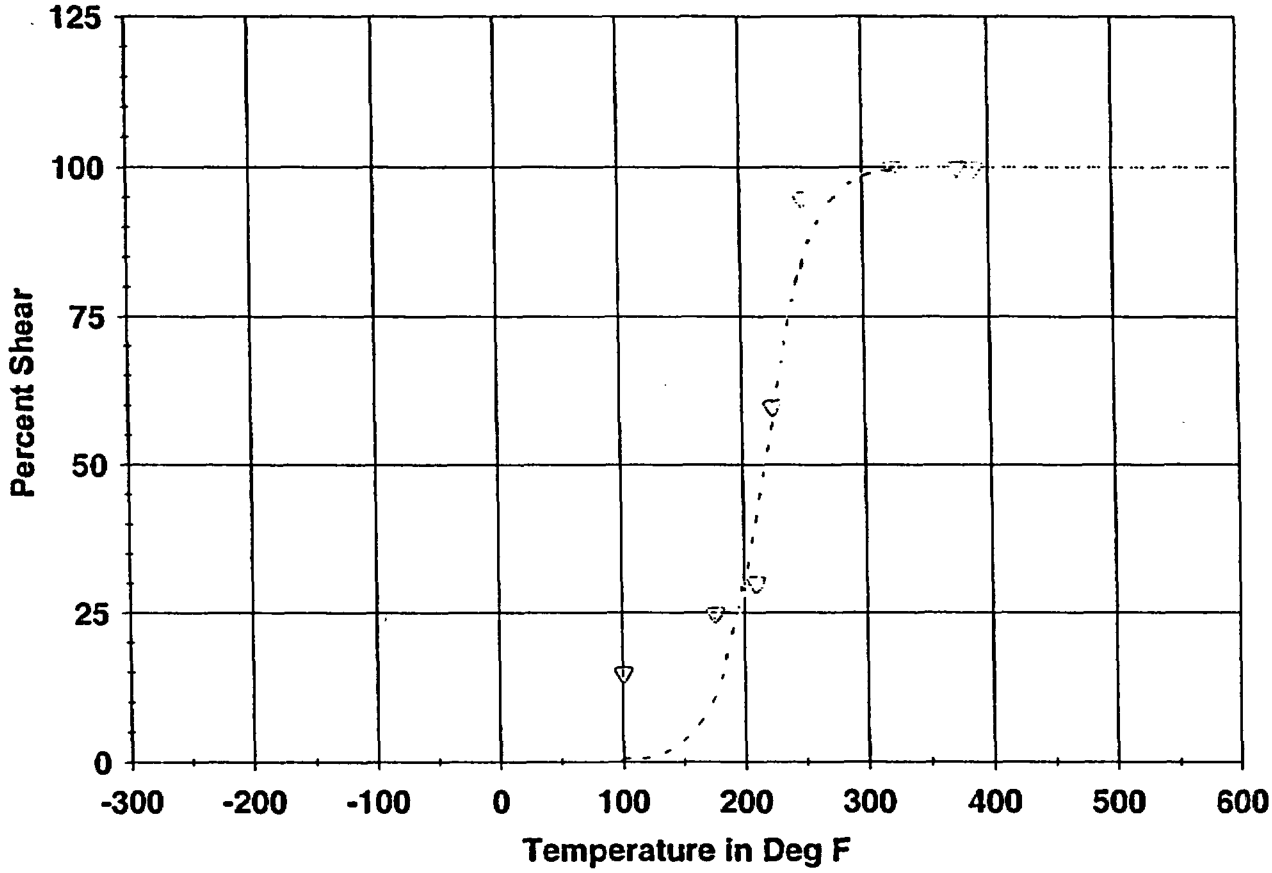
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
100.00	.00	1.84	-1.84
175.00	14.00	10.55	3.45
210.00	14.00	19.50	-5.50
225.00	25.00	23.87	1.13
250.00	34.00	30.72	3.28
325.00	38.00	41.81	-3.81
375.00	45.00	43.67	1.33
390.00	45.00	43.91	1.09

Correlation Coefficient = .980

CAPSULE X (TRANSVERSE ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:14 PM
Page 1
Coefficients of Curve 5
A = 50. B = 50. C = 37.97 T0 = 217.1 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 217.1
Plant: Indian Point 3 Material: SA302B Heat: A-0512-2
Orientation: TL Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100.00	15.00	.21	14.79
175.00	25.00	9.82	15.18
210.00	30.00	40.76	-10.76
225.00	60.00	60.26	-.26
250.00	95.00	84.98	10.02
325.00	100.00	99.66	.34
375.00	100.00	99.98	.02
390.00	100.00	99.99	.01

Correlation Coefficient = .978

UNIRRADIATED (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 02:26 PM

Page 1

Coefficients of Curve 1

A = 61.1 B = 58.9 C = 47.03 T0 = -37.11 D = 0.00E+00

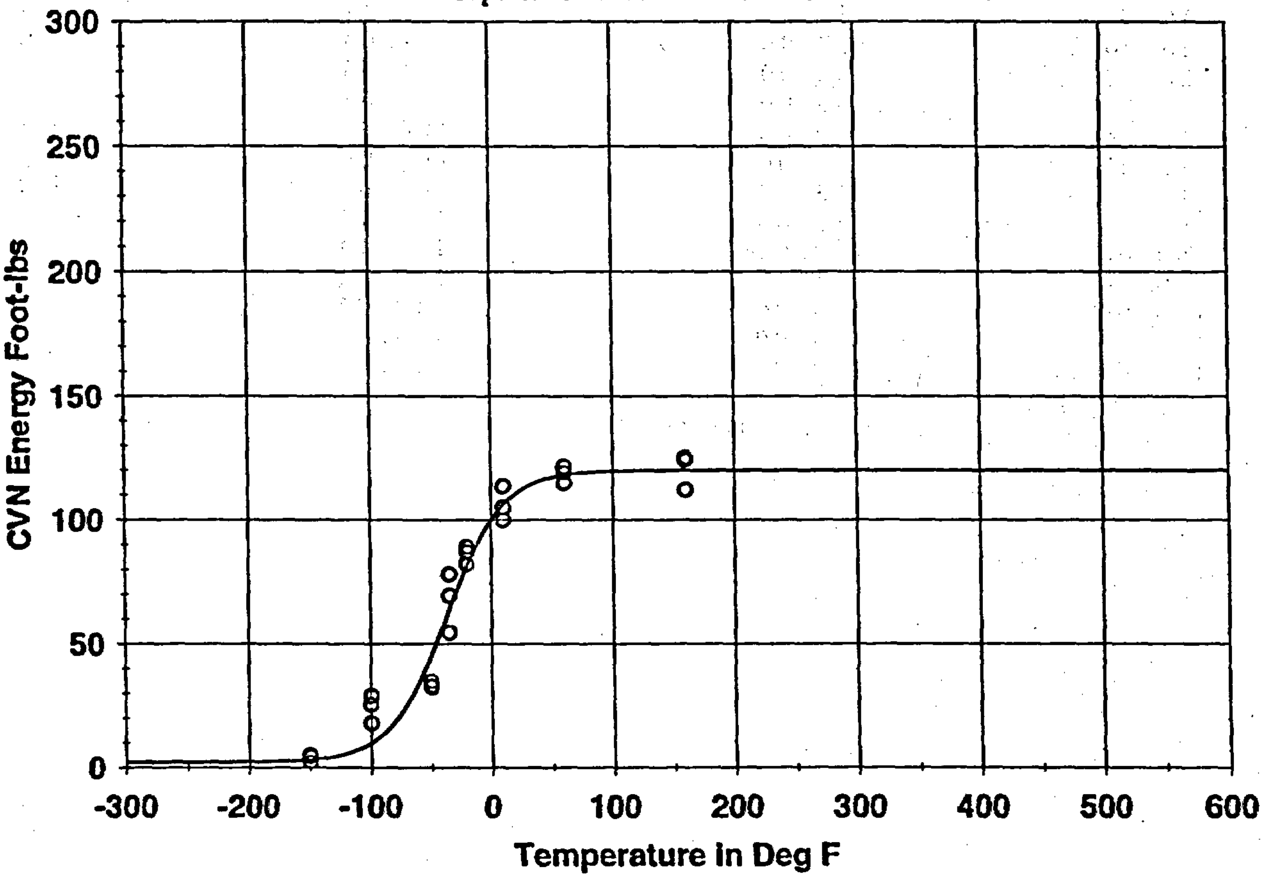
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=120.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=-64.7 Deg F Temp@50 ft-lbs=-46.0 Deg F

Plant: Indian Point 3 Material: SAW Heat: W5214

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



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-150.00	5.00	3.16	1.84
-150.00	2.00	3.16	-1.16
-150.00	4.50	3.16	1.34
-100.00	29.00	9.80	19.20
-100.00	18.00	9.80	8.20
-100.00	25.50	9.80	15.70
-50.00	35.00	45.35	-10.35
-50.00	33.00	45.35	-12.35
-50.00	32.50	45.35	-12.85

UNIRRADIATED (WELD)

Page 2
Plant: Indian Point 3 Material: SAW Heat: W5214
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-35.00	78.00	63.74	14.26
-35.00	69.50	63.74	5.76
-35.00	54.50	63.74	-9.24
-20.00	87.00	81.63	5.37
-20.00	82.00	81.63	.37
-20.00	89.00	81.63	7.37
10.00	100.00	106.00	-6.00
10.00	105.00	106.00	-1.00
10.00	113.50	106.00	7.50
60.00	115.00	118.14	-3.14
60.00	119.00	118.14	.86
60.00	121.50	118.14	3.36
160.00	124.00	119.97	4.03
160.00	125.00	119.97	5.03
160.00	112.00	119.97	-7.97

Correlation Coefficient = .981

UNIRRADIATED (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:10 PM

Page 1

Coefficients of Curve 1

A = 45.41 B = 45.41 C = 58.14 T0 = -45.8 D = 0.00E+00

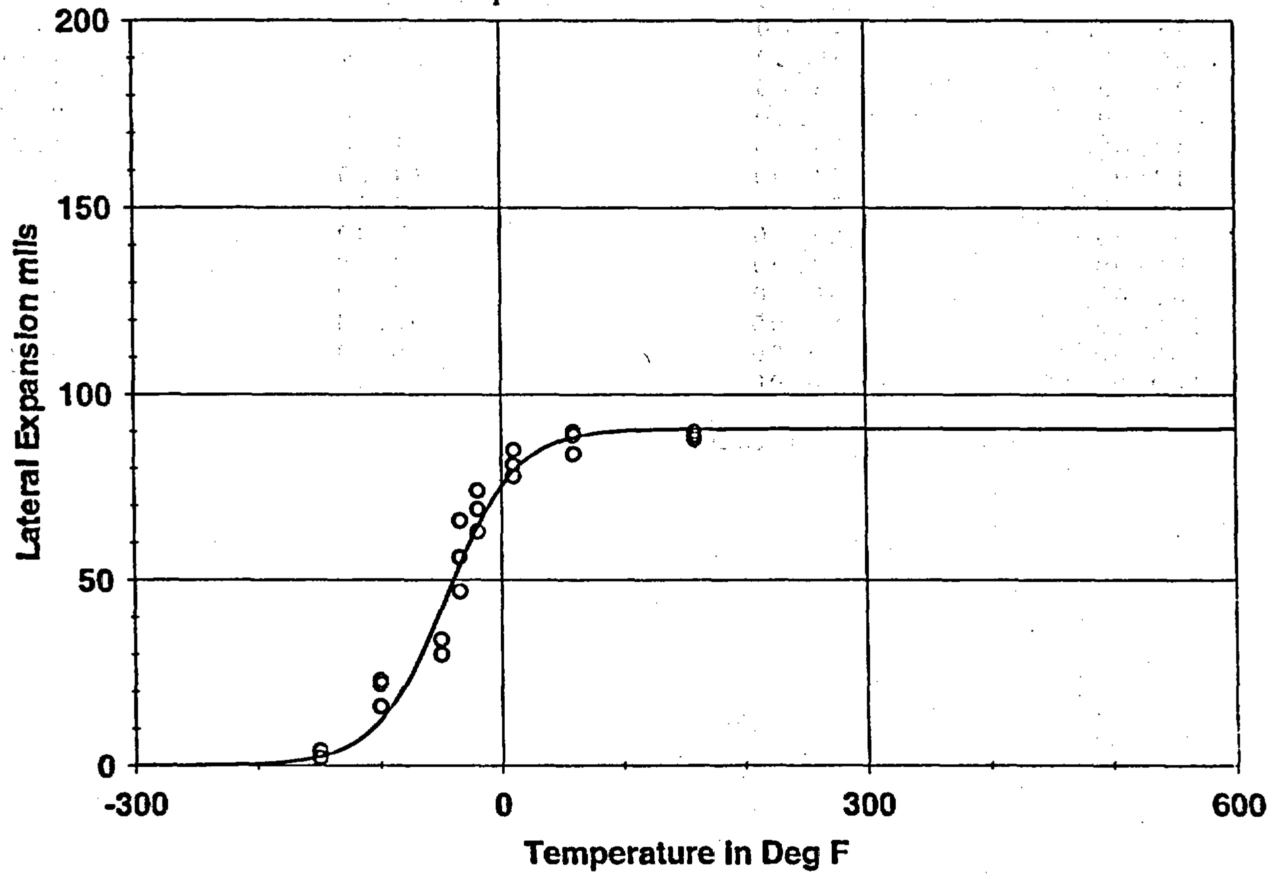
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=90.8 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=-59.3 Deg F

Plant: Indian Point 3 Material: SAW Heat: W5214

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-150.00	2.00	2.45	-.45
-150.00	2.00	2.45	-.45
-150.00	4.00	2.45	1.55
-100.00	22.00	12.19	9.81
-100.00	16.00	12.19	3.81
-100.00	23.00	12.19	10.81
-50.00	34.00	42.14	-8.14
-50.00	30.00	42.14	-12.14
-50.00	30.00	42.14	-12.14

UNIRRADIATED (WELD)

Page 2
Plant: Indian Point 3 Material: SAW Heat: W5214
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-35.00	66.00	53.75	12.25
-35.00	56.00	53.75	2.25
-35.00	47.00	53.75	-6.75
-20.00	69.00	64.34	4.66
-20.00	63.00	64.34	-1.34
-20.00	74.00	64.34	9.66
10.00	78.00	79.20	-1.20
10.00	81.00	79.20	1.80
10.00	85.00	79.20	5.80
60.00	89.00	88.49	.51
60.00	84.00	88.49	-4.49
60.00	90.00	88.49	1.51
160.00	88.00	90.74	-2.74
160.00	89.00	90.74	-1.74
160.00	90.00	90.74	-.74

Correlation Coefficient = .979

UNIRRADIATED (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 03:54 PM
Page 1
Coefficients of Curve 1

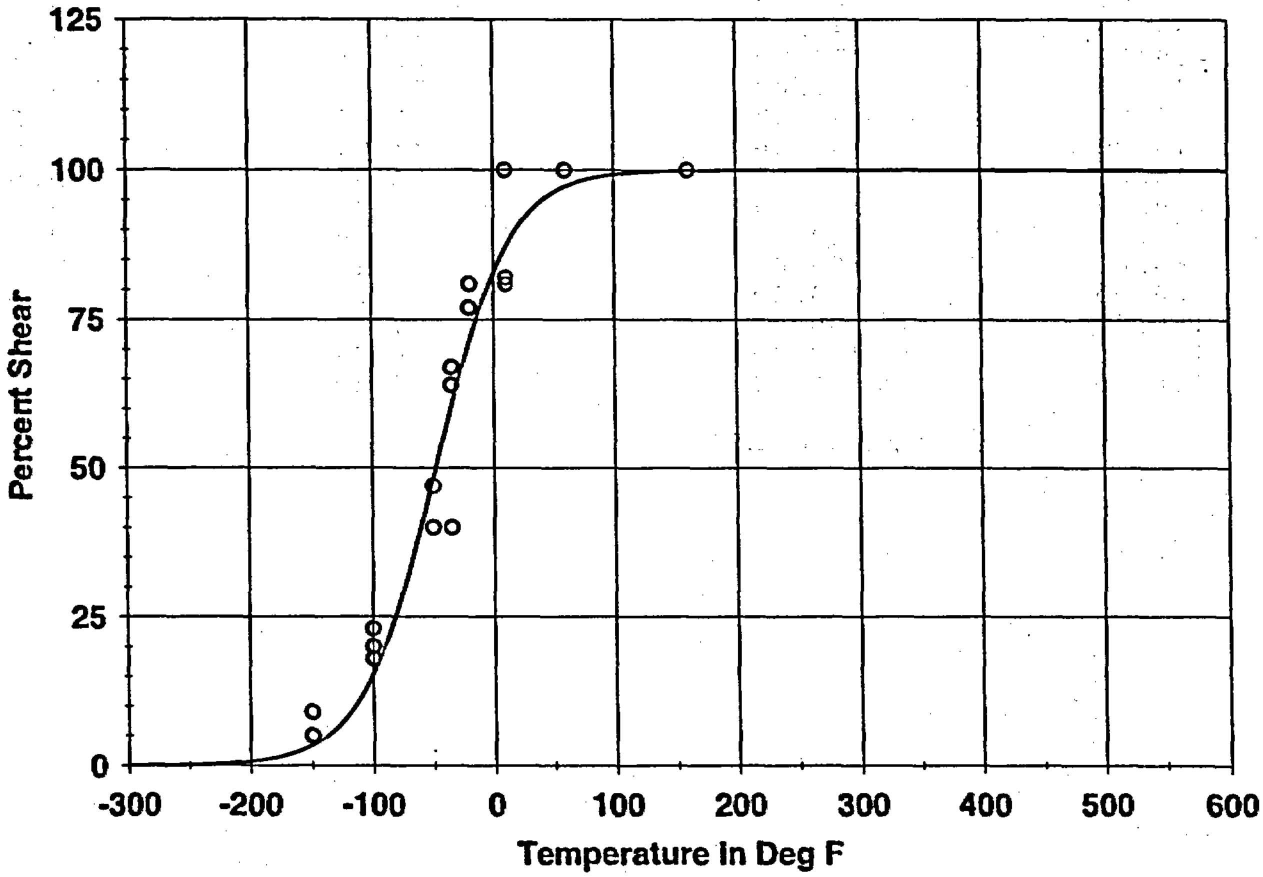
A = 50. B = 50. C = 60.8 T0 = -47.89 D = 0.00E+00

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

Temperature at 50% Shear = -47.8

Plant: Indian Point 3 Material: SAW Heat: W5214

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-150.00	5.00	3.36	1.64
-150.00	5.00	3.36	1.64
-150.00	9.00	3.36	5.64
-100.00	20.00	15.26	4.74
-100.00	18.00	15.26	2.74
-100.00	23.00	15.26	7.74
-50.00	40.00	48.26	-8.26
-50.00	47.00	48.26	-1.26
-50.00	40.00	48.26	-8.26

UNIRRADIATED (WELD)

Page 2
Plant: Indian Point 3 Material: SAW Heat: W5214
Orientation: NA Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-35.00	64.00	60.44	3.56
-35.00	67.00	60.44	6.56
-35.00	40.00	60.44	-20.44
-20.00	77.00	71.45	5.55
-20.00	77.00	71.45	5.55
-20.00	81.00	71.45	9.55
10.00	81.00	87.04	-6.04
10.00	82.00	87.04	-5.04
10.00	100.00	87.04	12.96
60.00	100.00	97.20	2.80
60.00	100.00	97.20	2.80
60.00	100.00	97.20	2.80
160.00	100.00	99.89	.11
160.00	100.00	99.89	.11
160.00	100.00	99.89	.11

Correlation Coefficient = .980

CAPSULE T (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 02:26 PM

Page 1

Coefficients of Curve 2

A = 43.1 B = 40.9 C = 87.09 T0 = 115.75 D = 0.00E+00

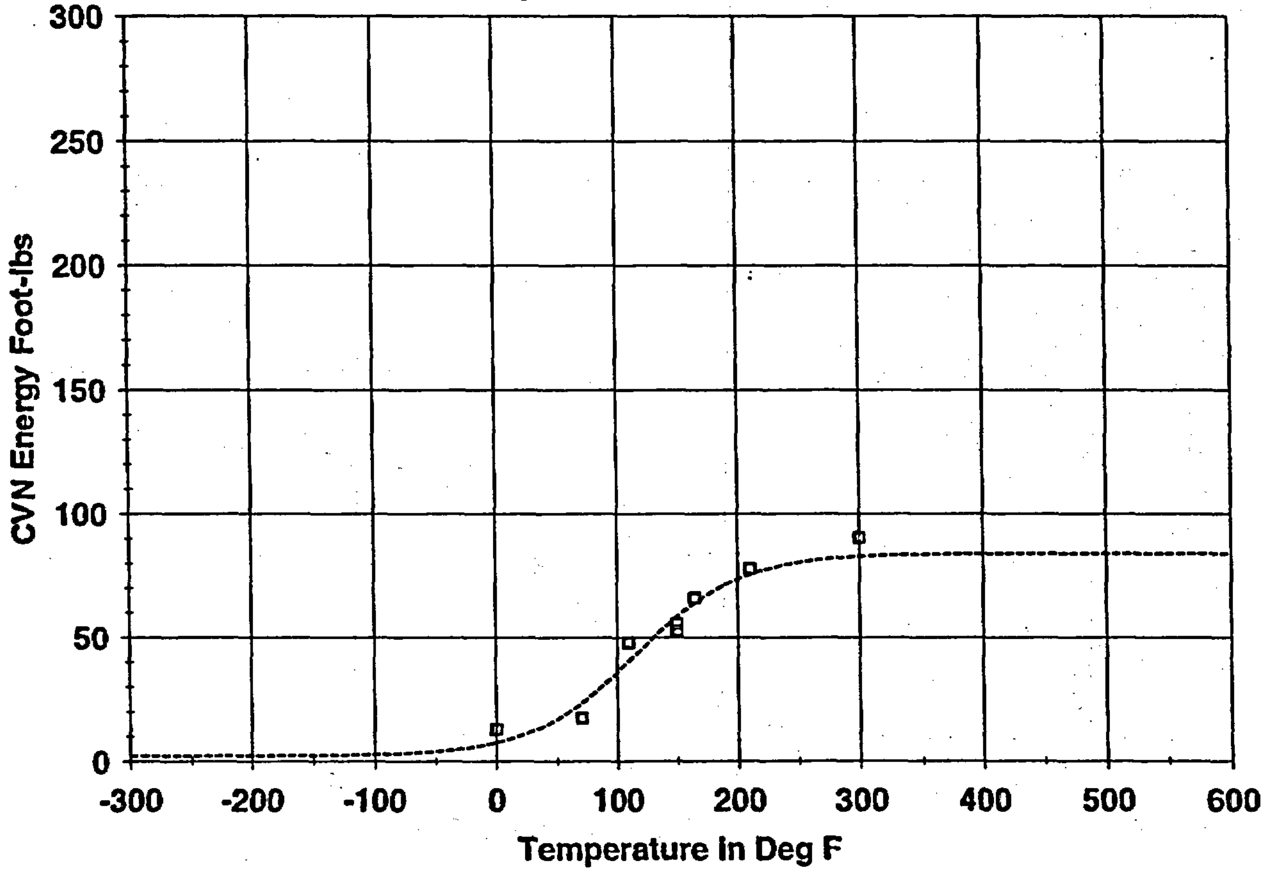
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=84.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=86.9 Deg F Temp@50 ft-lbs=130.6 Deg F

Plant: Indian Point 3 Material: SAW Heat: W5214

Orientation: NA Capsule: T Fluence: n/cm^2



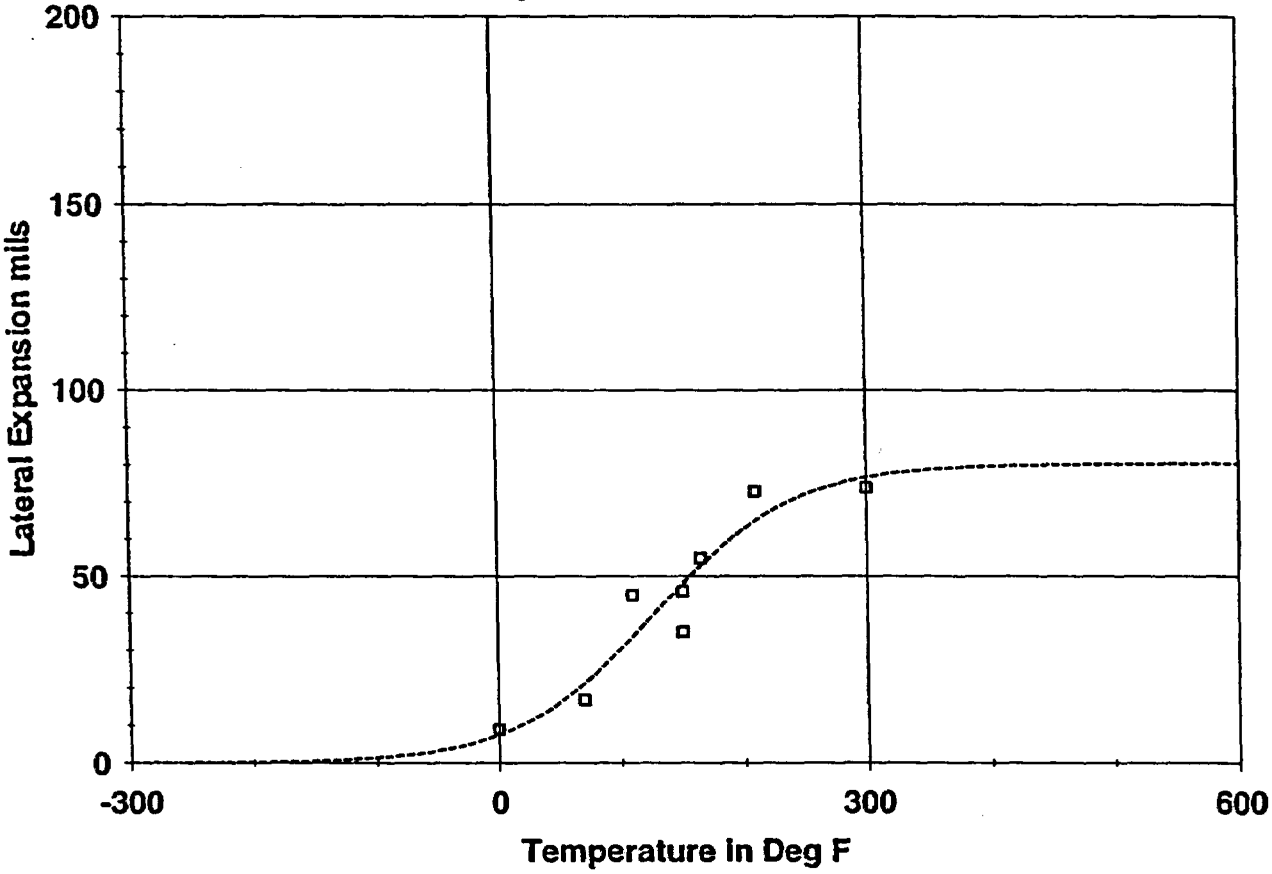
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
.00	13.00	7.56	5.44
70.00	17.50	23.39	-5.89
110.00	48.00	40.40	7.60
150.00	55.50	58.40	-2.90
150.00	53.00	58.40	-5.40
165.00	66.00	64.04	1.96
210.00	78.00	75.58	2.42
300.00	90.50	82.83	7.67

Correlation Coefficient = .979

CAPSULE T (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:10 PM
Page 1
Coefficients of Curve 2
A = 40.17 B = 40.17 C = 112.89 T0 = 127.9 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=80.3 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=113.3 Deg F
Plant: Indian Point 3 Material: SAW Heat: W5214
Orientation: NA Capsule: T Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
.00	9.00	7.55	1.45
70.00	17.00	21.20	-4.20
110.00	45.00	33.86	11.14
150.00	46.00	47.94	-1.94
150.00	35.00	47.94	-12.94
165.00	55.00	52.92	2.08
210.00	73.00	65.14	7.86
300.00	74.00	76.71	-2.71

Correlation Coefficient = .949

CAPSULE T (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 03:54 PM

Page 1

Coefficients of Curve 2

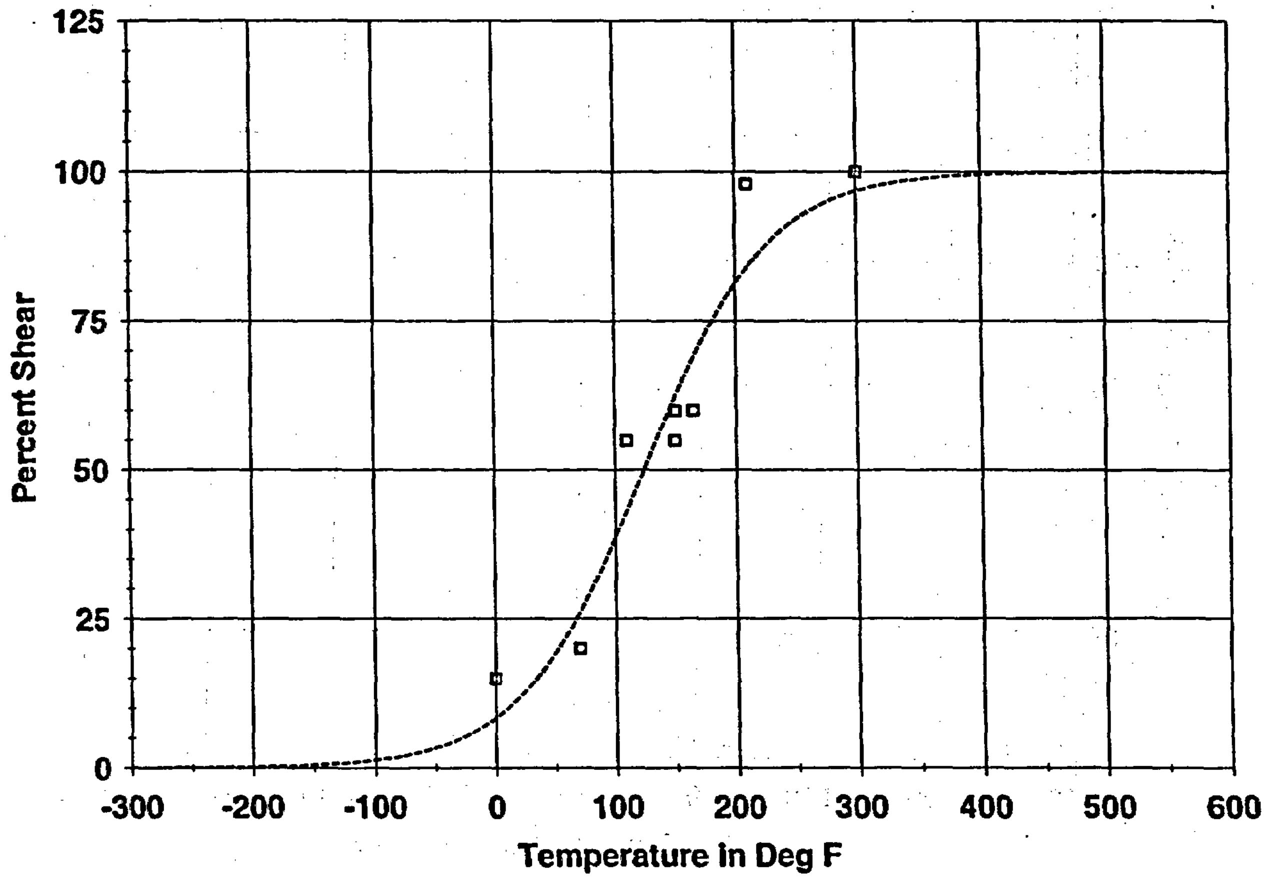
A = 50. B = 50. C = 103.39 T0 = 123.94 D = 0.00E+00

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

Temperature at 50% Shear = 124.0

Plant: Indian Point 3 Material: SAW Heat: W5214

Orientation: NA Capsule: T Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
.00	15.00	8.34	6.66
70.00	20.00	26.05	-6.05
110.00	55.00	43.30	11.70
150.00	60.00	62.34	-2.34
150.00	55.00	62.34	-7.34
165.00	60.00	68.88	-8.88
210.00	98.00	84.09	13.91
300.00	100.00	96.79	3.21

Correlation Coefficient = .958

CAPSULE Y (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 02:26 PM

Page 1

Coefficients of Curve 3

A = 35.6 B = 33.4 C = 90.16 T0 = 122.54 D = 0.00E+00

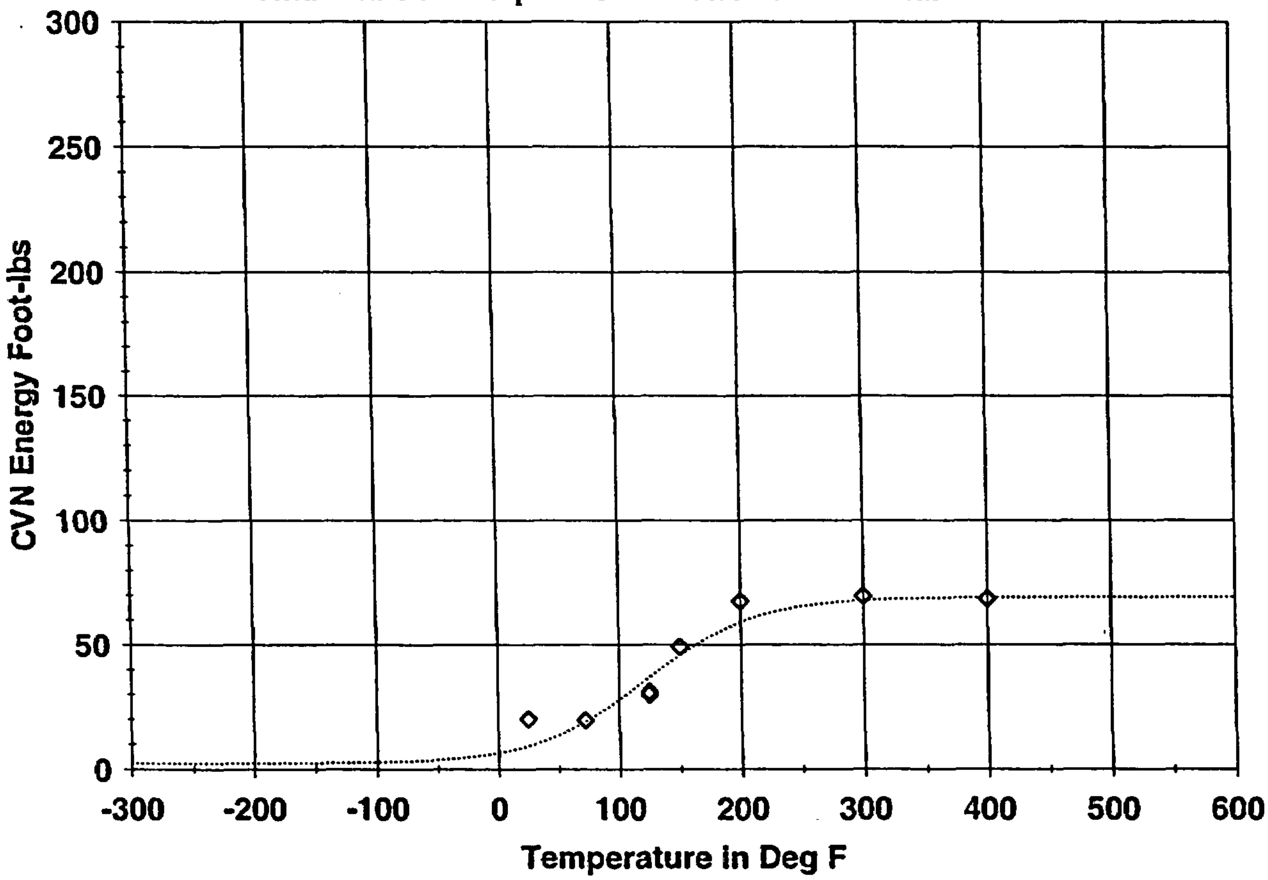
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=69.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=107.3 Deg F Temp@50 ft-lbs=164.2 Deg F

Plant: Indian Point 3 Material: SAW Heat: W5214

Orientation: NA Capsule: Y Fluence: n/cm^2



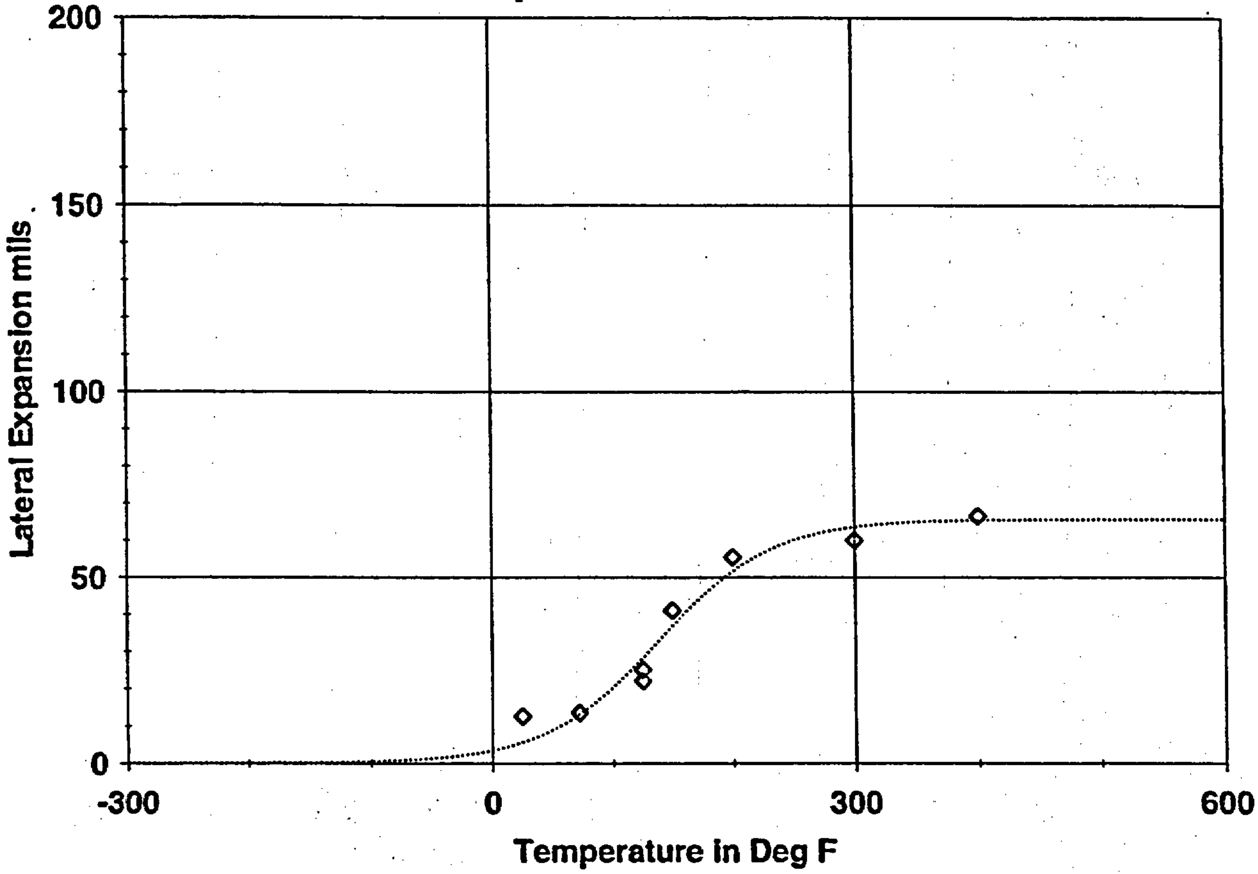
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
25.00	20.00	9.08	10.92
72.00	19.50	18.62	.88
125.00	31.00	36.51	-5.51
125.00	29.50	36.51	-7.01
150.00	49.00	45.47	3.53
200.00	67.50	58.84	8.66
300.00	69.50	67.72	1.78
400.00	68.50	68.86	-.36

Correlation Coefficient = .960

CAPSULE Y (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:10 PM
Page 1
Coefficients of Curve 3
A = 32.81 B = 32.81 C = 94.65 T0 = 138.68 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=65.6 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=145.0 Deg F
Plant: Indian Point 3 Material: SAW Heat: W5214
Orientation: NA Capsule: Y Fluence: n/cm^2



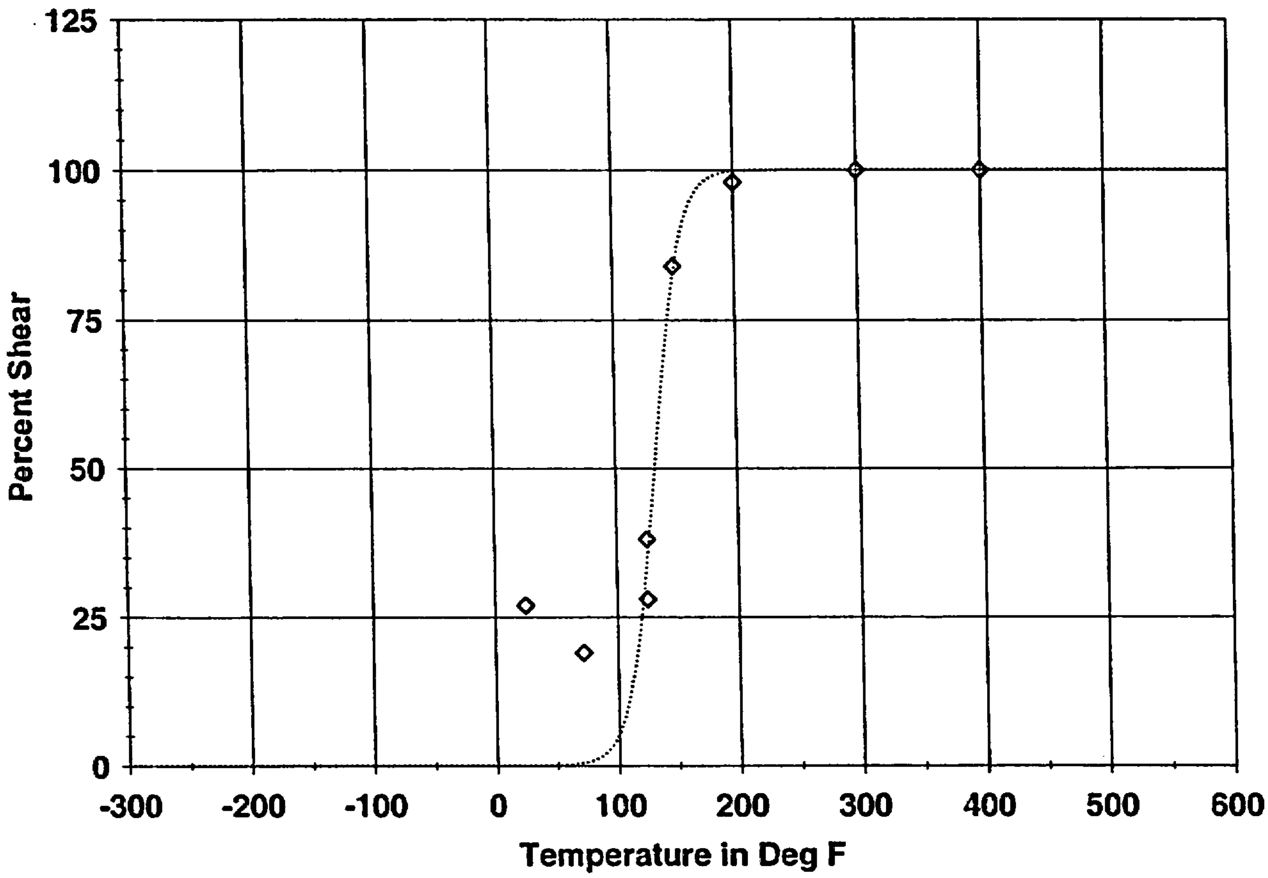
Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
25.00	12.50	5.45	7.05
72.00	13.50	12.89	.61
125.00	25.00	28.10	-3.10
125.00	22.00	28.10	-6.10
150.00	41.00	36.72	4.28
200.00	55.50	51.52	3.98
300.00	60.00	63.52	-3.52
400.00	66.50	65.36	1.14

Correlation Coefficient = .979

CAPSULE Y (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 03:54 PM
Page 1
Coefficients of Curve 3
A = 50. B = 50. C = 22.27 T0 = 132.59 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Temperature at 50% Shear = 132.6
Plant: Indian Point 3 Material: SAW Heat: W5214
Orientation: NA Capsule: Y Fluence: n/cm^2



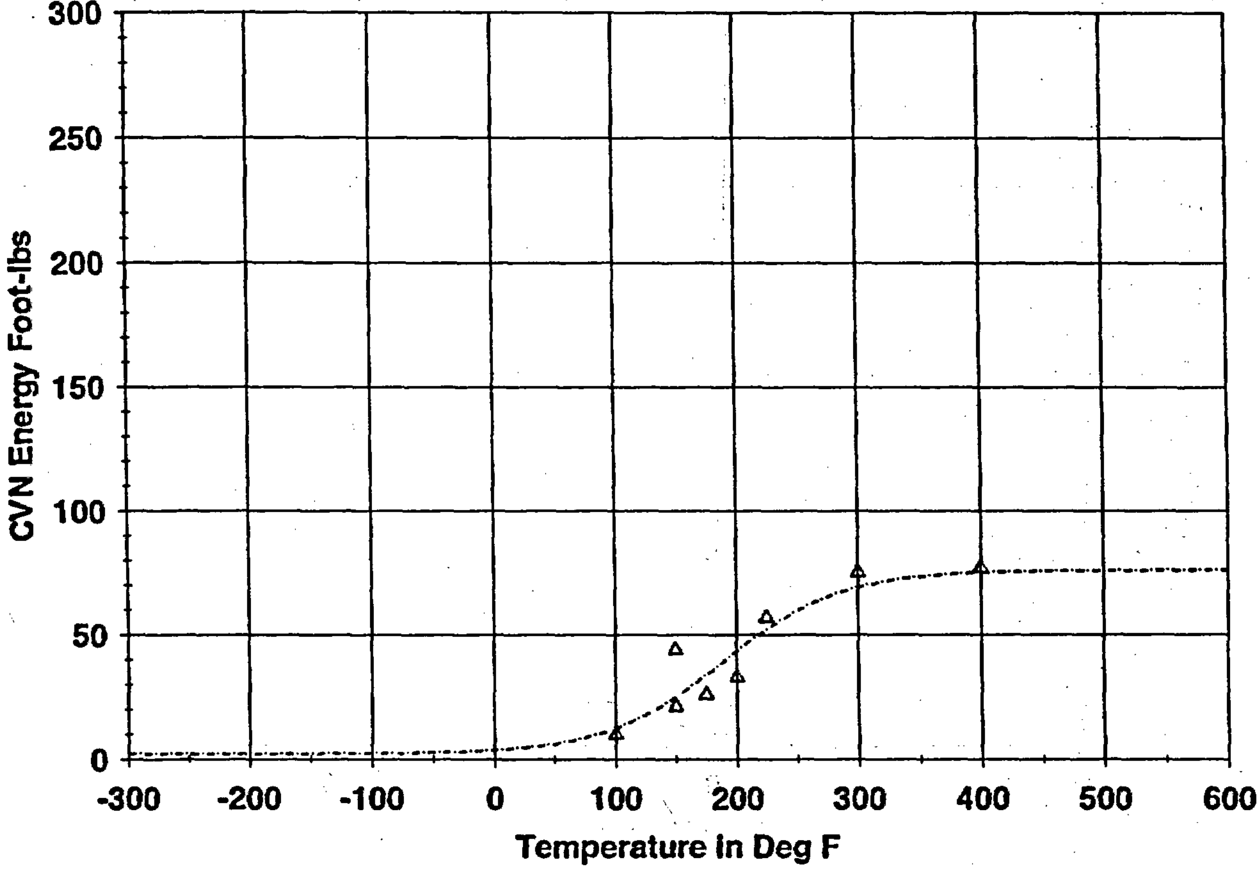
Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25.00	27.00	.01	26.99
72.00	19.00	.43	18.57
125.00	38.00	33.59	4.41
125.00	28.00	33.59	-5.59
150.00	84.00	82.69	1.31
200.00	98.00	99.77	-1.77
300.00	100.00	100.00	.00
400.00	100.00	100.00	.00

Correlation Coefficient = .978

CAPSULE Z (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 02:26 PM
Page 1
Coefficients of Curve 4
A = 39.1 B = 36.9 C = 97.52 T0 = 188.96 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=164.5 Deg F Temp@50 ft-lbs=218.7 Deg F
Plant: Indian Point 3 Material: SAW Heat: W5214
Orientation: NA Capsule: Z Fluence: n/cm^2



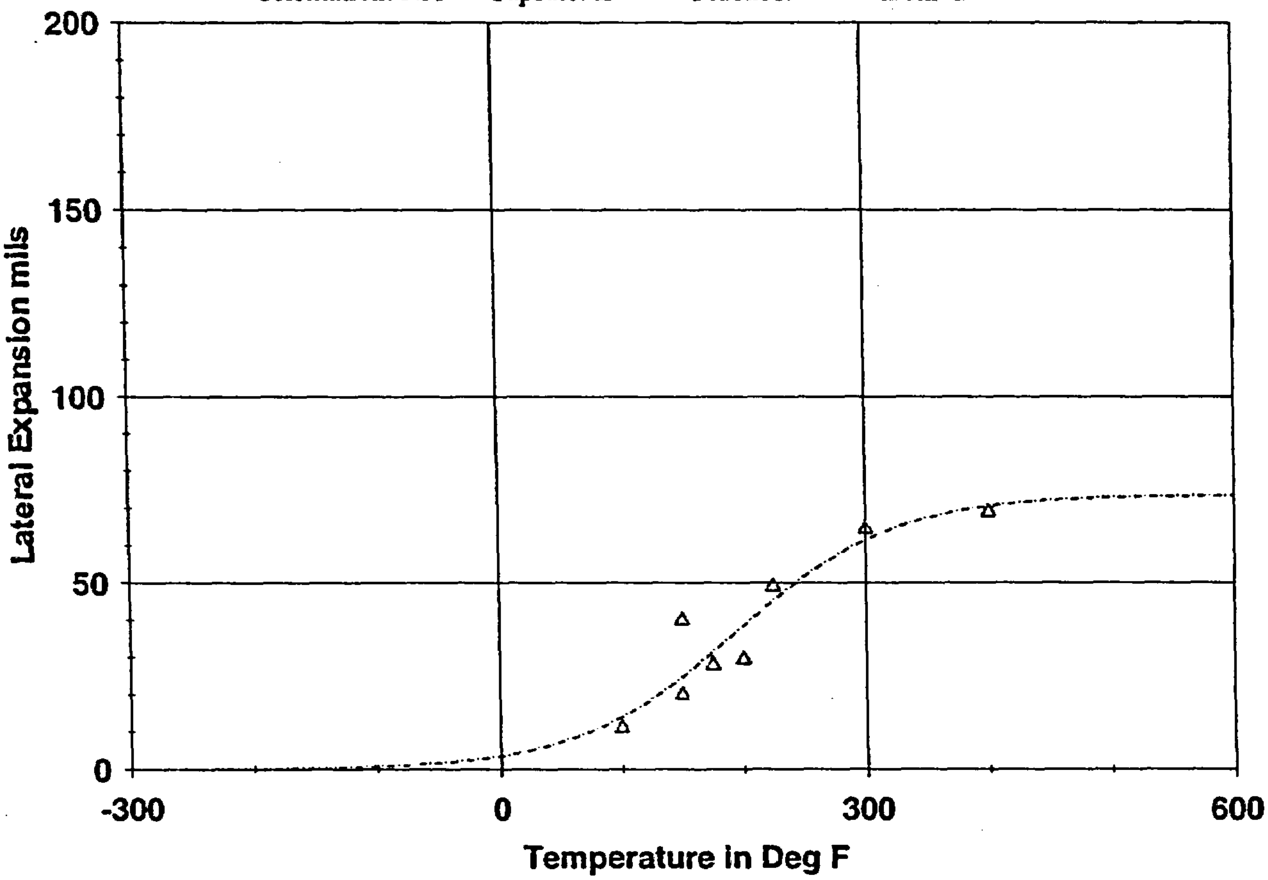
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
100.00	10.00	12.45	-2.45
150.00	21.00	25.10	-4.10
150.00	44.00	25.10	18.90
175.00	26.00	33.85	-7.85
200.00	33.00	43.26	-10.26
225.00	57.00	52.15	4.85
300.00	75.00	69.14	5.86
400.00	77.00	75.04	1.96

Correlation Coefficient = .929

CAPSULE Z (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:10 PM
Page 1
Coefficients of Curve 4
A = 36.77 B = 36.77 C = 129.86 T0 = 194.01 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=73.5 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=187.8 Deg F
Plant: Indian Point 3 Material: SAW Heat: W5214
Orientation: NA Capsule: Z Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
100.00	11.00	14.00	-3.00
150.00	20.00	24.77	-4.77
150.00	40.00	24.77	15.23
175.00	28.00	31.43	-3.43
200.00	29.50	38.47	-8.97
225.00	49.00	45.39	3.61
300.00	64.50	61.52	2.98
400.00	69.00	70.59	-1.59

Correlation Coefficient = .935

CAPSULE Z (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 03:54 PM

Page 1

Coefficients of Curve 4

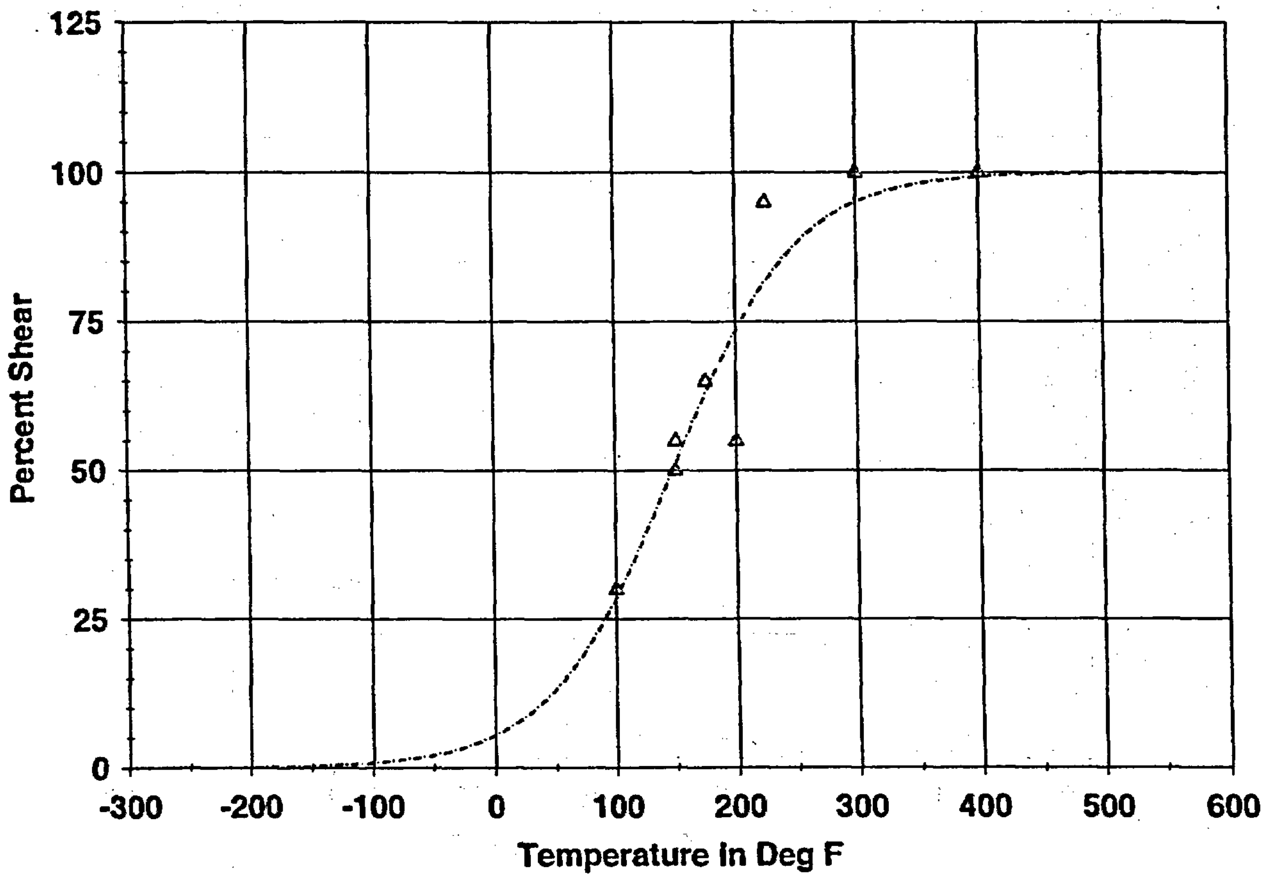
A = 50. B = 50. C = 103.22 T0 = 147.45 D = 0.00E+00

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

Temperature at 50% Shear = 147.5

Plant: Indian Point 3 Material: SAW Heat: W5214

Orientation: NA Capsule: Z Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
100.00	30.00	28.51	1.49
150.00	55.00	51.23	3.77
150.00	50.00	51.23	-1.23
175.00	65.00	63.04	1.96
200.00	55.00	73.46	-18.46
225.00	95.00	81.80	13.20
300.00	100.00	95.05	4.95
400.00	100.00	99.26	.74

Correlation Coefficient = .942

CAPSULE X (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 02:36 PM

Page 1

Coefficients of Curve 5

A = 38.1 B = 35.9 C = 118.98 T0 = 155.76 D = 0.00E+00

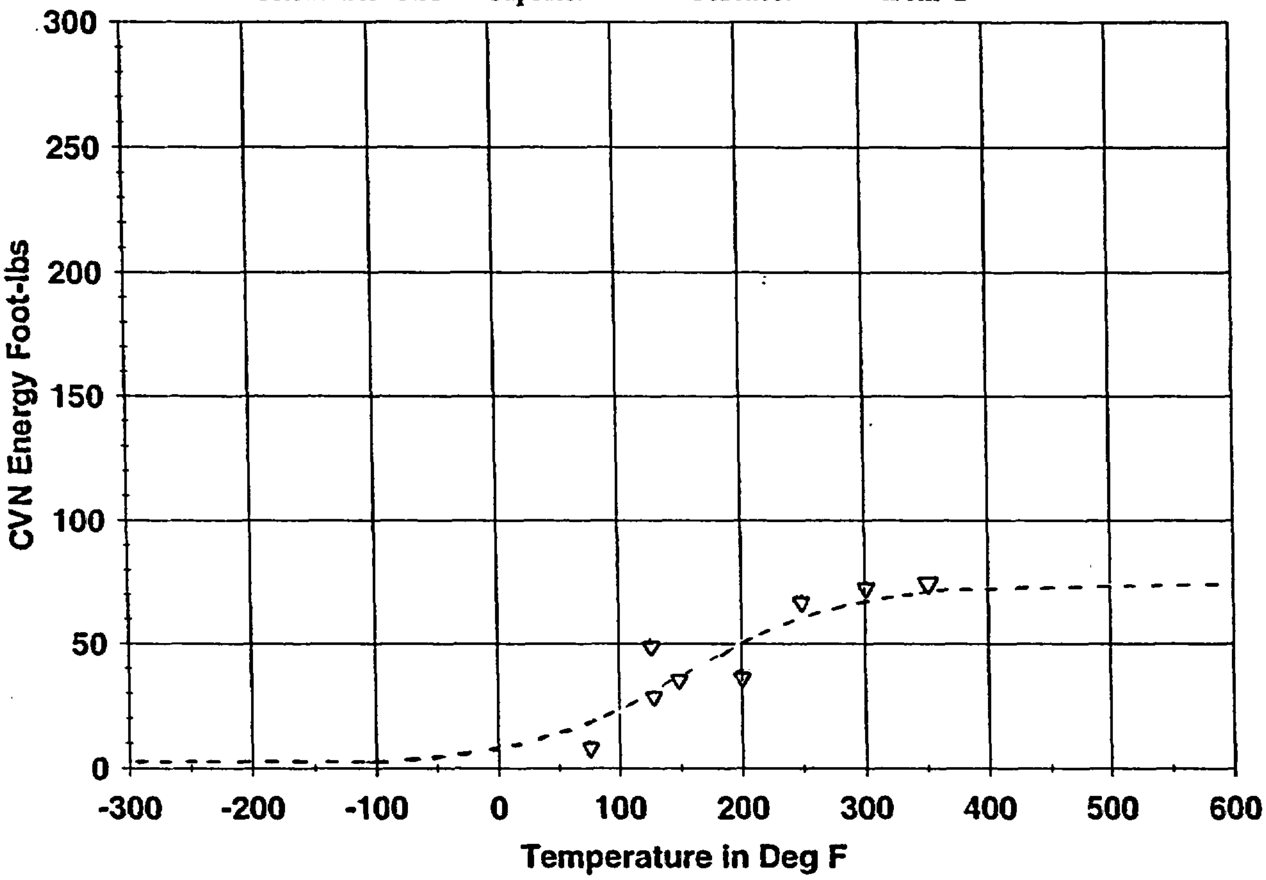
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=74.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=128.5 Deg F Temp@50 ft-lbs=196.8 Deg F

Plant: Indian Point 3 Material: SAW Heat: W5214

Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
75.00	9.00	16.89	-7.89
125.00	49.00	29.02	19.98
125.00	24.00	29.02	-5.02
150.00	35.00	36.36	-1.36
200.00	37.00	50.87	-13.87
250.00	67.00	61.78	5.22
300.00	72.00	68.16	3.84
350.00	75.00	71.36	3.64

Correlation Coefficient = .906

CAPSULE X (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 04:11 PM

Page 1

Coefficients of Curve 5

A = 31.07 B = 31.07 C = 134.21 T0 = 167.48 D = 0.00E+00

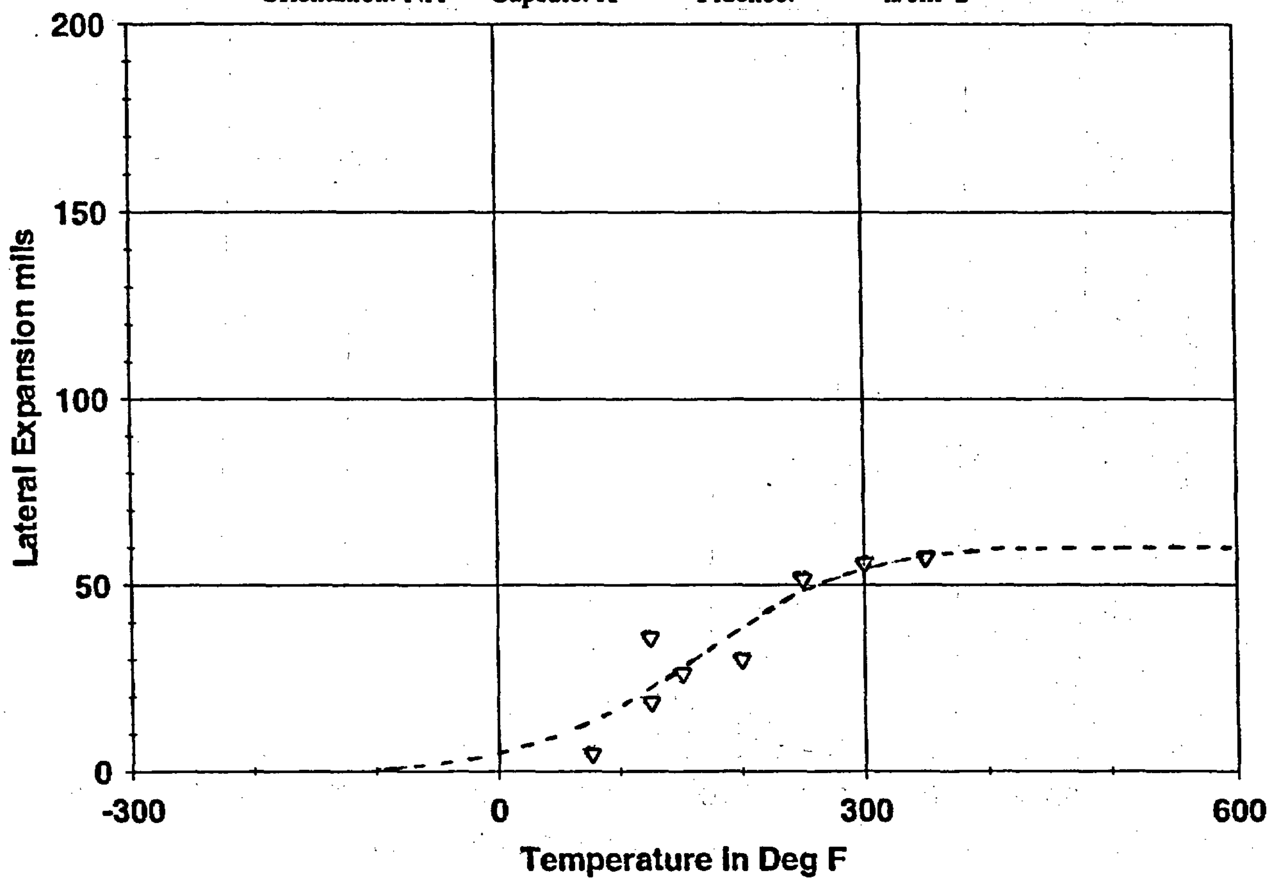
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=62.1 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=184.6 Deg F

Plant: Indian Point 3 Material: SAW Heat: W5214

Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
75.00	5.00	12.51	-7.51
125.00	36.00	21.55	14.45
125.00	19.00	21.55	-2.55
150.00	26.00	27.05	-1.05
200.00	30.00	38.45	-8.45
250.00	52.00	48.08	3.92
300.00	56.00	54.57	1.43
350.00	57.00	58.30	-1.30

Correlation Coefficient = .924

CAPSULE X (WELD)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 03:55 PM

Page 1

Coefficients of Curve 5

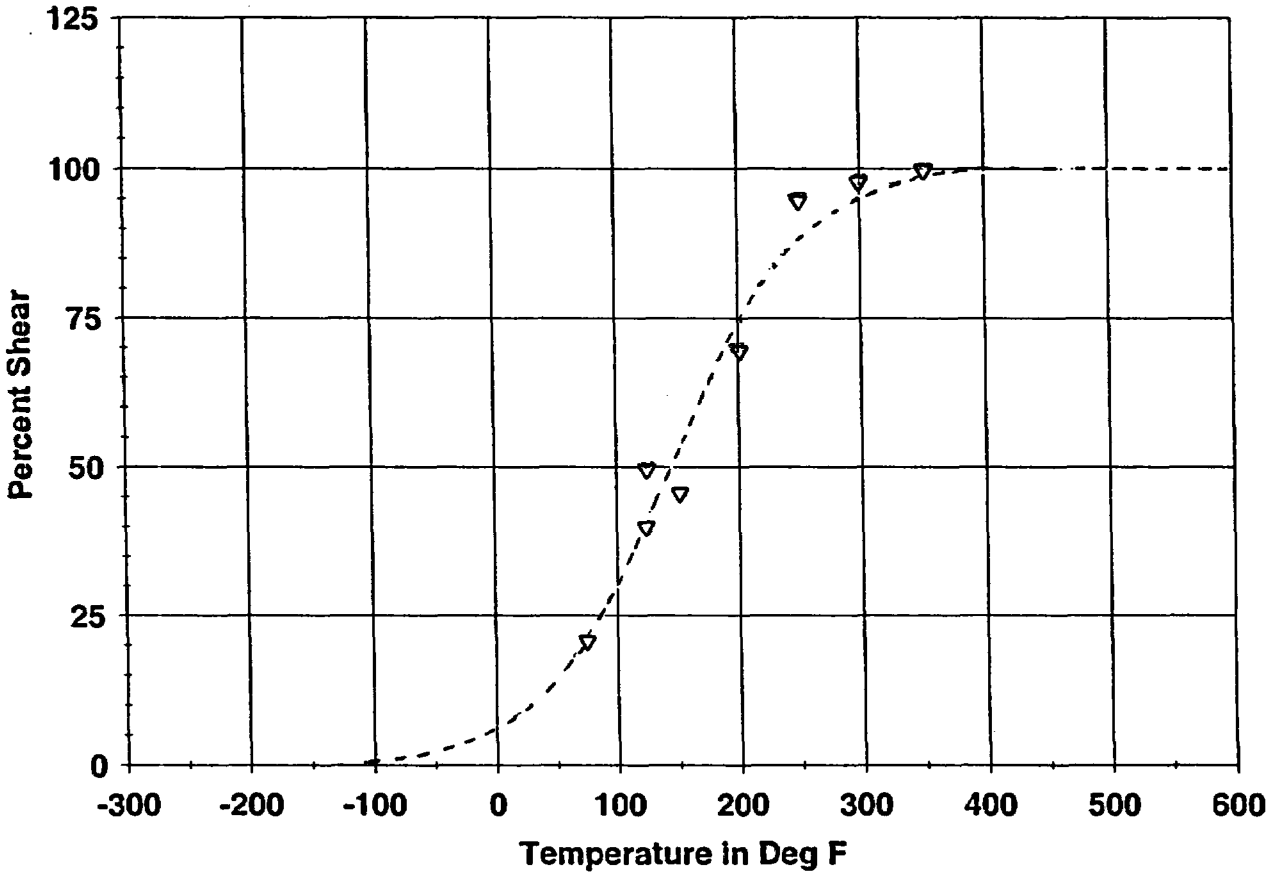
A = 50. B = 50. C = 102.97 T0 = 144.46 D = 0.00E+00

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

Temperature at 50% Shear = 144.5

Plant: Indian Point 3 Material: SAW Heat: W5214

Orientation: NA Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
75.00	20.00	20.60	-.60
125.00	50.00	40.66	9.34
125.00	40.00	40.66	-.66
150.00	45.00	52.69	-7.69
200.00	70.00	74.63	-4.63
250.00	95.00	88.59	6.41
300.00	98.00	95.35	2.65
350.00	100.00	98.19	1.81

Correlation Coefficient = .984

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:41 PM

Page 1

Coefficients of Curve 1

A = 63.6 B = 61.4 C = 84.72 T0 = -2.46 D = 0.00E+00

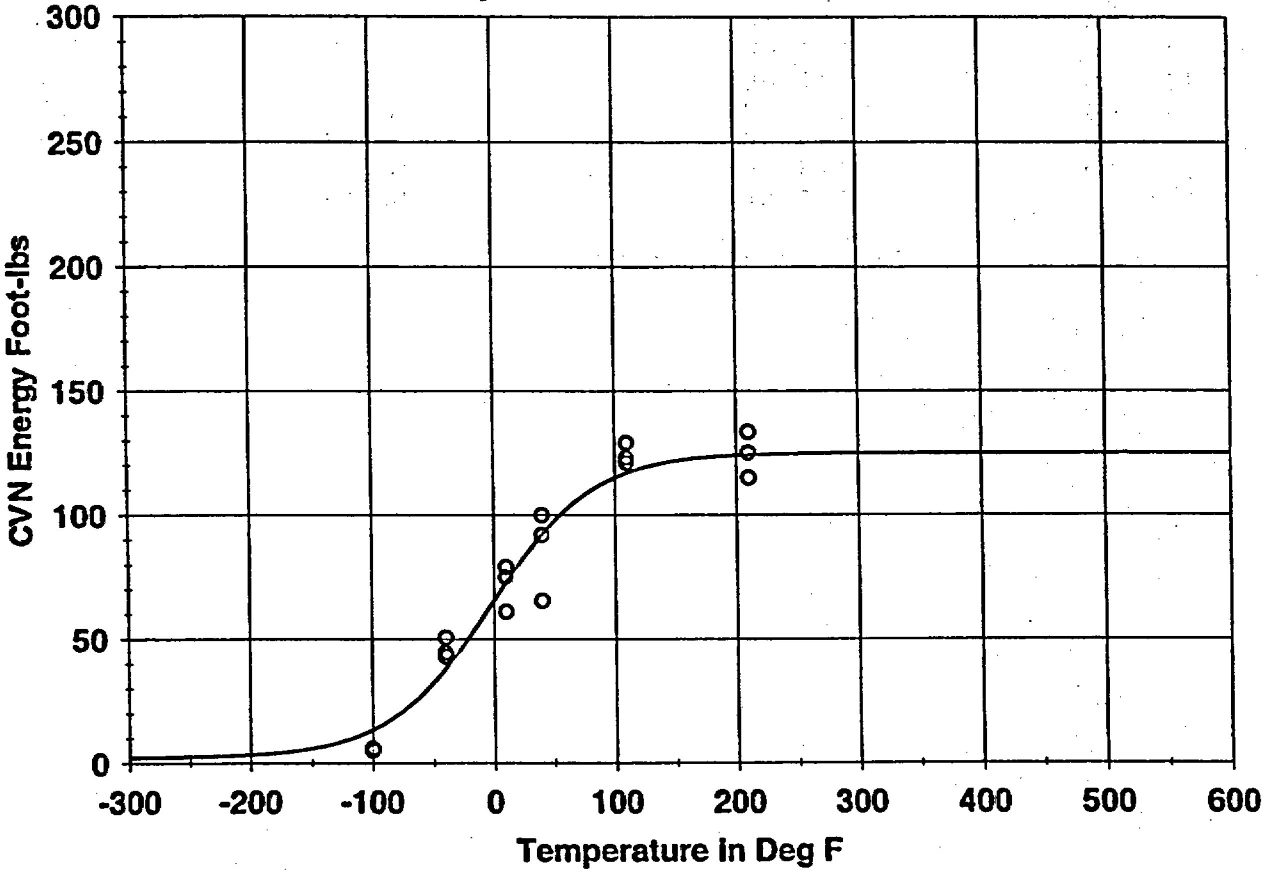
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=125.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=-54.5 Deg F Temp@50 ft-lbs=-21.5 Deg F

Plant: Indian Point 3 Material: SA302B Heat: A-0516-2

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



Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
-100.00	5.00	13.36	-8.36
-100.00	6.00	13.36	-7.36
-100.00	5.00	13.36	-8.36
-40.00	50.50	38.04	12.46
-40.00	43.00	38.04	4.96
-40.00	44.50	38.04	6.46
10.00	79.00	72.57	6.43
10.00	75.00	72.57	2.43
10.00	61.00	72.57	-11.57

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Plant: Indian Point 3 Material: SA302B Heat: A-0516-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
40.00	100.00	92.03	7.97
40.00	92.00	92.03	-.03
40.00	65.50	92.03	-26.53
110.00	123.00	116.93	6.07
110.00	121.00	116.93	4.07
110.00	129.00	116.93	12.07
210.00	133.50	124.19	9.31
210.00	115.00	124.19	-9.19
210.00	125.00	124.19	.81

Correlation Coefficient = .974

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:47 PM

Page 1

Coefficients of Curve 1

A = 39.9 B = 39.9 C = 69.47 T0 = -30.12 D = 0.00E+00

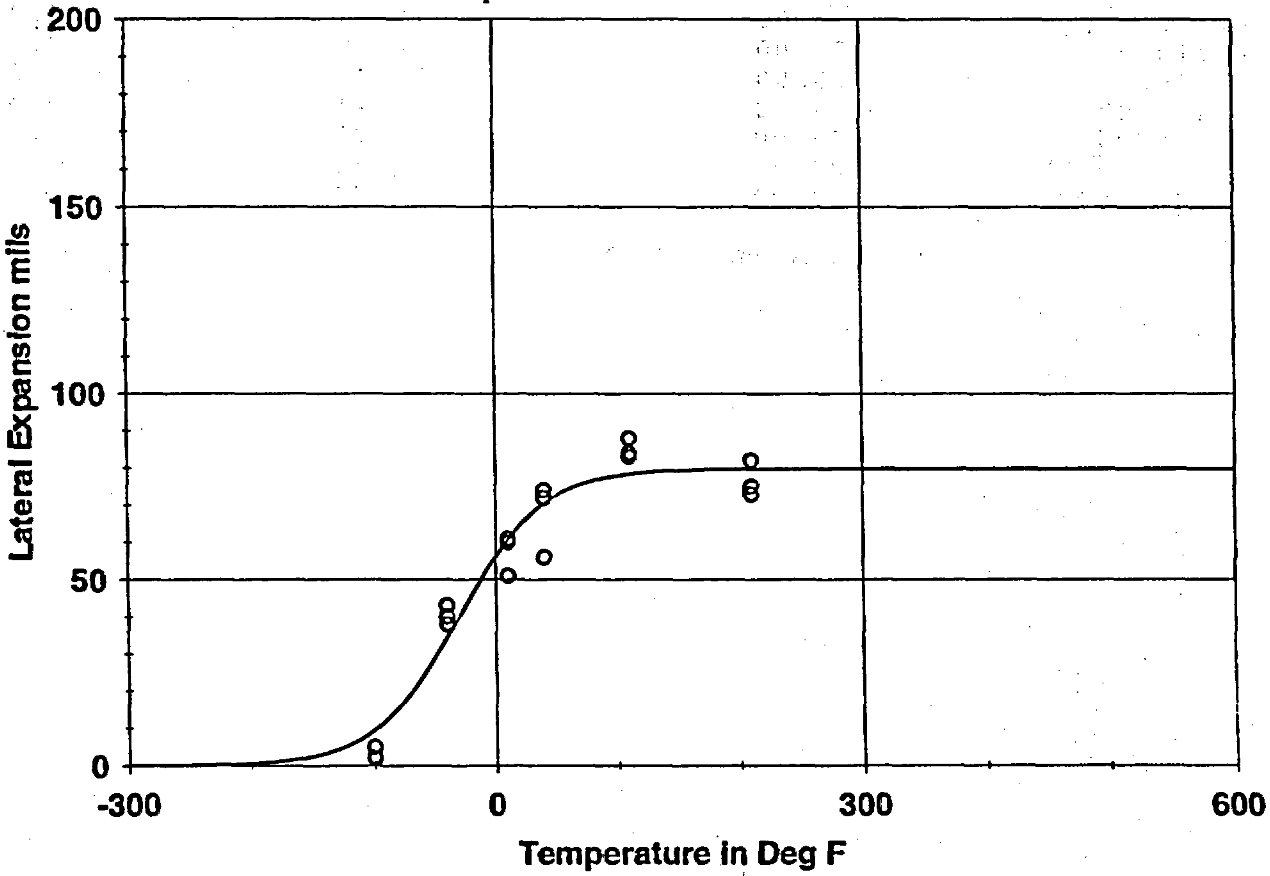
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf L.E.=79.8 Lower Shelf L.E.=.0(Fixed)

Temp.@L.E. 35 mils=-38.6 Deg F

Plant: Indian Point 3 Material: SA302B Heat: A-0516-2

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



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
-100.00	2.00	9.41	-7.41
-100.00	2.00	9.41	-7.41
-100.00	5.00	9.41	-4.41
-40.00	43.00	34.26	8.74
-40.00	40.00	34.26	5.74
-40.00	38.00	34.26	3.74
10.00	61.00	60.68	.32
10.00	60.00	60.68	-.68
10.00	51.00	60.68	-9.68

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Indian Point 3 Material: SA302B Heat: A-0516-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
40.00	72.00	70.44	1.56
40.00	74.00	70.44	3.56
40.00	56.00	70.44	-14.44
110.00	88.00	78.41	9.59
110.00	83.00	78.41	4.59
110.00	84.00	78.41	5.59
210.00	75.00	79.72	-4.72
210.00	82.00	79.72	2.28
210.00	73.00	79.72	-6.72

Correlation Coefficient = .972

UNIRRADIATED (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:44 PM

Page 1

Coefficients of Curve 1

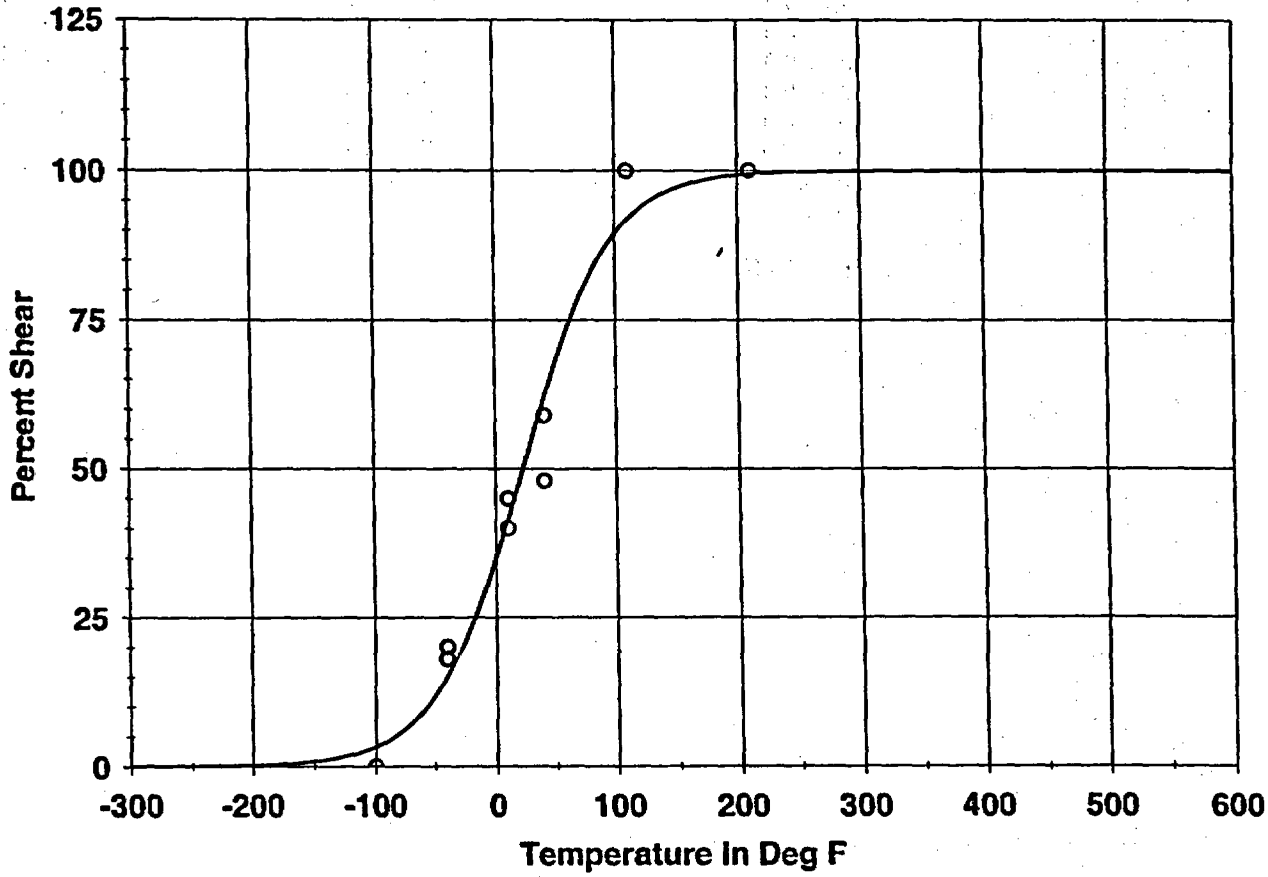
A = 50. B = 50. C = 72.31 T0 = 22.57 D = 0.00E+00

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

Temperature at 50% Shear = 22.6

Plant: Indian Point 3 Material: SA302B Heat: A-0516-2

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
-100.00	.00	3.26	-3.26
-100.00	.00	3.26	-3.26
-100.00	.00	3.26	-3.26
-40.00	20.00	15.05	4.95
-40.00	18.00	15.05	2.95
-40.00	20.00	15.05	4.95
10.00	40.00	41.40	-1.40
10.00	45.00	41.40	3.60
10.00	45.00	41.40	3.60

UNIRRADIATED (LONGITUDINAL ORIENTATION)

Page 2
Plant: Indian Point 3 Material: SA302B Heat: A-0516-2
Orientation: LT Capsule: UNIRR Fluence: n/cm^2

Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
40.00	59.00	61.82	-2.82
40.00	59.00	61.82	-2.82
40.00	48.00	61.82	-13.82
110.00	100.00	91.82	8.18
110.00	100.00	91.82	8.18
110.00	100.00	91.82	8.18
210.00	100.00	99.44	.56
210.00	100.00	99.44	.56
210.00	100.00	99.44	.56

Correlation Coefficient = .990

CAPSULE X (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:41 PM

Page 1

Coefficients of Curve 2

A = 53.6 B = 51.4 C = 109.99 T0 = 152.64 D = 0.00E+00

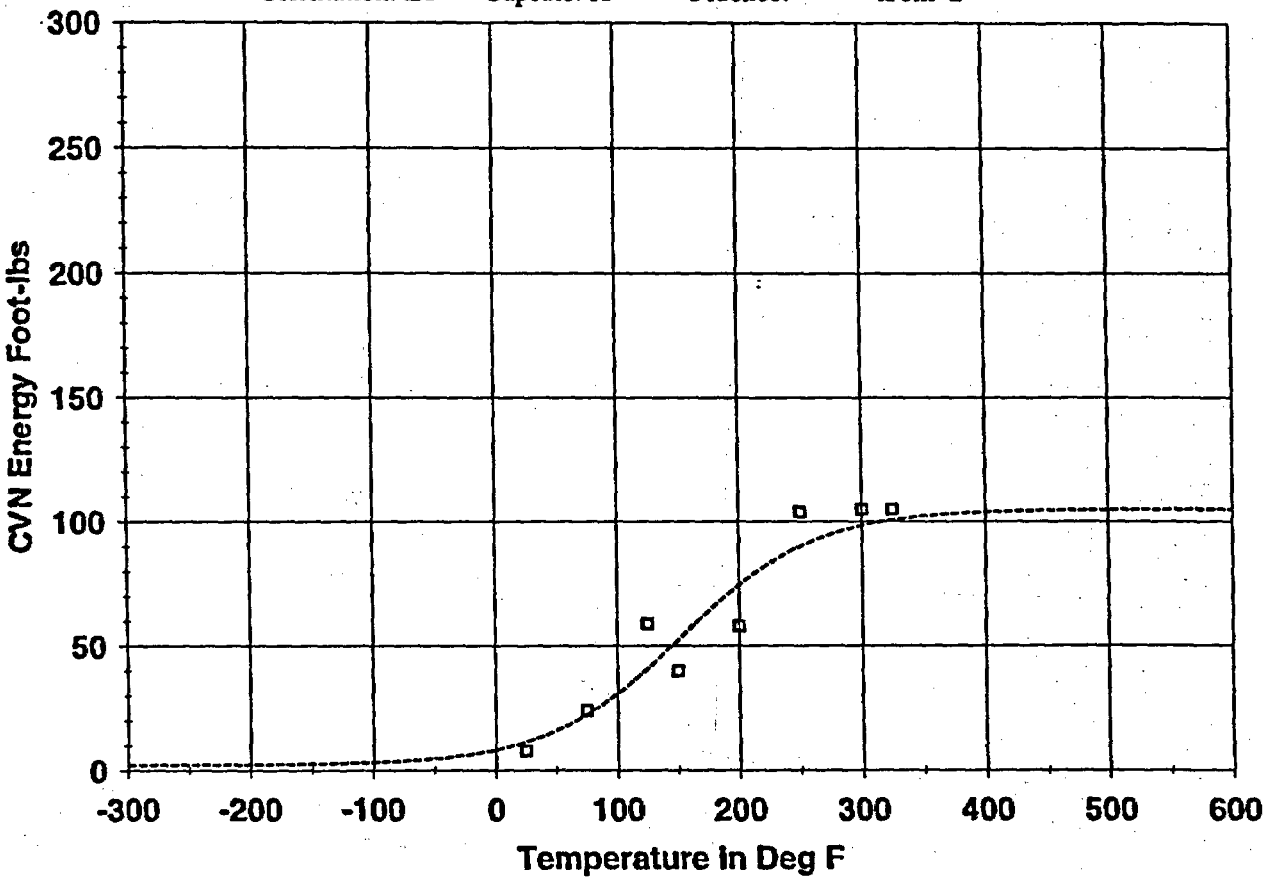
Equation is A + B * [Tanh((T-To)/(C+DT))]

Upper Shelf Energy=105.0(Fixed) Lower Shelf Energy=2.2(Fixed)

Temp@30 ft-lbs=98.1 Deg F Temp@50 ft-lbs=145.0 Deg F

Plant: Indian Point 3 Material: SA302B Heat: A-0516-2

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



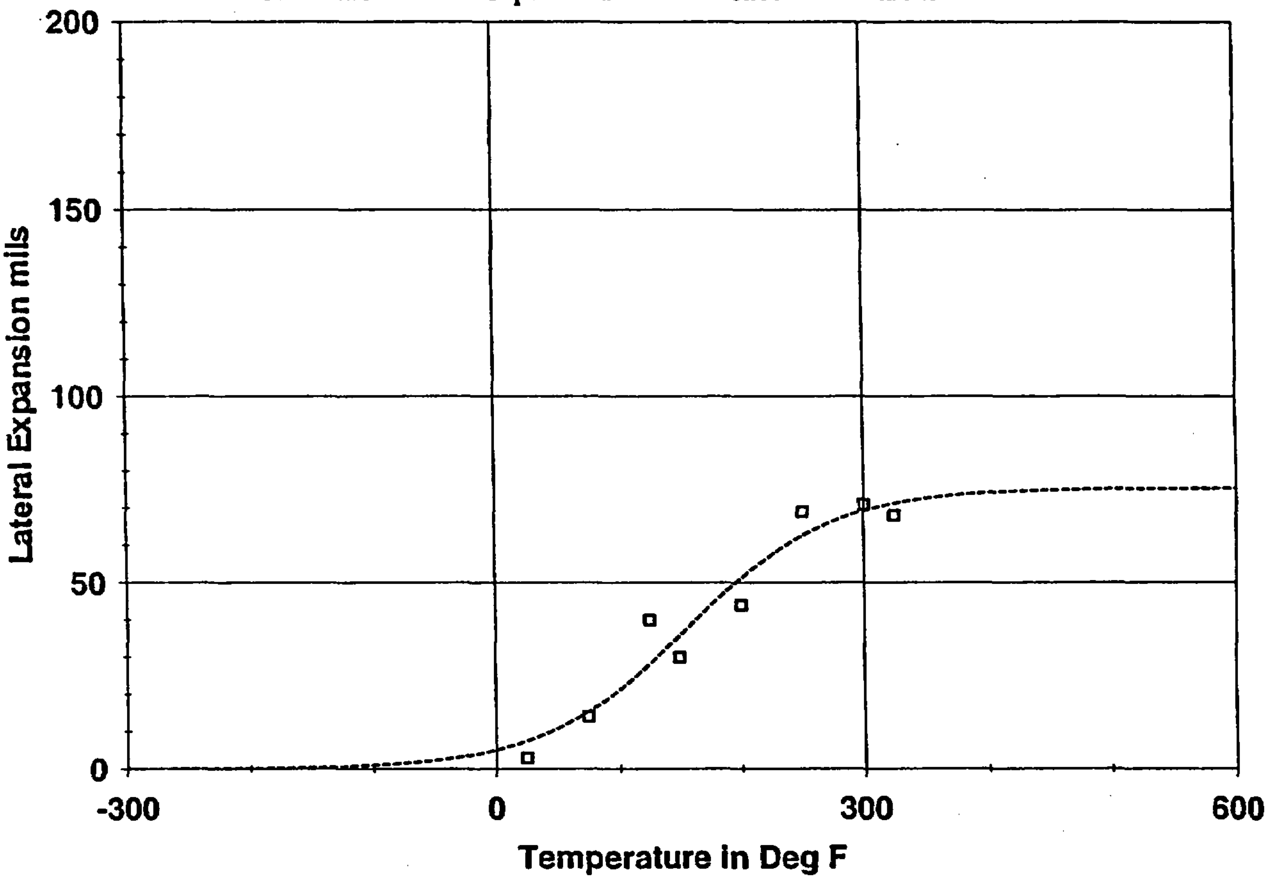
Charpy V-Notch Data

Temperature	Input CVN	Computed CVN	Differential
25.00	8.00	11.39	-3.39
75.00	24.00	22.34	1.66
125.00	59.00	40.95	18.05
150.00	40.00	52.37	-12.37
200.00	58.00	74.46	-16.46
250.00	104.00	90.04	13.96
300.00	105.00	98.40	6.60
325.00	105.00	100.71	4.29

Correlation Coefficient = .951

CAPSULE X (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:47 PM
Page 1
Coefficients of Curve 2
A = 37.62 B = 37.62 C = 118.27 T0 = 155.47 D = 0.00E+00
Equation is A + B * [Tanh((T-To)/(C+DT))]
Upper Shelf L.E.=75.2 Lower Shelf L.E.=.0(Fixed)
Temp.@L.E. 35 mils=147.3 Deg F
Plant: Indian Point 3 Material: SA302B Heat: A-0516-2
Orientation: LT Capsule: X Fluence: n/cm^2



Charpy V-Notch Data

Temperature	Input L.E.	Computed L.E.	Differential
25.00	3.00	7.46	-4.46
75.00	14.00	15.36	-1.36
125.00	40.00	28.14	11.86
150.00	30.00	35.88	-5.88
200.00	44.00	51.15	-7.15
250.00	69.00	62.58	6.42
300.00	71.00	69.23	1.77
325.00	68.00	71.19	-3.19

Correlation Coefficient = .968

CAPSULE X (LONGITUDINAL ORIENTATION)

CVGRAPH 5.0.2 Hyperbolic Tangent Curve Printed on 04/02/2004 05:44 PM

Page 1

Coefficients of Curve 2

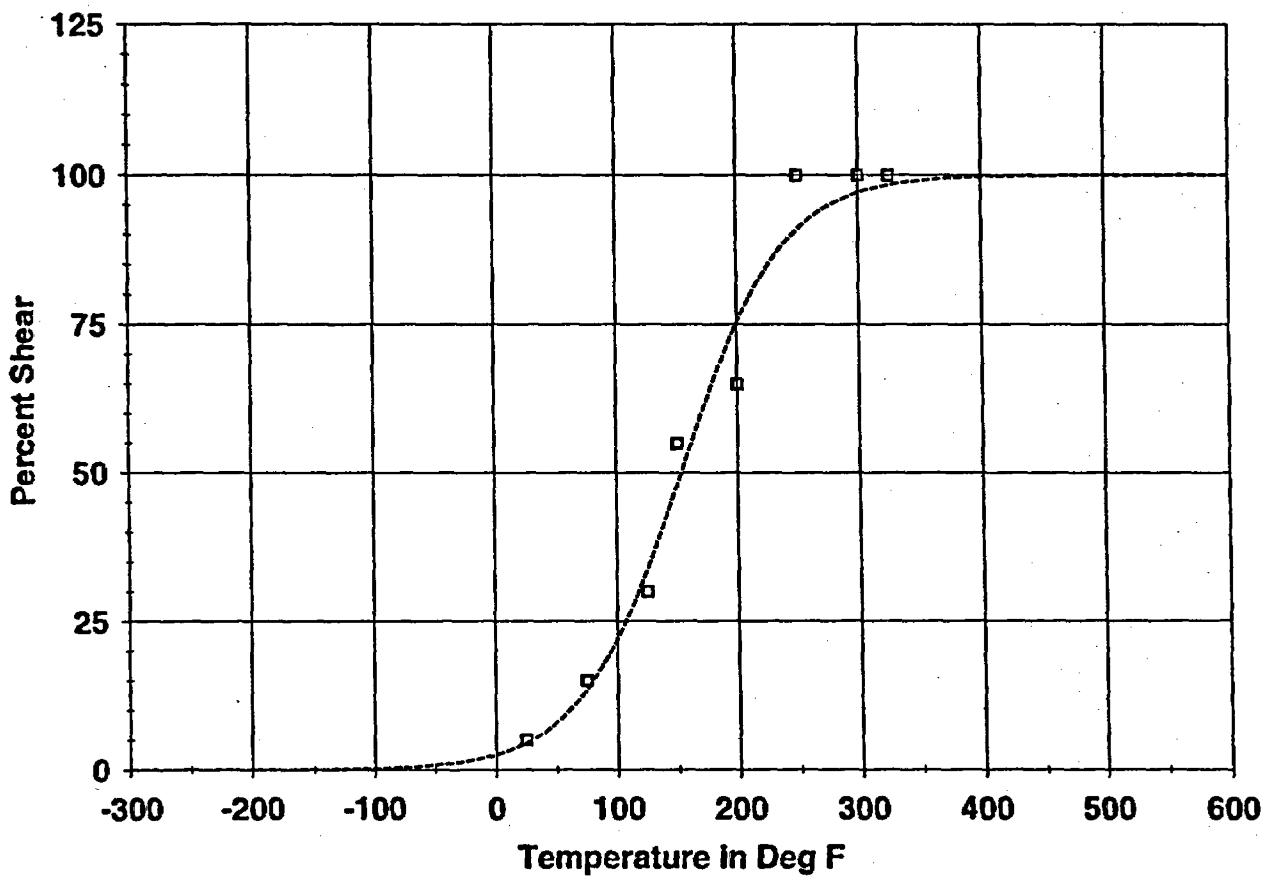
A = 50. B = 50. C = 83.85 T0 = 153.16 D = 0.00E+00

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

Temperature at 50% Shear = 153.2

Plant: Indian Point 3 Material: SA302B Heat: A-0516-2

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



Charpy V-Notch Data

Temperature	Input Percent Shear	Computed Percent Shear	Differential
25.00	5.00	4.49	.51
75.00	15.00	13.42	1.58
125.00	30.00	33.81	-3.81
150.00	55.00	48.12	6.88
200.00	65.00	75.35	-10.35
250.00	100.00	90.97	9.03
300.00	100.00	97.08	2.92
325.00	100.00	98.37	1.63

Correlation Coefficient = .988

APPENDIX D

INDIAN POINT UNIT 3 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 Indian Point Unit 3 reactor vessel. To use these surveillance data sets, they must be shown to be credible. In accordance with the discussion of Regulatory Guide 1.99, Revision 2, there are five requirements that must be met for the surveillance data to be judged credible.

The purpose of this evaluation is to apply the credibility requirements of Regulatory Guide 1.99, Revision 2, to the Indian Point Unit 3 reactor vessel surveillance data and determine if the Indian Point Unit 3 surveillance data is credible.

It should be noted that only surveillance plate B2803-3 will be evaluated for credibility for the following reasons: 1) The surveillance plates B2802-1, 2, and 3 do not contain sufficient irradiated data sets to be used in vessel material predictions, 2) The limiting surveillance plate B2803-3 has a significantly larger initial RT_{NDT}, where the remaining surveillance materials could not become limiting even with non-credible surveillance data (*i.e. using a full margin term*). 3) The surveillance weld heat is not the same heat as the beltline welds (*intermediate/lower shell longitudinal weld & intermediate to lower shell girth weld*), thus should not be used for vessel material predictions (*see discussion under Criterion 1*).

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 Indian Point Unit 3 reactor vessel consists of the following beltline region materials:

- Intermediate Shell Plates B2802-1, 2, 3
- Lower Shell Plates R2803-1, 2, 3
- Intermediate & Lower Shell Longitudinal Weld Seams (Heat # 34B009, Flux Type Linde 1092),
- Intermediate to Lower Shell Circumferential Weld Seam (Heat # 13253, Flux Type Linde1092).

Per WCAP-8475, the Indian Point Unit 3 surveillance program was based on ASTM E185-62. When the surveillance program material was selected it was believed that copper and phosphorus were elements most important to embrittlement of the reactor vessel steels. Lower shell plate B2803-3 had the highest copper weight percents, the highest initial RT_{NDT} and the lowest USE of all plate materials in the beltline region. Thus, it was selected as one of the beltline plate materials included in the surveillance capsules. Since Indian Point Unit 3 had eight surveillance capsules, there was sufficient room for additional plate materials, thus, specimens from each of the intermediate shell plates were also included, but not to the extent as lower shell plate B2803-3.

The weld material in the Indian Point Unit 3 surveillance program was made of the weld wire heat W5214, flux type linde 1092. This is the same heat as that from the nozzle shell longitudinal welds, but the same flux type as those welds within the beltline region. In addition, predictions made at the time the capsule program was developed indicated that weld heat W5214, linde 1092 would produce similar predictions as those weld heats within the beltline region and thus deemed the surveillance weld heat W5214 representative of the beltline region. Therefore it was chosen as the surveillance weld material.

Hence, Criterion 1 is met for the Indian Point Unit 3 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 upper shelf energy of the Indian Point Unit 3 surveillance materials unambiguously. Hence, the Indian Point Unit 3 surveillance program meets this criterion.

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

The functional form of the least squares method as described in Regulatory Position 2.1 will be utilized to determine a best-fit line for this data and to determine if the scatter of these ΔRT_{NDT} values about this line is less than 28°F for welds and less than 17°F for the plate. Following is the calculation of the best-fit line as described in Regulatory Position 2.1 of Regulatory Guide 1.99, Revision 2.

TABLE D-1

Calculation of Chemistry Factors using Indian Point Unit 3 Surveillance Capsule Data

Material	Capsule	Capsule f[(a)]	FF[(b)]	ΔRT_{NDT}[(c)]	$FF*\Delta RT_{NDT}$	FF^2
Lower Shell Plate B2803-3 (*Longitudinal*)	T	0.263	0.637	139.4	88.798	0.406
	Z	1.04	1.01	167.8	169.478	1.02
	X	0.874	0.962	159.6	153.535	0.925
Lower Shell Plate B2803-3 (*Transverse*)	T	0.263	0.637	105.9	67.458	0.406
	Y	0.692	0.897	148.9	133.563	0.805
	Z	1.04	1.01	157.9	159.479	1.02
	X	0.874	0.962	158.2	152.188	0.925
				SUM:	924.499	5.507
	$CF_{B2803-3} = \Sigma(FF * \Delta RT_{NDT}) + \Sigma(FF^2) = (924.499) + (5.507) = 167.9°F$					

Notes:

(a) f = fluence. Calculated fluence from Section 6 of this report [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 taken from Figures 5-1 and 5-4, herein [°F].

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:
Indian Point Unit 3 Surveillance Capsule Data Scatter about the Best-Fit Line for Surveillance Forging Materials.

Material	Capsule	CF (°F)	FF	Measured ΔRT_{NDT}	Predicted ΔRT_{NDT}[(a)]	Scatter ΔRT_{NDT} (°F)	< 17°F (Base Metals)
Lower Shell Plate B2803-3 *(Longitudinal)*	T	167.9	0.637	139.4	107.0	32.4	No
	Z	167.9	1.01	167.8	169.6	-1.8	Yes
	X	167.9	0.962	159.6	161.5	-1.9	Yes
Lower Shell Plate B2803-3 (Transverse)	T	167.9	0.637	105.9	107.0	-1.1	Yes
	Y	167.9	0.897	148.9	150.6	-1.7	Yes
	Z	167.9	1.01	157.9	169.6	-11.7	Yes
	X	167.9	0.962	158.2	161.5	-3.3	Yes

NOTES:
(a) Predicted ΔRT_{NDT} = (CF * FF) Per Equation 2 of Reg. Guide 1.99 Rev. 2 Position 1.1.

Conclusion for Criterion 3:

Table D-2 indicates that only 1 of 7 data points falls outside the +/- 1σ of 17°F scatter band for the lower shell plate B2803-3 surveillance data. One out of 7 data points is still considered credible. Therefore the lower shell plate B2803-3 surveillance data is deemed "credible" per the third 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 thermal shield and the vessel wall and are positioned opposite the center of the core. The test capsules are in baskets attached to the Thermal Shield. The location of the specimens with respect to the reactor vessel beltline provides assurance that the reactor vessel wall and the specimens experience equivalent operating conditions such that the temperatures will not differ by more than 25°F. Hence, this 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 Indian Point Unit 3 surveillance program does contain correlation monitor material, but not in Capsule X. Past capsule results for the correlation monitor material is contained in NUREG/CR-6413, ORNL/TM-13133, which shows a plot of residual vs. fast fluence. The data shown in this report indicates that the CMM tested to date falls within acceptable limits. Hence, this criteria is met.

CONCLUSION:

Based on the preceding responses to all five criteria of Regulatory Guide 1.99, Revision 2, the Indian Point Unit 3 surveillance plate (B2803-3) is credible.